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NOVEMBER/DECEMBER 2025

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Investigating the Effects of Wear, Lubrication and Material Pairing on the NVH Performance of Plastic Gears

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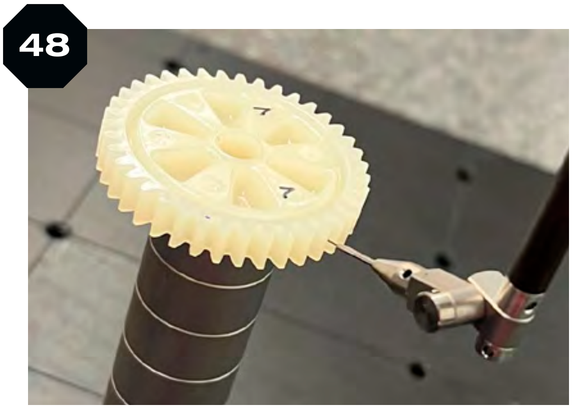

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BIG
Christmas
cheer!
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Seventy Years of Gears!
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gear TECHNOLOGY®

Vol. 42. No. 8

gear TECHNOLOGY®

GT REVOLUTIONS

Meeting the High Demands of the Agricultural Industry

Agritechnica 2025 took place in November in Hannover, Germany. The exhibition welcomed 2,800 exhibitors from over 50 countries, including 234 world premieres, presenting advanced farm equipment and solutions. With 430,000+ visitors and the entire 23 halls fully booked, this year's edition included exhibitors from 52 countries showcasing intelligent, connected technologies that make farming more sustainable, productive and user-friendly.

geartechnology.com/meeting-the-high-demands-of-the-agricultural-industry

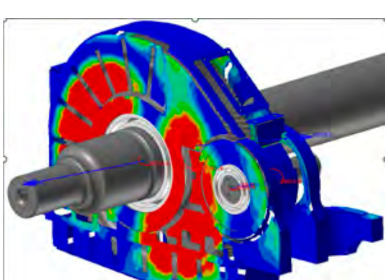
Machine Tool Remediation

Gear Headquarters, a specialty gear facility known for quick-turn breakdown and repair services, has installed the Hera 750 CNC gear hobbing machine from Helios Gear Products. The upgrade modernizes the company's legacy gear cutting operations, enabling the team to produce custom gears faster and more reliably, while bringing higher-volume OEM production in-house.

geartechnology.com/machine-tool-remediation

AS SEEN IN *PTE*

Tuning Flank Waviness for Minimized Mesh Force Variation



Loaded tooth contact analysis of gears, considering or neglecting gear misalignment, may be performed by gear design software such as *KISSsoft* or other similar tools. Approximately a dozen such commercial software programs are used in an international environment, most of them based on analytical approaches.

powertransmission.com/tuning-flank-waviness-for-minimized-mesh-force-variation

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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.*

THE GEAR INDUSTRY'S INFORMATION SOURCE

Where Did It Go?

One day you're celebrating the new year, and then—blink—2025 is over. It's the same every year.

And then you get to reflecting on what happened during the year—including all your personal achievements, experiences and setbacks. You remember all the places you've gone and the people you've seen, the hardships you've endured and the challenges you've overcome.

You think about how far you've come (or not) in your personal and professional goals, measuring your milestones against where you thought you'd be. You think about all the changes among the people you care about—weddings, funerals, graduations, births and so on.

Then you throw in all the crazy stuff that happened along the way—the things beyond your personal sphere that you have no control over but which impact your life nonetheless. You know, things like the economy, government, tariffs.

And don't forget about rapid changes in technology, including the explosion of AI. This year we saw AI introduced into just about everything—and its proliferation isn't slowing down any time soon.

So after thinking about it, I can recognize that 2025 flew by because it was so chock-full. If you never slow down, you can't tell how fast you're moving.

As long as we're reflecting, I'd like to thank all of the team members who help put *Gear Technology* together. Despite everything thrown their way, they manage to get it all done, every issue. In addition, I'd like to thank all of our advertisers, without whose support, none of this would be possible. Lastly, I'd like to thank the many authors and contributors whose knowledge we are privileged to share in these pages every issue.

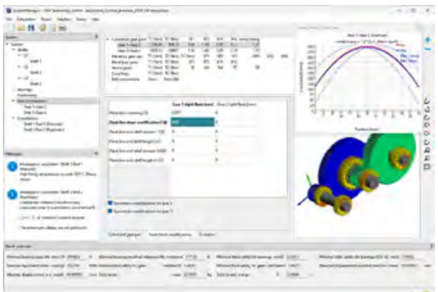
I'd also like to wish everyone in the gear industry a happy holiday season and a prosperous new year.

Don't blink, though. 2026 will be over before you know it.

Publisher & Editor-in-Chief
Randy Stott, Vice President Media

GWJ Technology

PRESENTS ADVANCED FEATURES FOR PRECISE DRIVETRAIN CALCULATION



GWJ Technology GmbH presents the new version of its *SystemManager*, which serves as an extension for the established calculation solutions *eAssistant* and *TBK*. With numerous innovations and optimizations, the software provides engineers with enhanced capabilities for modeling, calculating, and analyzing complex drivetrain systems.

A significant advancement is the integration of shaft-hub calculations for parallel keys, interference fits, and involute splines. This allows calculations and data to be managed and exchanged directly within the system, with the corresponding individual modules being accessible in the system environment.

The *eAssistant* or *TBK* modules can be opened directly in the system. Additionally, a new message window enhances transparency by centrally displaying notifications and results from the system calculation, as well as the bearing, gear, and shaft-hub calculations. The user interface has also been optimized: a new toggle in the status bar now allows for automatic recalculation after any input changes. All results, including graphics, are immediately updated, enabling users to instantly see the effects of parameter changes.

Furthermore, the STEP import for shaft geometries has been enhanced. A defeaturing option allows elements such as chamfers, radii, or holes to be removed. The bearing databases from SKF and NSK, along with the corresponding catalog data, have also been updated.

At the system level, multiple load cases can now be defined and flexibly selected for calculations.

The calculation of the line load distribution for gears has also been further developed. A supplementary flank line deviation (fma) can now be specified for the gear connection. This allows alignment errors, such as manufacturing-induced flank line deviations of the gears or parallelism errors of the shafts, to be taken into account. The line load calculation is then performed with the additional fma, where only the tooth engagement stiffness at constant gear tilt angles is considered. This is then incorporated into the loadbearing capacity calculation according to ISO 6336 Method B via the face load factor.

The representation of shaft stiffness through wheel bodies has also been significantly improved. Instead of the previous two options, there are now five possibilities available, including the use of a 3D FEM mesh to account for wheel body stiffness.

Additionally, rotationally symmetric wheel body geometries can now be defined directly at the force element, while complex geometries can still be represented via 3D elastic components. In the area of visualization, users benefit from expanded sectional views. In addition to quarter-section views, a 180-degree section is now available. Imported housings can be displayed with custom section directions, and 3D elastic components are also shown in the 2D views.

With these enhancements, GWJ Technology emphasizes its commitment to providing engineers and technicians worldwide with powerful tools for seamless and precise drivetrain calculations. The new version of the *SystemManager* enables the modeling of even more complex relationships in a realistic manner, significantly optimizing system design.

gwj.de

Wenzel America

OFFERS PRECISE METROLOGY SOLUTIONS AT MPT EXPO

Wenzel's participation in the Motion + Power Technology Expo in Detroit marked another milestone in advancing gear inspection and metrology innovation. The event provided a valuable platform to demonstrate the company's latest technologies and connect with engineers, manufacturers and industry leaders driving the next generation of motion and power solutions.

At the center of Wenzel's showcase was the introduction of extended GT tailstock configurations—engineered to deliver greater range, stability and precision for complex gear inspection applications. These new tailstock options extend measurement flexibility, allowing operators to handle a wider variety of workpiece lengths and diameters while maintaining submicron accuracy. Designed for compatibility across the GT series gear inspection systems, they enable faster setup times, improved repeatability and enhanced support for high-torque applications.

Whether in R&D labs, production lines, or calibration facilities, the extended GT tailstock represents a step forward in precision engineering and measurement reliability.

wenzelamerica.com

Weiler Abrasives

EXPANDS LINEUP OF COLOR-CODED BRUSHES FOR STAINLESS STEEL

Weiler Abrasives has expanded its color-coded product lineup to include some of its most popular brushes for stainless steel. The color-coding helps stop cross-contamination in operations working with both carbon and stainless steel by making it easy to identify the correct wire brush—even during operation. This helps operators get the job done faster, safer and better.

The color-coding is a visual change to the existing brush products. Users will enjoy the same premium performance they've come to expect of Weiler products. Part numbers and pricing will also remain the same.

Products that have been added to the stainless steel color-coded brush portfolio include roughneck stringer bead wheels, knot wire wheels, knot wire bevel brushes, knot wire cup brushes, crimped wire cup brushes, knot wire end brushes, crimped wire end brushes, controlled flare end brushes and circular flared end brushes.

weilerabrasives.com/color-coded-brushes

Solar Atmospheres

INCREASES CAPACITY WITH ADDITIONAL ALL-METAL HOT ZONE FURNACE

This installation marks the second all-metal hot zone vacuum furnace added to the climate-controlled processing area at Solar Atmospheres' Hermitage, PA facility. The new system significantly expands the company's capacity to heat treat highly sensitive materials such as precipitation-hardened stainless steels, nickel-chrome-based superalloys, titanium, and niobium.

Engineered for precision and performance, the furnace incorporates strategically placed isolation valves, an oversized main valve, a high-capacity diffusion pump, and a polished stainless-steel chamber. Together, these features

create an ultra-clean processing environment that meets the stringent demands of the aerospace and medical industries. Capable of achieving vacuum levels below 5 x 10^{-6} Torr, the system ensures bright, contamination-free results.

Michael Johnson, sales director at Solar Atmospheres of Western Pennsylvania, stated: “The all-metal vacuum furnace plays a critical role in delivering the purest possible processing environment. This level of cleanliness and control results in pristine end products that meet the most demanding industry standards. We’re proud to partner with the engineers at Solar Manufacturing to bring this advanced technology to fruition.”

solaratm.com

Walter USA

EXPANDS THREAD MILLING GRADE OPTIONS

Walter has expanded its product range with the addition of the new thread milling grade, Tiger·tec Gold WSM37G. The grade features the only PVD aluminum oxide (Al_2O_3) coating technology of its kind in the world, which provides an elevated level of temperature resistance and long tool life.

A titanium aluminum nitride (TiAlN) base coating on the carbide substrate offers a high level of wear resistance and the multi-layer coating is topped with a polished gold-colored zirconium nitride (ZrN) layer with the best friction resistance and wear detection. In addition, an extremely smooth rake face minimizes friction.

These new benchmark indexable inserts for thread milling have a positive basic shape geometry that has three cutting edges. They are available in either the D67 universal geometry for maximum tool life or the D61 geometry with anti-vibration land for a high level of operational smoothness when using large projection lengths or under difficult conditions.

WSM37G-grade inserts are for milling threads with a nominal diameter from 16 mm or UNC ¾. The indexable inserts can be used universally to thread mill steel, stainless steel, cast iron, nonferrous metals, heat-resistant super alloys and steel hardened up to 55 HRC (ISO P, M, K, N, S and H).

Thread milling inserts in grade WSM37G feature chip breakers specifically developed for thread milling and a defined corner radii for producing threads in accordance with various standards. End users will realize process reliability due to the perfect balance between wear resistance and toughness.

walter-tools.com/us

Visual Components

UNVEILS OMNIVERSE-POWERED VIRTUAL APPLICATION AT NVIDIA GTC DC

Visual Components announced its Omni Experience add-on virtual application with Nvidia at the Nvidia GTC global conference in Washington, D.C. Scheduled for release in early 2026, the integration enhances the Visual Components simulation platform with a new viewport built on Nvidia Omniverse's application programming interface (API).

The viewport delivers high-fidelity rendering, meaning any updates made in the simulation environment are immediately reflected and shown with accurate lighting and materials. This enables manufacturers and system integrators to explore and review factory layouts with greater realism and clarity, while seamlessly integrating into their existing workflows. Users do not need to rebuild models, use additional software or change their processes, as geometry, structure, and materials flow automatically into the Omniverse-powered display.

This additional development offers manufacturers and system integrators a more immersive and effective way to visualize, review, and present their layouts, all within their familiar Visual Components environment. The foundation is built for making simulation models look closer to reality and preparing them for future use in digital twin scenarios.

"This project is just the beginning of our collaboration with Nvidia," said Juha Renfors, vice president of product management at Visual Components. "By developing our application with Nvidia Omniverse APIs, we've created a strong foundation for future functionality of virtual simulation."

For customers, the application will help with faster alignment, stronger communication, and greater confidence when making design and investment decisions. Layouts created in Visual Components can now be reviewed and presented in a shared 3D space that looks and feels closer to reality, making proposals and alternatives easier to understand for both technical and non-technical stakeholders.

One of Visual Components' partners, MiTek, a global construction and engineering company, has already participated in previewing the new technology.

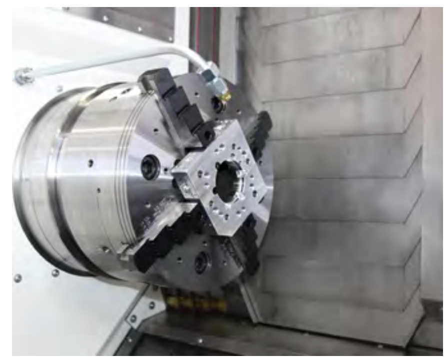
"Visual Components has become an integral part of our machine lifecycle over the past two years," said Xavier Ficquet, engineering manager of MiTek. "With this new add-on technology, we've been able to train our employees much more effectively through virtual simulation, bringing us closer than ever to the experience of working with the actual equipment."

By unveiling the add-on together with Nvidia at GTC DC, Visual Components underscores its commitment to helping manufacturers and system integrators progress from simulation models toward more realistic digital twins, setting the stage for future advances in how factories are designed, validated, and communicated.

visualcomponents.com

Schunk

PROVIDES ROTA THW3 2+2 POWER LATHE CHUCK



Contract manufacturers and machining companies know how important process-stable and versatile clamping devices are. Especially for batch size 1 and high part variability in custom production, short setup times and flexibility are essential. Since modern turn/mill centers perform turning and milling simultaneously, a reliable and flexible clamping device is indispensable for precise workpiece machining—particularly when geometrically undefined or irregular parts need to be machined in a second clamping operation. Schunk now provides an innovative clamping concept for these demanding requirements with the new ROTA THW3 2+2 power lathe chuck. This 4-jaw lathe chuck features two independent jaw pairs with subsequent centrally compensating workpiece clamping, enabling safe and reliable clamping of freeform parts, castings, or geometrically undefined workpieces. Thanks to the patented sealing, companies can confidently use this 2+2 compensation lathe chuck in harsh environments with dirt and fine chips. In addition, users benefit from consistently high clamping forces and significantly extended maintenance intervals, resulting in increased productivity without compromising quality.

Following the manual lathe chucks, Schunk now introduces a 2+2 jaw compensation lathe chuck for power lathe chucks, which is particularly indispensable for automated applications. The new power lathe chuck provides centrally compensating workpiece clamping for all workpiece geometries, making it an ideal solution for complex parts on lathes. This flexibility allows parts to be completed on lathes that previously required an additional milling operation. The integrated jaw quick-change system enables users to adapt the chuck quickly and easily to new clamping tasks, resulting in a significant increase in productivity. Thanks to the sealing, the maintenance effort is reduced, lowering lubricant consumption and minimizing used grease—making Schunk a key contributor to resource-efficient manufacturing processes. Schunk will offer the flexible lathe chuck from mid-2026 in sizes 230, 265, and 315 mm in dia.

schunk.com

Big Daishowa

ANNOUNCES INSERTS FOR ROUGH AND FINE BORING APPLICATIONS

Big Daishowa announces new negative inserts for its SW rough boring and EWN fine boring heads. These series feature proprietary six-edge designs to help machinists realize major productivity gains.

The SW roughing heads use trigon-shaped ZN inserts, which help reduce consumable costs by increasing the number of cutting corners per insert. Insert grades focused on steel and cast iron maximize tool life in challenging applications like mold and die and large welded parts.

The special cutting-edge preparation allows the insert to have a positive-geometry cutting action, so there's no relative increase in cutting tool pressure and equal-to or better performance compared to traditional positive inserts.

Customers can choose from two different ZN insert sizes and the range of insert holders available covers the boring range of Ø1.260-8.00 in.

"At Big Daishowa, we're focused on constant innovation when it comes to all of our products, and inserts are no exception," says Alan Miller, senior engineering manager. "The never-before-seen design of the ZN insert embodies that; all to help our customers realize exciting productivity gains."

The new triangle-shaped TN inserts were developed for the EWN fine boring heads and feature the same double-sided design and positive-geometry cutting edge. The TN insert holder program provides productivity boosts for the boring range of Ø1.614-6.024 in.

bigdaishowa.com

Walk with Purpose

How Jared Lyford of Forest City Gear walks the walk and talks the talk when it comes to workforce development

Aaron Fagan, Senior Editor

When you talk with Jared Lyford, director of operations at Forest City Gear and the newly appointed president of the Rock River Valley Tooling & Machining Association (RRVTMA), it becomes clear very quickly: workforce development isn't a program for him. It's a calling—and one shaped by lived experience.

The phrase that encapsulates his philosophy is one he heard as a teenager in an apprenticeship program at Forest City Gear himself: Walk with purpose. It was not a slogan; it was an ethos—instilled by a mentor who believed that the way you move through a building says something about the way you move through life. As the saying goes: How you do anything is how you do everything.

Lyford recalls, "He said, it doesn't matter if you're going from point A to point B, or you're going from your workstation to lunch, or you're leaving at the end of the day—always walk with purpose. Have your head up, walk forward, act like you have intention. If you act like you have intention, you're going to feel like you have intention and you're going to be recognized like you have intention."

More than 25 years later, that mindset still guides him—from the shop floor to the boardroom.

From Apprentice to President

Lyford's recent appointment to RRVTMA board president represents a full-circle moment in his career. The RRVTMA is a local chapter of the National Tooling & Machining Association (NTMA), serving area manufacturers through networking, training resources, and apprenticeship pathways.

"The purpose of the chapter is to organize local manufacturers to get the membership perks of the NTMA and more… one of the main things we provide is training and apprenticeship tracks for people within manufacturing."

The association offers a four-year precision machining apprenticeship with 8,000 hours of on-the-job training for gear manufacturing or a 10,000-hour tool and die track, and includes 160 hours of coursework through a partnership with Rock Valley College. Successful apprentices earn not only state credentials but federal recognition: RRVTMA apprenticeships are accredited by the Department of Labor, meaning graduates are officially indentured journeymen in the trade.

Lyford now leads the organization he once went through himself. "My initial ideas are to continue the work the board has started and provide ongoing strategic direction to improve member value—as well as the quality of output for the apprentices—to maintain or provide more offerings."

At Forest City Gear—A Workforce Strategy

At Forest City Gear, Lyford occupies a role with reach: coordinating manufacturing operations, facilities, and capital expenditures for a company that supplies gearing for aerospace, defense, and space applications.

"We are a contract manufacturer for loose gearing… We build completely to the customer's design."

But gearing alone isn't the biggest challenge—staffing is.

"There's a skills gap—and in order to find turnkey talent to satisfy immediate capacity needs is challenging."

Forest City Gear meets that challenge through extensive training, using both internal resources and outside expertise. "We utilize Helios, Gleason, Kapp, and all of their resources—and we're very active with the AGMA and AGMA's training—to help technicians get a more in-depth understanding of what they're doing."

The need is urgent. "We've just gone through a transitional time where the boomers are leaving the workforce and Gen X is aging… it becomes critical to build that pipeline."

The Long Path to Clear Direction

Lyford didn't arrive at this philosophy from a textbook. It was earned through trial, transition, and recalibration.

As a high school student, he entered a competitive vocational program supported by 21 local companies, including Forest City Gear. He was the highest-scoring aptitude test candidate from his school, and by the time he graduated, he was already setting up gear inspection equipment—getting hands-on experience that few students ever receive before entering the workforce.

He started full-time at Forest City Gear, but another principle stayed with him—this time from a tool and die maker who asked what he planned to do with his future. When Lyford admitted he wasn't sure, the man replied: "If you don't get a degree, get a trade."

He never forgot that. When someone else later suggested he would make a good tool and die maker, he followed the advice—left Forest City Gear—and eventually earned his journeyman's credential through the same RRVTMA program he now leads.

Then 9/11 hit. The company he worked for contracted. Lyford suddenly found himself overqualified for many positions and underutilized in others. He spent time working in automation and assembly, gaining new skills but questioning his trajectory.

One day in the tool room, everything changed again. Someone waved a newspaper in his direction. On the front page was Fred Young of Forest City Gear, standing beside a headline that read "In High Gear." Lyford called that night. Forest City Gear remembered him. A door reopened. A framed copy of that article is displayed above his desk.


BusinessMonday

IN HIGH GEAR

Forest City Gear profits from fresh approach to business

Associated with the best Home Equity rates Bank

Full Circle but Gear Shaped

In 2009, another challenge—and opportunity—arrived. Wendy Young approached him with a question: would he consider going back to school for a business degree? He said yes immediately.

"I went to Rockford University in their bachelor's program for business management… I graduated in 2013, and when I graduated, I really full-circled that and said, the thing was, if you're not going to get a degree, get a trade. I had gotten a trade… and then I had the opportunity to pursue the degree."

But he's quick to point out something crucial: for many people, the trade-first, degree-second path is not only viable—it may be more effective.

"If I had gone straight to college from high school, I wouldn't have had direction… I think a lot of people have to be able to walk with purpose—to show intent—and carve out a space for themselves."


Jared Lyford, director of operations, Forest City Gear.

That belief now shapes his approach to workforce development. Young people don't necessarily need immediate clarity—but they do need exposure. They need mentors. They need opportunity. Most of all, they need intention.

Walking Forward

Today, whether at Forest City Gear or RRVTMA, Lyford speaks about workforce development with conviction and commitment. Manufacturing relies on systems, but systems only work if people do.

When asked to summarize Forest City Gear's philosophy in a single sentence, he didn't hesitate:

"Training and workforce development is non-negotiable—that's something you have to do without consideration to risk or cost," Lyford said. "Yes, someone may leave after you've invested in them. But if you take a holistic view, that investment still develops the capability of our industry as a whole. You're building the future—whether they stay or not."

Looking back, the common thread is clear—and it brings him back to that phrase he first heard as an apprentice himself: Walk with purpose.

In an industry searching for talent, clarity, and direction, those three words may be more than personal wisdom. They may be the blueprint—for companies, careers, and the future of American manufacturing.

forestcitygear.com
rrvtma.com
ntma.org

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MPMA and Federtec Bridge the Global Skills Gap

Modernized, on-demand courses provide accessible gear education for the next generation of professionals

Aaron Fagan, Senior Editor

As the gear and power transmission industries evolve, companies worldwide face a critical challenge: how to ensure the workforce is skilled, prepared, and ready to tackle increasingly complex manufacturing processes. From digital manufacturing and automation to generational turnover, the demand for technically proficient employees has never been higher. In response, the Motion + Power Technology Association (MPMA) redeveloped its Workforce Training Series, modernizing its most popular on-demand courses with updated content, high-quality media, and a flexible, self-paced delivery model.

Now, in collaboration with Italy's Federtec, the series is available in Italian, expanding access to high-quality, gear-focused education across Europe. The partnership signed in March 2024 allows Italian members to access the translated courses at a discounted rate of $99 (USD), while members of both organizations enjoy free access to the series in English and Italian. The Italian-language courses have been available since July 2025.

Global Collaboration for Workforce Development

The MPMA-Federtec partnership exemplifies a growing international focus on standardizing and improving technical education in the gear industry. "As the gear and power transmission markets become increasingly interconnected, it's critical for MPMA to build strong alliances with international counterparts," says Leah Lewis, MPMA's senior director of events and education. "Working with Federtec not only expands the reach of our technical and educational resources, but it also fosters a more unified approach to standards development, workforce training, and innovation."

Sergio Sartori, vice president of Federtec and Federtec Academy, emphasizes the collaborative nature of the initiative: "By joining forces with MPMA, we are building a bridge between two industrial cultures. This partnership strengthens our industries, promotes technological innovation, and prepares the next generation of professionals for global competitiveness."

Federtec itself has grown into a dynamic hub for Italian industrial excellence. Founded in 2019 from the merger of ASSIOT, the Italian Association of Gear and Transmission Manufacturers, and ASSOFLUID, the Italian association for fluid power equipment, Federtec further expanded its reach in 2022 with the incorporation of FNDI, the National Federation of Industrial Distribution. Today, it represents companies across the mechatronic technology supply chain, supporting members with networking, specialized training, and innovation-focused projects.

Redeveloping the Workforce Training Series

The Workforce Training Series has long been one of MPMA's most downloaded resources. Recognizing the need for modernization, MPMA updated the series to reflect the latest technological advancements, improve accessibility, and better meet the needs of contemporary learners.

"These courses are designed to meet gear professionals where they are, whether they're just entering the industry or looking to sharpen specific skills," Lewis explains. "The redevelopment focused on making the material more visually engaging and easier to navigate, while ensuring that the technical content remains accurate, up to date, and directly applicable in the field."

Key updates include:

- High-quality diagrams, schematics, photos, and videos illustrating technical processes.

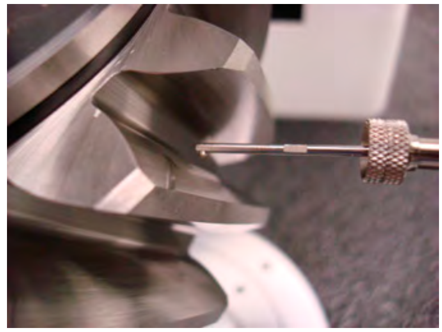
- On-demand access, allowing learners to complete courses at their own pace.
- Italian-language translations, expanding accessibility for European audiences.

Course Highlights: Technical Skills at Every Level

The redeveloped series includes several flagship modules, each providing foundational skills as well as practical guidance for immediate application.

Fundamentals of Gearing 2.0 provides a comprehensive overview of the gear industry. The course begins with a brief history of gearing, then proceeds to core concepts such as parallel-axis gear basics, involute tooth forms, diametrical pitch/module, pitch, and pressure angle. The module concludes with a glossary of 37 essential gear terms—ensuring learners have a solid technical vocabulary for both shop floor and engineering environments.

Hobbing 2.0 is designed for machine operators, gear technicians, and engineers. It covers the hobbing process, hob cutting tool terminology, generating gears, hobbing machine terminology, mounting and truing of hobs and workpieces, basic part inspection, and identification of common problems such as tooth size deviations and runout. This practical, application-focused approach helps learners translate theory into daily operational skills.



Parallel Gear Inspection 2.0 focuses on level-one gear inspection. The course introduces measurement categories, single and double flank composite inspection, measurement sequences, and evaluation of gear characteristics. Learners gain insight into when and how to measure gear elements and understand the classification of gear quality, preparing them for real-world quality control tasks.

"These programs are MPMA's most downloaded courses," Lewis notes. "We want to make sure they continue to provide the best resource for training new employees on the basics of gear manufacturing. As technology changes, our training must evolve with it."

Addressing Workforce Challenges Globally

The MPMA-Federtec partnership also tackles a shared workforce issue: succession planning. Both the U.S. and Italian gear industries face an aging workforce, coupled with a need for new talent to operate advanced machinery and implement digital manufacturing processes. "Succession planning is one of the most pressing challenges facing the gear industry today," Lewis says. "Through entry-level training, advanced engineering courses, and leadership development programs, we help companies cultivate talent internally while making gear manufacturing an attractive long-term career option."

Translated courses are particularly valuable for companies with multinational teams. Standardized training ensures employees in different locations share the same knowledge base, which helps improve efficiency, consistency, and overall workforce readiness. The Italian translation of the Workforce Training Series represents a first step toward making MPMA education more inclusive globally, with the potential for additional language offerings in the future.

The Strategic Value of Education

From Federtec's perspective, the collaboration underscores the importance of international cooperation in industrial education. "This strategic collaboration unites our strengths and is essential for spreading industrial culture and promoting technological innovation," says Mauro Rizzolo, Federtec president. "Together, we can share knowledge, experiences, and resources, strengthening the global competitiveness of our companies."

By combining MPMA's internationally recognized expertise in gear manufacturing with Federtec's local knowledge of the Italian industrial ecosystem, the partnership serves as a model for cross-border workforce development. It demonstrates that strategic alliances in education can have a tangible impact on operational excellence, innovation, and global competitiveness.

Looking Ahead

The Italian-language Workforce Training Series has now been fully integrated with MPMA's English offerings. Federtec continues to promote the courses among its members, targeting OEMs, suppliers, and training partners alike. As manufacturing continues to globalize, partnerships like this one provide a scalable solution for bridging skills gaps, standardizing knowledge, and preparing the next generation of gear industry professionals.

"The Workforce Training Series is more than just a set of courses," Lewis concludes. "It's a pathway to ensure that our industry remains competitive, innovative, and prepared for the future."

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Advanced Lubrication Technology

Shell Gadus OG grease enhances open gear operation in mining facility

Shell Lubricants

Lubricants selection is important, but not the only step miners must take if they want to drive operational efficiency through greater equipment health.

Operating for long hours, under extreme loads, in high temperatures and dusty environments, ongoing wear is a significant challenge for open gears. This can lead to unplanned downtime and reduced equipment life—creating a barrier to effective operations. Leading mining and cement companies use advanced grease technology and technical inspections to help prevent open gear failure, optimize service life and ensure the smooth running of their operations.

The Shell Gadus OG greases range delivers a tailored and reliable solution to the challenges of maintaining open gear operations. Along with its proven load-carrying capacity and protection for open gears under shock loads, it also delivers the right balance of additives to reduce wear.

Optimal graphite levels also provide emergency lubrication should unexpected spray system failures occur. In line with Shell's focus on safety, all our greases are REACH compliant, contain no harmful chemicals or heavy metals and apply easily for maintenance teams. The Shell Gadus OG greases range offers high-performance open gear protection—helping to maximize equipment life, minimize downtime and optimize grease consumption. By switching to Shell Gadus and working closely with the Shell LubeExpert team, the Maaden Barrick Copper Company (MBCC) in Saudi Arabia made estimated savings of almost $1.8 million.

Preventing Unplanned Downtime in Mining Operations

MBCC has operations spanning from the Red Sea to the central desert, and the company continues to explore new international opportunities. MBCC leverages cutting-edge technology such as the Typhoon geophysical survey—as well as AI and data modeling—to enhance mineral exploration in Saudi Arabia, enabling more precise targeting of critical minerals while reducing environmental impact and improving resource discovery efficiency.

MBCC's focus on sustainable innovation is visible across all projects. The company is pioneering new methods including a patent for circular recycling of gypsum and leveraging technology to reduce emissions and groundwater consumption as they build a sustainable future. Recently, while reviewing some of its open gear equipment, MBCC realized the components weren't adequately protected, risking both unplanned downtime and early replacement.

Struggling to protect their critical open gear mining equipment in Saudi Arabia, MBCC worked with Shell to carry out an audit of its existing lubrication practices. The audit by LubeExpert highlighted a range of issues with the open gear grease in use on the ball mill pinion gear, as well as with its application.

The previous grease product could not deliver adequate protection during the hottest and coldest periods of the year—a crucial feature needed by the mine to keep its open gear equipment running smoothly. In addition, the spray bar was poorly designed and placed. It delivered almost 60 percent of the grease to the unloaded side of the pinion gear, leading to 25 percent higher consumption than needed.

Combined with a lack of monitoring and lubricant support services from the supplier, these issues meant that the pinion was not expected to meet the OEM industry standard life for equipment of its type.

Delivering the audit of MBCC's pinion gear as part of the Shell LubeExpert service, the Shell technical team made recommendations designed to enhance open gear protection and extend the equipment's life. This included:

- Trialing Shell Gadus S4 OG Clear Oil 2000 as a higher-viscosity grease that offers better protection and pumpability in all weather conditions.
- Switching from the current grease to Shell Gadus S3 Repair as a preparatory step ahead of the trial.

Shell's expert team also:

- Redesigned the spray bar and moved it to a location where it could more effectively dispense lubrication.
- Installed larger 400 kg grease pots to increase the uptime on the lubrication system between refills.
- Made recommendations for the next planned shutdown of the open gear equipment.

The trial of Shell Gadus S4 OG Clear Oil 2000 was successful, with the Shell technical team monitoring its performance over a two-month period. As well as providing a stronger film and better protection in warmer weather (upwards of 100°C), the grease now delivers better protection in colder weather (below 10°C) due to its superior pumpability.

The redesign and relocation of the spray bar has eliminated the excess consumption of grease and improved its ability to protect the equipment. All of this has contributed to extending the lifetime of the pinion, reduced the labor costs associated with maintenance and prevented lost productivity from unplanned downtime.

Lubrication and Operational Efficiency in Mining

With equipment health crucial to the smooth running of mining operations, effective lubrication programs have a significant impact on the reliability and cost of site operations. By understanding the benefits of high-quality lubricants combined with digital services and expert technical advice mining facilities can build maintenance programs that improve their operational efficiency and support their sustainability goals.

This means focusing on operational efficiency and TCO, areas in which equipment maintenance has a critical role to play. Many sites are struggling to make the case for smarter investment in their lubrication programs whilst struggling with inefficient processes increasing the risk of costly breakdowns and unplanned downtime.

"One of the best arguments is highlighting how cheaper lubricants can end up costing you a lot of money," said Michael Longbottom, global LubeExpert coach, Shell Lubricant Solutions. "Quality lubricants might cost you more up front but, if you know they're being applied properly with the right processes in place, then the lubricant spend is going to be incredibly small compared to the wider maintenance budget."

Lubricants selection is important, but not the only step miners must take if they want to drive operational efficiency through greater equipment health. They must manage their lubrication systems as effectively as possible to make the most of the high-quality products they use. It is an aspect of maintenance where digitalization presents new opportunities for greater operational efficiency.

MBCC worked with Shell to carry out an audit of its existing lubrication practices in Saudi Arabia.

MBCC has operations spanning from the Red Sea to the central desert, and the company continues to explore new international opportunities.

"We are moving towards technology that allows operators to see a single lubrication point operating in the field and know if it performs as expected," says Longbottom. "We are also trying to move a lot of our inspection reports to digital so, when we get off the machine, we can press a button and send that report directly to the operators."

This can make a significant difference to mining operations when past process would typically see miners receiving an inspection report two or three days after the inspection was completed. Now, they can simply open an app to see information needed to make informed maintenance decisions.

Future Mining Priorities

MBCC is attempting to capture the potential of digital manufacturing across all its mining operations. Through a partnership with Hexagon, the company launched digital mining capabilities at Mansourah Massarah—a major step in enhancing efficiency, productivity and safety across the site. MBCC actively invests in Saudi Arabia's mining future by developing local talent and skills. By partnering with institutions like King Fahd University of Petroleum and Minerals, MBCC can offer specialized mining degrees equipping future mining leaders with advanced skills and technology expertise. Additionally, the company signed a memorandum of understanding (MoU) with MP Materials to explore a rare earth supply chain in Saudi Arabia. Collaboration with Fleet Space Technologies was also launched to enhance exploration through advanced geophysical methods.

shell.com

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Unique Pathways to Learning

GROB successfully implements European workforce development strategies in the United States

Matthew Jaster, Senior Editor

Participation in the GROB apprenticeship program in Bluffton, Ohio is growing 20 percent year-over year.

The disparities between workforce development in Europe and the United States are pronounced. For instance, apprenticeship programs in Europe commence at a significantly younger age and present a wider array of opportunities. While North American initiatives emphasize extensive cross-training in mechanical and electrical disciplines, the European approach delineates specific departmental and positional pathways much earlier in employees' careers. The challenge of training workers swiftly and effectively has long been a concern for manufacturing firms.

GROB has been at the forefront of manufacturing systems and machine tool development since 1926 in Munich. The company has production facilities in Germany, Brazil, China, the United States, Italy, and India, along with global service centers and sales subsidiaries.

In 2023, GROB Systems, Inc. commenced construction on a 135,000 sq. ft. U.S. expansion project. This addition augments the original 400,000 sq. ft. production and shipping space by approximately 35 percent and created approximately 200 new jobs at its U.S. headquarters and manufacturing site in Bluffton, OH. Celebrating a 34-year presence in the U.S. and significant growth in North America, the expanded area accommodates several of GROB's sub-assembly departments to enhance final production processes at the main facility.

Recently, *Gear Technology* engaged in a discussion about GROB's workforce development strategies in the United States with Thomas Neubert, chief sales officer of GROB Systems Inc. in Bluffton, OH. Like many international manufacturing companies, GROB has adapted several successful European programs for implementation in the U.S.

A Clearer Path Toward Skill Development

To retain skilled and qualified workers, GROB has identified several key focus areas. Neubert emphasized the importance of initiating conversations about growth opportunities and career pathways early in the employment process. "We need to support employees in pursuing further education, starting with competitive benefits—such as fully covered health insurance premiums and complimentary meals—while also fostering engagement through initiatives including holiday celebrations, company sports leagues, and organized running or cycling groups."

Neubert also highlighted the significance of being receptive to employee feedback. GROB's U.S. apprenticeship program, which mirrors the model used in Germany, has successfully integrated over 600 apprentices since its inception in 1990.

Another significant advancement has been in the implementation of an online learning management system. "Our headquarters in Germany began offering online training years ago, and we have recently developed our own library of courses. This format allows employees to access training on-demand and at their own pace," Neubert stated.

Currently, GROB's apprenticeship program combines paid, hands-on training with classroom instruction, mentorship on the shop floor, and exposure to various career paths. Apprentices receive a fully sponsored associate's degree in electro-mechanical engineering technology from Rhodes State College of Lima, OH, along with a state-recognized journey person certification. The program has transitioned from offering strictly mechanical or electrical degrees to a comprehensive electro-mechanical degree that equips apprentices with a broader skill set, enabling them to adapt to diverse roles as needs arise.

"Our program has expanded dramatically over the past decade, growing from 10 apprentices in 2015 to 60 in 2025. This nearly 20 percent year-over-year growth rate over the last five years reflects both the increasing demand for skilled trades and our commitment to nurturing talent from within GROB," Neubert explained.

In their second year, apprentices receive mentorship from shop floor technicians during departmental rotations. By their third year, they are placed in a specific department for specialized training, continuing to learn from seasoned technicians who provide invaluable insights and training.

Additionally, GROB has established a dedicated Learning and Development department focused on creating training initiatives for its workforce. "Our GROB Academy program, available to employees from their first day until retirement, provides various pathways for both technical and professional development. Collaboration across departments allows us to develop training that employees can choose or that management can assign," Neubert added.

The GROB Academy currently offers 143 online courses accessible on-demand. As of July 2025, 646 employees have completed 3,600 courses, dedicating 1,750 hours to learning since the online program's launch in April 2024. Moreover, 189 employees have attended in-person professional development workshops offered within the company in 2025.

"Our product lineup is continuously evolving, necessitating ongoing learning in advanced manufacturing processes. The CEO also hosts company meetings to educate employees about our product lines, current projects, and manufacturing trends. With our learning management system, we will keep developing training for new technologies as they emerge," Neubert noted. "We also leverage Articulate 360, a suite of online tools for creating interactive e-learning content, which includes a learning management system that hosts, delivers, tracks, and reports on employee training. Feedback surveys help us assess training needs."

A Productive Workplace

Critical thinking, problem-solving, and communication are essential for cultivating a collaborative and productive workplace. Neubert pointed out that proactive critical thinking is crucial, emphasizing that training employees to anticipate potential issues rather than merely reacting to them enhances productivity and efficiency.

Regular communication regarding employee expectations is vital to ensure that meeting these expectations is a reasonable challenge rather than a guessing game. Discussions around expectations can encourage dialogue, allowing employees to contribute suggestions for improving processes.

Furthermore, the strategic use of automation and robotics can positively influence workforce development. "Manufacturing companies nationwide, regardless of size, are facing challenges in sourcing candidates to meet their hiring needs. It's common to see 'Now Hiring' banners displayed prominently. By incorporating automation and robotics, we can reduce repetitive manual tasks, thereby requiring less manpower and allowing employees to concentrate on more technical responsibilities," Neubert elaborated.

Eliminating repetitive tasks creates a demand for new skills, such as data analysis, allowing GROB to focus on upskilling its workforce. "This enables employees to adapt to new technologies and advance to higher-value roles, ultimately enhancing job satisfaction and engagement," Neubert added.

Current & Future Workforce Strategies

The U.S. Departments of Labor and Education have recently announced a collaborative effort to integrate the federal government's workforce initiatives through an innovative partnership. They are launching an integrated state plan portal to streamline federal workforce development programs, enabling Labor and Education to jointly manage core "Workforce Innovation and Opportunity Act" programs. The Department of Education will allocate program funds and assign staff to the Department of Labor to bolster these efforts.

The current administration aims to optimize and direct federal investments in workforce development to align with the United States' reindustrialization needs and equip American workers to meet the rising demand for skilled trades

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and other professions. Additionally, they plan to strengthen and protect registered apprenticeships to build on their successes and seize new opportunities.

In the EU, several initiatives are underway, including the recently adopted union of skills communication and an AI continent action plan. Emphasizing anticipatory governance, fostering a culture of innovation, supporting diversity and inclusion in the AI workforce, and enhancing digital infrastructure are critical to ensuring the equitable distribution of AI benefits while mitigating its negative impacts. Aligning with European values is essential to promote fairness in this journey. The future prosperity of the EU hinges on harnessing AI's potential within a human-centric and ethically grounded framework that prioritizes transparency, accountability, and the well-being of individuals.

Targeted investment in EU-wide digital infrastructure and education emphasizing lifelong learning and skills development could promote balanced economic growth and enhance competitiveness in the global talent market. By exploring the complex interplay between AI, skills, and jobs, a viable path forward may emerge to address the needs of EU citizens and equip the future European workforce for success in an increasingly automated and AI-driven economy.

Closer to home, Neubert affirmed that GROB will continue collaborating with company leadership to anticipate future products, technologies, and customer needs, ensuring their training programs proactively prepare employees for upcoming challenges.

"GROB's apprenticeship program will evolve not only in size but also in scope. We are working to expand opportunities beyond traditional technician roles, creating non-traditional pathways for apprentices to apply their technical skills in areas such as engineering, sales, customer service, and project management. Our goal is to cultivate a dynamic workforce that actively supports career growth," Neubert concluded.

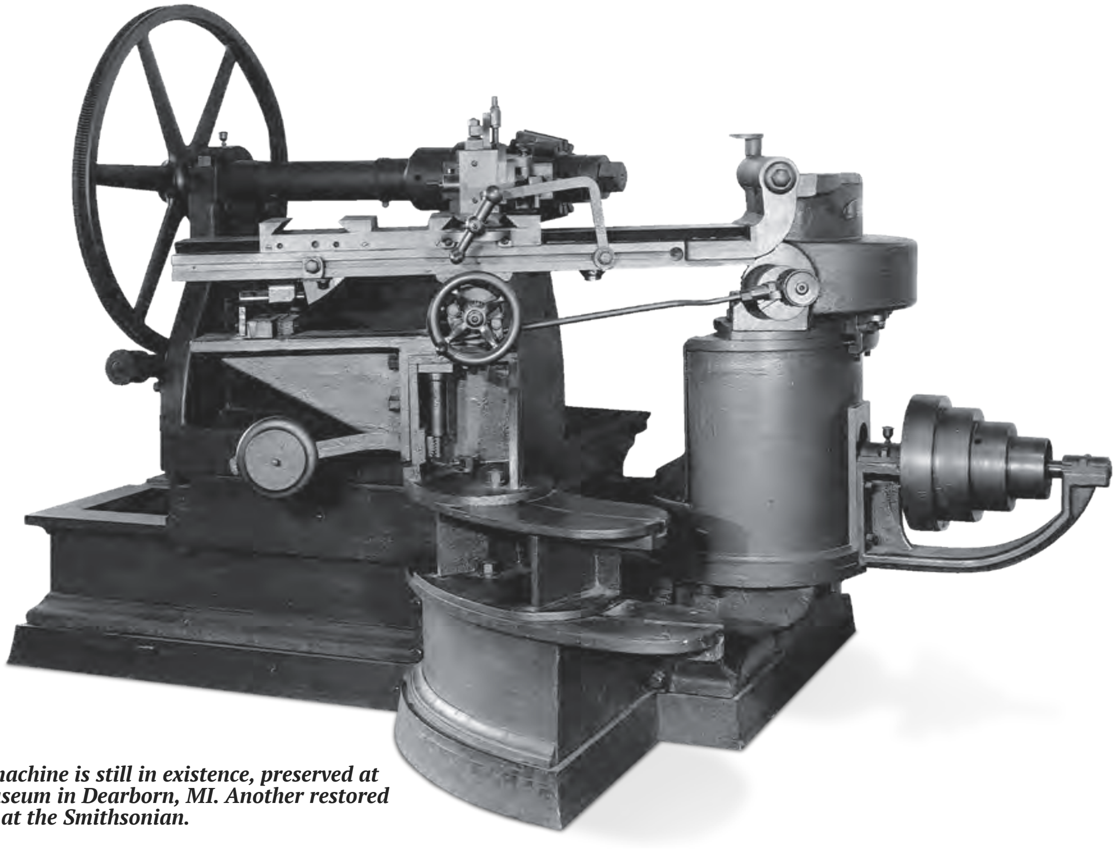
grobgroup.com/en

A Legacy of Precision, Innovation, and Global Leadership

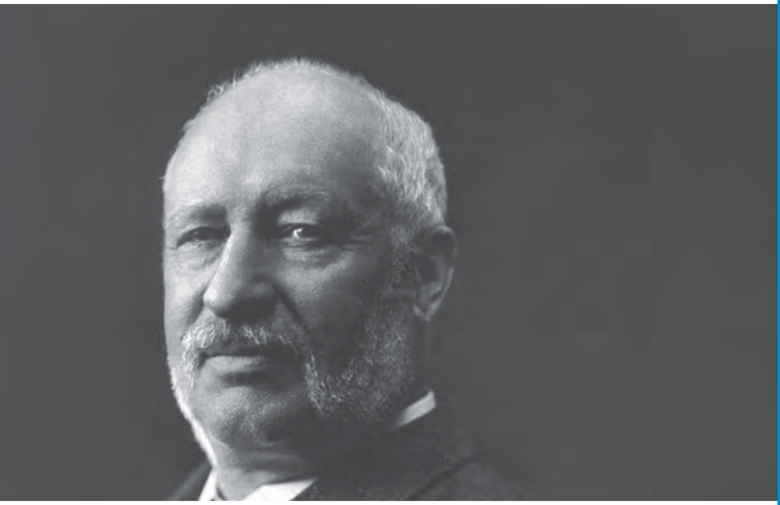
For over 160 years, the Gleason name has been synonymous with groundbreaking advancements in gear technology.

From its origins as a small machine shop to becoming a global leader in precision engineering, Gleason Corporation has continuously redefined the industry. This journey, marked by pioneering inventions and strategic expansions, has left an indelible mark on sectors ranging from automotive and aerospace to robotics and renewable energy.

The Gleason story began in 1865 when William Gleason established his first machine shop in the Brown's Race district of Rochester, NY. His commitment to precision engineering quickly gained recognition, but it was the invention of the first bevel gear planer in 1874 that transformed the industry. This innovation enabled the mass production of gears with unprecedented accuracy, setting the foundation for Gleason's future dominance. In 1876, the growing demand for precision gears led William to formally establish The Gleason Works—a company built on craftsmanship and a spirit of continuous innovation. What began as a small workshop soon evolved into a full-scale manufacturing enterprise supplying gear-cutting machines worldwide. As demand for high-quality gears grew, Gleason officially relocated in 1905 to University Avenue, Rochester, NY, which became one of the most advanced industrial sites in the region. The new headquarters allowed for increased production, research laboratories, and training facilities. In 1916, Gleason became a founding member of the American Gear Manufacturers Association (AGMA), helping to establish unified quality standards for gears—a commitment to precision that remains central to the company's philosophy today.



The first Gleason machine is still in existence, preserved at the Henry Ford Museum in Dearborn, MI. Another restored machine is located at the Smithsonian.

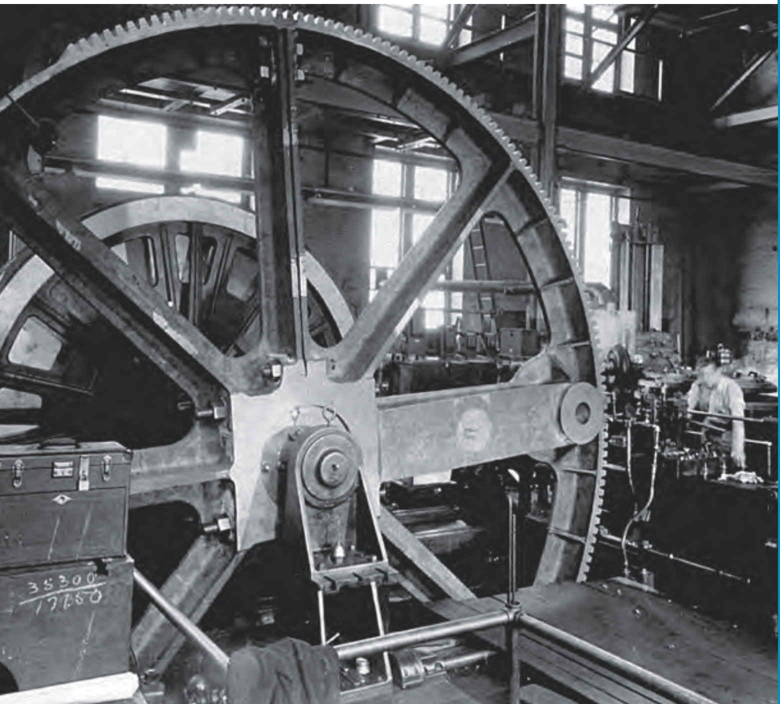


William Gleason was born in Ireland on April 4,1836. He was an accomplished mechanic before his service in the Civil War at Colt's Armory in Harftord, CT. Gleason's anticipation of post-war railroad expansion in the United States fueled his belief in metalworking and machinery as keys to the future.

Engineering Breakthroughs and Gear Education

Throughout its history, Gleason has been at the center of major industrial milestones. As early as the 1880s, its bevel gear technology powered railway expansion, ships, and mining operations during the height of the Second Industrial Revolution. By the early 20th century, Gleason machines were operating on nearly every continent. Gleason's innovations played a crucial role in numerous engineering landmarks, including the Panama Canal, where its precision gears were integral to the canal's lock systems. The massive gears, some exceeding 20 feet in diameter, were produced on specialized Gleason planers—a feat of mechanical engineering at that time.

A 20-ft. Gleason spur and internal gear planer is used to cut the gears inside the Panama Canal's locks and doors.



A Family of Innovators

The success of Gleason Corporation is deeply intertwined with the vision and dedication of the Gleason family. Each of them played a significant role:

A pioneering female engineer and business leader who expanded Gleason's global reach.

A technical innovator who played a crucial role in advancing gear manufacturing technology.

A distinguished mathematician who contributed to scientific advancements beyond the company.

The modern architect of the company's continued success and strategic global expansion.

Hypoid gear, designed by gear theory expert Ernst Wildhaber.

During the mid-20th century, Gleason continued its technological leadership by contributing to the Apollo Space Program, where its gears played a critical role in space exploration machinery.

Curvic Couplings for industrial and aerospace applications.

To sustain its rapid growth, Gleason launched its first Gear School in 1919, offering structured training for engineers and machine operators. This institution would later evolve into a global center of excellence for gear technology training, the very foundation of what today makes Gleason the number one in education and training for gear manufacturing worldwide.

The introduction of the Hypoid gear in the 1920s, designed by Gleason's Ernest Wildhaber, revolutionized the automotive industry by improving drivetrain efficiency, enhancing vehicle performance, and enabling modern differentials. Gleason's patented manufacturing process quickly became the global standard, powering the automobile revolution. During the 1930s and 1940s, the company also contributed to the aviation and defense industries, providing the precision required for aircraft and naval systems. Curvic couplings provided a highly precise gear connection, improving alignment and power transmission in industrial turbines and jet engines. These couplings became indispensable in the aerospace industry and were even used in NASA's Apollo Space Program, helping humanity take its first steps on the moon.

Expansion, Innovation, and Education

During the 1950s and 1960s, The Gleason Works expanded and modernized its production to meet booming demand from the automotive and defense industries. A new foundry opened in 1956, and the Rochester facility became one of the world's most advanced machine tool plants. In 1958, Gleason launched its first Gear School in Rockford, IL, establishing a lasting tradition of customer education in gear theory and manufacturing. At the same time, innovations such as the No. 116 Hypoid Generator and No. 606/607 Formate gear cutting cells with automation became bestsellers worldwide, setting new benchmarks in precision and versatility.

The 1980s brought about another leap forward: The launch of the Phoenix machine series introduced cutting-edge CNC bevel gear cutting and grinding solutions, setting a new industry benchmark for precision and efficiency.

The Phoenix machine series first appeared in 1988, and the latest editions to this line are the 100C and 500C bevel gear cutting machines.

Today, Gleason is at the forefront of technological advancements in wind power, e-Mobility, automation, and robotics.

Total Gear Solutions

In the 1990s, Gleason continued to diversify, acquiring German Hurth Maschinen und Werkzeuge as well as Hermann Pfauter Maschinenfabrik, leading European gear technology manufacturers that expanded the company's expertise into cylindrical gear technology. This period marked the beginning of Gleason's Total Gear Solutions concept—combining all gear manufacturing steps into one integrated process chain. The early 2000s also saw the introduction of the Genesis series, a line of modular machines that combined precision with flexibility, responding to new demands in automotive, aerospace, and energy sectors. The acquisition of KISSsoft AG in 2016 brought advanced simulation and design software into the company's digital ecosystem, making Gleason the only gear technology provider covering the complete value chain—from virtual design to finished gear inspection. In the following years, Gleason expanded its research partnerships with universities such as RIT and leading engineering institutions worldwide. In 2025, Gleason further expanded its global footprint and metrology program through the acquisitions of Fubri s.r.l in Italy and the Intra group of companies, strengthening its manufacturing network and service capabilities. Gleason's guiding principle remains unchanged since 1865: a dedication to precision, partnership, and continuous improvement.

A Future Driven by Innovation

The culmination of Gleason's expertise is encapsulated in its Design, Manufacture, Measure approach, based on digital twins and smart loop technology. This ecosystem of advanced simulation, real-time manufacturing, and precise metrology ensures superior quality and performance, redefining the future of gear production. As the company continues to explore new frontiers in digitalization, sustainability, automation and robotics, its legacy of precision engineering remains as strong as ever. With a steadfast commitment to excellence, Gleason is not just shaping gears—it is shaping the future of the industry itself.

gleason.com/160

What I Learned from the MPT Expo Power Breakfasts

Mary Ellen Doran, VP, Emerging Technology, MPMA

At the 2025 Motion + Power Technology Expo, we introduced a new format: Power Breakfasts—early morning expert panel sessions held before the show floor opened. Over three days, we hosted discussions on robotics, aerospace, and tariffs, providing valuable insights while giving attendees (and their coffee) a head start. I organized the robotics and aerospace sessions and want to share key takeaways from both.

MPMA is also expanding its advocacy efforts, particularly around policy and tariffs. This work will continue to grow in 2026 as member needs evolve.

Robotics Panel at MPT Expo, including Randy Howie, Founder and Managing Partner, New York Robotics; Mitch Tolon, CEO and Founder, Ally Robotics; Alex Shikany, Executive Vice President, Association for Advancing Automation (A3); and moderator, Mary Ellen Doran, VP Emerging Tech for MPMA

Robotics: Supply Chains and New Opportunities

The Robotics Committee has gained momentum over the past two years under the leadership of Robert Kufner, CEO and President of Designatronics. The committee authored two white papers, facilitated discussions with OEMs, and recently partnered with the Electric Vehicle Committee for a session featuring the inventor of the Hoop Drive. Though Robert was unable to attend the Expo, his guidance shaped the direction of our robotics panel.

Their central message was clear: robotics demand is accelerating, and the supply chain must stabilize to keep pace. Gearbox technologies continue to evolve—from strain wave and cycloidal designs to advanced planetary systems—and suppliers must be ready to support next-generation robot architectures.

Panelists agreed that stronger collaboration between robot manufacturers and component suppliers can reduce lead times, improve consistency, and support scalability. As automation spreads across industries, these partnerships will be critical.

They also emphasized opportunities for smaller suppliers. Over the next decade, advances in lightweight materials, integrated sensing, and modular robot designs will create access points for companies able to deliver agility and innovation.

Air Mobility: The Next Frontier

Aerospace is entering a rapid transition. With growing activity around hydrogen propulsion, eVTOL platforms, autonomous flight, and new certification models, the manufacturing base must adapt quickly.

Air Mobility Panelists

- **John Keogh**, LIFT (Manufacturing USA network)
- **Ted Angel**, National Advanced Air Mobility Center of Excellence
- **Dr. Amy Thompson**, Connecticut Center for Advanced Technology

These organizations are actively preparing suppliers for what's ahead—developing advanced materials, building workforce training programs, integrating digital threads, and working toward new frameworks that will support emerging aircraft technologies.

The supply chain, they noted, must evolve immediately—not gradually. Smaller manufacturers will need access to funding, training, and digital capability-building resources to participate in this shift. The question isn't only technological readiness—it's whether suppliers can engage at the right moment, with the right tools, at the right scale.

What Comes Next

Across both panels, one message stood out: manufacturers who collaborate, invest in digital workflows, and pursue continuous education will be best positioned for the coming decade. MPMA's role is to create the connections and conversations that accelerate this progress.

To that end, I am forming a new Emerging Technology Committee focused on air mobility and eVTOL systems. A call to action for the first meeting will go out in January, and I encourage anyone interested to participate.

Thank you to all speakers, committee members, and attendees who helped make the Power Breakfasts a success. The conversations we started in Detroit will shape the next wave of innovation across motion and power technologies—and MPMA is committed to helping lead that effort.

Send your thoughts to Mary Ellen Doran: *doran@motionpower.org*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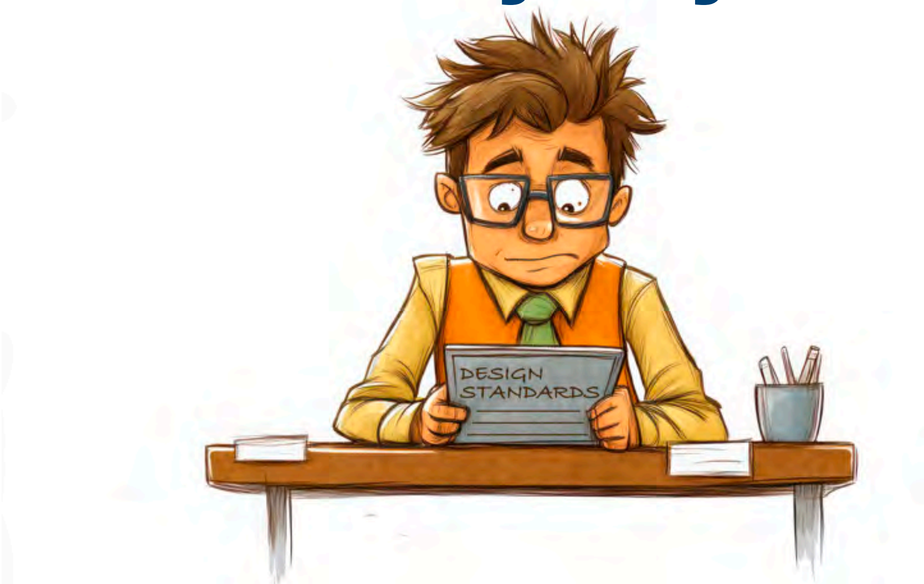

Todd Praneis, Vice President, MPMA Technical Division

Technical standards, like the ones managed by MPMA, can sometimes be daunting to pick up and know exactly what to do to properly understand and utilize them. Because we deal with a very technical subject matter, rolling element bearings and gearing, the information presented in the standards is very in-depth and requires a good understanding of the subject to really get the most out of the document.

On my first day of my first job after graduating from college (after all the HR paperwork), I was in my boss's office, excited for my first task. Go do a failure analysis on some dirty, broken gears? Help design the next big product? Solve some problem that's been stumping the other engineers? Not quite.

He handed me a printout of a gearset that had the basic information and a copy of AGMA 2001 and told me to go rate the gearset. Deflated, I went back to my desk and opened up the standard. A few days later, after many sheets of paper (I'm old, you know), I went back into that office and we went through the rating, comparing it to the computer-generated rating on file (it was a standard product gearset that had been in use for many years). I learned where I went right and where I went wrong.

In order to complete that task, I had to go through the document in detail and came away with a good understanding of the process. As I found out, one cannot just go to the final rating equation to plug in some numbers. There are layers upon layers of sub-calculations to get factors that go into another equation to finally get to the rating equation.

So, how would I suggest how to use our standards? A few ways:

- Read the foreword. It gives a summary of the history of the document and major changes over the revisions.
- Pay attention to the normative references. These are listed because it takes an understanding of those documents to fully understand the document in your hand; they are referenced somewhere in the body of the standard.
- If you are working with a standard that has equations, keep the symbols list handy. It'll save you lots of time trying to look through the text to find out what C_{ma} is…
- There are definitions in most of the standards, and they apply to that standard only.
- Pay attention to the text. I have been involved in technical committees for over 20 years and know how much time the committees and working groups spend on each sentence to make sure it conveys the right information.
- Know that standards are a basis of information or processes. The information is intentionally conservative so that one may use it to design a system that has the highest chance of success.
- Informative annexes and Information Sheets provide more in-depth or ancillary information on the subject matter. They are, as titled, information only and are there to help one understand the information that may or may not be in the scope of the standard or to convey processes that haven't been fully tested in the industry.
- If you want to know all there is about the subject, take a look at the bibliography. The entries there not only support the statements in the body of the document but also are references that the committee or working group felt are relevant to the subject matter.

AGMA has about 100 documents and ABMA about 50. Plenty of subject matter to practice on!

Design Method of System Tolerances in Cylindrical Gearboxes for Cost-Efficient Optimization of the Excitation Behavior

Laurenz Roth, Christian Westphal, Prof. Dr.-Ing. Christian Brecher

The design of cylindrical gears is currently often carried out separately from the development of surrounding gear components. This applies in particular to the procedure for defining the tolerance limits to be adhered to. In most cases, empirical design experience is used when the tolerance limits are defined on the drawings for housing components, gear shafts, roller bearings or gear bodies. The specification of the tolerance limits to be adhered to determines in detail the manufacturing processes for each individual component that are suitable for achieving the tolerance requirements. This has a major influence on the overall production costs. Due to the accumulating effect of the system tolerance chain, various types of deviations in surrounding gear components with an influence on the gear kinematics affect the tooth contact ratios to varying degrees. This means that not only profile and tooth flank deviations of the gear have a detrimental effect on the various components of the noise excitation, but also deviations on the housing, shafts and bearings as they have an impact on the gears' positions. At the same time, the specific costs per unit of deviation for the components used in a series gearbox are different.

State of the Art

The state of the art first discusses the methods available for determining manufacturing process costs. Existing models for mapping the deviation-cost relationship are then presented. Finally, methodical approaches to tolerance design on mechanical systems are presented.

Determining the Manufacturing Process Costs for Conventional Processes in Gearbox Production

Beckers has developed an evaluation model for the economic efficiency of production process sequences. Economic efficiency, which is defined as the quotient of yield per input of resources, is the result of the calculations. The use of resources (costs) can be classified into direct costs C_{in}, which can be directly allocated to the component, and overheads $C_{overall}$ (e.g., development costs or patenting costs). The overheads $C_{overall}$ are not further subdivided here in detail, as they are incurred independently of the selected process chain (Ref. 1).

The individual costs C_{in} can be further broken down into the costs of the raw part C_{RH} minus the income from returned material E_{RM} (chips or workpiece remnants). Other direct costs C_{SE} and the sum of all costs of the individual processes $C_{F,j}$. Other direct costs include transport, storage, etc. (Ref. 1). For the comparison of different manufacturing processes within the conventional process chain for gear production according to Klocke et al. the same values are assumed for E_{RM} and C_{SE} across processes, since, for example, transport scopes do not vary to any significant extent and the machined volume is identical (Ref. 2). This means that the processes used in a conventional process chain hardly differ in this respect. For the manufacturing costs of the individual process $C_{F,j}$ per component, a further breakdown can be made into labor costs $C_{L,j}$, machine costs $C_{M,j}$, tool costs $C_{W,j}$ and other items that are negligible for the following process chain comparisons (Ref. 1, 3). The expression formulated by Beckers for the individual costs K_{ein} is also proposed in a generalized form by Yu et al. for process sequences (Ref. 4). He uses the description to train a genetic algorithm to minimize the total costs. However, this approach is not further detailed.

The labor, machine and tool costs depend on the machining time of the individual part $t_{E,j}$ and the time of contact $t_{PA,j,k}$ of the tool. Changing the time of contact $t_{PA,j,k}$ by adjusting cutting parameters such as the feed rate or the number of strokes in turn has a major influence on the expected tool life $t_{SZ,j,k}$ and the quality parameters of the component. The time $t_{E,j}$ can be further broken down into basic time $t_{G,j}$, distribution time $t_{V,j}$, recovery time $t_{Er,j}$ and any waiting times $t_{W,j}$ (Ref. 1).

According to Klocke et al., the basic time $t_{G,j}$ can be determined by dividing it into primary machining and idle time $t_{h,j}$ and $t_{n,j}$. While the primary machining time $t_{h,j}$ includes all direct progress in the sense of process progress, the idle time tn,j includes supporting processes such as clamping, measuring, aligning the raw part in the machine or dressing the grinding tool (Ref. 3).

Consideration of the formulaic relationships shows that the cost variance is strongly influenced by the time per component. This time is subject, among other things, to the choice of cutting parameters and machining tactics (influence on primary machining time $t_{h,j}$) as well as additional expenses for calibrating the raw part in the machining position or changing to another tool (influence on idle time $t_{n,j}$), which are decisive for the quality parameters. The manufacturable component qualities of an individual process, therefore, correlate directly with the time per component in the process $t_{E,j}$, insofar as this is based on the basic time of the process $t_{G,j}$.

Correlations for Manufacture-Related Geometric Deviations and Resulting Costs

To determine the relationship between geometric deviation parameters and production costs, experience in the form of known values and subsequent interpolation can be used on the one hand, or an arbitrarily detailed modelling of the costs can be aimed for on the other hand, see section "Determining the Manufacturing Process Costs for Conventional Processes in Gearbox Production." Subsequently, a quality can be assigned to the total costs on the basis of measured values, production simulations or empirical knowledge. Modelling approaches for cost-tolerance functions (C-T functions) were therefore developed with the aim of enabling general applicability. The generally available data basis is not extensive, which poses a challenge. Many investigations were carried out under specific boundary conditions, which makes transferability to other manufacturing processes, tools or quantities challenging (Ref. 5–7).

If not only the individual process costs are considered, but the balance sheet limits are extended to the total costs of an assembly, additional costs arise due to fully assembled units. In addition to the individual component manufactured outside the tolerance, these include other good parts that are also discarded. If the individual tolerance is extended, the probability increases that the assembly will no longer fulfil its function. This approach results in the optimum for the total costs of an assembly for a simplified example shown in Figure 1, top left (Ref. 8).

For a generalized cost-tolerance description of the individual processes, He presents analytical approaches based on exponential functions and parameterizes these using a survey. He uses the developed correlations as a criterion for a generalized tolerance design. He compiles the costs for an acceptable workpiece property from individual cost items. The machine costs are only a subordinate part of this, see Figure 1, top right (Ref. 9).

Existing cost-tolerance modelling covers a wide range in addition to the actual production, which was described by Andolfatto et al. with a generalized formula for the individual costs Ci with hyperbolic, exponential and linear components, see Figure 1, bottom left (Ref. 10). The C-T functions of a manufacturing process should fulfil three conditions, which are in Equations 1–3.

$$t_A > t_B \rightarrow C(t_A) \leq C(t_B) \quad (1)$$

$$\lim_{t \to \infty} C(t) = C_0 \quad (2)$$

$$\lim_{t \to 0} C(t) = \infty \quad (3)$$

where

t is the size of tolerance;

C is the production costs, optional stated in a currency.

The relationship between a manufacturing process and the appropriate analytical description model is not always clear. Sanz-Lobera et al., therefore, present an alternative approach for determining a cost-tolerance relationship using measurement data and the assumed scatter shape of a geometric feature. He comes to the realization that the scatter shape has an important

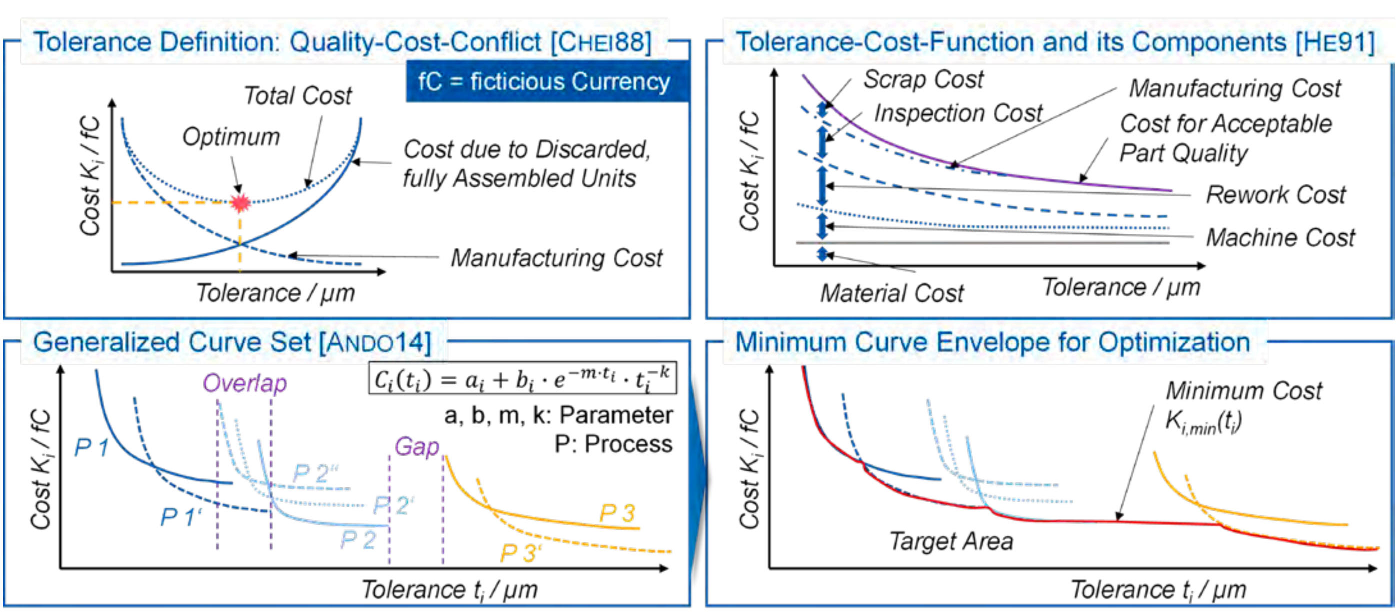

Figure 1—Quality-cost conflict, tolerance-cost function with its components and derivation of minimum costs according to Refs. 8–10.

influence on the cost-tolerance function and presents equations for some distributions (Ref. 11).

Hallmann et al. also described the selection of suitable cost-tolerance functions as challenging. In addition, the approach with higher-order methods, such as Artificial Neural or Fuzzy Networks, is mentioned there in order to identify suitable functional relationships. In particular, the fact that different processes can achieve identical qualities at different costs is also addressed there, see Figure 1, bottom right (Ref. 5).

Tolerance Design Methods for Mechanical Systems General

The aim of tolerance design is to minimize the effects of the deviation on the functional suitability of the product and to achieve an economically optimal distribution of the tolerances, taking into account the functional requirements (Ref. 12). For a cylindrical gearbox, for example, a function-orientated tolerancing of all components should be carried out in such a way that all units reliably pass the noise limit values in the end-of-line test at minimum cost. No additional costs are then incurred for reworking or scrapping. A distinction must be made between arithmetic and statistical tolerancing, whereby the latter represents the tolerance as a probability distribution or its characteristic values (Ref. 13).

Tolerance field-based micro geometry optimization has become established for the micro-geometric design of gears. After creating a full-factorial variant space in the FE-based tooth contact analysis, each variant is evaluated according to pre-defined criteria for the application behavior (Ref. 14).

Hallmann et al. presented a general method for tolerance optimization with regard to manufacturing costs and functionality. Initially selected tolerances were evaluated for the fulfilment of functionality and costs using a tolerance-cost function. Adjusted tolerances were assigned based on the results of the evaluation (Ref. 15). Schleich et al. presented a procedure for analyzing the geometric functional suitability of an assembly, based on finite surface models of the individual parts, in order to be able to take shape tolerances in particular into account (Ref. 16). Concrete approaches to tolerance optimization were not described.

Whitney developed a general systematic approach for the function-oriented design and mathematical modelling of assemblies (Ref. 17). DIN 7186 presents mathematical relationships for statistical tolerancing that allow the superimposition of statistical distributions and their parameters (Ref. 18). This is applicable for dimensional chains that are based on a Gauss normal distribution and in which there is a linear relationship between individual tolerance and overall tolerance. In real manufacturing and assembly processes, however, complex frequency density functions are often superimposed (Refs. 19, 20). Goetz et al. developed a general approach for assemblies with which preliminary tolerances can be defined economically at an early design stage using tolerance graphs (Ref. 21). However, this approach tends not to be suitable for complex systems such as gearboxes, including the quality parameters.

Schleich et al. investigated the influence of manufacturing-related deviations of the microgeometry on a pair of cylindrical gears on the transmission error by means of a regression adapted to the results of the tooth contact analysis (TCA). Interactions between different profile and lead line deviations were analyzed with the aim of achieving an appropriate tolerance of the microgeometric deviations, but not the influence of other component deviations (Ref. 22).

Conclusion on the State of the Art and Challenges

Currently, a function-oriented selection of all component tolerances under economic aspects for gear components that influence the operational behavior of the running gears is not state-of-the-art. However, there are only normative approaches in AGMA and ISO that relate individual deviations in the gearing to their effects on the load-carrying capacity (Refs. 23, 24). The preliminary work carried out is not readily suitable for the function-oriented definition of tolerances, taking into account scatter distributions for entire gearboxes. The reason for this is that there may be an unspecified correlation between the individual manufacturing deviations as input variables and the quality parameters as output variables. In addition, previous approaches do not take into account deviations due to tolerance interlinking, but only direct deviations at the gear flanks.

Studies that present tolerance optimization about both costs and functionality often refer to simple, linear dimensional chains and are therefore only applicable to complex cylindrical gears to a limited extent. For this reason, only static limit values based on experience or literature are usually used for tolerance optimization. In particular, the aspect that different components and tolerance types have different effects on the overall manufacturing costs is currently only of secondary importance in tolerancing.

Objective and Approach

The aim of this report is to develop a method that performs a tolerance design for different types of deviation within a cylindrical gearbox. The calculation approach for the tolerance design should take into account that the tolerance-cost correlations are different for different types of deviation. Instead of fixed acoustic limit values, variables from descriptive statistics are used to define the tolerance. To realize the objective, a geometric-analytical model is used to reduce relevant deviations of the surrounding gear components in the tooth contact. This is followed by a variant calculation in the finite element-based tooth contact analysis (Ref. 25), taking into account typical tooth flank and profile deviations. There, the calculation of excitation parameters is carried out in the form of the total transmission error for different orders. The deviation characteristics as input variables are used together with the output values (total transmission error) to train a neural network in order to achieve reasonable calculation times, see Figure 2, left.

A closed-loop optimization process is then implemented, which modifies the tolerances using the metamodel on the basis of tolerance-cost functions for manufacturing processes and the influence of each type of deviation on the total transmission error. In addition to a Particle-Swarm Optimization, a multi-criteria Pareto-Optimization is used, which determines a so-called Pareto-Front (Ref. 26). In addition to tolerance-cost correlations, the excitation statistics are used as input parameters for the evaluation, see Figure 2. Economically optimized tolerance limits are determined as the output of the calculation method, for which compliance with the excitation scatter is ensured, see Figure 2 on the right. Furthermore, the distribution of the acoustic excitation can be determined and compared with the target specifications.

Calculation Method for Designing the System Tolerances of a Cylindrical Gear Stage with the Integration of Manufacturing Efforts

Firstly, the calculation process is explained in general terms. This is followed by more detailed explanations of the implementation of the tolerance-cost functions and the optimization criteria. The software *MATLAB* is used to analyze the production costs and acoustic parameters, while the remaining calculations are carried out in Python.

Structure of the Algorithm, Input/Output Variables and Assumptions

The aim of the calculation algorithm is to determine a particularly economical tolerance specification for defined correlations between production costs and specifications for the variance of the excitation behavior of the running gearing. The determination of the tolerances is integrated into the development process of an overall gearbox at the point after the micro geometry design.

The macrogeometry of the gears, shafts and bearing distances are also taken into account. Furthermore, the displacement behavior of the housing and the bending lines of the shafts are used to consider the load-related displacement in the tooth contact. These parameters are integrated into a model of a finite element-based tooth contact analysis which, together with a software extension, takes system tolerances into account. In detail, the extension reduces important system tolerances such as concentricity deviations of the shafts, the roller bearings or position deviations of the bearing seats in the housing on the tooth contact in terms of axis tilt and skew, wobble, eccentricity and center distance deviation (Refs. 27, 28). It is also possible to consider load-free effective bearing clearances and modified micro-geometries of the tooth flanks that were previously designed.

It is assumed that neither the micro geometry of the tooth flanks (change in the resulting force application points) nor the deviations of surrounding components (e.g., change in tilting rigidity) significantly influence the load-related misalignment behavior of the gears. Further input parameters of the method are information on the occurring scatter shape of each geometry deviation, see Figure 3, top left.

The scattering forms are modelled as normally distributed for deviation types that can assume negative and positive values. Concentricity deviations and backlashes, on the other hand, can only take on positive values, so that these deviations are modelled with a first-order normal distribution. For real-world applications, it may be necessary to adapt the distribution shapes, as the dispersion of real processes can deviate from idealized assumptions (Refs. 29–31). In principle, all analytically describable density functions could be implemented here.

An analytical description of the probability density functions is required so that the optimization algorithm can generate the variants at a later point in time according to the corresponding distribution and adjust the scattering. In addition, an evaluation of the acoustic behavior and a weighting between excitation behavior and costs are required as input. The reason for this is that there is a design dilemma between low manufacturing deviations or low excitation behavior and low manufacturing costs, which requires a compromise solution.

To achieve this design objective, the calculation method iteratively generates a variant plan. Each variant contains a freely definable number n of simulations of virtual overall gearboxes whose

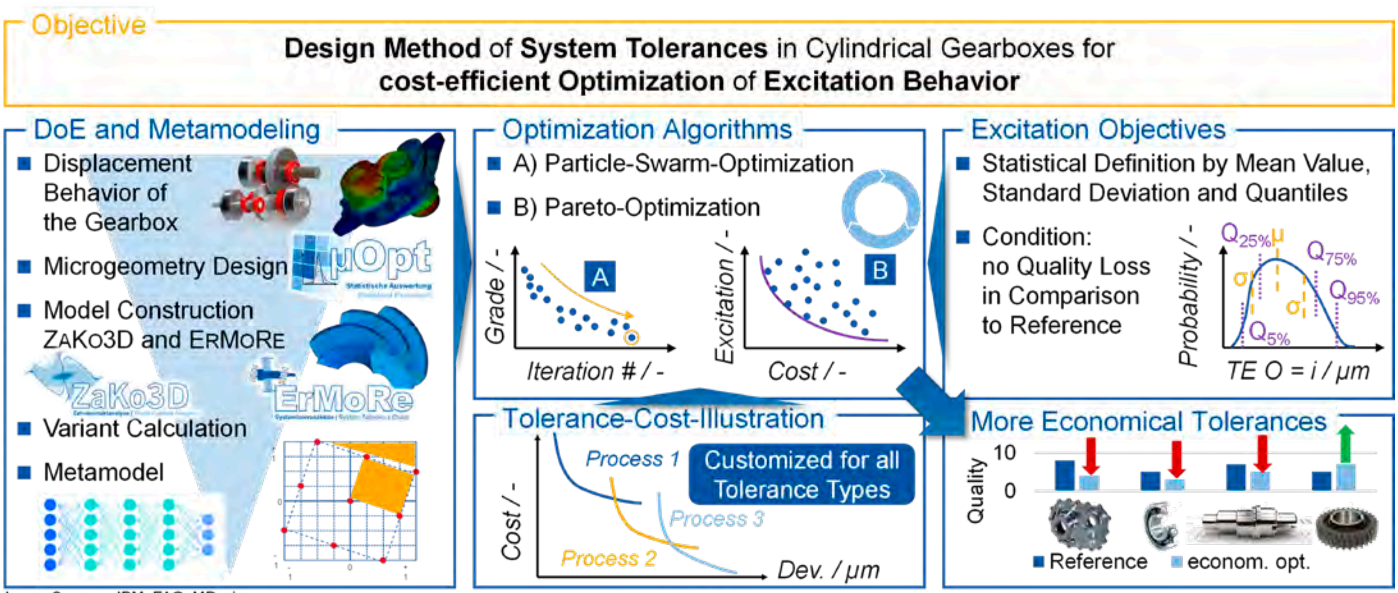

Image Sources: IBM, FAG, MDesign

Figure 2—Objective and procedure for determining economically optimized tolerances.

geometric scattering corresponds to the previously defined distribution shapes. The excitation behavior is afterwards calculated from the n individual points, see Figure 3 in the center.

Each iteration is then checked for fulfilment of the acoustic target criterion. For this purpose, descriptive statistical characteristic values are determined and evaluated for the variant, consisting of n individual points. These are the mean value, standard deviation and various quantiles for selectable order components of the transmission error. This is explained in detail in the following section. In addition, the manufacturing costs are estimated on the basis of the geometric deviations. Depending on the available process types, individual functions are parameterized for each geometric feature, see Figure 3, bottom left.

For each iteration cycle, the optimization procedure is used to adapt the variant plan for the geometry data. In addition to the uniform particle-swarm-optimization (PSO), the use of a multi-criteria PSO Pareto optimization is also investigated. The statistical tolerance specifications, which fulfil the excitation requirements with the lowest possible production costs, are derived from the calculation method, see Figure 3, on the right. Depending on the selected weighting and excitation evaluation, different designs result as solutions.

Evaluation of the Design of the Excitation Behavior

The design of the excitation behavior based on the total transmission error of a gear pair is often carried out by considering supposed worst-case scenarios in which the limit values of the geometric deviations are mapped. The main disadvantages of this approach are, on the one hand, that the maximum excitations do not necessarily have to occur at minimum or maximum deviation amounts, as different flank and form deviations have different effects on the course of the load-free transmission error and influence each other (Ref. 2). On the other hand, when assuming approximately normally distributed deviations, particularly high deviation amounts occur much less frequently, so that a worst-case consideration is often unsuitable.

For the reasons mentioned, parameters from descriptive statistics are used here to evaluate the excitation. In addition to the mean value, standard deviation, median and RMS value, these are the 80 percent, 85 percent, 90 percent, 95 percent and 98 percent quantiles. The latter determine the maximum values of the total transmission error for the associated probability and can be important quality parameters. Weighting factors can be used to set the aforementioned statistical variables, which are determined per tolerance iteration on n = 200 variants, in a preferred relationship to each other. For the calculations carried out here, all statistical parameters are weighted equally.

In detail, different orders of the total transmission error in the long-wave and short-wave range are analyzed. The rotational orders O = 1, 2, 4 of the pinion and wheel shaft are analyzed. In addition, the first to third gear mesh orders O = 23, 46, 69 (in relation to the pinion) and the neighboring sidebands of these (O = 22, 24, 45, 47, 68, 70 in relation to the pinion) are analyzed. On the one hand, the excitation orders can be set in relation to each other with a manual weighting in order to subsequently determine an overall score for the excitation of a tolerance design.

Another option is to implement an automated determination of the weighting factors. This first determines the frequency of occurrence of the drive speed at the pinion using a time-speed curve, which is taken from the WLTP test cycle for motor vehicles as an example (Ref. 32). This is done in intervals of Δn_{Pinion} = 100 rpm from n_{Pinion} = 100…18,000 rpm, which would correspond to the entire speed range up to the maximum speed of the car. The evaluation orders are converted into excitation frequencies along the speed segments with a step size of Δn_{Pinion} = 100 rpm. Each excitation frequency per speed step is then weighted with the A-weighting curve according to ISO 226 (Ref. 33). The value obtained

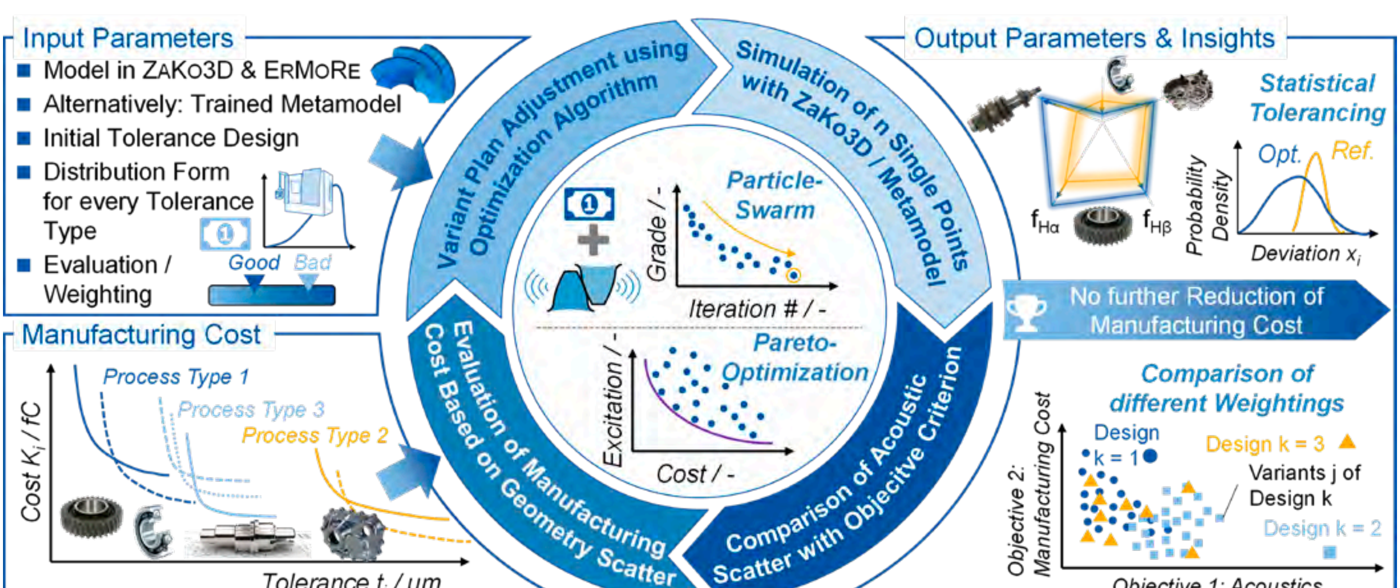

Image Sources: Auto BILD, FAG, MDesign, Porsche

Figure 3—Input and output variables and schematic sequence of the design method.

there is furthermore multiplied by the frequency of occurrence of the speed step under observation and then arithmetically averaged over all speed steps. In this way, weighting factors are obtained for each order of transmission error, which depend on the frequency of occurrence of the speed and the A-weighting of the human noise sensing.

Finally, a grade is awarded. A linear evaluation is carried out in the range g_A = 1…6 (good to bad). The acoustic grade g_A = 1 corresponds to a reduction of the statistical parameter by p = 5 percent compared to a conventionally estimated reference design. The grade g_A = 6 means a deterioration of p = +5 percent. Finally, the individual scores are arithmetically averaged to give the overall acoustic score. The reference thus achieves the overall grade g_{ref} = 3.5.

Modeling the Cost-Deviation Relationships for Geometric Features

The modeling of the cost-tolerance functions is based on the mathematical proposal by Andolfatto, which was presented in section 1 and uses a function comprising four parameters (Ref. 10). To determine a reference cost point, the method by Beckers is applied. It determines the process costs for a single non-purchased component by analyzing their parts. Data from machines from own use as also from machine manufacturers is used to realistically parameterize the equations for example. This applies to acquisition costs of the machines. A lifespan of t = 10 years is assumed for all machines. Labor costs are also assumed to be uniform and constant. The costs per component are largely dependent on the individual process time t_{Ej}. These are determined for a reference process on the basis of empirical knowledge or expert surveys.

The modeling includes the process combinations shown in Figure 4. For the input and output shafts, the possible variations of soft turning, heat treatment and optional hard turning or external cylindrical grinding treatment are modeled. For the latter, upstream regrinding of the centering bores is simulated as an option, which, based on experience, results in a cost increase of p = +18% in terms of an additional process. The interlinked processes transfer their deviation data to each other. The reason for this is that the effort required to achieve, for example, low concentricity deviations in a subsequent process is significantly greater if the input quality is low due to a poorer turning process. The quality levels are determined from estimates in specialist literature and are an approximation for demonstration (Ref. 34).

The manufacture of roller bearings as purchased parts is not simulated in individual processes. The simulated dimensions are divided into quality classes in accordance with ISO 492 (Ref. 35). The relative differentiation of procurement costs from the quality class is based on an expert survey of a bearing manufacturer. Compared to the standard quality class PN, this manufacturer sees a relative cost increase of p = +10 percent for quality class P5 and p = +15 percent for class P4. It should be emphasized that the internal clearance for a standard deep groove ball bearing is not decisive for costs, as the tolerance zone width remains almost constant in the various internal clearance classes and, in principle, only the tolerance zone position of the ball's changes. Cost increases of p = 3...5 percent are only to be expected for extreme internal clearance classes (C2, C5). Therefore, the influence of the internal clearance with regard to economic optimization is not considered further in the following.

Figure 5, top lists the assumed reference times and tool costs for average qualities for the various processes and geometric features. Their validity assumes that the previous process (hobbing) also fulfils its reference quality (class A 6.5). For turning processes, the values only refer to the finishing of a single feature. The variation for determining the coefficients of the cost-tolerance curves for the features includes the primary process time t_h, the secondary

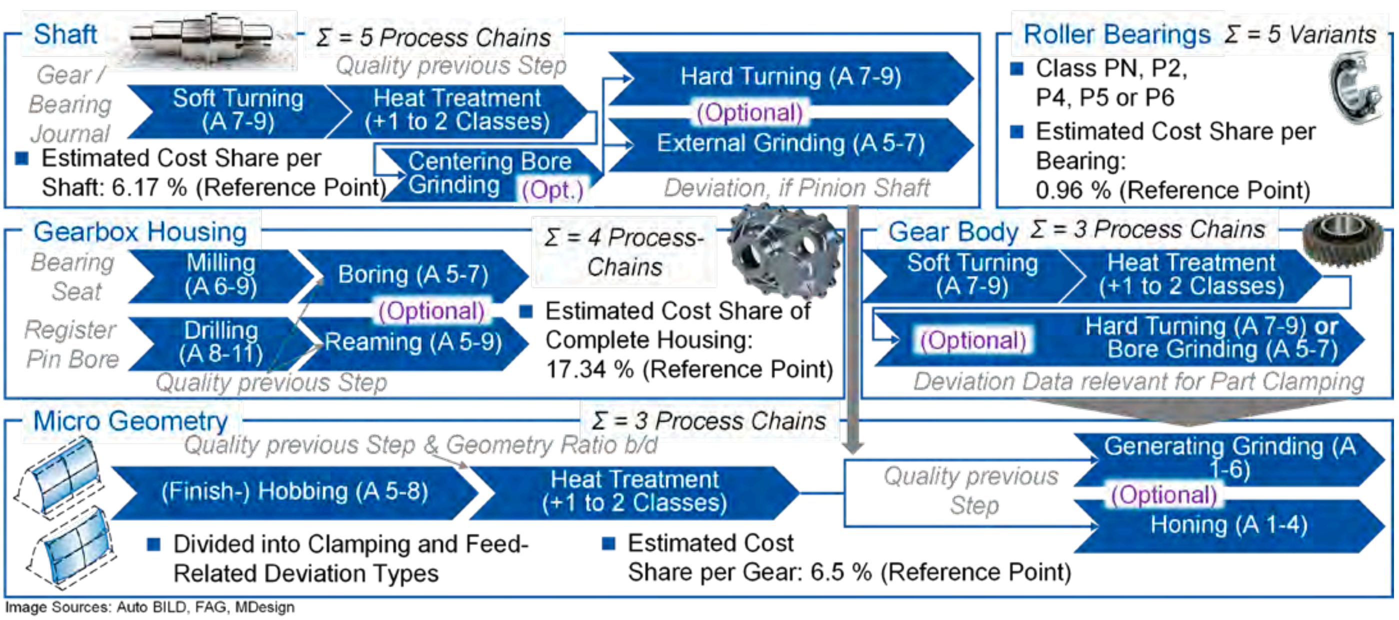

Figure 4—Modelled manufacturing process chains, quality variance and estimated cost shares of the components for a 2-stage 1-speed E-cylindrical gearbox for passenger cars.

process time t_n and the tool costs K_W. Other machine-specific costs such as procurement, depreciation, energy costs, etc. are recognized as non-qualified costs. Energy costs etc. are not considered to be decisive for quality and are kept constant for each process type. The values used correspond to own experience or information from machine manufacturers. The costs are stated in fictious currency (f_C).

For gear-specific processes, it was taken into account that different machining times and therefore also costs influence geometry parameters such as profile, flank and pitch deviations in various ways. For this reason, different cost-deviation curves (C-T curves) are used for the three deviation groups mentioned, which differ by constant factors for the sake of simplification. In this way, the aim is to map process-specific characteristics. For example, it is assumed for the profile deviations of the honing process that higher tool costs of p = +20 percent are incurred to achieve the same quality class than for flank deviations. The background to this is that the change criterion of the honing ring is the profile deviation. In addition, it is assumed that honing requires p = +40 percent longer idle times due to dressing in order to achieve the same quality level in the pitch deviations as in the profile and flank deviations. The same applies to the primary machining time. The reason for this assumption is that the elimination of pitch deviations on the workpiece or tool is more demanding. The parameterization involves assumptions that should be individually adapted by the user. After setting the reference points of each process concerning its machine times and assumed costs, the C-T curves are parametrized with factors according to the formula of Andolfatto (Ref. 10).

For the primary machining time of gear hobbing and finish hobbing, p = +25 percent longer primary machining times are assumed, which lead to better quality classes due to reductions in the feed marks. For generating grinding, in order to achieve better concentricity through an extended infeed process, a idle time that is p = 20 percent longer is assumed to achieve the same quality class level in concentricity/run-out, based on profile and flank deviations. Therefore, time and cost intervals for the tool are used for the reference quality levels, depending on the type of deviation. The characteristic values can be parameterized in the method and can therefore be individually adapted. Figure 5 below shows the C-T function resulting from the assumptions for various machining operations. These also include the five calibration points per curve. It was possible to approximate the Andolfatto description approach with coefficients of determination R^2 > 98 percent for all correlations (Ref. 10). For hard finishing of the gears, it can be seen that the C-T curves can also assume values for qualities A < 1. This purely mathematical, although no quality levels are defined in this area in reality. In addition to the aspect that a tolerance design in these particularly precise qualities quickly becomes unprofitable, the final tolerance design must always be checked for plausibility of the required quality class.

A relevant aspect for achieving a certain target quality is the pre-machining quality and the clamping situation, particularly for gear machining. For example, the effort required to achieve a low total pitch error after the honing process is only possible in the reference time if the input component has a pitch error that is at maximum two quality levels higher. Otherwise, the pitch error could only be further reduced by extending the primary machining time. Another example is a clamping situation with concentricity errors or wobble due to poor pre-machining quality of the bearing seats or the wheel bore. In this case, there is a helix and profile angle deviation that the hard finishing process cannot compensate for, as this is specific to the component's clamping. These deviations are therefore subtracted from the process result. The calculation method also takes into account the deviation of the process input quality compared to the reference quality of the previous process (mean values of the

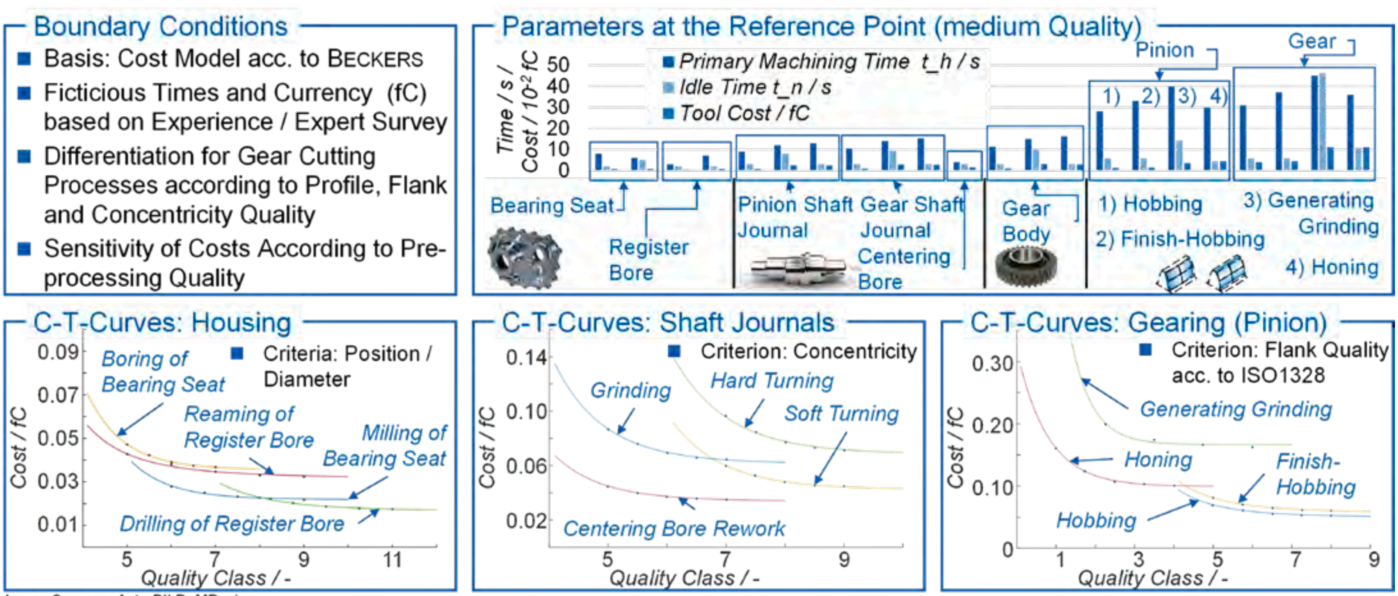

Figure 5—Process parameters in the reference point for calibrating the C-T curves.

intervals specified in Figure 4) in accordance with Equation 4. When calculating the costs for a quality point, the factor f_{Dev}, in is multiplied by the hyperbolic and exponential components of Andolfatto's approach. If the input quality is worse than expected, the factor is f_{Dev}, in > 0 and makes the downstream process more expensive, thus reducing its profitability. The sensitivity is assumed to be s_{WS} = 1 for generating grinding and s_H = 1.5 for honing, which means that the honing is more dependent on the input quality.

$$f_{Dev,in} = \frac{Q_{pre,is} - Q_{pre,ref}}{Q_{pre,ref}} \cdot s + 1 \quad (4)$$

where

$f_{Dev,\,in}$ is the multiplication factor of the hyperbolic and exponential part of the C-T function;

$Q_{pre,is}$ is the actual quality class of the upstream (previous) process;

$Q_{pre,ref}$ is the reference quality class of the upstream (previous) process;

s is a process individual sensitivity factor.

As the absolute costs of a single component in a transmission depend on the process and the number of units produced, the costs for purchased parts (roller bearings) must be calibrated according to the number of units (Ref. 36). As there is no data in the state of the art on cost distribution in electric car transmissions, the cost shares determined in a study for a 7-speed dual clutch transmission (DCT) were converted and calculated according to the number of components of an e-drive transmission (Ref. 37). It was assumed that the assembly and testing costs in the EoL test are p = -75 percent lower than for the 7-speed DCT, as fewer components (N_E = 16 instead of NDCT = 52 components) are required. Furthermore, the housing can be considered to be about half the size and complexity of the e-drive transmission compared to the 7-speed DCT and the mechatronics are completely eliminated. The rescaling of the cost shares then results in a distribution according to Table 1.

The cost distribution is subsequently considered to be independent of the number of units. Total fictitious costs of C = 28 fC are assumed for the entire gearbox. This results in a unit price per bearing on the pinion shaft of $K_{Bearing,Pinionshaft}$ = 0.40 fC, while that of the wheel shaft is assumed to be p = +15 percent higher due to the dimensions.

Evaluation and Weighting System for a Tolerance Design

The evaluation of a tolerance design is carried out for the acoustics in the form of a score, which is determined for the various excitation orders in accordance with the section "Evaluation of the Design of the Excitation Behavior." A price is determined as a fictitious currency (fC) for the production costs. This is set in relation to the fictitious price of the reference design. The result is an overall score according to the formula in Figure 6 on the right.

Assembly / EoL Test	6.74% (7%)	Differential	23.12% (6%)
Shift Actuators/ Parking Lock	8.48% (11%)	Gears	26.2% (14%)
Roller Bearings	5.78% (4%)	Housing	17.34% (9%)
Shafts	12.33% (8%)	Mechatronics / Clutch	0% / 0% (31% / 10%)

Table 1—Assumed cost distribution for the reference point of the tolerance in an e-drive transmission; values for a 7-speed DCT in brackets from Ref. 37.

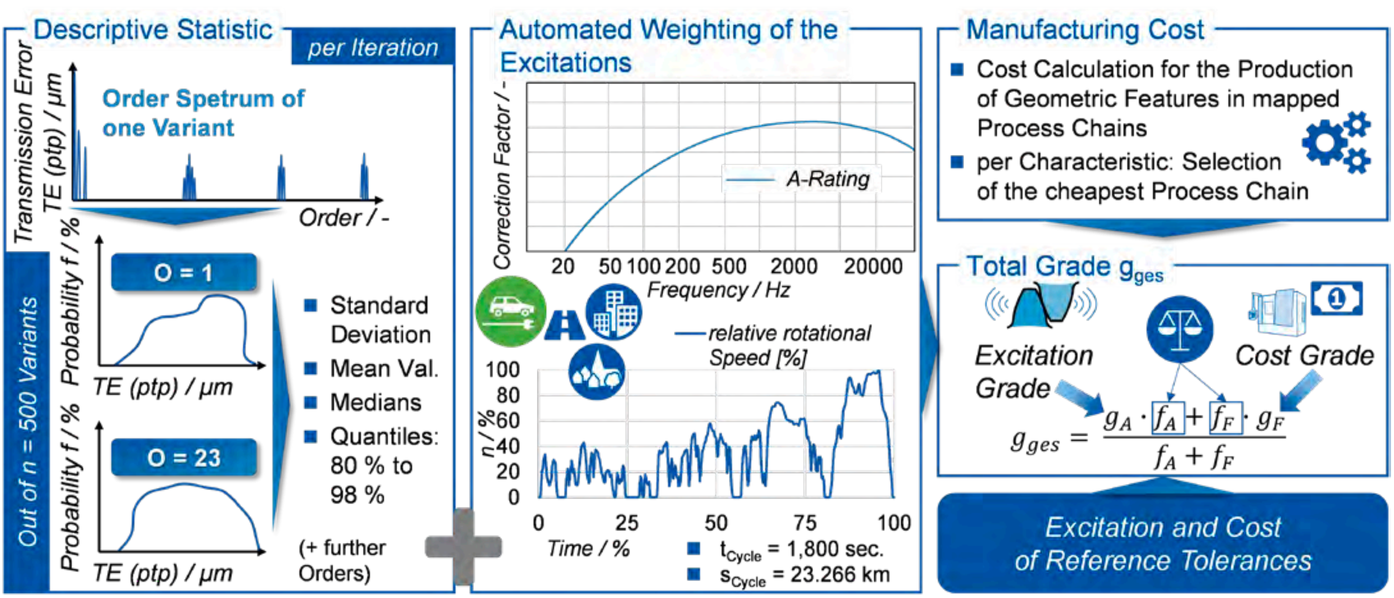

Figure 6—Determination of the overall grade on the basis of statistical transmission error parameters, a speed profile, the acoustic evaluation curve and the manufacturing costs.

Manufacturing costs for the geometry features reduced by p = -25 percent compared to the reference mean the grade g_F = 1, costs increased by p = +25 percent set the cost grade for manufacturing linear to g_F = 6. In this case, the individual grades g_A and g_F are multiplied by freely selectable weighting factors f_A and f_F. The overall grade g_{ges} assumes values less than $g_{ges} < 3.5$ if both the manufacturing costs as determined in the section "Modeling the Cost-Deviation Relationships for Geometric Features" and the excitation behavior are lower than the reference case. The procedure for determining the excitation grade g_A in accordance with the procedure in the section "Evaluation of the Design of the Excitation Behavior" is also shown in Figure 6 on the left and in the middle.

Optimization Problem and Solution Approaches

The evaluation of acoustic behavior and production costs results in a design dilemma in which costs and noise excitation are contradictory. From this, a multi-criteria optimization problem can be derived, for which there are solution methods. While the goal of a conventional Particle-Swarm Algorithm is to minimize a single output variable (here: total score g_{ges}) with a certain combination of input variables (here: quality classes of different deviation types), an ideal combination of input variables can be determined iteratively with a Pareto Optimization. The enveloping curve over all combinations of input variables that lead to the best fulfillment of the different objectives is referred to as the Pareto front (Ref. 38).

Advanced algorithms combine the approaches of genetic particle swarm optimization with multi-objective optimization. One example of this is the metaheuristic MOPSO (Multi-Objective Particle Swarm Optimization) method (Ref. 26). In this approach, the swarm population is used to determine the Pareto front in a time-efficient manner. The weighting between excitation quality and production effort as an overall score is omitted in advance. Instead of an ideal solution, this results in a set of solutions that differ in terms of their degree of fulfillment of the subline. The properties of the variants on the Pareto-Front can then be compared using the weighting function and the best individual compromise solution can be selected.

Acceleration of the Method by Meta Modelling

In order to use iterative metaheuristic optimization approaches, it must be possible to determine the excitation and cost parameters quickly in order to obtain a tolerance design with a reasonable amount of time. To increase speed, a meta model is therefore used which, after training with training data generated by a finite element-based tooth contact analysis, determines the total transmission error based on the gear micro geometry and axial position deviations. Figure 7 shows the procedure for creating and integrating such a meta model in the form of a deep neural network (DNN) with *TensorFlow Keras* based on Python (Ref. 39). After the creation of n = 6,330 training data sets in the FE-based tooth contact analysis, the training parameters are optimized, which takes about t = 2 h. This is done by varying the network parameters. The network is trained for a small number of epochs by varying the network parameters and a suitable parameter set is determined based on the training loss. This includes the number of layers, activation functions, number of neurons, etc. After training, the model is validated and the DNN is integrated into the cycle instead of the finite element-based tooth contact analysis. Figure 7 shows the training process and the prediction result for the transmission error (TE) in the third gear mesh frequency 3rd f_z.

In detail, the optimized parameters were the hyperparameters listed in Figure 8 on the left. With a training effort of $t \approx 192$ s, the predictions of the DNN compared to the calculation results from the finite element-based tooth contact analysis are shown for the first rotation order with regard to pinion and

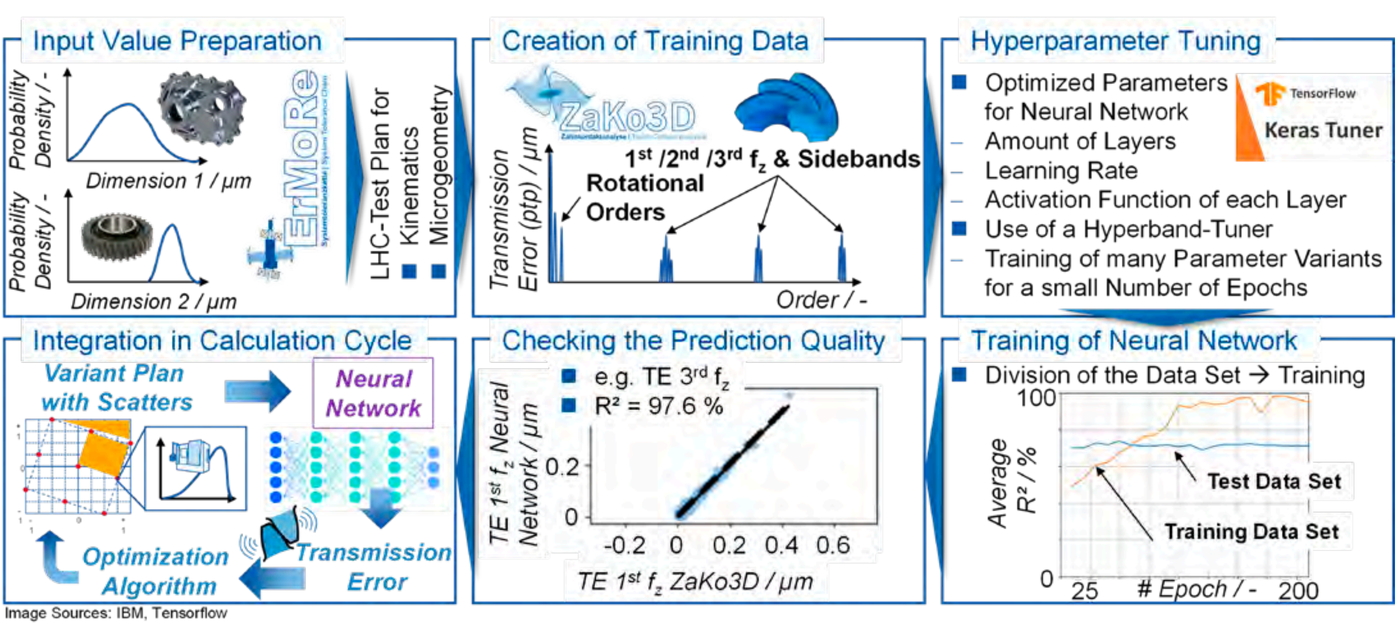

Figure 7—Procedure for increasing the performance of the calculation system with a meta model.

wheel as well as the first and second gear mesh order. For validation, $n = 499$ other variants not included in the training data set were used. The prediction qualities for all orders are R^2 >88 percent and are therefore sufficiently suitable for prediction of the acoustic behavior.

Better values were achieved for the rotational orders and their higher harmonics, see Figure 8, top. Isolated sidebands of the gear mesh orders proved to be more difficult to map due to their very low amplitudes and their partly stochastic dependence on modulation effects. The gear mesh frequencies (1st to 3rd f_z) are not affected by this, as can be seen Figure 8, bottom. It is relevant for the training data that these are available within wide limits. This was ensured by limits that correspond at least to the factor $f = 3$ of the reference tolerances.

Application of the Calculation Method to an Electric Car Gearbox

The design method presented in the section "Calculation Method for Designing the System Tolerances of a Cylindrical Gear Stage with the Integration of Manufacturing Efforts" is applied as an example to a series-like e-drive gearbox. First, general data on the application is presented. Subsequently, the results for an optimized tolerance design are compared with the reference tolerance definition in terms of excitation variance and manufacturing costs.

Gearbox and Gear Data

As an example, an e-drive gearbox is used (Ref. 40). It was designed to have similar characteristics as a real series gearbox in terms of geometry, material and stiffness. The first, high-speed cylindrical

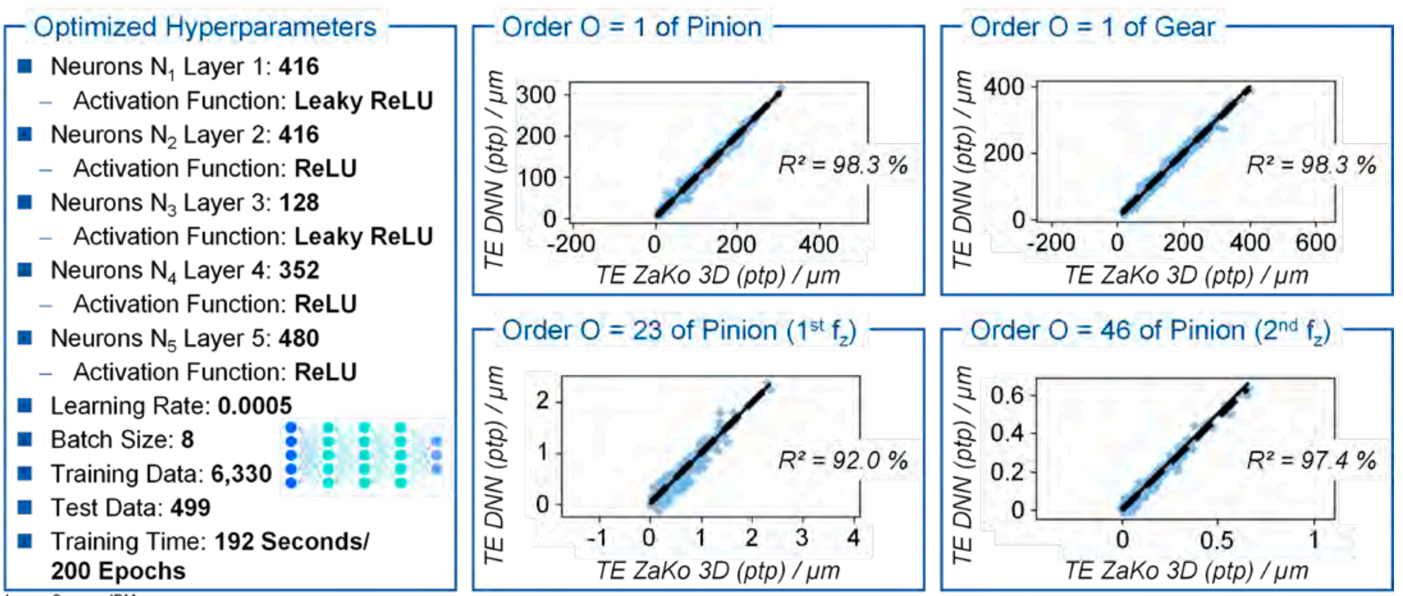

Image Source: IBM

Figure 8—Training parameters of the DNN and selected prediction results.

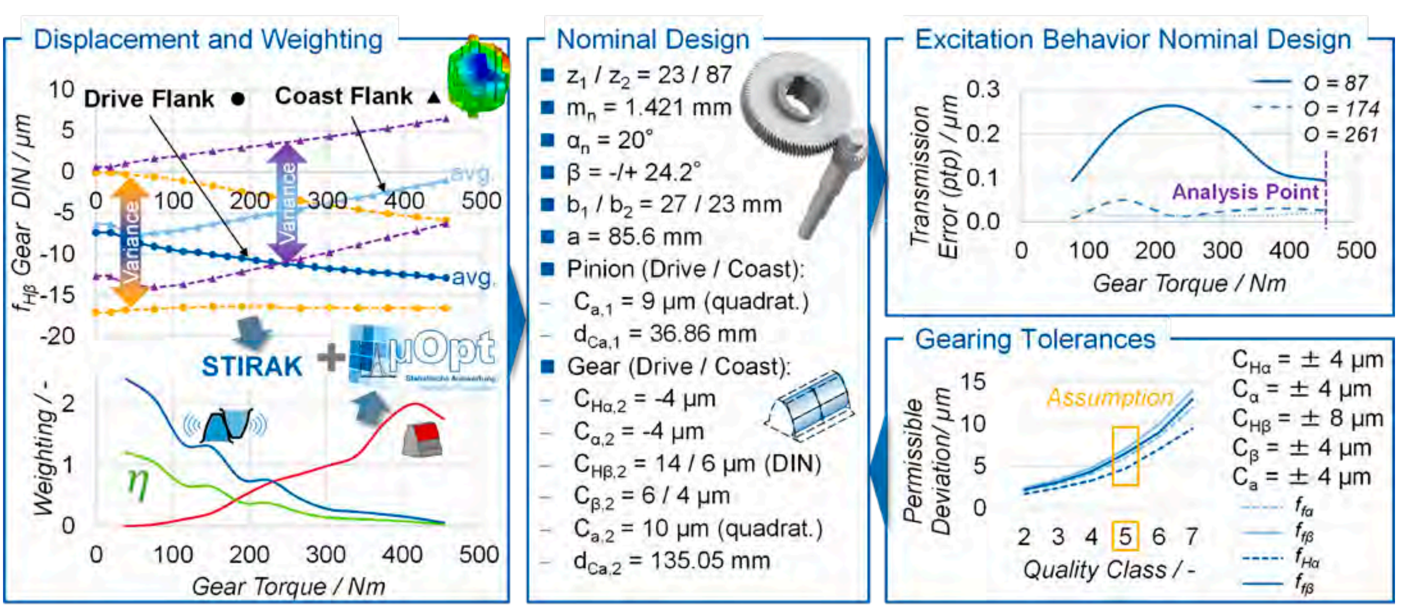

Figure 9—Consideration of misalignment behavior, weighting and gearing tolerances to identify the nominal microgeometry.

gear stage is considered. The helix angle deviations due to load-induced deflections at the gear shown in Figure 9, top left, are obtained, which were integrated into the FE-based tooth contact analysis in order to perform time-efficient variant calculation. The diagram shows the wide variance of the possible helix angle deviations resulting from different bearing clearances. These result from the minimum (minimum of class C2) and the maximum permissible bearing clearance (Ref. 41). This results in scattering of $\Delta f_{H\beta}$ > 10 µm, only due to the selection of the bearing clearance class and the possible manufacturing scatter. A medium tolerance was used for designing the micro-geometric nominal design.

A microgeometry variation comprising n = 1,908,360 variants resulted in the micro geometry shown in the center of Figure 9 as the best compromise variant, given the weighting shown in Figure 9, bottom left, which is based on the driving profile of a WLTP test cycle (Ref. 32). To identify the best nominal design under consideration of geometric scatter, the manufacturing tolerances derived from quality class A 5 in Figure 9, bottom right were defined. They were increased with regard to the helix angle deviation due to the additional influences of other components on the deviation error of axes and inclination error of axes described above. The tolerance field design approach for the microgeometry stated by Brecher et al. was applied (Ref. 14). If the deviations assumed during the nominal microgeometry design in tooth contact change significantly due to the tolerance design of the overall system, the nominal microgeometry should be redesigned in order to ensure a suitable nominal microgeometry.

Reference Tolerance Design

For comparison purposes, the possible variance in the excitation behavior is determined, which is set for a conventional tolerance design of the reference based on experience. For this purpose, the tolerance limits for profile and flank deviations are defined in accordance with quality class A 5 and normal or magnitude-normal distributions of the characteristic variables are assumed, see Figure 10, top center. Furthermore, quality class A 7 is used for the other basic tolerances on shafts and housings. The selected tolerance limits generally represent experience-based specifications that have not been further optimized. The cost calculation according to the procedure in the section "Modeling the Cost-Deviation Relationships for Geometric Features" results in geometry-relevant costs of C = 3.4627 fC. It should be noted that this is an optimized cost calculation according to the modelling, as it determines the most favorable process combination for this specific tolerance assumption. The costs are distributed over the roller bearings with p = 50.99 percent, which are included in the calculation with their full costs due to their consideration as purchased parts. In contrast, the other component costs only include the processes that determine the final geometry, meaning that the shares are lower. Especially, material costs, upstream process costs (e.g., casting of housing) are not included herein.

It was determined that it is most economical to produce the dowel pin bores on the housing by drilling alone. The bearing seats can also be machined most economically in the reference design by pure milling. For the shaft shoulders, a combination of soft turning and grinding without reworking the centering bores is the most economical. For the gears, the method of hobbing with honing is proposed for both gears. It is noticeable that the production of the pinion gearing is stated to be more cost-intensive than that of the wheel, which initially seems implausible. This is due to the fact that different clampings are used during the gear-cutting process. While the pinion shaft is clamped on the bearing seats, which can have concentricity deviations of quality class A 7, the wheel is held in the bore. The possible concentricity deviations at the bearing seats result in clamping deviations (wobble), which cause a profile and helix angle deviation, which the honing process with the target specification A 5 has to eliminate. The effort required to achieve this target is far greater for the pinion shaft than for the wheel due to

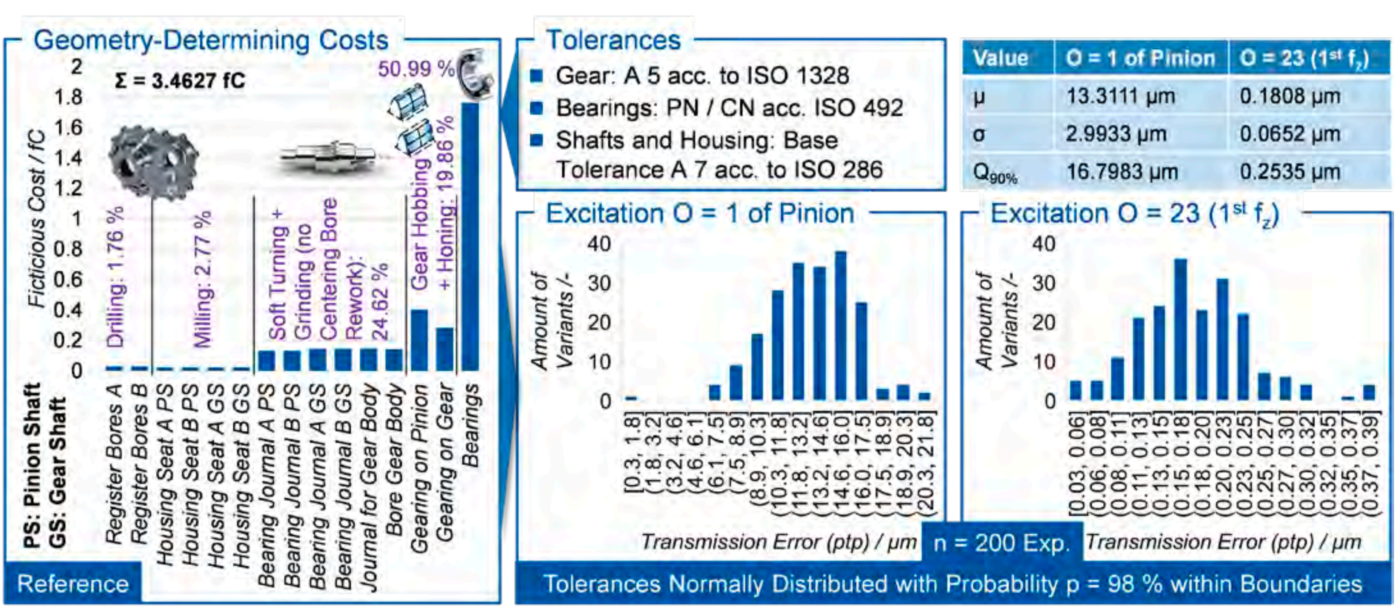

Figure 10—Geometry-determining costs and excitation distributions of the reference design.

the clamping situation. As a result, the cost of the pinion also increases.

Figure 10 below shows the distribution of the total transmission error for M_{in} = 120 Nm. It can be seen that in particular the first gear mesh order O = 23 with respect to the pinion (corresponds to O = 87 with respect to the wheel) exceeds the nominal design of the excitation in Figure 9, top right by a factor $f \approx 2.5$ with a 90 percent probability. This is only caused by the possible tolerance utilization.

Identifying Differently Weighted Tolerance Designs

Figure 11 on the left shows the Pareto front determined after n = 20,000 iterations for the opposing grading of production costs (g_F) and gear excitation behavior (g_A). A population size of n_{pop} = 100 particles per iteration was used, whereby the oblivion rate α = 0.1 was parameterized. The mutation rate was set to m = 0.1. In sum, n = 6,042 tolerance designs were identified in a target range that was narrowed down to score values g < 10. Tolerance designs whose manufacturing grade g_F < 3.5 (lower costs) are marked as triangles, while optimizations in the excitation are shown with squares. It was also possible to identify various variants that fulfill both aspects better compared to the experience-based reference tolerance design. These are marked with an asterisk. For the grading of the variants in the ranges $g_{A/F}$ = 1…6, the different percentage referring to the reference must be taken into account.

An overall score g_{ges} can be determined from the designs close to the Pareto front by parameterizing the weighting factors f_A and f_F. Depending on the weighting selection, the focus can thus be placed on compliance with the acoustics or on reducing the production costs. In the diagrams in Figure 11 on the right, the best variants with a better (lower) overall score gges are listed in ascending order. Two variants were selected for comparison. One for an increased focus on acoustic, the other on cost reduction. The full identification of the Pareto-Front is an iterative and evolving process, so its characteristics can change as the number of iterations increases.

Comparison of the Different Tolerance Designs

The variants determined by MOPSO on the Pareto-Front were weighted for two exemplary cases. As an example, Figure 12 compares two design points that emerged as the best solution for the different weightings. For the optimization point with f_F = 90 percent and f_A = 10 percent, a tolerance design was identified that is p_F = 7.5 percent cheaper to manufacture on the basis of the C-T cost model used compared to the reference. Based on the tolerance position of the geometric features in Figure 12, left, it can be seen that the tolerances of the gear have been increased compared to the reference tolerance design. To achieve the qualities of the gear, the algorithm suggests using finish hobbing instead of a honing process (estimation of quality loss due to heat treatment pinion shaft: -2.07 quality classes, gear: -1.55 quality classes), as this is the most cost-effective for the reduced tolerance requirements of the gear.

The tolerances for the pinion are also extended in order to reduce costs. One exception is the tolerance for the profile angle deviation, where a restriction is made to A 3.6, which corresponds to a virtual interpolated intermediate class. In particular, the stricter tolerancing of the geometric features on the housing is evident, which is carried out in return for the tolerance extension on the gears. In particular, the bearing seats of the pinion shaft require a reduction from the former quality class A 7 to A 4.4 in some cases. This is a plausible behavior, as the smaller bearing distance to gear on the shorter pinion shaft means that the effects of fitting deviations and bearing clearances have a much greater influence on axial position deviations than on the wheel shaft, which is longer. In the acoustic assessment, however, the design falls behind by around p_A = +3.2 percent,

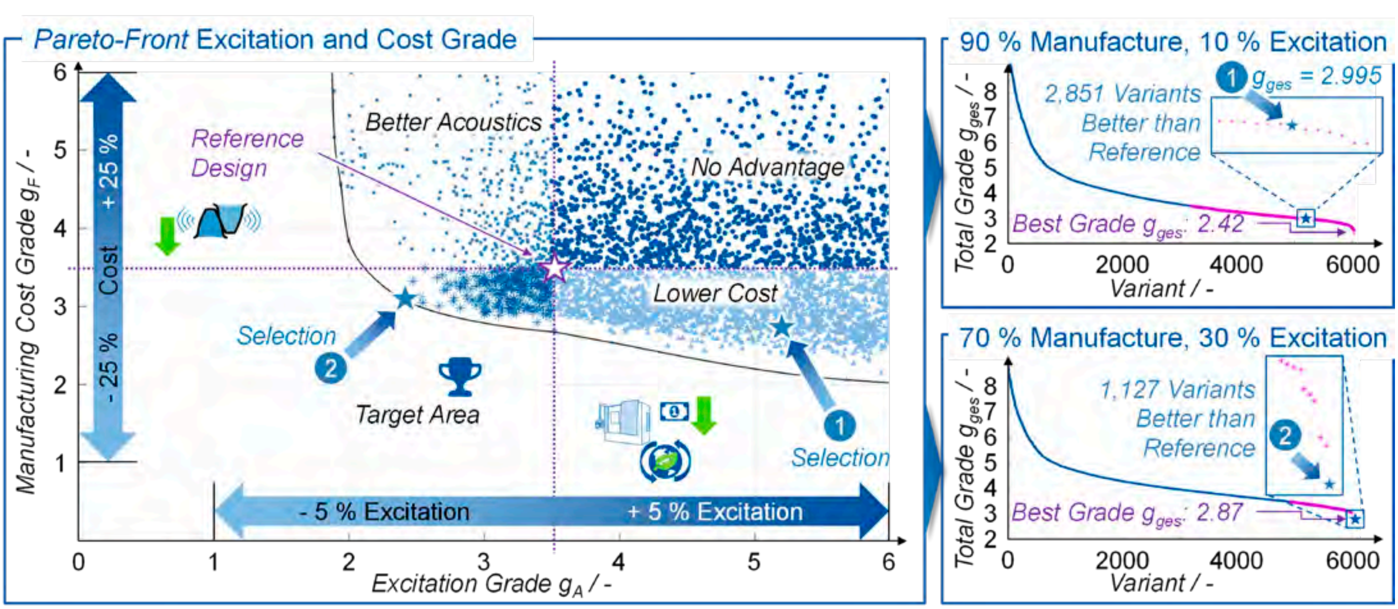

Figure 11—Pareto-Front generated with MOPSO and variant position of the target layouts.

which is still within the acceptable rating of $g_A = 5.2 < g_{A,max} = 6$. The plausibility of each favored design must be checked in detail to ensure its validity.

A tolerance design aimed at stricter compliance with the acoustic limit values can be seen in Figure 12 on the right. Here, an improvement in the acoustic behavior and the manufacturing cost score is achieved by limiting the tolerance of most of the features on the housing while at the same time increasing the gear and roller bearing tolerances, but while retaining the reference process chain. The comparison with the reference quality classes on the pinion shows, with the exception of the quality requirement for the flank form deviation $f_{f\beta}$, a possibility for extending the tolerances, which results in potential cost savings for the overall gearbox.

The percentage cost changes shown in Figure 12 relate to the reference costs determined by the stored cost model. It can be seen that for both compared designs, the main savings are made in the gearing of the pinion shaft and wheel. Due to the higher absolute cost shares of the gear geometry compared to, for example, dowel pin bores or bearing seats, cost savings can be achieved in total. The percentage savings for the pinion gearing can correspond to more than $p > |50 \text{ percent}|$, whereas the geometry-determining production steps for inserting precisely fitting bearing seats in the housing can sometimes be more expensive by $p > |+150 \text{ percent}|$. This reciprocal exchange of tolerance specifications enables the excitation quality to be maintained, although the overall costs can be reduced. However, it can be stated that especially housing tolerances such as of the bearing seats or the positioning pins are relatively cheap features which should be manufactured in good quality. This is especially relevant if the distance of gear to the bearing seat is smaller.

Summary and Outlook

The clever selection of manufacturing tolerances is crucial for reducing production costs while maintaining excitation quality. Tolerancing is often based on experience from previous designs. In this report, a tolerance design method for the entire gearbox was proposed based on metaheuristic methods using cost-tolerance functions (C-T functions) for different manufacturing processes. In addition to micro geometric gear tolerances, this also includes deviations on bearing seats of housings, shafts, roller bearings and gear bodies.

The aim of the method is to achieve cost savings while maintaining or even optimizing the transmission error. C-T functions for conventional manufacturing processes were first parameterized on the basis of experience and assumptions regarding primary process time, auxiliary time, tool costs, machine costs, wages and space costs. These are used to determine the manufacturing costs compared to a reference design. However, the data for modelling the C-T curves have to be taken from experience or assumptions to apply the described method. Based on n = 200 individual variants per iteration, for which statistical descriptive variables of the total transmission error scatter are determined, a metaheuristic algorithm searches for tolerance combinations that promise lower costs at same or better acoustic behavior. A deep neural network is used for this purpose, which shortens the calculation time per iteration and determines the transmission error in the rotational and gear mesh orders from the tolerance inputs.

For a reference tolerance design of the gears in quality class A 5, basic tolerances of A 7 and roller bearings in accuracy class PN, the fictitious geometry-determining total costs for the pinion and wheel shaft, the gears, the bearing seats and fitting bores as well as the roller bearings amounted to C = 3.4627 fC (fictitious currency). For the deviations in the form of normal or magnitude-normal distribution, reference transmission errors in various dominating orders were obtained, which were used as a standard of assessment. In a subsequent

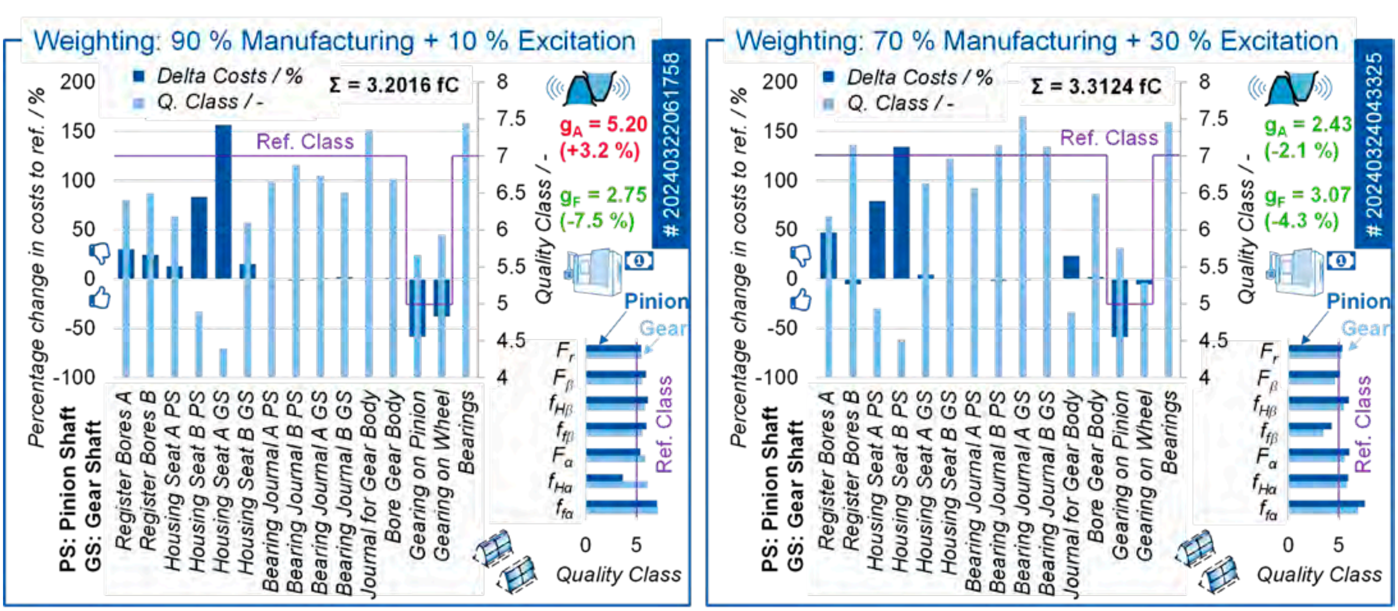

Figure 12—Quality and cost characteristics of two differently weighted tolerance designs.

multi-criteria particle swarm optimization (MOPSO), a Pareto-Front was determined, which shows tolerance designs that perform better in terms of production and acoustic grading. Variants could be determined that have lower costs of up to p_F = -7.5 percent according to the cost modeling implemented here, while almost maintaining the excitation behavior, whereby the reference design was already optimized in terms of process costs. This was mainly achieved by extending the tolerance limits on the gears, which allowed a change to the finish hobbing process for one gear, for example, which contributed to the cost reduction.

Further processes and their chains can be considered in future studies. Furthermore, the cost determination for the parameterization of the C-T functions can be further detailed in order to achieve an increased precision of results. So far, the interpretation algorithm assumes that the distribution forms of the deviations remain constant. In future work, this could be extended so that the scattering form of the deviation variables is determined under the specification of a desired excitation distribution and additionally the produced part amount is considered.

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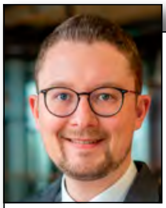

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Investigating the Effects of Wear, Lubrication and Material Pairing on the NVH Performance of Plastic Gears

Dr. Damijan Zorko, Rok Kalister and Dr. Borut Černe

High-performance polymer gears are increasingly supplanting their metallic counterparts across diverse engineering applications, attributable to their multifaceted advantages. These include a markedly lower density contributing to weight reduction, intrinsic self-lubricating properties obviating the need for external lubrication, cost-efficient scalability in production, enhanced noise, vibration, and harshness (NVH) performance, and superior resistance to chemical degradation and corrosion. Injection molding remains the predominant fabrication technique for thermoplastic gears, offering extensive design latitude. This process enables the consolidation of multiple functional elements into a singular, integrally molded component. Furthermore, it facilitates precise modifications to gear macro- and microgeometry, such as increased fillet radii at the tooth root and tailored tooth profile configurations (Ref. 1).

Despite their advantages, polymer gears exhibit several limitations relative to metallic gears. Principal disadvantages encompass lower load-bearing capacity, reduced thermal conductivity, limited thermal stability, and comparatively lower dimensional accuracy during fabrication. Among these, the constraint in load-bearing capacity is deemed the most critical, thereby motivating extensive research efforts aimed at its enhancement. These efforts include the development of optimized gear geometries (Ref. 2) and the formulation of advanced polymer materials engineered to withstand higher mechanical stresses (Ref. 3).

Amidst escalating customer expectations, the acoustic performance—specifically the noise, vibration, and harshness (NVH) characteristics—of polymer gears has emerged as a critical design consideration. A seminal study by Hoskins et al. (Ref. 4) systematically investigated the acoustic behavior of polymer gears, examining the influence of material composition and operational parameters on the resultant sound frequency spectrum. The study identified surface topography, wear, and thermal conditions—arising from interfacial interactions between meshing gear teeth—as principal determinants of acoustic energy intensity.

Trobentar et al. (Ref. 5) investigated the acoustic behavior of polymer gears featuring distinct tooth geometries, namely conventional involute profiles and S-type profiles. The latter are characterized by a convex addendum and a concave dedendum, resulting in a smoothly curved contact trajectory analogous to the shape of the letter "S." The study demonstrated that S-gears generated lower acoustic emissions compared to involute gears, a phenomenon attributed to more favorable and continuous meshing conditions. In a related investigation, Polanec et al. (Ref. 6) evaluated the acoustic performance of polyoxymethylene (POM) gears subjected to various physical vapor deposition (PVD) surface treatments. The study examined the effects of aluminum, chromium, and chromium nitride coatings. Results indicated that uncoated gears exhibited the lowest sound pressure levels, implying that the applied coatings did not facilitate acoustic attenuation. Moreover, the coatings experienced degradation during operation, which exacerbated frictional interactions and disrupted meshing dynamics, thereby elevating the emitted sound pressure levels.

Van Wissen et al. (Ref. 7) conducted a comprehensive study on the noise, vibration, and harshness (NVH) characteristics of gears fabricated from Polyamide 46 (PA46). The investigation focused on the acoustic performance of two configurations: a homogeneous PA46 gear pair and a hybrid pairing of PA46 and steel. Experimental trials were performed across three discrete rotational velocities—200 rpm, 500 rpm, and 800 rpm—and torque levels ranging from 0.2 Nm to 1 Nm. The findings revealed a pronounced escalation in acoustic emissions with increasing rotational speed, accompanied by analogous trends under elevated torque conditions, underscoring the sensitivity of NVH behavior to both dynamic and load parameters.

A comprehensive investigation into the NVH characteristics of polymer gears was undertaken by Cathelin (Ref. 8). The study underscored the multifactorial and condition-sensitive nature of NVH behavior in plastic gears. Multiple unreinforced polymer grades were evaluated, with each test configuration employing gear pairs composed of identical materials. Comparative analyses against a reference steel gear pair operating under equivalent conditions demonstrated the comparatively superior NVH performance of the polymer gears, highlighting their potential for noise-sensitive applications

The present study proposes an experimental framework for characterizing the NVH performance of polymer gears under conditions representative of real-world applications. Furthermore, it delineates material selection criteria aimed at optimizing NVH behavior in gear systems. Five distinct polymer material pairings—comprising both unreinforced and fiber-reinforced formulations—were evaluated, with each test employing dissimilar materials for the meshing gear components. The resulting acoustic and vibrational responses were systematically analyzed and benchmarked against those of a conventional steel gear pair.

Methodology

Sample Preparation

The test gears were fabricated via injection molding using a single-cavity mold. Molding operations were conducted on an Engel Victory 50 injection molding machine (Engel Austria GmbH, Austria). A three-plate mold configuration incorporating a hot-runner system and a centrally positioned pin-point gate with a 1.3 mm diameter was employed. Gear geometry conformed to the specifications outlined in VDI 2736, Part 4, Table 1, corresponding to Size 1 geometry (Ref. 9). The gear body was engineered with a wavy structural design, maintaining a consistent wall thickness of 2.5 mm (Figure 1). A symmetric groove was integrated at the interface between the gear body and tooth region to promote uniform material flow and complete cavity filling during the molding process.

The gears were manufactured from seven commercially available thermoplastic compounds widely utilized in gear production. The injection mold was engineered with an interchangeable cavity system, enabling the use of multiple cavity inserts tailored to accommodate the differential shrinkage behavior associated with the various tested materials. This strategy ensured that all gear specimens were produced to a consistent quality standard, thereby minimizing the influence of dimensional and geometric variations on NVH performance. To maintain commercial confidentiality, only the chemical compositions of the employed materials are disclosed:

1. Polyoxamethylene (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 reference for comparative analysis, three sets of steel gears were fabricated from heat-treated 42CrMo4 alloy, maintaining identical gear geometry as specified in Table 1. Steel gear specifications are shown in Figure 2.

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.

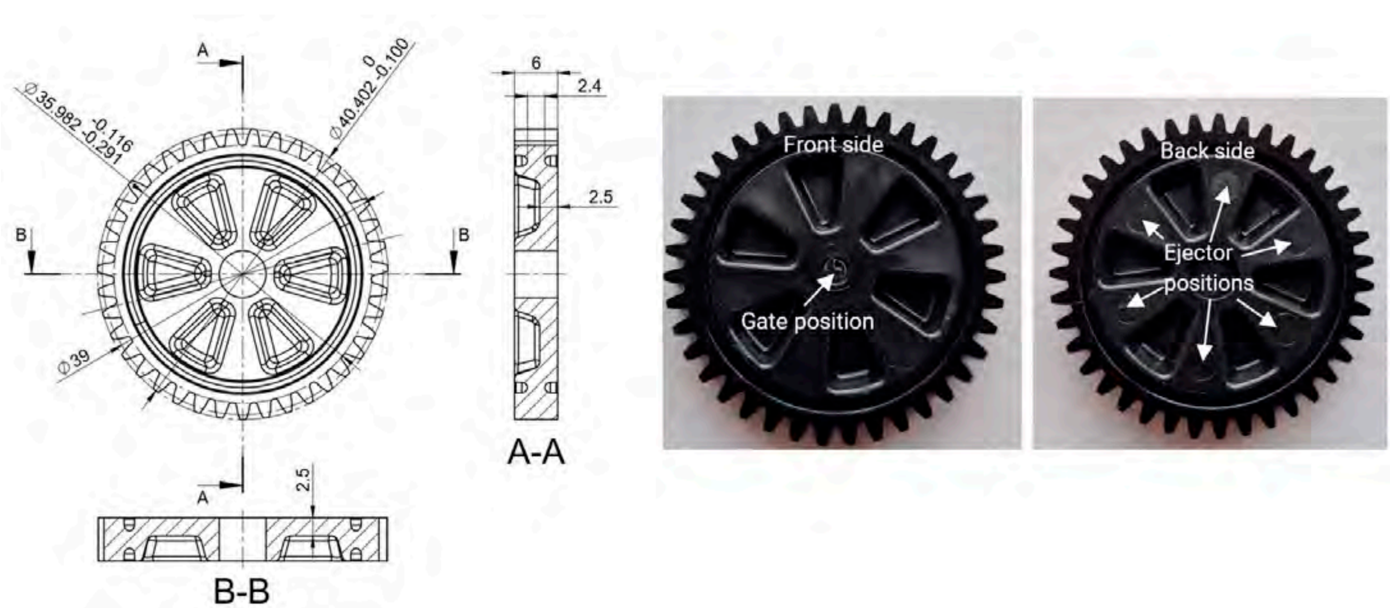


Figure 1—Plastic gear samples employed for the testing procedures.

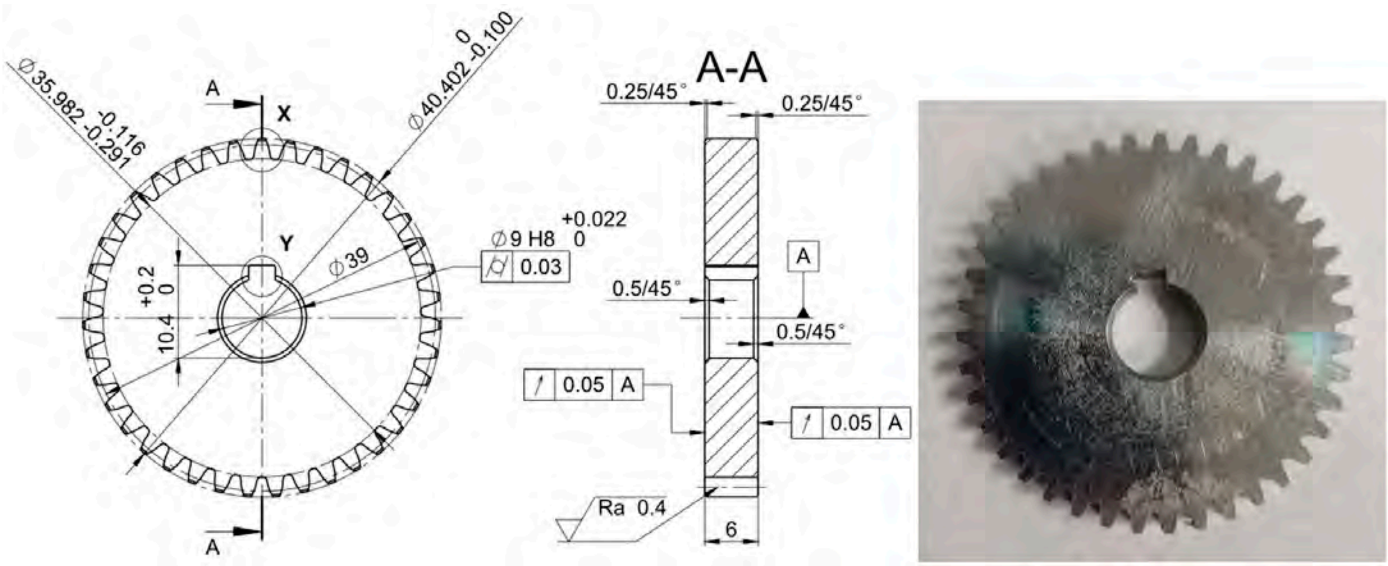


Figure 2—Steel gear samples employed for testing.

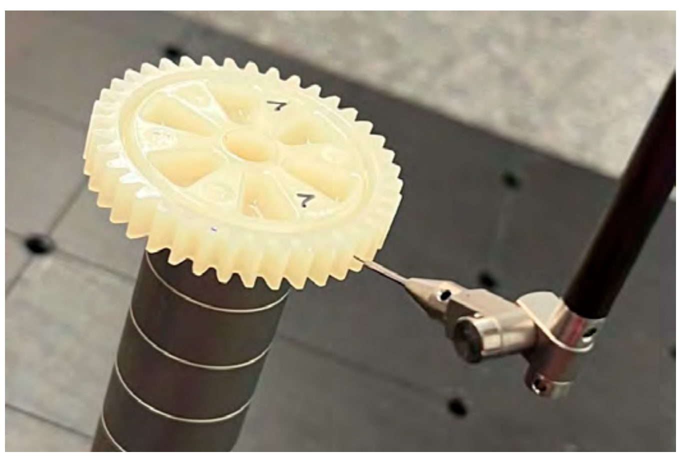


Figure 3—Geometric quality inspection on the plastic gear sample.

	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—Evaluated quality grades for produced gears.

Gear Quality Inspection

Geometric quality assessments were conducted on three gear specimens from each material group using a Zeiss Coordinate Measuring Machine (CMM) equipped with a Zeiss VAST XXT scanning probe (Fig. 3). The evaluation encompassed critical gear parameters, including profile deviation, lead variation, pitch error, and runout, all measured in accordance with the ISO 1328 standard for gear quality inspection (Ref. 10). The quantified parameters and their corresponding quality grades are summarized in Table 2. As the quality grades among the polymer gear sets exhibited minimal variation, it was assumed that geometric quality had a negligible effect on the observed NVH behavior during testing. Although the steel gears demonstrated superior geometric precision, they were included in the experimental matrix to enable quantification of NVH differences attributable to material substitution.

Testing Conditions

The gear pairs were evaluated within an enclosed acoustic chamber integrated into the gear test rig, effectively isolating the test specimens from external acoustic interference. This setup ensured that only the noise generated by the meshing gear pair was captured, eliminating the influence of extraneous sound sources. Throughout all experiments, rotational speed, applied torque, and gear temperature were rigorously controlled (Figure 4). Given the sensitivity of NVH performance to operating conditions, each gear pair was tested at two discrete torque levels, with three corresponding rotational speeds per torque level, to assess the influence of both parameters. Gear temperature was actively regulated and maintained at 80°C, measured directly in the tooth engagement zone. The complete matrix of test loads is detailed in Table 3. Testing was conducted under both dry and, for selected combinations, grease-lubricated conditions. For each material pairing, three independent test repetitions were performed, with a new gear pair employed in each instance to eliminate the effects of wear. All gear sets operated at a fixed theoretical center distance of 38.45 mm, established using a high-precision positioning mechanism with an accuracy of ±0.01 mm.

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

Table 3—Summary of the testing conditions.

Seven distinct polymer material combinations, selected from commercially available grades commonly utilized in gear applications, were evaluated in this study. For comparative benchmarking, a steel gear pair of identical geometry was also tested. The evaluated material pairings are as follows:

7. Steel–Steel
8. Steel–POM (run in dry and grease-lubricated conditions)
9. POM–PPA+30%GF
10. PA66–PPA+30%GF
11. POM–PA66 (run in dry and grease-lubricated conditions)
12. PA6+15%G–POM+10%AF
13. POM–PA66+30%GF

One key advantage of plastic gears is their ability to operate in dry conditions without external lubrication. However, many gearboxes with plastic gears still use grease, as it typically improves efficiency and reduces wear. To reflect common practical applications, most of the tested material combinations were evaluated under dry conditions, except for the Steel–POM and POM–PA66 gear pairs, which were tested in both dry and grease-lubricated environments. The lubricant used was a grease formulated from synthetic hydrocarbon base oil thickened with a barium complex soap. The kinematic viscosity of the base oil

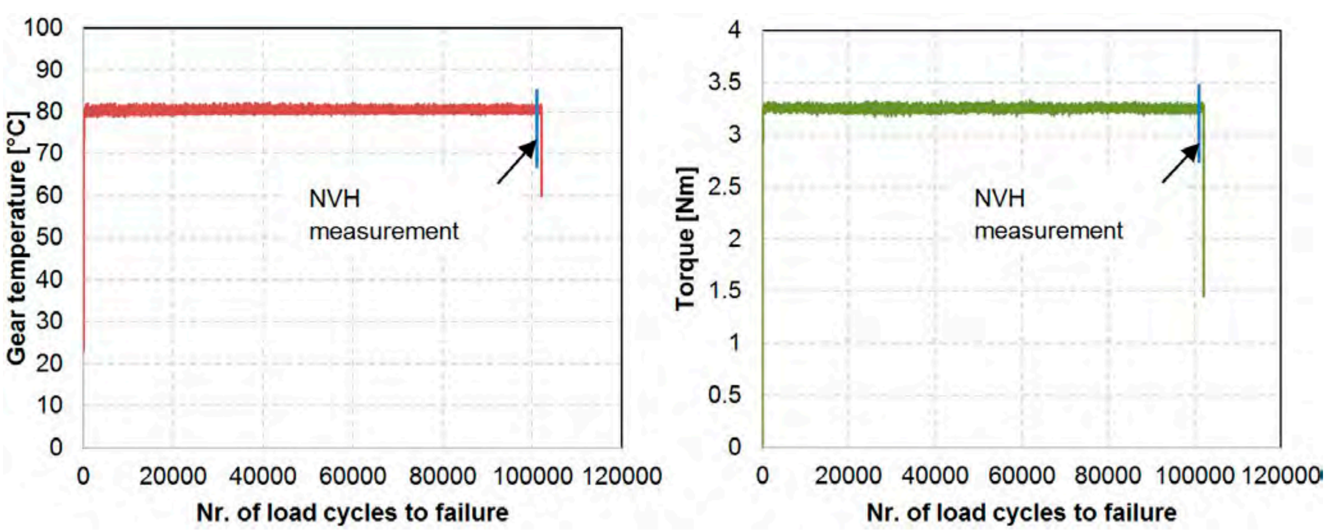


Figure 4—The gear's temperature and the transmitted torque were precisely controlled during each test. NVH measurements were done when 105 load cycles were reached.

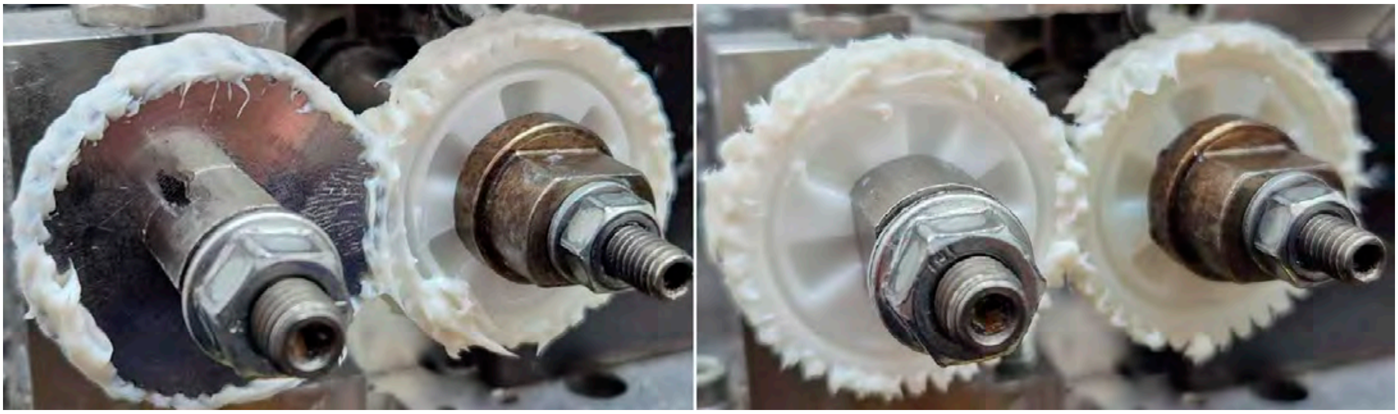


Figure 5—Grease applied on the gear pair before the tests in grease-lubricated conditions. (Left: Steel—POM gear pair; Right: POM—PA66 gear pair.)

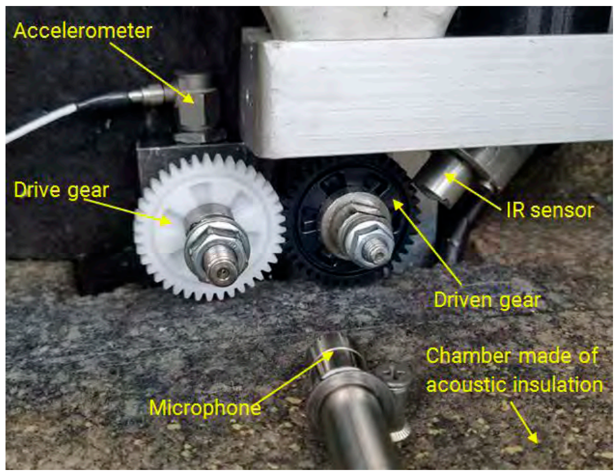


Figure 6—NVH testing set-up.

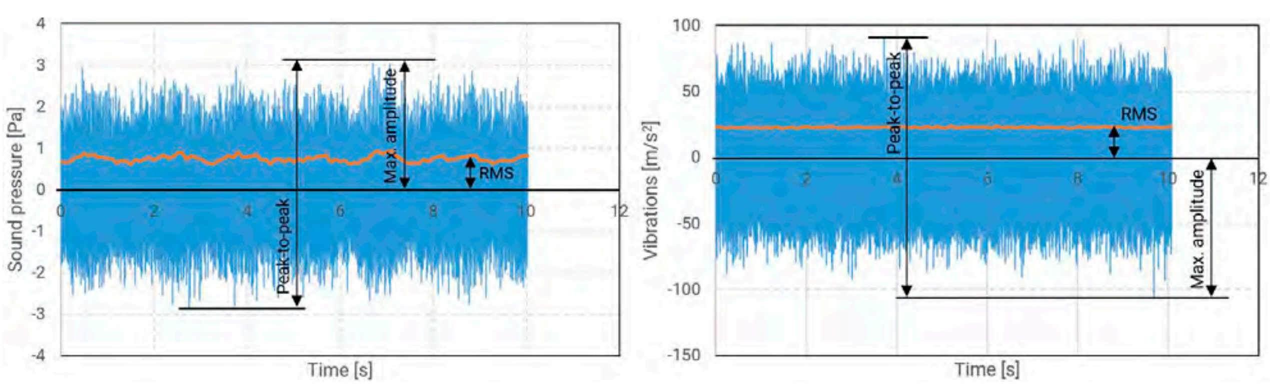


Figure 7—Acquired sound pressure and vibration signal.

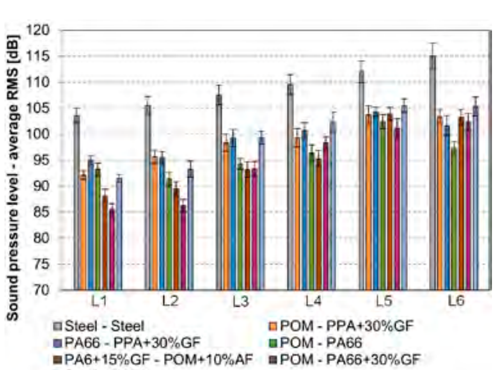


Figure 8—Sound pressure level, measured for the tested gear pairs. The temperature of plastic gears was controlled at 80°C in all tests (temperature measured on the teeth).

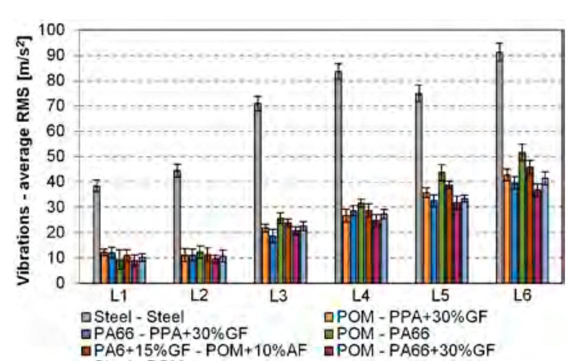


Figure 9—Vibrations, measured for the tested gear pairs. The temperature of plastic gears was controlled at 80°C in all tests (temperature measured on the teeth).

at 80°C was measured at 10.3 cSt. Prior to testing, the grease was manually applied to the gear teeth, ensuring complete coverage of the meshing surfaces on both gears (Figure 5). No additional grease was supplied during the test runs.

NVH Measurement

The NVH testing setup is depicted in Figure 6. A Dytran 3055D1T accelerometer (Dytran Inc., USA) was affixed to the bearing housing adjacent to the drive gear to capture vibrational data, while a PCB Piezoelectronics 378B02 free-field microphone (PCB Piezoelectronics Inc., USA) was positioned 50 mm in front of the meshing gear pair to record airborne noise emissions. Data acquisition was carried out using the SIRIUSm data acquisition module from Dewesoft (Dewesoft d.o.o., Slovenia). NVH measurements for polymer gear pairs were conducted after 105 load cycles, a point at which the system was presumed to have reached thermal and mechanical steady-state conditions, with wear effects considered negligible in terms of influencing NVH characteristics. Acoustic and vibrational signals were recorded over a 10-second interval, employing a sampling frequency of 20 kHz. Representative signal traces are shown in Figure 7. For steel gear pairs, measurement was performed following a brief stabilization period, sufficient for torque and rotational speed to reach steady state, given the shorter operational duration of these tests.

Three principal quantitative metrics are typically extracted from the acquired vibration and acoustic signals: the peak value (maximum instantaneous amplitude), the peak-to-peak value (the range between maximum and minimum amplitudes), and the root mean square (RMS) value. These parameters are illustrated in Figure 7. The peak and peak-to-peak values reflect singular extrema within the signal and are particularly sensitive to transient phenomena or high-amplitude anomalies. As such, these metrics may be disproportionately influenced by isolated impact events or momentary disturbances, which do not necessarily reflect the sustained dynamic behavior of the system. In contrast, the RMS (Root Mean Square) value provides a robust representation of the signal's effective energy content over the entire sampling period. It is calculated as follows:

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

From an applicable standpoint, the RMS value serves as a quantitative measure of the system's vibratory energy. In contrast to the peak and peak-to-peak metrics—which capture instantaneous amplitude extremes and are susceptible to transient events—the RMS value offers a time-averaged representation of the total energy contained within the signal, thereby providing a more comprehensive and stable indicator of vibrational intensity.

The measured sound pressure was converted to sound pressure level (SPL), expressed in decibels (dB), which represents a logarithmic scale of the sound pressure relative to a standardized reference pressure of 20 μPa—commonly recognized as the threshold of human hearing. This threshold corresponds to the quietest sound perceptible to the average young, healthy individual under ideal conditions. The conversion was performed using the following equation:

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

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

Results and Discussion

Effect of the Material Pair and Operating Conditions

The mean RMS values of the sound pressure levels are presented in Figure 8, while the corresponding RMS values of the measured vibrational signals are shown in Figure 9. These results represent the arithmetic average of three independent test repetitions conducted under each operating condition, with error bands denoting one standard deviation to reflect variability in the measurements. For the benchmark steel gear pair, a relatively linear increase in sound pressure level was observed with rising torque and rotational speed. In contrast, the polymer gear pairs demonstrated a more complex and nonlinear acoustic response to changes in operating parameters. Notably, the steel gear pair consistently produced sound pressure levels approximately 10 dB higher than those of the noisiest polymer gear combination. Within the polymer gear group, a sound pressure level differential of approximately 10 dB was recorded between the highest and lowest performing material combinations at the lowest tested rotational speed. As rotational speed increased, a corresponding rise in sound pressure levels was observed. However, at the highest rotational speed, the variation in noise emissions across the polymer gear combinations diminished significantly. It is important to highlight that a sound pressure level difference of approximately 3 dB is typically considered the minimum perceptible threshold for the average human listener. Differences below this value, particularly at absolute levels exceeding 100 dB, are generally imperceptible under normal auditory conditions.

It is important to underscore that all gear pairs were evaluated within an acoustically isolated chamber, ensuring that the recorded acoustic signals originated solely from the gear pair under test. In practical gearbox applications, however, the dominant source of radiated noise is typically the gearbox housing. This noise arises primarily from structural vibrations induced by the meshing gears, which are transmitted to the housing through the shafts and bearing interfaces. The RMS vibration values measured for the steel gear pairs were, in certain cases, more than double those observed for the polymer gear combinations. This substantial increase in vibratory energy suggests that gearboxes employing exclusively steel gears are inherently predisposed to higher acoustic emissions, due to more pronounced excitation of the housing structure.

All material pairings were evaluated under identical operating conditions, including fixed torque, rotational speed, and actively controlled gear temperature. Nevertheless, the dynamic (modal) characteristics of the gear pairs varied due to differences in material density and stiffness. Consequently, the natural frequencies (eigenfrequencies) of each gear configuration were located at distinct positions within the frequency spectrum. For instance, the steel–steel gear pair exhibited eigenfrequencies that differed not only from those of the polymer–polymer pairs but also among the various polymer–polymer combinations themselves. When a mechanical structure is excited at or near one of its eigenfrequencies, it responds with significantly amplified vibration amplitudes—ideally exponentially approaching resonance. As a result, a specific material combination may exhibit elevated vibrational levels at one operating speed while demonstrating reduced response at another, depending on the excitation frequency relative to its modal properties. This phenomenon has practical relevance, as real-world gearboxes frequently encounter fluctuating loads and speeds. To verify that the observed NVH responses originated specifically from gear meshing and were not influenced by ancillary noise sources such as motor emissions, bearing noise, or environmental interference, fast Fourier transform (FFT) analysis was applied to both the vibration and acoustic signal datasets. It was critical to confirm that the dominant spectral peak in all analyzed signals corresponded to the gear meshing frequency. As illustrated in Figure 10, this criterion was met, thereby validating that the recorded NVH characteristics were attributable solely to the dynamic interaction of the meshing gear pair.

The superior NVH performance of steel–polymer and polymer–polymer gear pairs arises from a combination of physical and material-specific properties. First, polymers have a lower elastic modulus than metals, which reduces contact stiffness during meshing. This softer interaction lessens impact-induced excitation and enables smoother load transmission, thereby lowering the intensity of impulsive noise. Second, polymers possess much higher material damping than metals, allowing vibrational energy to dissipate as heat rather than propagate through the system. Their lower mass and density further decrease inertial forces, which helps minimize excitation amplitudes and structure-borne noise. In addition, the conformability of polymer gear teeth enhances load distribution, reduces localized stress concentrations, and limits micromechanical impacts, all of which contribute to quieter operation. Finally, favorable tribological characteristics—such as reduced stick-slip tendency due to lower friction coefficients—help suppress high-frequency vibrations and tonal noise components. Collectively, these factors lead to a marked reduction in both sound pressure levels and structural vibrations.

Effect of Wear

The effect of wear was investigated using Steel–POM and POM–PA66 gear pairs operating under dry conditions. Tests were carried out at a torque of 2.0 Nm, a rotational speed of 1,400 rpm, and a gear temperature of 80°C. Each gear pair was subjected to five consecutive test intervals, with 2 million load cycles per interval. An initial benchmark NVH measurement was performed on unworn gears at the start of the first interval. Subsequent wear assessments and NVH measurements were conducted after every 2 million load cycles (approximately 24 hours of operation), up to a total of 10 million load cycles. For each material combination, three independent tests were performed.

Wear was quantified based on the reduction in chordal tooth thickness. To ensure measurement consistency, the chordal height specific to the gear geometry was first established. A customized Mitutoyo micrometer screw gauge equipped with round anvils was utilized for the chordal thickness measurements. The chordal addendum was fixed at 0.7 mm from the tooth tip, using a gauge block affixed to the stationary anvil of the micrometer (Figure 11), thereby standardizing the measurement location across all test intervals. To eliminate variability due to gear positioning, all intermediate wear measurements were conducted with the gears mounted on the test bench, preserving a constant center distance throughout the testing campaign. For each gear, four representative teeth, uniformly distributed along the circumference, were marked and used for repeated measurements. Final wear measurements were performed after the gears were removed from the test rig. Figure 12 illustrates the correlation between progressive wear and NVH behavior. Over the test duration, the sound pressure level increased by an average of 6 dB for the POM–PA66 gear pair and 4 dB for the Steel–POM combination. Concurrently, the RMS vibration amplitude rose from 21 m/s² to 45 m/s² for the POM–PA66 configuration and from 18 m/s² to 38 m/s² for the Steel–POM pair. This increase in vibrational response

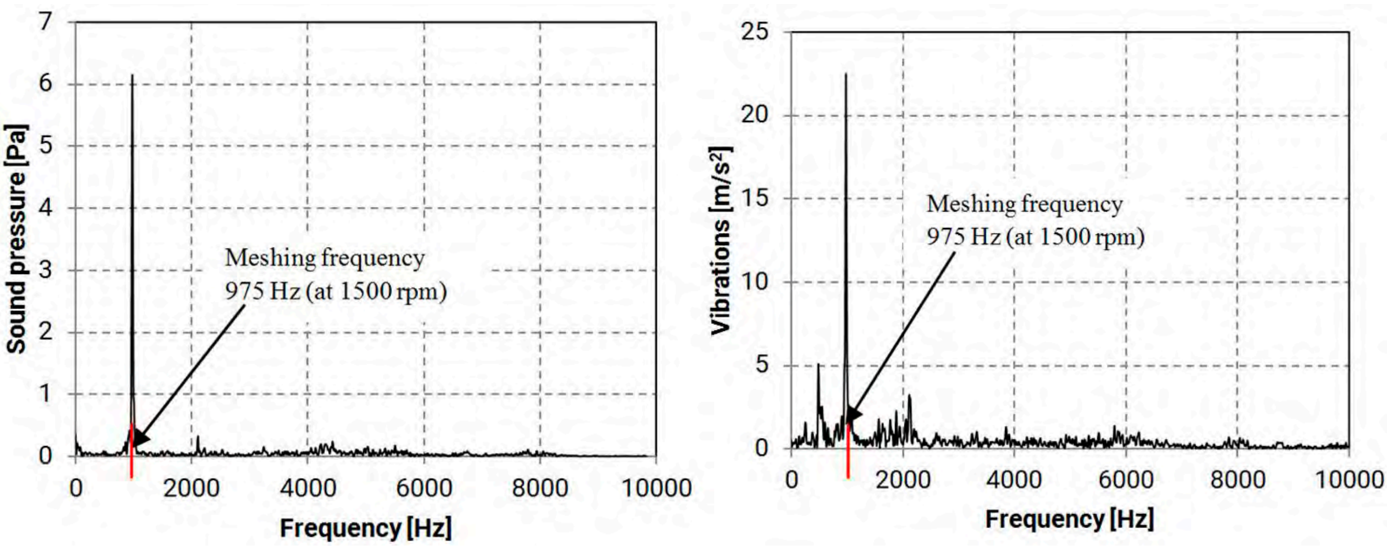


Figure 10—FFT of the measured vibrations and sound pressure signal. The rotational speed of the test was 1,500 rpm.

is attributed primarily to elevated transmission error induced by gear wear. Černe et al. (Ref. 11) previously characterized this phenomenon through numerical simulation, reaching comparable conclusions.

Effect of Grease

A comparative analysis of the measured sound pressure levels for dry and grease-lubricated conditions in Steel–POM and POM–PA66 gear pairs is presented in Figure 13, with corresponding vibration levels summarized in Figure 14. While differences at the lowest tested rotational speed were relatively minor, a marked improvement in NVH performance was observed at intermediate (L3, L4) and high (L5, L6) speed levels under lubricated conditions.

Overall, the application of grease exhibited a beneficial effect, acting as an additional damping medium within the gear tooth contact zone. This led to a reduction in impact-induced noise and vibration, as well as a suppression of stick-slip phenomena. The improved dynamic response is attributed to the lubricating film's capacity to mitigate direct surface interactions and absorb vibratory energy during meshing. In between measured sound pressure level for dry and grease lubricated tests with Steel–POM and POM–PA66 combinations are shown in Fig. 13. Measured vibration levels are summarized in Fig. 14. While at the lowest tested rotational speed the differences were not so evident a quite significant improvement could be observed at the medium (L3, L4) and high (L5, L6) rotational speeds. In general, a beneficial impact of grease could be observed, which can be considered as an effect of an additional damping element in the contact, generating less impact noise and vibrations, while also reducing the stick-slip effect.

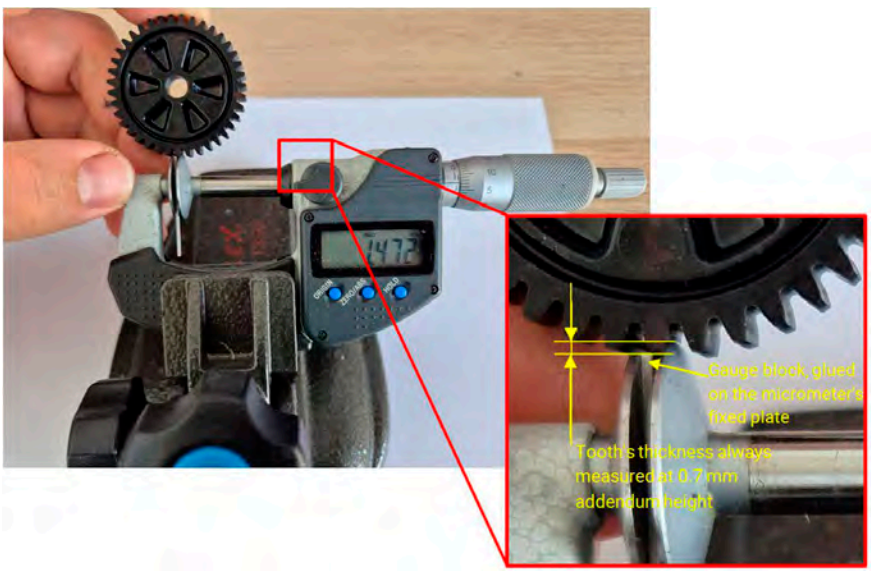


Figure 11—Wear measuring method—measured is the reduction in tooth thickness at the selected addendum height.

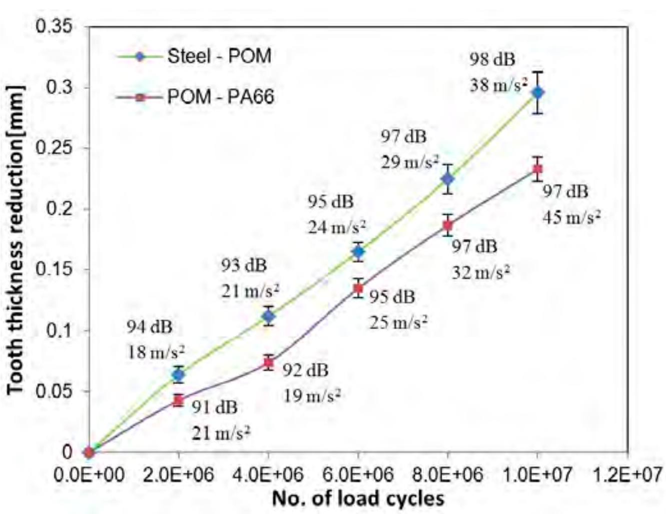


Figure 12—Average measured NVH in respect to the average wear measured for the tested gear pairs. Test conditions: 1,400 rpm, 2.0 Nm, 80°C.

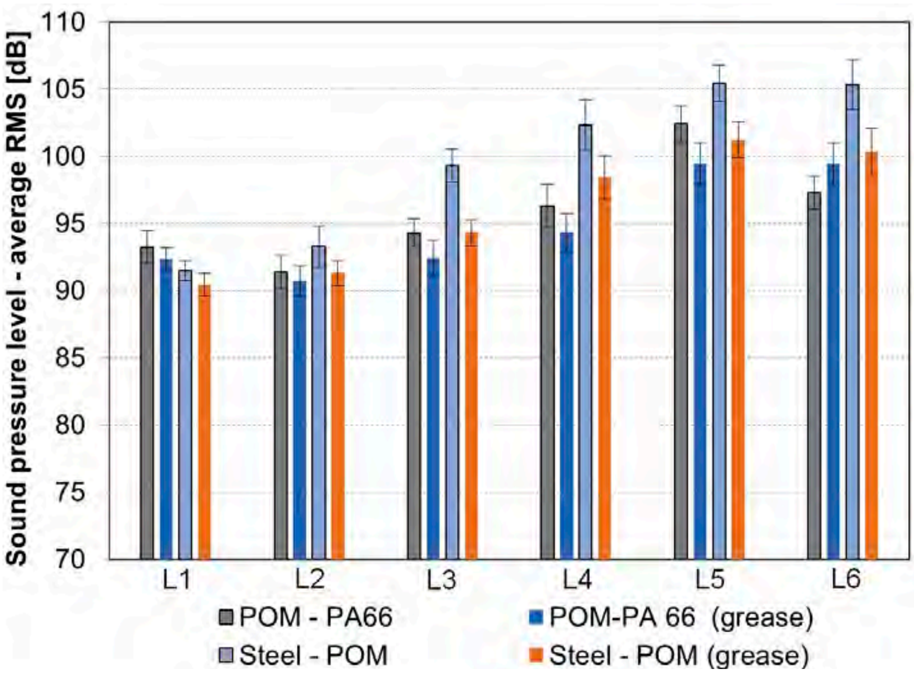


Figure 13—Comparison between measured sound pressure level for dry-run and grease-lubricated tests.

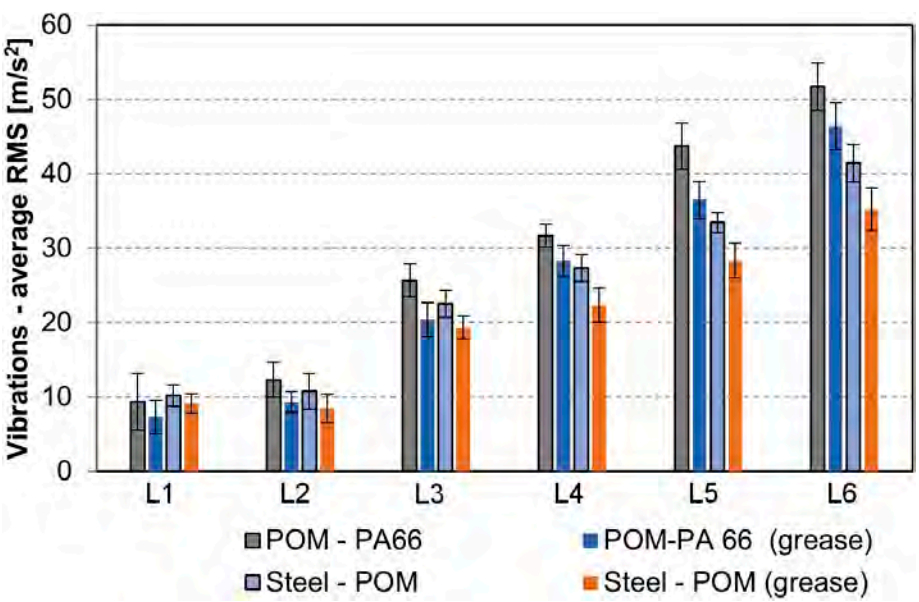


Figure 14—Comparison between measured vibrations for dry-run and grease-lubricated tests.

Conclusions

The study presents a comprehensive experimental assessment of the NVH performance of plastic gears in comparison to conventional steel gear pairs. The key findings are summarized as follows:

1. Plastic gear pairs exhibited substantially better NVH characteristics than steel gears. Sound pressure levels were reduced by up to 10 dB, while vibration levels decreased by more than 50% in some cases, underscoring their potential for noise-sensitive applications.

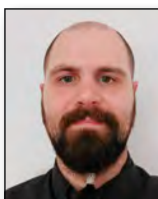
2. Among the tested pairs, POM–PA66+30%GF gears achieved the best NVH performance, benefiting from higher meshing stiffness and lower transmission error. In contrast, the POM–PA66 pair showed the highest vibration levels among plastic gears, linked to lower stiffness and greater transmission error.

3. Gear wear led to a noticeable deterioration in NVH performance. Over 10 million load cycles, sound pressure levels rose by 4–6 dB, and vibration amplitudes nearly doubled, emphasizing wear as a critical determinant of long-term acoustic performance.

4. Grease-lubricated gears consistently outperformed dry-running pairs, particularly at medium and high rotational speeds. The improvement is attributed to grease acting as a damping medium, which reduces impulsive forces and mitigates stick-slip effects.

These results provide valuable guidance for gear designers and engineers in selecting suitable polymer materials and lubrication strategies to achieve superior acoustic behavior. Future research may focus on advanced wear monitoring techniques and dynamic modeling approaches to enable predictive NVH performance under real-world operating conditions.

Dr. Damijan Zorko is a Co-CEO at RD Motion. He studied Mechanical Engineering at the University of Ljubljana and received his Ph.D. in 2019. Having 15 years of experience in gear transmissions, he was deeply involved in developing RD Motion's modern test benches and testing methods for experimental research on gears.



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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DKSH and Klingelnberg

ADVANCE GEAR TECHNOLOGY WITH GRAND OPENING OF DEMO CENTER

DKSH and Klingelnberg celebrated the grand opening of the DKSH-Klingelnberg Demo Center in Taicang, China, marking an important milestone in their joint commitment to advancing gear technology and promoting industrial innovation in China.

The ceremony began with welcoming remarks and speeches by William Li, general manager of the technology business unit, DKSH China, followed by Prof. Dr. Zhaoyao Shi, vice president and executive secretary-general of the China General Machine Component Industry Association, and Heinz Eder, sales director of Klingelnberg AG.

"The DKSH-Klingelnberg Demo Center is an innovation platform that combines Klingelnberg's centuries of expertise in gear and precision measurement technology with DKSH's over 30 years of market experience in China," emphasized Li, highlighting the strategic significance. "Through this center, we create greater added value for our partners. At the same time, we are building a hub that drives technological progress and industrial development throughout the entire gear industry."

Following this, Shi emphasized the broader context of the rapidly developing Chinese gear sector and the importance of international cooperation: "China's gear industry is experiencing a rapid rise with continuous technological development and growing market potential. As a global leader in gear technology, Klingelnberg has long contributed to the advancement of Chinese gear manufacturing through its state-of-the-art machines and innovative concepts. As China's manufacturing industry continues to move up the value chain, we need more opportunities for deeper collaboration between Chinese and international companies. Such partnerships not only promote technological progress but also build trust and a shared vision for the future."

In this spirit, Eder underlined the strong, decades-long partnership between DKSH and Klingelnberg: "DKSH and Klingelnberg have enjoyed a close partnership for 32 years, driven by our shared pursuit of excellence and technological advancement. We see the Demo Center in Taicang not only as a showcase for advanced gear technologies but also as a bridge for knowledge exchange, collaboration, and shared success. The new Demo Center will further strengthen our cooperation with partners as we jointly face future technological and market-related challenges. DKSH and Klingelnberg are true strategic partners, and together with all our industry partners, we look forward to a successful and promising future."

After the speeches, a ceremonial ribbon-cutting and a traditional lion dance symbolized the successful beginning. Afterwards, guests were invited to tour the new Demo Center, where all Klingelnberg machines currently used for passenger car electric drives are available for customer trials. During the tour, visitors gained direct insight into how Klingelnberg's state-of-the-art machines increase productivity, precision, and process reliability. Topics such as digital integration, automation, and quality optimization were discussed in detail, demonstrating how these innovations can promote sustainable manufacturing and competitive advantages across various industries.

In a special session, the latest technologies were presented, including "Quiet Bevel Grinding"—a software for bevel gear grinding that uses a new, innovative approach for low-noise, high-precision hypoid and bevel gear teeth. Also showcased was the production planning and monitoring software "Smart Factory," which attracted great interest among the participants.

The successful opening of the DKSH-Klingelnberg Demo Center marks a new chapter in the collaboration between the two companies and provides customers with a local point of contact to experience, test, and explore cutting-edge solutions firsthand.

klingelnberg.com

Klingelnberg Mexico

CELEBRATING 25TH ANNIVERSARY

Klingelnberg México, S.A. de C.V. is celebrating its 25th anniversary this year. Since its founding in November 2000, the company, based in Querétaro, Mexico, has developed into a significant subsidiary of the Klingelnberg Group.

"The 25th anniversary is an important milestone for us and underscores the continuous development of our location," explains Adrian Hernandez, Managing Director of Klingelnberg México. "Especially in the early years, we faced the challenge of orienting ourselves and establishing a foothold in a new market environment. Through strategic action and dedicated teamwork, we were able to successfully master this phase."

Today, Klingelnberg México supports numerous installed machines throughout the country. This growth reflects the trust of our customers and the successful collaboration with our partners. The 20 employees of the Mexican subsidiary possess extensive expertise and offer a wide range of services. They make a significant contribution to ensuring that the location is perceived as a reliable partner in the industry. "The anniversary marks the beginning of a new chapter in our company's development. We look forward to continuing to implement innovative solutions together with our customers and partners in the future and to further strengthening our location," says Adrian Hernandez.

klingelnberg.com

Gleason's Prof. Dr. Hermann Stadtfeld

MARKS 70TH PATENT WITH MICROFORM INNOVATION

Gleason Corporation's Prof. Dr. Hermann J. Stadtfeld, Vice President of Bevel Gear Technology and R&D, has been awarded a new patent for his latest invention, "Psychoacoustic Tooth Flank Form Modification"—also known by its working name MicroForm. The innovation marks his 70th patented invention, continuing a career dedicated to advancing the science and manufacture of bevel gears. *Gear Technology* caught up with Dr. Stadtfeld to field a few questions about this latest milestone.

Could you describe the focus or technical significance of your most recent patent?

Bevel and hypoid gears will become quieter without increasing the gear quality. This is important for the mass production of bevel gears for electric vehicles, but also important for conventional vehicles.

How does this invention fit into the broader evolution of your work on bevel gears and drive technology?

More and more bevel gears are ground, which poses the problem, that ground gears, which have a very low indexing error, are often noisy, due to the precisely timed impact of the teeth, getting into mesh. In case a located tooth contact is located, with low motion error within the contact pattern, this noise can be reduced by increasing the gear quality even more and by adding additional finishing operations, like fine honing, polishing, or lapping. The result is a quiet gear set, manufactured at twice the cost. The new patented technology allows us to achieve quieter operating bevel gears, which are even quieter than fine honed, polished, or lapped gears, by simply grinding them with MicroForm turned on. MicroForm will not increase the grinding time and therefore produce premium, noise-reduced sets at the original manufacturing cost.

What continues to inspire your research and development after so many years of contributions to the field?

Gears and, in particular, bevel gears have become my life. Gears are the most complex machine elements, and the machines that produce them are the most complex and sophisticated machine tools in the industry. The gear theory, the gear mathematical software, as well as the production machines and the processes they perform, are fascinating for me. It is a blessing to be able to do fascinating work every day, and work becomes a hobby.

Do you see any particular trends or challenges in gear design and manufacturing that this patent addresses?

The notion of reducing gear noise started with conventionally propelled luxury vehicles. Then the need for especially quiet transmissions in electric vehicles came up, forced by the low noise from the electric motors, which made transmission noise more audible. In the meantime, also the manufacturers of truck construction and agricultural equipment also ask for transmission noise reductions. The fact that the cost per gear, made with MicroForm, does not increase vs. conventional grinding makes this new process very attractive for new bevel gear developments.

gleason.com

Motion + Power Technology Expo

WELCOMES OVER 4,000 INDUSTRY PROFESSIONALS

The Motion + Power Manufacturers Alliance (MPMA) co-hosted the Motion + Power Technology Expo (MPT Expo) and ASM Heat Treat that welcomed 4,425 industry professionals October 21–23 at the Huntington Place Convention Center in Detroit. Additionally, the MPMA Fall Technical Meeting (FTM), the premier gear and bearing technical conference in the U.S., gathered the foremost experts from around the world.

Professionals from all sectors of the power transmission industry came to the show, including executives, engineers, plant managers, supply chain experts, military personnel and so much more. There were 170 exhibiting companies from more than 12 different countries. The tradeshow was last hosted in Detroit in 2023.

"MPT Expo continues to be a value-focused marketplace and we appreciate the support of the entire power transmission industry that visited the show, attended special sessions we produced, and took the time to connect with our innovative exhibitors," noted Matt Croson, president of MPMA. "The show was a success because of the commitment of industry leaders bringing running equipment, providing examples of gears and bearings they can produce, and highlighting the solutions they offer to literally dozens of industries. We are also grateful for the city of Detroit and their support; we think we have found a solid home for the power transmission industry to gather every two years."

Attendees and exhibitors were able to participate in numerous networking events including the What's Brewing Power Breakfast Panels, Ask the Expert, Solution Center speaking opportunities, the MPT Expo Podcast Studio (hosted by Tony Gunn, MTDCNC), and seven education courses held throughout the week.

"This year's show brought in the kind of people who mean business," said Steve Janke, 2025 chair of MPMA's Show Committee and president of Brelie Gear. "Attendees came with real challenges and left with real solutions. The energy on the floor was incredible, connections were happening everywhere. It's been an honor to help shape this event, and I'm excited to hand things off to Shane Hollingsworth, our incoming chair, who will keep that momentum going strong."

MPMA would like to thank Steve Janke for his service on the committee and are thrilled to have Shane Hollingsworth, vice president of sales at Kapp Niles as the incoming chair of MPMA's Show Committee.

"I've experienced this show from every angle, first as a manufacturing engineer, then as a gear and gearbox supplier, and now as a machine tool exhibitor," said Hollingsworth. "No matter the role, I've always believed this event delivers the best value for the North American gear industry. It's focused, it's relevant, and everyone here shares the same commitment to advancing our field. I'm honored to step into this leadership role and continue building on the strong foundation Steve and the committee have created."

motionpowerexpo.com

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JANUARY 6–9

CES 2026

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. 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. As CES 2026 approaches, the spotlight is once again on robotics — a sector that continues to redefine how we live, work and interact. This year's show floor promises a remarkable array of innovations, underscoring how robots are becoming deeply integrated into everyday life, from home automation and healthcare to hospitality and logistics.

geartechnology.com/events/ces-2026

JANUARY 20–22

PowerGen 2026

PowerGen (San Antonio, TX) is the premier networking and business hub for power generation professionals and solution providers. It unites power producers, utilities, EPCs, consultants, OEMs, and large-scale energy users. As the industry evolves toward cleaner and more sustainable energy, PowerGen fosters a progressive environment for both established professionals and new energy leaders driving the transition to a more sustainable future. The show invites technology experts, engineers, suppliers, decision-makers and thought leaders to join in exploring innovative solutions, learning from past and present projects and shaping the future of power generation. This includes a focus on The Total Energy Mix: Powering the Future, ensuring that all energy sources are considered in the journey towards sustainability.

geartechnology.com/events/powergen-2026

FEBRUARY 10–12

AIoT World Expo 2026

The AIoT World Expo (Fort Lauderdale, FL) is the premier event for exploring the convergence of Artificial Intelligence (AI) and the Internet of Things (IoT). This event serves as the gathering point for industry professionals to discover advancements, market opportunities, and understand the transformative power of AIoT across industries. Technologies include scalability, Edge, and AI data analytics, cloud solutions, machine learning (ML), and predictive analytics, cyber security and hybrid models. The show includes two key tracks AIoT Solutions and Services as well as AIoT Applications and Vertical Markets. Attendees will include corporate executives, IT, developers, engineers, data analysts, channel executives and more.

geartechnology.com/events/aiot-world-expo-2026

FEBRUARY 24–26

Additive Manufacturing Strategies – New York

This industry touchstone 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. Topics include energy, medical devices, aerospace, defense, future forecast, software and more. MPMA's VP of Emerging Technology, Mary Ellen Doran, joins moderator Filippos Voulpiotis, managing director, 3Dnatives, Kevin Kassekert, chief executive officer, VulcanForms and Michael Corliss, vice president of technology, SBO/Knust Godwin for a panel on high-volume industrial part production at 9:55 am, Feb. 25, 2026.

geartechnology.com/events/additive-manufacturing-strategies-new-york

MARCH 17–19

The Bearing Show and Lubricant Expo North America 2026

The Bearing Show (Detroit) is North America's newest exhibition and conference, connecting the evolving needs of bearings end-users with the latest technologies serving, OEM development, maintenance professionals and R&D engineers. Meet visitors from OEM's, machine manufacturers, industrial plants, global distributors and more. Gain insights into emerging trends such as energy efficiency, sustainability, and cost-effective maintenance strategies. The show is co-located with Lubricant Expo North America, a destination for connecting lubricant solution providers with end-user buyers and the entire supply chain. The Lubricant Expo brings together exhibitors and attendees from over 80 countries, covering everything from finished lubricants to formulation ingredients and equipment.

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ADDENDUM

Lessons Learned at Motion + Power Technology Expo 2025

Matthew Jaster, Senior Editor

MPT Expo 2025 welcomed 4,425 industry professionals including executives, engineers, plant managers, supply chain experts, military personnel and more. Some personal highlights:

Celebrate Your Wins in Gear Manufacturing

A great story coming out of MPT Expo was Vector Companies' acquisition of Northend Gear & Machine. Vector has an exciting story to tell and this acquisition reenforces their mission to deliver a unified platform of products and technologies. While many manufacturing companies are closing their doors, Vector's Northend Gear & Machine acquisition expands their portfolio to include large-diameter gears, heavy shafts, precision wire EDM and full gearbox repair and remanufacturing. This is but one example of how collaboration and diversification will be key to long-term growth in gear manufacturing.

Tedious Tasks A Thing of the Past?

My conversation with Rahul Garg, vice president industrial machinery vertical at Siemens Digital Industries Software, for the Ask the Expert series reenforced the need for more automation and robotics across all industrial segments including gear and power transmission. While some remain concerned that conveying systems, cobots, AMRs and humanoids are replacing good manufacturing jobs for humans, you can't argue with the productivity gains when it comes to tedious tasks on the shop floor.

Case in point: Chik-Fil-A's renowned lemonade was once processed by factory workers tasked with sorting, examining and ***manually squeezing*** each individual piece of fruit. Today, the company relies on driverless forklifts and robotic arms to sort, squeeze and package the lemons saving the company **10,000+ work hours** per day. Another example of using robotics and automation to take on monotonous and dangerous jobs freeing shop workers to focus on more appropriate tasks.

Culture is Just as Important as Quality

If you were lucky enough to attend Forest City Gear president Kika Young's presentation at the Solution Center, "The Human Side of Precision: Why Culture & Story Are Your Competitive Edge," you learned how company culture as well as prioritizing the values, beliefs and behaviors of your staff are key to building a successful organization. What we need more than anything in manufacturing today is to embrace originality, diversity, critical thinking and dare I say a little more humor and humility.

Markets fluctuate, egos run amok, it's criminally underrated to support every member of the organization as each one brings their own story, work ethic, knowledge and unique qualifications to work every day. I've watched this play out at FCG since 2007 and it's no surprise that the company has been so successful for 70+ years in gear manufacturing.

Quality Leads Over Quantity

Sure, we live in a data-driven world obsessed with numbers and bottom lines, but there's so much value to be found in a smaller, more focused trade show environment. 25+ exhibitors I spoke with were thrilled with the quality of sales leads from MPT Expo. Unlike larger events where things can get overwhelming (almost chaotic) the quality of the leads continued to be a talking point during MPT Expo.

It's very rare to find a dedicated event for gear and mechanical power transmission technologies where so much business is not only conducted between exhibitors and attendees but also solely between exhibitors. The focus and relevance of MPT will continue to gain momentum moving forward. The next Motion + Power Technology Expo takes place October 26–28, 2027 in Detroit. We hope to see you there!

motionpowerexpo.com