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AUGUST 2025

Industrial Gears
Software
MPT Expo 2025
and more

TECHNICAL

Morphology of FZG-A Test Gears

A Review on Gear Transmission Error

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The Star Cutter 5-axis NXT CNC Tool Grinder

In the world of gear manufacturing, tool grinders play a critical role in ensuring that gears are produced with high precision and accuracy.

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The Star Cutter NXT is extremely well-suited for sharpening and shaping complex gear cutting tools like helical hobs, helical shapers, stick blades, dish shapers, and other tools to perform optimally during production. The precision and reliability of these machines cannot be overstated as they ensure that gear tools can produce gears that meet the required specifications such as tooth profile, pitch circle diameter (PCD), helix angle, and surface finish.

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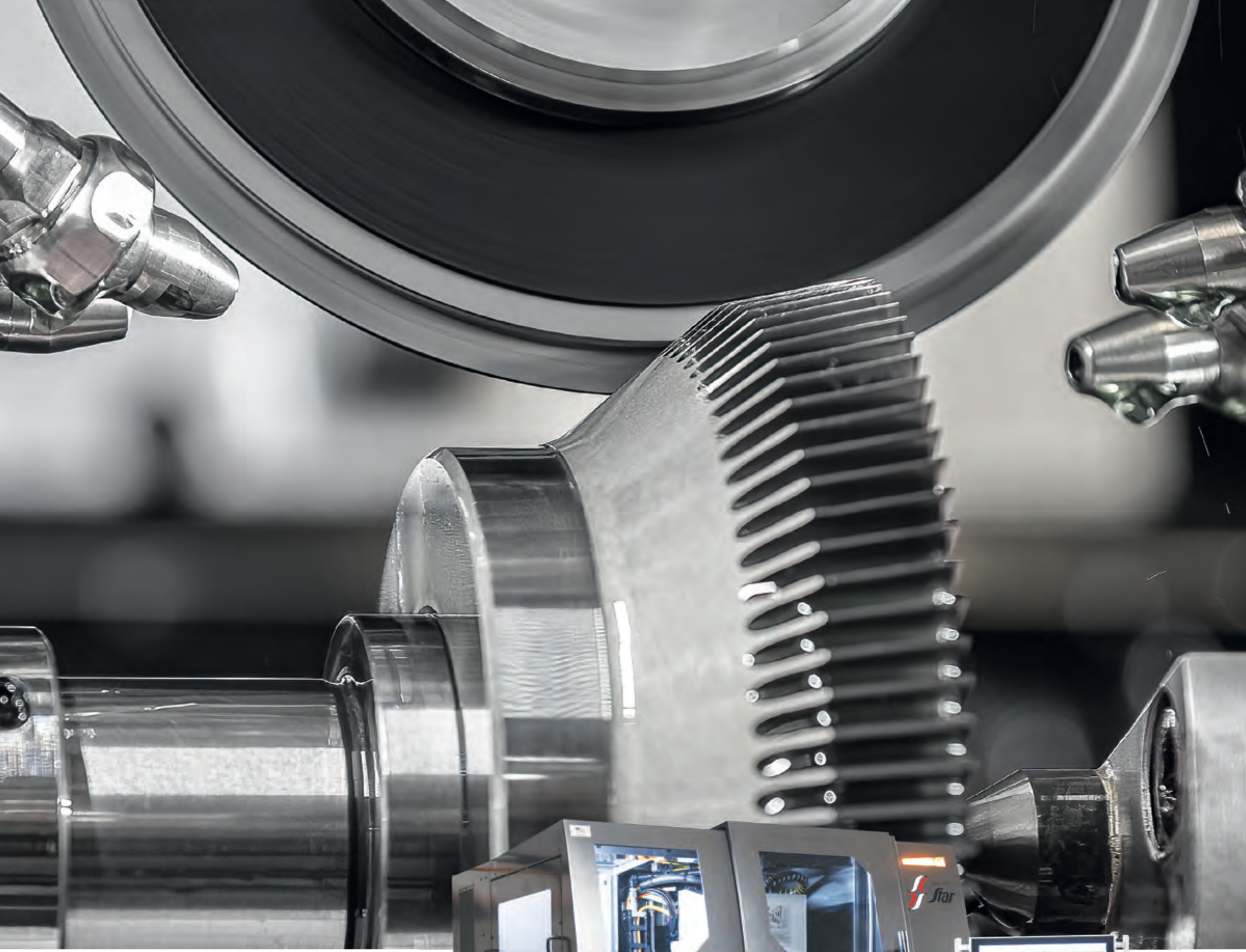

A key advantage of working with the Star Cutter team is our ongoing application support. Star application engineers are here to design, develop and implement programs and processes that are fine-tuned to your particular application.

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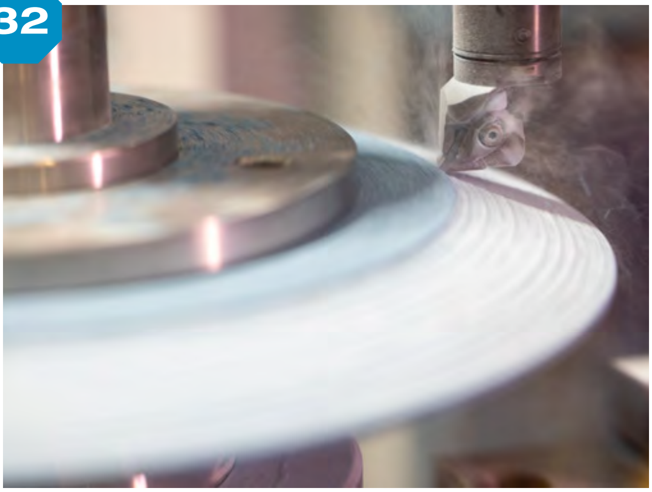
feature



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American Gear Manufacturers Association®

ABMA® American Bearing Manufacturers Association

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At MPT Expo, we offer programming for everyone. Between the tradeshow floor, education courses and exclusive networking events, your team will leave better informed, educated and connected than before. Make sure to get the advance pricing for all the events going on and be sure to share the opportunities with your peers!

motionpowerexpo.com

Monday, October 20

Analytical Gear Chart Interpretation | Dwight Smith
12:00 pm – 4:00 pm [4-hour course]

Why Bearings are Damaged | Matt Nagel & Garret Lenz
12:00 pm – 4:00 pm [4-hour course]

Tuesday, October 21

What's Brewing in Robotics: Breakfast and Panel
8:00 am - 10:00 am

Women in Manufacturing & Engineering Breakfast
7:00 am – 9:00 am

EV Course | William "Mark" McVea Ph.D P.E.
8:00 am – 5:00 pm [1-day course]

Integration and Trade-Offs in Gear and Bearing Systems | Michael Berhan, Ford Motor Company
8:00 am – 5:00 pm [Day 1, of 2-day course]

Wednesday, October 22

What's Brewing in Aerospace and Defense: Breakfast and Panel
8:00 am - 10:00 am

Fall Technical Meeting (FTM) | Three-Day Technical Conference

Basics of Gearing | William "Mark" McVea Ph.D P.E.
8:00 am – 5:00 pm [Day 1, of 2-day course]

A Practical Approach to Managing Gear Noise | Robert White
8:00 am – 5:00 pm [1-day course]

The Materials Fusion Experience – Wednesday Social Networking Event
6:00 pm – 9:00 pm

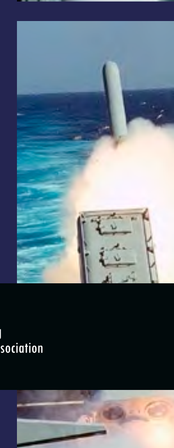
Thursday, October 23

What's Brewing in Workforce and Advocacy: Breakfast and Panel
8:00 am - 10:00 am

Design and Performance Rating Procedures for Plastic Gears (Spur and Helical) | Damijan Zorko & Borut Černe
8:00 am – 5:00 pm [1-day course]

Materials Selection and Heat Treatment of Gears | Carl Ribaudo, Sarah Tedesco, and ASM
8:00 am – 5:00 pm [1-day course]

Fall Technical Meeting Networking Reception (open to non-conference attendees)
6:30 pm – 8:30 pm



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American Gear Manufacturers Association®

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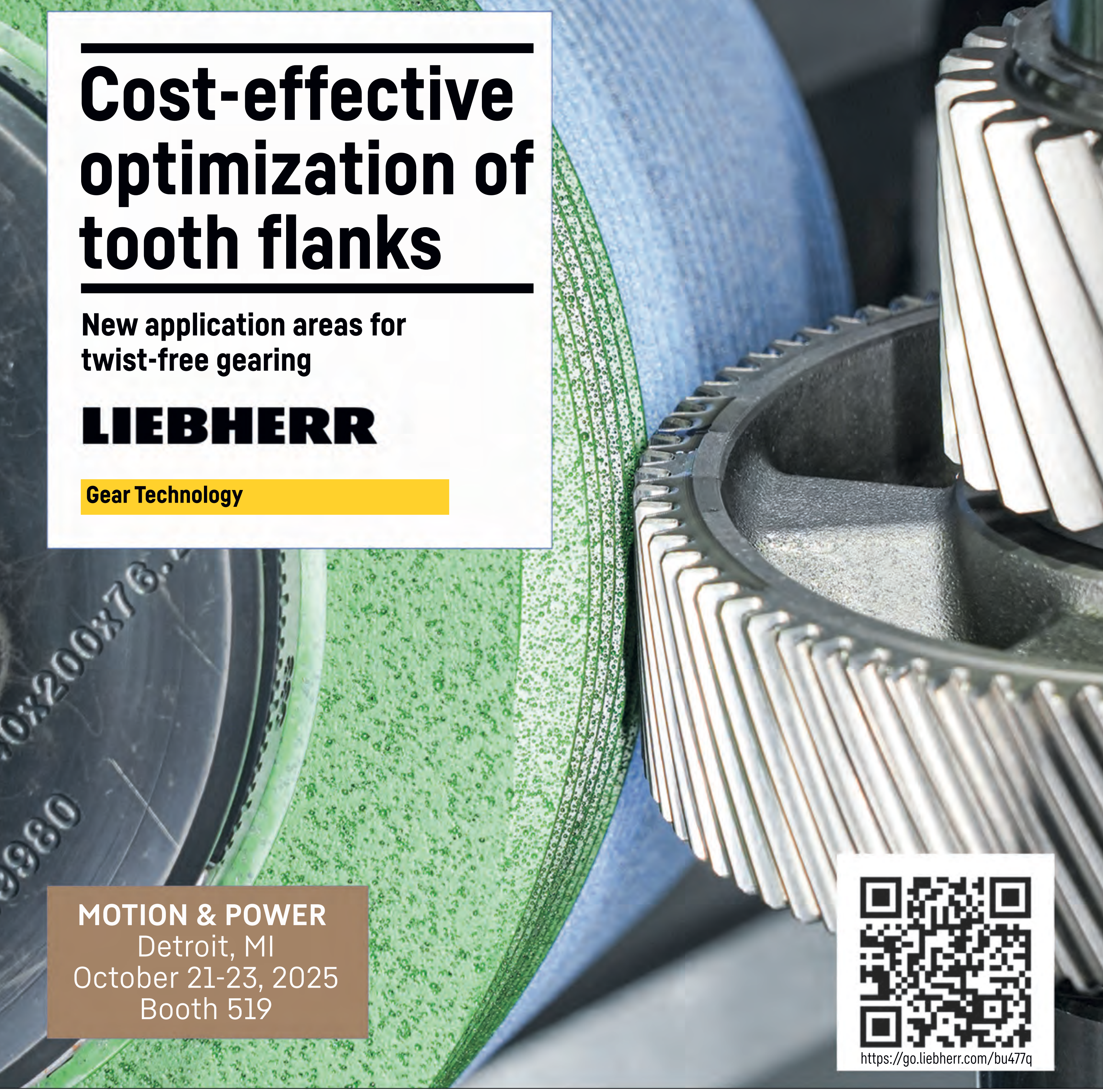
Courtesy of Rapid Gear



Efficiency gains in twist-free generating grinding

By advancing twist-free generating grinding, Liebherr-Verzahntechnik GmbH is elevating efficiency and quality in hard-fine machining to the next level The machining times when using dressable grinding worms have been reduced to almost the same level as conventional methods – even with asymmetrical gear teeth.

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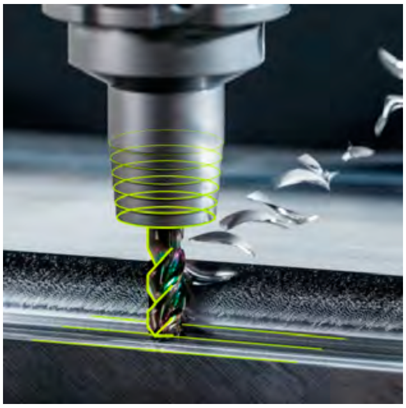
GT REVOLUTIONS

EMO Hannover Spotlights Software, AI, Robotics and Machine Learning

Founded in 1975, EMO Hannover has stood for innovation, internationality, inspiration and the future of metalworking worldwide. This trade fair for production technology offers a unique platform every two to four years in Hannover under the motto "Innovate Manufacturing" to establish international contacts, tap into new business opportunities and gain a comprehensive overview of the industry's global offering.



geartechnology.com/emo-hannover-spotlights-software-ai-robotics-and-machine-learning

What's New in Robotics?

Manufacturers continue to see the value of automation and robotic technologies as industrial sectors outside of automotive look towards these solutions in 2025 and 2026 to bolster efficiency and fill much needed workforce gaps. AMRs, cobots and next-gen vision systems highlight the latest robotic and automation solutions.

geartechnology.com/what-s-new-in-robotics-technology

AS SEEN IN *PTE*

Mass Production

GROB has always been synonymous with the development and manufacturing of machines and production lines. Its machining centers, including the Universal line, feature unique retractable spindles and a wide range of automation capabilities. Noteworthy, is the fact these machines are built right in Bluffton, OH.

powertransmission.com/mass-production

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

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MPT Expo Has It All

The Motion + Power Technology Expo takes place October 21–23 in Detroit. Here are the top 10 reasons to book your trip today:

10. **Hundreds of exhibitors,** all focused on power transmission technology, representing the complete supply chain—including software to design, materials to meet the design requirements, machines and tooling to manufacture parts, service providers, as well as manufacturers of components and complete systems for gears and gearboxes. See p. 28 for our show coverage, including sneak peeks from some key exhibitors.
9. **Colocation with the ASM Heat Treat show.** Learn more at *www.asminternational.org/heat-treat-2025/*
8. **AGMA's Fall Technical Meeting.** See page 30 for our "Insights from the AGMA Fall Technical Meeting" article.
7. **Emerging Technology.** One of the hallmarks of the Motion + Power Manufacturers Alliance is its focus on emerging technologies and how things like AI, robotics and electric vehicles will impact the future of our industry. See page 36 for our update on what to expect at MPT Expo.
6. **Educational Opportunities.** Apart from the Fall Technical Meeting, MPT Expo also features a dedicated educational program including popular courses like "Analytical Gear Chart Interpretation," "Why Bearings are Damaged," "Basics of Gearing," and much more. For a full course lineup, visit *motionpowerexpo.com/education-courses/*
5. **Networking Opportunities.** MPT Expo comes with a full lineup of opportunities to meet and network with your peers, including the Women in Manufacturing and Engineering Breakfast, the "What's Brewing" power breakfasts and the Materials Fusion Experience evening social networking event. See *motionpowerexpo.com/networking-events/* for more information.
4. **Tony Gunn live podcast.** Throughout the show, Tony Gunn, will conduct live interviews with thought leaders, MPMA members and experts from around the world.
3. **Ask the Expert Live.** *Gear Technology* and *PTE* editors will return to host panel sessions of our popular "Ask the Expert" sessions. We're planning panel discussions on Automation, Workforce Development and The Future of Gear Manufacturing.
2. **Detroit.** The show's central location makes it convenient for much of industrial America. Huntington Place is conveniently located downtown, close to transportation, nightlife and much more.
1. **Meet Our Team!** Please stop by the MPMA booth (#444) to talk to our editors, renew your subscription, learn more about how the MPMA is working to keep the gear and bearing industries strong. Find out how you can participate in the many technical, educational and networking opportunities we provide throughout the year!

PTE

Randy Stott

Publisher & Editor-in-Chief
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Building Tomorrow's World: From Steam Trolleys to Space Transportation

Sara Zimmerman, Vice President, CX and Product, Sumitomo Machinery Corporation, Chair, Motion + Power Manufacturers Alliance

Picture this: A century ago, as steam-powered trolleys clanked through city streets and the first automobiles puttered down dirt roads, a group of visionary manufacturers recognized something crucial. The future of human mobility would depend not just on innovation, but on everyone speaking the same language of safety and reliability.

These pioneers in power transmission technology didn't just compete—they collaborated. They understood that for society to embrace revolutionary transportation, every component, every system, every standard had to work seamlessly together. From their foresight emerged what we now know as the Motion + Power Technology Manufacturers Alliance (MPMA).

Fast-forward to today, and that 108-year-old legacy surrounds us. We step confidently onto trains, drive across continents, and fly between cities because those early standards became the invisible foundation of modern mobility. But the next chapter of this story is just beginning.

Participation in MPMA offers employees more than just the chance to shape the future of mobility—it's an opportunity to expand their expertise, build invaluable networks, and develop skills that directly enhance both their personal growth and their company's success. By contributing to groundbreaking standards and innovations, employees not only influence the next generation of transportation but also gain the tools to advance their careers and make a lasting impact on the industry.

Consider what it takes to step into an autonomous vehicle or board a commercial space flight. That act of trust isn't just about the technology—it's about knowing that every component, every software protocol, every safety system has been rigorously tested and standardized across the entire industry.

This is where MPMA's modern mission becomes critical. Just as the alliance once brought order to the chaos of early transportation, today's members are working across the entire ecosystem—from component manufacturers to software developers, from government regulators to research institutions—to establish the frameworks that will make tomorrow's transportation both revolutionary and reliable.

The path forward isn't about any single breakthrough or company. It's about convergence—bringing together diverse expertise, competing interests, and shared values to solve challenges that no one can tackle alone. When a humanoid robot needs to navigate a crowded sidewalk, when a flying car must integrate with air traffic control, when an autonomous vehicle encounters an emergency, the solutions require industry-wide collaboration and consensus-driven standards.

MPMA serves as the crucial convener in this complex ecosystem, fostering the partnerships and establishing the standards that will define the next century of human mobility. Through education, advocacy, and collaborative problem-solving, the alliance ensures the future isn't just about having new technology—it's about having the trust to use it. And that trust, like the standards that enable it, is built one collaboration at a time.

I encourage you to engage with MPMA if you are a member—join our committees, explore our work in emerging technology—and be part of the pioneering spirit that started us 108 years ago! If you aren't a member—join us! We are truly setting the standards of tomorrow, right now! Come find out how we can make a difference to your company's efforts to innovate and grow.

As Chair, and the first one for the combined ABMA and AGMA, I am committed to advancing these fundamental tenets in everything we do at MPMA. I look forward to working with our current and future boards, listening to our industry needs from members, and driving our organization into this exciting future.

Together, we will keep tomorrow moving!

Sara Zimmerman, Vice President, CX and Product, Sumitomo Machinery Corporation, Chair, Motion + Power Manufacturers Alliance


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Nidec

INTRODUCES MGC300: A NEXT-GENERATION MULTIFUNCTION GEAR CENTER

Nidec Machine Tool Corporation has launched the MGC300, a state-of-the-art multitasking gear center designed to meet the evolving needs of the US gear manufacturing industry. Available now, the MGC300 combines a vertical 5-axis machining center with advanced gear-processing capabilities, delivering a powerful solution for manufacturers seeking to boost productivity, streamline operations, and reduce costs.

The MGC300 is engineered to perform general machining, simultaneous 5-axis operations, and a full suite of gear-processing functions—including hobbing, skiving, and gear tooth chamfering—all in a single setup. By minimizing machine setups and reducing the need for multiple jigs, the MGC300 significantly lowers operator workload and supports the industry's drive toward automation and labor efficiency. Its consolidated processes are ideal for component and gear manufacturers producing small batches of diverse products, helping them stay competitive in a fast-changing market.

Key features of the MGC300 Multitasking Gear Center:

1. Efficient, High-Precision Machining

Built on a compact, rigid gantry design with a low-overhang axis configuration, the MGC300 delivers exceptional accuracy and speed. The main spindle achieves up to 15,000 rpm, while the direct-drive, high-speed table—specifically developed for gear machining—enables synchronized, high-precision gear cutting.

2. Productivity Through Process Integration

The MGC300 supports both three- and five-axis machining, as well as hobbing, skiving, deburring, and chamfering—all with a single chuck and no additional setup time. This integration allows for efficient gear shaping, even with a general-purpose end mill, and expands the range of machining operations possible in gear manufacturing.

3. User-Friendly Operation

Featuring an intuitive, interactive data-entry interface, the MGC300 is accessible to both experienced machinists and those new to gear manufacturing. Operators can easily create gear machining programs and control machine functions, reducing training time and increasing shop floor flexibility.

nidec-machinetoolamerica.com

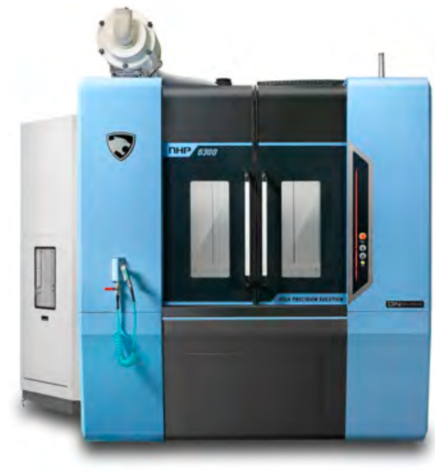
DN Solutions

UNVEILS NHP 6300 HORIZONTAL MACHINING CENTER

DN Solutions recently unveiled its second-generation NHP 6300 horizontal machining center, offering reduced cycle times, enhanced spindle performance, and seamless automation integration.

Engineered to slash non-cutting time, the second-generation NHP 6300 boosts spindle acceleration and deceleration rates by 20 percent over its predecessor. Table indexing is 35 percent faster, and table rotation speed has more than doubled, significantly reducing cycle times and driving higher throughput. Tool change times are 30 percent faster, further minimizing downtime between operations.

The second-generation NHP 6300 features a high-speed 12,000 r/min 50 taper built-in spindle, with a 15,000 r/min spindle available as an option. Vibration and thermal distortion are minimized to deliver exceptional stability and precision during heavy-duty cutting or extended operation. Integrated cooling for the spindle shaft and nut assemblies, paired with advanced thermal compensation, preserves machining accuracy throughout prolonged cycles.



A hallmark of the NHP series is its standard B-axis rotary table and automatic pallet changer (APC). These components enable complete five-sided machining in a single setup and support uninterrupted production by alternating between two pallets.

Automation-ready, the second-generation NHP 6300 seamlessly integrates with systems such as the Linear Pallet System (LPS) and enables 24/7 lights-out manufacturing via smart tool-wear prediction, advanced process scheduling, and defect-prevention logic.

To enhance operational efficiency, the second-generation NHP 6300 features an optional Sludge-Free Coolant (SFC) tank that automatically filters chips and sludge, reducing maintenance downtime and maximizing machine availability.

With its robust design, precision control, and automation flexibility, the second-generation NHP 6300 provides a comprehensive solution for manufacturers seeking faster, smarter, and more reliable horizontal machining.

dn-solutions.com

Sandvik Coromant

INTRODUCES NEW EXCHANGEABLE–TIP DRILL

Sandvik Coromant introduces its second-generation exchangeable-tip drill, CoroDrill DE10. Engineered for high-volume drilling across all materials, CoroDrill DE10 sets new standards in productivity, efficiency and sustainability. With its innovative geometry, this tool delivers true plug-and-play functionality and uncompromised performance.

Building on the success of CoroDrill 870 for H9-H10 hole tolerances, CoroDrill DE10 introduces advanced features that enhance versatility and operational ease. Users will appreciate the familiar pre-tension clamping interface, thoughtfully designed to align with operator experience while delivering enhanced security. The solution prioritizes robustness, enabling quick tip changes, reliable high-speed drilling and

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extended drill body life with more tips per tool. Its unique -M5 tip geometry delivers unmatched performance across diverse materials and cutting conditions.

CoroDrill DE10 addresses several common drilling challenges, particularly for manufacturers tasked with producing large quantities of holes in a single operation. With high feed capabilities, the tool achieves superior penetration rates, boosting productivity and lowering the cost per hole. Additionally, both tool inventory and cycle times can be significantly reduced, as CoroDrill DE10 eliminates the need for a pilot hole to guide the drill into place.

As a true plug-and-play solution, CoroDrill DE10 integrates seamlessly into existing setups and is easy to use while enhancing operational efficiency and performance. This innovative tool is designed to streamline manufacturing processes, delivering consistent results with minimal downtime.

"CoroDrill DE10 marks a new era in exchangeable-tip drills," said Mikael Carlsson, global product specialist for indexable rotating tools at Sandvik Coromant. "Testing against competing solutions has demonstrated its superior robustness, faster and easier tip changes, enhanced feed capacity, extended tool life and reduced cost per hole. It's an ideal solution for high-volume hole making across all industries, for typical components including heat exchanger plates, automotive components, shafts, pumps and valves and I- and H-beam drilling."

CoroDrill DE10 also enhances sustainability by enabling higher cutting parameters, faster metal removal and lower cutting forces, which reduces CO2 emissions. Its durable design minimizes waste through predictable wear patterns and maximized tool longevity, further supporting responsible manufacturing goals.

The tool has been tested against multiple competing tools, each time showing significant advantages. "One customer testing CoroDrill DE10 overcame the challenge of high cutting forces generating deformation on the drill body of their previous solution," continued Carlsson.

"When using CoroDrill DE10 to drill holes for a batch of gear box housings, the customer experienced no wear on the drill tip and a 17 percent increase in productivity. Another customer, this time machining stainless steel plates, saw a 43 percent increase in tool life and a 57 percent increase in productivity when switching to CoroDrill DE10 from a competing tooling solution," said Carlsson. "These are just two of many successful tests we have conducted, and for each one, customers have already seen unprecedented productivity gains."

For comprehensive tool data and optimized machining practices, CoroDrill DE10 is compatible with Sandvik Coromant's CoroPlus Tool Guide, providing users with precise cutting data recommendations from the outset.

sandvik.coromant.com

EMAG

SET TO PRESENT MSC 5 DUO AT EMO 2025 IN HANNOVER

In today's world, manufacturing companies are facing major challenges: increasing cost pressure, a shortage of skilled workers and rising energy costs. This combination requires machine tools that generate more output with less manpower and are energy-efficient at the same time. The MSC 5 DUO from EMAG was developed in response to these requirements and will be officially presented for the first time at EMO 2025 in Hannover.

The MSC 5 DUO is a two-spindle front-loaded CNC turning center designed for automated batch production. As components of the EMAG Classic series, it is characterized by an optimal ratio of functionality and capital investments. The machine focuses on high-productivity soft turning and combines proven EMAG technologies with cost-optimized basic equipment.

Peter Gröner, product manager of the turning business unit at EMAG, explains this approach: "The Classic series stands for optimized basic machines at attractive capital investments. While our modular and customer-specific machines offer a wider range of options and customization possibilities, with the Classic machines we concentrate on what is absolutely necessary."

The split-bed design forms the foundation for precision machining results. This design of the machine base mechanically decouples the two work areas from each other and thus prevents the transmission of vibrations during simultaneous machining. This ensures constant dimensional accuracy on both spindles, even during demanding machining processes.

The main spindles of the MSC 5 DUO have been designed for a wide range of applications. With a maximum motor speeds of 4,500 rpm and a standard spindle power of 5.5 kW in continuous operation or 7.5 kW for up to 30 minutes, there is sufficient reserve power available for demanding machining tasks. A more powerful version with 7.5 kW in continuous operation and 11 kW for 30 minutes is available as an option.

The constant torque in the speed range from 1,125 to 4,500 rpm is particularly important for consistent machining results. It ensures constant cutting performance for different materials and machining requirements. The A2-5 spindle nose can accommodate various chucks up to 210 mm in diameter. The thermally optimized spindle bearing with precision bearings ensures maximum concentricity, while an intelligent cooling concept with active temperature monitoring guarantees constant machining conditions even in continuous operation.

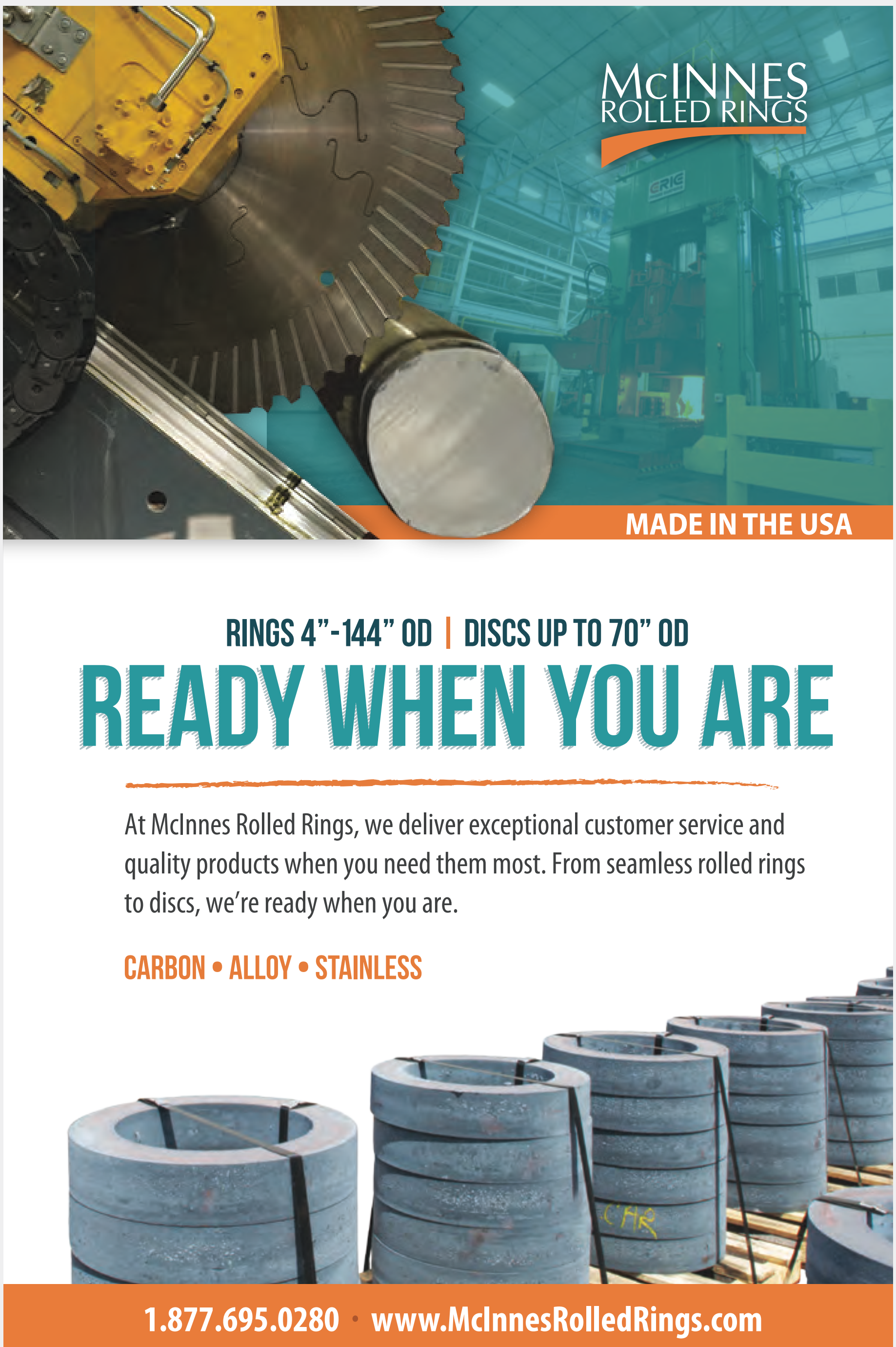
Eight tool positions are available as standard, with an optional extension to twelve positions. Compared to conventional VDI- holders, the BMT tool interface offers significantly higher rigidity, which has a positive effect on machining quality and tool life.

This interface enables the mounting of boring bars up to 40 mm in diameter for internal machining as well as tools with a 25 × 25 mm shank for external machining. The servo-controlled indexing in combination with hydraulic clamping ensures short tool change times and high positioning accuracy.

A decisive productivity factor in batch production is the reduction of non-productive times. The 3-axis gantry loading system of the MSC 5 DUO, which is fully integrated into the machine control system, automatically loads and unloads the workpieces. Parts handling is fast and precise thanks to the use of servo motors in all axes. The workpiece turner integrated as standard enables the complete machining of workpieces from both sides within one machine, which considerably simplifies the material flow and significantly reduces lead times in production.

As Gröner emphasizes: "It is important to us that we do not create complexity for the sake of complexity. The MSC 5 DUO offers precisely the technical functions that our customers need for their specific production tasks—no more and no less. We consider this focus on the essentials to be a decisive factor."

emag.com



Fanuc

INTRODUCES ENHANCED, NEXT-GEN ROBOGUIDE ROBOT SIMULATION SOFTWARE

Rebuilt and redesigned, Fanuc announces the release of *Roboguide Version 10*, the latest and most advanced iteration of its offline robot programming and simulation software. Designed to enhance efficiency, visualization, and user experience, *Roboguide* continues to be the go-to solution for companies seeking to streamline automation design and implementation. The software allows users to create, program and simulate robotic work cells in 3D without the need for physical prototypes, reducing costs and improving accuracy in automation planning. With the launch of this next-generation software, Fanuc is introducing several powerful upgrades including new virtual reality capabilities, 64-bit architecture, modernized user interface, enhanced support for native CAD import and more. "With the release of our enhanced *Roboguide V10*, we're delivering a smarter, more powerful simulation tool that meets the evolving needs of the automation industry," said Eric Potter, general manager, robot application segment, at Fanuc America. "Across nearly every industry, this immersive simulation software allows manufacturers to effectively visualize work cell effectiveness before actual installation, without the physical need or expense of a prototype setup."

Roboguide V10 is now available to users alongside the previous version, sharing a single license and ensuring that Fanuc customers can take advantage of the latest advancements in robotic simulation.

fanucamerica.com

Rego-Fix USA

HIGHLIGHTS AUTOMATIC TOOL CLAMPING UNIT AT SOUTHTEC

Rego-Fix USA will spotlight its ForceMaster spindle drawbar pull-force tester and its powRgrip PGS 25 Automatic Tool Clamping Unit at Southtec 2025 on October 21–23 in Booth #1337. Both the ForceMaster and the PGS 25 allow shops to maintain the highest precision and reliability in their part machining operations.

The ForceMaster is part of the Rego-Fix precision metrology line and ensures proper machine tool spindle drawbar pull-force, which is an important aspect of overall spindle preventive maintenance and performance. Rego-Fix developed its ForceMaster drawbar tester for shops with a variety of machine tools on the floor. With more than a dozen available adapters, ForceMaster works on virtually any machine tool spindle interface, including HSK, SK, BT, CAT and others.

ForceMaster features an IP67 certified dust and waterproof body ergonomically designed for a sure grip and comes with a rugged protective case tough enough for the shop floor. In use, operators simply thread on the appropriate adapter, insert the tool into the machine spindle and push a switch.

ForceMaster easily integrates into digital production environments and is fully accessible via a mobile phone app available for Apple and Android devices. Shops can then mirror the tool's dashboard to perform measurements remotely, and all information is downloadable for analysis and tracking.

The Rego-Fix PGS 25 Automatic Clamping Unit provides shops a cost-effective entry point into the company's well-known powRgrip (PG) toolholding system. Optimized for the single size PG 25, the PGS 25 is ideal for shops that require frequent tool changes. The unit features a single button for clamping and releasing and is intuitive and easy to use. Switching between clamping and releasing is accomplished by simply rotating the unit's head.

The Rego-Fix powRgrip system provides industry-leading clamping power without hydraulics, heat or fumes associated with other toolholding systems and is incredibly fast for improved production. The PGS 25 clamps tools within five seconds and provides maximum clamping force and total system runout (TIR) of ≤ 3 µm at 3 × D even after 20,000 tool changes.

Like all products in its portfolio, Rego-Fix designed, manufactured and tested the ForceMaster and PGS 25 Automatic Clamping Unit at the company's industry-leading ISO-certified facility in Tenniken, Switzerland, with legendary Swiss precision and quality.

regousa.com

Lights-Out Hobbing Performance

IPG runs the SH210 hobber unattended to boost overnight output

Ross Wegryn-Jones, Director of Sales & Marketing, Machine Tool Builders, Inc.

For those responsible for running a precision gear shop these days, sleep can be hard to come by. Most are trying to do more with less, particularly the short supply of skilled machine operators who make these shops tick. But Illinois Pulley & Gear's General Manager Richard Wolter reportedly sleeps like a baby, knowing that when he arrives at his factory in Schaumburg, IL, bright and early every morning, hundreds of high-quality, made-to-order spur gears, pinions and IPG's bread and butter—tight-tolerance timing pulleys—will have been hobbed overnight, deburred and neatly stacked. Better yet, it's all done on a productive late-model vertical hobbing machine that's proven reliable enough to leave it running completely unattended throughout the night, thus adding a much-needed 2nd and 3rd shift without the added cost of a skilled operator—and the hiring angst that goes with it.

SMG's SH210 vertical hobbing machine, paired with Halter LoadAssistant automation, runs reliably unattended overnight, effectively adding second and third shifts.

It's the Hobber They Always Wanted—But Never Heard Of

Wolter and his team weren't considering an SMG SH210 CNC Vertical Hobbing Machine when they went to the 2021 Gear Expo to kick the tires on a new hobber they hoped could replace several manual hobbing machines and add capacity to their burgeoning business. Despite SMG's excellent reputation in its home country of South Korea and a widespread customer base of big-name OEMs throughout Asia, the brand at the time was virtually unknown in North America and had just arrived via US distribution partner Machine Tool Builders Inc. (MTB). Imagine the IPG team's surprise when, after first considering all the usual hobber brands, they found the "machine of their dreams" at the MTB booth.

Operator loads the Halter's palletized stacker storage with gear blanks for completely automated, unattended hobbing overnight.

"MTB's Ken Flowers and John Waxler put the SMG SH210 show machine through its paces, and we saw right away that it checked all the boxes," recalls Wolter. "I particularly liked the fact that it was a machine with full boxway construction, which told us it was well built and could deliver the exceptional hobbing rigidity we were looking for."

According to Wolter, the SH also came equipped with additional bells and whistles that he wouldn't have expected in a machine priced at a deep discount as compared with the better-known machines in the 210 mm gear diameter size range. "We could see right away the throughput potential for a machine equipped with a ring loader for automatic workpiece handling, along with an on-board chamfering/deburring device," says Wolter. "These features, coupled with its inherently robust design, very competitive feeds and speeds, and even its unusually long Z-axis vertical slide travel that came standard, made for the perfect fit for our very diverse array of timing pulleys and precision gears."

Four Times Faster, with Fewer Operators

The SH210's 4-station ring loader automates loading and unloading, eliminating non-productive time and operator strain. Integrated chamfering/deburring during hobbing removes the need for manual downstream handling.

Wolter says the SH210 exceeded expectations right out of the box, and the company has never looked back. The new machine immediately replaced two manual hobbing machines, doing the work that once took five 8-hour days in just two. Furthermore, the SH210's 4-station ring loader automated load/unload and eliminated all the burdensome non-productive time and operator wear and tear that previously existed. And since the chamfering/deburring process could be performed right on the machine simultaneously with hobbing, the additional time needed for operators to manually unload, transport and set up for this addi-

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A FANUC 6-axis robot loads gear blanks from Halter's palletized stacker into the SH210's ring loader, then unloads finished parts back to storage.

tional operation downstream was eliminated. "Also, speeding changeover and contributing to workpiece accuracy and repeatability was the use of high precision collets that make changeover part to part much faster as compared to arbors used on the older machines, which necessitated a lot of dialing in and operator expertise," explains Wolter. "The SMG collet is inherently much more accurate, with a tapered design that essentially reduces runout to a small fraction of what could be achieved previously and without any manual adjustment by the operator."

Hobbing Lights Out and Unattended

With the SMG SH210 now firmly entrenched as IPG's hobbing workhorse, operating with remarkable reliability, dependably holding 'size' and, as Wolter says, "Delivering aggressive feed rates and appetite for more…"—a lightbulb went on at IPG. By coupling the SH210 to the Halter LoadAssistant robotics system IPG already had in-house, it would now be possible to run the hobber productively around the clock and completely unattended overnight. "Halter confirmed that we could easily move and integrate our existing LoadAssistant robotics system with the SH210," says Wolter. "It's plug-and-play; the robotics sits close to the SH210, such that workpiece blanks already loaded into the Halter's integrated palletized stacker storage are loaded via its FANUC 6-axis robot arm directly into the SH210's ring loader. Then the process is reversed to unload finished workpieces back to the Halter's pallet storage. The system's been running like clockwork ever since."

Day-to-day operation of both the hobber and Halter has been, according to Wolter, remarkably easy and reliable. Both systems feature conversational, easy-to-learn FANUC CNC, making it simple for operators to program and run IPG's very diverse array of workpiece types. Longer batch runs of the same part are scheduled for unattended production, such that part-specific collets and robotics grippers don't need to be changed over.

MTB Localizes Service and Support

Purchasing a next-generation hobber from a relatively unknown South Korean builder was a risk well worth taking, concludes Wolter, since MTB backs the installation with renowned gear machine service expertise and localized support. "The streamlined process, from sale to installation to the remarkable productivity we're experiencing today with this machine is a tribute to not only the SH210, but MTB and its can-do ethic," he says. "Working with MTB has given us one less thing to worry about at night!"

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Streamlining Drivetrain Design

A new engineering tool accelerates early-stage gearbox modeling and optimization

Cengiz Yilmaz, Product Manager, KISSsoft

Figure 1—Working with sketcher, user interface and 3D geometry on separate screens.

KISSsoft System Module allows intuitive concept design on a system level. In addition to the elementary components, complete gearboxes can now be designed in a separate module. The focus lies on fast concept building and fast calculations of complex kinematics. This is of benefit particularly in the initial phase of a project, when an engineer needs to be able to roughly model different variants of possible solutions to compare critical criteria.

The *KISSsoft System Module* is a versatile tool used in various scenarios, including:

- Designing new products based on key requirements.
- Modifying legacy systems for new conditions.
- Re-engineering reference designs.
- Analyzing existing designs documented through drawings.
- Managing and comparing design variants with the same topology.
- Creating databases of gearbox series with different ratios for different torque ranges.
- Visualizing, explaining, and promoting concepts, proposals, and preliminary designs.
- Elaborating on concepts for costs, mass, and size to enable quotations.
- Connecting, managing, and safeguarding *KISSsoft* files used for modeling individual components.

Working Modes

With *KISSsoft*, the user can choose between the three working modes: Component Level Only, System Level and Collaborative Approach.

The Component Level Only mode involves using *KISSsoft* modules other than the *System Module*. It's a detailed, low-cost, and time-saving approach suitable for less complex systems where calculations for individual components are done independently from each other. This mode is ideal for projects requiring maximum speed, efficiency, and simplicity.

The System Level mode integrates components into a holistic system, combining power flow analysis, spatial and collision-free arrangement, and top-level requirements-driven conceptual design. It is highly efficient for experienced designers with a deep understanding of all aspects of gearbox or transmission design. It is the mode of choice for most licensees globally.

Finally, there is the Collaborative Approach mode, which supports a team-based design process. Domain experts work on individual components using independent *KISSsoft* instances, performing detailed sizing, optimization, and analysis. Iterative design improvements are uploaded into the system model, gradually enhancing its fidelity.

Switching between these modes is seamless, with data exchange enabled through *KISSsoft* files as well as bespoke and neutral formats (e.g., *Gleason GAMA, GEMS, GDE, REXS*).

Target Users

Target users are, on the one hand, gear and bearing experts, and on the other hand, system architects. The module is suitable for gear and bearing experts because it provides an environment for managing all single components within their expertise. Components are sized, optimized, and rated in familiar *KISSsoft* modules, and once optimized, they can be integrated back into the system model with a single click. System architects, however, focus on ratios, design space, power flow, system reliability, operating conditions, and comparing design variants. They need a clear, communicable design description for stakeholders and are concerned with team-wide access to consistent product data, managing design iterations, and ensuring design survivability under different load regimes.

The software's user interface is tailored to the needs of both experts and system architects, allowing each to view the work in their preferred way without imposing an unfamiliar perspective.

Learning Curve and Required Skills

Familiarity with *KISSsoft* modules significantly reduces the learning curve. The user interface and sketcher are intuitive, leveraging common mouse and keyboard operations. New users can grasp the basics within a day and model complex systems within a week. Users

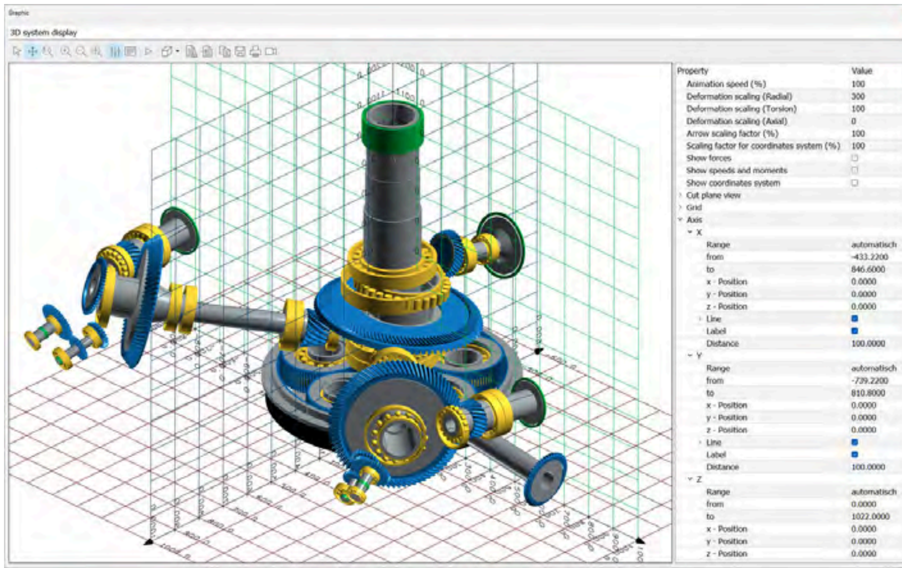

Figure 2—3D view of a gearbox with information about size and scaled deformation.

Strength

Gear			z1	z2	z3	z4
Calculation			z1z2	z1z2	z3z4	z3z4
Shaft			s1	s2	s2	sc
Drawing number			z1(z1z2)	z2(z1z2)	z3(z3z4)	z4(z3z4)
Number of teeth	z		25.0000	88.0000	28.0000	99.0000
Normal module	m_n	mm	1.7000	1.7000	2.2000	2.2000
Speed	|n|	1/min	15000.0000	4261.3636	4261.3636	1205.2342
Torque	|T|	Nm	150.0000	528.0000	528.0000	1866.8571
Power	|P|	kW	235.6194	235.6194	235.6194	235.6194
Number of gears	p		1	1	1	1
Lubrication type			Oil bath lubrication	Oil bath lubrication	Oil bath lubrication	Oil bath lubrication
Lubricant			ISO-VG 46	ISO-VG 46	ISO-VG 46	ISO-VG 46
Lubricant temperature	T_S	°C	65.0000	65.0000	65.0000	65.0000
Root safety	S_F		1.8076	1.6589	1.6527	1.5275
Flank safety	S_H		1.0156	1.0556	1.0369	1.0779
Safety against scuffing (integral temperature)	S_{intS}		3.3096	3.3096	3.5731	3.5731
Safety against scuffing (flash temperature)	S_B		4.3296	4.3296	4.9581	4.9581
Safety against micropitting	$S_{\lambda(B)}$		3.4049	3.4049	2.3713	2.3713
Gear mesh frequencies	f_z	Hz	6250.0000	6250.0000	1988.6364	1988.6364

Figure 3—Information about strength rating of all gears in the system in an overview table.

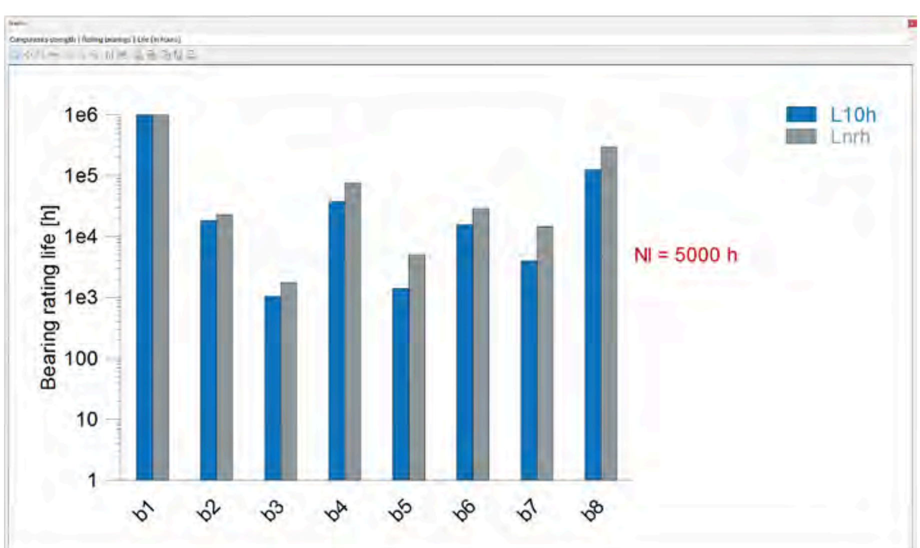

Figure 4—Comparison of bearing lifetimes of all bearings in the system.

need to master transmission design complexities, including load cases such as spatial and performance conditions. Experience with tree structures, context menus, tables, tabs, multiple windows, and standard engineering terminology is essential. The highly specific terminology used in *KISSsoft* is typically based on ISO, DIN, and AGMA standards. Familiarity with these standards is essential to correctly understand the intention, purpose and limitations of menu options, fields and buttons. To choose settings sensibly, assume derating factors properly, select calculation methods appropriately and use reasonable ranges for e.g., lubrication temperature, tolerance values or required lifetime, the user must have a thorough understanding of e.g., gear theory and methodology implemented in *KISSsoft*.

In summary, the skills and knowledge needed to make the most of the *System Module* are engineering domain-specific, not software-specific.

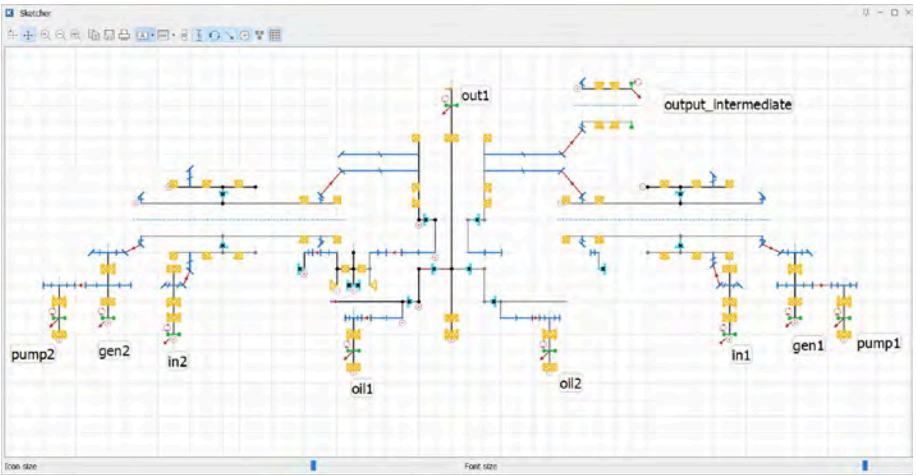

Figure 5—Sketcher window of a helicopter gearbox with multiple boundary conditions: A schematic view of all mechanical components. Power flow in the system is marked with red arrows.

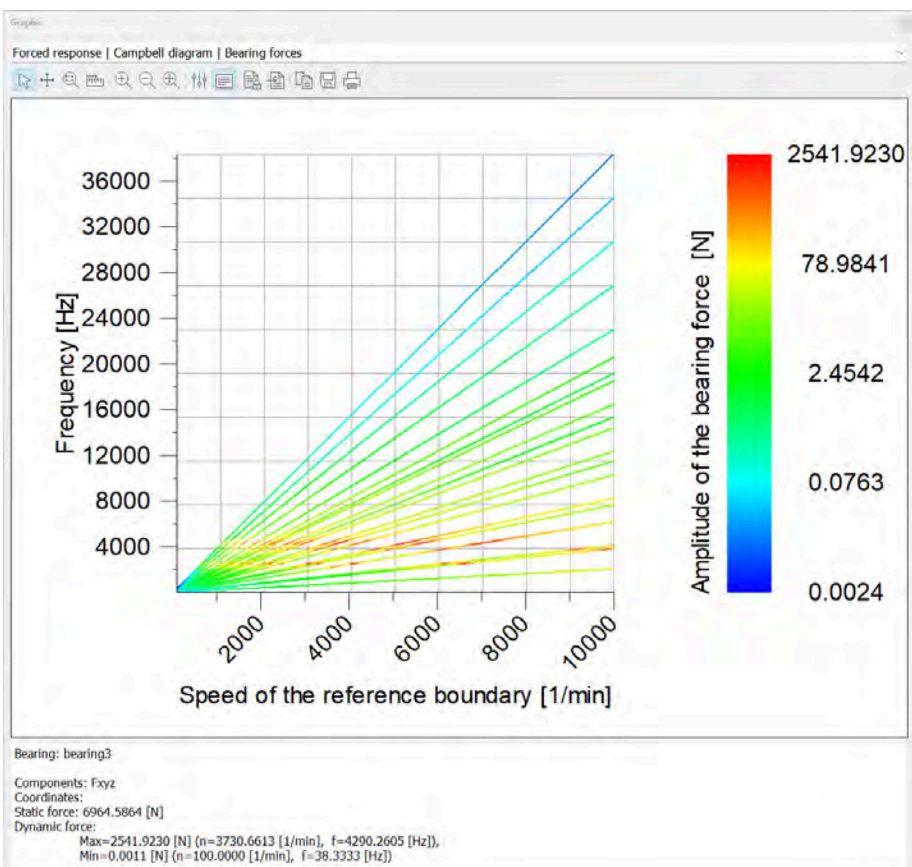

Figure 6—Result of forced response calculation: Campbell diagram of bearing forces and their amplitudes over a defined speed range.

Return on Investment

The *System Module* supports parameter-based modeling that simplifies the management of complex gearbox and bearing design data. By reducing the need for manual data transfer between components, it helps minimize input errors and supports consistency across design iterations.

In practice, engineers have reported shorter project timelines and greater confidence in early-stage concept validation. Even in basic applications, the system-level approach allows for faster variant comparison and refinement, particularly once users are familiar with the interface and workflows.

As proficiency with the module increases, many engineers adopt it as their preferred environment for both preliminary layouts and detailed system integration tasks.

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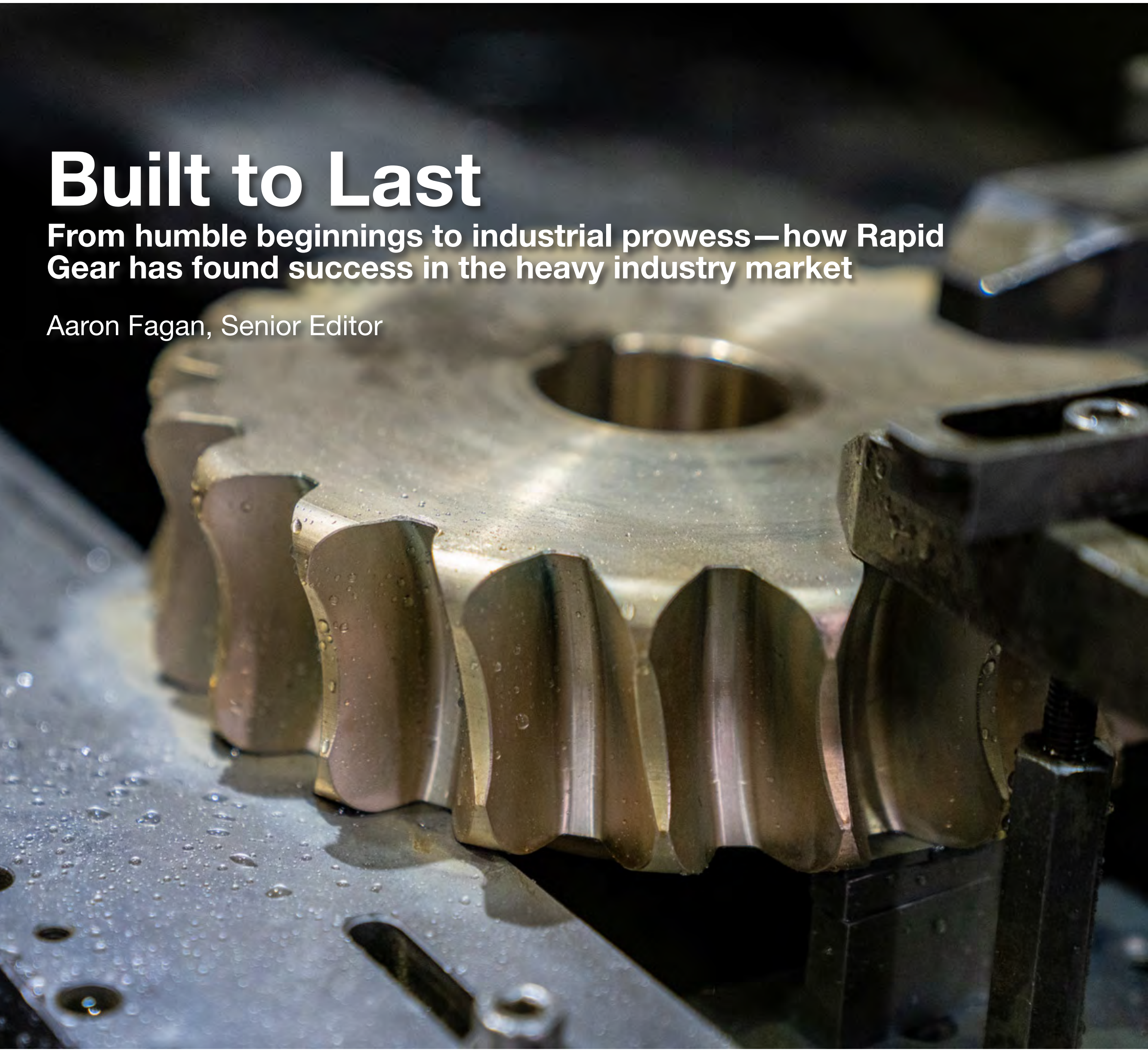
Built to Last

From humble beginnings to industrial prowess—how Rapid Gear has found success in the heavy industry market

Aaron Fagan, Senior Editor



From a small, rented space with a single machine to a reputable force in heavy industry, Rapid Gear's story is as much about resilience as it is about engineering excellence. Founded nearly five decades ago by Julian and Ana Sabados, Rapid Gear is more than a gear manufacturer—it's a testament to the power of hard work, determination, and a willingness to adapt to the needs of an ever-evolving industry. This article explores the journey of Rapid Gear, its milestones, industry impact, and the values that have anchored it in a competitive market. Through exclusive insights from company President Tania Sabados, we uncover how Rapid Gear has continually pushed boundaries, embraced new technologies, and cultivated a supportive company culture that nurtures both legacy and innovation.

Founding and Vision

Origin Story

In 1976, Julian and Ana Sabados, both immigrants to Canada from different regions of the former Yugoslavia, took a leap of faith. Julian, a trained mechanical technician, had spent nearly a decade working at Havlik Gear, gaining hands-on experience across different departments. Yet, he always envisioned more. Together with a fellow Yugoslav, he bought a machine, rented a modest space, and worked late into the night after finishing his day job, driven by the idea of building a gear shop of his own. This was the birth of Rapid Gear.

With three young children at home, Ana supported Julian's venture from behind the scenes, balancing the responsibilities of parenthood and the ups and downs of a fledgling business. "They came with nothing, and they didn't have much to lose," Tania Sabados says of her parents. "Their excitement came from building something they never imagined possible." Julian's initial partnership ended on February 14, 1980—the day his fourth child was born—but he and Ana forged ahead. They continued investing in the business, propelled by the shared satisfaction of seeing their efforts transform into a sustainable venture.

Early Challenges

Rapid Gear's early vision was simple yet ambitious: to create quality gear products while building a company grounded in integrity and grit. This meant investing in both machinery and people, a theme that has continued through subsequent generations. The Sabados family's resolve to grow from modest beginnings set the tone for a company philosophy that prioritizes quality, reputation, and adaptability over rapid expansion.

Pioneering Projects

One of Rapid Gear's earliest milestones came when it partnered with a raiseboring company in Northern Ontario. This mining company, itself in the early stages of growth, needed custom-made parts for its raiseboring equipment, and Rapid Gear delivered. The partnership was a turning point, providing the financial stability and industry connections that allowed Rapid Gear to expand its capabilities and reputation.

Another breakthrough came in the late 1970s with General Motors Diesel (now General Dynamics). Mowag, a Swiss company, was producing parts for military vehicles in Canada and faced difficulties finding a gear shop capable of meeting European standards. When Rapid Gear was recommended, they seized the opportunity, producing components to Mowag's exacting standards where other companies had failed. "We're still producing those parts today," says Tania Sabados, "along with several new generations of components." This success laid the foundation for decades of orders and solidified Rapid Gear's reputation for high-quality, reliable gear manufacturing.

Industry Evolution and Innovation

Adapting to Change

Since its inception, Rapid Gear has continually adapted to technological advances in the gear manufacturing landscape. In its early days, the company relied heavily on Maag machines for both roughing and finishing operations. Today, Rapid Gear utilizes faster milling techniques, advanced modeling, and robust tooling to rough out gears—including technically complex worm sets—before finishing them on Maag or Kapp Niles grinding machines.

Investments in equipment like large-capacity wire EDM machines and cutting-edge measurement tools ensure that the company can meet tight tolerances and deliver consistent quality. "We've made investments not just in our gear production, but in our entire machine shop," Tania explains. "It allows us to support a full range of machining and engineering services under one roof."

Julian Sabados and Tania Sabados

Staying Competitive

Rapid Gear's strategy to remain competitive focuses on strengthening its presence across heavy industries. "We're always working to make our name and capabilities known in sectors like mining, steel manufacturing, and press equipment repair," says Tania. These industries require dependable, high-precision gears, and Rapid Gear consistently delivers—thanks in part to its partnerships with material suppliers and subcontractors that help meet deadlines and expand capacity.

Products, Services, and Customization

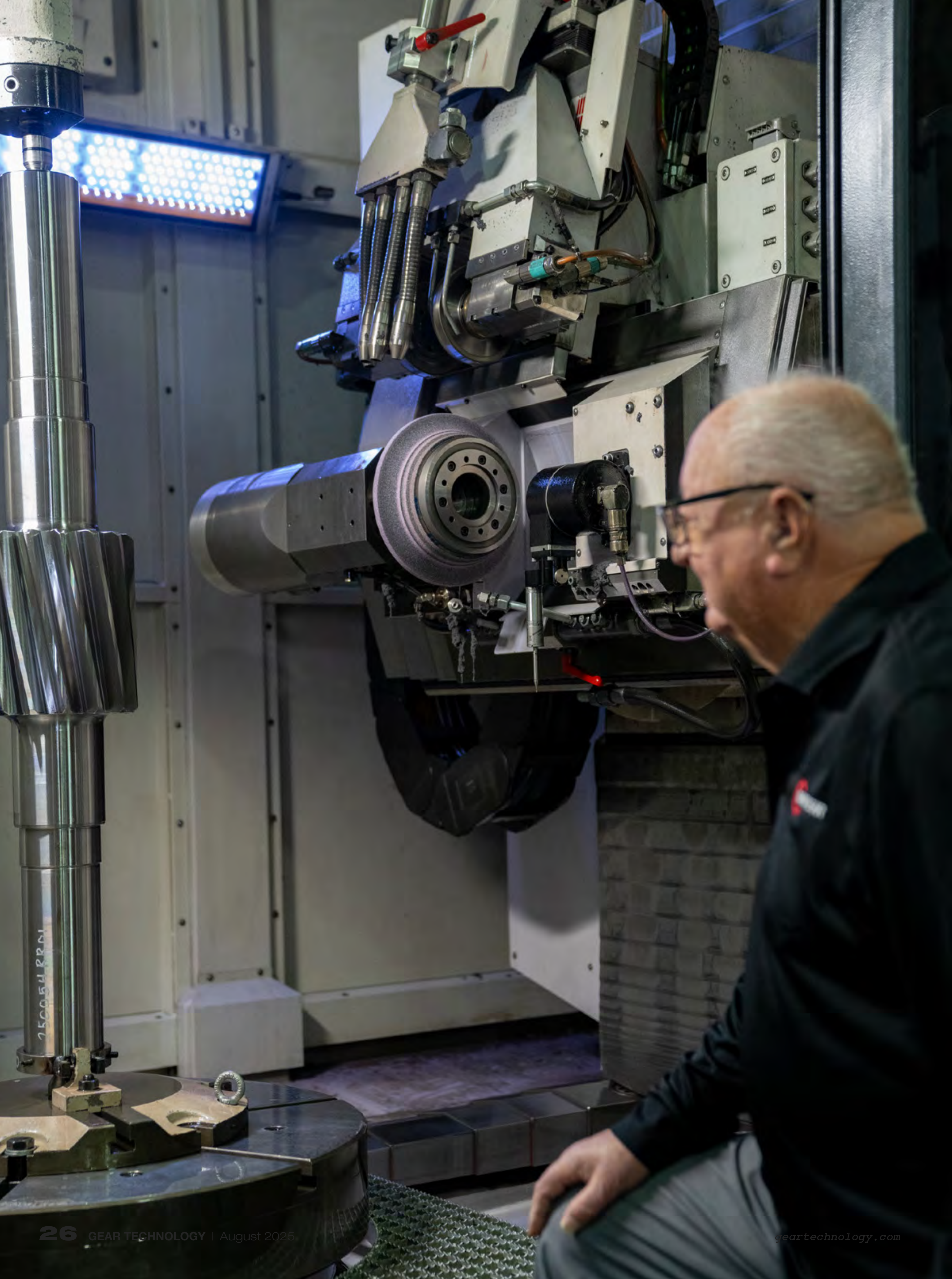
Customer-Centric Approach

Customization is a core part of Rapid Gear's value. The company has built a reputation for tackling unique and complex industrial challenges through reverse engineering and creative problem-solving. "We're not afraid of a challenge," says Tania. "We've developed an engineering team that's capable of finding solutions for almost any request—and we've backed that with the right equipment."

This integrated approach has also expanded Rapid Gear's role in the repair and refurbishing space. "We've become a go-to for gearbox repair because we have the engineering support, the machining infrastructure, and decades of experience to do it right," Tania adds. "Even in tough economic times, equipment still needs to run—and that's where we come in."

Repair and Refurbishing

Rapid Gear's in-house capabilities and extensive job archives give it a unique advantage in gearbox repair. "We track the history of what we've done, which means faster, more accurate repair and reproduction," says Tania. Their precision-focused approach minimizes client downtime, providing critical value in industries where every minute of operation matters.



Client Relationships and Industry Impact

Serving Heavy Industries
Rapid Gear serves a wide spectrum of clients across the heavy industrial landscape. With the ability to produce gears ranging from 2 inches to 200 inches in diameter, the company plays a key role in maintaining and powering equipment of all shapes and sizes. "We produce gearing for almost every kind of industrial equipment," Tania notes. "That includes everything from mining machinery to massive steel presses."

Building Trust
Transparency and accountability are the cornerstones of Rapid Gear's client relationships. "We're honest about what we can do, and we stand behind our workmanship," Tania emphasizes. "If something goes wrong, we show up—and we make it right." That commitment has allowed the company to build lasting relationships, grounded in reliability and results.

Company Culture and Leadership

Values and Management Philosophy
Rapid Gear's culture is rooted in humility, accountability, and teamwork. Tania describes her management style as hands-on and inclusive. "My philosophy is that I'm never too good or above anyone else to do what needs to be done," she says. "If that means cleaning the toilets—then that's what I'll do."

That kind of leadership fosters mutual respect and a positive work environment. Mistakes are treated as learning opportunities, not failures. "We're in this together," Tania says. "When something doesn't go as planned, we support each other and figure it out as a team."

Attracting Talent
In a competitive labor market, Rapid Gear sets itself apart by investing in people. The company offers competitive wages, supports apprenticeship programs, and maintains strong ties with local colleges and trade schools. Tania serves on advisory boards and is active with the Canadian Tool Manufacturers Association (CTMA), advocating for trades and manufacturing careers. "We're doing our part to make manufacturing visible again—especially to younger generations," she explains.

Lessons and the Future

Overcoming Today's Challenges
Managing a business in the gear industry comes with serious pressures, especially for family-run operations. "Even with a great team, the weight of financial responsibility and client expectations ultimately falls on leadership," says Tania. "It's a heavy burden."

But those pressures have taught valuable lessons. "You can't dwell on what you can't control. You focus on what you can do—and do that as well as possible," she adds. "Sometimes you have to make hard decisions about people and processes, but every time we've done it, it's turned out to be the right move."

Generational Continuity and Female Leadership
Rapid Gear's continued success also reflects a powerful story of generational continuity and female leadership in a traditionally male-dominated field. The company remains proudly family-owned, with Tania Sabados—daughter of founders Julian and Ana—now serving as president.

Since assuming leadership in 2014, Tania has led the company through significant growth while honoring its founding values. "There aren't many women in gear manufacturing," she notes, "but I grew up in this world, and I believe strongly in its value to our economy and the skilled people who make it thrive."

Her leadership has not only brought strategic innovation and investment but also reinforced the cultural foundation of mutual respect, integrity, and a deep sense of purpose. Tania's role represents a positive and inspiring signal for the future of North American manufacturing—one where tradition and innovation move forward hand in hand.

Conclusion
Rapid Gear's journey is a story of determination, innovation, and family values. From its humble beginnings to its current position as a trusted partner in heavy industry, the company has built a legacy rooted in quality, resilience, and adaptability. As Rapid Gear looks to the future, it remains committed to providing clients with the same excellence that has defined it for nearly 50 years. With a focus on technology, people, and partnerships, Rapid Gear continues to drive forward, proving that true success is built to last. From one generation to the next—supporting the North American industrial economy.

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Multidomain Innovation at MPT Expo 2025

This year's show explores cross-sector solutions in power transmission and high-performance system integration

Aaron Fagan, Senior Editor, and Matt Jaster, Senior Editor

The Motion + Power Technology Expo (MPT Expo) returns to Detroit from October 21–23, 2025, bringing together a comprehensive cross-section of the mechanical, fluid, and electrical power transmission sectors. Hosted in one of North America's manufacturing hubs, the event serves as a convergence point for engineers, technologists, researchers, and decision-makers involved in the design, production, and integration of power transmission systems.

The MPT Expo provides a technical showcase of state-of-the-art solutions spanning gear design and manufacturing, electric drive systems, hydraulic and pneumatic components, motion control, and system-level integration. Over 300 exhibiting companies will present hardware, software, and process innovations relevant to the evolving demands of high-performance mechanical systems, particularly those targeting greater efficiency, durability, miniaturization, and system interoperability.

The expo is structured to promote technical exchange across traditional silos. Mechanical exhibitors will include manufacturers of gears, splines, gearboxes, enclosed drives, bearings, machine tools, cutting tools, heat treatment systems, and inspection technologies.

Beyond the exhibit floor, MPT Expo features a technical education program tailored to both early-career professionals and experienced engineers. The curriculum includes hands-on training sessions, application-specific technical panels, and advanced manufacturing case studies. The event also integrates the MPMA Fall Technical Meeting (FTM) [see sidebar page 30 for more details], where peer-reviewed research will be presented by global experts across gear mechanics, materials science, tribology, metrology, and systems integration. This offers a structured venue for attendees to engage with the latest R&D in gear and transmission technology.

Heat Treat 2025, colocated with the MPT Expo and organized by ASM International, deepens the metallurgical and process engineering context of gear and transmission system development. Technical papers at Heat Treat 2025 explore advanced carburizing methods, thermal distortion modeling, low-pressure vacuum technologies, and novel alloy formulations, all of which are increasingly critical in high-performance gear applications. For professionals working at the intersection of materials science and mechanical design, the combined venue presents a rare opportunity to correlate heat treatment process variables with system-level performance outcomes in drivetrain and transmission components.

Live manufacturing demonstrations and real-time machine simulations will provide attendees with process-level insight into the performance of grinding, hobbing, shaping, skiving, honing, and broaching technologies. In addition, several new networking and panel events—such as the "What's Brewing" breakfast series—will address sector-specific challenges in robotics, aerospace, defense, workforce development, and industry policy.

MPT Expo 2025 arrives at a critical point for power transmission professionals. As the boundaries between mechanical, fluid, and electric drive systems continue to blur—driven by demands for higher power density, noise reduction, sustainability, and digital integration—the need for cross-disciplinary understanding is more important than ever. Whether focused on design optimization, high-precision manufacturing, or systems engineering, participants will find an environment grounded in technical rigor and practical application.

Croix Gear
Booth 613

Croix Gear, a US-based manufacturer of custom gears, has recently achieved AS9100D certification, aligning its quality management system with aerospace and defense industry standards. The certification applies to the company's full range of manufacturing processes and reflects implementation of documented traceability, process control, and continuous improvement protocols.

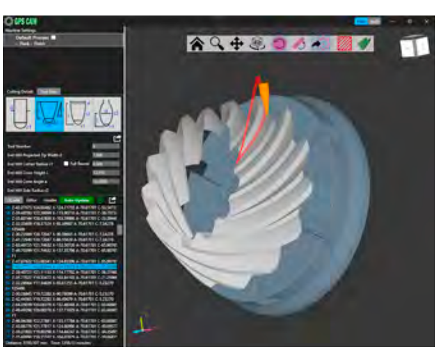
Best known for its specialization in bevel gears—including spiral bevel, straight bevel, hypoid bevel, and Zerol® configurations—Croix Gear serves a range of industries requiring application-specific gear geometries and high dimensional stability. The company also produces spur, helical, internal, and worm gears and maintains capabilities for high-accuracy gear inspection and quality documentation to customer specifications.

With AS9100D now in place, Croix Gear is positioned to support more complex requirements in aerospace and defense applications, where performance tolerances, material conformance, and process traceability are critical. The company's bevel gear expertise includes precision matching, optimized tooth contact patterns, and consistent profile control across batches.

Croix Gear is exhibiting at Booth 613 at this year's Motion + Power Technology Expo. Technical representatives will be available to provide details on gear manufacturing capabilities, inspection protocols, and aerospace-related production workflows.

croixgear.com

Dontyne Systems
Booth 213



Dontyne Systems has released a second update to the *Gear Production Suite (GPS)* in 2025 to reflect the volume of recent technical additions. Originally developed in 2008, *GPS* integrates gear design, machining simulation, and inspection data into a single environment to identify and mitigate manufacturing issues at the design stage.

The software's *Loaded Tooth Contact Analysis* functionality has been extended to hypoid gear geometry. Additional design and analysis features have been introduced to support non-standard gear forms requested by users in specific application domains.

Manufacturing simulation capabilities have continued to expand. Modules for plunge shaving and internal profile grinding have been added alongside existing processes such as hobbing, shaping, external shaving, and form grinding. The skiving simulation supports both internal and external cylindrical gears and is used to optimize tool design, machine settings, and cutting conditions over the life of the tool, including post-sharpening states. The module has been adapted for non-involute profiles and is compatible with both dedicated machines and 5-axis CNC platforms.

The honing simulation now includes analysis of contact line distribution to evaluate force balance during generation. It can also incorporate data from upstream roughing processes—such as hobbing or skiving—to improve calculation of stock allowance and breakout location at the tooth root.

The *GPS CAM* module has been extended to simulate the production of straight and spiral bevel gears using fixed tools on 5-axis CNC machines. This workflow is suited to batch production where machine utilization and toolpath control are critical. Dontyne continues to support prototyping and gear testing, providing output in the form of CAD models, *GPS* project files, and inspection reports.

The *Inspection Centre Module* interfaces with coordinate measuring machines (CMM) and dedicated gear inspection systems, maintaining consistent surface definitions between design and measurement. Measurement data may be imported into *GPS* for closed-loop feedback in load distribution analysis or for compensating deviations from machining processes.

A standalone inspection package, the *Dontyne On Machine Measuring System* (*DOMMS*), has been introduced to perform gear geometry evaluation directly on machine platforms. *DOMMS* is compatible with multiple hardware configurations and produces measurement data that integrates with *GPS* analysis modules.

dontynesystems.com

Forest City Gear
Booth 419

Forest City Gear, a precision gear manufacturer based in Roscoe, Illinois, specializes in fine- and medium-pitch custom gears for critical applications in aerospace, defense, robotics, medical instrumentation, and other high-reliability sectors. The company operates two facilities: its primary gear cutting and inspection plant and a dedicated turning facility known as Roscoe Works.

The company's manufacturing capabilities include the production of spur and helical gears, involute splines, worms, worm gears, sprockets, and other cylindrical gear types. These components are produced in a wide range of materials and geometries, including small-scale parts held to tight tolerances for use in environments with extreme thermal, mechanical, or vacuum conditions. Their gears have been deployed in terrestrial and aerospace systems, including the International Space Station and various NASA rover platforms.

Forest City Gear supports both complete part manufacturing and contract gear cutting. Under its "Make Complete" workflow, parts are manufactured from raw stock through final inspection, including material sourcing, turning, heat treatment coordination, and finish grinding. Design-for-manufacturability input is offered at the early stages of project development. The "Cut Teeth Only" workflow applies to customer-supplied blanks and includes gear cutting, measurement, and final inspection. The company maintains a tooling inventory of over 7,000 hobs and 5,000 shaper cutters, enabling short lead times on a wide range of standard and custom profiles.

Forest City Gear holds ITAR registration and maintains certifications to

AS9100D / ISO 9001:2015 and ISO 13485:2016, with Nadcap accreditation for magnetic particle inspection (MPI). The company is an active member of the American Gear Manufacturers Association (AGMA).

Representatives will be available at Booth 419 to provide technical information on current capabilities, tolerances, materials, and lead time estimates.

forestcitygear.com

Gleason Corporation
Booth 529

Gleason Corporation will showcase a full range of gear technology innovations. The company's presentation centers on Smart Loop Gear Manufacturing—a digitally integrated approach spanning gear design, production, and metrology.

The latest release of *KISSsoft*, now integrated with the System Module, enables simulation of complete drivetrains at the concept stage. This system-level engineering tool supports component optimization and design validation early in development.

For bevel gear manufacturing, the Phoenix 100C supports small and medium-sized production with simplified setup and high accuracy for robotic and industrial gearsets. The Coniflex Pro Manufacturing System advances differential gear production with closed-loop process control aimed at minimizing surface stress, improving root strength, and reducing NVH.

In metrology, Gleason introduces the 175GMS nano—a submicron-capable gear inspection platform equipped with skidless probes, waviness analysis, and *KTEPS* transmission error prediction software. New INTRA Single and Double Flank Testing systems offer fully automatable solutions for in-line and cell-based inspection environments.

Tooling updates include fast-change QFS Quick-Flex workholding systems (under 30 seconds per changeover), alongside newly developed hydraulic and mechanical clamping systems for precision machining across a range of gear types.

Gleason will also present expanded offerings in hard finishing tools, including power skiving cutters compatible with multiple machine platforms, along with coarse pitch and worm gear hobs for automotive and industrial applications.

For molded parts, Gleason Plastic Gears combines *KISSsoft*-driven optimization with moldability analysis, custom materials, multi-cavity tooling, and advanced molding strategies such as weld-line elimination and over-molding.

Gleason Global Services rounds out its offerings with on-site demonstrations of digital maintenance platforms, lifecycle support tools, and modernization programs to maximize machine availability and long-term process capabilities.

gleason.com/mpt2025

Insights from the AGMA Fall Technical Meeting

Held alongside MPT Expo 2025, the AGMA Fall Technical Meeting (FTM) remains the gear industry's most focused forum for peer-reviewed research in design, manufacturing, and performance. This year's sessions highlight a continued push toward fully integrated design-to-manufacture workflows that address rising demands for noise control, power density, thermal stability, and complex geometries.

Several papers explore microgeometry and surface modifications, particularly in relation to load distribution and excitation behavior. Researchers present strategies for twist control in grinding using advanced kinematic paths and adaptive flank corrections derived from loaded tooth contact analysis. These methods aim to balance surface finish, tool wear, and topological fidelity across various shift and dressing strategies.

A recurring theme involves extending loaded contact analysis to non-standard gear forms, including asymmetric, hypoid, and non-involute geometries. These studies adapt existing meshing algorithms to account for discontinuities in curvature and variable stiffness profiles—moving toward predictive models that bridge the gap between digital design and manufacturable reality.

Other technical highlights include:

- Closed-loop workflows that integrate inspection data with simulation, enabling profile compensation through CMM feedback.
- Investigations into surface integrity following honing and superfinishing, with a focus on residual stress and subsurface structure.
- Development of non-traditional test rigs for high-speed, small-module gears, addressing inertia effects, backlash, and thermal behavior in miniature systems.

The 2025 FTM program reflects a discipline that continues to evolve its toolset—pushing measurement limits, expanding simulation capabilities, and refining manufacturing precision under increasingly demanding operating conditions.

motionpowerexpo.com/fall-technical-meeting-2025

Kapp Technologies
Booth 219

Kapp Technologies L.P. has established in-house production of diamond dressing tools at its Boulder, CO, facility. The move complements existing domestic manufacturing of CBN grinding wheels and allows Kapp to supply diamond dressers with reduced lead times and improved supply flexibility for North American customers.

The first diamond dressing tool produced entirely in Boulder marks the beginning of full-scale domestic production. These dressers are compatible with Kapp's grinding systems and are designed for precision conditioning of grinding tools across a range of gear manufacturing applications.

Kapp will also demonstrate the KNM 2X at the expo, a compact analytical measuring machine designed for gears, gear tools, and rotationally symmetrical parts up to 300 mm in diameter. The system includes a quick-change clamping setup, a vibration-damping air spring design, and a smart tailstock configuration for improved ergonomics and accessibility. The unit enables fast measurement cycles and integrates with production machines in closed-loop systems to support high-precision, in-process verification.

kapp-niles.com/en

Liebherr
Booth 519

Liebherr-Verzahntechnik GmbH will highlight its latest developments in twist-free generating grinding, which include process optimization for asymmetrical gear teeth and the integration of fine grinding or polishing in a single machining cycle. Updates to machine kinematics and software functions now allow the use of dressable grinding worms at cycle times comparable to conventional generating grinding, with improved control of surface finish and profile accuracy.

The latest twist-free generating grinding process enables more flexible shift strategies. Enhanced kinematic control allows operators to separate shift position from shift length, minimizing profile deviations and allowing for precise definition of diagonal zones using the LHGearTec control interface. By segmenting the grinding worm to alternate between roughing, finishing, and polishing regions, users can influence tooth flank geometry and surface structure with greater precision.

These developments support applications requiring targeted load distribution, reduced excitation noise, or high flank surface quality. Standard dressing tools may be used, and double-sided dressing is supported, reducing tooling complexity and cost.

Liebherr's technology is applicable to a broad range of transmission components, including e-mobility and heavy-duty industrial gearboxes. The process enhancements are supported by the rigidity and stability of Liebherr's machine platforms and are designed to reduce both machining time and the number of required finishing steps.

liebherr.com

Nidec Machine Tool America
Booth 336

Nidec will feature several developments in gear manufacturing systems, including the Federal Broach MVRT, a dual-station, 10-ton vertical broaching machine with a 1,500 mm stroke. The machine supports both manual and automated load/unload systems and includes configurable integration options such as gantry, robot, and conveyor packages. Designed to accommodate variable production volumes, each station can be independently operated, minimizing idle time and mechanical wear. The machine features adjustable cutting and return stroke speeds and an electromechanical drive system designed for energy efficiency and low noise levels.

Nidec will also highlight two additional machines:

- GE25CF: A gear hobbing machine with integrated chamfering capability, designed to consolidate gear cutting and chamfering in a single operation. The system targets high-efficiency production of precision gears for EVs and similar applications.
- MGC300: A vertical 5-axis machining center with dedicated gear-processing functionality, designed to increase throughput and reduce part handling by combining operations into one platform.

nidec-machinetoolamerica.com

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Keeping Your Wheels Turning

How to avoid grinding wheel supply problems

Dennis Brown, Technical Sales Manager, Weiler Abrasives

It's important to look for a wheel manufacturer that has a wheel designed to resist burn and chatter to provide better grind results and longer life.

Gears are fundamental components in countless applications across diverse industries. From the heavy machinery used in construction and agriculture to the precision engineering required by automotive companies and even the specialized needs of small gear shops, the production of high-quality gears is paramount to operational success.

Gear grinding is a particularly vital part of gear manufacturing, often serving as the final step in the process before a product is shipped to the customer. This makes the quality and consistency of the grinding process not just important, but absolutely critical for gear manufacturers. However, the gear manufacturing landscape is not without some challenges that can affect production efficiency and final product quality and potentially delay customer orders.

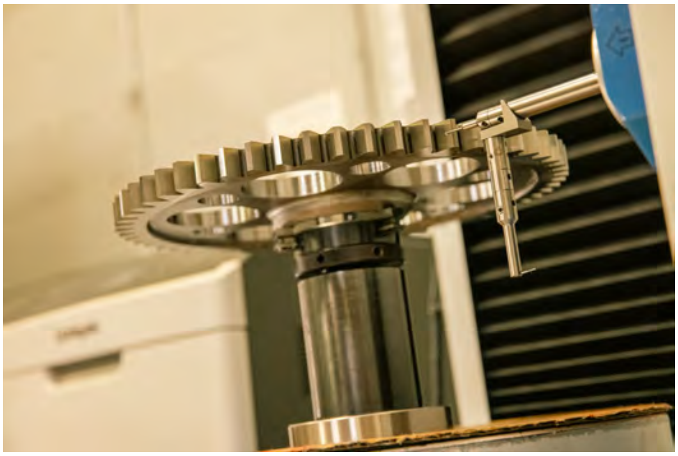
Common Gear Grinding Challenges

Several industry trends and challenges can negatively impact gear grinding productivity and efficiency for many manufacturers. These include:

- **Long lead times:** In today's economic landscape, supply chain issues related to gear grinding wheels can be especially problematic for gear manufacturers. Long wait times for grinding wheels may stem from raw material shortages, shipping delays caused by overseas production or sourcing, or supplier backlogs. Often, lead times can run months or even a year or more. Delays in acquiring the right grinding wheels for a specific job can trigger a detrimental domino effect, potentially bringing entire production lines to a halt and delaying customer orders.

- **Inconsistent wheel quality:** Raw material shortages can result in inconsistencies in grinding wheel quality. Some wheel manufacturers may also consolidate wheel product lines or make unannounced raw material changes, which can lead to production problems and affect the final product's quality for end users. The precision required in gear manufacturing means that any compromise in the grinding wheel's quality directly impacts the gear's geometry, surface finish, and overall performance, ultimately affecting the end user's ability to compete in the market.

- **Lack of technical support for end users:** Another key challenge can be a lack of technical support from wheel manufacturers. Whether the issue is production delays on the supplier end or a change to the raw materials used in wheel production, consistent communication is key for end users to best plan and prepare in their gear grinding operation.



This image shows a gear being measured to ensure it meets specifications. Manufacturers should prioritize grinding wheel suppliers that offer advanced wheel technologies designed to optimize performance, extend wheel life, and resist common issues like burn and chatter.

Practical Strategies to Address the Challenges

The consequences of an unreliable grinding wheel supply extend beyond mere inconvenience; they can lead to costly machine downtime, increased maintenance expenses, and a complete standstill in product shipment if wheels are unavailable. Therefore, understanding and mitigating these common challenges for grinding wheels is not just a logistical concern, but a strategic imperative for gear manufacturers.

Here are five practical strategies to proactively mitigate the risks of grinding wheel shortages and delays and keep gear production on schedule:

1. **Dual sourcing:** One of the main ways to avoid long lead times, production delays and other supply chain problems is to use a dual sourcing strategy. Having a second source for grinding wheels provides manufacturers with a back-up option and can keep production lines moving.
2. **Forecast sharing and communication:** Proper communication with a wheel supplier is important to help ensure a continued supply of the right grinding wheels. The more information that can be shared with the wheel supplier, the more prepared that supplier will be to fulfill specific orders in a timely manner. If an influx or production demand is expected, informing the supplier helps ensure everyone is on the same page.
3. **Maintain safety stock for critical wheels:** Keep back-up stock of critical wheels that are already qualified and ready to go on the shelf for emergency situations. This is especially important for high production environments such as aerospace or automotive manufacturing.
4. **Implement modular wheel design:** Working with a wheel manufacturer to implement a modular wheel design that can be flexible across an array of geometries can help operations avoid shortages and delays.
5. **Track key KPIs:** Monitoring important key performance indicators in the gear grinding operation provides data that helps for planning ahead regarding orders and inventory.

Choosing the Right Wheels and Wheel Suppliers

There are technologies available that can help gear manufacturers optimize grinding wheel life, performance and end results. If grinding wheels are wearing out too fast and requiring too-frequent replacement, for example, it's important to look for a

This image shows the cell where wheels are profiled as part of the Weiler Precision Express program, which cuts lead times for gear grinding wheels from months to weeks with on-demand wheel finishing.

A gear grinding wheel is profiled at the Weiler Abrasive facility in Cresco. The Precision Express program from Weiler Abrasives cuts lead times for gear grinding wheels from months to weeks with on-demand wheel finishing. Precision Express matches an in-house profiling cell with a broad range of on-hand stock.

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wheel manufacturer that has a wheel designed to resist burn and chatter to provide better grind results and longer life. Using the latest grain and bond technologies that are specifically designed to reduce thermal damage can deliver the desired quality, wheel life and performance in many applications.

Some options are also available to help address challenges related to wheel inventory and procurement. The Precision Express program from Weiler Abrasives cuts lead times for gear grinding wheels from months to weeks with on-demand wheel finishing. Precision Express matches an in-house profiling cell with a broad range of on-hand stock. Even when gear manufacturers see a spike in demand or need a custom profile at a moment's notice, they can get consistent availability and delivery. With a sizable stock inventory at Weiler Abrasives' North American headquarters in Pennsylvania, custom wheels can be produced within two weeks.

Real-World Example

A Georgia-based gear manufacturer known for rapid emergency repairs to paper mill equipment faced a major challenge: unreliable grinding wheel supply was threatening their ability to deliver under pressure. Their previous supplier offered poor support, long lead times and inconsistent performance. When they partnered with Weiler, everything changed. Through Weiler's Precision Express service, a custom test wheel was delivered in weeks—not months—backed by on-site engineering support and remote troubleshooting. Weiler's advanced porous wheel technology cut cycle times by 30 percent, eliminated adjustment delays and significantly boosted efficiency. With five machines now running and plans for 24/7 operations, this partnership transformed a critical vulnerability into a competitive edge.

Addressing Gear Grinding Wheel Supply Challenges

As many gear manufacturers deal with supply chain challenges and wheel delays and shortages, the importance of choosing the right wheels and wheel suppliers cannot be overstated. Manufacturers should prioritize suppliers that offer advanced wheel technologies designed to optimize performance, extend wheel life, and resist common issues like burn and chatter. Beyond product quality, the availability of robust technical support and on-site troubleshooting from suppliers is crucial for minimizing downtime and ensuring continuous operation.

By implementing practical strategies such as dual sourcing, sharing forecasts with suppliers, and maintaining safety stock for critical wheels, manufacturers can proactively mitigate the risks of gear grinding wheel shortages and delays. In addition, adopting innovative approaches like modular wheel designs and partnering with suppliers offering on-demand finishing services, can significantly reduce lead times and enhance operational agility.

weilerabrasives.com

Look for the Emerging Technology at MPT Expo 2025

Mary Ellen Doran, AGMA Vice President, Emerging Technology

In just a few weeks, our industry will gather in Detroit for the 2025 Motion + Power Technology Expo (MPT Expo). This flagship event shines a spotlight on gears and their crucial role in motion systems. The show offers unmatched opportunities for in-person networking, learning and exploration with top experts across the gear and bearing industries.

This year, we have designed several activities specifically focused on emerging technologies that could transform—or even disrupt—the way we think about motion and power. Make the most of your time at MPT Expo 2025 and take advantage of these sessions to stay ahead of the curve.

What's Brewing Power Breakfasts

Each morning of the Expo features a targeted discussion led by the Emerging Technology Committees. Tuesday morning, join us for a discussion about the future of robotics. Robotics Committee Chair, Robert Kufner, CEO at Designatronics, will moderate a panel of experts on a discussion of trends in robot mechanisms. We will highlight the trajectory of humanoid robots and discuss the types of gear sets being used in prototypes and initial productions. We will also discuss the impact on subsequent markets like prosthetics and exoskeletons because of this work. On Wednesday, we will discuss the future of aerospace, space and defense. Noel Mack, CTO at LIFT, will provide his expert knowledge alongside invited members from government and the supply chain. How will the gear and bearing markets be impacted with new plane and drone designs? What demands may OEMs put on the supply chain? And on Thursday, join us for a discussion on the future of the workforce. We will be discussing some of the cutting-edge training for manufacturers, making them ready for artificial intelligence (AI), model-based definition and the digital thread, and more.

Curated Show Floor Tours

Our self-guided curated show floor tours return in 2025—designed around specific gear industry themes to help you connect with the right exhibitors. New in 2025, we will have one staff-led curated tour each day for those interested in learning more about emerging technology. These emerging technology tours will show attendees upcoming trends in gears as they relate to our four committees: 3D Printing, IIoT, Electric Vehicle Technology, and Robotics.

Full-Day Courses

We are offering ten courses at this year's event that range from basics to expert, half-day to two-day courses. Several of these courses have been updated to reflect emerging technology trends. The electric vehicle one-day course will look at concept, development, design and initial analysis of EV transaxle gearboxes. Instructor Mark McVea will explore common EV transaxle architectures and discuss the key difference between EV transaxles and traditional transmissions with a focus on gear noise. And instructors of the materials course, a joint effort between AGMA and ASM, will make sure to include new information on materials in the additive space.

Fall Technical Meeting (FTM)

The Fall Technical Meeting is a conference dedicated to high-level, gear-industry innovation. Renowned for its rigor and technical depth, FTM showcases over 30 peer-reviewed papers that push the boundaries of emerging technologies. It is the original source for emerging technology in gearing. One session to note is Technical Session 2, which specifically has papers on the topics of electric vehicles and emerging technologies.

I look forward to seeing you at the 2025 Motion + Power Technology Expo in October. Please come seek me out and let's discuss emerging technology in our industry!

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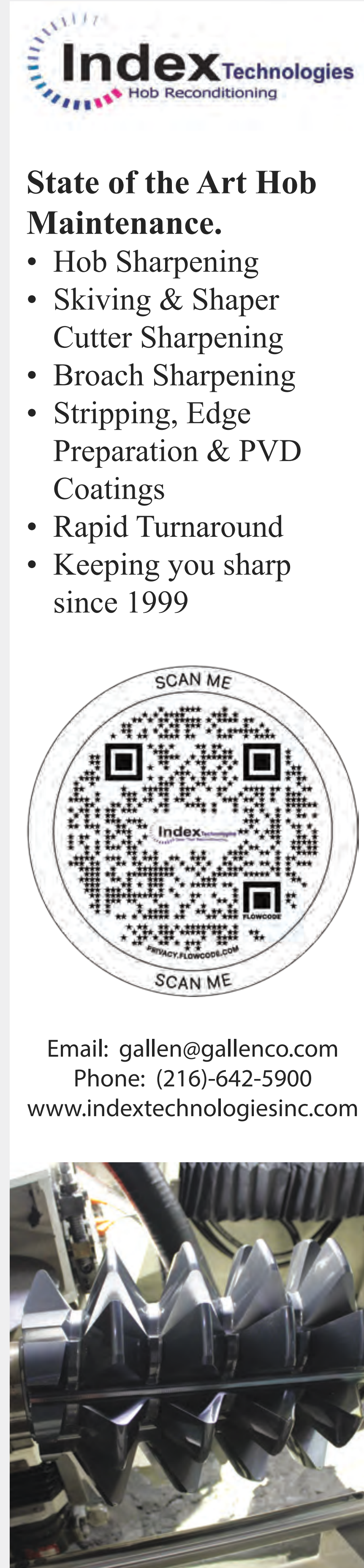
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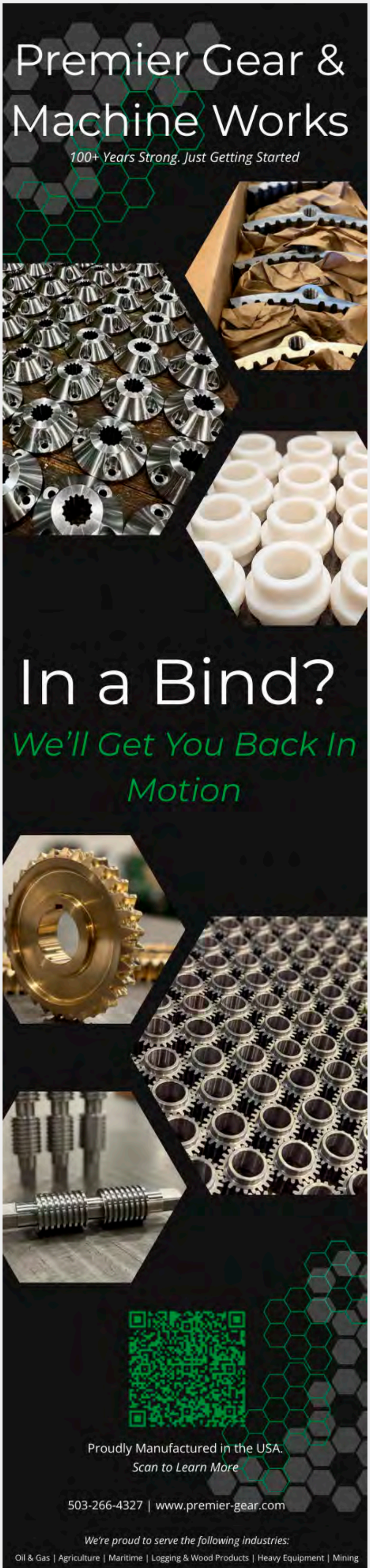

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ISO TC 60 and TC 4 Standardization Work—Our "Alter Ego"

Todd Praneis, AGMA Vice President, Technical Division

Many of our favorite movie characters carry an alter ego: Clark Kent and Superman, Jekyll and Hyde, Bruce Wayne and Batman…you get my point. Neither nefarious nor secret, the Motion + Power Manufacturers Alliance (MPMA) carries a similar twin. You may be involved in one of our 15 technical committees and the sub-working groups that are involved in one of the 14 open projects (found at *agma.org/committees/standards-projects/* or *americanbearings.org/industry-standards/*), but both AGMA and ABMA divisions are busy helping to develop international standards on the gear and bearing technical committees within the International Standards Organization (ISO). Our ISO "alter ego."

Like our working groups and committees that bring together companies, academia, and consultants to manage, create, and revise standards, ISO working groups (WG) bring together member countries. Members are split into two groups: P-members are actively participating and have voting and participation expectations, while O-members observe the activities of the working group and can comment on developing standards.

There is only one member to ISO per country and that member for the United States is the American National Standards Institute (ANSI). ANSI has delegated all activity under ISO TC 60 (gears) and ISO TC 4 (rolling bearings) to MPMA.

Just as Superman "talks" to Clark Kent, MPMA communicates with ISO. It's a two-way street of information where the US brings suggested content from our standards to ISO WGs for consideration. This can be a portion of a US document, or the entire document. Conversely, the US can adopt an ISO document or utilize content from the ISO document in our own standard. All of this is in addition to actively participating in the WG activities. MPMA facilitates a US delegate to join each WG as a subject matter expert to bring the US position and help with the standards development process.

Keeping active with our alter ego ensures that our processes are globally considered and fosters a consistent language when doing business.

If you have any questions or want to learn more, please contact: *tech@agma.org*

Morphology of FZG-A Test Gears

Robert Errichello and Liam Coen

Nomenclature

FZG-A	FZG type A test gears
LOM	Light Optical Microscopy
SEM	Scanning Electron Microscopy
SAP	Start of Active Profile
EAP	End of Active Profile

For closer inspection, of the full-size figures in this technical article, please follow the link below:

geartechnology.com/fzg-a-figures

Introduction

This study explores the failure mode morphology of FZG-A test gears. It aims to examine the morphologies of scuffing, scoring, scratches, and polishing using high-magnification light optical microscopy (LOM) and scanning electron microscopy (SEM) images.

Specifications for FZG-A Tests

The FZG-A test rig is described, including specifications for the test procedures according to the industrial standards ISO 14635-1 (Ref. 1), ASTM 5182-19 (Ref. 2), and CEC L-07-95 (Ref. 3). These three standards are considered technically equivalent.

Figure 1—FZG-A Pinion.

Description of Figure 1

Figure 1 illustrates an FZG-A spur pinion with 16 teeth that meshes with a spur gear featuring 24 teeth. Detailed geometric information about both the pinion and the gear can be found in Annex A. For the LOM and SEM investigation, teeth 2 and 3 were removed by cutting along the red radial lines indicated in the figure.

Description of Figure 2

Figure 2 illustrates scuffing on teeth 2 and 3. Tooth 2 exhibits scuffing nearly across the entire face width, while tooth 3 shows a narrow band of scuffing. The other teeth, which do not exhibit scuffing, display the unique surface texture produced by the MAAG 15-degree crisscross grinding method.

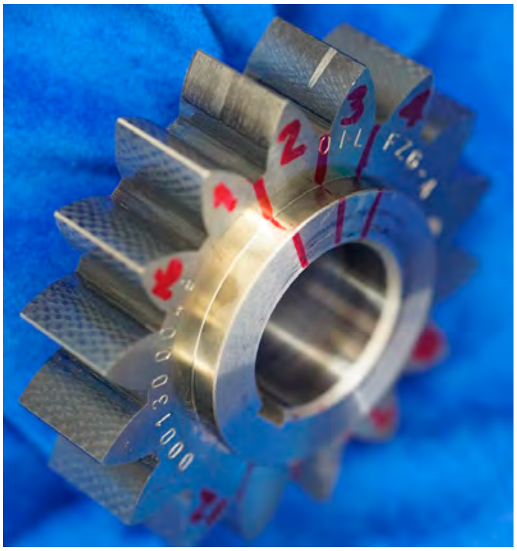

Figure 2—Typical scuffing on teeth 2 and 3.

Description of the FZG-A Test

The FZG-A gear test consists of twelve 15-minute stages, each with increasing load, until scuffing occurs or the testing sequence is completed. After load stage 4, and at the end of each subsequent stage, the pinion tooth flanks are visually inspected for signs of scuffing, which are recorded. The visual inspection is done without removing the gears from the test rig, and without the aid of magnification. The test concludes when the summed total width of scuffing on all 16 pinion teeth exceeds 20 mm, and the failure load stage is reported. If load stage 12 is completed without any scuffing, the failure load stage is reported as greater than 12.

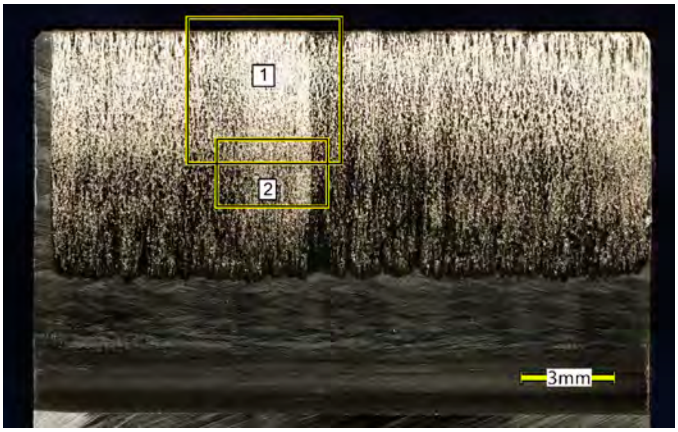

Figure 3—LOM image of tooth 2 shown in Figure 2.

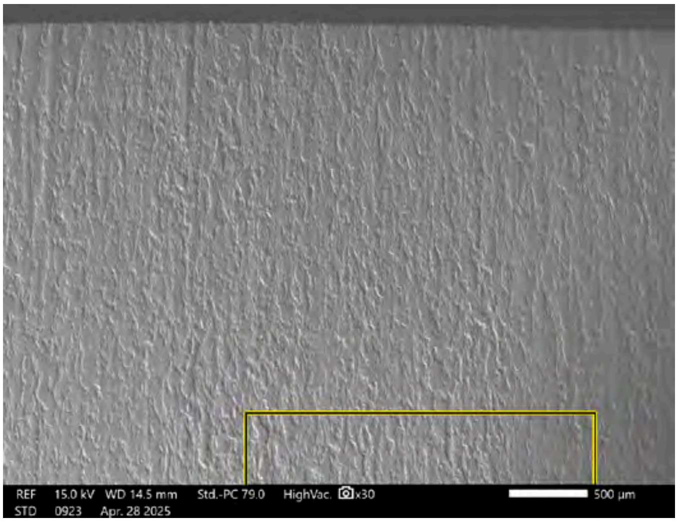

Figure 4—SEM image of Box 1 shown in Figure 3.

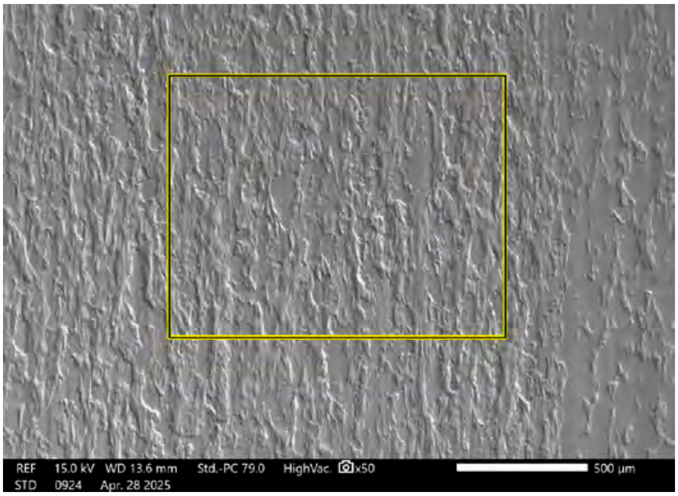

Figure 5—SEM image of Box 2 shown in Figure 3.

FZG-A Failure Mode

Four failure modes can occur in FZG-A test gears, including scuffing, scoring, scratches and polishing. ASTM 5182-19 defines the failure modes as follows:

1. *Scuffing*—wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface.
2. *Scoring*—a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding.
3. *Scratches*—the result of mechanical removal or displacement, or both, of material from a surface by the action of abrasive particles or protuberances sliding across the surfaces.
4. *Polishing*—a mild form of abrasive wear resulting in minor loss of material and typically characterized by a smooth finish and removal of all or part of the initial grinding marks.

Description of Figure 3

Figure 3 shows the scuffing observed on tooth 2, which is also illustrated in Figure 2. The scuffing measures 19.5 mm in width, almost covering the total face width of 20 mm. To the unaided eye, or when viewed under LOM, the scuffed area appears as a dull grey surface.

An enlarged SEM image of Box 1 is shown in Figure 4, followed by a series of SEM images of Box 2 at progressively higher magnifications.

Description of Figure 4

Figure 4 shows that scuffing results in a rough surface, which covers the original grinding marks. The top of Box 2 is shown at the bottom of Figure 4 and in Figure 5.

Description of Figure 5

Figures 5 through 8 are SEM images of scuffing shown at progressively increasing magnification from 50× to 750× magnification.

Description of Figure 6

Figure 6 illustrates the area of the Box depicted in Figure 5. The area within the Box in Figure 6 is represented in the subsequent Figure 7.

Description of Figure 7

Figure 7 shows the area of the Box shown in Figure 6. The area within the Box in Figure 7 is represented in the subsequent Figure 8.

Description of Figure 8

Figure 8 shows the area of the Box shown in Figure 7. It illustrates the morphology of the transferred particles, which appear as discrete islands of raised patches. These patches were transferred from the meshing flanks of the wheel and welded onto the pinion flanks. The top surfaces of these patches have become smooth due to abrasive wear, as shown by the abrasion lines that run in the vertical sliding direction. The tractional shear stresses associated with this abrasion have led to the formation of several cracks within the transferred patches. If the shear stress on the top surface of a transferred patch exceeds the shear strength of the weld interface on its lower surface, the patch may dislodge and become a freed debris particle.

Description of Figure 9

Figure 9 illustrates the left corner of tooth 2, where scuffing does not extend to the left end of the face width. The original grind marks are visible in the area that remains free of scuffing. Additionally, plastic deformation of the transferred material has flowed over the tip of the tooth.

Description of Figure 10

Figure 10 illustrates that the transferred patches are elevated above the original ground surface of the tooth flank. As a result, the load is carried exclusively by these transferred patches, while the areas of the original ground flank are unloaded. This situation leads to self-aggravating scuffing.

Description of Figure 11

Figure 11 illustrates a 1.4 mm-wide band of scuffing that starts at the lower part of the tooth and extends up to its tip.

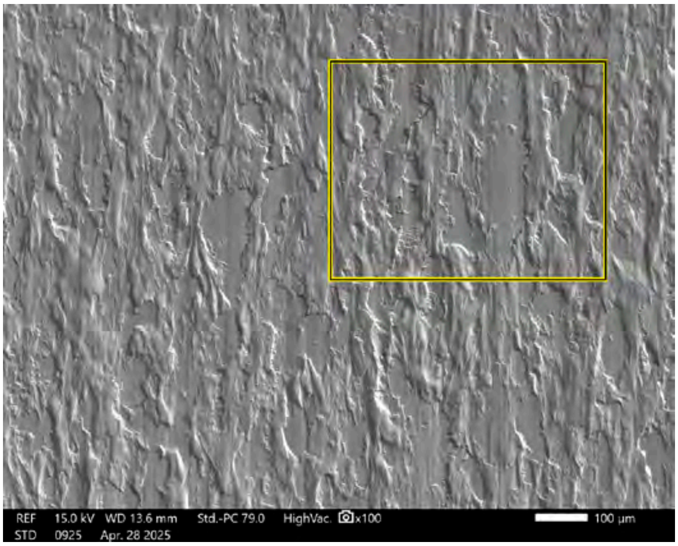

Figure 6—SEM image of Box shown in Figure 5.

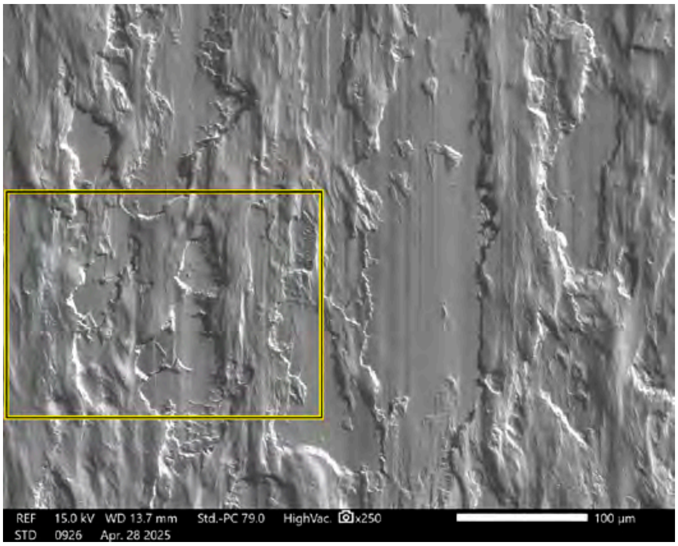

Figure 7—SEM image of Box shown in Figure 6.

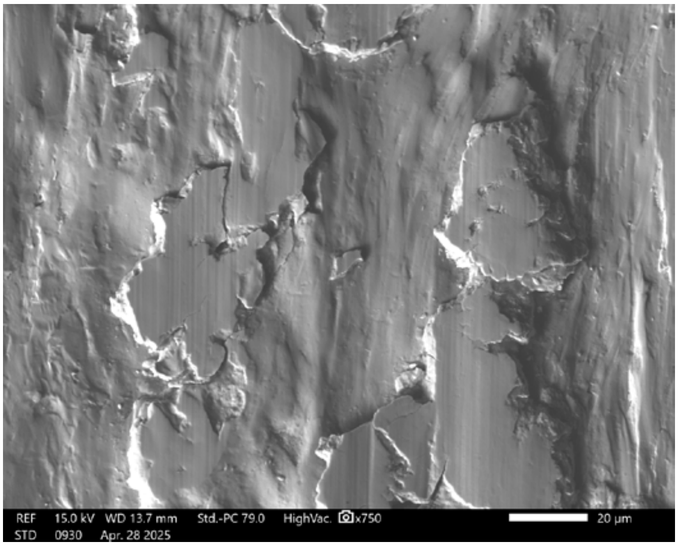

Figure 8—SEM image of Box shown in Figure 6.

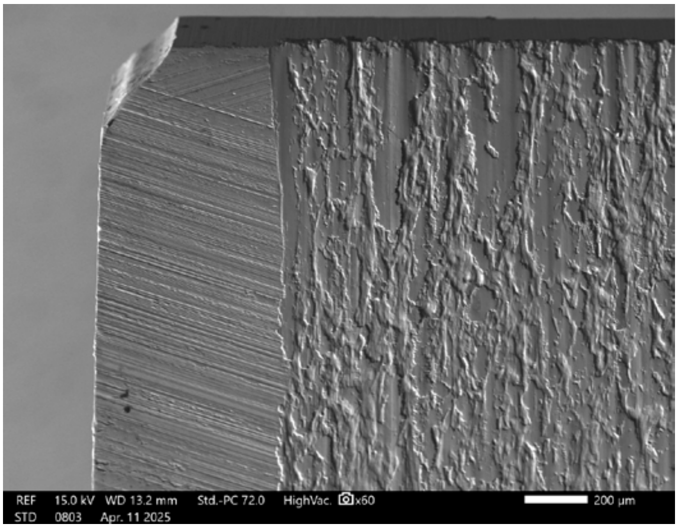

Figure 9—SEM image of left corner of tooth shown in Figure 3.

Figure 12—SEM image of Box 1 shown in Figure 11.

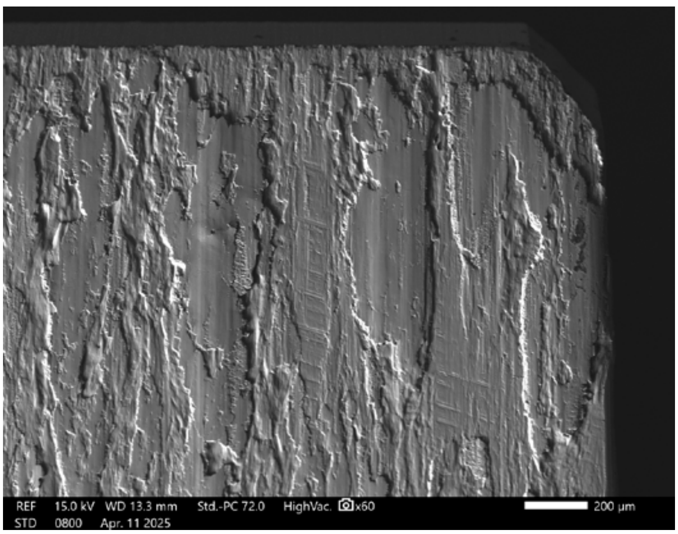

Figure 10—SEM image of right corner of tooth shown in Figure 3.

Figure 13—SEM image of Box 2 shown in Figure 12.

Figure 11—LOM image of tooth 3 shown in Figure 2.

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Additionally, there is a narrow band of scuffing along the edge of the tooth tip and a narrow band of scuffing near the root of the tooth, at the start of the active profile (SAP). FZG-A gears lack tip or root relief on their profiles, which leads to high loads at both the SAP and the end of the active profile (EAP) at the tips of the pinion teeth. This condition increases the likelihood of scuffing in these areas.

The three Boxes labeled 1, 2, and 3 designate areas for the following SEM images.

Description of Figure 12

Figure 12 shows the area of Box 1 that includes the tip of the tooth at the top of the image and the edge of the scuffing at the right side of the image. The Box in Figure 12 corresponds to Box 2 in Figure 11. The area within the Box in Figure 12 is represented in the subsequent Figure 13.

Description of Figure 13

Figure 13 shows the area of Box 2 at a 50× magnification. Prominent vertical lines, which indicate abrasive wear, are clearly visible. In the background, the original crisscross grinding marks can still be seen, offering insight into the depth of the abrasive wear. The area within the Box in Figure 13 is represented in the subsequent Figure 14.

Description of Figure 14

Figure 14 provides an enlarged view of the Box depicted in Figure 13. The vertical lines of abrasive wear have erased the original grinding marks. Additionally, the Box in Figure 14 highlights an area of localized scuffing and plastic deformation. The area within the Box in Figure 14 is represented in the subsequent Figure 15.

Description of Figure 15

Figure 15 presents an enlarged view of the Box shown in Figure 14. It illustrates scuffing and plastic deformation of the surface material, which has removed the original grinding marks in certain areas. Additionally, the Box in Figure 15 highlights an area of localized plastic deformation. The area within the Box in Figure 15 is represented in the subsequent Figure 16.

Description of Figure 16

Figure 16 provides a closer view of the Box depicted in Figure 15. Plastic deformation has caused the surface material to flow upward into the original grind marks, aligning with the upward direction of the sliding motion on the pinion tooth.

Description of Figure 17

Figure 17 shows the area of Box 3 from Figure 11, emphasizing the scuffed region on the right side of the image and the signs of abrasive wear on the left. The Box in Figure 17 outlines an area that exhibits scoring, scratches, and polishing.

Description of Figure 18

Figure 18 is identical to Figure 17, but it has been annotated to highlight the failure modes of scuffing, scoring, scratches, and polishing. It is evident that scoring and scratches share the same morphology; however, they differ in width.

Description of Figure 19

Figure 19 presents an enlarged view of the Box shown in Figure 17. Figure 19 shows that scoring and scratches exhibit similar abrasive wear patterns, characterized by smooth, clean furrows that align

Figure 14—SEM image of Box 2 shown in Figure 13.

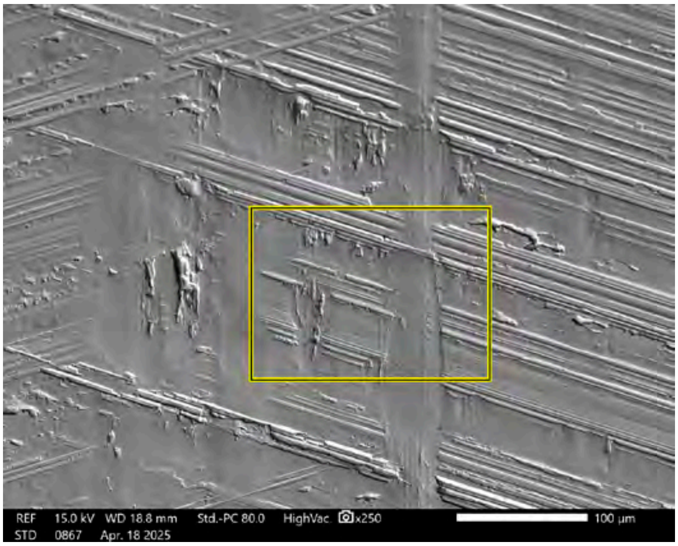


Figure 15—SEM image of Box 2 shown in Figure 14.

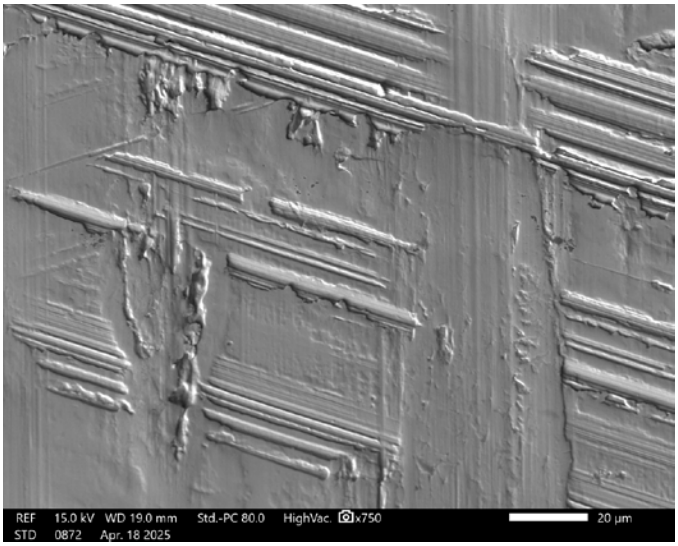


Figure 16—SEM image of Box 2 shown in Figure 15.

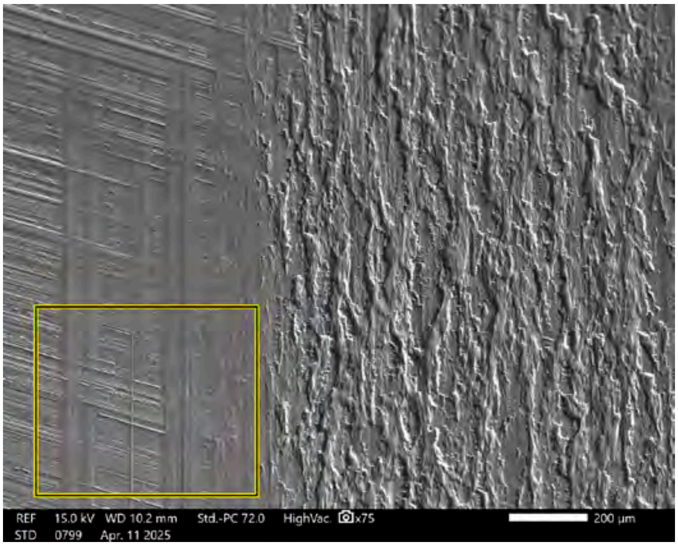


Figure 17— SEM image of Box 3 shown in Figure 11.

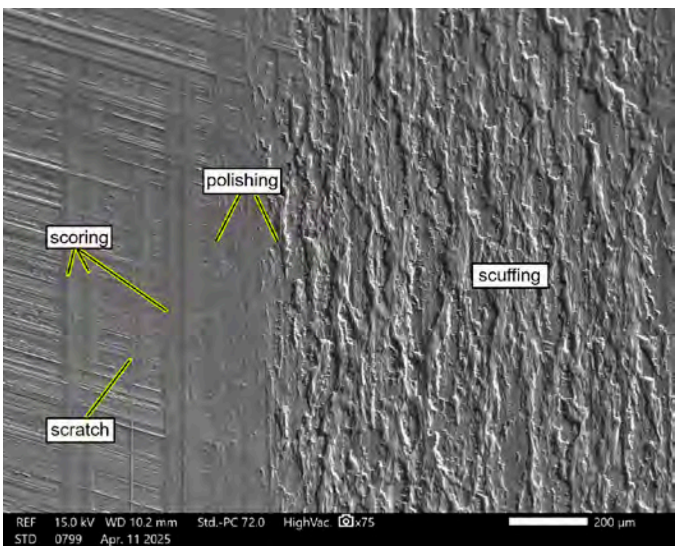


Figure 18—SEM image with labeled features of interest from Figure 17.

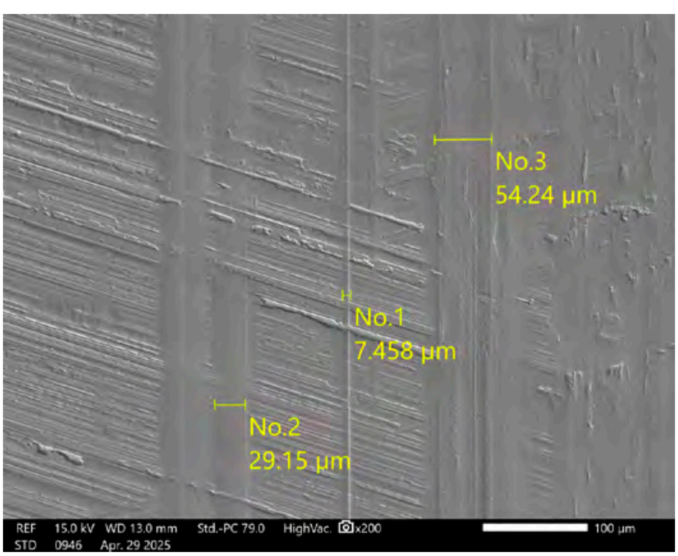


Figure 19—SEM image of Box 3 shown in Figure 17.

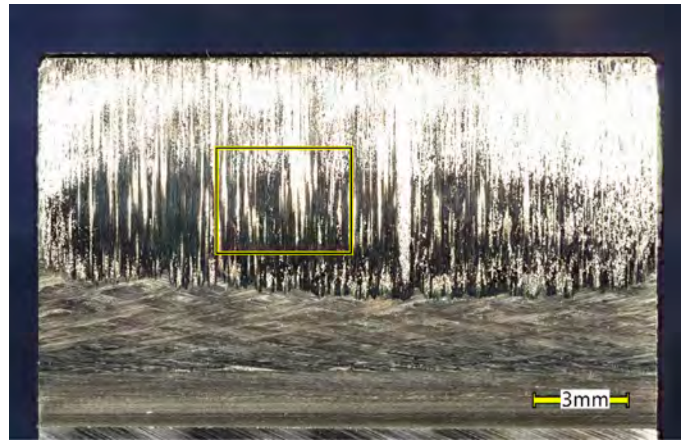


Figure 20—LOM image of tooth 8 shown in Figure 1.

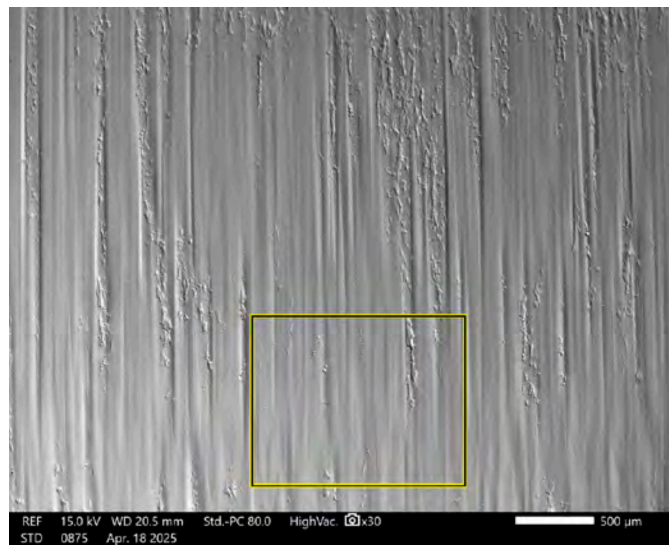


Figure 21—SEM image of Box shown in Figure 20.

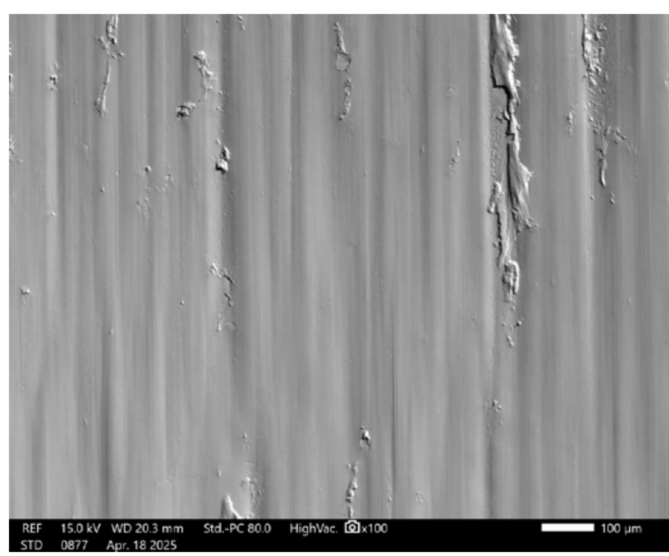


Figure 22—SEM image of Box shown in Figure 21.

with the direction of sliding. However, under intense oblique light, scratches become more noticeable due to specular reflection. Generally, scratches are typically less than 30 µm wide, while scoring is usually wider than 30 µm.

Description of Figure 20

Figure 20 shows that tooth 8 has scuffing and polishing. The Box shown in Figure 20 outlines an area of polishing. The area within the Box in Figure 20 is represented in the subsequent Figure 21.

Description of Figure 21

Figure 21 shows the area of the Box depicted in Figure 20. It predominantly features polishing along with some lightly scuffed areas. The Box represented in Figure 21 is displayed at a higher magnification in Figure 22.

Description of Figure 22

Figure 22 shows the area of the Box referenced in Figure 21. Polishing wear has completely removed the original grinding marks, resulting in a smooth, mirrorlike surface finish. If the scuffing is not too severe, and the operating conditions remain stable, polishing wear can give the appearance of healing the scuff marks. However, it is important to note that the polished surface shows undulations, with scuffing occurring at the peaks of these undulations. Therefore, while polishing can improve surface appearance, it can also be harmful if it removes a significant amount of surface material.

Conclusions

1. The morphology of scuffing is characterized by transferred particles, which appear as discrete islands of raised patches. The patches are transferred from the meshing flanks of the wheel and welded onto the pinion flanks.
2. Scoring and scratches exhibit similar abrasive wear patterns, characterized by smooth, clean furrows that align with the direction of sliding. However, under intense oblique light, scratches become more noticeable due to specular reflection. Generally, scratches are typically less than 30 µm wide, while scoring is usually wider than 30 µm.
3. Polishing results in a smooth, mirrorlike surface finish. If the scuffing is not too severe, and the operating conditions remain stable, polishing wear can give the appearance of healing the scuff marks. However, it is important to note that the polished surface shows undulations, with scuffing occurring at the peaks of these undulations.

Appendix A

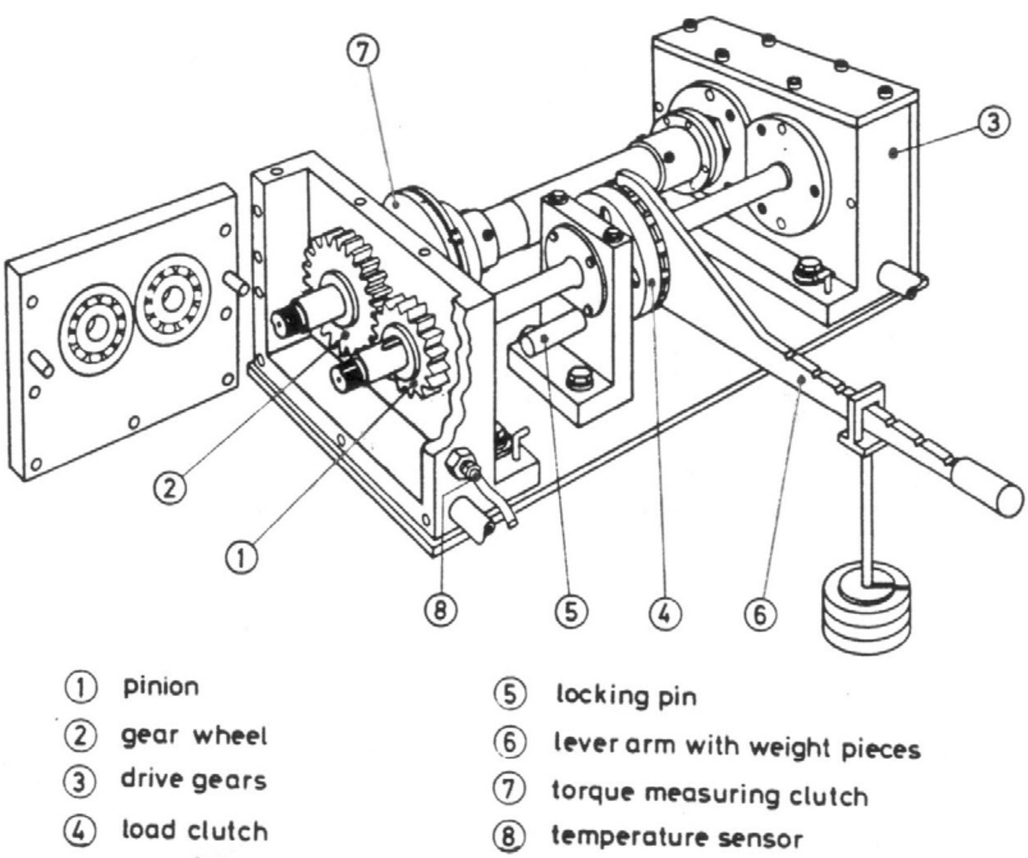


Figure A1—FZG Test Machine.

Item	Symbol	Unit	Pinion	Wheel
Center distance	a	mm	91.5	
Number of pinion teeth	z_1	---	16	
Number of gear teeth	z_2	---	24	
Normal module	m_n	mm	4.5	
Normal pressure angle	α_n	deg	20	
Helix angle	β	deg	0	
Face width	b	mm	20	
Pinion profile shift coefficient	x_1	---	0.8635	
Gear profile shift coefficient	x_2	---	-0.5103	
Pinion tip diameter	d_{a1}	mm	88.7	
Gear tip diameter	d_{a2}	mm	112.5	
Material alloy	$---$	---	20MnCr5	
Heat treatment	$---$	---	Carburized	
Flank surface roughness	R_a	µm	0.35 ± 0.1	0.30 ± 0.1
Pitchline velocity	v_t	m/s	8.3	

Table A1—Data for FZG-A test gears.

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

Liam Coen is a Senior Engineer at INNIO Waukesha Gas Engines. His 30-year career spanned across aviation, diesel-electric locomotives, and large industrial gas engines. He earned a BS in aeronautics from St. Louis University. He is an active member of the ASME Milwaukee Section and AGMA..

References

1. ISO 14535-1, "Gears-FZG test procedures- Part 1: FZG test method A/8.3/90 for relative scuffing load-carrying capacity of oils."
2. ASTM D 5182-19, "Standard Test Method for Evaluating the Scuffing Load Capacity of Oils (FZG Visual Method)."
3. CEC L-07-A-95, "Load Carrying Capacity Test for Transmission Lubricants (FZG Test Rig)."

A Review on Gear Transmission Error

Zhaoyao Shi and Huiming Cheng

The transmission error (TE) of gear is a fundamental concept in the field of gear transmission engineering. It is utilized in guiding high-performance gear design, characterizing gear quality, analyzing gear process errors and predicting dynamic properties of gears (such as vibration and noise). The definition of TE is relatively simple, yet it encompasses a wealth of implications. Understanding the role of TE is essential; however, more importantly, recognizing its limitations is crucial (Ref. 1). Unfortunately, there has been insufficient research on the shortcomings of TE to date. As a result, when applying the concept of TE, its limitations and deficiencies are often overlooked, leading to conclusions that warrant further discussion.

In the study of TE, there is a widespread belief in the current literature that research on TE began in the 1950s. In 1958, Harris (Ref. 2) introduced the concept of gear TE while studying gear vibration and noise. His work also laid the theoretical foundation for modern TE research. Undoubtedly, Harris's contributions to TE research are significant, but the above statement requires further investigation. Upon examining the history of gear technology, it becomes clear that there have always been two forces driving TE research: one group consists of researchers engaged in gear quality control and measurement technology, and the other comprises those involved in gear design and dynamics. As early as the 1930s, to control the quality of gear transmission, researchers obtained the single flank composite error, i.e., TE, of a pair of gears through comparative measurement with standard discs, as shown in Figure 1. This achievement then enabled the control of gear transmission accuracy, and the study of TE originated from this very effort (Ref. 3).

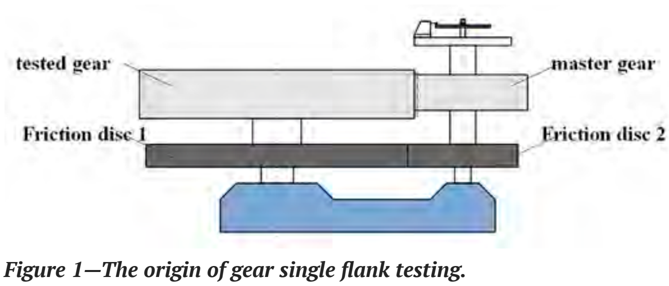


Figure 1—The origin of gear single flank testing.

In 1963, Harris introduced the Harris graph, a graphical representation of the relationship between quasi-static load and TE for modified gears (Ref. 4). This graph aimed to provide a theoretical prediction of load-bearing deformation. During the 1960s, R.G. Munro (Ref. 5) developed an optical-grating instrument for single flank testing, which became the first apparatus to utilize a grating technology for TE measurement. This breakthrough marked a significant advancement in the potential for high-precision dynamic measurement of TE. In 1970, Huang Tongnian from China first proposed the concept of Gear Integrated Error (GIE) and developed the measurement technology for GIE (Refs. 6–8). This technology utilizes a specific multi-start worm to implement single-flank testing, as shown in Figure 2. This innovation represented a significant advancement in TE measurement technology and effectively addressed the limitations associated with TE measurement. Concurrently, in the 1980s, the pursuit of smooth gear transmission led Litvin et al. (Ref. 9) to incorporate TE as an objective function in gear design. This approach sparked new developments in the field of gear design.

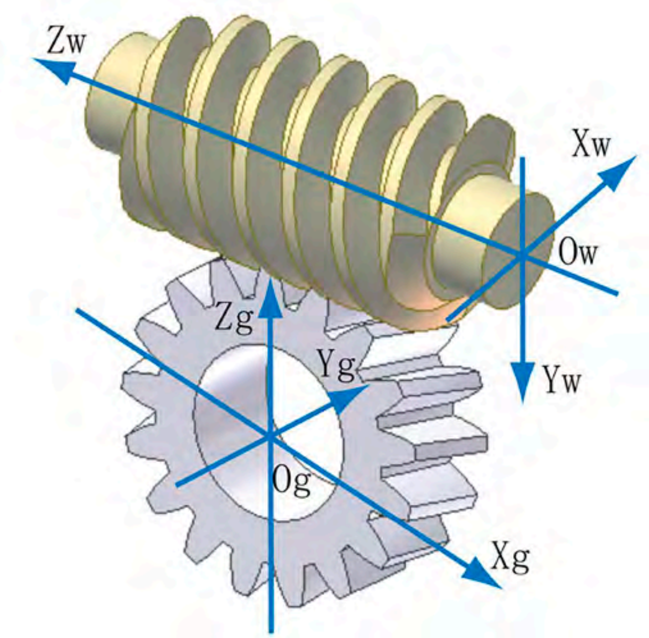


Figure 2—Gear integrated error (GIE).

In 1978, W.D. Mark (Refs. 10–11) introduced the discrete Fourier transform (DFT) method, which allowed the decomposition of TE into elemental deviations of gear. Mark also derived the mathematical expression for TE under low-speed load conditions. Following this, in 1981, Yelle (Ref. 12) developed a mathematical model for cylindrical gear pairs, as depicted in Figure 3, and derived the corresponding mathematical expression for TE. This model accounted for factors such as gear tooth stiffness and pitch deviation. In 1988, J.D. Smith (Ref. 1) identified certain limitations associated with TE. Subsequently, in 2008, as a response to the challenge of TE measurement for fine-pitch gears, Z. Y. Shi proposed the "bidirectional drive synchronous measurement method" for single-flank test of fine-pitch gears (Refs. 13–14).

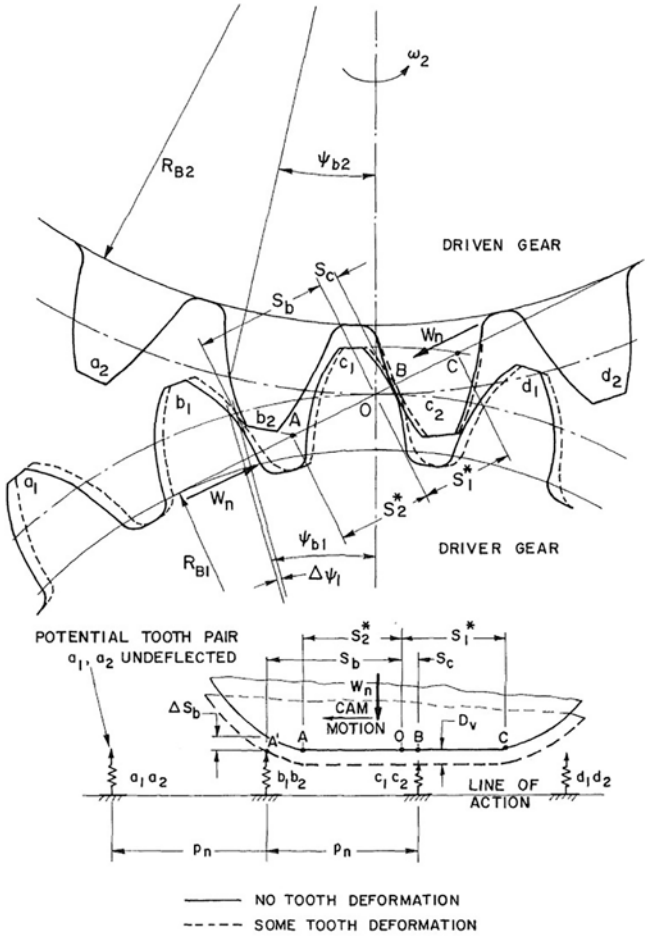


Figure 3—Model of cylindrical gear pair (Ref. 12).

The development of gears has passed through three stages: geometry, kinematics, and dynamics. The understanding of gears has evolved from "static geometric element" to "moving rigid transmission element," and then to "dynamically deformed elastic transmission element." Reviewing the nearly century-long research history of TE, it is found that the understanding of TE also went through three stages: geometric error, kinematic error, and dynamic error. With the widespread application of TE in areas such as gear design, manufacturing error analysis, NVH prediction, and gear pairing, further understanding of TE is particularly urgent. This paper will review the development process, current research status, characteristics, functions, and measurement methods of TE. It will analyze the difficulties and core issues existing in the basic theory of TE, clarify the limitations and deficiencies of TE, and explore ways to overcome the shortcomings of TE.

Concept

Definition

TE refers to the difference between the actual position of the output and the ideal position that the output shaft of a drive would occupy if the drive were perfect (Ref. 15). Further, TE has three basic forms: tangential composite deviation of a gear, TE of a gear pair, and TE of a gear transmission chain.

The tangential composite deviation of a gear is equivalent to the TE of a tested gear mated with a master gear (Ref. 16).

The TE of a gear pair represents the difference between the actual position of the driven gear and its theoretical position based on the position of the driving gear. The mathematical expression for the TE of a gear pair can be represented by Equation 1. Among them, $\theta_1(t)$ and $\theta_2(t)$ respectively represent the angular displacement of the input and output gears, and z_1 and z_2 respectively represent the number of teeth of the input and output gears.

$$TE(t) = \theta_2(t) - \frac{z_1}{z_2}\theta_1(t) \tag{1}$$

A gear transmission chain refers to a system consisting of multiple gear pairs. In such a chain, TE is defined as the difference between the actual position of the output end gear and its theoretical position based on the input end gear. The mathematical expression for TE of a gear transmission chain is provided in Equation 2 (Refs. 17–19). Among them, TE_n is the TE of the nth level transmission, and i_{n-1} is the total transmission ratio of the transmission chain of n pairs of gears.

$$TE = \frac{TE_1}{i_{n-1}} + \frac{TE_2}{i_{n-2}} + \cdots + \frac{TE_{n-1}}{i_1} + TE_n \tag{2}$$

The Relationship Between TE and Gear Elemental Deviations

Gears exist in pairs, and TE is a comprehensive representation of the elemental deviations of both the driving and driven gears. However, it is not possible to derive the elemental deviations of the driving and driven gears from the TE of a gear pair. Figure 4 reflects the combination of tooth profile deviations (Ref. 16). In 1969, R.G. Munro (Ref. 20) conducted theoretical and experimental research on single-flank and double-flank testing of gears. Munro also provided composite error curves for single and double testing that correspond to the combination of various tooth profile deviation shapes of involute gears.

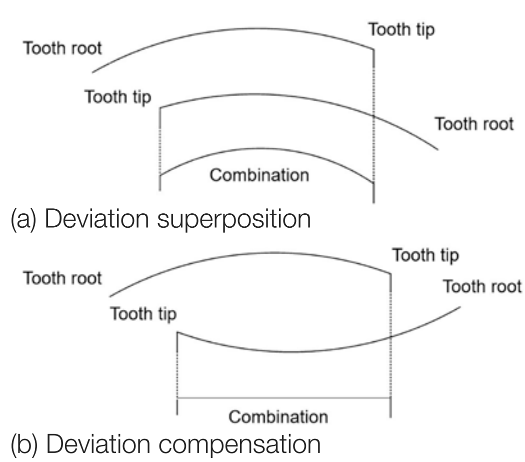


Figure 4—Profile deviations combination.

It is difficult to separate the elemental deviations of gears from the TE curve alone, which means it is impossible to analyze the main factors affecting gear transmission or to clarify the process of TE generation. The GIE measurement technique proposed by Huang Tongnian has solved the above problems. A typical GIE curve is shown in Figure 5, where the TE curve is the outer envelope of the GIE curve. By examining the GIE curve, one can clearly observe the change-over process from 2-pair-teeth contact to 1-pair-teeth contact, distinguish between the 1-pair-teeth contact zone and 2-pair-teeth contact zone, and isolate the elemental deviations, which cannot be achieved through the TE curve alone.

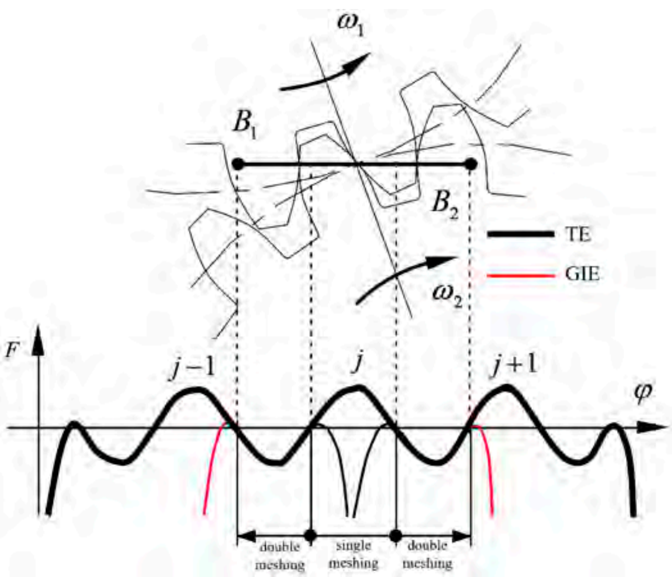


Figure 5—Comparison between GIE and TE.

Classification of TE

In this study, TE is divided into three main types: static transmission error, quasi-static transmission error, and dynamic transmission error.

Static TE (STE)

STE exclusively considers the impact of geometric errors, such as manufacturing and assembly errors, without considering the influences of loading deformation, vibration, and tooth-pair disengagement. It needs to be measured at low speed and without load, which can be represented by equation (3), where u represents the geometric error of the gear.

$$STE = u \tag{3}$$

Quasi-Static TE (QSTE)

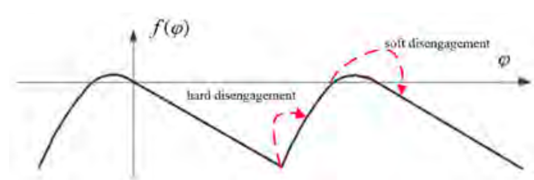
The STE varies when the gear is loaded, and this variation depends on the gear's rotational speed and loading deformation. When the gear bears a load and runs at low speed, the difference between the actual position of the driven gear and its ideal position is referred to as the QSTE. The QSTE considers the effects of manufacturing errors, assembly errors, and loading deformations but does not consider factors such as tooth-pair disengagement. It needs to be measured under low-speed loading and can be represented by formula (4), where L denotes the gear dynamic error.

$$QSTE = u + L \tag{4}$$

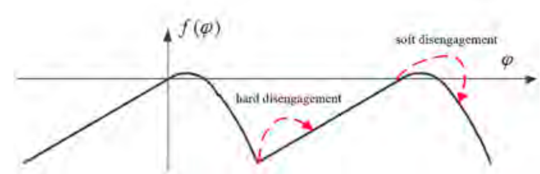
Dynamic TE (DTE)

QSTE is measured at low speeds and under load, without considering the impact of acceleration and deceleration on TE during high-speed operation of gears. As the rotational speed increases, the transmission error caused by acceleration and deceleration becomes more apparent and may even lead to the tooth-pair disengagement of the driving and driven gears, resulting in a clash due to disengagement.

Disengagement is divided into hard and soft disengagement. Hard disengagement refers to the situation where the driven gear is suddenly accelerated during tooth shifting, causing the tooth profiles of the driving and driven gears to disengage. Soft disengagement occurs when the driven gear attempts to maintain its original speed due to inertia during deceleration, leading to the disengagement of the tooth profiles. Hard disengagement generally occurs at the point of tooth alternation, while soft disengagement typically occurs during deceleration. As shown in Figure 6, the solid line represents the TE curve, and the dashed line represents the TE curve after disengagement. Soft disengagement is generally easier to occur, while hard disengagement can only happen under certain conditions. Typically, as the gear rotation speed increases, the likelihood of disengagement also increases. As the load increases, the likelihood of disengagement decreases. Due to the impact of disengagement, the continuity of gear transmission is lost.



(a) Tooth-pair change-over in



(b) Tooth-pair change-over out

Figure 6—Detachment impact (Ref. 21).

DTE takes into account the combined effects of geometric error, kinematic error, and dynamic error. It is essential to measure DTE at high speeds in order to obtain a comprehensive understanding of the transmission system's behavior. It can be represented by formula (5), where η represents gear kinematic error.

$$DTE = u + \eta + L \tag{5}$$

Composition of TE

Sources of TE

TE can arise from various sources, primarily categorized into five aspects:

1. Manufacturing Errors: These arise from various inaccuracies in the manufacturing process system, including tools, machine tools, workpiece fixtures and so on.
2. Assembly Errors: Gears are mounted on shafts within a housing, supported and fixed by bearings. Assembly errors primarily reflect eccentric mounting and parallelism issues with the axis.
3. Elastic Deformation: Under load, gears undergo elastic deformation, causing one gear to rotate slightly relative to another, leading to transient changes in the meshing position during transmission.
4. Thermal Deformation: As gears operate, temperature rise occurs, resulting in thermal deformation that disrupts the original involute tooth profile. This causes instability in the direction of force transmission and variability in the gear ratio, affecting motion smoothness.
5. Gear Disengagement: Due to gear deviations, there can be instances where the tooth profiles lose contact, leading to impacts from disengagement.

Contact Point Motion

Gear Pair Without Errors

Gear transmission operates by utilizing the interaction between the teeth of the driving gear and the teeth of the driven gear. This process entails the sequential engagement of the conjugate tooth surfaces. Figure 7 illustrates the meshing process of involute cylindrical gears, where two involute gears (labeled as o_1 and o_2) rotate around their respective fixed axes. o_1 represents the driving gear and o_2 represents the driven gear, and the base circle radii are r_{b1} and r_{b2}, respectively. P is the pitch point. As gear o_1 drives gear o_2, the path of moving of contact point of the conjugate tooth surfaces is the line of action $B_1 - B_2$. The driving gear transfers motion and force to the driven gear by their interaction, along the direction of the line of action (Refs. 22–23).

During the transmission cycle of a pair of teeth, the contact point starts from the point G_1, and the meshing sequence is G_1B_1, $\overline{B_1PB_2}$, and B_2G_2. The G_1B_1 segment represents the entry stage, which is the edge contact section of the driven gear, where the contact point moves from the tooth mid to the tooth root on the tooth surface of the driving gear. The B_2G_2 segment is the exit stage, which is the edge contact section of the driving gear, with the contact point moving from the tooth root to the tooth mid on the driven gear's tooth surface. For involute spur gears, the GIE curve during the edge contact segment is parabolic. The $\overline{B_1PB_2}$ segment illustrates the normal involute contact process, corresponding to the middle smooth section on the GIE curve, where the contact point moves from the tooth root along the involute to the tooth tip on the driving gear's tooth surface, and from the tooth tip along the involute to the tooth root on the driven gear's tooth surface.

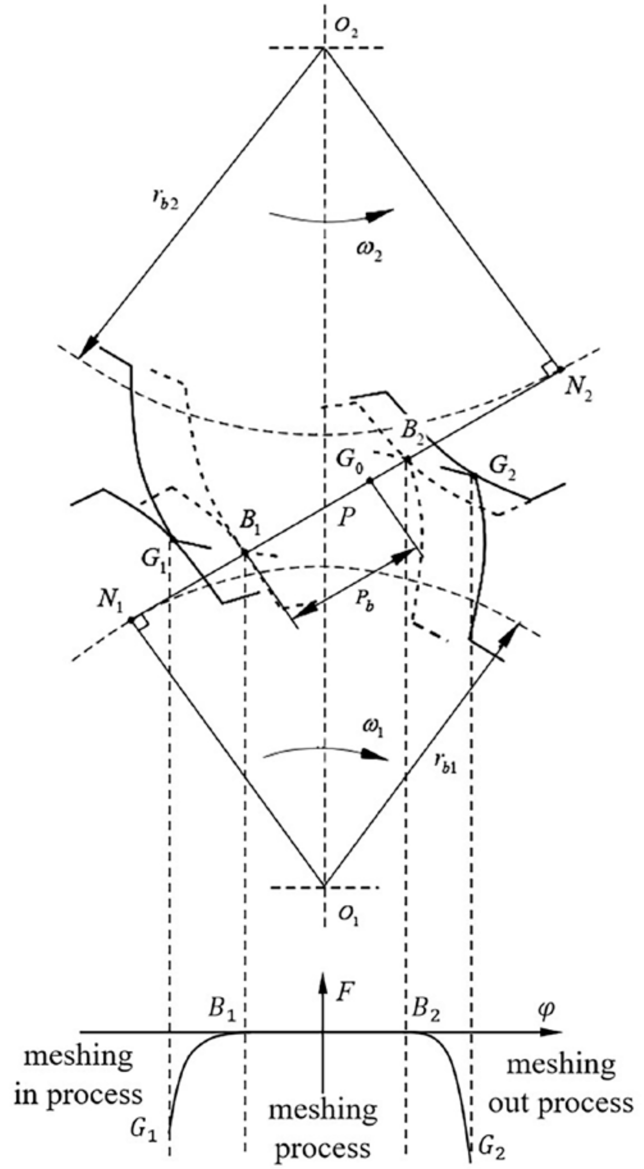


Figure 7—The meshing process of involute gears.

Gear Pair with Errors

Figure 8 illustrates the meshing phase of a pair of gears. The driving gear is perfect, while the driven gear exhibits a positive base pitch deviation Δf_{pb}, with the driving gear rotating at a constant speed. In this case, the driving and driven gears cannot directly enter the involute meshing segment, resulting in the meshing process EA_2 shown in Figure 8. In the EA_2 segment, the contact point first appears at point E, and then moves from point E to point A_2 on the tooth surface of the driving gear. Starting from point A_2, it enters the involute contact section, where the contact point gradually moves from the tooth root to the tooth top on the driving gear tooth surface.

As depicted in Figure 8, for the driving gear, the radius of point E exceeds the radius of point A_2. This procedure signifies a transition from the tooth apex to the tooth root direction, constituting the meshing process of the upper edge of the driven gear.

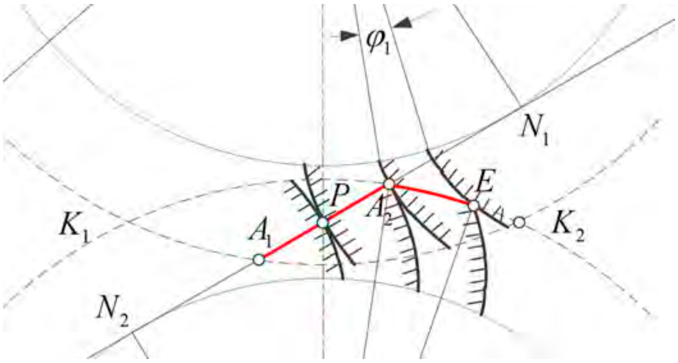


Figure 8—Gear meshing process with positive base pitch deviation.

The process mentioned above corresponds to the TE curve shown in Figure 9. By taking the first and second derivatives of the TE curve, we can obtain the velocity error curve and acceleration error curve, respectively. The entry impact point marked λ plays a significant role in these calculations. At that point, the driven gear experiences the greatest change in rotational speed, with a jump occurring at this point. Theoretically, the acceleration is infinitely large at this moment; however, due to damping and elastic deformation, a pulse is formed.

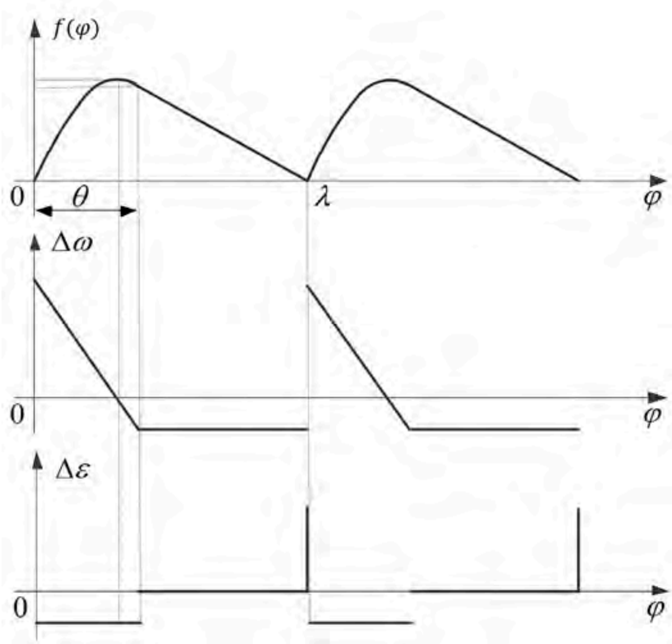


Figure 9—TE curve of gear with positive base pitch deviation.

Gear Pair Under Load

Figure 10 displays the GIE curve of a perfect gear pair. During light load transmission, there is no error, as indicated by the non-fluctuating portion of the TE curve in the figure. However, when the gear pair bears the load, the teeth of the gears bend, causing the TE curve to sink as a whole. This leads to the driving gear moving backward and the driven gear moving forward, as depicted by the red curve in the figure.

Under the action of load, the dynamic performance of a perfect gear pair deteriorates. On one hand, the driven gear tooth tip enters into contact with the driving gear tooth root ahead of time in the meshing process, causing meshing-in impact; on the other hand, after the ideal meshing is interrupted, the driving gear tooth tip still contacts the driven gear tooth root, causing meshing-out impact when they separate. Due to the meshing in and out impacts, the gear speed loses continuity and fluctuates, resulting in degraded performance of the ideal gear.

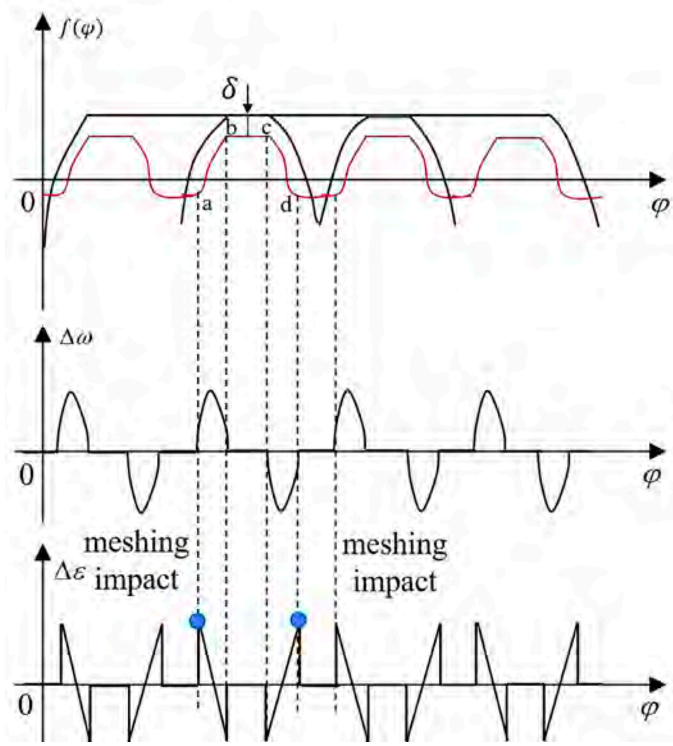


Figure 10—TE curve of a perfect gear pair under load.

Gear Pair with Modified Flank

The case of an ideal gear is shown in Figure 11, where the corresponding GIE curve is smooth and straight, without any meshing-in and -out impact. When the gear is under load, tooth deformation disrupts smooth transmission, causing meshing-in and -out impacts. To achieve good transmission performance, gear modification is often employed to avoid meshing-in and -out impacts. Typically, the tooth surface is modified to a crowning shape, as shown in Figure 12. The key issue in gear modification is the control of the modification curve and the amount of modification. When the gear is loaded and if the amount of modification is less than the amount of deformation, meshing-in and -out impacts still occur, as shown in Figure 13.

Functions and Limitations

Functions

Guidance Design

In gear design, TE curves are commonly employed as a reference for design guidance, particularly in the modification and utilization of high-order polynomial functions of transmission error (H-TE) (Refs. 24–27). The concept of H-TE was originally developed for spiral bevel gears, where the transmission function ideally exhibits linearity. However, due to assembly

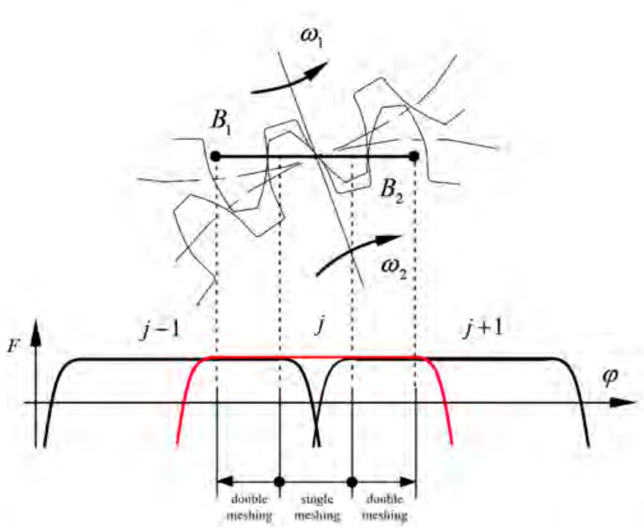


Figure 11—The smooth process of ideal gears.

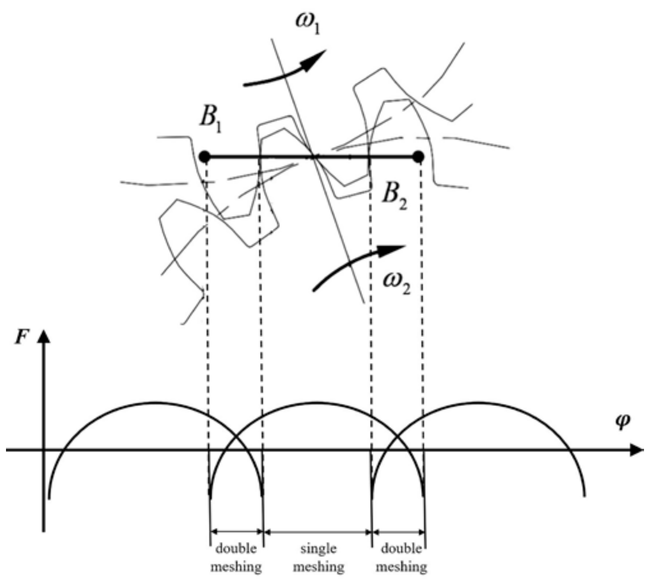


Figure 12—The smooth change-over process of the crowning profile.

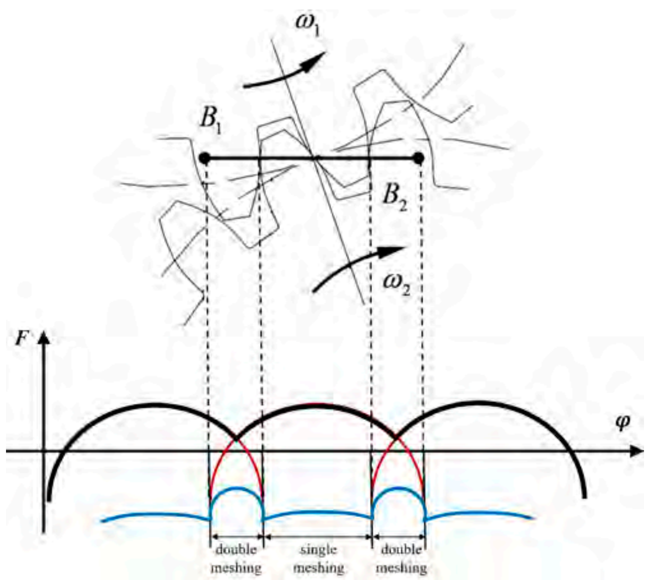


Figure 13—The nonstationary change-over of the crowning profile.

errors, the transmission function becomes piecewise linear, resulting in a larger amplitude of geometric transmission error at the tooth pair transition point. This adversely affects the dynamic performance of the gear and can lead to meshing apart in severe cases, as depicted in Figure 14.

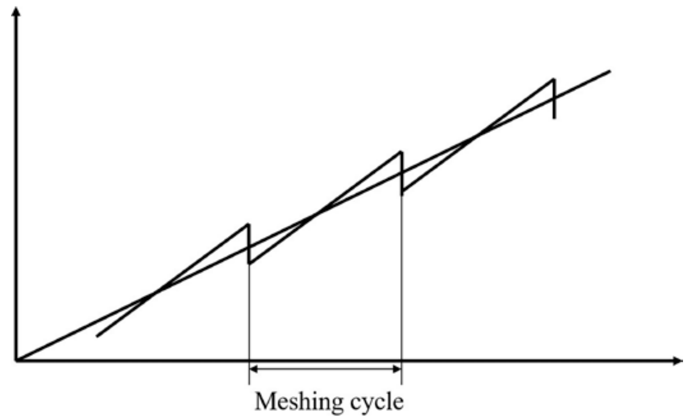


Figure 14—Piecewise linear function of TE.

Litvin et al. (Ref. 9) addressed the linear transmission error resulting from assembly errors by introducing a TE parabolic function, as depicted in Figure 15. With this approach, the angular velocity jump at the tooth pair transition is reduced, thereby mitigating the impact. Compared to second-order transmission error functions, higher-order transmission error functions exhibit a lower steepness at the transition point of the meshing cycle, as evident from the mathematical expression of the curve. Consequently, the amplitude at the transition point is minimized, which helps to diminish the impact. From a strength perspective, less material is removed from the tooth surface, alleviating the reduction in tooth strength. In the past, achieving the tooth surface of H-TE through traditional machining methods posed challenges. However, with the increasing maturity of intelligent control technology in CNC machine tools and greater flexibility, numerous scholars are exploring machining methods for H-TE.

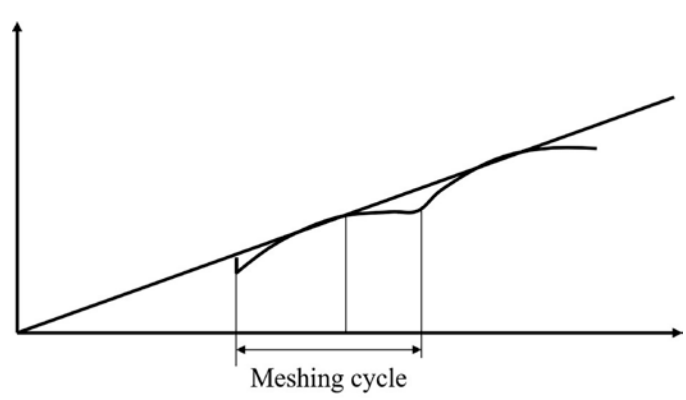


Figure 15—Parabolic transmission function.

Process Error Analysis

Gear machining errors can stem from various factors (Refs. 28–30), and based on their manifestation, they can be classified as follows, as illustrated in Figure 16.

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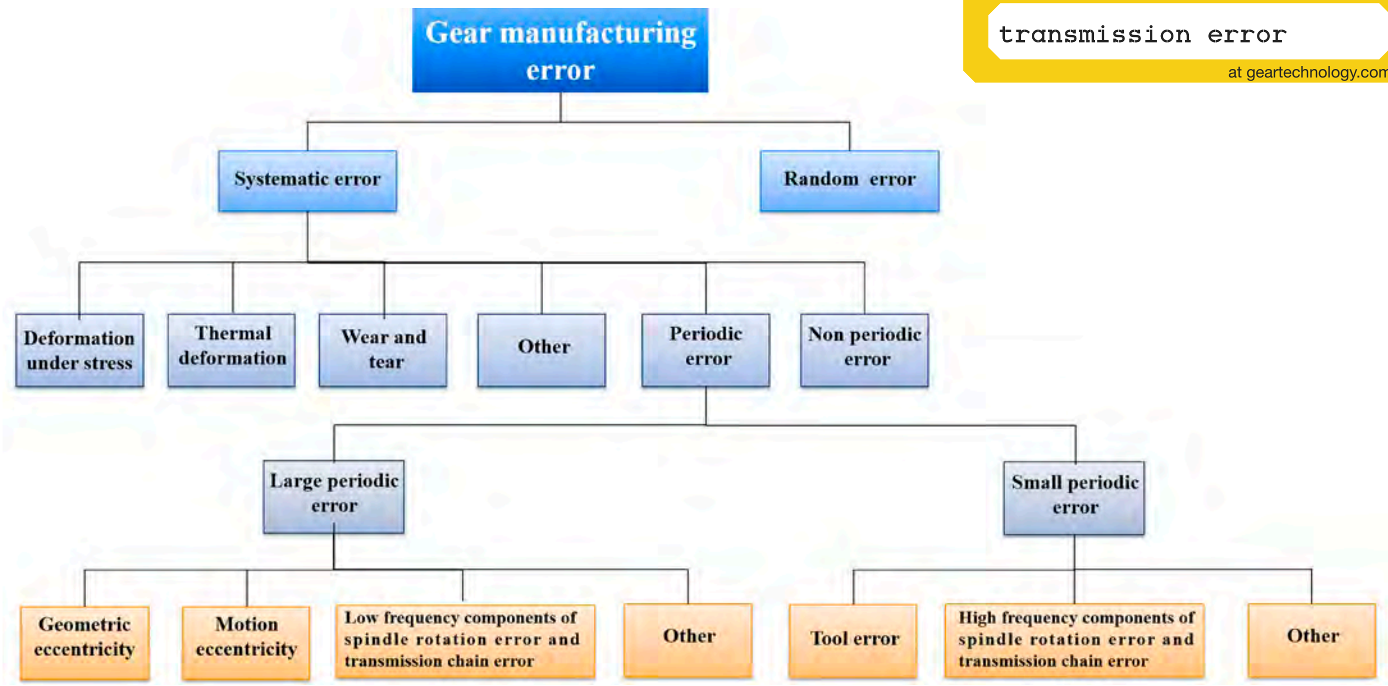

Figure 16—Gear machining errors and their causes.

TE has found extensive application in the analysis of process errors. A single flank testing is used to obtain the TE curve of the tested gear, which is then subjected to order analysis using Fourier transform FFT (or finite Fourier transform DFT). Several researchers have made significant contributions to understanding the causes of the TE spectrum and its various spectral components.

Figure 17 presents the TE curve of a gear exhibiting radial runout due to eccentricity in the machine tool. The order analysis revealed the presence of eccentricity, with a larger amplitude observed in the first order and the appearance of side frequencies near other prominent orders. These findings suggest the existence of errors on the gear teeth as a likely cause.

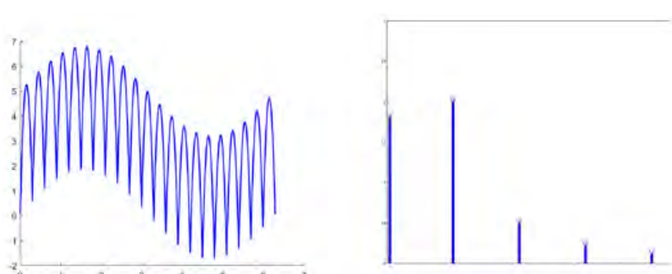

Figure 17—TE curve with radial runout and order analysis.

The spectrum diagram also reveals the presence of ghost frequencies, which are orders that are not multiples of the number of gear teeth. These ghost frequencies arise from various machining errors, making it challenging to pinpoint their main source. Figure 18 illustrates the TE curve of a gear with Z teeth, displaying prominent orders such as Z, 2Z, 3Z, 4Z, 5Z, and 6Z. However, numerous ghost frequencies are observed between these orders.

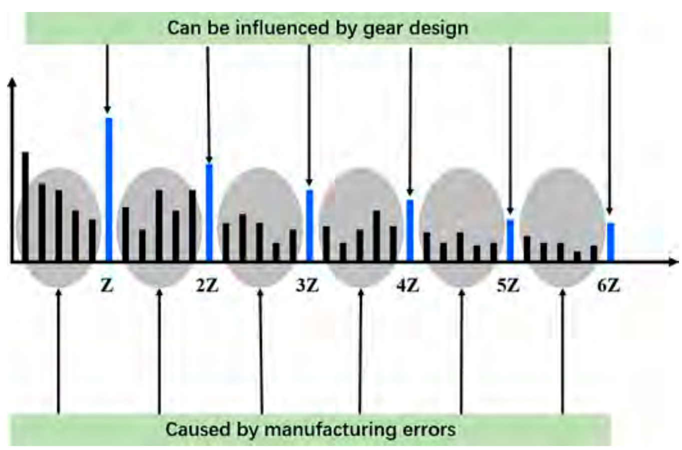

Figure 18—TE curve with pitch deviation and order analysis.

Practical applications of TE analysis often involve the examination of eccentricity, which represents long-period errors. However, it is challenging to separate elemental errors, which correspond to short-period errors, due to the presence of kinematic errors in TE.

Accuracy Characterization of Transmission Chains

TE is a robust indicator encapsulating the comprehensive attributes of a transmission system, making it the optimal parameter for characterizing the accuracy of the transmission chain. The TE in a machine tool's transmission chain is a holistic precision index receiving extensive attention from academic circles both nationally and internationally over numerous years. Beginning in the 1950s, notable scholars, including K. Stepanks (Refs. 17–19), Qin et al. (Ref. 31), and Peng et al. (Ref. 32), have invested considerable effort in exploring the detection principles, methodologies, and equipment for assessing TE in machine tool transmission chains.

The gear hobbing process is broadly utilized in gear manufacturing, with a typical gear hobbing machine tool depicted in Figure 19. The generative motion correlation between the hob and the workpiece is ensured by the machine tool's transmission chain. In this context, errors in the transmission chain directly implicate the machining accuracy of the gear hobbing tool, culminating in workpiece gear issues like tooth pitch error and tooth shape error. This can even instigate vibrations during the hobbing process (Refs. 33–34).

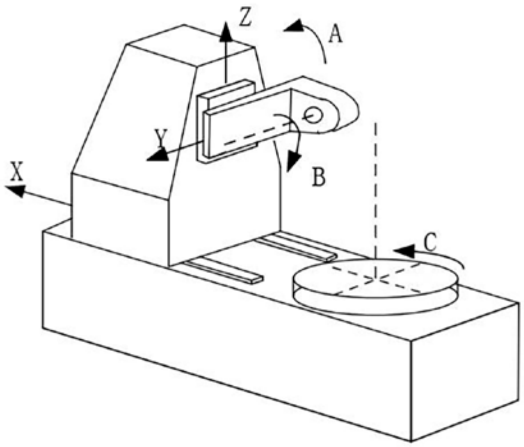

Figure 19—Gear hobbing machine tool structure.

Figure 20 demonstrates the measurement principle for TE within the hob machine tool's transmission chain. Both the hob shaft and the end of the workbench are fitted with circular gratings B and C, respectively. As the workbench and hob shaft rotate, the two circular gratings produce sinusoidal signals. An interpolator, also known as a subdivision box, processes and subdivides these two signals. The digital signal acquisition card then detects the falling edge of the two signals. Subsequently, a calculation program reads the count values and computes the rotation angles of both the hob shaft and the workbench. This ultimately allows for the determination of the transmission chain's TE. Beyond just machine tools, accurate TE measurement is also imperative for precision transmission machinery like observatories, radars, weapon systems, and printing machinery. This is necessary to ensure the transmission chain's quality and precision. Once the TE of the transmission chain is obtained, it becomes necessary to trace and compensate for any identified error.

Performance Prediction

With the advancing electrification of the automotive industry, electric vehicles demand higher standards for noise, vibration, and harshness (NVH) in their transmission systems. In traditional internal combustion engine vehicles, the engine noise eclipses that of the gearbox, thereby reducing the need for stringent control of gearbox noise. However, in electric vehicles, the gearbox becomes the primary source of noise. This noise becomes even more critical as motor speeds in newer electric vehicles reach or exceed 30,000 rpm, necessitating effective control over gearbox noise and setting standards for individual gear noise levels.

TE stands as a crucial metric for quantifying gear noise levels. By charting the TE curve of a singular gear and carrying out order analysis, the noise level of the gear can be assessed (Refs. 35–36). Gear transmission noise originates from two key sources: firstly, the noise generated by impacts during the alternate meshing transmission of crossing teeth, which predominantly contributes to high gear noise, and secondly, resonances caused by gear rotation due to eccentricities and other long-term errors. An inspection of the TE curve alone does not allow for the identification of the single and double meshing zones. Therefore, when employing the TE curve to predict gear transmission noise, only resonance-generated noise can be analyzed, while impact noise remains unpredictable.

Currently, the state-of-the-art technique for predicting gear noise both domestically and globally involves assessing gear noise levels by analyzing gear surface waviness, which fundamentally employs TE (Refs. 37–38). The red curve in Figure 21 is derived by aligning the tooth profile deviation of each tooth on the gear with the rotation angle and tooth pitch. The blue line is produced by the gear's radial runout, and the ripples on the tooth surface are clearly visible in the figure. This ripple is precisely what gives rise to the gear's noise characteristics. An order analysis and separation are then performed on the curve shown in Figure 21.

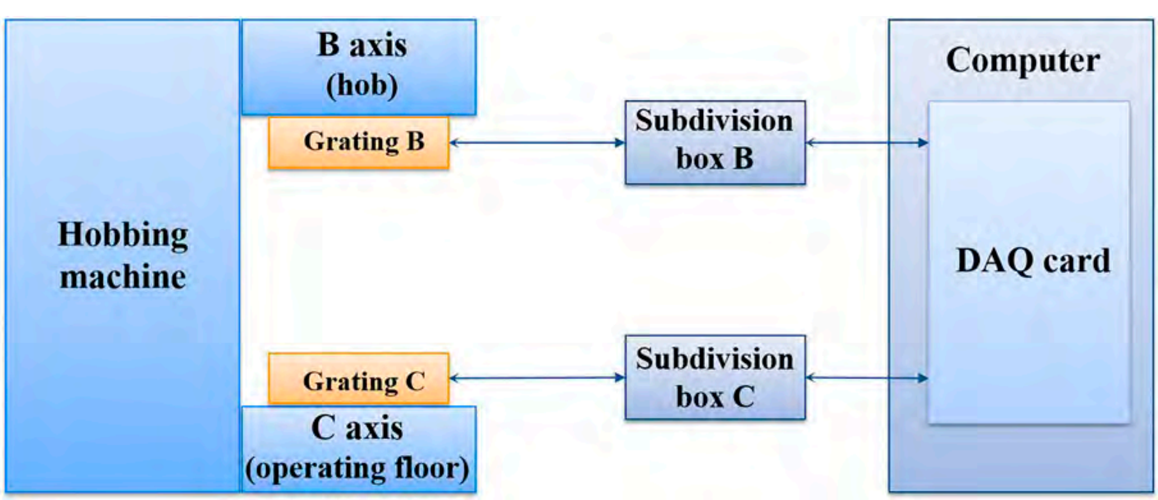

Figure 20—Measurement principle of TE for transmission chain of hobbing machine tools.

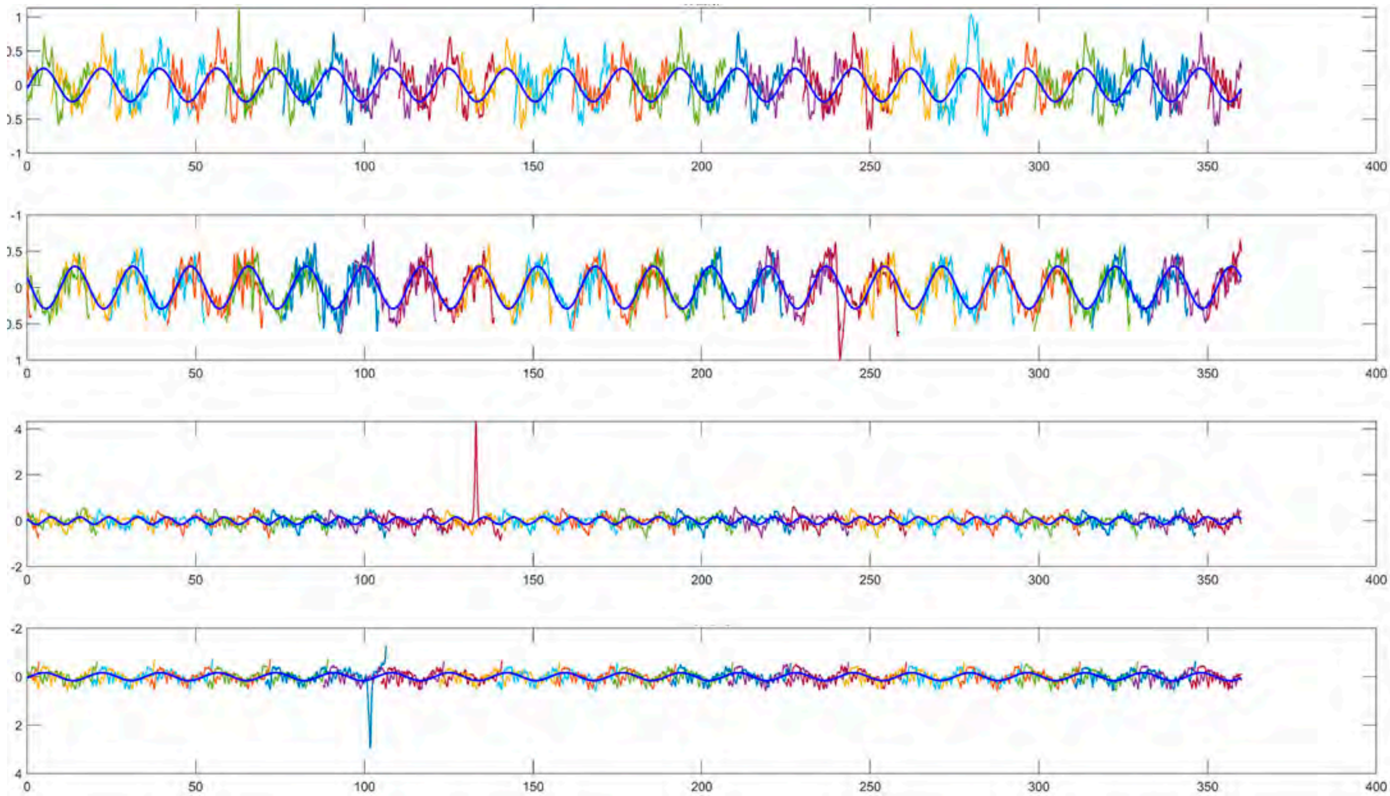

Figure 21—TE from profile deviations and Fourier analysis.

Limitation

Five primary constraints and shortcomings associated with TE can be delineated as follows:

1. TE is composed of geometric errors, kinematic errors, and dynamic errors. The low-frequency components are mainly due to geometric and assembly errors, while high-frequency components encompass all three types of errors. Therefore, it is not feasible to infer the geometric error components of gears from the measurement results.
2. The TE measurement outcomes are not full and fail to completely encapsulate the transmission attributes of gears. When the gear is being tested with a master gear, only a part of the tooth profile (where the contact ratio is less than 1) is inspected. Meanwhile, the unexamined segments often emerge in actual transmission operations under specific gear pair error amalgamations.
3. The TE curve represents aggregate data that does not distinguish which gear teeth are meshing and cannot differentiate between single and double contact zones. This results in a knowledge gap concerning the influence of meshing impacts on transmission and a lack of further comprehension of TE.
4. Merely observing the TE curve makes it impossible to discern the change-over form of tooth-pair during gear transmission; identical TE curves can produce completely different effects.
5. The existing dynamic equations for gear transmission superimposed with transmission errors cannot reflect the differences between double and single contact zones.

Overcoming TE Defects: Gear Pair Integrated Error (GPIE)

1. In contrast to transmission error, the gear integrated error inherent in a gear pair carries more comprehensive error data. Not only can it evaluate the transmission quality of the gear pair, but it can also scrutinize which tooth surface or surfaces are the source of the error. It allows for an exploration of how the errors from two pairs of teeth engaged in meshing reciprocally affect the transmission quality in the double meshing zone. This enhances the control over the transmission quality of the gear pair and lays a foundation for adjustments in gear technology and enhancements in gear design.
2. The integrated error of a gear pair consolidates the collective errors of the primary and driven gears. This not only exhibits the outcome of the interaction between the primary and driven gear errors during the meshing process but, more significantly, reflects the nature and progression of this interaction. It especially illuminates the alternating process of the meshing teeth.
3. The integrated error of a gear pair intimately merges the geometric error of the driving and driven gears with the kinematic error of the gear pair. It can unveil the actual contact process of gears with errors and the influence of gear geometric error on transmission quality.
4. By employing the overall error of gear pairs, the direction of error changes post gear loading can be investigated. Coupled with dynamics, it enables the study of gear impact, subsequently predicting dynamic gear characteristics such as vibration and noise.

Conclusion

Research on TE has a history of nearly a hundred years. TE is widely used in characterizing the quality of gear transmission, analyzing the dynamic characteristics of gears (vibration, noise, etc.), gear pairing, and guiding the design of high-performance gears. Although TE seems simple, it encompasses a plethora of intricate manufacturing operations, elastic deformations, energy conversions, energy transfers, and issues related to motion control. This paper provides a summary of the mechanisms, features, functions, and measurement methods of TE and, importantly, elucidates its limitations and drawbacks. The article suggests that the path to circumvent the drawbacks of TE is through the integrated error of the gear pair. This integrated error of gear pair represents a further evolution of TE. By investigating other gear-related issues, a series of results that were previously challenging to attain can be acquired, thereby offering a novel pathway for the future evolution of TE.

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Huiming Cheng received the Ph.D. degree in Mechanical Engineering from Beijing University of Technology, Beijing, China, in 2024. He is currently a teacher at Beijing University of Technology, with research focused on robot joint testing technology.

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In Memoriam:

Barney Berlinger (1937–2025)

FOUNDER OF ASI TECHNOLOGIES, INDUSTRY LEADER, AND AGMA PAST CHAIRMAN

Barney Berlinger

The gear and motion control industry mourns the passing of Barney Berlinger, founder of ASI Technologies and longtime contributor to the American Gear Manufacturers Association (AGMA). A respected engineer, entrepreneur, and leader, Barney's impact on the industry spanned decades and will not be forgotten.

Barney earned his Bachelor of Science in Mechanical Engineering from the University of Pennsylvania, where he also excelled as a student athlete. He set a then-school record in the pole vault and was named first-team All-Ivy League in football in both 1958 and 1959. In his senior year, he captained Penn's first Ivy League championship football team—an early indication of the leadership and tenacity that would define his professional life.

After beginning his career at Quaker City Gear Works, his family's gear manufacturing business, Barney went on to found ASI Technologies in 1985. Under his leadership, ASI became a trusted provider of engineered drive solutions, particularly for battery-powered applications. Barney led ASI until his retirement in 2020, guiding the company through decades of innovation and growth.

Barney was also a dedicated advocate for the gear industry. He served on the AGMA Board of Directors from 1983 to 1984 and as Chairman of the Board in 1986. His commitment to advancing the industry and mentoring future leaders earned him wide respect among peers and colleagues.

Barney's legacy lives on through the company he built, the people he mentored, and the standards of excellence he championed. He will be remembered as a passionate contributor to our field and a builder in every sense of the word.

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Seco/Warwick USA

PROMOTES TOM HART TO DIRECTOR OF SALES FOR NORTH AMERICA

Seco/Warwick USA has announced that Tom Hart has been promoted to director of sales for North America.

Tom Hart

With over two decades of experience serving the precision manufacturing and heat treatment technology sectors—underscored by his leadership in industry groups, including the American Gear Manufacturers Association (vice-chair materials and metallurgy committee, member of the aerospace committee and planning committee), Gear Research Institute (Aerospace Bloc), ASM International and the Material Treating Institute. Hart brings deep technical expertise and market insight. His work spans heat treatment systems for aerospace, automotive, medical, tool and die, industrial, energy and commercial sectors.

Hart's promotion comes at a pivotal time, as Seco/Warwick consolidates its US operations, combining vacuum, atmosphere and aluminum heat treatment to streamline service and strengthen its market presence. His leadership will be instrumental in this next chapter.

"Tom has earned this position based on his proven success as a product engineer, developing meaningful client relationships and pairing them with the best technical solutions for their heat treating needs," says Piotr Zawistowski, managing director of Seco/Warwick, USA. "We are excited about the future of Seco/Warwick Corp. with Tom at the helm of our North American sales team."

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Solar Atmospheres of Western PA

BEGINS TITANIUM DROP BOTTOM FURNACE INSTALLATION

The foundation is now in place at Solar Atmospheres of Western PA for the installation of a state-of-the-art titanium drop bottom water quench furnace. Engineered for precision and performance, this new furnace is rated for a maximum operating temperature of 1,850°F ±10°F and is designed to process titanium bar and forging loads of up to 7,500 pounds.

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This investment marks a significant step forward, opening the door to expanded titanium solution treating capabilities and reinforcing Solar Atmospheres' commitment to innovation and customer-driven thermal processing solutions.

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SEPTEMBER 8–11

Fabtech 2025

Fabtech 2025 (Chicago) will span more than 800,000 square feet of exhibits showcasing the latest in metal forming and fabricating, welding and finishing equipment, automation and robotics and smart manufacturing technologies. With 200+ conference sessions, Fabtech offers hands-on learning, expert-led keynotes, and panel discussions on everything from shop floor strategies to emerging trends in AI, sustainability and workforce development. Whether you're a shop owner, engineer, or executive, Fabtech 2025 is your chance to network, discover new solutions, and prepare for what's next in manufacturing.

geartechnology.com/events/fabtech-2025

SEPTEMBER 10–12

11th International VDI Conference on Gears 2025

The 11th International VDI Conference on Gears 2025 will be held in Garching, Munich at the Gear Research Centre (FZG) of the Technical University of Munich. Supported by national and international associations, the conference brings together 500+ leading experts from the international gear and transmission industry. Visiting the conference gives attendees the opportunity to take part in this leading international forum and learn about the latest developments and research results in the powertrain industry and academia. The conference is a unique meeting point for propulsion system manufacturers and researchers of gear and transmission systems.

geartechnology.com/events/11th-international-vdi-conference-on-gears-2025

SEPTEMBER 15–17

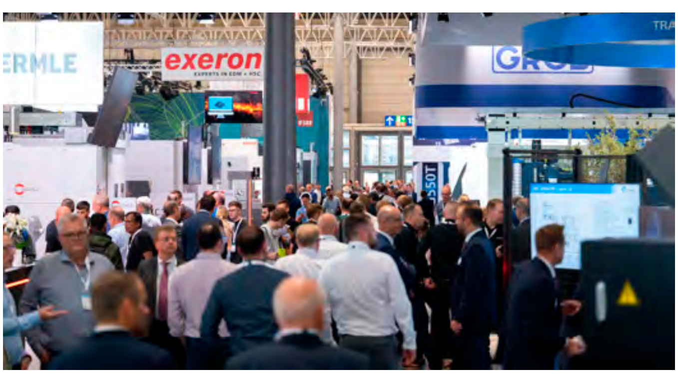
CAR Management Briefing Seminars 2025

The Center for Automotive Research (CAR) MBS leads the industry in providing a context for auto industry stakeholders to discuss critical issues and emerging trends while fostering new industry relationships in daily networking sessions. The CAR Management Briefing Seminars take place at Michigan Central Station in Detroit. Seminars include sessions on manufacturing strategy, connected and automated vehicles, advanced powertrain, supply chain, sales forecasting, purchasing, talent and designing for technology, future factories, design optimization, the mobility ecosystem and more. Roundtables will focus on cybersecurity, policy updates, sustainability, decarbonizing, electrification and more.

geartechnology.com/car-management-briefing-seminars-2025

SEPTEMBER 22–26

EMO Hannover 2025

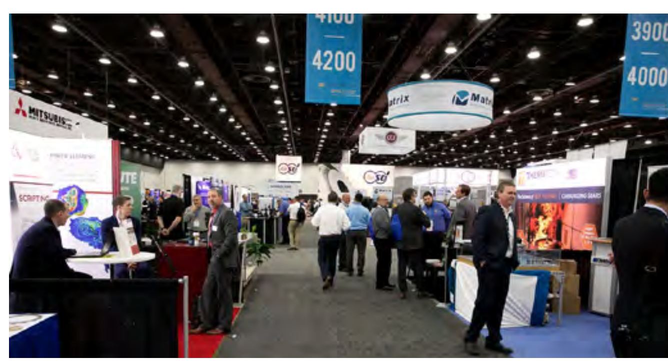


Founded in 1975, EMO Hannover has stood for innovation, internationality, inspiration and the future of metalworking worldwide. This trade fair for production technology offers a unique platform every two to four years in Hannover under the motto "Innovate Manufacturing" to establish international contacts, tap into new business opportunities and gain a comprehensive overview of the industry's global offering. Most recently in 2023, over 92,000 visitors from 140 countries and around 1,850 exhibitors took part in the event. EMO showcases the entire metalworking value chain including cutting and forming machine tools, manufacturing systems, precision tools, automated material flow, computer technology, industrial electronics and accessories. Exhibitors and visitors with a high level of expertise discuss the megatrends in manufacturing, exchange ideas with representatives of international production research and develop solutions for existing challenges.

geartechnology.com/events/emo-hannover-2025

OCTOBER 21–23

Motion + Power Technology Expo 2025



Produced by AGMA, Motion + Power Technology Expo (Detroit) is a three-day show that connects professionals looking for motion power solutions with manufacturers, suppliers, and buyers. Attendees will find new power transmission parts, materials, and manufacturing processes. Buy, sell, and get business done with organizations in aerospace, automotive, agricultural, energy, construction and more. Forge partnerships at one of the largest gatherings of CEOs, owners, engineers, sales managers, and other professionals in the electric, fluid, mechanical and gear industries. End-users can shop the latest technology, gear products, and services from leading manufacturers. No matter your industry, you will find new ideas and solutions that can benefit your plant and company. Hundreds of exhibitors and attendees means MPT Expo is a unique opportunity to find partners that can help fulfill your specific production needs.

geartechnology.com/events/motion-power-technology-expo-2025

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Gleason Index Plates for Models 19, 29 & 120 Curvic
Gleason Index Plates for Models 724, 725 & 726
Gleason Lift & Drop Cams for 112
Gleason Drop Cams for 109
Gleason 54 Straight Planer Cams
Gleason Test Bars #14 & #39, #14 & #14, #39 & #39, Long & Short
Reishauer 62-84mm & 104mm Grinding Wheel Hubs
Hurth KF32A & LF Index Plates
Fellows Model 36 Cutter Holders
(2) Gleason Universal Lower Dies for Quench Presses

CHANGE GEARS

Barber Colman 16-16 & 14-15
Fellows Models 3, 3-1, 6, 6A, 10-2 & 10-4, 36 & Z Large & Small Bore
Gleason 2A, 7A, 12, 12B, 14, 16, 24, 24A, 26, 28, 102, 104, 106, 108, 112, 114, 116, 118, 463, 606-610 641, 645, 650 Spur & Helical

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ADDENDUM

Next Steps in Artificial Intelligence

Matthew Jaster, Senior Editor

Representatives from Mercedes, Siemens, Beckhoff, Arburg, Hawe, KSB and Sick, among others, spent three days this summer discussing the relationship between humanoids and AI, the revival of reinforcement learning and AI utilization. As AI implementation becomes easier for manufacturers, the focus is evolving to address challenges and new opportunities across the entire industrial sector.

Intelligent Robots/Intelligent Bodies

Hannover Messe reports that several robots are already performing many AI tasks today. While the software is becoming ever more powerful, the mechanical construction (the body, for example) often falls by the wayside. Edoardo Milana, junior professor of soft machines at the University of Freiburg, advocates a paradigm shift: away from rigid machines and towards flexible, body-intelligent robots.

One example: four-legged robots, so-called quadrupeds, need around 300 watts to move around. A real dog, on the other hand, only needs 30 watts—with significantly more complex movements. The reason lies in nature itself: Biological bodies use their mechanical properties to perform movements efficiently and flexibly.

Milana emphasizes the importance of "embodied intelligence," a concept from philosophy and psychology that states that intelligence is not only anchored in the brain, but also in the body. For robotics, this means that the body of a robot should not just be passively controlled by the software but should actively contribute to intelligence.

A robot that can adapt to its environment requires less central computing power and energy. This allows resources to be used for more complex tasks such as planning and perception.

Milana's research focuses on soft robots/machines made of soft, flexible materials, inspired by simple and aquatic organisms.

One fascinating example is robots with self-oscillating valves: Air pressure causes these valves to open and close rhythmically, controlling the robot's movement—completely without digital microcontrollers.

Such designs show that physical principles can be used to achieve movement and adaptability without having to rely on complex software. The combination of soft materials and intelligent design enables robots to interact with their environment more safely, efficiently and agilely.

Agentic AI/Proactive Intelligence

Schneider Electric is launching a multi-year initiative to build an AI-based ecosystem for sustainability and energy management. At the heart of the initiative is the new Agentic AI technology—intelligent software that acts independently or in collaboration with customers and consultants, analyzes complex environments, and adapts in real time. Unlike traditional software, Agentic AI is designed to proactively take on tasks, marking the shift toward an AI-native, agent-based software system.

The new system serves as a strategic control center that transforms fragmented sustainability measures into intelligent, connected processes. AI agents work closely with specialists and existing systems to continuously achieve better results.

"Our vision is collaborative intelligence—agent-based AI that works alongside human experts as a true digital teammate," explains Steve Wilhite, president of sustainability business at Schneider Electric. "This technology enables us to achieve a multiplier effect: complex data analysis and tasks are automated, allowing our customers to focus on strategic initiatives and innovation—the levers that deliver real impact. This is a fundamental shift in how organizations can accelerate their path to energy transition and decarbonization."

"Agent-based AI is only as powerful as the expertise that underpins it," emphasizes Amy Cravens, research director, sustainability and ESG Software at International Data Corporation (IDC). "With deep consulting expertise, Schneider Electric is developing a system that helps companies overcome complex challenges and make sustainability measurable."

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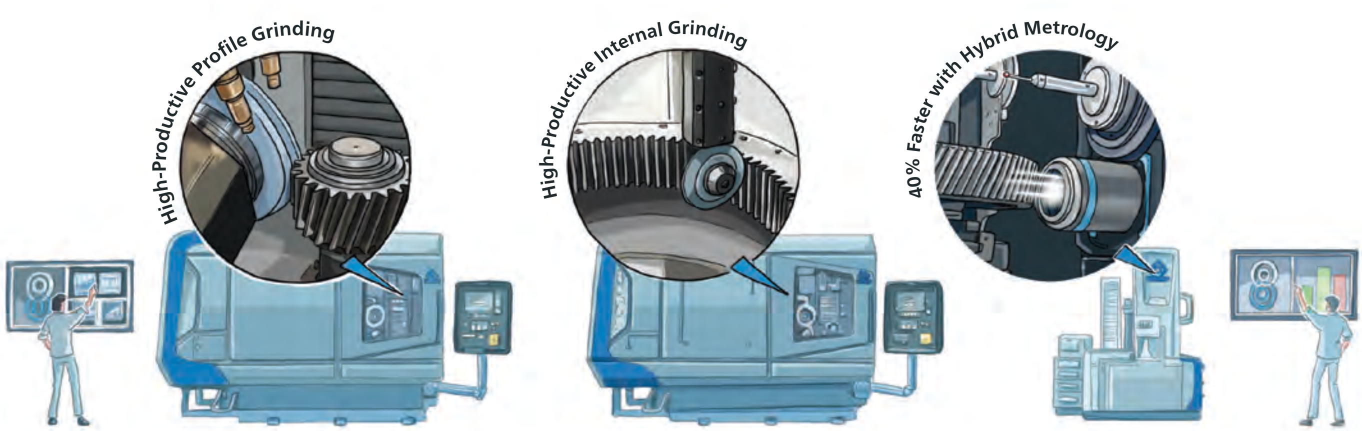

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