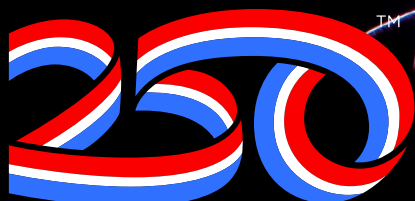


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Design and Load Capacity of Crown Gears in
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- Skiving Cutters
- Shaving Cutters
- Rack and Saw Cutters
- Master Gears, Ring and Plug Gauges
- Advanced Coatings Available





GEAR CUTTING SOLUTIONS



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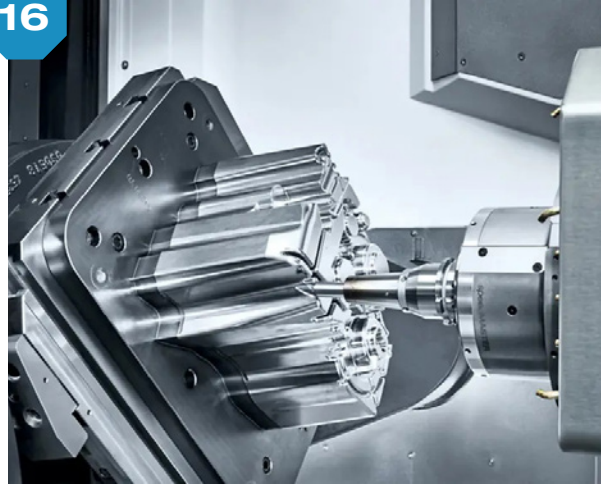
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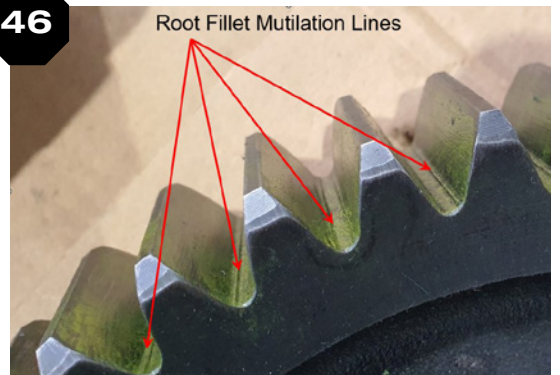
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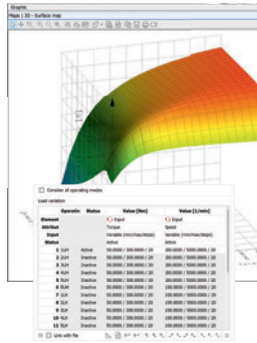
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Gear Technology celebrates America250!





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With the upcoming 250th anniversary of America, we're looking at some key manufacturing legacy companies pivotal to innovation here in the United States:

MICHAEL GOLDSTEIN GEAR TECHNOLOGY LIBRARY

The Birth of an Industry

As with many technologies, gear manufacturing was transformed by war. In the case of gear manufacturing in the United States, the initial motivation appears to have been the Civil War. Before 1860 gear making appears to have been the province of watchmakers, foundries, and blacksmith shops.

geartechnology.com/the-birth-of-an-industry



Photo above: Five Falk employees stand inside the foundry. (Image: wisconsinhistory.org)

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GT VIDEOS

Keeping Things Moving with Horsburgh & Scott

The Horsburgh & Scott engineering team has over 135 years of experience designing, manufacturing and maintaining gearboxes in heavy-duty applications around the world. They have proven design standards for gearboxes up to 5,000 hp and 4 million ft-lbs. with speeds from 0.5 to 3,600 rpm. If they don't have a standard gearbox to meet customer's needs, they can design a custom gearbox for a specific application.



geartechnology.com/videos/keeping-things-moving-with-horsburgh-scott

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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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Still Turning

Aaron Fagan, Senior Editor

This month, the United States turns 250. The republic that followed the adoption of the Declaration of Independence became, among many other things, a movement. We tend to tell the national story in documents and battles, but it can just as fairly be told in the things that turn.

Gears are older than the nation that came to depend on, and thrive because of, them. In this issue, Hanspeter Dinner traces noncircular gears back to the notebooks of Leonardo da Vinci, sketched between 1478 and 1519, well before there was a United States to put them to work. But it was here, across the long American century that followed independence, that geared motion was set loose at scale: in the line shafts of the early mills, the machine tools that made other machine tools, the automobile, the aircraft, and eventually the spacecraft. None of it ran without teeth meshing somewhere, reliably, out of sight.

Our own part in that story is younger and a good deal more modest. *Gear Technology* was founded in 1984 by Michael Goldstein, who recognized that a field this specialized—and, in his own words, this insular—needed a publication devoted entirely to it. For more than four decades, the assignment has not really changed: to gather what the industry knows and put it where the industry can find it. The Michael Goldstein Gear Technology Library, now freely available to anyone with a connection, remains the largest open record of that knowledge anywhere. It is, in a real sense, the field's memory.

This issue is a fair cross-section of the work as it stands in 2026. There is deep theory: Dr. Hermann J. Stadtfeld's third excerpt from *Gear Technology Solutions* takes apart the geometry of root interference, the kind of fault that hides from a roll tester and surfaces, years later, as a fractured tooth. There

is research crossing into practice: Dr. Joachim Thomas and Jürg Fürst, in a paper first delivered at last year's FTM, weigh crown gears against bevels and find real weight savings hiding in a less familiar geometry. There is measurement: Gleason's Mark Cowan describes pulling waviness data from a standard probe in a single inspection cycle. And there is the frontier: Mike Fish of Dontyne reports double-digit power-density gains from gears that abandon the involute altogether, tuned for the demands of electric drive.

Set alongside these are the surveys and dispatches that keep the rest of us oriented—Matthew Jaster's look at the 5-axis machines now defining what a complex part can be, and Mary Ellen Doran's notes from the additive, drone, and robotics show floors, where our MPMA members, she is glad to report, were already standing.

The institution doing the recording is changing, too. In 2025, AGMA and ABMA joined to form the MPMA, and this October, STLE joins the FTM as a co-host. As Todd Praneis explains in this issue, the FTM is pitching a bigger tent—making room beside the peer-reviewed papers for the practitioners whose hard-won, undocumented experience has always shaped what actually happens on the floor. Continuity, it turns out, is not the same as standing still.

That is the through-line worth marking at the United States semiquincentennial. A country runs on the things that keep turning, and the things that keep turning run on people who understand them well enough to make them better. Our share of that is small—four decades against two and a half centuries—but the charge has been steady, and it is the one we take up again here.





We are looking for Member participants to join the following projects

Powder Metal Gearing:

AGMA 936-Axx Calculated Bending Load Capacity and Pitting Resistance of Powder Metallurgy, PM, External Spur and Helical Gears. Looking for some members to help develop this document.

Wind Turbine Gearbox Field Inspection:

AGMA 950-Axx: Guidelines on proper photograph techniques, categories for gearbox condition, and a consistent nomenclature for evaluating issues found during field or teardown inspections. Looking for some members to help develop this document.

Flexible Couplings Committee:

AGMA 9013/9113: Flexible Couplings – Potential Unbalance and Mass Elastic Properties. Looking for members to help finalize this document and participate in the committee activities.

Wind Turbine Atlas of Roller Bearing Failures:

ABMA 601-Axx: Atlas of Roller Bearing Failures in Wind Turbines. Looking for members to help update the document and add examples of WT bearing failures.



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You don't need to be an expert to join these committees or working groups! As long as you can participate in the work of the group and attend meetings, we would appreciate your involvement.

HWR Workholding

DEMONSTRATING NEW SOLUTIONS AT IMTS 2026



HWR Workholding USA has announced that IMTS 2026 will feature the North American debut of two new products within its INOFlex family of flexible, high-performance 4-jaw chucks. The company will also be showcasing a comprehensive sampling of its full range of workholding solutions for turning and milling applications. Additionally, attendees who visit the company's Booth #431579 in the West Building will receive a commemorative German-style beer boot pint glass.

All INOFlex chucks incorporate a centric compensating clamping system that allows each pair of jaws to move independently of the other. This design automatically centers and securely holds workpieces, regardless of if they feature a round, rectangular, or asymmetric geometry. The resulting level of flexibility allows users to efficiently process a wide range of parts.

Developed specifically for the optimization of automation on milling machines, INOFlex VF-A chucks use hydraulic actuation for fast, precise workpiece transfer. The VF-A is available in chuck sizes from 220 mm (8.7 in.) to 700 mm (27.6 in.).

A power chuck featuring a quick-change jaw system for fast changeovers, the INOFlex VT-Q includes a through-hole for open-center or partial open-center clamping. The VT-Q is

available in chuck sizes from 220 mm (8.7 in.) to 400 mm (15.7 in.).

HWR will also be showcasing INOFlex VL chucks featuring a unique weight-reduced design that makes them ideal for integration within 5-axis milling machines. Visitors to HWR's booth will see the VL100, which accommodates parts to a maximum diameter of 2,000 mm (40.0 in.). INOFlex VL is available in chuck sizes ranging from 325mm (12.8 in.) to 2,000 mm (78.7 in.)

Manufacturers working with delicate or thin-walled parts will have the chance to see two complementary solutions for these challenging applications. INOZet pendulum bridges allow manufacturers to quickly and easily double the number of jaws on nearly any existing chuck that is 200 mm or larger. This more effectively distributes clamping forces and reduces the risk of part distortion.

INOTop hybrid clamping jaws take a two-stage approach, first centering a workpiece using external pressure, then securing it with internal clamping force. This achieves exceptional results in finishing operations with critical dimensional tolerances.

HWR's SOLIDLine family of modular, zero-point workholding dramatically reduces setup times and increases machine utilization across milling applications. A key focus area at IMTS will be SOLIDBolt, which provides a straightforward path to zero-point adoption by allowing manufacturers to install a zero-point plate directly onto their existing machine tables or pallets. Fully compatible with every major machine tool brand, SOLIDBolt give shops immediate access to a broad ecosystem of vises, risers, chucks and pyramids without requiring significant investment in new equipment.

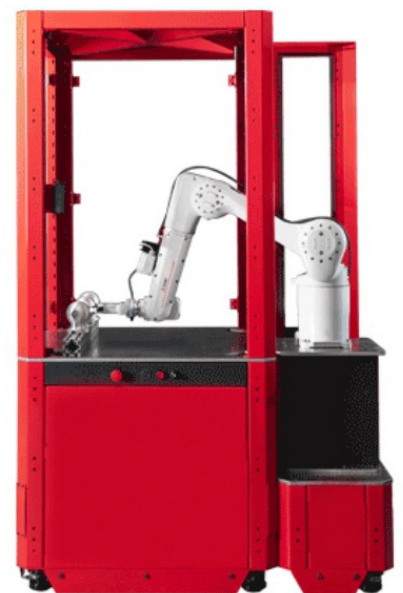
HWR's will also showcase a variety of solutions that complement SOLIDBolt, including the SOLIDGrip vise family, SOLIDPoint zero-point system, SOLIDClick 5-axis centering vise for contour clamping, and SOLIDStamp stamping system. Tombstones and additional modular components will be on display to illustrate the full range of configurations enabled by a zero-point workholding system.

Mitsubishi Electric Automation

BRINGS CNC AND ROBOTICS EXPERTISE TO MACHINE TENDING

At IMTS 2026, Mitsubishi Electric Automation will feature live demonstrations of LoadMate Plus and ARIA, two pre-engineered robotic machine tending solutions designed to help manufacturers automate CNC mills and lathes with confidence, flexibility, and scalability. Automated machine tending enables longer spindle uptime, improved process consistency, and redeployment of skilled workers to higher value tasks. Robotic tending also reduces unplanned downtime and supports lights out or extended hours.

“For many manufacturers, robotic machine tending is one of the most practical and financially justifiable entry points into automation,” said David Simak, product manager (service) at Mitsubishi Electric Automation. “When implemented correctly, it delivers productivity improvements that can be measured quickly on the shop floor.”



LoadMate Plus™

With decades of experience in CNC, robotics, and factory automation, Mitsubishi Electric Automation brings OEM level engineering and support to machine tending applications. Since Mitsubishi Electric is the original equipment manufacturer of both the CNC and the robot, the company offers a single point of accountability, long term product support, and solutions designed to remain compatible as production needs evolve.

LoadMate Plus is designed for quick setup and long-term deployment at a single machine. It can be customized for different machine layouts, part sizes, and safety requirements while integrating directly with Mitsubishi Electric CNCs and robots.

ARIA (Automated Robotic Industrial Assistant) is a compact, configurable solution for mill and lathe tending in space constrained environments. It supports multiple robot types and can be relocated within a facility, making it ideal for shared or expanding automation strategies.

Attendees can visit the Mitsubishi Electric Automation Booth #338136 to view live machine tending demonstrations, speak with application experts, and discuss ROI considerations for their specific operations.

mitsubishielectric.com



ARIA

Mazak

MEETS ACCELERATING PRODUCTION DEMANDS WITH ADVANCED TECHNOLOGY

Mazak will showcase advanced machine tool, automation and digital solutions designed to help manufacturers increase throughput and do more with fewer resources at IMTS 2026, in Booth #338300. As production demands accel-

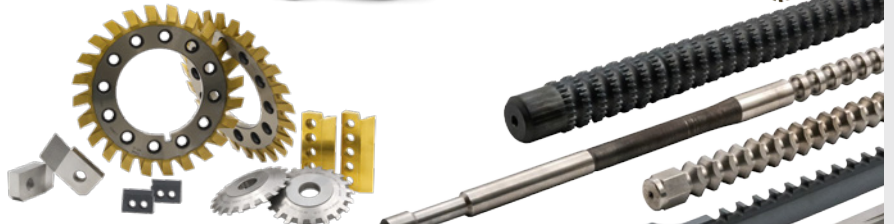
erate across key industries, manufacturers are under increasing pressure to boost output while managing labor and cost constraints. Mazak's technologies address these challenges through integrated machining, automation and digital connectivity.

Manufacturers in the semiconductor, aerospace, medical, oil and gas, defense and other key growth industries will learn how to drive their results with Mazak innovation. Live, real-world part cutting



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demonstrations will showcase the advantages of Mazak machines for multitasking, full 5-axis machining, vertical and horizontal machining, CNC turning and Swiss-type production turning. Additionally, all Mazak machines offer seamless automation integration, and the company will spotlight several of its productivity-enhancing solutions that range from simple bar feeders and gantry loaders to standalone cobot systems and full multimachine palletized cells.

“In an environment of rising labor costs, tariffs, inflation and other economic demands, we maintain our focus on providing high-value, high-performance and productive solutions,” said Dan Janka, president of Mazak. “Today’s shops are under tremendous pressure to increase their production in less time. To succeed, they need to do more with less, and they will accomplish that with the highly productive machines and automation technologies that Mazak will showcase at IMTS 2026.”



Among the 15 machines Mazak will feature at IMTS are models from its Neo and Ez series multitasking machines and Syncrex Swiss-style production turning series. Neo series machines are the result of Mazak’s continuous improvement and redesign of existing models in line with the current needs of manufacturers. Neo series machines at the show will include the Integrex i-200ST Neo multitasking machine outfitted with gantry loader automation and the HCN-5000 NEO horizontal machining center paired with Mazak’s multi-pallet pool (MPP) compact multi-level pallet stoker system.

Mazak’s Kentucky-built and designed Ez series of machines offers high value, high performance and a step above today’s commodity machines. From the series, Mazak will bring its VC-Ez 20 vertical machining center equipped with an optional Mazak Mazatrol SmoothG CNC control and a two-pallet changer. The machine provides ease of operation, fast installation, and long-term reliability for leveling up performance in any production environment.

Multitasking technology is one of Mazak’s core strengths, and the company will demonstrate its Done In One part processing on the QRX-50MSY and QTE-100MSY multitasking machines. The QRX-50MSY’s combination of milling capability, second turning spindle and y -axis functionality with advanced technology, productivity and value delivers exceptional performance for shops machining small parts such as EV input shafts, mid-shafts, valve fittings and other components exceeding 2 in. dia.

Mazak will pair its QTE-100MSY with a gantry loader at IMTS. The machine sports a second turning spindle, milling capability and y -axis off-center-line machining. Its main spindle features

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a 6 in. chuck and 1.77 in. (45 mm) through hole for efficient processing of a wide range of smaller parts.

At IMTS, the company's Quick Turn 350 multitasking machine will be outfitted with the company's Ez Loader compact, collaborative robot automation system. It uses a cobot arm, vision sensor and dedicated software to safely improve production. *Editor's Note: See additional coverage on page 16.*

mazak.com

230-2 accuracy is provided. A choice of milling heads is offered on the machine to suit a variety of applications.

Optional equipment includes touch probe, tool measuring system, work area cover, tool changer, chip conveyor, mist/dust extraction system, minimum quantity lubrication and a vacuum system. The machine to be displayed at IMTS also features an ultrasonic system for cutting aerospace insulation.

zimmermann-inc.com

Platinum Tooling

WILL DISPLAY PRODUCTS TO ENHANCE SWISS CNC LATHES

At IMTS 2026, Booth #432201, Platinum Tooling Technologies, Inc., the exclusive importer of Heimatec live tools and angle heads, will display a variety of complementary products designed to

Zimmermann

DISPLAYS ADDITION TO ITS PORTAL MILLING LINE



Zimmermann will feature a 5-axis portal milling machine for lighter weight machining applications aimed at large structures at Booth #339336.

With FZU22, Zimmermann adds a machine that's capable of machining various workpiece shapes, sizes, and materials. Aluminum, plastic, wood and other substrates can be processed, as well as finishing carbon fiber reinforced and other composite materials. The overhead gantry provides precise production of models and molded parts. A standard machine includes a tool changer for 24 tools and a CNC from Siemens or Heidenhain for full motion control and tracking, while a specially developed 5-axis milling head with a 15 kW spindle can mill complex contours and tight pockets in large molds.

The FZU22 boasts a substantial working range, from 71 in. to 98 in. in the x-axis, 118 in. to 138 in. in the y-axis, and 49 in. in the z-axis. A feed rate of 2,756 ipm in the x- and y-axes is standard while the acceleration on the machine is max. 118 in/sec² to 197 in/sec². With a compact footprint of 11 ft. x 15 ft., the machine fits in any small space available in a shop with minimal foundation requirements. ISO

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CLP-35SF Gear Tester

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Fax: 1-586-329-3965

rodney.soenen@involutegearmachine.com

enhance the capabilities of Swiss CNC lathes, including such popular brands as Citizen, Star and Tsugami. In addition to the live tooling and angle heads, Platinum will display speed multipliers in gear ratios of 1:2, 1:3 and 1:4 with max speeds to 48,000 rpm to significantly boost production in the busy shop. Live and static tools and speeders for Swiss machines are in stock at Platinum Tooling in Chicago and many supply chain outlets to serve the North American machine tool market.

Swiss-type tooling from Platinum is manufactured with high spindle bearing technology and ground gear components. Tooling includes straight and 90-degree heads, woodruff key cutters, thread whirling tools, multiple spindle heads and adapters.

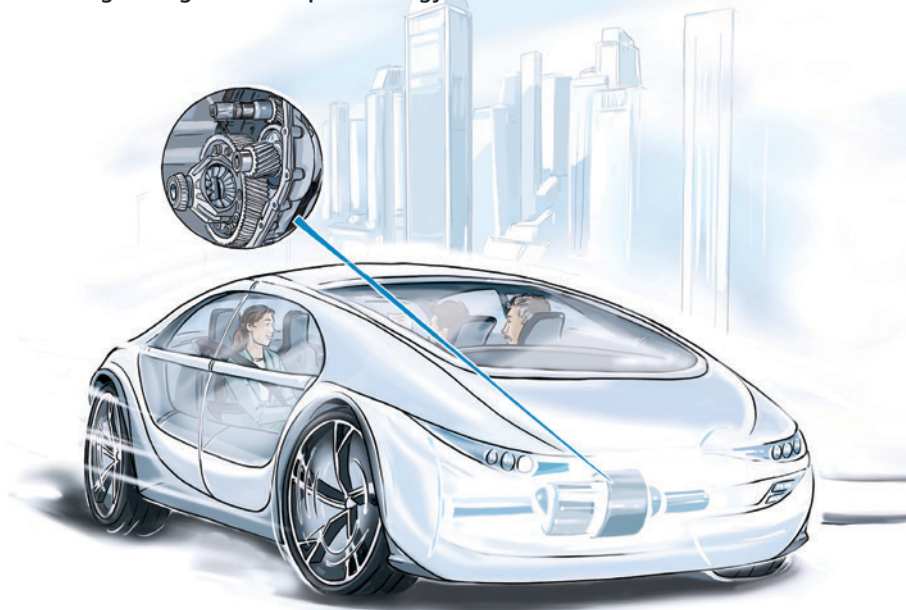
With the growth of medical and other high-precision, high-volume manufacturing with the use of Swiss-style machines, speed increasers have become vital to this segment of the machine tool industry. As components

get smaller, the cutting tools required also get smaller, necessitating higher rpm to provide maximum performance. Heimatec speeders for Citizen, Tsugami and Star machines are in stock at Platinum Tooling. These speeders are known for the stability and the enhancement of precision cutting tool performance.



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In addition, the company offers Hommel + Keller Quick knurling and marking tools. Cut and form knurling tools are used for applications such as barbells, hand tools and dental instruments. Marking tools assist with part identification and traceability, critical in many industries today. Part numbers, logos and other production data can be marked reliably in less time than laser marking.

Components such as collets and guide bushings are also available for numerous Swiss machine brands and various material processing, under the Tecnicrafts and Dunner brand names, also carried in stock by Platinum Tooling.

platinumtooling.com

Sandvik Coromant

HIGHLIGHTS END-TO-END MACHINING SOLUTIONS AND EXPERTISE

Sandvik Coromant will highlight its comprehensive approach to solving real-world challenges in machining, metalworking and production at IMTS 2026.

Exhibiting at Booth #338348 in South Hall, Level 3, Sandvik Coromant invites attendees to come with their toughest shop problems and leave with

a solution. Visitors will have access to a deep roster of consultants ready to collaborate on specific manufacturing challenges, ranging from design and process planning to production logistics and machining. They can also receive expert support for topics on machine investment, tool selection, process evaluation, cutting strategies, CAM programming, verification and more.

“Gaining an edge in today’s fast-paced shop environment involves more than just the tools you use; it’s about how your entire process works together from beginning to end,” said Veronica Messersmith, Americas president for Sandvik Coromant. “At IMTS, we’re bringing together our full offer—tooling, digital solutions and expertise—into a collaborative space designed for problem-solving, with a focus on manufacturing wellness to help shops build more resilient, efficient operations across the entire value chain.”



Booth visitors can also explore the broad Sandvik Coromant offering through advanced digital experiences. Using an interactive 3D component simulation table, attendees can learn about machining a variety of components from industries such as aerospace, automotive and energy. Showcasing models like an aero engine casing and a fracking block, the platform displays the component, machine programming and setup tips, tooling selection and application videos for each stage of the machining process. In addition, visitors can get a firsthand look at the latest Sandvik Coromant milling, drilling and turning tools

running in partner booths throughout the hall.

The company is also featuring an immersive virtual reality kiosk offering an exclusive tour of the Sandvik Coromant training center and production facility in Mebane, NC. The interactive experience provides a behind-the-scenes look at how the company tests and applies its own tooling, technology and data-driven approach to achieve manufacturing excellence.

As a hub for learning and collaboration, the Sandvik Coromant booth also highlights Manufacturing Wellness, a concept that considers a holistic view of eight habits—from developing people to using technology and eliminating waste—to improve operations. Sandvik Coromant’s “yellow coat” specialists will provide Manufacturing Wellness assessments and scorecards to help visitors gauge their progress toward more efficient production.

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Complexity Without Compromise

Five-axis machining provides high-speed, high-accuracy for the future of part design

Matthew Jaster, Director, Editorial Content

There's a growing list of challenges facing manufacturers today that goes beyond supply chain, energy and workforce obstacles. Many machinists and engineers cite customer requests for shorter lead times, tighter tolerances and improved part quality as imperative to future success. Unfortunately, many standard machine tools lack the necessary functions and capabilities to overcome uneven tool paths, complex surface geometries and long machining times.

Here's where 5-axis machining provides an excellent option for complex parts. When a part requires multiple setups machine operators prefer less handling, fewer errors and better surface finishes. Quality and efficiency are also critical to get the best return on your machine investment. As gear manufacturers continue to diversify their product portfolios, there's a growing need for precision that outperforms traditional machining methods. Here's a rundown of some reliable and efficient 5-axis machine tools today. Some are new in 2026; others have been around for years and come highly recommended by machinists for their reliability and production capabilities.

DMG Mori Introduces Enhanced DMU 65 H monoBLOCK2



Applications for the DMU 65 H monoBLOCK2 include workpieces on high clamping towers, complex 5-axis geometries, and reliable deep hole drilling. (Image: DMG Mori)

Horizontal machining centers impress with their performance, stability, and process reliability—reasons for the continued popularity of the DMU H series from DMG Mori. The machine tool manufacturer presented the enhanced machine at its open house in Pfronten, Germany earlier this year. The powerful, efficient, and universal 5-axis horizontal machining center

creates all the conditions necessary for successful Machining Transformation (MX). Process integration, flexible automation solutions, and digital tools ensure efficient and resource-saving production. This benefits industries such as die and mold, aerospace, and general mechanical engineering applications.

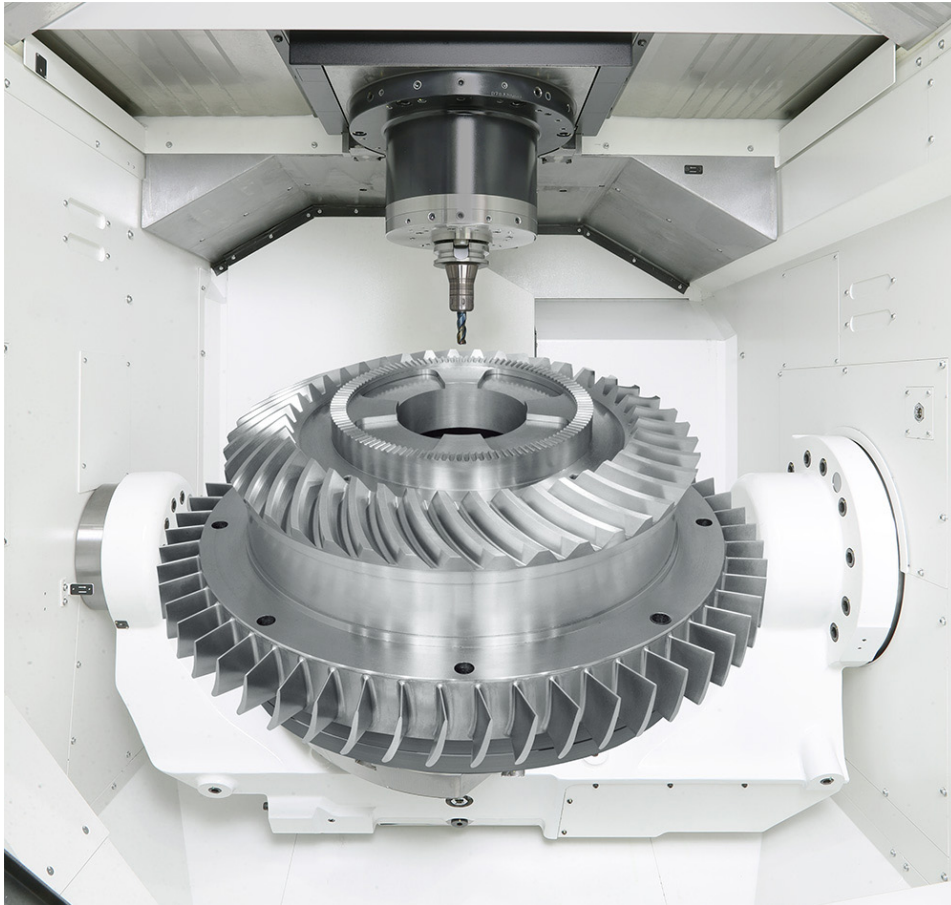
The rigid cast iron machine bed with 3-point support and three guides in the x -axis provides the DMU 65 H monoBLOCK 2 with an optimal basis for powerful heavy-duty machining. Together with the thermos-symmetrical design and extensive cooling measures, it achieves a continuous accuracy of up to $5\ \mu\text{m}$ even in the standard version. The robust moving column design with low moving masses ensures high dynamics with acceleration of up to $8.5\ \text{m/s}^2$. The large working area allows for a wide range of machining operations. The application spectrum includes workpieces on high clamping towers, complex 5-axis geometries, and reliable deep hole drilling. The E-Pallet further supports the variety of machining operations. The smart interface provides power for fully electric clamping devices and sensors as well as hydraulics and pneumatics. This upgrades the classic machine table and enables the use of smart clamping devices and intelligent software. Due to the horizontal design, machining benefits from optimal chip removal and good heat dissipation, resulting in maximum process reliability.

The double-sided swivel rotary table is designed for components up to $\varnothing 840 \times 770\ \text{mm}$ and 600 kg and allows flexible machining of workpieces—up to 5-in-1 process integration of milling, turning, grinding, measuring, and gear cutting. The wheel magazine has space for up to 453 tools with a maximum length of 650 mm, a diameter of $\varnothing 280\ \text{mm}$, and a mass of 22 kg. The spindle range offers variants up to 30,000 rpm as well as options for powerful machining with 288 Nm and HSK-A 100 tool holders.

us.dmgmori.com

Mazak Offers Latest Variaxis Machine Models

The next generation Variaxis i-700 NEO Vertical Machining Center provides advanced multi-surface, 5-axis machining for parts with complex profiled surfaces. The machine handles parts up to 33.46 in. dia. and 19.69 in. high. A 40-taper spindle with compact nose design increases z -axis stroke while a rotary/tilt table with roller gear cam technology eliminates backlash.



The Variaxis series offers a wide range of automation and tooling options. (Image: Mazak)

The Variaxis i NEO series uses AI to detect milling spindle vibration and adjust machining conditions automatically to produce unsurpassed surface finishes and high productivity. With the AI, even a less-skilled operator can make adjustments easily in a short time.

Setup can optionally be supported with hydraulic fixtures that enable clamping/unclamping of the workpiece. The number of ports can be up to nine ports for the single table version, four ports inside the machine and eight ports on the workpiece setup station for the two-pallet changer version. Pneumatic fixtures are also available.

The pallet changer option provides rapid workpiece change-over for continuous machining operation. To achieve higher productivity, the next workpiece can be set up while the current operation is being machined. The two-pallet changer offers a compact design and is suitable for mass production.

Two Variaxis machine models, the Variaxis C-700 and Variaxis i-800T, will represent Mazak's vertical machining center technology at IMTS 2026. Both machines are solid first steps into 5-axis machining for shops and are highly capable machines with versatile sheet-metal enclosures ready for a comprehensive range of automation solutions. Mazak offers several spindle options for the machines to help shops find the ideal balance of speed and power. Furthermore, the "T" model of the Variaxis i-Series machines features turning capability on their tilt/rotary table.



The new Variaxis i-800 Neo offers faster machining cycle times, expanded workpiece capacities and more automation options. (Image: Mazak)

The new Variaxis i-800 Neo offers faster machining cycle times, expanded workpiece capacities and more automation options. When it comes to speed, the machine now achieves rapid traverse rates of 1,890 ipm (48 m/m) in the *x*, *y* and *z* axes that contribute significantly to reduced cycle times.

In addition to speed, the Variaxis i-800 Neo boasts an all new two-pallet changer that incorporates a four-cone clamping system for higher precision and speed. Beyond that, the Mazak Multi-Pallet Pool (MPP) compact multiple pallet stocker system and modular Mazak Palletech System both take the machine to entirely new levels of automation flexibility.

New with the Variaxis i-800 Neo is the Mazatrol SmoothAi CNC, with *Smooth Project Manager Gateway* software as an available option. In conjunction with external CAM software such as *Autodesk's Fusion 360*, this software provides access to internal machine data, which enables the *Fusion 360* programmer to query the machine for machine models, current tooling configuration, offset data, stroke limits and many other configuration parameters. This information can then be used at the CAM workstation to create more accurate machine programs configured to the limits and capabilities of the actual machine.

mazak.com

Heavy-Duty Cutting with the Okuma MU-5000V

The Okuma Universal Center MU-V series provides the power of process-intensive machining and high-speed,

high-accuracy cutting through the combination of turning and 5-axis multitasking machining. The fast yet powerful trunnion table allows simultaneous 5-axis machining and one-chuck multi-sided machining of complex shapes. This machine tool is ideal for die and mold shops and highly complex aerospace components.

The MU-5000V 5-axis vertical machining center achieves high efficiency and high productivity in 5-axis, multi-sided machining. This CNC vertical machining center's highly rigid and accurate double-column structure and low center of gravity in workpiece movement (trunnion table) enable both heavy-duty cutting and high-speed finishing.

The MU-5000V can easily be adapted for use with APC, multiple ATC, automation, or FMS without compromising operability because this expansion takes place at the back of the machine. Built on a thermo-friendly structure, this machine will perform consistently from the first part to the last, regardless of warm-up time or ambient temperature. The larger MU-6300V of this series was honored with several awards.

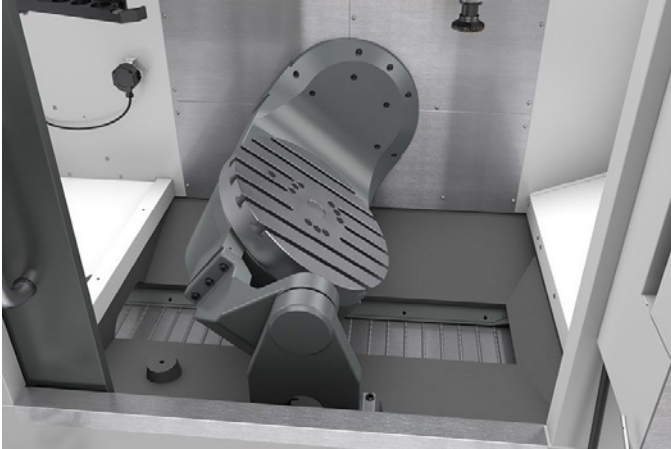
With the option to factory integrate any automatic pallet changer to these machining centers, this automation category delivers flexibility and productivity with as many pallets as you need. The pallet changer enables continuous production and spindle uptime with automated loading and unloading, increased hours of unattended machining, storage areas for finished parts and the pallet changers are supported by Okuma Factory Automation 24/7/365.

okuma.com



The MU-5000V 5-axis vertical machining center achieves high efficiency and high productivity in 5-axis, multi-sided machining. (Image: Okuma)

The Haas UMC-750 Increases Accuracy and Part Capacity



The trunnion provides +120 and -35 degrees of tilt and 360 degrees of rotation to provide excellent tool clearance and large part capacity. (Image: Haas)

5-axis machining is an effective means to reduce setups and increase accuracy for multi-sided and complex parts. The Haas UMC Series universal machining centers are cost-effective solutions for 3+2 machining and simultaneous 5-axis machining. The UMC-750 has an integrated dual-axis trunnion table with a 500 mm diameter platter that features standard T-slots and a precision pilot bore for fixturing versatility. The trunnion

provides +120 and -35 degrees of tilt and 360 degrees of rotation to provide excellent tool clearance and large part capacity.

The Haas Pallet Pool family increases spindle run time, and allows for unattended automation, so machinists can run more parts. Offering up to 20+1 pallets, the pallet pool systems boost throughput and are available on a wide range of Haas machining centers.

The Haas-designed 120+1 side mount tool changer holds 120 tools, plus one in the spindle, providing plenty of locations for back-up tooling, or setting up tools for multiple jobs. It is the perfect choice for high-volume production, or for unattended, lights-out operation with a pallet pool, cobot, or robot. A remote load station with automatic lockout function allows tool inspection, loading, and unloading while the machine is cutting, simplifying tool maintenance, and eliminating the need to load tools through the spindle.

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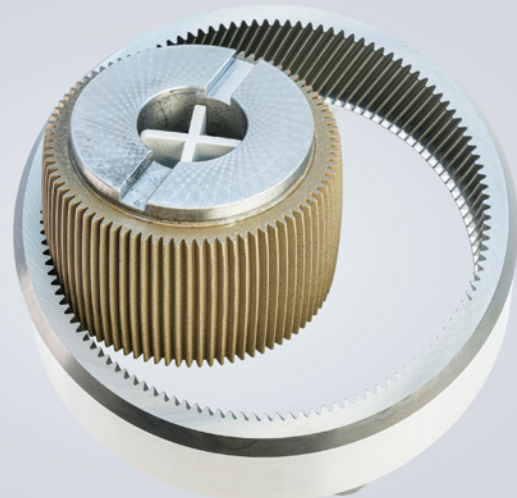
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Skiving's Motion, Grinding's Finish

A new process runs skiving kinematics with an abrasive CBN tool, targeting a long-standing gap in internal-gear finishing

Aaron Fagan, Senior Editor



Hard finishing, the accuracy-restoring operation that follows heat treatment, is for external gears a crowded field: generating grinding, profile grinding, and gear honing all compete, and the engineer mostly selects among mature options on cost and quality. For internal gears, the choices are far fewer, and they pull in opposite directions. SkiveFinishing, which Liebherr-Verzahntechnik introduced publicly at EMO Hannover in September 2025, is aimed at that shortfall. To understand why it matters, look first at what makes the internal gear the awkward case.

The Dilemma

The difficulty is geometric. An internal gear presents its teeth on the inside of a ring, with concave flank curvature and a bore that limits both the tool's size and how it can approach. The threaded-wheel generating grinding that dominates external-gear finishing depends on a worm-form wheel that will not fit inside most internal gears, so its productivity is largely unavailable here. What remains divides between hard skiving and profile grinding.

Hard skiving sits on the defined-edge side: gear skiving after hardening, with a pinion-shaped cutter ground to a known geometry. It is fast and reaches inside the ring well, but as a defined-edge process on hardened steel, it meets a quality ceiling. Profile grinding sits on the undefined-edge side: an abrasive wheel reaching into the bore to form-grind each flank. It delivers precision, but the small wheel diameter forced by the bore, plus the form-grinding stroke, makes it slow and costly, justified only where quality demands outweigh cycle time, as in high-volume e-Mobility and commercial-vehicle work.

Hybrid Design

SkiveFinishing runs the kinematics of gear skiving but replaces the defined-edge cutter with an electroplated tool carrying cubic boron nitride (CBN). Material comes off by the microcutting action of abrasive grains, as in grinding.

Gear skiving is a continuous generating process: the pinion-type tool and the workpiece rotate in a fixed ratio about axes set at a shaft angle, and the resulting sliding velocity along the tooth does the cutting. The tool feeds axially along the line of contact, removing stock with a single galvanically bonded layer of CBN rather than a sharpened edge. That is the source of the fine surface finish, and the reason for a constraint discussed below.

Why CBN?

Liebherr describes CBN as the second-hardest cutting material after diamond, which invites the question: why not the hardest? The answer is a piece of mate-

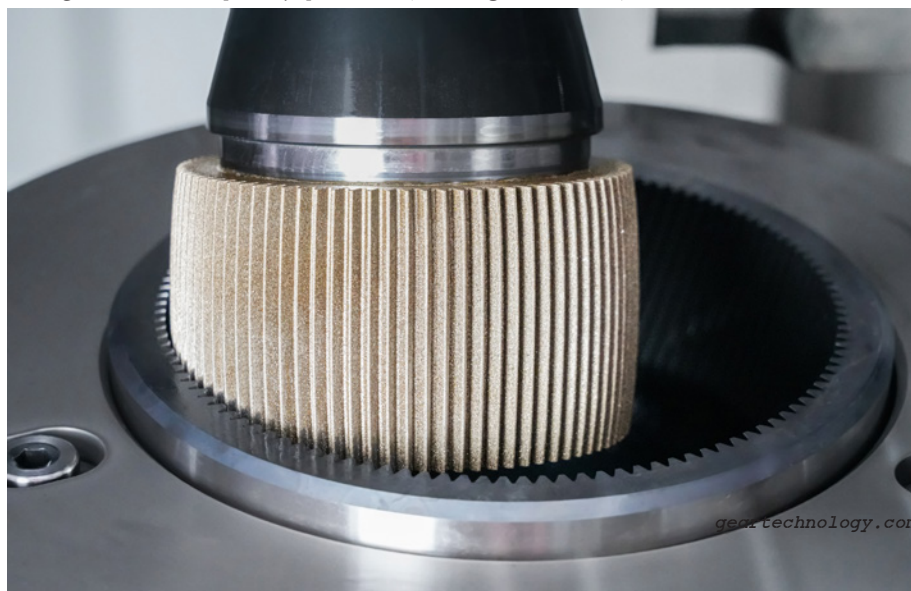
rials engineering that promotional language tends to skip. Diamond is carbon, and at cutting-zone temperatures, carbon diffuses readily into iron, so a diamond tool wears chemically and fast, on ferrous workpieces, whatever its hardness. CBN is chemically stable against iron and holds its hardness when hot, which is why it, not diamond, is the standard superabrasive for hardened steel. The choice is not a compromise on hardness but the right one for the material.

The approach has a longer history than the product. Mehr's own doctorate concerned hard precision machining of gears by gear shaping with diamond-coated tools. SkiveFinishing can be read as that idea carried to internal gears, trading the reciprocating shaping stroke for skiving's continuous kinematics.

The Tool

The electroplated CBN tool is non-dressable, and that single fact shapes the

SkiveFinishing is based on the same kinematics as gear skiving. Non-dressable, electro-plated skiving tool with multiple shift positions. (All images: Liebherr)



process. A grinding wheel can be re-profiled in-house when it loses form; a single plated layer of grit cannot be touched up that way, so when it wears out, the tool goes back to Liebherr's Ettlingen site to be stripped and re-plated.

The design compensates in two ways. The tool has a crowned form and several shift positions across its width; as one wears, it indexes axially to fresh CBN, much as a hob is shifted along its length. And because that form is fixed, the flank modifications normally dressed into a grinding wheel, such as tip relief, profile crowning, and lead, are built into the tool instead and imparted directly to the part, even on internal gears that would otherwise require profile grinding.

The trade runs both ways. Taking the dressing step out of the cell simplifies operation and suits high volume, but it ties the user to the supplier for re-plating, with the turnaround that implies, and fixes the flank geometry in the tool rather than at the machine. Whether that favors a given shop depends on its parts, its volumes, and how settled its flank specifications are.

Implications

In initial trials on its LK-series skiving machines (designated by workpiece-diameter range, LK 180–280 and LK 300–500), Liebherr reports gear quality within ISO 1328-1 Class 5 and surface roughness of $R_a < 0.4 \mu\text{m}$, figures Mehr presents in his Emerging Technology webinar (see sidebar). Class 5 places the accuracy in the range more often associated with ground gears than cut ones.

The process is also credited with raising tooth-flank load capacity through higher residual compressive stress. This is plausible: well-controlled CBN machining runs comparatively cool and tends to leave compressive stress, unlike the tensile stress and white-layer risk that accompany grinding burn. A compressive surface benefits bending and contact fatigue, so the claim is reasonable, though, as with the accuracy figures, the data come from Liebherr.

Against its incumbents, the picture is straightforward: higher quality and finish than hard skiving, from the abrasive mechanism and the residual-stress benefit; greater productivity than profile grinding, from the continuous kinematics and the ability to carry modifications

Watch the Full Presentation

Dr.-Ing. Andreas Mehr, Head of Technology Development, Liebherr-Verzahntechnik GmbH, lays out SkiveFinishing in greater depth in an on-demand webinar from MPMA's Emerging Technology series. "SkiveFinishing—Introduction of a New Hard Finishing Process for Internal Gears" walks through the conventional options for hard-finishing internal gears, the process principle, and the machining results cited here, then closes with a side-by-side comparison against hard skiving and CBN profile grinding.

Free with registration at: motionpower.org/skivefinishing-introduction-of-a-new-hard-finishing-process-for-internal-gears-2

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in the tool. The applications Liebherr names, aerospace, e-Mobility, and the planetary gearing of trucks and tractors, where less heat-treat distortion allows smaller, lighter gearboxes at equal power, are where that combination pays off.

What Remains

For a process this new, the open questions are the ones any specifying engineer will ask, and public material does not yet answer them: independent quality and surface data; comparative cycle-time and cost-per-part studies against profile grinding on representative parts; and the practical

envelope, namely module range, minimum bore and gear size, and how the non-dressable tool performs across a varied part mix.

None of this detracts from the promise of the idea itself. If the reported quality holds up under independent scrutiny and the economics work at volume, SkiveFinishing closes a gap in internal-gear hard finishing that has been open for a long time. That is reason enough to watch this technology closely and to follow the data.

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Beyond the Involute

Tooth forms tuned for EV power density, and a production suite that now spans compound planetary design, linked skiving-honing simulation, and on-machine measurement

Mike Fish, Director, Dontyne Gears



An in-house back-to-back rig built for non-involute gears. (All images: Dontyne)

Editor's Note: Dontyne Gears and Dontyne Systems share Booth 237118 (North Building, Level 3) at IMTS 2026. Dontyne Gears reports on its non-involute gear testing for EV and other automotive applications; Dontyne Systems introduces the GPS 5.9 software series. The *Gear Production Suite (GPS)* features in both.

Non-Involute Gears for EV Applications

Dontyne has invited several automotive companies to present applications to assess the suitability of non-involute technology. There are not always advantages over involute designs, but EV applications seem especially suited, and 15–25 percent power-density gains are typical. There are also consequential benefits,

such as reduced gearbox housing and transport costs. One client's request for an existing design analysis showed that it was also suited to their final drive design despite the deflection during operation. Dontyne has designed and manufactured its own back-to-back rig to test this application. The British Gear Association has funded further testing and a more detailed report on this extend testing is available through them.

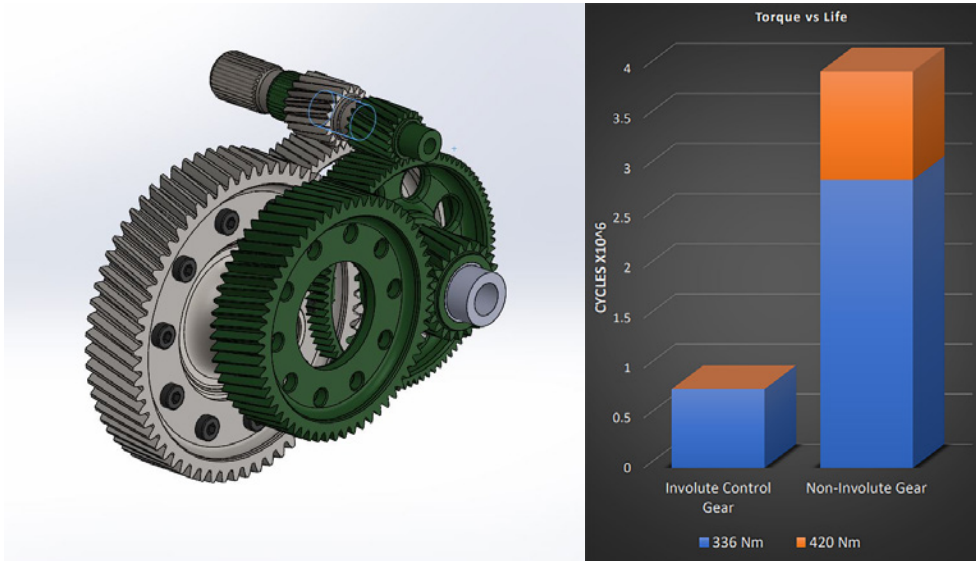


Figure 1—Comparing a typical design of EV using involute (gray) and non-involute (green) and the results of durability testing for a final drive design.

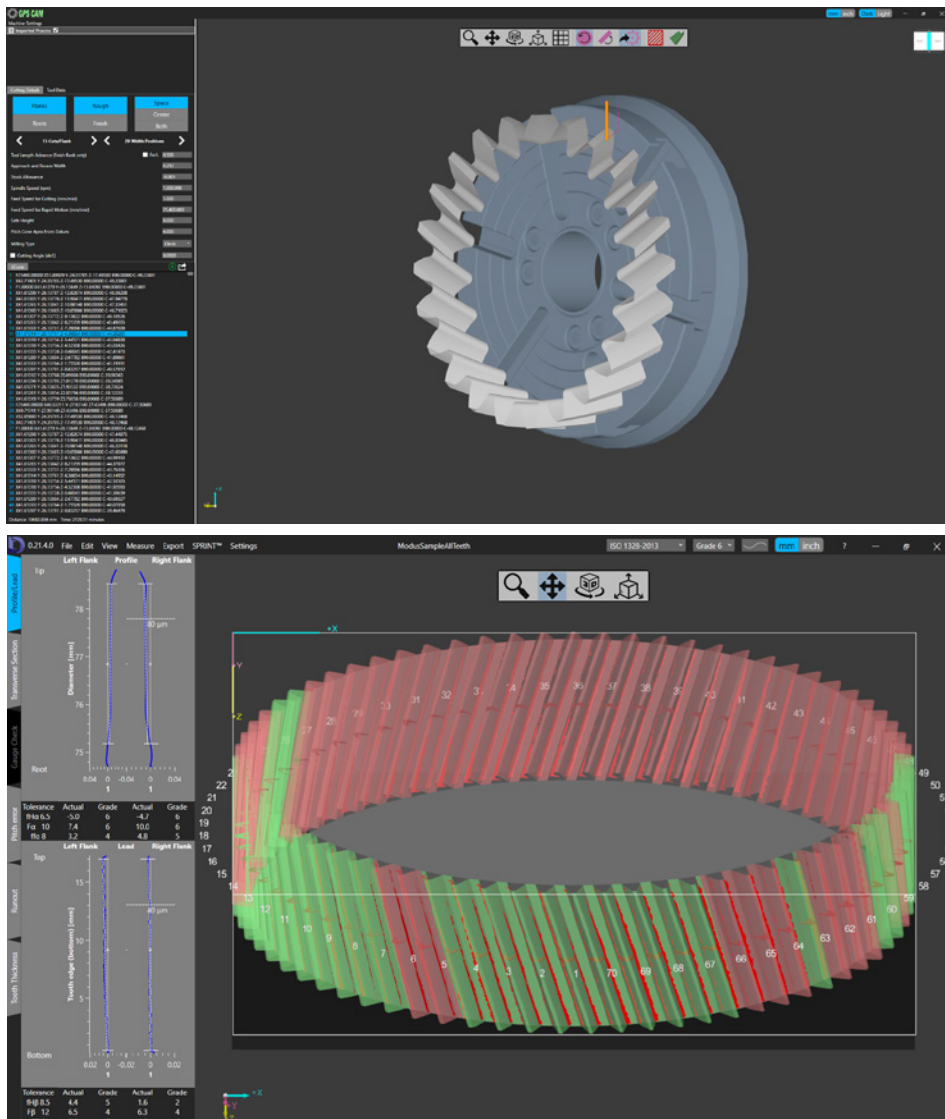


Figure 2—A function has been added to GPS to generate G-Code for gear teeth (top). The DOMMS software (bottom) for evaluating gear measurements on inspection devices includes traditional and modern evaluation displays and can be used with 5-Axis CNC Machine production.

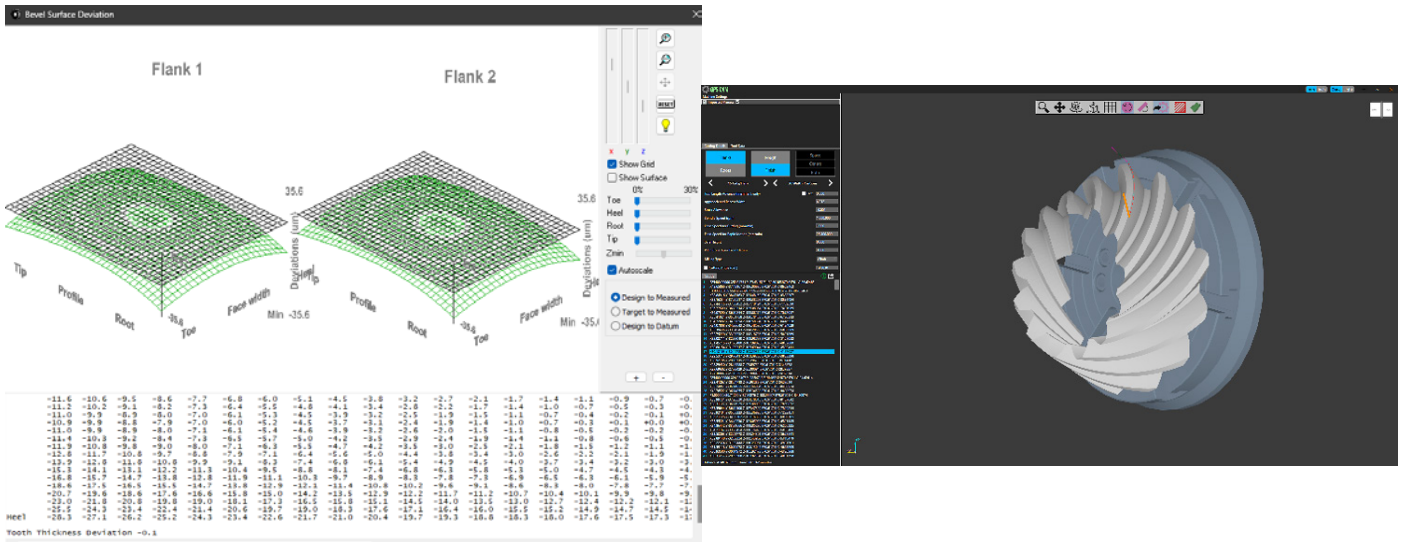


Figure 3—Measured data can be utilized in GPS to migrate gear production to 5-axis CNC platforms.

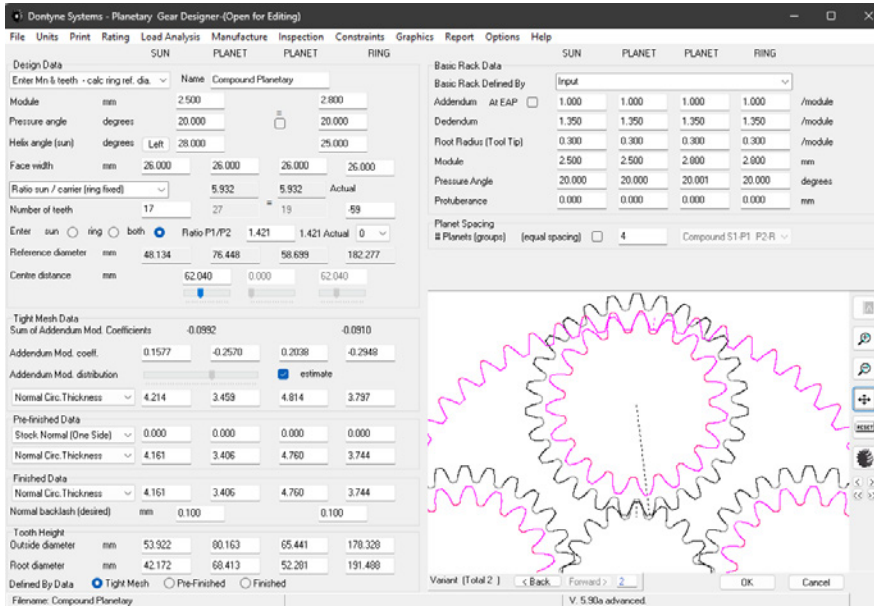


Figure 4—Stepped (or compound) planetary design added to GPS.

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The test program has utilized some of the latest developments in *Gear Production Suite (GPS)*, such as *GPS CAM*, to enable in-house manufacture of test and slave gears on our 5-axis CNC machine, even when hardened. Dontyne Systems has developed a software program, *Dontyne On Machine Measuring System (DOMMS)*, to enable gear evaluation on CMM or other inspection hardware. This also has a link to *SPRINT* from Renishaw plc for measurement directly on machine tools. As well as the traditional evaluation plots, there

are several displays to utilize the possibilities now available in CAD systems.

GPS can use measurement data to correct errors in production, such as deflection, wear, and thermal changes. Measured data can be utilized in *GPS* to migrate gear production to 5-axis CNC platforms, which enables companies to produce complex gear forms, such as hypoids, in-house. This has been taken up by motorsport and aerospace, and also by Tier 1 to produce test gears without utilizing volume production platforms.

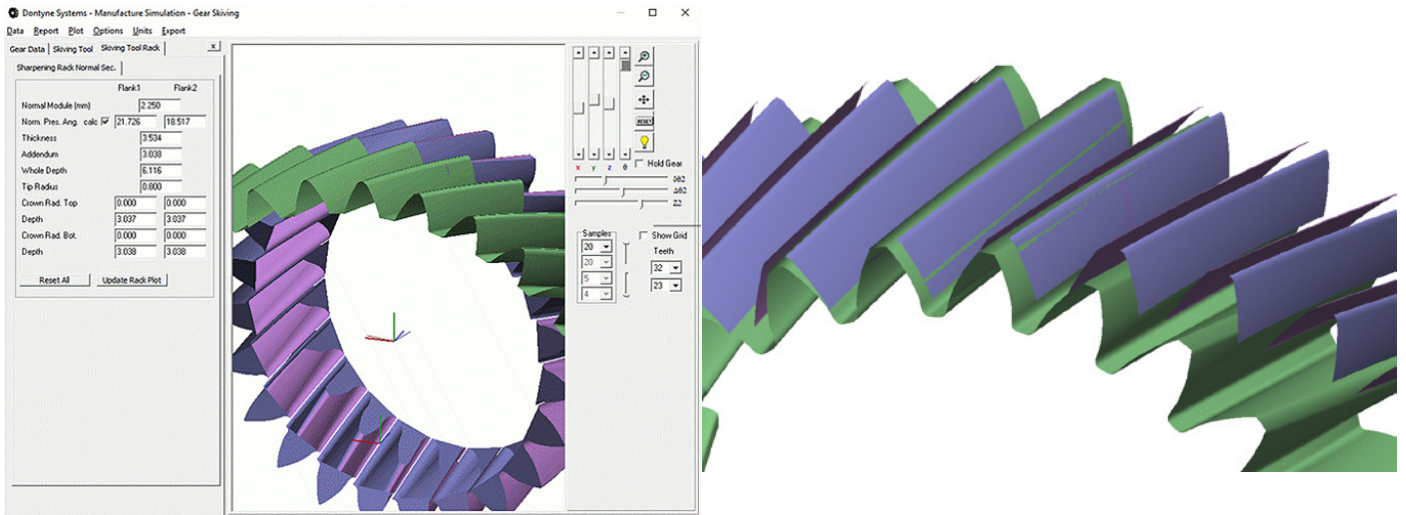


Figure 5—Skiving and honing simulations linked in GPS.

Compound Planetaries and Linked Simulation

Following a large amount of new development over several releases of the *GPS 5.8* series in the last two years, this year will see the *GPS 5.9* series introduced. The most significant addition is stepped, or compound, planetary design.

The *Machine Centre* module supports tool design and gear production. The simulations for skiving and honing were improved in *GPS 5.8* but are now linked. The results of the

skiving simulation, when considered as a pre-finishing process, can now be imported into the honing simulation. The fully finished profile can be defined by the honing simulation for a more accurate picture of the finished gear surface.

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Next-Generation Bevel Gear Metrology

Unified surface and geometry analysis in a single inspection cycle

Mark E. Cowan, Gleason Metrology Systems Corporation

Modern bevel gear manufacturing increasingly requires inspection systems that go beyond traditional flank form evaluation. Surface-related characteristics—particularly waviness and roughness—play a critical role in defining gear performance under load, directly influencing noise behavior, efficiency, and fatigue life.

Conventional measurement of these parameters typically relies on specialized surface roughness instruments when high-resolution roughness evaluation is required. However, this approach often introduces additional complexity, longer inspection times, and the need for separate measurement setups.

This article presents new measurement capabilities that enable accurate and efficient assessment of waviness and form using industry-standard spherical probe tips. By eliminating the need for dedicated surface roughness hardware, these advancements streamline the inspection process while maintaining high measurement fidelity, ultimately supporting faster diagnostics and improved manufacturing efficiency.

Separation of Form Error, Waviness, and Surface Roughness

A fundamental requirement of surface characterization is the clear separation of form error, waviness, and surface roughness. International standards define a

cutoff wavelength—typically 0.8 mm (λ_c)—to distinguish between these components. Deviations with wavelengths exceeding this cutoff are classified as waviness, while shorter wavelength deviations are attributed to surface roughness. Accurate surface roughness evaluation, therefore, requires the systematic removal of both form and waviness components through appropriate filtering techniques.

Limitations of Roughness-Derived Waviness

Surface roughness measurement requires a significantly higher sampling density, which directly impacts scanning speed due to limitations in data acquisition rates (samples per second). While surface roughness analysis typically involves the collection of many thousands of data points, waviness evaluation can be performed with substantially fewer samples.

As a result, the increased data density required for roughness measurements can limit the achievable scan length and reduce overall inspection efficiency.

In addition to throughput limitations, conventional surface roughness measurement systems involve higher hardware costs. The extremely fine stylus tips required for high-resolution roughness evaluation are considerably more expensive and inherently fragile. These probes are highly susceptible to damage if not handled carefully (see Figure 2), leading to increased maintenance requirements and potential downtime. Furthermore, such systems rely on dedicated electronics optimized for high-frequency signal acquisition, adding complexity to the measurement setup.

In contrast, waviness evaluation does not require the same level of resolution or specialized hardware. By leveraging industry-standard spherical probe

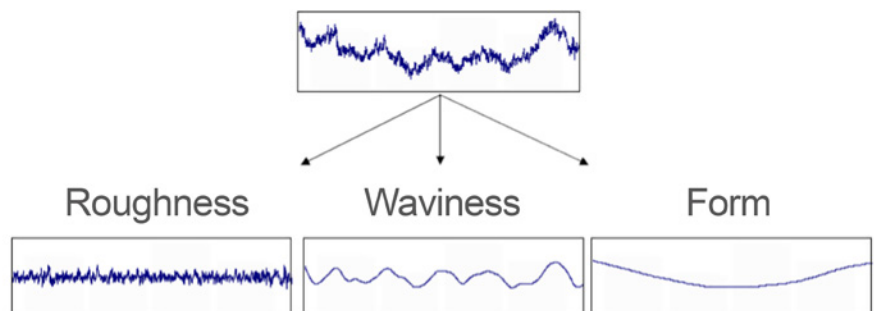


Figure 1—Conceptually illustrates the separation using filtered surface profiles. (All images: Gleason Corporation)



Figure 2—Skidless surface finish probe.

tips—commonly used for form measurement—it is possible to accurately capture waviness characteristics without the need for dedicated surface roughness instrumentation. This approach significantly reduces system cost and complexity while enabling longer scan lengths and faster measurement cycles. As a result, waviness analysis using spherical probes provides a practical and efficient solution for identifying surface-related deviations that influence noise, efficiency, and durability in bevel gears.

Surface Roughness Measurement

Surface roughness measurements are typically performed using skidless probes to preserve long-wavelength surface information (see Figure 3). Automatic stylus orientation is employed to maintain perpendicular contact with the tooth flank throughout the scan, ensuring accurate data acquisition across the profile. In contrast, skidded probes are not suitable for waviness extraction, as the skid mechanically filters out longer wavelength deviations. However, skidded probes do offer certain practical advantages—such as robustness and ease of implementation—and are therefore utilized in some large-scale gear inspection systems, including those developed by Gleason.

Given these limitations, dedicated waviness evaluation methods provide a more reliable and consistent solution. By avoiding the constraints of skidded probe designs and eliminating the need for high-resolution roughness

instrumentation, waviness-focused measurement approaches—particularly those based on spherical probe tips—enable efficient, repeatable characterization of surface deviations that are critical to gear performance.

Bevel Gear Waviness Analysis

Recent developments by Gleason Metrology Systems enable waviness testing using a standard spherical ruby stylus without the need for dedicated surface roughness hardware (typically 1–2 mm tip diameter). For cutoff wavelengths above 0.8 mm, a reduced sampling density is sufficient, allowing for significantly faster scans and reduced measurement cycle times.

Measurements are performed along the pressure angle direction, which is particularly well suited for detecting the predominant waviness patterns on the tooth flank. This orientation aligns with the typical surface lay produced by common bevel gear manufacturing processes, improving the sensitivity and relevance of the measurement results.

Advanced mathematical spline fitting algorithms are employed to effectively increase the nominal XYZ point density of the measured surface. This enables high-resolution waviness characterization while utilizing the standard 9×5 flank form measurement grid typically generated by bevel gear design software.

The required increase in data density for waviness evaluation is achieved dynamically during the measurement cycle, while preserving the original

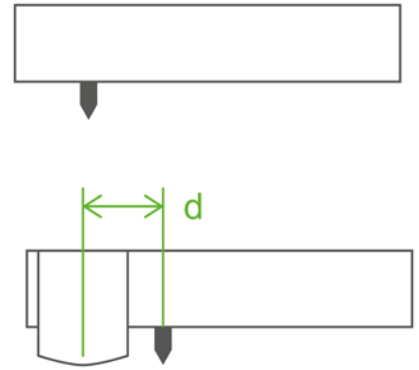


Figure 3—Skidless versus skidded probe.

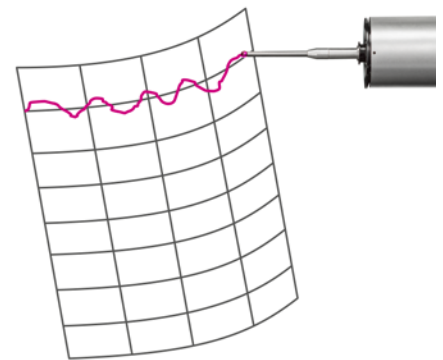


Figure 4—Illustrates waviness along the tooth depth.

flank form results that are transmitted to machine correction software. This approach eliminates the need to create separate part programs with finer flank form grids solely for waviness analysis. Furthermore, it allows waviness evaluation to be seamlessly integrated into the standard inspection process without impacting existing correction workflows or requiring additional measurement passes.

Software Implementation and Programming

Waviness analysis is fully integrated into the *GAMA* software environment, providing a flexible and user-friendly interface for evaluation. Operators can select individual or multiple grid columns, apply averaging functions, define independent tolerance limits for drive and coast flanks, and choose from multiple filtering strategies, including Gaussian and form-following methods, to tailor the analysis to specific application requirements.

All bevel gear measurements—including index, flank form, tip and root depth, and waviness—are completed within a single automated measurement cycle without the need for operator intervention. This integrated approach ensures consistent results, reduces inspection time, and minimizes the potential for user-induced variability, while supporting efficient and comprehensive gear quality assessment.

This enhanced visualization and evaluation capability allows operators and engineers to quickly interpret surface behavior, identify recurring patterns, and take targeted corrective actions, further improving process control and gear quality.

Advanced Waviness Charting

New charting functionality enables the visualization of multiple waviness traces for each tooth and flank, supporting rapid identification of systematic and localized deviations. Key waviness parameters— W_a (arithmetic mean waviness), W_c (maximum peak-to-valley height), and W_t (total waviness height)—are calculated for each trace and automatically compared against user-defined tolerance limits.

Enhanced Bevel Gear Charting

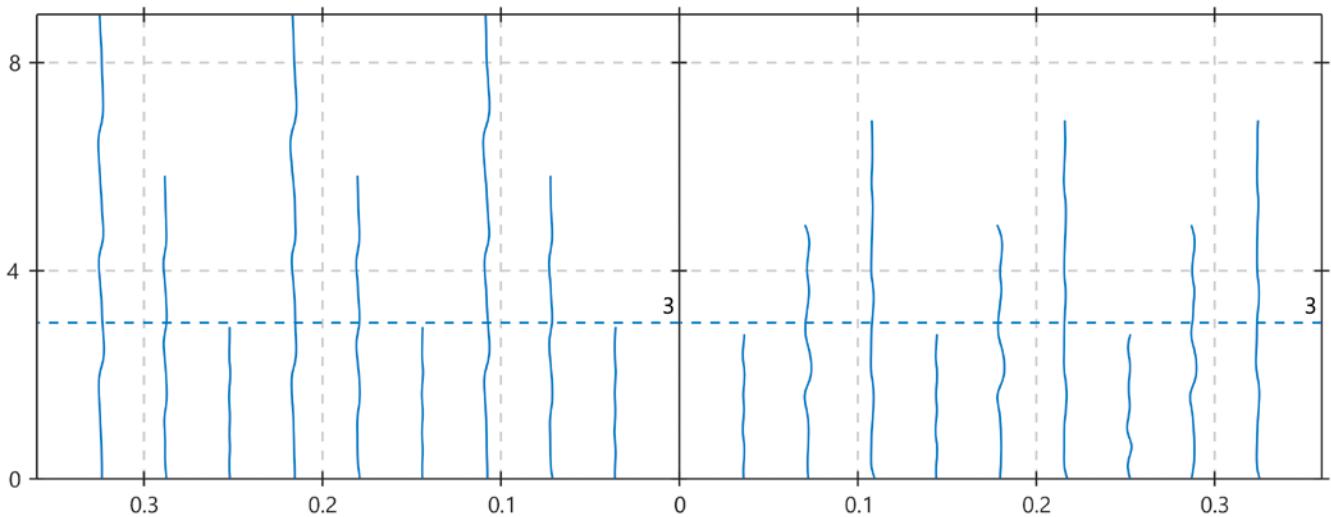
A new portrait-style gear chart consolidates deviation data, surface quality metrics, and key geometric characteristics into a single comprehensive report, enabling more efficient analysis and interpretation (see Figure 8).

In addition, a new bevel flank Form analysis has been developed to evaluate form deviations on a per-column basis along the flank form grid. This analysis incorporates the removal of longer-wavelength form elements—such as crowning (see Figure 7)—through second-order polynomial fitting. By filtering out these intentional



Figure 5—Shows an example of waviness programming within the GAMA interface.

Part Number	GMS Pinion1	Operator	M E Cowan	Z	10	Mounting Distance	116.0000 (mm)
Part Name	Bevel	Date		Teeth Measured	1 2 3	Traces Per Tooth	1
Part Revision		Time		Waviness Filter Cutoff	0.80 (mm)	Columns (Toe/Middle/Heel)	3/5/8
Serial #	3 teeth flank-waviness 3locs	GMS Model	300GMSL	Filter Tension Type	Form Follow	Filter Discard	Default
		GMS Serial #	7418	Probe Name	SN7418 xPlus 2.0mm		
Process		Part Type	BEVEL	Customer		Job Number	
Value Units	(μ m)						



Tol	Mean	7-3-Pa-F1	7-2-Pa-F1	7-1-Pa-F1	4-3-Pa-F1	4-2-Pa-F1	4-1-Pa-F1	1-3-Pa-F1	1-2-Pa-F1	1-1-Pa-F1	Tooth-Trace	1-1-Pa-F2	1-2-Pa-F2	1-3-Pa-F2	4-1-Pa-F2	4-2-Pa-F2	4-3-Pa-F2	7-1-Pa-F2	7-2-Pa-F2	7-3-Pa-F2	Mean	Tol
4.00	0.44	0.72	0.42	0.12	0.70	0.47	0.15	0.74	0.42	0.19	W_a	0.22	0.67	0.35	0.19	0.71	0.35	0.44	0.65	0.37	0.44	5.00
2.00	0.52	0.85	0.50	0.15	0.84	0.54	0.18	0.90	0.49	0.21	W_c	0.26	0.88	0.44	0.22	0.94	0.42	0.55	0.81	0.46	0.55	1.00
3.00	1.98	3.25	1.84	0.64	3.32	1.98	0.69	3.50	1.83	0.76	W_t	0.91	3.81	2.30	0.85	3.94	1.99	2.37	3.57	2.10	2.43	4.00

Figure 6—Presents an example waviness chart.

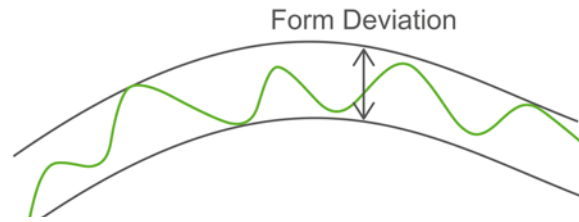
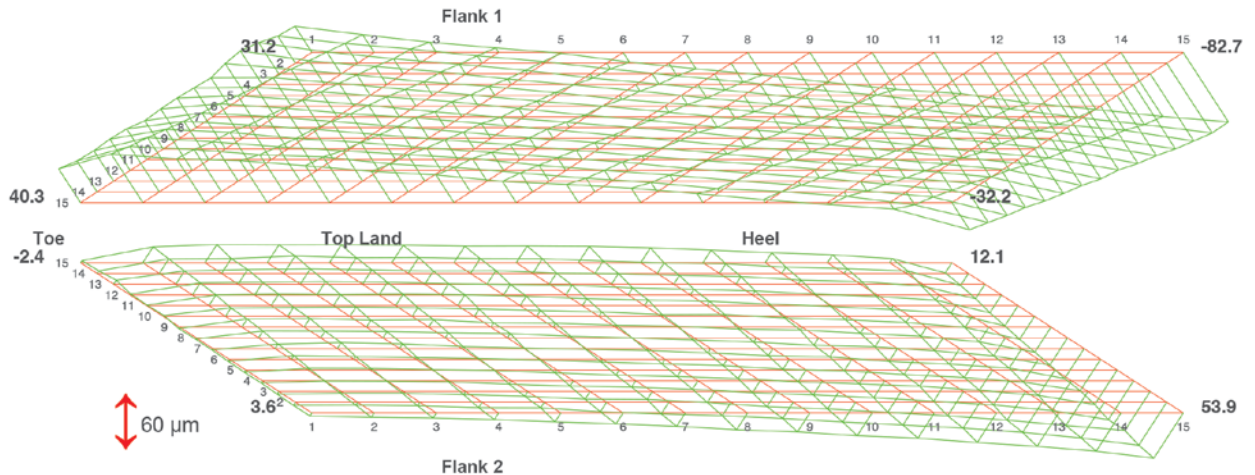


Figure 7—Form deviation analysis at each column of flank form measurements.

Gleason

Part Number	Sample Bevel Gear 1	Operator	M E COWAN	Z:	43	Pd:	175.3 mm
Probe Tip	Bevel-Gear zPlus 2.0mm	Date	5/15/2026	Mn:	4		
Job Number		Time	8:49:00 AM				
Serial Number	Flank-Depth-Waviness	Teeth Measured	Tooth One Only			b:	35.9 mm
Index Location	8-8	Process					
Journal Reference	On Part	Bevel Gear	Machine ID	7418			
Units	(mm)	Gama/Chart Version	3.2.406.0/2.0.164				

v 5.000mm/s () (A, R) nS/d 10/0.4 New Fa/Fb, -||- Form



Parameters	Nominal	Actual	Dev	I. Tol.	u. Tol.	Unit
Sum of Squared		0.00050191				inch^2
Tooth Thickness Var			387.9			μm
Difference Angle	-3°, -25', -43"	-3°, -42', -39"	0°, -16', -57"			D,M,S
Mounting distance		61.2400				mm
Avg Tooth Height-Middle	.0000	9.2377	9.2377	.0000	.0000	mm
Tooth Depth-Middle		511.1	.0	.0	.0	μm
Tip Cone Angle	70°, 33', 49"	70°, 11', 1"	0°, -22', -47"	0°, 0', 0"	0°, 0', 0"	D,M,S
Root Cone Angle	64°, 24', 8"	64°, 29', 34"	0°, 5', 26"	0°, 0', 0"	0°, 0', 0"	D,M,S

Parameters	Flank 1 - convex			Flank 2 - concave			Unit
	Dev.	I. Tol.	u. Tol.	Dev	I. Tol.	u. Tol.	
Pressure Angle Fa	0°, -33', -52"	0°, 0', 0"	0°, 0', 0"	0°, 25', 28"	0°, 0', 0"	0°, 0', 0"	D,M,S
Spiral Angle Fb	0°, 9', 37"	0°, 0', 0"	0°, 0', 0"	0°, 3', 12"	0°, 0', 0"	0°, 0', 0"	D,M,S

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Units
Flank1 ffa Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank1 Form Err	4.0	.7	1.9	.7	1.3	2.2	.7	.9	.6	.3	1.8	2.2	.3	1.6	5.5	μm
Flank2 ffa Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank2 Form Err	.3	1.3	.6	1.5	.2	1.3	1.3	1.3	.6	.8	.5	1.1	1.1	.9	2.0	μm

	C1	C2	C3	C4	I. Tol.	u. Tol.	Unit
Flank1	31.2	40.3	-82.7	-32.2	.0	.0	μm
Flank2	3.6	-2.4	53.9	12.1	.0	.0	μm

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Units
Flank1 u. Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank1 I. Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank1 Max Val	40.3	57.9	52.1	50.1	44.0	37.3	33.0	25.2	21.8	17.3	10.8	3.5	-2.4	-7.7	-32.2	μm
Flank1 Min Val	31.2	21.2	12.1	5.3	-1.0	-11.5	-19.6	-26.9	-35.8	-44.1	-49.2	-60.4	-67.9	-76.3	-83.2	μm
Flank2 u. Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank2 I. Tol.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	μm
Flank2 Max Val	3.7	5.2	6.1	7.8	10.6	13.0	15.9	20.0	22.6	27.1	30.0	35.2	39.8	45.6	53.9	μm
Flank2 Min Val	-4.8	-18.9	-21.7	-21.3	-21.4	-20.9	-19.8	-19.9	-19.6	-17.8	-15.0	-11.9	-9.3	-4.8	12.1	μm

Waviness	Flank 1				Flank 2			
Tol	5.00	5.00	5.00	I	5.00	5.00	5.00	I
Tooth	Wa	Wc	Wt	I	Wa	Wc	Wt	I
1-1	0.30	0.35	1.79	I	0.18	0.22	0.93	I

Figure 8—Bevel portrait chart.

macrogeometry features, the resulting form-deviation data more accurately represents localized surface variations critical to gear performance.

GAMA further enhances this functionality by allowing independent tolerance definitions for form deviations at each measurement column, organized across five distinct regions from heel to toe. This capability supports the application of region-specific tolerances along the spiral angle, accommodating intentional surface modifications—such as ENDREM—while maintaining precise control over critical areas of the tooth flank.

Bevel Gear Root Scanning

Root scanning capability enables the measurement of multiple critical features—including flank geometry, tooth spacing, top land, root depth and angles, as well as detailed root geometry—within a single automated inspection cycle. Root measurements are evaluated relative to theoretical design coordinates, ensuring accurate comparison to nominal values.

Nominal root data is stored in dedicated root definition files, allowing both standard flank form measurements and root scan evaluations to be performed within the same measurement cycle. This integrated approach improves measurement efficiency, maintains consistency between datasets, and supports comprehensive analysis without the need for separate setups or additional inspection steps.

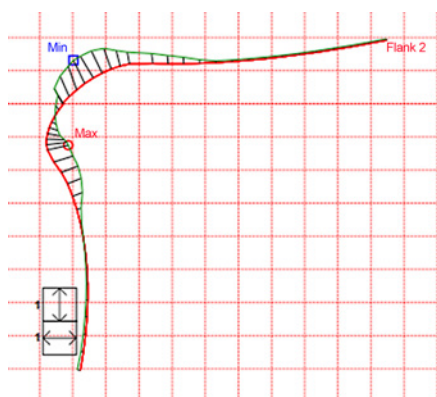


Figure 9—Flank and root fillet scan using nominal points from design software.

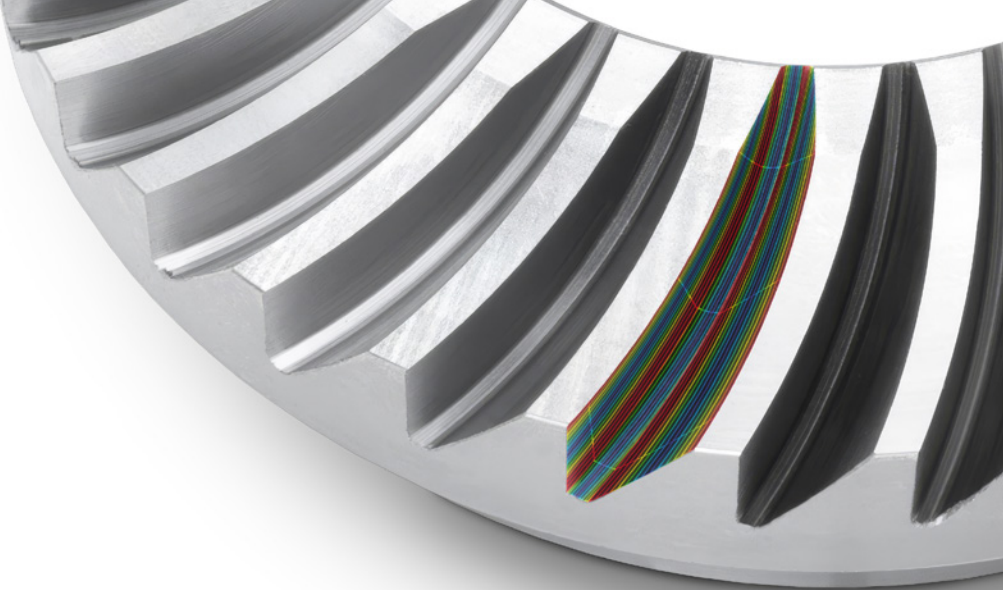


Figure 10—Root fillet scanning selectable locations along the face width.

Conclusion

Increasing performance demands in bevel gear applications—driven by higher torque density, stricter acoustic requirements, and extended durability expectations—necessitate more advanced and comprehensive inspection methodologies. Traditional flank form evaluation alone is no longer sufficient to fully characterize the surface-related deviations that directly influence gear performance.

The advancements presented in this work demonstrate a significant evolution in bevel gear measurement capabilities. By enabling accurate waviness analysis using standard spherical probe tips, the need for specialized surface roughness hardware is eliminated, reducing system cost, complexity, and sensitivity to probe damage. At the same time, dynamic data density enhancement and advanced spline-based processing allow high-resolution surface characterization without compromising measurement speed or requiring modified inspection programs.

Integration within the *GAMA* software environment further enhances usability and efficiency, allowing flexible parameter selection, advanced filtering strategies, and fully automated multi-parameter inspection within a single

measurement cycle. New visualization tools—including multi-trace waviness charting and portrait-style gear reports—provide improved diagnostic capability, enabling rapid identification of systematic deviations and facilitating targeted process corrections.

Additional innovations such as per-column flank form analysis, region-specific tolerance control, and integrated root scanning expand the scope of measurement beyond traditional limits, delivering a more complete representation of gear geometry and surface condition. The ability to evaluate these characteristics relative to theoretical design data within a unified workflow ensures consistency and traceability across all measurement results.

Together, these technologies provide a powerful and efficient solution for modern bevel gear quality control. By combining faster measurement cycles, reduced hardware requirements, and enhanced analytical capability, they enable manufacturers to achieve higher product quality, improved noise and efficiency performance, and more robust process control in increasingly demanding applications.

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Differentiating Noncircular, Elliptical, and Oval Gears

Are noncircular, elliptical, and oval gears all the same thing?

Hanspeter Dinner, Managing Director, EES Gear GmbH

Noncircular Gears

Noncircular gears are found as early as the sketches of Leonardo da Vinci in his *Codice Atlantico*, documenting his work from 1478 to 1519. The gear community is, of course, familiar with this; refer to, e.g., Aaron Fagan's Addendum column "Noncircular Gears: The Unicorn of Machine Technology" in the June 2022 issue of *Gear Technology*. Their use is limited; they are a niche component due to their complexity of design and manufacturing. The advent of servo motors solved the problem of controlled motion in a more general approach, reducing the need for noncircular gears further. Still, they remain high-performing mechanical solutions. The dedicated book by Faydor L. Litvin et al, *Noncircular Gears: Design and Generation* (Cambridge University Press, 2009), is widely known and gives a dense overview of the topic. In the context of this paper, we

will limit the observations to convex elliptic, Figure 2 and oval gears Figure 3. Gears 1 and 2 have the same properties.

These two types of noncircular gears transform motion between parallel axes, where a continuously changing transmission ratio results within a single revolution. Unlike linkage mechanisms but similar to cam-follower mechanisms, elliptical and oval gears provide a compact arrangement for delivering periodic speed variations, making them suitable in e.g., packaging systems, textile machines, flow meters, or heavy press machines, with a slow working stroke and a fast return stroke. This document focuses on the differences between elliptical gears and their oval cousins. In extremis, both are transformed into circular gears, Figure 1.

The defining feature of noncircular transmissions is the momentary (instantaneous) ratio i . In circular gears, the ratio i is constant and may be determined from the number of teeth,

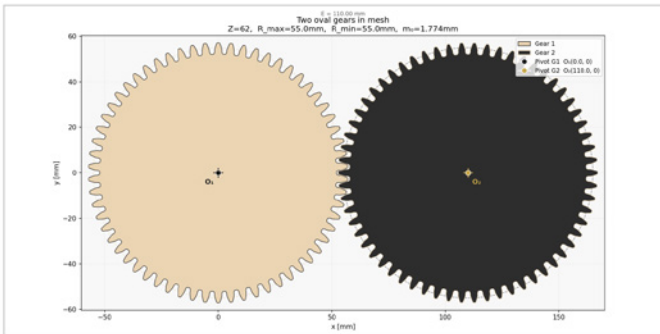


Figure 1—Two circular gears in mesh. Gear 1 is the driver, the gear on the left, rotating at constant speed. Gear 2, driven, is rotating at constant speed (neglecting manufacturing errors, teeth deformation, and so on). (All images: EES Gear GmbH)

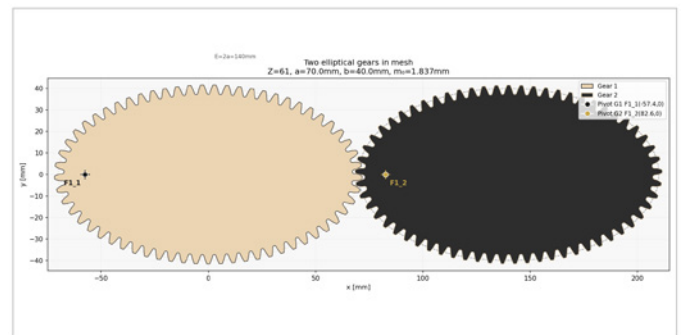


Figure 2—Two elliptical gears in mesh. Again, Gear 2 will not rotate at a constant speed. Ratio in this configuration changes from $i_{max}=10.2$ to $i_{min}=0.1$. Note that both gears start the meshing cycle with major axes aligned.

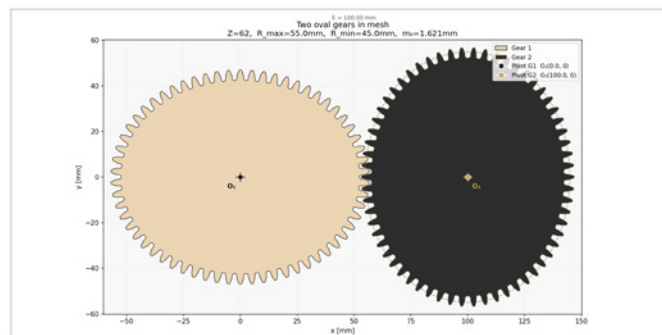


Figure 3—Two oval gears in mesh. Obviously, Gear 2 will not rotate at a constant speed. Ratio in this configuration changes from $i_{max}=2.0$ to $i_{min}=0.5$. Note that both gears start the meshing cycle with major axes in a rectangular arrangement.

Figure 4. In elliptical, Figure 5, and oval gears, Figure 6, it is a continuous function of the polar angle of rotation ϕ : $i(\phi) = \omega_2 / \omega_1 = r_1(\phi) / r_2(\psi)$. With the sum $E = r_1 + r_2 = \text{constant}$, the ratio is a function of the driver's radius alone $i(\phi) = r_1(\phi) / (E - r_1(\phi))$.

Circular Gears Rotate Around Their Centers

Obviously, the ratio of two circular gears is constant, and while trivial, the momentary ratio is shown in Figure 4 for reference.

Elliptical Gears Rotate Around the Focal Point

The elliptical gear is defined by a pitch curve (centrode) as a standard ellipse. A significant kinematic difference exists in circular gears rotating around an eccentric axis: to maintain a constant center distance E while rolling without slip, a pair of identical elliptical gears must rotate about one of their foci, O_1 or O_2 , rather than their geometric centers O , as with circular gears.

This requirement stems from a geometric property of the ellipse that for any point on the pitch curve, the sum of the distances to the two foci is constant and equal to the major axis length $2 * a$. When the rotation centers are placed at the foci, the sum of the instantaneous radii of the two ellipses, $r_1 + r_2$, equals the axial distance $E = r_1(\phi) + r_2(\psi)$, ϕ and ψ being the rotational angles of the two ellipses. For identical elliptical gears where one revolution of the driver corresponds to one revolution of the driven gear, the center distance is $E = 2 * a$, where a is the major axis length.

In polar coordinates, the elliptical centrode rotating about its focus is $r(\theta) = p / (1 - e * \cos(\theta))$ with $p = a * (1 - e^2)$, a is the semi-major axis, and $e = c / a$, the eccentricity, and c is the distance from the ellipse center to the focal point. This rotation about the focal point results in a single, smooth speed fluctuation cycle per revolution, Figure 5.

With the eccentricity chosen, the ratio spread is $10.1515 / 0.0985 = 103$. The dynamics in a real-world application will be challenging.

The momentary ratio course is a function of a / b (major to minor half axis), as shown below for one of the horizontal axes, Figure 6. For $a / b = 1$, we have a circle; the ratio is then constant at $I = 1.00$, see the left front edge of the color plot. In dashed red, the current design is shown. As the ellipse gets slimmer and slimmer (a / b increasing), the ratio spread goes towards several orders of magnitude (note that the vertical axis is logarithmic).

Oval Gears Rotate Around Their Center

While a elliptical gears rotating around the focal points result in one speed cycle per revolution, industrial applications may require multiple speed cycles. This requirement led to the development of the oval gear, which is technically a modified elliptical gear characterized by multiple lobes (in our case, just two).

Oval gears rotate about their geometric centers O . The polar equation for the oval gear centrode is $r_1(\phi) = p / (1 + e * \cos(2 * N))$. A two-lobed oval gear ($N = 2$) will produce two ratio cycles per revolution of the driving gear, Figure 7. This

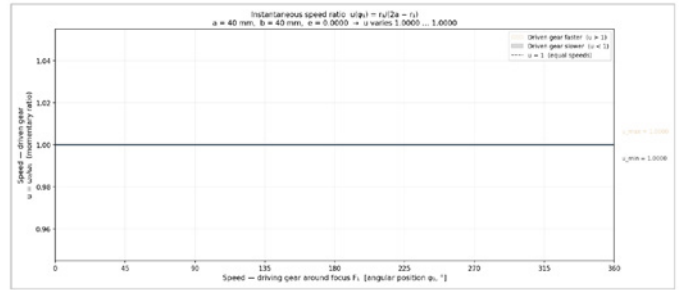


Figure 4—Momentary ratio expressed as speed ratio for the centrodes rotating without slip. For circular centrodes.

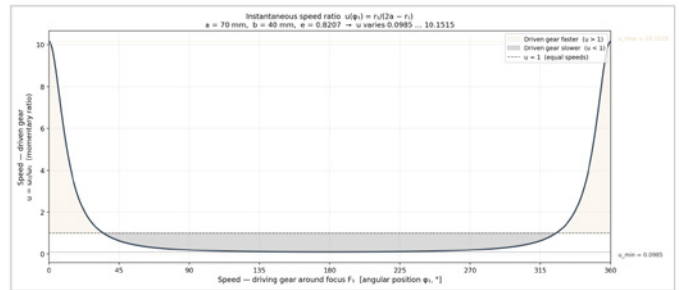


Figure 5—Momentary ratio expressed as speed ratio for the centrodes rotating without slip. For elliptical centrodes.

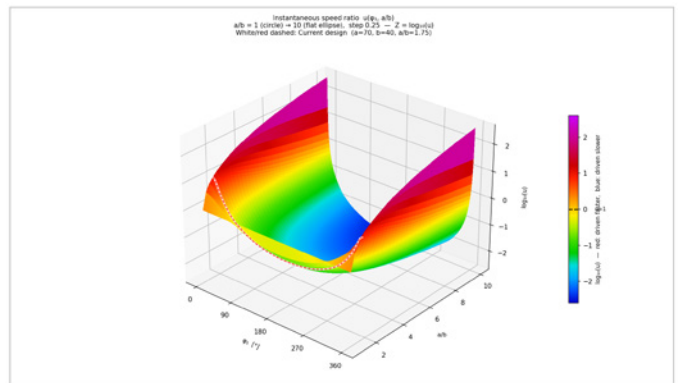


Figure 6—Ratio between two elliptic gears as a function of the rotational angle of the driving gear and the ratio a / b .

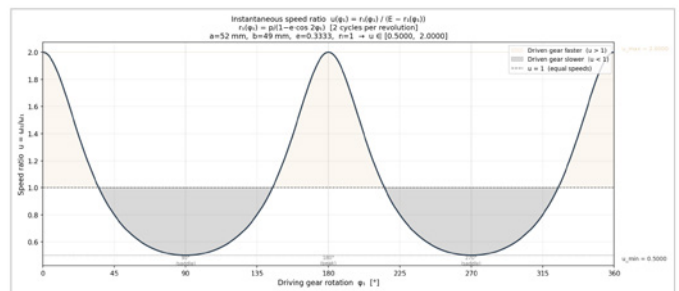


Figure 7—Momentary ratio expressed as speed ratio for the centrodes rotating without slip. For oval centrodes.

symmetry ensures that the gears are balanced, a critical factor for the high-speed rotation.

For oval gears, if the ratio between maximum radius $R_{max} = \max(r_1(\phi))$ and minimum radius $R_{min} = \min(r_1(\phi))$ is too high, the centrode turns partially concave, Figure 8. Concave centrodes are more difficult to manufacture; they require a shaping cutter-type tool (or e.g., wire erosion) as opposed to a rack-type tool. The centrode remains convex if the oval gear has radii that fulfill the condition $R_{min} > R_{max} * (1 - 2 / N^2)$, or, with $N = 2$, $R_{max} / R_{min} < 2.0$. In Figure 10, the geometry for $R_{max} / R_{min} = 2.0$ is shown. If the ratio exceeds this limit, the centrode has concave areas, Figure 8.

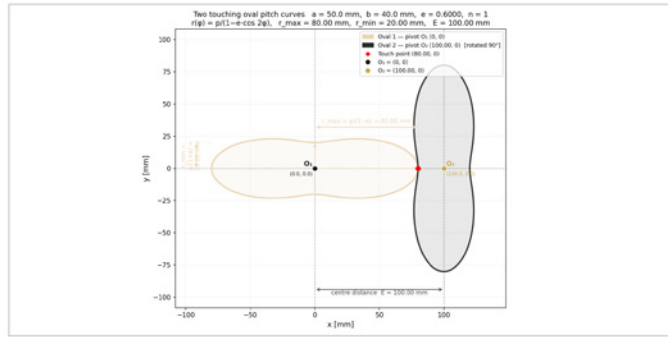


Figure 8—Two oval gears in mesh. $R_{max} > 2 * R_{min}$, centrode develops a slim waist.

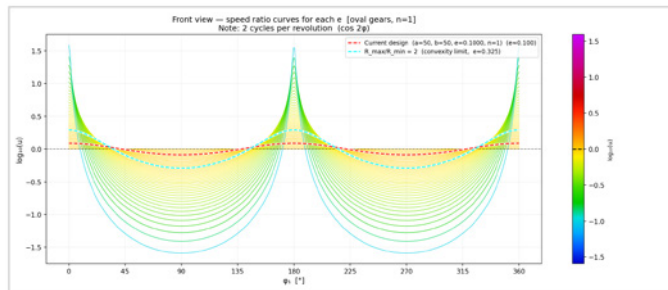


Figure 9—Momentary ratio for different oval gears (blue dashed line = current design, red dashed line = $R_{max} = 2 * R_{min}$).

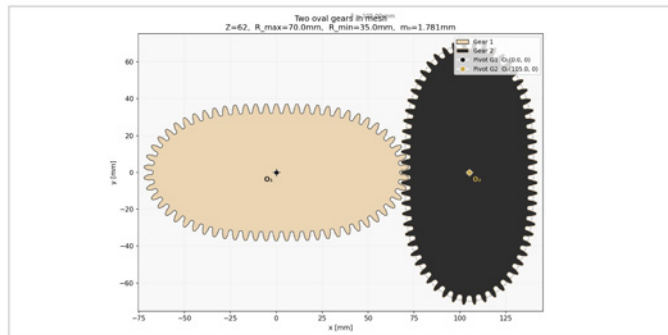


Figure 10—Oval gears with $R_{max} = 2 * R_{min}$. The slimmest shape occurs before the concave shape occurs.

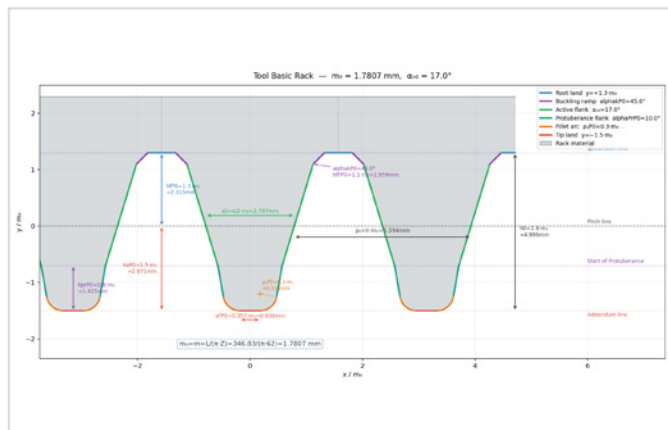


Figure 11—Rack definition.

Gear Generation with a Rack-Type Tool

Tooth geometry is generated with a rack-type topping tool, Figure 11. The cutter (manufacturing profile shift is applied for backlash) has a straight reference line that rolls on the centrode without slip. The contact point is the momentary center of rotation for the rack. The movement of the rack equals the arc length of the centrode when the contact point travels from the start position to the current position.

For noncircular gears to operate continuously, the circumference L of the centrode must be exactly equal to an integer number of teeth, z , times the pitch, $L = m * z$, where m is the module chosen to satisfy this condition.

Elliptical gears require an odd number of teeth. This ensures that if a tooth is centered on, say, the left major half-axis, a gap is present on the right major half-axis. Into this gap, the tooth on the left major half-axis of the mating gear will fit. Note that the major axes are aligned at the start.

For oval gears, the number of teeth must be even but not divisible by four. This ensures there are two teeth on the major axes and two gaps on the minor axes, again fulfilling the meshing condition, as at the start of the mesh, the gear major axes are arranged perpendicularly.

Calculations were implemented using *Python* in the Google Colab environment.

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On the Road for You

Mary Ellen Doran, VP, Emerging Technology, MPMA



Mary Ellen Doran pictured with Heath Rohrbaugh (left) and Brian Richards (right) from WD Bearing Group at the 2026 Boston Robotics Show. (Image: MPMA)

Part of my job is getting into rooms that our members may not have time to visit themselves. Over the past two months, I attended three events covering the emerging technology spaces most relevant to the gear and bearing industry: RAPID in Boston, April 13–16; Xponential, the premier drone and unmanned systems show, May 11–14; and the Boston Robotics Summit, May 27–28. Here is what I took away from each one.

RAPID: A Show That Has Grown Up

RAPID felt different this year in the best possible way. The booths were more realistic in size, the conversations more grounded, and the overall feel was of a larger, more serious show with more companies represented. The additive manufacturing (AM) industry has moved past the phase where everyone is trying to impress you with what might be possible. The focus now is on what is actually being produced, qualified, and sold.

I always enjoy seeing the Pantheon booth, and this year was no exception. But the highlight for me was walking the floor with Art Reardon of Reardon Metals, a member of our 3D Printing Committee. Art recently received patents on a line of steels that may be the first of their kind: the patents specifically identify the steels as being designed for AM. That is a significant development. The materials side of AM has long been a limiting factor for precision component manufacturers, and work like Art's points toward a future where the gap between what AM can produce and what our industry requires continues to close.



Metallurgist Art Reardon (left) discusses printed gears in Filmatrix's booth with Ryan Besch (middle) and Logan Pensinger (right).

Xponential: Drones Are Here, eVTOL Is Still Coming

Xponential covers the full spectrum of unmanned and autonomous systems, and the drone side of the show was vibrant and active. The eVTOL space, however, was quieter than the headlines might suggest. There is significant development underway, but the commercial eVTOL market is not yet at the stage where it dominates a show floor. For members following the work of our Air Mobility Technology Committee, that is an honest assessment of where things stand. Technology is advancing, regulatory frameworks are developing, and supply chain conversations are beginning. But we are still in the early chapters of that story.

Boston Robotics Summit: Our Members Were Already There

The Boston Robotics Summit was the most directly relevant of the three shows for MPMA members, and the presence of our community on that floor made that clear. I visited member companies on the show floor, including EMAG, CGI Inc., Cone Drive Gearing Solutions, Regal Rexnord, Schaeffler Group USA, SEW-Eurodrive, and Sumitomo Machinery Corporation of America. I also talked with Robotics Committee member Brian Dengel at KHK USA. I walked the floor with Zain Jamal from Bevel Gears India and colleagues from WD Bearing. The gear and bearing industries were well represented, and that is exactly where we should be.

The sessions reinforced a theme I have been hearing consistently: design for manufacturability from the start. Speaker after speaker returned to the same practical warning. Do not build your prototype from whatever components are convenient. If they are not scalable, not regularly available, and not designed with production in mind, you will pay for them when the time comes to manufacture at volume. This is a message our members are positioned to deliver and solve if they are engaged early enough in the development process.

Across all three shows, I came away energized. The emerging technology spaces our committees are tracking are maturing, the opportunities for motion and power transmission manufacturers are real, and our community is already showing up. I will continue to bring these conversations back to you through our committees and our programming. If you want to be part of that work, reach out.

To get involved with any of the MPMA Emerging Technology Committees, contact Mary Ellen Doran, VP of Emerging Technology, at doran@motionpower.org.



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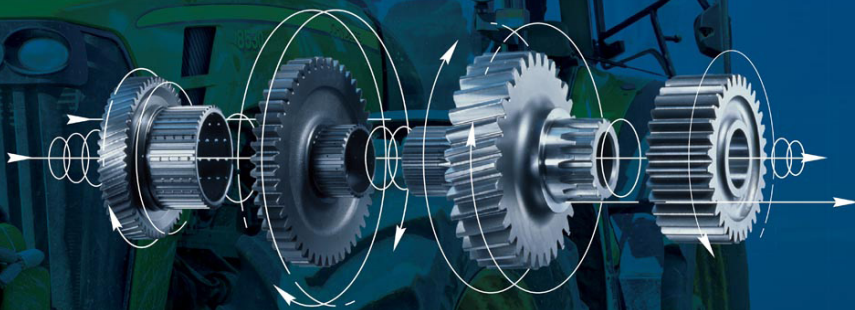
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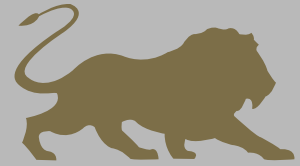
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A Bigger Tent

Todd Praneis, VP, MPMA Technical Division

The Fall Technical Meeting (FTM) is expanding its format—and its audience. Here's why researchers and practitioners alike should be paying attention.

As a reader of this magazine, you understand first-hand the quality of the research that goes into past FTM presentations, because many of the papers are printed here as technical articles. That tradition isn't going anywhere. But starting this October, FTM is unveiling a bigger tent, open to practitioners whose hands-on experience in the industry has not had a regular place at the table.

The 2026 FTM, held October 5–7 at the Hilton Rosemont–Chicago O'Hare, marks the first year the event will run a dual-track format. Alongside the classic peer-reviewed technical paper sessions, a new presentation-only track opens the floor to case studies, manufacturing breakthroughs, inspection innovations, and emerging technologies, the kind of practical, experience-driven knowledge that is rarely formalized but shapes how real production decisions get made every day.

The expanded format also reflects a bigger organizational shift. In 2025, AGMA and ABMA merged to form the Motion + Power Manufacturers Alliance (MPMA), uniting the gear and bearing communities. This year, the Society of Tribologists and Lubrication Engineers (STLE) joins as a co-host, dedicating a full session to topics from its triennial Trends Report: AI and digitalization, thermal management, decarbonization, and more. The payoff is a conference that now speaks fluently across disciplines that have long influenced each other without always sharing a stage.

For professionals in manufacturing, quality, sales, or business development, the new presentation track changes the equation, drawing in parts of the industry that have long worked in parallel without crossing paths. A 20-minute session with Q&A, focused on how a real company solved a real problem, complements the peer-reviewed technical sessions.

Key registration dates at a glance:

- **Early bird:** June 29 to August 14. \$150 discount from non-member price.
- **Advance:** August 15 to September 25. \$100 discount from non-member price.
- **Late:** September 26 to onsite

Questions? Reach the organizing team at: FTM@motionpower.org

FTM is three days—a tight program that rewards early planning. So, we look forward to seeing you and encourage you to share the event information within your organization and bring a friend!



Design and Load Capacity of Crown Gears in Comparison to Bevel Gears

Dr. Joachim Thomas and Jürg Fürst

Compared to bevel gears, crown gears (also known as face gears) have some clear advantages. One of the most important is the axial freedom of the pinion. Therefore, it is not necessary to position the pinion at the exact mounting distance, and there is freedom from axial forces on the pinion side, at least as long as a spur gear is used as the pinion. On the other hand, there is a certain limitation of face width. Depending on the gear ratio, the beginning of the tooth root fillet of the crown wheel runs towards the tooth tip if the inner diameter becomes too small. The top land becomes too narrow if the outer diameter is too big. This limitation may lead to high Hertzian pressure on the tooth flank. It is therefore essential to calculate the load-carrying capacity of crown gears as accurately as possible, ideally using the same calculation methods that have been established for bevel gears for many years. As soon as this is carried out, there will be a clear answer if the usage of a crown gear is possible or whether a bevel gear set is to be preferred.

Development Process for Bevel and Crown Gears

Spiral bevel gears, in particular, have special features that prevent a simple design. Although it is certainly possible to estimate the load capacity of bevel gears as a first step, just by using macrogeometry data with the aid of standardized calculations. The microgeometry cannot be described with the aid of simple deviations from an involute profile, as is the case with cylindrical gears. This led to the development of flank generators many years ago, with which a manufacturing simulation can be carried out from the machine setting data and precise tool profile data. All points of the flank and

tooth root can be determined in three dimensions. As soon as the results for the pinion and wheel are available, the flank data generated in this way can be virtually paired and rolled without load. From this load-free tooth contact analysis (TCA), contact patterns, rotational errors, and ease-off can be derived as representations of the effect of crowning in the load-free state. These results already provide a lot of information on the sensitivity of the contact pattern position and the running behavior.

In a further step, a TCA under load is usually connected. In this final step, not only are the local pressures and tooth root stresses determined, but local load capacity values can also be calculated for the flank and root. If the calculations are based on a load spectrum, local damage sums can also be determined. If axis displacements in the gearbox were calculated in advance and for the respective loads using CAE software, these displacements can be easily accounted for in the TCA under load. This ultimately results in realistic load-bearing patterns under load and the corresponding load capacities. If necessary, the microgeometry can be optimized in a development loop so that optimum load capacities are ultimately achieved.

This approach has been used for many years in the development of spiral bevel gears, whereby the manufacturing simulation, in particular, was predominantly tied to software from the well-known bevel gear machine manufacturers. With the help of independent software tools that use flank generators for practically all conceivable gear types, it has also been possible for some time to carry out ease-off calculations for spur bevel gears. Since the relevant loaded tooth-contact analysis

(LTCA) software tools are no longer tied to internal flank generators for spiral bevel gears but instead use point clouds provided by the flank generators as input data, TCA under load can now also be carried out easily, e.g., for differential bevel gears (see Refs. 1 and 2). In a further step, these possibilities have now been transferred to many other types of gears, so that the procedure described above can now also be applied to the development of crown gears (Ref. 3). Since the same tools are now used to determine the load capacity, the results calculated for crown gears can be compared 1:1 with the results for bevel gears. This allows us to directly compare advantages and, where applicable, disadvantages of crown gears compared to bevel gears for specific applications. This is shown in the following two examples.

Examples

Example 1: Differential Gear Set

The first example is a differential gear that was initially designed as a classic forged bevel gear differential, with modified tooth root on toe side. While differentials were largely inconspicuous with classic drive technology, the situation with regard to the requirements for differentials has changed fundamentally with the increasing introduction of hybrid and electric drives. In particular it should be emphasized that due to the recuperation mode and the increased drive power when cornering, e-drive solutions also lead to significantly higher torques. Above all, this means that the very high Hertzian pressures on the flanks no longer occur predominantly only when driving straight ahead and thus when the differential is stationary, but also when cornering. This leads to a

significantly higher risk of flank damage such as pitting or flank breakage.

Following the macrogeometry data for the original bevel gear design:

- Number of teeth: Pinion $z_1 = 11$, gear $z_2 = 16$
- Mean normal module: $m_{mn} = 3.792$ mm
- Face width: $b = 22$ mm
- Ball diameter: $d_c = 80$ mm
- Pressure angle: $\alpha_n = 22.5^\circ$
- Two output bevel gears, four planets (pinions)

The total gear output torque (design torque) is 4,026 Nm, which, with two output gears and four pinions, results in a pinion torque of the single mesh of $M_{t1} = 346$ Nm with the given transmission ratio. These are forged bevel gears with tooth root geometries adapted to the toe to enable the largest possible internal diameters. The weight of the pinions is approx. 0.3 kg each, that of the wheels approx. 0.7 kg each. The total weight of the complete wheel set is therefore approx. 2.6 kg. Figure 1 shows the design model of a pair of bevel gear sets that was created using gear design software (Ref. 4).

For a pair of gears described above, the microgeometry and target-oriented ease-off were first developed using the design software. The Hertzian pressure and tooth root stress for the design torque were then calculated using LTCA software (Ref. 5). Figure 2 shows the distribution of the maximum Hertzian pressure on the tooth flank, and Figure 3 shows the course of the maximum tooth root stress over the face width.

In a further step, a crown gear differential with the same number of teeth was developed. It has approximately the same Hertzian pressures at the design torque as the bevel gear differential. Again, a gearing model was initially developed with the help of the design software. During development, it immediately became apparent that the realizable face width of crown gears is limited, especially with such small ratios, as already described in the introduction, the tooth root fillet starts too close to the tooth tip when the inner diameter becomes too small, and the tooth tip becomes too pointed when the outer diameter

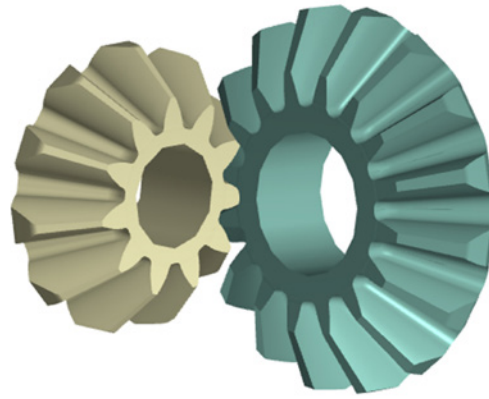


Figure 1—model of a differential bevel gear set.

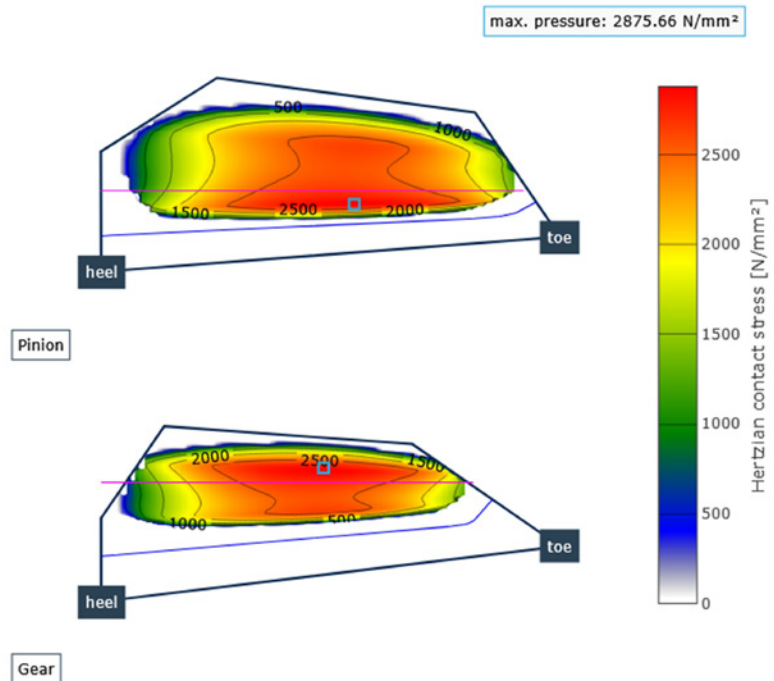


Figure 2—Hertzian Pressure of a differential bevel gear set.

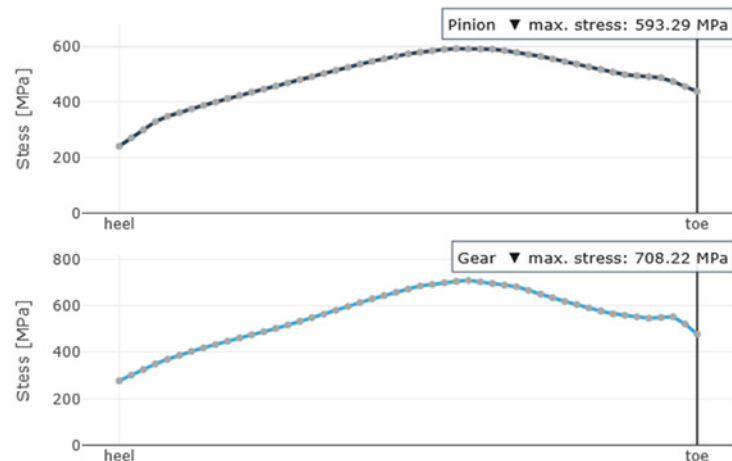


Figure 3—Tooth root stress of a differential bevel gear set.

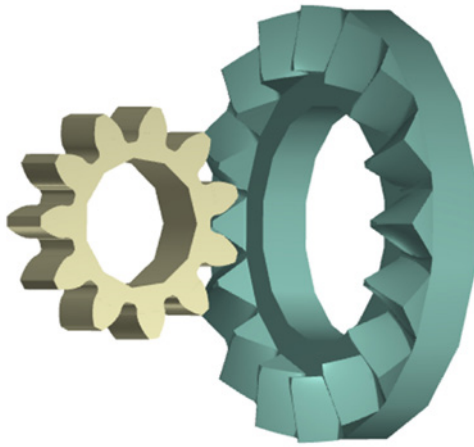


Figure 4—Model of a differential crown gear set.

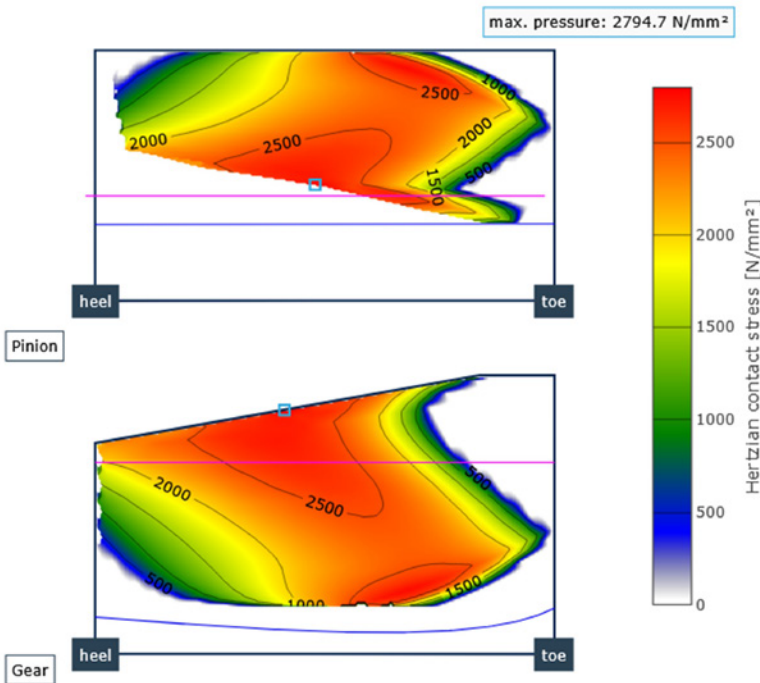


Figure 5—Hertzian pressure of a differential crown gear set.

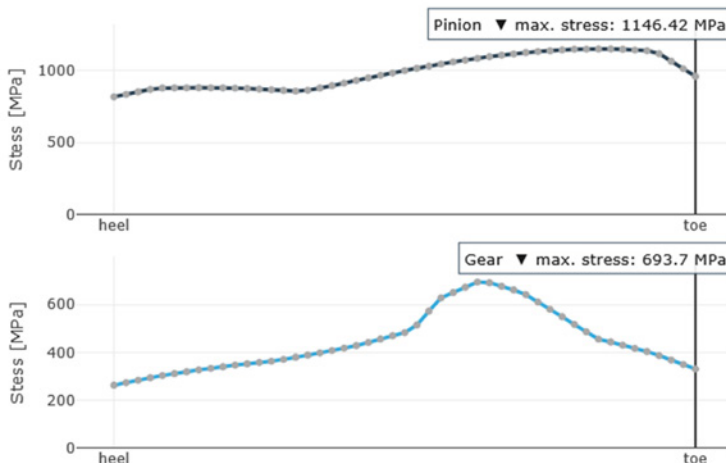


Figure 6—Tooth root stress of a differential crown gear set.

becomes too large. This results in a smaller face width compared to the bevel gears, which may have to be compensated for by an overall larger diameter.

The following macrogeometry of the crown gear pairing has proven to be promising in this specific case:

- Number of teeth: Pinion $z_1 = 11$, gear $z_2 = 16$
- Average normal module: $m_{mn} = 4$ mm
- Face width: $b = 15$ mm
- Outer wheel diameter: $d_{e2} = 100$ mm
- Pinion pressure angle: $\alpha_{n1} = 20^\circ$
- Two output bevel gears, four planets (pinions)

The weight of the pinions is approx. 0.1 kg each, that of the crown gears approx. 0.5 kg each. The total weight of the complete gear set is therefore approx. 1.4 kg and is thus approximately 45 percent lighter than the bevel gear set. Figure 4 shows the design model of the crown gear set that was created with the help of the same design software as used for the bevel gear set.

In the next step, the LTCA software was again used to calculate the Hertzian pressure and the tooth root stress for the design torque. This is possible because the software in question works with the aid of point clouds and is no longer tied to an integrated bevel gear flank generator. The design software provides the point clouds for the crown gears in the same way as those for the bevel gears. Figure 5 shows the distribution of the maximum Hertzian pressure on the crown gear tooth flank; Figure 6 shows the course of the maximum tooth root stress over the face width.

In comparison with the results for the bevel gear set, the Hertzian pressure on the crown gear set is more or less at the same level. However, higher tooth root stresses are to be expected, especially for the pinions. This means that the crown gear set would have approximately the same flank load capacity, a significantly lower weight, and considerably simplified bearing of the pinions due to the lack of axial force, with less risk of scoring in the pinion hub. However, with a slightly smaller overall width, this results in a slightly larger diameter of the crown gear and lower tooth root load capacity on the pinions. In contrast to bevel gears, the pinions of crown

gear sets cannot be forged, but must be milled or even ground. The crown wheel can also be forged, which may even be easier. In addition, no adjustments need to be made to the tooth root geometry of either component, as is usually the case with forged bevel gears. Figure 7 shows a realized crown gear differential including the differential housing.

As the pinions can be mounted very simply due to the lack of axial forces, a further step was taken to investigate whether five pinions could be used instead of four. This measure cannot be carried out while using bevel gears. For the new crown gear configuration, the number of teeth on the crown gear was reduced by one. Overall, this results in the following macrogeometry data:

- Number of teeth: Pinion $z_1 = 11$, wheel $z_2 = 15$
- Average normal module: $m_{mn} = 4$ mm
- Face width: $b = 15$ mm
- Outer wheel diameter: $d_{e2} = 96$ mm
- Pinion pressure angle: $\alpha_{n1} = 20^\circ$
- Two output bevel gears, five planets (pinions)

Of course, the pinion torque must be recalculated and adapted to the slightly smaller transmission ratio, so that a pinion torque of $M_{t1} = 295$ Nm results in the same total gear output as used before. As expected, this leads both to a reduced Hertzian pressure (see Figure 8), which is now already close to the static limit strength that is usual for running gears, and also to a reduced tooth root stress on the pinion with a slightly higher tooth root stress on the crown gear (see Figure 9).

The weight of the pinions remains unchanged at approx. 0.1 kg, while that of the wheels is reduced slightly to approx. 0.45 kg. The total weight of the complete gear set is therefore still only approx. 1.4 kg and thus remains approximately 45 percent lighter than the bevel gear set. The overall gearbox is slightly heavier due to the additional fifth pinion bearing, but the diameter is reduced while the width remains the same. However, it should be noted that with five pinions, it is even more difficult to ensure that all planets are evenly loaded than is already the case with four pinions. The uneven loading of the planets has not yet been taken into



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Figure 7—Photograph of a realized differential with crown gears.

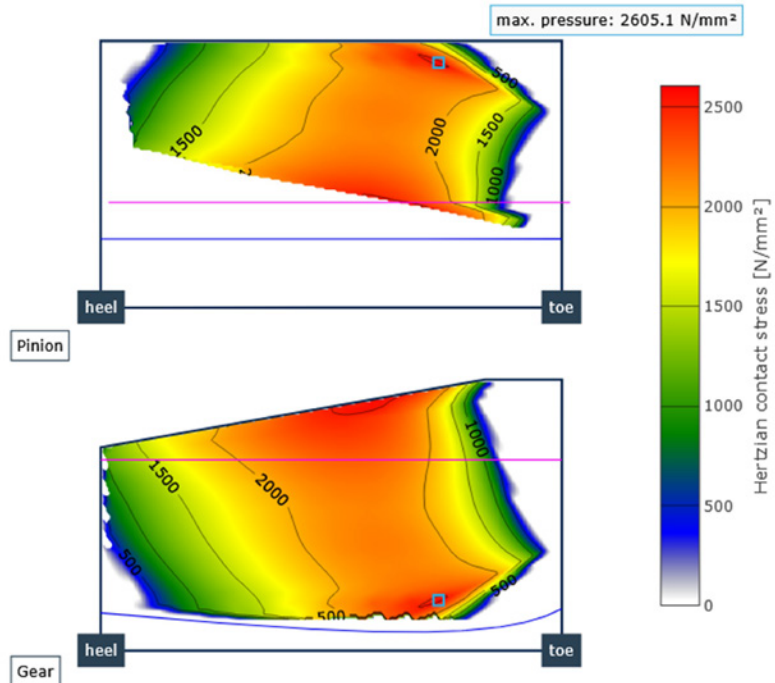


Figure 8—Hertzian pressure of an improved differential crown gear set.

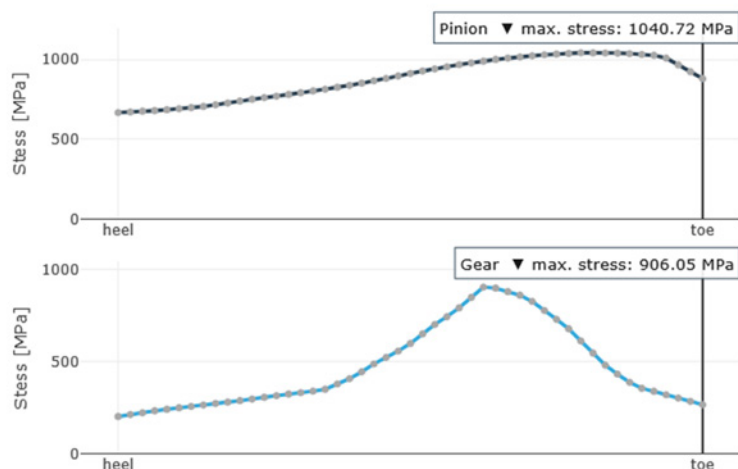


Figure 9—Tooth root stress of an improved differential crown gear set.

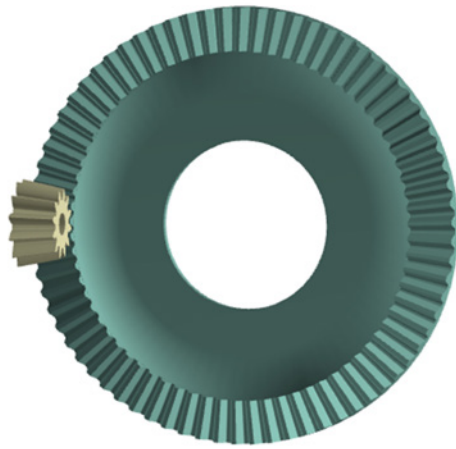


Figure 10—Design model of an actuating bevel gear set.

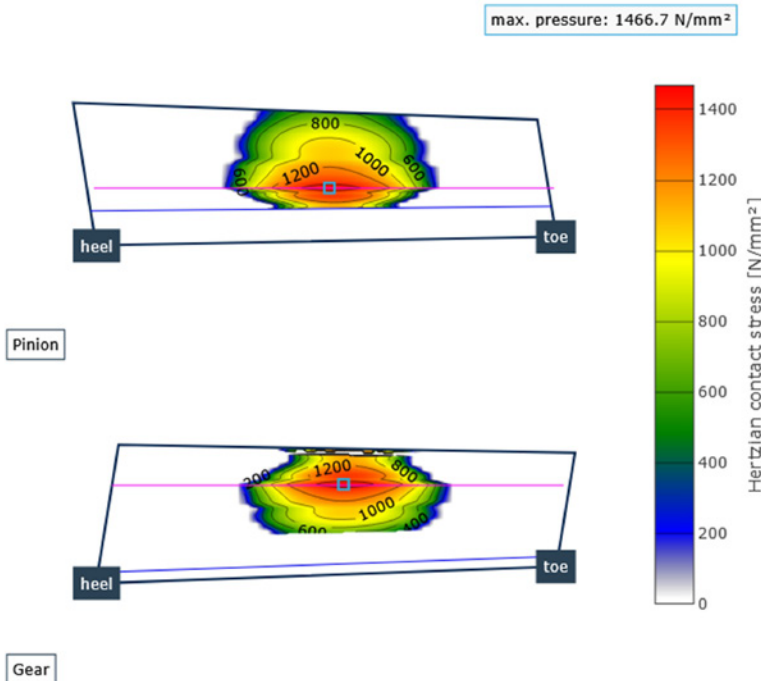


Figure 11—Hertzian pressure of an actuating bevel gear set.

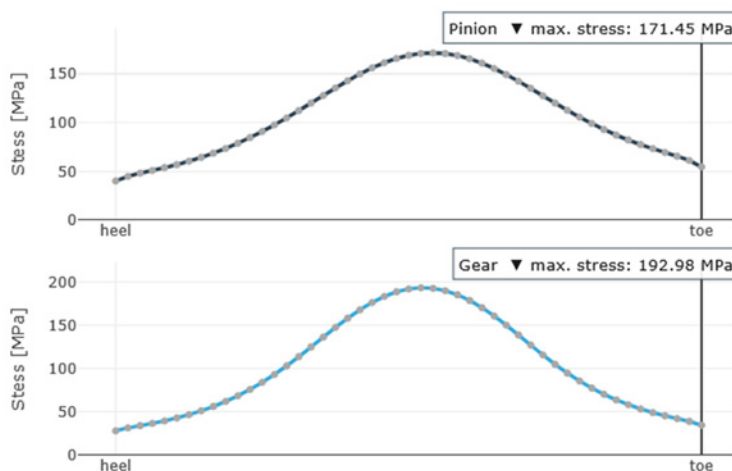


Figure 12—Tooth root stress of an actuating bevel gear set.

account in the calculation model, and it is therefore conceivable that with five pinions, compared to four, additional loads may result for one of the pinions.

Replacing a bevel gear differential with a crown gear differential is possible and can have many advantages with few disadvantages, but it also depends on the available diameter. Table 1 attempts to provide an overview of the advantages and disadvantages of the individual gearing types without claiming to be complete.

	Differential bevel gear		Differential crown gear	
	Pinion	Gear	Pinion	Gear
Low weight	-	0	+	+
Low diameter	0	0	+	-
Low costs	+	+	-	+
Simple assembly	-	-	+	-
Simple bearing concept	-	0	+	0
No axial forces	-	-	+	-
Low tooth root stress	+	+	0	+
Low Hertzian pressure	0	0	0	0
- Disadvantage 0 Neutral + Advantage				

Table 1—Weighting table of advantages of differential gear types.

Example 2: Actuating Gear

The second example is a straight bevel actuating gear set with the following macrogeometry:

- Number of teeth: Pinion $z_1 = 12$, Gear $z_2 = 73$
- Mean normal module: $m_{mn} = 0.864$ mm
- Face width: $b = 7$ mm
- Outer wheel diameter: $d_{e2} = 70$ mm
- Pinion pressure angle: $\alpha_{n1} = 20^\circ$

Figure 10 shows the bevel gear set model, Figure 11 shows the Hertzian pressure at a pinion torque $M_{t1} = 1$ Nm, and Figure 12 shows the tooth root stress at the same torque.

The high effort required to adjust the contact pattern proved to be unfavorable for this gearbox, as the overhung pinion could only be installed and removed with great effort. In addition, relatively large bearings had to be used to absorb the axial force from the pinion. It was therefore investigated whether this gearbox could be replaced by a crown gear gearbox.

Due to the significantly larger transmission ratio compared to example 1, the same face width can be realized with the crown gear as with the bevel gear. Apart from a slightly reduced normal module of $m_{mn} = 0.8$ mm, the macrogeometric data are the same as for the bevel gear set. Figure 13 shows the gear set model, Figure 14 shows the Hertzian pressure at a pinion torque $M_{t1} = 1$ Nm, and Figure 15 shows the tooth root stress at the same torque.

The comparison of the two gear sets shows that the Hertzian pressure is in the same range, possibly even slightly lower for the crown gear. The tooth root stress on the crown pinion increases slightly but is far from the fatigue limit, while the tooth root stress on the crown gear decreases. At the same time, there is no axial force on the pinion, so that smaller bearings can be used and the pinion installation dimension no longer must be maintained exactly. The crown gear, therefore, proves to be a reasonable, if not a better alternative than the spur bevel gear. Table 2 attempts to provide an overview of the advantages and disadvantages of the individual gearing types without claiming to be complete.

Additional Considerations

A comparison of crown wheels with spiral bevel gears was deliberately omitted here. Crown gears can only withstand this comparison if it is carried out with helical crown wheels. However, this negates the aforementioned advantage of the pinion being free of axial force. Of course, crown gear sets can also be designed in which only the gear has a helix angle. However, this leads to gear sets with axial offset, which would then be comparable to hypoid gear sets. In contrast to hypoid gear sets, however, the pinion diameter of crown gears does not increase with increasing axial offset, which means that in a direct comparison, crown gear trans-

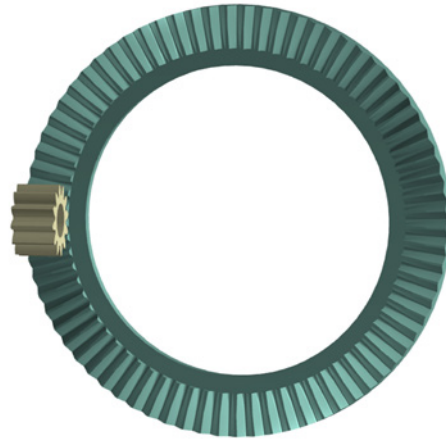


Figure 13—Design model of an actuating crown gear set.

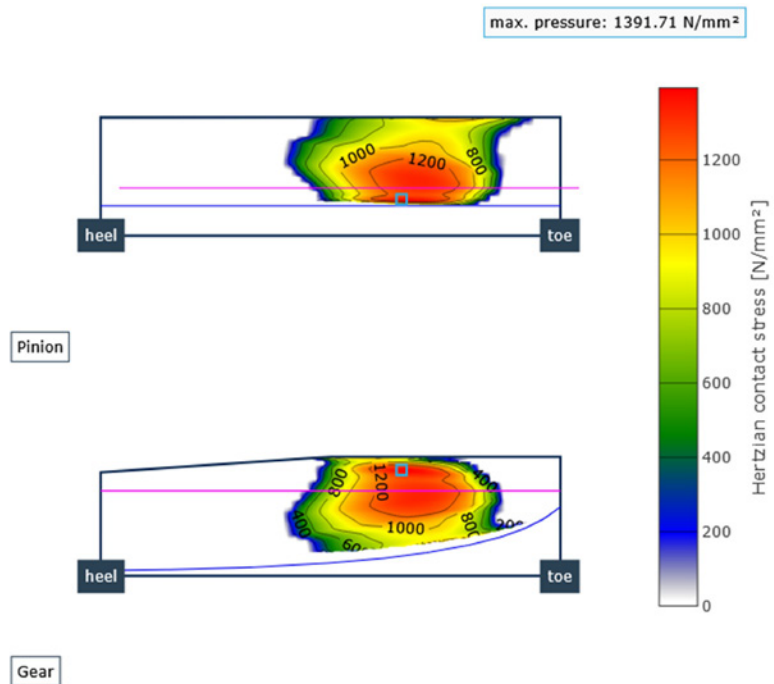


Figure 14—Hertzian pressure of an actuating crown gear set.

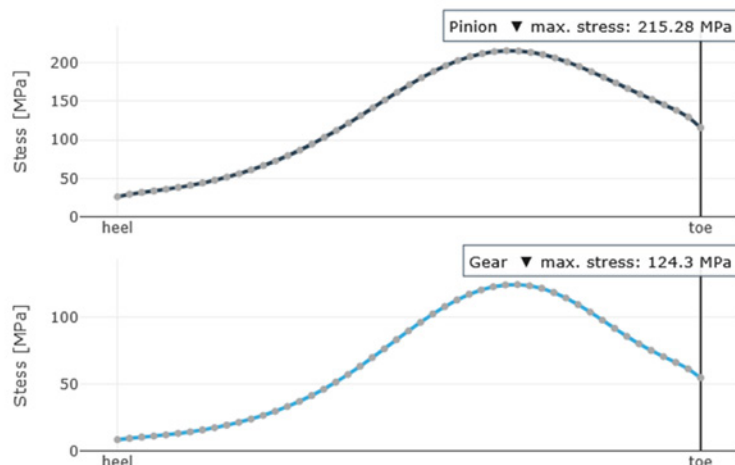


Figure 12—Tooth root stress of an actuating bevel gear set.

	Actuating bevel gear		Actuating crown gear	
	Pinion	Gear	Pinion	Gear
Low weight	0	0	0	0
Low costs	0	0	0	-
Simple assembly	-	-	+	-
Simple bearing option	-	0	+	0
No axial forces	-	-	+	-
Low tooth root stress	0	0	-	+
Low Hertzian pressure	0	0	0	0

- Disadvantage
0 Neutral
+ Advantage

Table 2—Weighting table of advantages of actuating gear types.

missions are at a disadvantage, especially in terms of tooth root load capacity; however, the advantage of no axial force would remain in such a case.

Nevertheless, in some cases, it may make sense to replace spiral bevel or hypoid gears with crown gears. This is particularly true when the housing geometry makes it difficult or even impossible to check or correct the exact mounting distance of the pinion. Crown gear sets are insensitive to pinion distance. Only the gear must be precisely adjusted.

To assess whether replacement with a crown gear gearbox is possible and advisable, the method described in the “Development Process for Bevel and

Crown Gears” section can also be used here, whereby the same proven software tools are used for both gear set design and load capacity analysis.

Summary and Outlook

The two examples show that straight-toothed bevel gear sets can be replaced by suitable crown gear sets in many cases and can offer several advantages. In particular, it should be emphasized here that straight-toothed pinions are completely free of axial force in crown gearboxes, and there is no need for time-consuming adjustment of the contact patterns using the pinion mounting distance, as is always necessary with bevel gears.

Replacing spiral bevel gear sets or hypoid gear sets with crown gear sets may also be advisable and possible in some cases.

However, each application is subject to a case-by-case assessment, and only then can the advantages and disadvantages be weighed up against each other. In any case, it is essential to develop the different gearbox types with the same software tools. Above all, these newly extended tools make it possible to calculate the load capacity under load for bevel and crown gears in the same way, as shown in the examples under 2. Therefore, the load values can now be compared directly with each other, and the load capacity of the individual gearbox types can be assessed.



Dr. Joachim Thomas is an independent developer and consultant with his company ZG Hypoid GmbH. After his doctoral thesis at FZG (Technical University of Munich), he spent years in

industry as a bevel gear expert. He convenes the ISO bevel gear working group (ISO/TC60/SC2/WG13) and lectures at TU Munich.



Jürg Fürst studied Mechanical Engineering at Bern University of Applied Sciences. He worked in powertrain development at BMW Formula 1 and Porsche Motorsport from 2004–2017,

then served as Project Manager at Air Liquide. In 2019, he became Managing Director of Balance Drive AG.

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Root Interference

Dr. Hermann J. Stadtfeld

The following chapter is from Gear Technology Solutions (*The Gleason Works, 2025*) by Dr. Hermann J. Stadtfeld. This is the third of four excerpts provided to Gear Technology readers to preview the book's insights into bevel gear theory, design, and manufacturing.

Dimension Sheet Analysis of Root Fillet

On the first page of the Gleason Dimension Sheet for bevel gears, the section below “Cutter Radius” shows the outer, mean, and inner slot widths. The finishing cutter blade point is a number, which is smaller than the smallest slot width. In Figure 1, the finishing cutter blade point is 10 microns below the inner slot width of the pinion. This is not the top width of the cutting blade for the first flank or the top width of the cutting blade for the second flank, but the distance between the two opposite blade tip corners (if they are superimposed). The top width of the individual blades in praxis is chosen to be 85 percent of the point width. With Coniflex Plus cutters, the first and second flanks are cut with the same blades (Ref. 1).

The yellow line in Figure 1 marks the maximal radius the cutter blades can accommodate. The green line shows the maximum cutting-edge radius possible before mutilation occurs. The blue line tells that edge radii larger than the numbers printed will cause interference. The last line highlighted in purple shows the effectively chosen blade edge radius. As a

rule of good practice, the blade edge radius should be smaller than the lowest of the highlighted line above. In Figure 1, the chosen blade edge radii are too large.

The effects and rules regarding mutilation, interference, and maximal cutter blade radius are not only applicable to straight bevel gears but equally valid for spiral bevel and hypoid gears. The Gleason *GEMS* software calculates the maximum recommended radii precisely; however, some exceptions can be made based on the analysis of the Dimension Sheet data by a gear engineer. For example, tip relief, or Toprem, allows for slightly larger than recommended radii.

Maximal Cutter Blade Radius

The first highlighted line in Figure 1 shows the maximal cutting-edge radius the outside and inside blade can have to machine a fully rounded root. This is the maximal radius that can be used without the risk of a “Gothic arc” blade tip and root bottom. The condition of using the maximal possible radii that fill out the entire root with a theoretically perfect blend with the flank surfaces is visualized in Figure 2 and can be calculated as follows:

$$WROW = WP / [(\cos \alpha_1 + \cos \alpha_2) - (1 - \sin \alpha_1) \cdot \tan \alpha_1 - (1 - \sin \alpha_2) \cdot \tan \alpha_2]$$

Whereas:

- WROW... Blade edge radius
- WP... Blade point
- α_1 ... Inside blade pressure angle
- α_2 ... Outside blade pressure angle

MEMBER	PINION	GEAR
CUTTER RADIUS	4.500 "	4.500 "
SYM. RACK GEAR POINT WIDTH		2.33 mm
CALC. GEAR FINISH. PT. WIDTH		1.99 mm
GEAR FINISHING POINT WIDTH		1.82 mm
PINION ROUGHING POINT WIDTH		
OUTER SLOT WIDTH	3.24	3.01 mm
MEAN SLOT WIDTH	2.19	2.00 mm
INNER SLOT WIDTH	2.14	1.99 mm
FINISHING CUTTER BLADE POINT	2.13	mm
MAX. RADIUS - CUTTER BLADES	1.45	1.35 mm
MAX. RADIUS - MUTILATION	1.45	1.37 mm
MAX. RADIUS - INTERFERENCE	1.21	1.21 mm
CUTTER EDGE RADIUS	1.40	1.40 mm

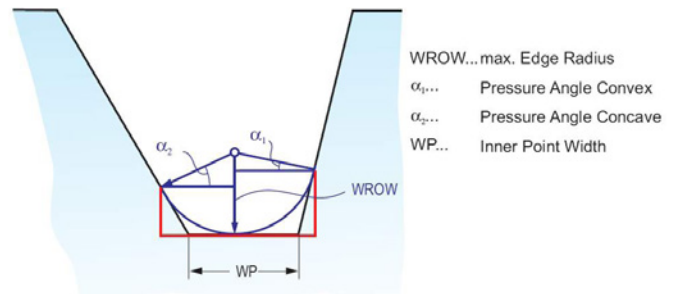


Figure 2—Maximal blade edge radius for a fully rounded root.

Figure 1—Maximal limit blade edge radii.

Mutilation Limit

Mutilation happens if the clearance side of a blade leaves a scratch or even a notch in the opposite flank, which is not cleaned up when the opposite flank is generated. The cause of mutilation is an oversized blade top width and/or a sharp corner on the clearance side blade tip, as shown in Figure 3. The mutilation effect in Figure 3 will slide higher up into the flank surface while generating the profile.

The mutilation lines in Figure 4 are typical for straight bevel gears machined with two tool generators. The blade segments that are used in two tool generators always have sharp corners on the clearance side tip. It is recommended to use blades with a small overlap in the center of the root. However, manufacturers like to use the same blade segments for a variety of different designs that have the same pressure angle.

This often leads to a large blade top width overlapping up to the point where the clearance edge cuts scratches or ridges in the opposite flanks. The mutilation lines are found in and above the root fillet.

Coniflex cutting with interlocking solid cutters on older cradle-style machines also leads to the same problem. These cutters always have sharp clearance side tip corners without

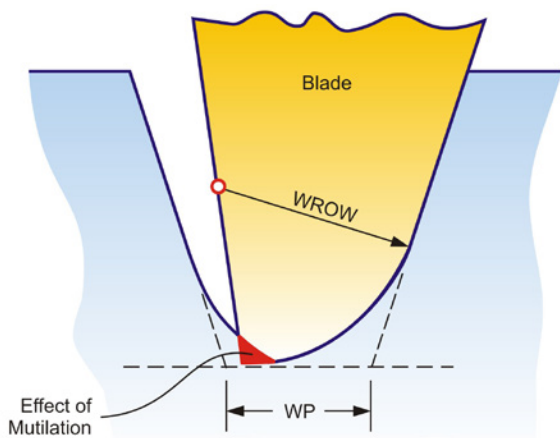


Figure 3—Sharp blade clearance corner causing mutilation.

any radius. Trying to use the same cutter for a certain job variety often exceeds the point where the top width of the cutter blades is equal to the point width (equal slot bottom width).

Mutilation commonly does not lead to interference because the mutilation lines or scratches represent a stock off condition. However, if these scratches are within the flank surface working profile, then a sliding of the opposite member top land corner across the scratches might be possible and would result in a certain mesh disturbance.

Interference Limit

Interference occurs when a disturbing step is at or above the transition between the root fillet and the flank surface. If the blade cutting edge radius, according to Figure 1, is larger than the maximum recommended value, then the most common interference is created.

If a root fillet transition is inside the active working depth, as shown with the blue profile in Figure 5, then an interference zone has been created. The green drawn fillet radius in Figure 5 indicates the maximal acceptable radius, which has its transition to the flank surface below the working depth.

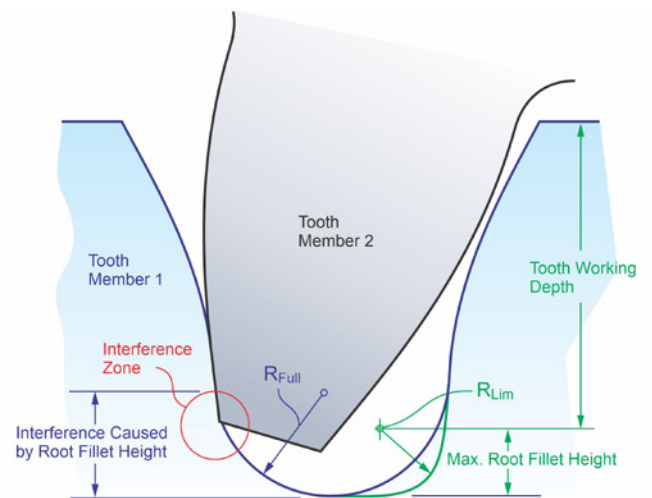


Figure 5—The interference phenomenon.

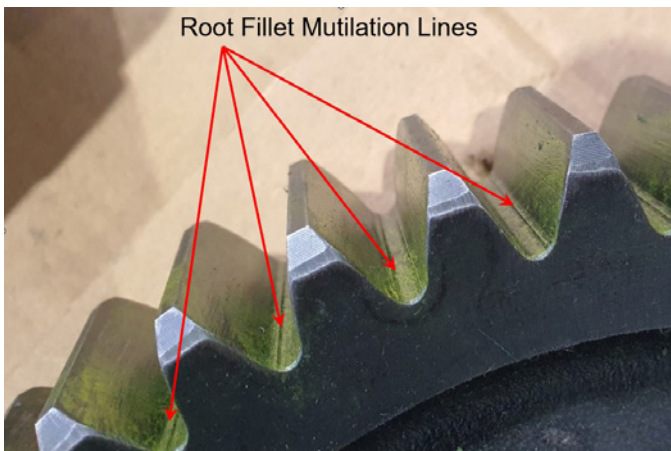
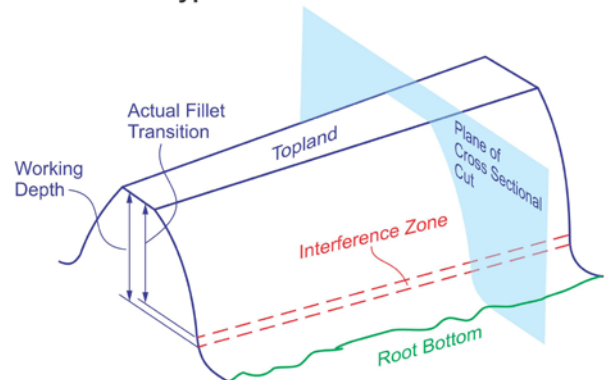


Figure 4—Mutilation lines.

Typical Fillet Interference



In Cases of high Contact Ratio and Profile Crowning the Interference might not be visible on a Roll Tester but only under Load.

Figure 6—Critical interference zone.

The location and extension of the interference zone is depicted in Figure 6. Before any damage is visible in the interference zone, it is typical to detect noise on a roll tester and to obtain a larger motion error than expected. Often, interference cannot be detected visually after rolling the gear set on a tester. In this case, a single flank test might show larger-than-expected errors. A fast Fourier transformation (FFT) of the single flank results will show a first harmonic amplitude that is larger than the motion error amplitude from the design calculation.

At the interference limit, when no interference can be detected in a roll test, only small deflections or assembly tolerances will make the interference audible, and after some rolling, also visible.

Visible interference lines of a straight bevel gear that has been cut on a two-tool generator are shown in Figure 7. These lines are within the interference zone. Below the interference lines, steps are visible mainly on the right side of the root fillet transition. The steps indicate that the cutting depth of the two blades in a two-tool generator had been adjusted differently. The left side blade was adjusted deeper and formed the right-side root fillet. The right-side blade started with its root fillet radius about 0.5 mm higher and was not able to form its root fillet radius all the way to the deepest root line.

It appears as if the interference lines at the right-side flanks are within the starting fillet radius, which the right-side blade could not finish because it was not adjusted deep enough. This blade and machine setup error caused the typical interference as shown in Figure 5.

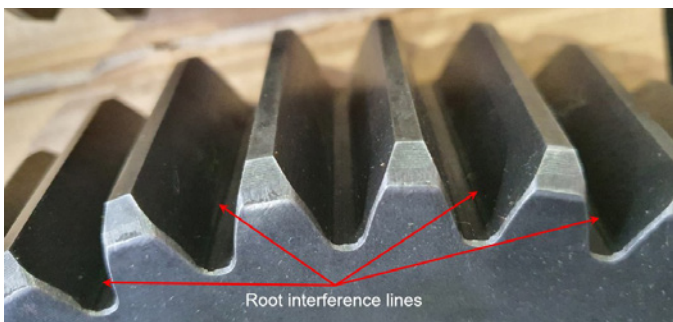


Figure 7—Visible root interference lines and steps.

Consequences of Interference Noise and Failure

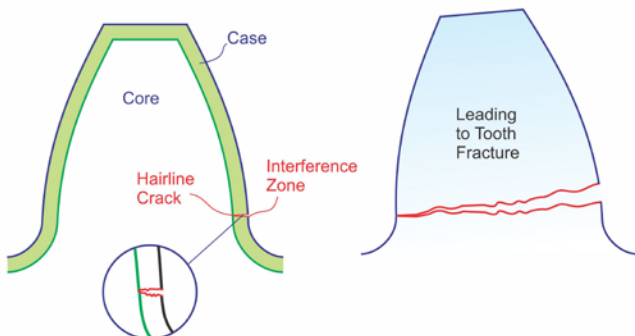


Figure 8—Tooth fracture initiated by interference.

The Consequences of Interference

It appears that straight bevel gears, manufactured with two-tool generators as shown in Figures 4 and 7, have been designed with their blade edge radii at or above the interference limit. Although the root fillet looks cleaner with the larger blue fillet radius in Figure 5 and suggests higher bending strength, the reality is different.

The result of an interference is often failure after many service hours of a straight bevel gear transmission. Some small interferences can polish out and “heal themselves” during the first 20 to 100 hours of service. If the interference is more severe, the first scratches within the upper area of the root fillet become visible after a break-in of the gear set. During some fraction of the calculated lifetime of the gear set, the scratches will initiate the population of hair cracks in the case depth, most commonly in profile direction. Over time, the load cycles make the hair cracks grow, which results in some cases in tooth fracture (see Figure 8).

What looks like a smooth and fully rounded root radius can reduce the strength and lead to a catastrophic failure if the chosen radius is larger than the interference limit radius.

The root fillet step problem, which was discussed in connection with Figure 7, is investigated further with Figure 9. Figure 9 shows a profile that is very similar to the real profile in Figure 7. If the 30-degree tangent to the root fillet is drawn into the profile, then the tangent point is at or close to the point with the highest notch effect. The 30-degree tangent

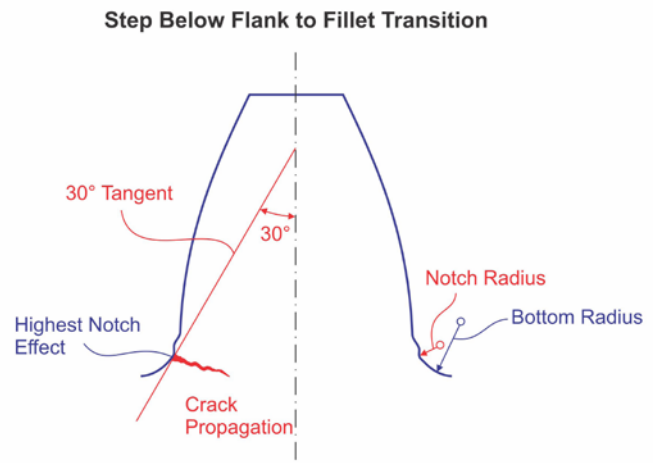


Figure 9—Tooth fracture initiated by steps below the root transition.

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has been proven in numerous finite element calculations and in the analysis of real-world fractures to be the point with the highest risk of a tooth fracture.

This means that imperfections in the root fillet transition, as shown in Figures 7 and 9, can cause tooth fracture if the gear set is used in a power transmission. A fracture, as shown in Figure 9, is independent of an interference problem. However, because interferences and root transition steps have been observed together on the same gears or pinions, it should alert gear engineers when root transition steps are recognized. Steps and fins at the bottom of the root are rather harmless. They are far enough away from the 30-degree tangent and are merely an aesthetic disturbance.

Straight Bevel Gears with Coniflex Plus

For common designs with a face width that is equal to or smaller than 26 percent of the cutter radius, the root width is the smallest at the toe and the largest at the heel. In case of larger face widths (smaller cutter radius), the root width between toe and heel has an hourglass shape, like in the photo in Figure 10. This makes the root width the smallest at midface, which is why the maximal blade edge radii in the Dimension Sheet are calculated, in this case, based on the midface slot width.

The straight bevel gear in Figure 10 has a fully rounded root at the center of the face width with small gables at the toe and



Figure 10—Fully rounded root at midface.

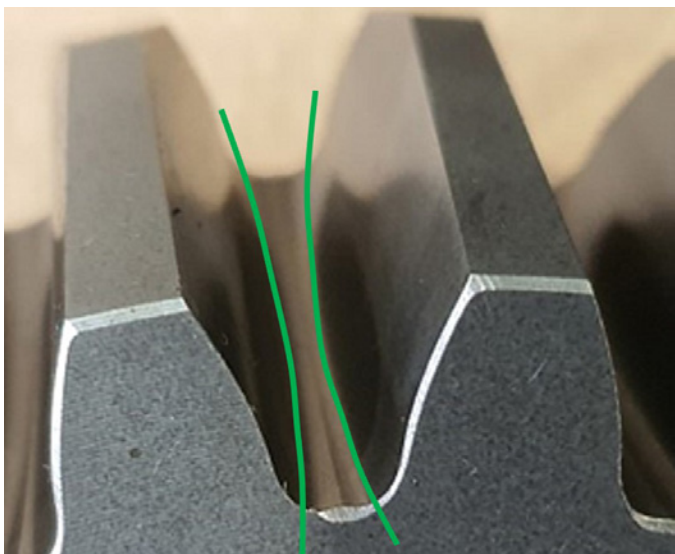


Figure 11—Hourglass root width provides a dam effect.

heel. The flanks are generated below the working depth without the potential of interference. This condition is superior to the flank and root appearance in Figures 4 and 7 of the same gear designs but cut with two-tool generators.

Strength Advantages due to Hourglass Effect

The hourglass effect in the root of straight bevel gears cut with Coniflex Plus cutters provides the shape of a dam. The dam effect is one of the reasons why the convex side of spiral bevel ring gears is preferred as the side with the major load (drive side).

The dam effect increases the root bending strength, which is proven with FEM calculations and field tests with spiral bevel and hypoid gears.

Blade Radii Optimization

For straight bevel gears, more than for spiral bevel gears, the criteria of kinematic undercut exist. The projected tooth in Figure 12 shows a gear tooth with the active working area drawn in blue. Both the lost area above the pinion root and the lost area above the gear root should be avoided. First, the question of the nature of the lost area must be answered. Possible causes are:

- Edge radius too large—causes interference
- Kinematic undercut—causes possible interference
- Physical undercut—weakens teeth but causes no interference

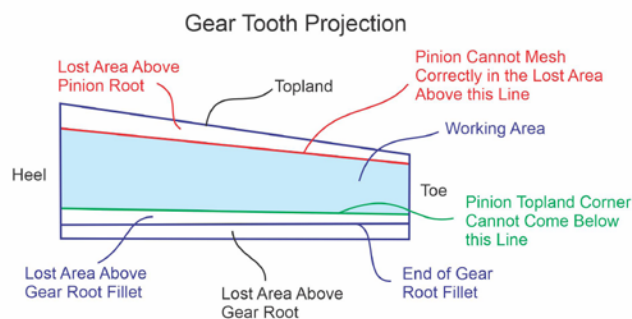


Figure 12—Lost working areas drawn in gear tooth projection.

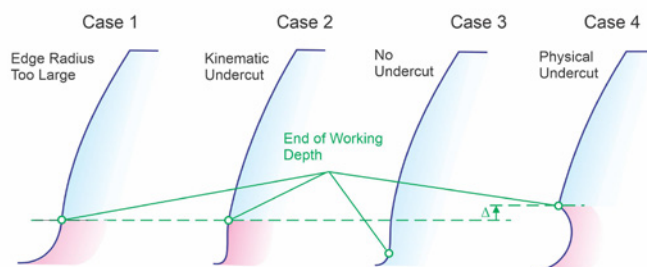


Figure 13—Lost working area.

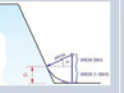
Maximal Radius Blades Pinion/Gear [mm]	Mutilation Limit Pinion/Gear [mm]	Interference Limit Pinion/Gear [mm]	Top-Root Clearance Pinion/Gear [mm]	Optimized Blade Radii Pinion/Gear [mm]
				
1.49/1.80	1.84/2.00	1.87/1.87	1.49/180	1.49/1.80

Figure 14—Final choice of edge radii and clearance.

The lost areas in Figure 12 indicate the three fundamentally different mesh deficiencies, listed above. The first lost area between the top-land of the gear and the red border line exists because the gear top-land corner will not mesh above the red line. The second lost area between the end of the gear root fillet and the green line exists because the pinion top-land corner will not mesh below the green line. In both cases of lost area, either the edge radius of the blades is too large, or a kinematic undercut or physical undercut exists.

A distinction between physical undercut, kinematic undercut, or interference due to an oversized blade edge radius is difficult in the design stage. The graphics in Figure 13 propose a procedure that reveals the reason for a lost dedendum (root) area. If the edge radius is too large, then it limits the working depth (case 1). When the edge radius in the calculation is changed to a small value, for example, 0.1 mm, and the lost area in Figure 12 stays the same, then a kinematic undercut exists (case 2). If the end of the working depth drops down and matches the end of the gear root fillet in Figure 12, then the blade edge radius was too large, or the clearance is too small (case 3). An increase in the lost area after reducing the edge radius reveals a physical undercut (case 4) (Ref. 2).

Reducing or eliminating kinematic or physical undercut can be achieved with an increased pressure angle or a larger profile shift. However, restrictions regarding pressure angle or profile shift exist because both reduce the top-land thickness and the root width.

To come to a final choice of suitable blade-edge radii, the Table in Figure 14 was created. Basically, it follows the recommendations from the Dimension Sheet. The smallest

radius of the three limit radii in the Dimension Sheet should be selected:

- Maximal Radius Cutter Blades
- Maximal Radius Mutilation
- Maximal Radius Interference

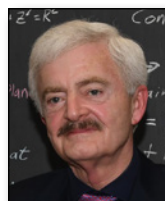
An important additional criterion is the top root clearance, which should have the same value as the blade edge radius. Because the maximal permissible edge radii are mostly different for pinion and gear, the *Coniflex Pro* software has separate input values for pinion and gear clearance. If the clearance is lower than the edge radius, an interference will occur, although the edge radius is below the interference limit. The clearance amount should not be below the maximal root fillet height shown in Figure 5, which is approximately equal to the blade edge radius.

In some cases, for strength reasons, or because the same cutter should be used across a variety of different job designs, the edge radius must be larger than recommended in the Dimension Sheet and in Figure 14. The solution to this conflict is to apply top relief on the teeth of the pinion and gear. Top relief can be realized by a simple top-land chamfering or by applying a kinematic top relief. The kinematic top relief for *Coniflex Pro* is integrated in the generating cycle and requires no additional machining time.

Summary

Root interference is a common problem not only for straight bevel gears but also for cylindrical gears, as well as for spiral bevel and hypoid gears. Interferences are often difficult to detect, but their influence on the performance of a gear set is significant. Interference lines and increased single-flank errors are, in many cases, only present if deflections under load are applied. Even the smallest interference leads to noisy operation and often causes flank surface damage or tooth fracture.

The Gleason Dimension Sheet shows what the maximally permissible blade edge radii are. The gear engineer who designs a new bevel gear set should select the smallest value of the three different limit radii for the cutter edge radius. In addition, attention has to be paid to the top-root clearance. If this value is too small, then an interference will still occur, although the blade edge radii have been chosen correctly.



Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany.

Gear Technology Solutions continues and completes his 2019 work, *Practical Gear Engineering*. Recently awarded a patent for MicroForm, the innovation marks his 70th patented invention.

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2. Stadtfeld, H.J. "Practical Gear Engineering—Answers to common Gear Manufacturing Questions," Company Publication, The Gleason Works, Rochester, New York, 2019, ISBN 978-0-578-46376-6, Pages: 107–116.

Forest City Gear

CELEBRATES RETIREMENT OF JEFF MAINS

Forest City Gear announced the retirement of Jeff Mains, director of technical operations, following many years of dedicated service and leadership within the company. Mains's transition from his full-time role went into effect on Friday, May 29.



Jeff Mains

Mains joined Forest City Gear in 2011 as a Manufacturing Engineer, where he reviewed customer prints and specifications, developed production routings, and helped support manufacturing processes through his expertise in machining, metallurgy, heat treating, and quality control. In 2012, he was promoted to Engineering Manager, overseeing the day-to-day management of the engineering team and providing leadership on technical initiatives and corrective action processes. In 2013, Mains assumed the role of Director of Technical Operations, where he led engineering and quality assurance initiatives, supported customer design engineers, managed vendor qualification systems, resolved quality concerns, and provided oversight on technical reviews and quoting processes.

Throughout his career at Forest City Gear, Mains became known as a trusted technical resource and problem solver for both customers and colleagues alike. His deep industry knowledge, calm leadership style, and unwavering commitment

to customer success played a critical role in supporting complex gear manufacturing programs and strengthening long-standing customer relationships.

“Jeff has been an incredible asset to Forest City Gear and to the customers he supported over the years,” says Kika Young, president of Forest City Gear. “His technical expertise, integrity, and dedication helped shape countless projects and partnerships across the industry. More importantly, Jeff brought a steady presence and genuine care to everything he did. We are deeply grateful for his contributions and the legacy he leaves behind.”

While Mains is retiring from his full-time responsibilities, he will continue supporting Forest City Gear remotely on a part-time basis during the transition period. In this role, he will assist with project handoffs, technical continuity, and onboarding support to help ensure a seamless experience for customers and team members.

Forest City Gear has been carefully preparing for this transition to maintain continuity, responsiveness, and the high level of technical support customers have come to expect. The company plans to formally introduce Mains's successor in the coming weeks.

On behalf of the entire company, Forest City Gear extends its sincere gratitude to Mains for his years of service, leadership, and friendship, and wishes him a happy and well-earned retirement.

forestcitygear.com

Klingelberg LAUNCHES GEARS FOR EARS PODCAST



The Klingelberg Group has commissioned its own podcast studio at its Hückeswagen site and is launching the new podcast series “Gears for Ears.” With this step, Klingelberg is establishing a professional audio format for

internal and external communication in the field of gear technology.

The decision in favor of a dedicated podcast format stems from the aim of conveying current topics, technological innovations and insights into the company in a contemporary, personal and at the same time technically sound manner. Podcasts offer a flexible medium for presenting complex content in an understandable way and making it accessible to a broad audience—from employees to customers, partners and industry stakeholders.

Under the title “Gears for Ears,” experience reports, background discussions and specialist knowledge relating to Klingelberg will be made audible in the future. The format reflects the growing importance of digital communication channels and underscores the company's ambition to explore new avenues in knowledge and information transfer.

Professionally equipped studio at the Hückeswagen site

For the implementation of the project, a dedicated room at the Hückeswagen site was converted into a podcast studio. Targeted renovation work and modern technical equipment have created a professional environment for high-quality audio productions. The pleasant and quiet studio atmosphere provides ideal conditions for focused and open conversations with guests.

Regular episodes focusing on technology and practice

From now on, a new podcast episode lasting 30 to 45 minutes will be released at regular intervals. In terms of content, “Gears for Ears” covers a broad spectrum of current, relevant topics, including:

- Use of artificial intelligence in manufacturing companies
- Challenges and solutions in industrial everyday life
- Insights into different corporate departments
- Innovations, technology and industry trends

The series is hosted by Dr. Christof Gorgels, vice president of technology

and innovation, who welcomes the guests and guides them through the discussions. In each episode, he talks with changing guests from within the company as well as with external experts. This creates a varied format that combines practical relevance, technical expertise and a culture of dialogue.

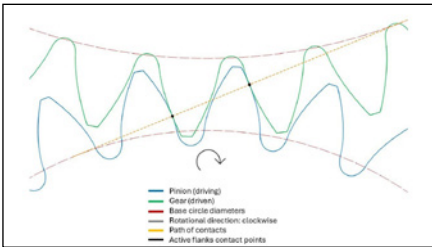
Availability on Spotify and YouTube

The “Gears for Ears” podcast series is available exclusively on Spotify and YouTube. All published episodes can be streamed there regardless of time and place. In Episode 01, Dr. Christof Gorgels welcomes Matthias Göken, director of operations, to discuss the current challenges in manufacturing.

klingelberg.com

MPMA

RELEASES NEW INFORMATION SHEET: ELECTRIFIED VEHICLE DRIVETRAINS



The Motion + Power Manufacturers Alliance (MPMA) announces the release of a new industry guideline addressing the rapidly evolving EV landscape: AGMA 948-A26, Electrified Vehicle Drivetrains. This provides industry guidance on electrified drivetrains for vehicles, including hybrid electric (HEV), battery electric (BEV or EV), or plug-in hybrid electric (PHEV) vehicles, with the prime mover power source or sources as any combination of battery, fueled ignition engine, and/or fuel cell. These can generally be referred to as xEVs.

“I was very pleased with the speed at which the group completed this project,” stated project leader, John O’Neil of Star SU. “We felt from the start that it was necessary to move quickly as the technology was evolving. It’s always a

pleasure to work with a group of dedicated individuals and companies willing to share their time and expertise with the Motion + Power community, especially on this project, as it covered a wide range of subject matter and vehicle types.”

The document addresses new technology in this space. The drivetrains covered include ground and marine applications such as passenger vehicle (car or light truck), heavy duty/commercial, construction, agricultural, mining, tracked, propeller/waterjet, and similar drivetrains.

“Having our first meeting in June 2024 and releasing a 74-page technically reviewed document in June 2026 is unprecedented at MPMA. The dedication of the individuals involved, along with the support of the member companies to sponsor those individuals, was the key ingredient to producing this information sheet in record time,” stated Todd Praneis, VP Technical, MPMA.

The document is now available in the MPMA store. It was distributed to MPMA member companies as part of their membership benefits.

motionpower.org

STLE ANNOUNCES STEFFEN BOTS AS PRESIDENT

The Society of Tribologists and Lubrication Engineers (STLE)—the technical society serving individuals, companies and organizations that comprise the tribology and lubrication engineering business sector—announced that Steffen Bots, vice president of global sales & R&D at ADDINOL Lube Oil GmbH, in Leuna, Germany, has assumed the role of 2026–2027 president for a one-year term beginning May 19.

Bots serves as the society’s principal executive officer and chair of its board of directors. During his one-year term, he will focus on education, international representation, and OEM and lubricant consumer participation with STLE.

“Steffen brings a powerful combination of technical expertise, visionary leadership, and deep commitment to the tribology and lubrication engineering

community,” said Rebecca Lintow, CAE, STLE executive director. “His longstanding involvement with STLE and passion for advancing our mission make him uniquely positioned to lead STLE into an exciting new chapter. We are confident his presidency will strengthen STLE’s impact, expand our reach, and inspire continued innovation in the field.”



Steffen Bots

Bots received his master of business administration and engineering degree from the Munich University of Applied Science. He is a frequent presenter at the STLE annual meetings and other industry conferences in North America, Europe, and Asia. In his current role at ADDINOL, Bots is responsible for global sales operations of the German lubricant manufacturer, which operates in over 120 countries with 15 affiliate companies and more than 90 distributors worldwide. His work focuses on technical sales support and market development, particularly in the Asia-Pacific region and North America through ADDINOL North America Inc. In addition, he oversees the strategic direction of the company’s R&D activities.

Joining him on the STLE executive committee for the 2026–2027 term are vice president Dr. William B. Anderson (Afton Chemical Corp.), secretary Peter Lee (Southwest Research Institute), treasurer Douglas Sackett (Dilmar Oil Co.), immediate past president Kevin Delaney (Vanderbilt Chemicals, LLC), and STLE executive director Rebecca Lintow.

stle.org

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JULY 15–16

WZL Gear Conference USA

The WZL Gear Conference USA will take place on July 15 and 16, 2026, at Klingelberg America, Inc. (Saline, MI). This renowned conference brings together North American companies with the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University and offers a compact overview of current developments and research topics in gear technology. Participating companies will have the opportunity to network with leading experts, discuss trends, and gain concrete insights to apply in their daily work.

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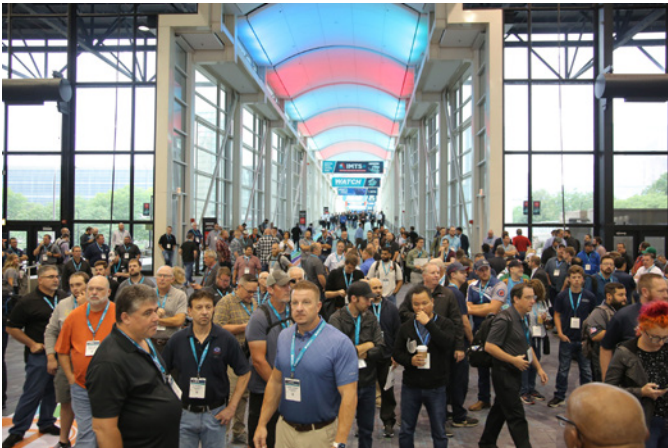
JULY 29–30

Advanced Manufacturing Expo (AME) 2026

The Advanced Manufacturing Expo (AME) (Grand Rapids, MI) is the premier gathering for professionals shaping the future of manufacturing. It's where innovation meets production — connecting industry leaders, cutting-edge technology, and real-world solutions under one roof. Explore the latest in automation, metalworking, MRO, safety and Industry 4.0 technology across four dynamic halls. From hands-on demonstrations to expert-led sessions, AME provides smarter, faster, and more efficient manufacturing solutions. Watch Autonomous Mobile Robots (AMRs), autonomous forklifts, and emerging humanoid robots perform real material-handling and manufacturing tasks in a dynamic, real-world environment in the live demo area.

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SEPTEMBER 14–19

IMTS 2026

The largest manufacturing technology trade show in the Western Hemisphere (Chicago) and among the largest in the world, IMTS attracts nearly 90,000–130,000 attendees from over 112 countries. Pavilions include Gear Generation, Additive Manufacturing, Machine Components, Metal Cutting & Machining Centers, Tooling & Workholding Systems, Controls & CAD-CAM and Quality Assurance. From quality and inspection to process optimization, downtime reduction, cybersecurity, ergonomics, safety, and demand forecasting, the Industrial AI Arena showcases breakthrough tools, prototypes, and platforms — real solutions that redefine what's possible on the manufacturing floor.

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SEPTEMBER 22–24

TPS (Turbomachinery & Pump Symposia) 2026

TPS (Houston) is a vital industry event, offering a forum for the exchange of ideas between rotating equipment engineers and technicians worldwide. Now surpassing 54 years, TPS is known for its impact on turbomachinery, pump, oil & gas, petrochemical, power, aerospace, chemical and water industries through two pathways: an exhibition and a technical program. The TPS technical program is hand-selected by advisory committees made up of key industry players and led by highly respected practitioners and leaders in their fields. Topics cover maintenance, reliability, troubleshooting, instruction on emerging designs, technology, and best practices that include case studies with real-world relevance on problems solved and lessons learned.

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GEAR TOOLING

Barber Colman 6-5 & 10-12 & HSC Index
Plates

Gleason Index Plates, Lift Cams, Drop Cams
and Genevas for Models 605 – 610

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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Firetruck

Aaron Fagan, Senior Editor



Charles Ray, *Firetruck*, 1993; painted aluminum, fiberglass, and Plexiglas; 144 × 96 × 558 in. Photo by Joshua White / JW Pictures. Courtesy of the artist, Matthew Marks (New York and Los Angeles), and Jeffrey Deitch (New York and Los Angeles). Collection of The Broad Art Foundation. © Charles Ray

In light of the United States' semiquincentennial, few images are more quintessentially American than a Fourth of July parade with bright red fire engines. There's a Charles Ray sculpture that caught my attention—owned by The Broad and rarely on view, but recently shown indoors, of all things, at Jeffrey Deitch Gallery in Los Angeles—titled *Firetruck* (1993). It's a child's toy fire engine built at the scale of a real one. Is this a real fire engine that has become a toy, or is it the other way around?

Ray reads a cultural object down to its engineering and then sets it just slightly wrong against the world, so that one might notice the world more and the object less. We have all noticed things that somehow feel a bit off in a way we can't quite explain. These moments rouse our attention from its automatism, curing us of a numbness to our surroundings, however briefly, allowing us to see what we had stopped seeing. The term for this technique is *ostranenie*, meaning *defamiliarization* or, more specifically, making what is familiar strange and what's strange familiar.

Part of how *Firetruck* sits wrong is that it is gloriously hollow. The materials list is modest: painted aluminum, fiberglass, and Plexiglas. A form that promises an entire machinery of

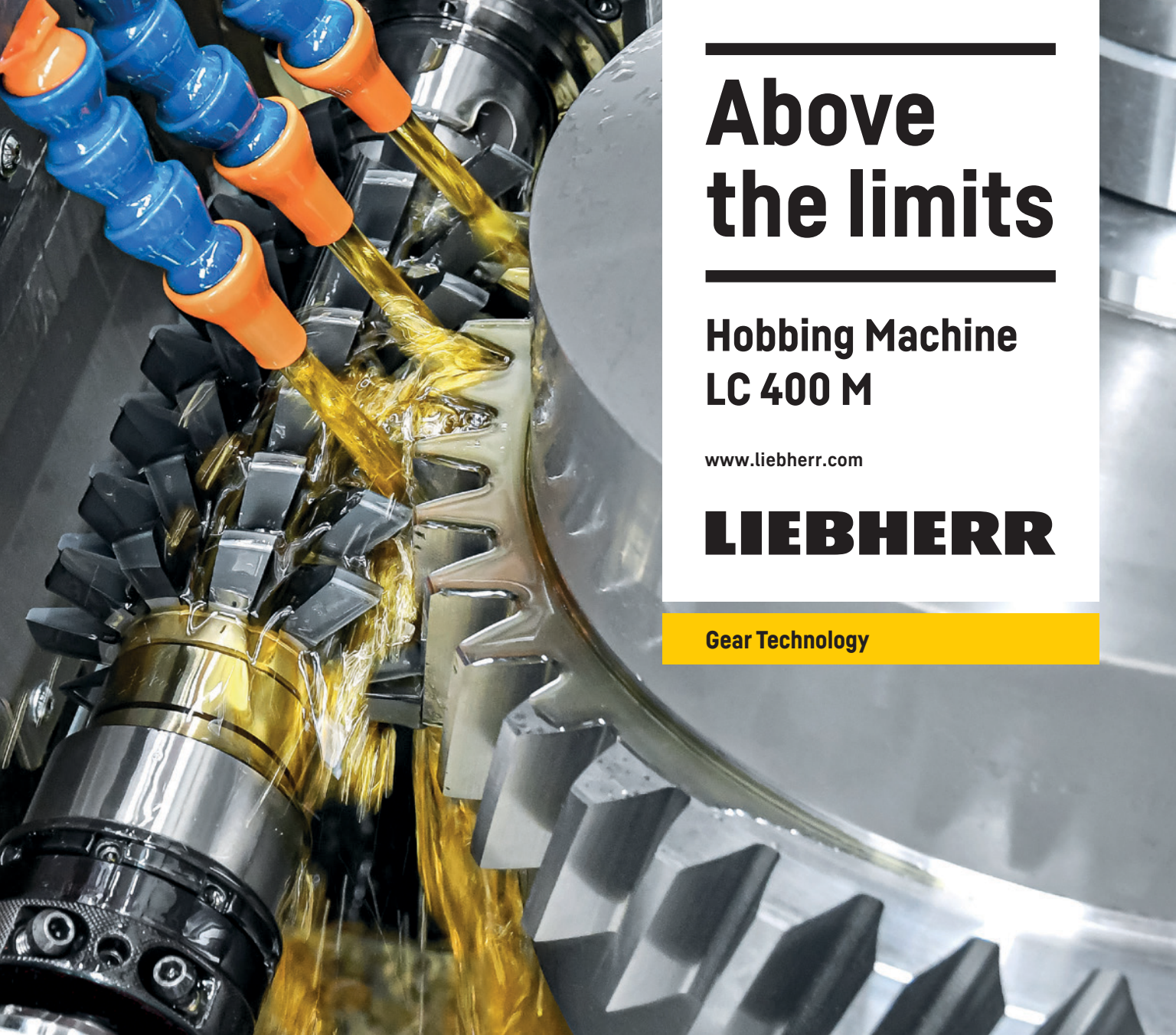
function and then doesn't contain any of it. A fire engine with no engine. Imagination fills in the blanks because some part of us knows what a fire engine is supposed to be.

Suppose Ray had built the engine. Suppose the gears were in there, cut and meshed and correct, turning nothing. Real gears but toy gears. The meaning of a gear is contingent on its function within a whole; alone, it is a beautiful, useless artifact. So while the gear is a part without a whole, *Firetruck* makes me see the other side; it is all whole and no parts.

Ray has been resistant to showing *Firetruck* indoors up to now, suggesting it was meant to live outdoors and weather "like a toy abandoned in a sandbox," as Deitch Gallery put it. A toy left out long enough stops being a toy at all. And so it is with our country, old at being young and new at being old.

Two hundred and fifty years on, the United States has weathered into something true. We are old enough now to know there is something hollow at the heart of the American Dream and to love it anyway, because we know exactly what we pour into it. Not a plaything outgrown, but a thing made real by being left out long enough to take the weather.





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