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Star SU carries a line of FFG Modul chamfer/deburring machines that best suits your requirements, whether you opt for a standalone machine (CD 250), an automated solution for your line (CDA 250) or a flexible all-in-one (CDX 250).

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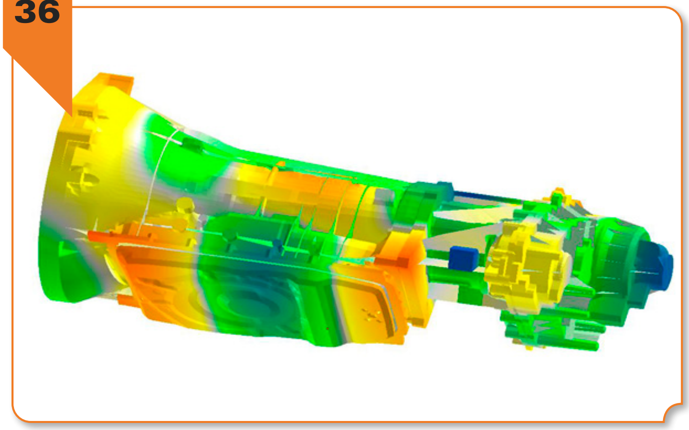

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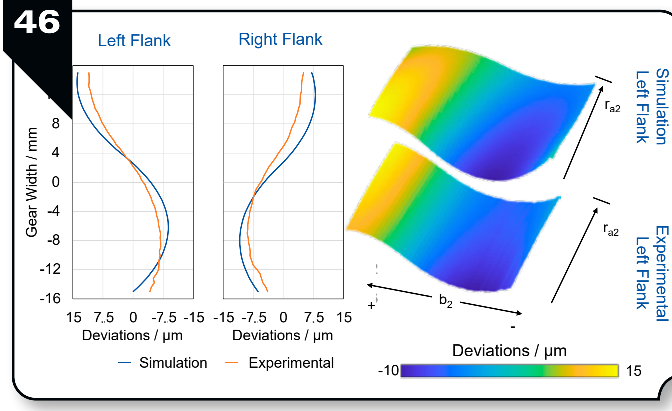

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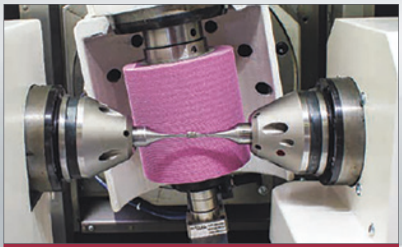
BZ Series Profile and Generating Grinding Machines

FINISH IN FIRST

In the race for more gear grinding speed and precision, who can afford to finish second?

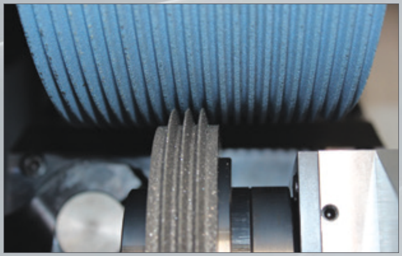
The new generation of German-built Burri Profile and Generating Grinding Machines from Machine Tool Builders packs versatile performance into a series of highly economical platforms. Every model delivers faster chip-to-chip times with generating grinding, automation, and on-board dressing options. For workpieces up to 300 mm in diameter, the BZ300 offers profile grinding as well to produce custom precision gears with special features.

To finish first, start at Machine Tool Builders.



BZ70: Double-spindle design for fast genernative grinding of smaller workpieces.

BZ300: A single platform for profile, generating and worm grinding.



A multitude of on-board dressing options.

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GT Videos

Fanuc Collaborative Mobile Machine Tending

Fanuc demonstrates mobile machine tending. This mobile manipulator solution is produced by Capriol and features a Fanuc CRX-20iA/L collaborative robot integrated with an Otto 100 Autonomous Mobile Robot (AMR). The mobile manipulator demonstrated autonomous, on-demand tending of a Robodrill vertical machining center, feeding blanks into the machine via a magazine and removing machined parts via a basket.

geartechnology.com/media/videos/play/269

Helios Gear School

A quick look inside the 2023 Helios Gear School in South Elgin, IL. These gear school seminars and clinics are designed for entry-level gear manufacturing personnel including manufacturing management, engineers, supervisors, set-up technicians, operators, and quality control.

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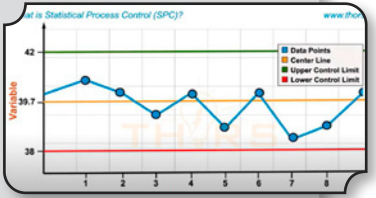
Thors eLearning Examines Statistical Process Control



What is Statistical Process Control (SPC)? Find out in this preview for the SPC Basics course from Thors eLearning Solutions. Thors offers a growing library of online courses, custom course services, and productivity tools for OEMs and suppliers in manufacturing across the globe.

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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 38 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 *michael@geartechnology.com*.

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Streaming Now to a Device Near You

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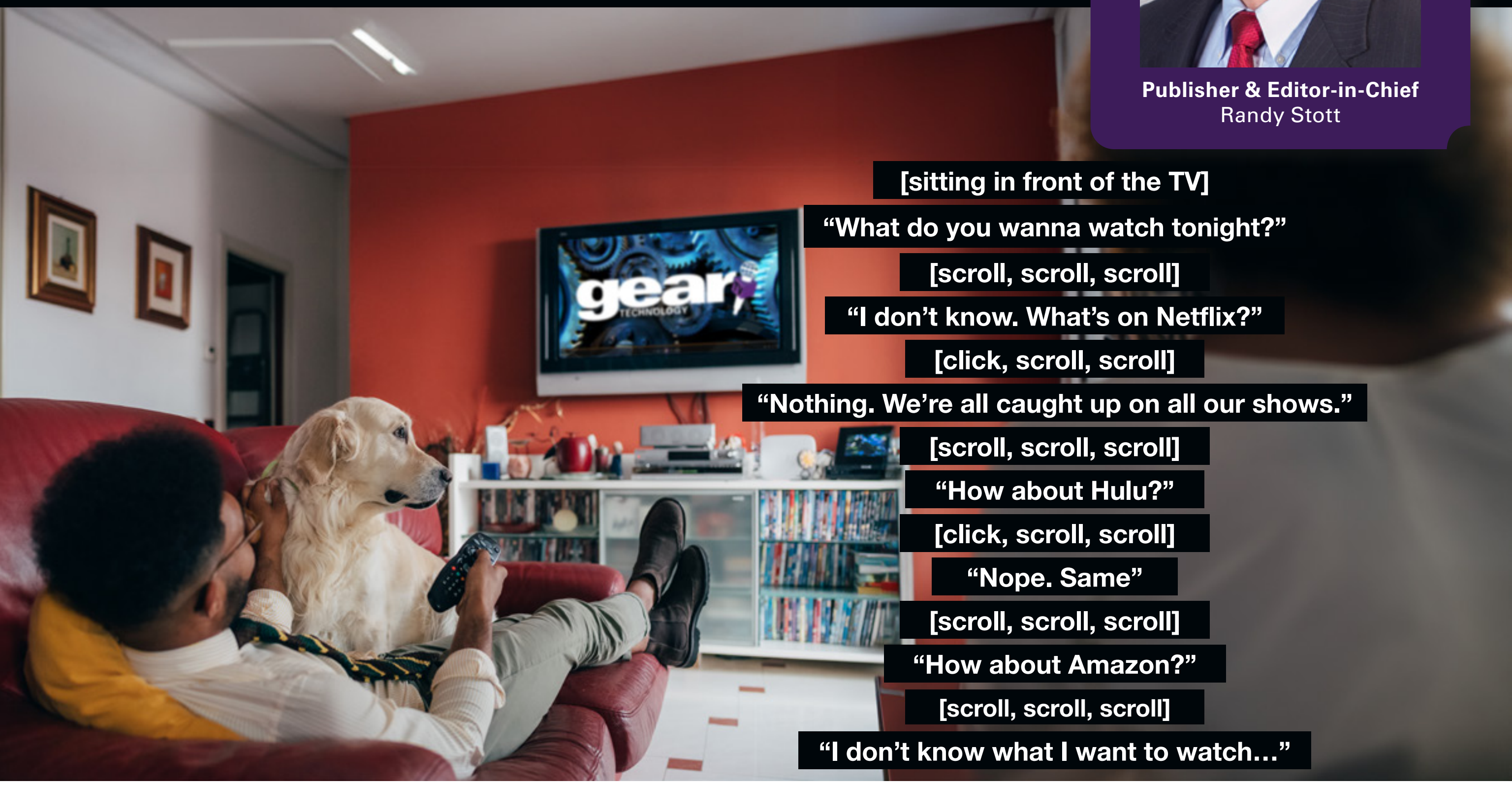


If this sounds like your household, have I got a solution for you: *Gear Technology TV*.

OK, maybe you won't find any crime dramas or romantic comedies or dark sci-fi (because—see above—you've already watched all those). And, no, we don't have a gear-related reality competition series (yet!) But we do have a lot of really cool videos about gear design, manufacturing, inspection, heat treating and more.

Gear Technology TV is the home for original gear-related content created by our editors in conjunction with a lot of really smart people in our industry whom we've had the pleasure to interview on camera or include in one of our discussion panels.

For years, we've been building our library of video content, and we've just added a bunch more.

The latest examples are the videos we recorded at MPT Expo in October, including our live expert discussion on "The Future of Gear Manufacturing" (featuring Joel Neidig of ITAMCO, John Perrotti of Gleason Corporation, Carlos Wink of Eaton Corporation and Dr.-Ing. Karsten Stahl of the Gear Research Centre (FZG) at the Technical University of Munich).

In fact, if you go to *youtube.com/geartechnology*, you'll see that we have a whole playlist devoted to the various "Ask the Expert Live" sessions we've held over the years. You might also be interested in this year's discussion on manufacturing EV Gears (featuring Pascal Diggelmann of Reishauer, Dr. Oliver Winkel of Liebherr and Dr. Hermann Stadtfeld of Gleason), or maybe past discussions on "Gear Design," Cutting Tools" or many other topics from our panel discussions in past years.

In addition, you'll see we have a playlist devoted to our many "Revolutions" interviews, where our editors sit down one-on-one with the technology experts in the field to learn about the latest innovations that can help you make better gears, faster, or at a lower cost.

If you didn't make it to MPT Expo, this is a great way to catch up with some of the machine tools, workholding, cutting tools, grinding wheels, software and other technologies that were on display. Maybe you can learn about a new potential supplier or better understand how new technology might fit in your business.

In any case, there are many hours of significant educational content available on *Gear Technology TV*. I hope you'll go and watch some of it.

In the meantime, we'll keep working on those pilot episodes. I think "Undercover Gear Engineer" and "Gear Shop Makeover" could be huge hits!

Randy Stott

ANCA

MX7 LINEAR ASSISTS CLORTECH WITH TOOLING NEEDS

Founded in 1987 by Clorindo Mattei, Clortech Precision Cutting Tools is a family business with wife Carmela handling bookkeeping, while son Patrick is the vice-president of production and sisters Emilia and Mena are the managing director and quality assurance director respectively. The company is a Montreal manufacturer of custom precision tools that sells to various industries including aerospace, recreational vehicles, rail and automotive. Products include shafts, gauges, broaches, bushings, extra-long reamers, special diameter formed end mills, special contouring tools.

In the '80s and '90s, business was made up entirely of aerospace customers. However, events like 9/11 and the global financial crisis, showed how temperamental that sector could be and prompted diversification beyond it. With its high-performance holemaking tools, including drills and special end mills, Clortech expanded into the automotive industry. It also provides drills for rail and tie installers, as well as tools (reaming, milling and holemaking) to help the Canadian Armed Forces in the maintenance and overhaul of tanks and other military equipment. Besides MRO tooling services, they also offer regrinding and reconditioning services to old tools and kit inventory services. Their 360 degree Approach is aimed at companies that don't have the necessary resources or workforce to make their own tools, while the AOG 911 service produces or modifies aircraft tools with the shortest lead times.

Currently, the job shop is equipped with CNC lathes, milling machines, cylindrical grinders, tool and cutter grinders and six 8-axis NC ANCA grinding machines (two TG7 Plus grinders, two TX7 machines and two TX7 Linear machines).

While Clortech uses all of its ANCA machines, Patrick Mattei pointed out that more complex/ higher volume parts are manufactured on the ANCA MX7 Linear due to its speed, precision and software which is more detailed than older machines. The machines are used to make round tools such as: endmills, drills and reamers. Most are solid carbide, while some have carbide tips. All tools are manufactured to customer specifications.

Discussing what features stand out on the MX7 Linear, Patrick mentioned the Toolroom software, which allows them to simulate a tool before making it. This greatly reduces scrap. The program's integrated 3D graphics make on-machine programming easy, as grinding simulation is performed after any parameter change providing instant feedback. When they are satisfied with the geometry, operators take that program and put it on the machine to run it. "The simulation software and offline programming is a very strong feature allowing the machine to run while [operators] work on other programs for different parts that they will be running later. The versatility with lots of axes allow them to make the most intricate type parts." The importance of the software is further evidenced by the fact that raw materials are very expensive and hard to come by so the ability to run a 3D model of the tool beforehand makes a big difference. Most of the company's tools are designed from A to Z, offering a turnkey solution. The 3D model can be taken to the customer, and they can simulate the cutting conditions in their machine tool. Thus, Clortech can give the customer something before the actual part is delivered.

Recently, Clortech helped a customer in the automotive industry who was making dovetail type cutters. These cutters require an extremely high degree of precision, and the company couldn't maintain the tight tolerances. Clortech received the parts and reground them using the MX7. When completed, not only where the tools done within specification but the "product was better than what the customer was making themselves."

Before they started using ANCA, Patrick mentioned they were doing a lot of work on conventional machines. Challenges they encountered included capacity and precision. The machines ran continuously but couldn't match the speed and efficiency of a CNC grinder. Another challenge was having enough people to work the machines. With the integrated automation on ANCA machines, one operator can run more than one machine at once, making the company more profitable and efficient. Additionally, Clortech used to regrind 500–1,000 tools conventionally each year. With CNC machines, they are regrinding 1,100–1,500 each year. This is an efficiency improvement of 1,000 percent. Although the set-up time on a CNC machine is longer, the output efficiency outweighs the time it takes.

The company's first ANCA machine, a TG7 Plus Grinder, was purchased in 1997 after meeting Russell Riddiford at a trade show. At the time, Clortech was looking to purchase a machine and they chose ANCA because of its software features. Patrick believes ANCA machines symbolize efficiency and reliability, as the first one he purchased is still running smoothly.

Patrick considers ANCA "part of the family" and enjoys speaking to the same people who know the company and his needs. He can call ANCA and there is always someone he can talk to regarding software issues, and everything is always resolved in a timely manner. He added that "… if we want to do something on the machine that hasn't been done before, ANCA can even develop software for the product. They are always solution focused and working to figure out how to resolve any issue."

anca.com

Sandvik Coromant

COROCUT 2 OFFERS VERSATILE PARTING AND GROOVING TO STAY ON TRACK

Cutting tool and tooling system specialist Sandvik Coromant is upgrading its long-established CoroCut 1-2 parting and grooving concept. Improved stability, even greater flexibility, and significant productivity gains are just some of the benefits offered by the new CoroCut 2 system.

CoroCut 1-2 has long been a cornerstone of parting and grooving, and the concept's renowned versatility and reliability have made it a real asset to many a workshop. The concept is set to receive a major upgrade, which will see it renamed CoroCut 2.

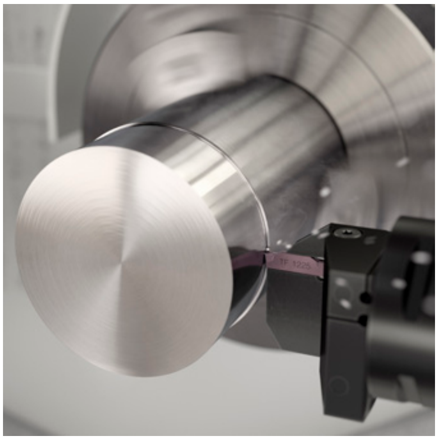
What can we expect from the new CoroCut 2? "For a start, all the features and benefits you have come to expect from the existing concept—versatility, cost-efficiency, and secure machining—are still there," says Jenny Claus, product manager, parting and grooving, at Sandvik Coromant. "We work in close cooperation with our customers, sharing our knowledge while striving to listen and be attentive to their needs and their constructive viewpoints. The result has been overwhelmingly positive."

Stability is key when working with all parting and grooving operations. The main challenge is keeping the insert in place to minimize all forms of insert movement. The well-established rail interface, previously available on medium and large inserts, offers more precise insert positioning and makes the insert resilient to any lateral forces exerted on it. This rail interface will now also be available on smaller insert sizes, guaranteeing stability in all operations.

CoroCut 2 parting blades are upgraded with internal coolant and an improved clamping finger design, which offers a higher clamping force and better side stability—a welcome advantage when making chamfers before parting off. Tool holders with precision coolant are updated with a screw clamp solution, which—combined with the rigid rail insert seat design—keeps insert movement to a minimum without any loss of clamping force.

Other important features included in the upgrade are new and updated grades and geometries, including the new first-choice grade GC1225, a wiper design for all parting geometries, and greatly enhanced edge line quality on all inserts.

"What makes this solution unique is the in-house developed and patented production technology," says Fredrik Selin, product application specialist at



Sandvik Coromant. "With better blank quality from our new production technology, we achieve less spreading of the edge line. This means we can have a lower tolerance and perform smaller edge rounding than before, with a longer, more predictable insert tool life as a consequence."

CoroCut 2 can be used in all types of parting and grooving applications with cutting depths suitable for double-edged inserts. The related CoroCut QD and CoroCut QF concepts are recommended for larger depths of cut, while CoroCut QI is the first choice for internal grooving and face grooving on small diameters.

sandvik.coromant.com

Jergens

ADDS ADAPTIX VISE JAWS FOR VERSATILE PART HOLDING

Jergens partners with Norgren to engineer the Adaptix vise jaw system into its line of production vises. The unique design—which incorporates sliding fingers with replaceable studs and fingertips—clamps challenging workpieces quickly and securely for machining. With this, Adaptix is mounted to the vise body in place of standard jaws to accommodate part configurations, adapting to asymmetrical and other features quickly.

The high gripping force ensures precision throughout the machining process. Once the lockable fingers have been adjusted to the workpiece, which takes only moments, the remaining parts are clamped in and out quickly and with high repeatability, resulting in more uptime and tight tolerances. Because these shapes can be set up very fast, Adaptix is well-suited for high-mix, low-volume applications including short production runs and prototyping. The moving parts of the jaws—fingers, studs, and fingertips—have been engineered for many thousands of actuations and are also easily field serviced if needed.

Adaptix offers a productive solution where soft jaws leave off. Often a choice when holding workpieces with unusual features, soft jaws perform well but require, among other things, a longer time to set up. In some cases, that is upwards of two hours, whereas Adaptix requires an average of approximately 20 minutes and offers superior accuracy and repeatability. Additionally,

this flexible system reduces the need for multiple soft jaws, helping to lower overall tooling inventories and associated costs.

Adaptix is designed so fluids and chips won't interfere with operation. The system's studs are available in different materials including aluminum and steel. Step profiles and other shapes provide gripping flexibility. The jaw system is compatible with industry vises such as Jergens 6" production vise. Packages with vise and jaws, or Jaws only, are available.

jergensinc.com

GMTA

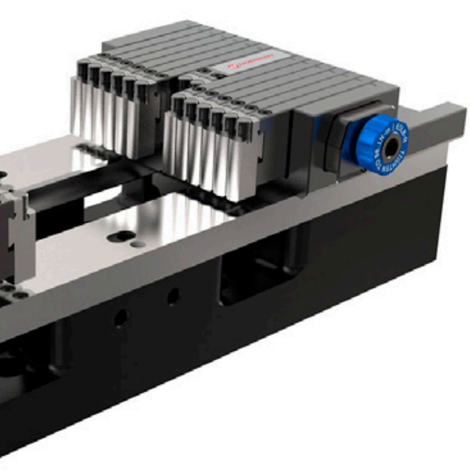
OFFERS PROFILATOR 300-V WITH LINEAR DRIVES TO NORTH AMERICAN MARKET

German Machine Tools of America (GMTA) is now selling Profilator 300-V with linear drives in the North American market.

This modular machine platform used to cut gears, is equipped with one or two workpiece spindles in a compact design. It offers maximum flexibility due to modular design and is individually configurable for various machining processes (i.e., Scudding, hobbing, cycloidal milling, pointing, chamfering, and deburring). State-of-the-art linear drives in the x and y axis, as well as a torque drive in the a axis offers high machine dynamics for short cycle times and maximum accuracy/low costs. High machine rigidity is available for Hard Scudding of inner and outer diameters.

Additional features include an intuitive user interface for easy setup and programming and is Industry 4.0 ready (optionally equipped with additional sensors). Various automation concepts are easily adaptable. The 300-V is easy to set up and maintain due to the "walk-in" machining area. An optional tool charger is available for maximum machining efficiency.

All Profilator machines are designed for dry machining. This brings several advantages such as: an optimized machining area, no coolant, and no coolant mist. The inverted, vertical spindle(s) allow free chip fall into the central chip conveyor at the bottom, while no coolant means no washing of the workpiece is required and the lack of coolant mist signifies an extraction system isn't needed.



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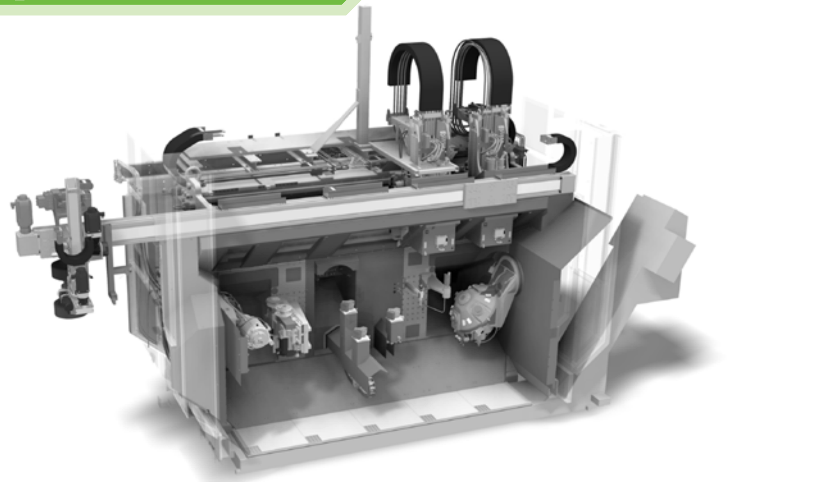


Users of the Profilator 300-V reap benefits regarding the environment, energy efficiency, investment and operating costs. There is no carryover of the coolant outside the machine. Therefore, no disposal is required for this environmentally friendly machine. It saves energy and money by not requiring a coolant and extraction system. Lower operating costs are achieved thanks to a reduction in energy costs and media supply.

gmtamerica.com

Jorgensen

INTRODUCES NEW CONVEYOR, FILTRATION AND COOLANT SOLUTIONS

Jorgensen Conveyor and Filtration Systems showcased several conveyor, filtration, and coolant system solutions on the national level in early October with two stops at major manufacturing shows. Visitors to the Wisconsin Manufacturing & Technology Show 2023 (WIMTS) experienced demonstrations of the company's Will-Fill automated coolant solution, FlexForce high-pressure coolant system and Auger Assist conveyor. Jorgensen also featured several conveyors with the enhanced, first of its kind, EcoFilter 80 filtering solution at Mazak's Discover 2023 event.

In a partnership forged with Belgian-based Will-Fill late last year, Jorgensen provides customers a revolutionary Will-Fill add-on solution that offers trouble-free care and monitoring of metalworking emulsion. The system combines automatic measuring, filling, conditioning, and reporting. Will-fill systems provide a quick ROI in applications machining high-value parts requiring a high level of precision and accuracy such as within the aerospace and medical industries.

WIMTS attendees watched the Will-Fill system, linked to a high-performance control unit, regulate machining fluid level and condition automatically. Alternatively, Will-Fill can alert operators via Wi-Fi capability when attention is required. The system easily adapts to Jorgensen's robust line of filtration systems or retrofits onto customers' existing coolant systems.

Jorgensen also featured its advanced FlexForce high-pressure coolant system with variable flow rates from two to eight gallons per minute (GPM). The variable flow rate options for the high-performance through-spindle coolant system (TSC) adapt easily to a variety of applications to provide safe and efficient operation. A maintenance-friendly design incorporates an oil sight glass and oil drain chute and requires no partial disassembly for oil changes. The system's small footprint easily integrates with existing coolant systems. FlexForce's plug-and-play design allows it to be readily interchanged with the industry's standard high-pressure units. Unlike industry equivalent high-pressure systems with piston pumps and inconsistent pressure output, FlexForce uses Hydra-Cell diaphragm pumps as a standard feature for virtually pulse-free operation.

The standard eight-GPM flow rate and variable flow rate options are available in 500 or 1,000 psi configurations. They are designed to break through the heat-generated vapor barrier created at the cutting tool and workpiece interface that causes surface deformities and tool damage. Because FlexForce gets coolant directly to the cutting zone, it improves lubrication and heat dissipation as well as cutting speeds and feeds, chip control and part surface finishes. Standard units filter to 10 microns, with additional filtration options available upon request.

At WIMTS, shops with machine tools that utilize augers to discharge chips discovered how Jorgensen's Auger Assist Conveyor increases production by enabling machines to handle higher chip volumes. As a result, the Auger Assist's 48-in. discharge height allows for the use of larger collection bins, greatly reducing labor needed for chip hopper management. Seven inches of discharge height adjustment provide the flexibility to adapt to many different machine tool models. Additionally, the Auger Assist's chute is adjustable in 90-degree increments and can be arranged in three possible positions to accommodate any plant layout requirement. The unit features a coolant collection area and a drain plug to reclaim coolant. It can be used as a stand-alone solution or as the first step in an entire chip processing system.

The following week after WIMTS, Jorgensen joined Mazak for its immensely popular Discover 2023 where visitors from across North America gathered to see the latest advancements in machine tool technology and automation. In addition

to displaying conveyors on several Mazak Integrex and Ez Series machines, Jorgensen highlighted its enhanced industry-leading, two-stage chip removal and coolant filtration EcoFilter conveyor. The new EcoFilter 80 features an advanced filter box configuration that enables efficient filtration of fine chips to 80-micron nominal. The EcoFilter 80 is the first economical non-drum style conveyor below 100-micron filtration.

EcoFilter conveyors use a two-stage chip removal and filtration process that carries out large chips on a hinged or scraper belt. Fine chips flow with used coolant between the belt runs to a flow-through EcoFilter cell where they are separated from the coolant. Clean coolant is discharged to the coolant tank while filtered fines are brushed from the filter screen and flow to the bottom of the conveyor and out the discharge.

By dramatically reducing the number of chips that migrate to a machine tool coolant tank, the amount of downtime for tank cleaning and maintenance is significantly reduced while improving pump, tooling, and coolant life. The EcoFilter is environmentally friendly, uses no consumables, and the single-drive design reduces energy consumption. As a result, shops gain increased production and profitability. Jorgensen custom engineers EcoFilter conveyors for a variety of lengths, widths, heights, and incline angles. Additionally, current EcoFilter-ready conveyors can be considered for an EcoFilter 80 field retrofit.

jorgensenconveyors.com

Bega Special Tools

QUICK-HEATER CAN BE USED FOR MOUNTING, DISMOUNTING, AND PREHEATING

Bega Special Tools introduces a portable multi-purpose induction heater on the North American market. The MF Quick-Heater 3.0–3.5 kW can be used for mounting, dismounting and pre-heating purposes. Weighing less than 8 kg and fitting in a small carrying case, this easy-to-use but powerful tool is just plugged into the mains 230 V. It can be used in difficult circumstances where other systems are impossible to operate, for instance where there is little space to work in or where no open fire is permitted. The heater's flexible inductors are ideal for a large variety of parts with a maximum diameter of 120 mm. Application examples can be found in all types of industries.

Induction heaters are used for industrial heating of ferro-magnetic parts including bearings, sleeves, gears, inner rings etc. The portable, multi-purpose heater from Bega has a maximum power output of 3.5 kW. The new model is part of the MF Quick-Heater 3.0 series, varying from 10 kW to 44 kW capacity. "The MF Quick-Heater can be a real problem solver for dismounting jobs, but is also used for mounting and pre-heating purposes," says Richard Imbro, National Sales Manager for Bega in the USA. "It is very easy to use—just plug it into the mains 230 V. Here in North America, this is making it a very attractive device for small to midsize workshops. A lot of the heating equipment of similar technology come in 400 V or even 480 V, but smaller shops can't use this high voltage equipment, making the MF Quick-Heater 3.5 kW a perfect fit."

The heater combines a small generator with a flexible inductor that can be wrapped in or around a workpiece or both, offering a multifunctional solution for various shapes or sizes. The inductors can be used for parts with a maximum diameter of 120 mm and are suitable to heat to a maximum temperature of 180°C or 356°F. The parts are heated either extremely fast or controlled, depending on the application and purpose of dismounting, mounting, or preheating. The heater has four different heating modes. Two temperature sensors make it possible to measure the internal and external temperature of a workpiece. When this Delta-T function is enabled, the maximum preset temperature difference between two points can never be exceeded. Smart electronics take care of an optimal operation frequency. The heating process is displayed in a 4.3-in. touchscreen. A log function can save or export data via the USB connection.

"Induction heating is a highly efficient and eco-friendly method for industrial heating applications," says Richard Imbro. "There are many other reasons why to look at induction heating in comparison with conventional methods. Heating is controlled, fast and energy efficient. The quality of work is better and enhances machine up-time. Since there is no open fire, there is no polluting smoke or noise. Personal safety is also a serious point to take into consideration as heating no longer involves open fire, hot oil, or other hazardous methods."

Recent application examples include dismounting a sleeve or bushing from a pump used in the dredging industry. After 3.26 minutes the bushing was heated up to 143.5°C and could be pushed off the shaft. Another example is dismounting a coupling from the electric motor of a yacht. After 2.2 minutes the coupling was heated up to 101°C and could effortlessly be removed from the shaft. In the rail industry, sequential dismounting of wheel set bearings was required. Using the MF Quick-Heater, the first inner ring reached a temperature of 120°C after 105 seconds and could be pushed off. The second inner ring reached the same temperature in 110 seconds and could also be removed effortlessly.

The MF Quick-Heater consists of one generator MF 3.0–3.5 kW for 230 V, two magnetic temperature sensors, and flexible inductors which are available in optional lengths of 5 m, 7.5 m and 10 m. The kit also includes one pair of heat resistant gloves.

Headquartered in Vaassen in the Netherlands and with a North American office in New York, Bega manufactures and distributes special tools for safe, cost-effective mounting and dismounting of bearings and transmission parts. These tools substantially improve the quality and ease of maintenance and installation of rotating parts in machines, resulting in longer lifespan. They are used in production and maintenance departments of MRO and OEM companies within various types of industries and include special solutions for the wind energy, railway, mining, and steel industries.

begaspecialtools.com

Workforce Development in 2023

MPT Expo "Ask the Expert" stage examines trends, topics, and future considerations

Matthew Jaster, Senior Editor

At the Motion + Power Technology Expo in Detroit, I had the privilege to sit and discuss workforce development challenges with Kris Ward, senior director, strategy, and business development at SME, Kika Young, president, Forest City Gear, Mary Ellen Doran, director, emerging technology and executive director for the AGMA Foundation and Megan Schrauben, executive director, MiSTEM Network. The following is an edited transcript of this panel discussion. (Special thanks to Forest City Gear for sponsoring this live event.)

What tools and resources are essential to help solve workforce development challenges in manufacturing today?

Ward: The workforce system is extraordinarily difficult for manufacturers to navigate. We think it's one of the biggest challenges because you have an educational system, you have a workforce system, you have community-based organizations. So many organizations say they are doing wonderful things, but it's difficult to identify what the right programs and partners are. There are resources that are needed to take those local successes and scale them nationally so that we're not recreating the wheel every time a new initiative comes out. The system needs to really kind of bring itself together more effectively to support manufacturers today.

Young: In the area that we're in, most of the local high schools have some STEM and some manufacturing programs. We support those and are very active in the development of new ones.

What's frustrating to us is we're within 10 or 15 miles of 15 different school districts, seven of whom are doing a great job on this, but they're not connected to each other at all. So, we must have redundancy in what we're doing to support the different organizations, and that's just the schools. There's a ton of other programs too, so it can be difficult to navigate.

The tool most important for FCG is determining what partnerships make the best sense for us. The goal is finding those quality partnerships and utilizing continuing education programs.

Doran: Well, I think one thing we need to do is make it simpler. We need to make sure that we're not reinventing the wheel. We're not making people jump through four and five hoops. The AGMA Foundation has a tool kit for manufacturers that they can download, slap their logo on and go out to a workforce event and be able to have information about the gear industry at their fingertips so they don't have to do it themselves. So, it's making it simpler, building those lines of communication and getting as many kids as we can into the workforce.

Schrauben: I think part of the reason why STEM was created in the first place was to try to scale, but also to scale those best practices so that you don't have to connect with every single school separately. That's where our MiSTEM regional directors can be of help—they would know all the different assets that are available in that local community.

But I think another piece we need to really consider is that we tend to think about our short-term needs and so a lot of our programing is focused on the high school level or just after graduation. What we need to start asking is, how do we become part of the community and engage with educators early on in a child's life? This allows the community, and our students, to be more aware of what that company does and what type of career opportunities are out there.

What are some successful strategies for manufacturers to attract and retain a more diverse workforce?

Ward: The manufacturer must be willing to address their culture, because as you look at diverse populations,such as people who are uniquely abled or neurodivergent, you cannot bring individuals into an organization and expect it to be business as usual.

So, the first thing that must happen is a company's got to commit to making an inclusive environment and then finding those organizations again that can help you. The State of Michigan, for example, has an absolutely wonderful CTE program within the justice system. I've had the privilege of actually visiting the Jackson State Prison. Their CTE programing is so amazing. They only have, I think the last time I looked, a six percent recidivism rate. And you look nationally, that recidivism rate is probably ten times, if not more than that. So there are wonderful pockets of opportunity of bringing people to the manufacturing sector. It's, again, a challenge in the system to find those organizations that can help you connect those dots.

SME has been spending an awful lot of time in the past couple of years trying to make those connections and helping organizations bring that diverse talent in as part of their attraction strategy.

Doran: And building off what Kris said, you have to look at the retention part of the equation, too. Once you get them in the door, once they figure out what the job is, you need to figure out what their needs are on an individual basis. It's not all money for everyone. It's time off, it's flexibility. It's feeling like they belong and are part of the workforce and the team that is working on the shop floor.

Schrauben: Research shows that basically students make up their mind of whether they even belong in a particular career field by third or fourth grade. So, what we're talking about is how do we get in front of them or engage with their families at an earlier level? And that could be done by opening your space to host a family STEM night, and being very intentional about the employees that you put in front of those students so they see people who are just like them in that space.

How do we get in front of them at the earlier ages where they're not essentially already being shown pictures of what's possible and what careers they potentially belong in?

What role does personality, geography and opportunity play in an employee's development process and how can organizations keep in-house skilled talent long term?

Ward: I 100 percent agree with the comments about retention and making sure people see clear career pathways; getting into job progression programs because someone coming in the door is not going to be at the same talent or skill level as someone who's been with the organization for 30 years. So, you're ensuring you're going to have the skills long term as an employer, but also that it becomes that mutual relationship between the employee and employer, where that employee now is going to be a lifelong learner.

Now you've got to think about things like cybersecurity. You've got to think about data collection. Maybe the OEMs are supplying or asking for things that you're not prepared for yet. You need someone who's able to learn to build those skills so that you can respond to those market conditions.

Young: Retention is a big part for us as well. We have a very, very low turnover rate amongst employees. As long as they make it past the first two years, then our turnover is very, very low. But retaining your talent is important, especially in a close and competitive industry like we're in. Most people aren't quitting their job, right? They're quitting the people at their job.

We spend—the majority of us—spend more time with the people that we're at work with than we do with our own families, spouses, or kids. So, making sure that you're reflecting the values that are going to keep people with you is really important to us at FCG.

We have a list of core values that are truly important to us. And the very first one is families matter and always will. So, we know that we are not our employee's family. They're working to support their family. So being able to be flexible with folks when they're going through a difficult period in their lives or when they need help is a big part of retaining our workforce and just making it not a place that they hate going into every day.

Schrauben: Our message to the state is that authentic, real-world ways of solving problems is what engages students in their learning.So, moving away from a siloed textbook approach—the primary way that we probably all learned in school - and having it be much more like working with the company next door and saying, "What problems are you working on?"

What we've seen in some of these programs is really that people want to feel like they are part of their community. Are you providing incentives for your employees to have volunteer hours in their local community?

One of the successful programs we've seen is a 4th grade engineering design challenge every single year. Basically, the Science and the English Language Arts (ELA) teachers work together on these problems.

And then the manufacturing groups are actually building prototypes of what the students are designing. And the manufacturers are saying, "This is like the highlight of my year! We are going to continue to be engaged in these programs." They're seeing the excitement from the young people as these designs come to life. You're not only building the potential future workforce, but you're also helping to retain your current workforce.

Doran: When people have positive things to say about where they work, they're saying it to their friends who may need jobs. This grows into a community of people you want to go to work with and see every day.

How are today's grade school, high school and college students better prepared for the data driven analytics approach to manufacturing and business today?

Ward: As someone who sits on the Industry Advisory Council for the Accreditation Board for Engineering and Technology, and experience with SME, this is a concern in undergraduate education especially.

What I see are some wonderful things though, that are starting and I can speak to programs that SME does. We have a program called SME PRIME(Partnership Response in Manufacturing Education) where we work with the school and the manufacturers to bring career and technical education in manufacturing and engineering with a relatively 'low lift' for the school.

As industry is evolving, we're evolving the curriculum, aligning that curriculum to state standards, but also incorporating things like "How do you use Excel to really analyze data?"

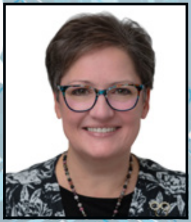
If you're a CNC or a machining program, you're getting data off that piece of equipment.

How are you taking it out and doing some analytics to understand what's happening so that as those students keep moving on, they can then kind of bridge back to that, learning some of the new things they might have to do in the workforce.

Those are just examples, but it's really about that integrated education that needs to happen and that interdisciplinary education that needs to start occurring more frequently.

Schrauben: Speaking as a trained educator, former high school teacher, if I hadn't sought out those opportunities to see what I was being asked to teach or how it was being applied in the real world, I wouldn't have had those examples. I would have only known textbook math. I would have only known textbook physics. We are designing opportunities for educators to see what industry is doing. There are some exciting problems that the world is trying to solve.

We're trying to head in that direction. Students coming out of college might be ready, but not out of K-12. We're literally at the point of trying to help schools understand that we should


Kris Ward


Kika Young


Mary Ellen Doran


Megan Schrauben

be teaching computer science. We should be having conversations that everything they're being asked to teach is important for a well-rounded education, and you shouldn't just be cutting the arts program because you're trying to jam something else in. Those integrated, real-world examples help us to be much more effective and efficient in our education system.

Doran: My son had a fantastic robotics program in his grade school that was integrated where they taught the instructors how to use them first. There were kids leaving 5th grade knowing how to code in Python and using it in art and science class. I wish to see more of that. He was in a public school; it was a trial run and then the program just died and it didn't continue. We need more of those types of programs to exist and we need to build on them.

What incentive programs and recruitment tools are available specifically for gear manufacturers today?

Ward: I can't speak to gear manufacturing specifically because what gear manufacturers are facing is what every manufacturer is facing. There's a lot of funding out there. I'll talk about the new'incumbent workforce' or 'net new to industry workforce' because even though we're talking about pipelines of talent and building that K-12 system, there are so many hidden populations and so many so many underserved, underrepresented groups that if a manufacturer is willing to take that risk to address things in their culture, there is so much funding out there to help you do just that.

Whether it's federal dollars, state dollars, you have the Manufacturing Extension partnership system that can help navigate that. You have academic economic development agencies that can help navigate some of that. The resources are out there. Sometimes manufacturers don't know where to look, and doing a better job at highlighting those resources is absolutely critical.

Young: Forest City Gear is in Illinois and there are several, both state and I think partially federally funded programs, available for workforce development and workforce training. Wherever you are, there is almost certainly a local partnership or extension office that you can contact to get those dollars. And sometimes those dollars can be a lot of dollars that you're eligible for reimbursement for training both on the job and outside training, bringing in trainers, etc.

Now, of course, anything that is connected to government dollars is not going to be an easy thing to do paperwork-wise, right? I mean, it's application after application, but those local extension offices will really help you navigate that and make it easier for you. And it truly is a good way to take advantage of some of that.

Doran: Additionally, we've seen a lot of our members that are going into universities and helping with project-based learning. There's not a lot of gear training in universities right now. They may touch gears for a quarter of one of their manufacturing classes over the course of their four- or six-year education, depending on whether they have internships.

We have companies that are now moving into a position to help with some of these bigger programs, whether it's building robots or building cars or building vehicles that are solving a certain problem. They work with the with the students hands on to be able to cut the gears and figure out the gears that are necessary for the transmissions and the drive lines for those vehicles. So, there are some opportunities that we're starting to see for gear manufacturing specifically.

What skills and capabilities do you believe will be most critical in manufacturing moving forward?

Ward: A lot. And that's not to sound funny about it, but we don't know. There are skills that are going to be needed five years from now that we haven't even thought about. Right now, the hot topic is AI machine learning, you know, data analytics, cybersecurity, connecting O.T. and I.T. But as those evolve and the talent base catches up, that next thing is going to become a really fast behind and really what we need is that philosophy of being lifelong learners.

You know, we're experimenting with, we actually got a DARPA award to look at AI applications in educational technology and taking people skills, marrying them up with job roles and job role requirements, seeing what jobs people might qualify for, but also helping them build out a learning pathway for potential future jobs that are coming down the pipe.

Young: It's a little corny, but my dad always used to say, "We're going to look for the three A's in an employee."

The first one is aptitude, right? They don't have to have the skill. I can teach them the skill, but do they have the capability of learning that skill? Do they have the aptitude needed to be able to learn?

The second is attitude. Do they want to learn? Are they nice? Are they going to be a good coworker? Are they going to fit our culture? We said it earlier. You spend more time with the people you work with than the people you live with. I don't want the guy working next to me to be a jerk all day. Nobody wants that.

And the third one seems so basic. But in today's age, it might be our biggest difficulty and it's attendance. Just come to work and don't ghost me.

Doran: There are so many new things coming at employees that to some degree they just need to be good at their job. We need gear manufacturers. We need gear designers. We need people who understand when the gear mesh happens, whether or not it's right. We can't rely on the technology itself. My biggest fear regarding technology is electricity. We're putting all of this effort into AI, which is a big electric suck. We're putting all this effort into cars which will be electric vehicles. So, are we thinking about generating enough electricity, clean electricity, to be able to 20 years from now support these things we're talking about?

Schrauben: I would just add the human element. As humans, we thrive on social connections and all our earlier answers are really around the culture of the community that you are establishing. The technologies are always going to be changing, so we really need to remember our human abilities and how we can work and adapt to meet these challenges.

Hear the complete discussion at:

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The "Differential Difference" in E-Drives

Forged differential gears don't deliver the stronger, quieter performance required by e-drives—for that, there's Coniflex Pro

Dr. Hermann J. Stadtfeld, Vice President Bevel Gear Technology and R&D, Gleason Corporation

Uwe Gaiser, Director Product Management and Bevel Gear Technology, Gleason Corporation

Differential gear manufacturers began moving away from the tried-and-true Revacycle broaching process to forgings some 30 years ago. At the time, forged differential gears seemed almost tailor-made to meet the needs of automotive, truck, and other vehicle producers: Relatively inexpensive when produced in high volumes; able to deliver the high power densities necessitated by the severe size constraints imposed by a differential cage; durable and robust.

Then Came E-Drive

If forged differential gears seemed ideally well suited for traditional combustion engine vehicles, the opposite could be said to be true for most, if not all, e-drive applications. Where the relative motion for differential gears used in combustion engine applications occurs mostly when driving around a curve, e-drives demand a lot more from their differential gears. Most electric vehicles, for example, have one electric motor per driven axle which transmits motion and torque through a single or two-speed transmission to the wheels. However, between the final drive gear of the transmission and the drive shafts to the wheels, a differential is required. These differential gears are subjected to the peak torque electric motors can provide, which can be a multiple of the maximum torque of a combustion engine in a comparable vehicle. Another important consideration is differential noise. Forged differential gears aren't inherently designed for "quiet," since differential noise is not as significant a consideration for combustion engine vehicles as it is for electrical vehicles, where the differential as a source of sound becomes much more obvious. Additionally, some advanced e-drive designs have operating conditions with multiple times higher relative motion between the differential gears compared to the traditional differentials, thus adding to the potential for noise.

The new performance requirements demanded by electrical vehicles have made it imperative for gear manufacturers to reconsider—and reinvent—how almost everything was done in the age of combustion engines. In recognition of the significant limitations of forged differential gears when applied to e-drives, Gleason has embarked on the development of a new process for the production of differential gears in e-drive applications. This process, which combines new *Coniflex Pro Design Software* with proven Gleason Coniflex Plus Cutter System and Gleason Phoenix Bevel Gear Cutting Machines, is based on initial customer trials that are producing gears far superior to those made from forgings. Now, for the first time, gear manufacturers have an alternative process for differential gears that meets the strength, noise, and production levels required in many e-drive applications.

The new process builds on Gleason's Coniflex Plus high-speed cutter system, using advanced Pentac coated-carbide stick blades, in conjunction with the latest Gleason Phoenix bevel gear cutting machines. Over the years, Gleason's Coniflex Process for straight bevel gears has steadily evolved, from the ubiquitous mechanical Coniflex Generators to the first application on a new generation of Gleason Phoenix Machines in 2005, to today's greatly improved Coniflex process, made possible with the development of the Coniflex Plus, the first high-speed dry cutting tool system for manufacturing straight bevel gears. With the Coniflex Plus Cutter Head and the indexing motion of the gearless direct drive work spindle of the Phoenix machines, the production of straight bevel gears was now overall faster compared to the traditional Coniflex Process using HSS blades.

Significantly, with the introduction of Coniflex Plus, manufacturers of differential gears began to see the many benefits of applying this high-quality production technology as an alternative to forged differential gears, particularly in low- to mid-volume applications. Now, with the development and application of *Gleason's Coniflex Pro Design Software,* the latest generation of Phoenix Machines and Coniflex Plus Cutter System all operating together in a fully Closed Loop system, we're proving that differential gears can be readily produced to meet the quality, noise, and productivity requirements of e-drives for automotive, truck, and off-road applications.

The Design Limitations in Forged Differential Gears

Forged differential gears are a good solution for the mass-produced differential of cars and trucks with internal combustion engines. Differentials generally have a high power density because they must fit inside of the differential cage which is inside of the final drive gear. The size of a transmission depends therefore on the size of the differential unit because the transmission is built around it. The severe constraint in size led designers to introduce stiffening webs in the root at the toe and heel, which, in addition to a certain tooth stiffening, also reduces the outer diameter while still maintaining an acceptable wall thickness between the toe and bore. The stiffening webs give a higher root bending strength at moderate loads; however, they also constrain the tooth bending and therefore cause increased subsurface stresses below the area of the webs which in the case of high loads or shock loads can lead to cracks and flank fracture. The increased tooth stiffness also prevents the desirable small amounts of tooth bending which allows the neighboring teeth to provide a load sharing which reduces the root bending stress.

Forging scale is another undesirable side effect of die forging. In free-form forging the scale flakes off during the forming process. In the case of die forging, the exposure to oxygen is minimized and a high surface pressure is applied. As a result, a very thin scale is formed and becomes a permanent part of the surface structure. The thickness of the scale is between 0.001 to 0.006 mm and is dominated by its ferrite concentration. The forging scale does not form oil pockets like the generating marks of a cut gear. The low relative speeds of differential gears require a certain surface structure to retain some oil film between the contacting tooth flanks which is ideally given by generating marks rather than by a smooth surface. A further obstacle with forged differential gears is the variation in tooth size, indexing and flank form throughout the tool life of the die. This is also reflected in the gear quality according to AGMA or other standards.

Making the case for Coniflex Pro

The new Coniflex Pro Design and Manufacturing System, when integrated into Gleason's *GEMS Bevel Gear Design Software* and operating in conjunction with the latest Gleason Bevel Gear Cutting Machines, opens a world of exciting new differential gear design and manufacturing possibilities ideal for e-drive applications—in stark contrast to the inherent limitations of forgings. Coniflex Pro gears are cut in a high-speed, dry PowerCutting process using the Coniflex Plus Cutter System. The cutting blades can be two- or three-faced ground and are preferably all-around coated. Flank form geometry, indexing error, and surface finish of this process are excellent.

With Coniflex Pro, digital flank form information including correction matrixes can be transferred via the Closed Loop network to gear inspection systems and a closed correction loop between measurement and production can be established. Also, the machine summaries for blade grinding, cutting, and grinding are generated in GEMS and can be transferred to the manufacturing machines.

Note, too, that all Coniflex Pro differential gears can, additionally, be ground. Standard differentials might, in extreme cases, see a maximum of 400 rpm relative speed between side gear and planet. For some e-drive designs, the maximal relative differential speed is six times higher, which calls for a hard finishing operation after heat treatment. For that operation, GEMS generates grinding summaries and grinding wheel geometry and design data. The grinding wheels are permanently coated with CBN and can be recoated 6 times which results in low grinding wheel cost per ground part. Cutter head and grinding wheel consolidation between different gear designs are easily possible because the profiles of blades and grinding wheels are simply straight.

Surface Stress and Root Bending: Cut vs. Forged

Since differential gears are subject to significantly higher torque conditions in e-drive applications, this root bending stress and surface stress comparison between Coniflex Pro cut and forged gears, performed with the ANSYS Finite Element Method is illustrative of a major Coniflex Pro benefit as compared to forgings. In this

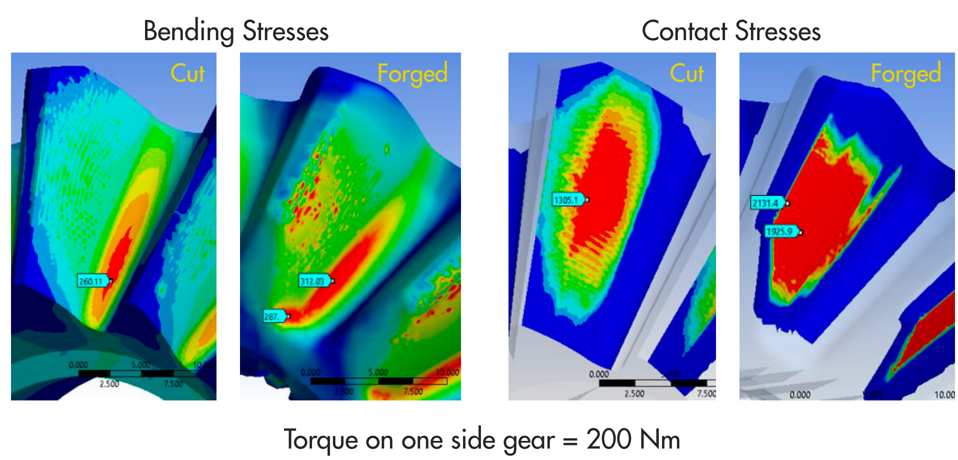

Figure 1—Stress comparison, Coniflex Pro cut vs. forged (input torque = 200 Nm).

case, a Coniflex Pro differential gearset was designed to replace the originally forged version. STEP files of the cut and forged version had been converted to the ANSYS native format. Also, a model of the side gear spline was created, and the input torque was transmitted from the splined shaft via the internal spline in the side gear bore to the side gear teeth. A rotational constraint was applied to the planetary pinion to create the reaction torque.

Results for an input torque of 200 Nm are shown in Figure 1. The left two graphics in Figure 1 show the bending stress comparison. The maximum bending stress in the cut side gear is 260 N/mm², compared to 312 N/mm² of the forged side gear. This presents a 20 percent higher bending stress of the forged side gear. It is noticeable that in the toe web area, a high-stress value of 287 N/mm² occurs, compared to about 50 N/mm² of the cut gear in the comparable area. Already with rather low torque, the constrained elastic bending of the forged gear shows a remarkable influence. Larger differences and a sizeable advantage of the cut version become evident in the two right-side graphics of Figure 1 with the comparison of the contact stress. The forged side gear has a 63 percent higher surface stress than the cut version. Also, the fact that the plain profile crowning as was used with the forged differential gear pair results in a nearly straight and abrupt contact pattern cutoff below the tip and above the root transition. In the case of the cut gear, the center contact stress reduces smoothly in all four directions as shown by the color change, from bright red to orange, yellow, green, and blue.

A realistic operating torque of 1,000 Nm was applied in a second calculation. The bending stress results to the left in Figure 2 show a 13 percent to 17 percent advantage of the cut side gear. It is noticeable by the red patch inside of the web area that the web has a high contribution to transmitting the torque. Also, the contact stress to the right in Figure 2 shows up to 65 percent higher values for the forged gear. The especially high value of 3,753 N/mm² in connection with the high bending stress in the same area will result in high sub-surface stresses which can cause case crushing. Case crushing often leads to flank fracture.

Also, for 1,000 Nm torque, the area with high surface stress of the forged version extends to the top land and the toe boundary. In the cut gear, there is also a smooth stress reduction towards the tooth boundaries for 1,000 Nm input torque.

In the third step, the unrealistic high input torque of 5,000 Nm was applied to the cut and forged side gear. Such an extremely high torque will cause stresses in the root as well as on the surface which are well above the allowable material properties, yet it is used in test rigs to simulate shock loads and to record how many revolutions (or

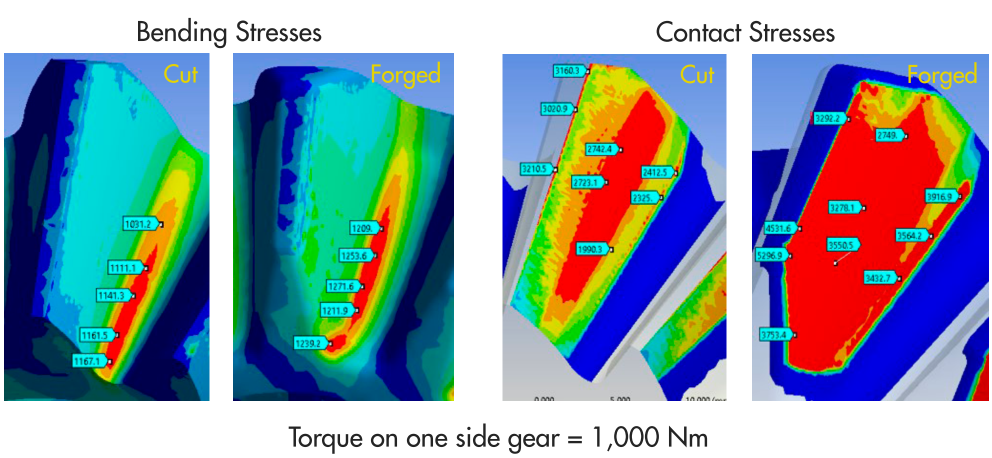

Figure 2—Stress comparison, Coniflex Pro cut versus forged (input torque = 1,000 Nm).

fractions thereof) the gearset will sustain. The fracture which consequently will occur is then analyzed with practical conclusions for the potential for failure of the differential during a lifetime load collective.

In Figure 3 the stress results of such a high abuse torque are presented. The graphics for the bending stress results still reflect a 10 percent advantage in bending stress of the cut side gear versus the forged version. Although the forged gear has about the same contact stress values in the heel section, the high-stress area is smaller in profile direction and increases in the web area.

Also interesting is the difference in contact stress. In the heel top area, the forged version has about 22 percent higher stress values. This trend increases in the toe direction, and at the toe the contact stress is even 87 percent higher compared to the cut side gear. These results reinforce the statements made earlier regarding the disadvantage of the webs when high torques are applied and the highest possible power density is required. The linear elastic deflection of the forged teeth is compromised by the webs. One result is the high contact and bending stress concentration in the web area which can result in case crushing and cracks.

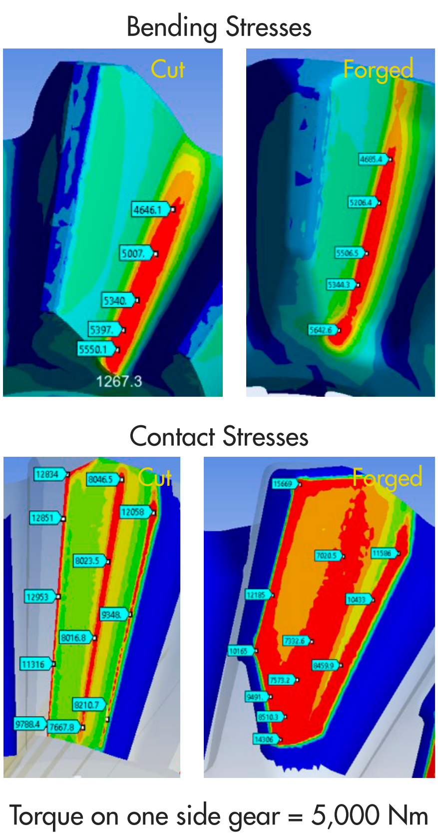

Figure 3—Stress comparison, Coniflex Pro cut versus forged (input torque = 5,000 Nm).

Test Rig and Field Testing

Coniflex Pro takes advantage of the geometric and kinematic freedoms available in today's Phoenix Machines. The advantages of conjugate base geometry and the free control of length and profile crowning with the possibility of a kinematic tip relief are compelling benefits for manufacturers of differential gears for electric vehicles. Although the specific results of actual test rigs and field tests are confidential information of the respective manufacturers, it can be stated that the overall performance of the surface and root of Coniflex Pro gears is potentially up to twice as strong as their forged counterparts.

Finally, NVH (Noise-Vibration-Harshness) properties as confirmed by Fast Fourier Transformation (FFT) testing show that Coniflex Pro differentials roll significantly quieter than forged differentials or differentials cut with the older Revacycle method. To achieve the highest possible power density, all Coniflex Pro differential gears use the duplex taper which has proven highly successful over many years in the well-established Revacycle process. This blank geometry applies an especially high addendum and dedendum angle (10 degrees and more) which results in very strong teeth with the highest strength at the heel where the contact under high load concentrates.

Summary

Coniflex Pro, in initial customer tests, has shown to deliver significant advantages over forgings differential gear manufacturers are greatly in need of, with power density up to two times that of conventional differentials, and quiet-rolling low-NVH properties. It will help to usher in this new age of stronger, quieter, more dependable differential gears for e-drive.

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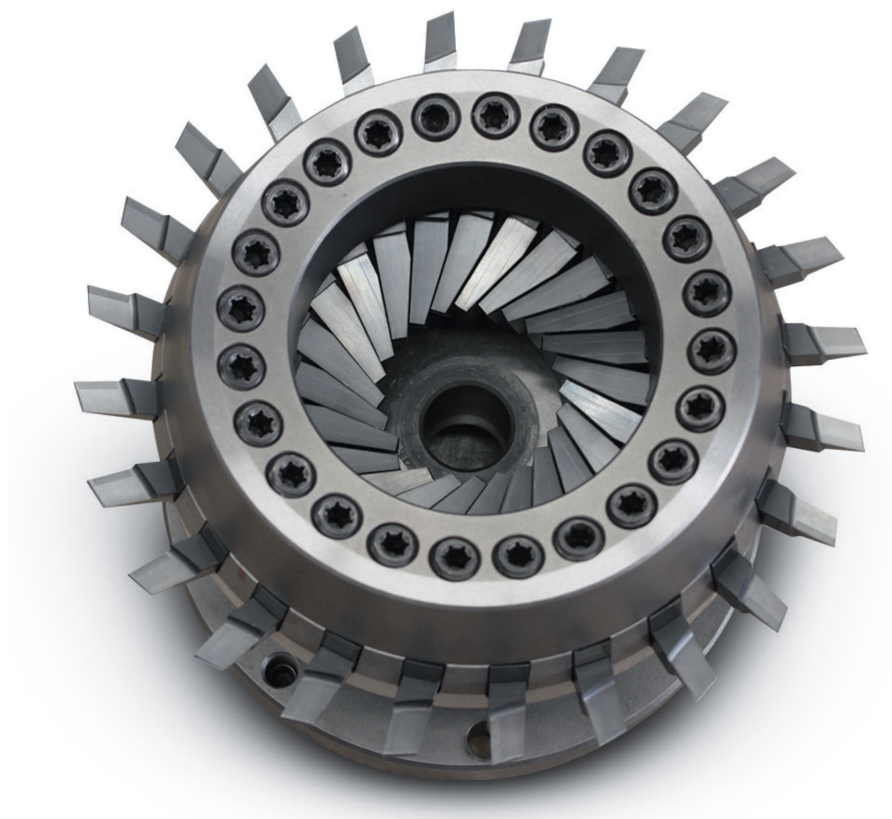

The cutting tools used for Coniflex Pro are Coniflex Plus peripheral cutters with diameters ranging from 9 in. for cars and 15 in. for heavy trucks.

Getting into Gear

An interview with four women from the gear industry

Aaron Fagan, Senior Editor

National STEM Day, celebrated on November 8th this year, provided a platform for *Gear Technology* to engage in a conversation with four remarkable women shaping the manufacturing industry: Ruthie Johnston, CEO and Owner of Croix Gear; Robin Olson, Senior Manager, Applications Engineering—Engineered Gear, Regal Rexnord; Michelle Maddox, Sales and Business Development Manager, B&R Machine and Gear Corp.; and Claudia Hambleton, Office Manager and Corporate Treasurer, German Machine Tools of America (GMTA). Each of these women, driven by a shared passion for fostering the next generation of female leaders, revealed their unique journeys and perspectives in this male-dominated field.

The insights provided by these women offer a compelling narrative of resilience, innovation, and determination, inspiring future generations to fearlessly pursue STEM careers in manufacturing. Their stories underscore the transformative power of mentorship, education, and breaking down gender barriers in shaping the future of the gear industry.

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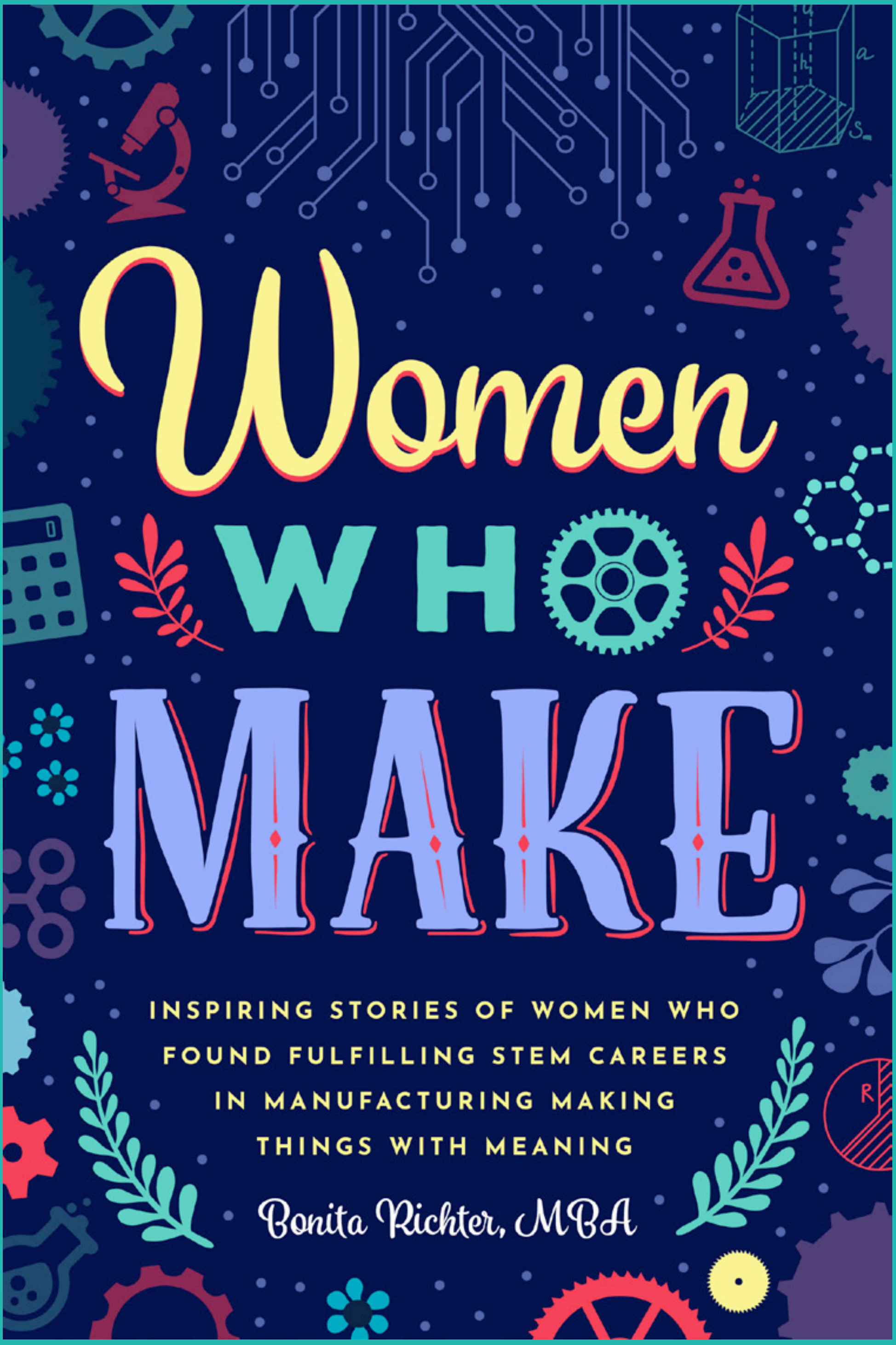
Women Who Make: Inspiring Stories of Women Who Found Fulfilling STEM Careers in Manufacturing Making Things with Meaning by Bonita Richter, MBA

Women Who Make busts myths and directly challenges misconceptions by sharing the true and inspiring, real-life stories of thirteen women who made the socially bold, unconventional, and even controversial choice to find their careers in manufacturing.



Introduction and Background

Can you share a bit about your background and how you got involved in the gear industry?

Ruthie Johnston: I became the Owner of Croix Gear 13 years ago when my husband passed away. It wasn't a choice that I made; it was an opportunity that was placed in front of me. I unknowingly stepped into it. I fell in love with gear manufacturing.

Ruthie Johnston, CEO and Owner of Croix Gear

Robin Olson: I started college as a marine engineering major but moved over to physics halfway through. As I was graduating with my master's degree, the Department of Energy funding for fusion research fell through, and finding a job in that field became particularly challenging. I started looking for engineering jobs and found an interesting opportunity to become a Gear Software Engineer for the Falk Corporation. Through my coursework and my graduate project, I was experienced with scientific programming. I applied and got the job.

Robin Olson, Senior Manager, Applications Engineering—Engineered Gear, Regal Rexnord

Michelle Maddox: I have been given the unique opportunity to be involved in this industry since childhood. The world of gearing has been a cornerstone throughout my entire life. B&R was and still is a family-owned corporation since 1974. My grandparents founded B&R, with contributions from multiple family members over the years. My (overused) joke is that I have been involved with the business for longer than I'm legally allowed to discuss. Let's just say I learned office etiquette at a very young age.

Michelle Maddox, Sales and Business Development Manager, B&R Machine and Gear Corp.

Claudia Hambleton: I think the manufacturing business has so many offshoots; it's the backbone of America. The paths you could go down are endless. And I don't think I realized that when I was beginning. I think a lot of women aren't aware of the opportunities since that's the topic: women in the gear industry. I think a lot of women currently in the gear industry didn't set out saying, "I'm going to be in the gear industry!" I think some of them ended up here by accident. But that's where we ended up. And I also think the reason for that is we still must change that whole narrative that it's a man's industry and that women don't even think of that as a choice. A lot of times, I think it's changing, but I do think we've got a narrative or a sort of societal mindset that doesn't really see women in manufacturing.

Claudia Hambleton, Office Manager and Corporate Treasurer, German Machine Tools of America (GMTA)

What motivated you to pursue a career in STEM and/or manufacturing?

Ruthie Johnston: I found it to be amazing. I started on a journey of discovery. I was in a brand-new role, learning about something that was also brand-new to me. I feel I am still on that journey today.

Robin Olson: My parents had technical hobbies when I was growing up such as amateur radio, computing, and sailing. They took classes and joined groups where they could learn more. Because they did all this together, my sisters and I also attended many meetings and activities with them. That created an environment where it was normal to learn, build, and communicate technical topics and where it did not matter if you were male or female. When I was eleven, they encouraged me to get my amateur radio license. That helped me to realize that I was capable of understanding and enjoying technical topics.

Michelle Maddox: Being involved with a family business has its own challenges, but one of the biggest motivating factors to stay involved is that we can define our own success. In a family full of entrepreneurs, you learn that your own level of commitment is the determining factor in your overall success. Having the opportunity to continue in a business that was created to provide for our family was an easy choice to pursue.

Career Journey

Could you describe some key milestones in your career within the gear industry?

Ruthie Johnston: The first thing I did was accept that I was a beginner. The next step was to seek out those who were willing to teach me. I needed to learn about gear manufacturing and learn about business. I was very fortunate that I have some very knowledgeable mentors and coaches who have been willing to believe in me and invest in me.

Robin Olson: I was hired at the Falk Corporation as a Gear Software Engineer and joined the AGMA Software Committee in the same year. That started my involvement in the gear industry. I was later promoted to supervisor of gear software, CAD systems, and engineering records. In 2009, I was promoted to manager and my role was expanded to take on product cost-outs and improvements, warranty, test lab, and technical services. That transition took a lot of work and there were many stressful days at first! I was offered my current role in Applications Engineering in 2016. It has been a refreshing change to work with customers to modify our gear drives to fit their application needs.

Michelle Maddox: Each step I have taken at B&R has been a journey much like the manufacturing process. As most would expect (from the stereotypes of being a woman in manufacturing), I began my journey in the office. I have held roles within all units of the organization, including accounting, human resources, purchasing, and my personal favorite: sales. Each new role has been a milestone throughout my career giving me the foundational knowledge of how our business operates inside and out.

What challenges have you faced as a woman in a traditionally male-dominated field, and how did you overcome them?

Ruthie Johnston: I was lucky there were a few well-respected women in this field before me, like Wendy Young. We were anomalies in this industry, but the gear industry is different. Everyone I have exposed to it comments on how close we all are. And that it is like no other they have ever been part of.

Women executives in general have problems being recognized. I think we often get underestimated and treated differently. Women still have hurdles, but it is the awareness that will change it. I really don't think most of the men I deal with intentionally try to discount women. They need to learn new ways of doing things. Women need to be in conversation with them and not demand but explain how they want to be treated.

Robin Olson: The biggest challenge I faced was when my husband and I wanted to have children. We both wanted to continue working, but we also wanted to be active parents. My husband worked for Baxter Healthcare, which had a mature work-from-home policy and somewhat flexible workdays. I was able to take that model to my boss, who was open to providing some flexibility to me as well. As our children grew up, Dave and I were able to work together so that one or both of us could be involved in their activities, be home when they were sick, or work with their schools on any academic or disciplinary issues.

Michelle Maddox: My experience is somewhat twofold. Being a woman in manufacturing and being in a family-owned business hasn't exactly been an easy task. As elementary as it may sound, my biggest personal challenge has been wanting people to believe in me. Believe in my dedication, my vision, or even my knowledge in this field. Whether it be from internal or external sources, people at times have the notion that women are "pencil-pushers" or just "secretaries"—that we don't know what a gear might be or how it even gets made. (Even writing those terms makes me queasy). It is degrading, unfortunate, and creates self-doubt. I have found the only way I overcome this is to keep my head down and keep working, do my best to lead by example, and most of all believe in myself regardless of the stereotypes.

Inspiration and Role Models

Who or what inspired you to enter the gear industry, and were there any women who served as role models for you?

Ruthie Johnston: My inspirations here are not specific to the gear industry. My inspiration here is the two women I probably knew the best or at least the longest in my life. The first is my mom. My father died when I was four. She went on to raise four kids alone. She was not the typical mom of the 50s, 60s, etc. My mom wore jeans and a sweatshirt. She played semi-pro softball; she was an athlete. She served in WWII.

From her, I learned to be a survivor and it was ok to be different. She always told me as a mother to treat my daughter the same as my sons. And she always said take time to teach. She loved learning new things. She watched PBS. She dug in and worked hard. The other woman was my mother-in-law. She was a wonderful caring lady. She knew how to make people feel like they were the most important person in the room. She was always dressed and had social graces. She started Marine Associates (the parent company of Croix Gear) and worked alongside her husband until they both retired. I feel I got the best of both worlds.

Robin Olson: When I started, there was a female engineer at Falk who had been there since the late 1960s. She was the person who trained and mentored me in the first three years of my career. She was very competent in her knowledge and abilities, but humble and gracious when working with the other engineers. The other engineers respected her.

Michelle Maddox: Without question, my mother and grandmother were my biggest role models in this organization. In my opinion, they were the backbone of this company. The behind-the-scenes daily heroes if you will. Both women faced their own challenges in their own time but never backed down from any of them. Women who didn't hesitate to lead quietly when needed. Women who didn't hesitate to be assertive when necessary—especially in a time when women shouldn't be. They taught me no matter my age or gender, the only limitation in life is me. Do more, think bigger, and lead by example! I had the very best examples set for me (but I might be slightly biased).

How important do you think it is for young women to have role models in STEM and/or manufacturing fields?

Ruthie Johnston: So important! I hate to say this, but men and women do see things differently at times. We do Manufacturing Day Tours and have the schools come through. Every time our production techs tell us the best questions are coming from the young women on the tour. Those different views expand thinking. That collaboration improves outcomes. Women entering these areas will continue to raise women throughout all avenues of life. Wages, respect, the list is long.

Robin Olson: It is hard for anyone to enter a career in which they cannot picture themselves. With STEM fields still being mostly men, there are also situations that young women may not know how to navigate—such as advocating for themselves or speaking up when they have a different opinion than the majority. Role models provide an image and an example of how to be a productive contributor.

Michelle Maddox: Having role models is extremely important for all genders—especially young women interested in any STEM-based field. Finding a person who motivates you, someone who is relatable, someone you can learn from—this is critical to motivating and encouraging young women to be involved.

Encouraging Young Women

In your experience, what barriers do you think young women face when considering careers in STEM and manufacturing?

Ruthie Johnston: I was just in a conversation about women executives and the views of millennials on the male/female views. These people who came from different industries are not seeing improvement from that age group in how women are viewed. That truly begs the question of what we are doing or not doing to change this. My generation fought for these rights. We still haven't passed the ERA. Will it take a social/political shift?

Robin Olson: To succeed in STEM and manufacturing, students need to have an interest in math and technology as well as an understanding of how things are made. Young women do not necessarily grow up with exposure to these things. As a result, they are not confident in STEM and do not choose it as a career.

For those who get engineering degrees and find jobs in STEM and manufacturing, it can be difficult to have children and raise families without flexibility for parental leave, sick children, after-school care, etc. This is particularly tough when other engineers do not need the same considerations because the work culture may not include the ability to request flexibility.

Michelle Maddox: The overall gender bias that women simply do not engage in these types of careers is one of the largest barriers women face. We have come a long way since the old notion that women belong at home, but still have a very long way to go. Even potential discrimination—whether gender-based, pay equality, or even harassment—can deter young women from participating in these fields. An overall lack of support from parents, teachers, or even peers can also be a deterrent.

How can the gear industry specifically attract and retain more women professionals?

Ruthie Johnston: This is one I stumble on. The young women who are coming through as leaders now are fabulous! I would really like to see an actual forum maybe via Zoom/Teams quarterly that continues to support this group so they can support each other and possibly be in conversation to address issues they see. They are living it. What better source is there?

Robin Olson: We need to get women interested in mechanical engineering and gearing when they are still in middle and high school. The gear industry can focus on training and mentoring to allow students and engineers the chance to build their knowledge and confidence in our field. This can include attending school career talks, volunteering in STEM activities in schools, or facilitating training and mentoring programs in our companies.

Having a workplace that understands the needs of employees to take care of their families will also retain women—and men as more couples are sharing the workload of raising children. The ability to work virtually makes it possible to make up time on projects by working later at night from home.

Michelle Maddox: I recently had the opportunity to attend a networking event for Women in Manufacturing and Engineering at the MPT Expo. It was an event to highlight women at various stages in their careers discussing the adversities and challenges of their respective journeys. Hearing from a panel of my peers was not only insightful but also inspiring.

Women in this specific industry are continually stepping up to lead by example, mentor, and provide insight into this industry. We must continue to do so to encourage the next generation of women!

Educational Outreach

Have you been involved in any initiatives to promote STEM and/or manufacturing education and careers among young women?

Robin Olson: I mentor a FIRST Robotics Competition team at our local high school as a robot design mentor. Our team is a little over 30 percent female students. I am so proud of the team's STEMinists! They occupy technical roles in the robot construction and programming efforts where they contribute alongside the young men. We also have young ladies in lead roles in our business team. It is exciting to see these kids graduate from high school and move on to challenges and success as adults.

What strategies do you think are effective in encouraging girls to pursue STEM and/or manufacturing subjects from an early age?

Ruthie Johnston: Locally with the high schools and International Women's Day Events.

Robin Olson: I find that when you teach a girl to do something firsthand, such as use a drill or work a calculation, she stops being intimidated by it. After that, the barriers to trying something new become shorter because she is building her experience and her confidence. I am sure this is true of young men, too, but the first hurdle for girls seems to be higher. We need to put tools and projects into girls' hands so that they can get experience and learn to succeed with them.

Michelle Maddox: Early education is key! It is critical that our education system implements STEM/STEAM-based courses from an early age, preferably from an elementary level. It is vital that those within those roles encourage and inspire young women to pursue STEM-based careers.

I am very lucky to have a best friend who also happens to be a middle school teacher. (Hats off to her!) She is a young woman actively engaged in extracurricular activities that are largely STEM-based. She sponsors two different programs both of which create innovation, collaboration, and creative thinking - all the while promoting STEM as something fun and exciting! Programs like this are vital for the next generation of manufacturing leaders. She herself is a role model, especially to the young women who might not have become involved if not for her encouragement.

It is critical to have an early education in the world of STEM subjects and it is a particular bonus if you have a teacher who actively promotes the opportunities in these fields.

Claudia Hambleton: You don't know what you don't know. It's important for younger people to just try new things and take risks. I always tell my kids: do the things you're a little bit scared to do because those are the things that pay off. And a college education isn't necessarily for everybody. I think we need more apprenticeship programs and different sorts of mentorship programs along the lines of what some of these companies are doing. Sort of the German apprenticeship model, I think works well for a lot of people. And to see more women coming into those roles would be great. Different ways of thinking and having different mindsets and different perspectives are a huge resource a lot of companies are missing. Especially with the skills gap now, how are we going to fill all these positions when you exclude a whole group of potential workers? We must think differently.

Skills and Education

Are there specific educational programs or initiatives you would recommend for aspiring female engineers and manufacturing professionals?

Robin Olson: I highly recommend that girls in elementary, middle, and high school become involved in the FIRST Robotics programs. These programs require students to design, build, program, test, and compete with a robot created to carry out a series of tasks. Students learn to research solutions, build components, and troubleshoot the results. The teams are sponsored and mentored by businesses, which gives students the chance to learn current business practices and tools as well.

Michelle Maddox: Education, education, and education! The AGMA has multiple educational opportunities available for members and nonmembers alike. These courses are gear-specific and provide a solid knowledge base for all levels of learning. In addition to the AGMA, there are several member companies that offer "gear schools" to further enhance your education. It is impossible to remain assertive and confident if you lack knowledge in your respective fields. Education is key!

Personal Achievements

Can you share a particularly rewarding or proud moment in your career within the gear industry?

Ruthie Johnston: Elected to the Board of Directors of AGMA, President of the Foundation.

Robin Olson: I have the honor of being the US delegate to the ISO working group on gears, which covers mechanical and thermal rating practices for spur and helical gearing. Being elected to that position by AGMA was a proud moment because it meant that my colleagues in the US gear industry felt I was capable of the responsibility.

Michelle Maddox: B&R has been a member of the AGMA since 1982. We have been involved in the association at various levels, but mostly quiet participants throughout our membership. I wanted to increase our involvement and in 2021 I joined the SNL committee (formerly SRN). By 2022, I had been nominated and elected by my peers to serve on the Board of Directors for the AGMA. This is particularly rewarding in many ways professionally and on a personal level, I can't help but think that the founders of B&R would be proud.

How do you hope your experiences can inspire other women to pursue similar paths?

Robin Olson: I hope that they see that it is possible to be a woman and have a career in engineering with contributions to your company and industry without sacrificing your family.

Industry Trends and Future Outlook

How do you see the role of women evolving in the gear industry in the coming years?

Ruthie Johnston: I see more women encouraged and excited to step out and do more. More choices. I have more women working on the Team at CG. They are in many roles. "Traditional" lines for roles are blurring and that is great.

Robin Olson: There is a big effort to make STEM education and experiences available to more students in grade school, middle school, and high school. This is going to bring more young women into mechanical engineering and gearing. They will bring a unique perspective to the industry as contributors and as they are promoted to leaders.

Advice for Aspiring Women in STEM

What advice would you give to young women who are considering a career in the gear industry or STEM fields?

Ruthie Johnston: Go for it! You may find purpose and something you love as I did. You can always reinvent; I was 57 years old.

Robin Olson: Find a mentor (female or male) who can guide you through the culture and situations that you will encounter. Be curious and ask questions so that you can learn quickly. Most importantly, find your seat at the table in meetings and productively participate in the discussions.

Michelle Maddox: Be vigilant, dedicated, and unwavering. Don't be ashamed to be assertive—it means you believe in what you are saying—you will never get people to believe in you if you don't believe in yourself! Lastly, I learned a quote many years ago and I do my best to live by this each day: "To be humble in success, and without bitterness in defeat."

Claudia Hambleton: Do those things you're uncomfortable doing. They will become less and less uncomfortable, and you'll become an expert, or you will become quite comfortable dealing with uncertainty. And that's a real skill. And I don't think most people are born that way. Nobody is. It takes practice, and you must put yourself out there and try it.

So that will help change the narrative, too, for women. We must give more opportunities to women and get them to just try new things, and that's hard. But I think that would be my biggest advice is, yeah, do the things that make you a little uncomfortable and try those new things because they pay off. I guess that would be my biggest advice piece.

How can they navigate potential challenges and thrive in a male-dominated industry?

Ruthie Johnston: With my executive coach I developed my leadership declaration. It is my rock and my foundation that I stand on especially when I am being pulled away from it or struggling through tough things. Find a small group that will always care about what you care about and be honest enough to challenge you to be your best. That may be only one or two people.

Robin Olson: They must have a voice and advocate for themselves. This means asking for flexibility when it's needed but being considerate of business goals and objectives. It means speaking up tactfully when stereotypes or biases are creating a challenging environment. It means applying for new responsibilities when they want the next challenge. Mentors are wonderful guides for this!

The Evolution of Gear Dynamics and Gear Noise

Raj Singh reflects on the short courses and gear research at Ohio State University

Matthew Jaster, Senior Editor

Laboratory tour and demonstration led by Prof. Ahmet Kahraman, discussing advanced gear whine and rattle excitation measurements.

A deep dive into the world of gear dynamics and gear noise has led many a mechanical engineer to Columbus, OH in search of the methods by which gear noise is measured and predicted as well as the techniques employed in gear noise and vibration reduction. Over the past 40+ years, about 2,550 engineers and technicians from 385+ companies have attended the Gear Dynamics and Gear Noise Short Course at The Ohio State University.

"Our audience is diverse ranging from gear designers, test engineers, manufacturing engineers, noise and vibration specialists, CAE professionals to even fresh graduates from engineering colleges. Introductory overview lectures are useful to the gear designer with minimal knowledge of noise and vibration analysis as well as to the noise specialist with little knowledge of gears," said Raj Singh, emeritus professor, department of mechanical and aerospace engineering, The Ohio State University.

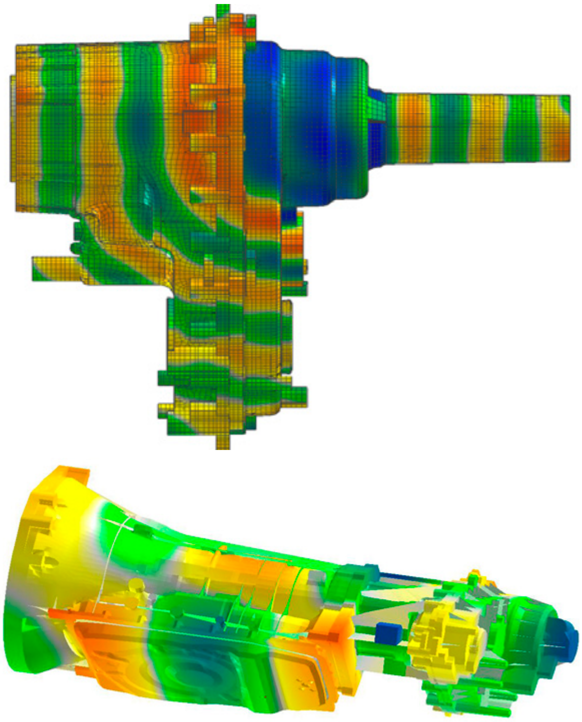


Illustration of typical noise calculations from practical gear casing structures, as covered by Prof. Raj Singh in his lectures.

Given the diverse needs within the gear industry, Singh said attendees always find something that has a direct relevance to their work or the current problems they are facing.

The course was founded by Prof. Don Houser in 1978, and Dr. Singh joined in 1979. Initially, two lecturers from the UK participated as well to provide the European and historical context. The course continued to evolve based on the progress made on the research front, and now it is taught by a team of world-class experts, led by Professors Singh, Kahraman and Talbot.

"In the early days (spanning four decades), we focused just on the gear whine, design methods and measurements. Gradually, we introduced other topics which were the by-products of OSU's Gear Lab research since the 1980s. These include gear contact analysis and robust design calculations, CAE tools for static, dynamic, and acoustic analyses, transmission error measurements using modern instrumentation, gear rattle, etc.," Singh said. "In the coming years, we may introduce timely topics such as e-vehicle geared drives, high speed gear dynamics, tribology issues, and the like. There has been a great synergy between the short courses and the gearing research carried out at Ohio State. As a result, Ohio State is a premier institution for research, graduate education, and training of gear industry practitioners."

Given the fact that gear noise is a hot topic due to the push for electrification across the automotive and transportation industries, it's not surprising to see these conversations come up regularly at Ohio State.

"We have started to mention the electrification issues in several lectures especially the motor excitation frequencies, torque pulsations, dynamics associated with high-speed operations and so on. Of course, we must introduce more e-mobility topics in the future offering of the short course. Synergy with the Gear Lab will also bring in the latest methods or tools to the course," he added.

Gear noise, however, has been a challenge for several manufacturing segments through the years.

"Industries that find this course helpful include transportation, off-highway vehicles, wind-energy, process machinery, aircraft, appliance, robotics, and all gear manufacturers, in addition to automotive (including the e-vehicles)," Singh said.

An Inside Look at the Lectures

The Gear Dynamics and Gear Noise Short Course is a comprehensive overview that bolsters classroom discussions with real-world examples. On day one, lecturers discuss why even perfect gears

make noise. They present in both qualitative and quantitative terms how gear design parameters and manufacturing errors affect noise. The concept of gear transmission error, one of the major contributors to gear noise, is developed, and methods of predicting transmission errors from design and manufacturing data are presented. Participants get a clear physical insight into the problems they face and how they may apply course knowledge to help solve their gear noise problems.

On day two, lecturers concentrate on gear system dynamics and acoustics, dynamics of parallel axis and planetary gears, transmission error calculations and measurements. The role of spacing error is also discussed. The third day's lectures briefly discuss the sources of gear rattle and design robustness for whine problems as well as spending several hours in the case history workshop. (see the preliminary agenda at *nvhgear.org/home.html*).

Case History Workshop

This novel approach to discussing "real life" gear noise and dynamics problems has been used in this course since its inception. The workshop, which has been lauded by past attendees for its practical flavor, takes place on the third day of the course. The purpose of this workshop is to allow the course instructors and participants to interact and to discuss gear noise and dynamics case histories presented by course attendees. They are asked to present a brief synopsis of problems they have encountered or of a procedure they have used for gear noise analysis and reduction. Possible approaches to solve each problem will be discussed.

Laboratory Exercises

"Most attendees eagerly look forward to the laboratory and computer software demonstrations that are used to illustrate gear noise measurement and analysis techniques. The unmatched facilities of the Gear and Power Transmission Research Laboratory (*gearlab.org*) and the Acoustics and Dynamics Laboratory (*mae.osu.edu/adl*) are utilized for such demonstrations," Singh said.

An Adaptive Training Course

The course is of particular interest to people involved in the analysis, manufacture, design specification, or utilization of simple and complex gear systems. Topics range from transmission error (the main source of gear whine), measurements for gear noise diagnosis, noise, vibration and perception issues, gear tooth, shaft and bearing, dynamics, profile design, and manufacturing issues and transmission paths and housing acoustics.

Singh said the analysis tools as well as the methods to address gear noise are changing as we approach 2024.

"Faster and more efficient calculations for both components and systems are of interest. Yet another one is the integration of various CAE tools. In fact, the verification (such as comparison of two analysis tools) and validation (comparing predictions with measurements) issues are arousing more interest as attendees are raising those questions. We will enhance the presentations to emphasize these issues in the future."

Multiple areas of a gearbox assembly must be analyzed to come up with the most effective tools to combat gear noise, according to Singh.

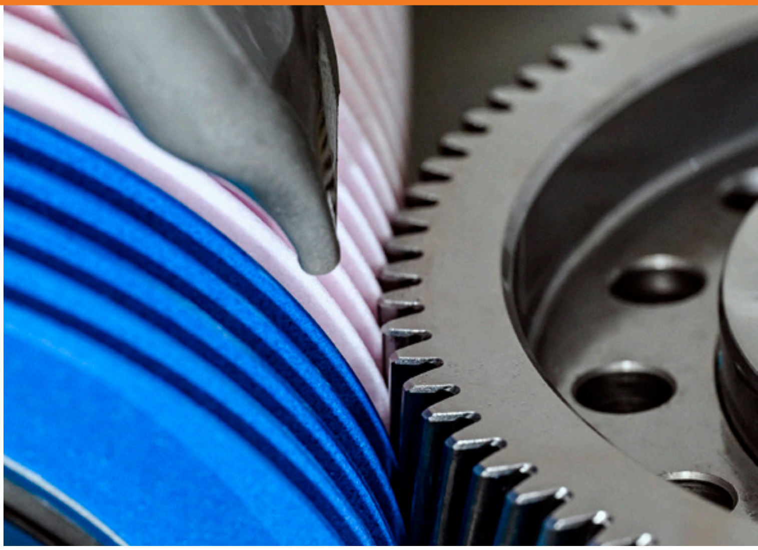
"Primary sources such as the transmission errors and mesh stiffness variations should be addressed first. Beyond that, secondary issues such as sliding friction, misalignments, spacing errors, ghost noise, bearing clearances and the like should be examined depending on the customer complaints or measurements. Thus, a structured problem-solving approach is needed based on design targets and application perspectives," Singh said.

In the future, Singh said the education may include the use of AI in design optimization and diagnostics, development of digital twin tools, application of 3D printing methods to gearbox components, ultra-precision machining or finishing methods, etc.

The next Gear Dynamics and Gear Noise Short Course takes place June 3–6, 2024. Go to *nvhgear.org/home.html* for additional details.

Gear Lab tour led by Prof. Isaac Hong, illustrating some of exceptional experimental facilities.

Discussion of gearbox vibration and acoustics by Prof. Raj Singh as part of the laboratory demonstrations



Polish Grinding of Gears

Surface quality and efficiency go hand in hand

Walter Graf, Senior Project Manager, Reishauer AG, Switzerland

This article introduces the process of polish grinding of gears. Improved surface quality increases the overall efficiency of gearboxes, resulting in reduced friction and torque loss, higher power density, and noise-optimized gears (lower NVH); all these factors are highly relevant, especially for electric drives. When Reishauer developed polish grinding in 2012, the process aimed to improve the efficiency of ICE engine transmissions, and the set goals were easy to achieve. Today, in 2023, the situation is dramatically different. While an ICE engine operates at around 3,000 rpm and supplies acoustic masking of the gear noise, EV drivetrains feature up to 20,000 rpm and offer no such masking.

For this reason, EV gears must run substantially quieter. Furthermore, both left and gear flanks must perform identically for acceleration and deceleration due to regenerative braking. When looking at the surface texture, we must distinguish between roughness, waviness, and form. Any of these parameters can influence the performance of a gear. Polish grinding can only influence the roughness, not waviness or form. The grinding process must control form errors and waviness before polishing takes place. However, the continuous generating gear grinding process has proven to supply excellent quality in form, waviness, and pitch. Continuous generating gear grinding delivers a surface roughness of around Ra 0.3 µm, which has to be reduced by a subsequent polish grinding stroke. Let's take a moment to ponder the term surface roughness:

> "It's common to hear 'surface roughness' described as a number that can be measured by a gauge. But describing surface texture with a number is a lot like describing a concert in decibels: Loudness is just part of the story. A rock band, an orchestra, and a chainsaw can all produce 100 decibels, but the full picture is much more complex and interesting." (Ref. 1)

The Process

The basic technology for polishing grinding is continuous generating grinding. Based on a dressable grinding worm, this method has proven itself in terms of flexibility and high productivity. The kinematics of this process can be understood as a worm drive with rotational movements of the grinding worm and the workpiece (n_B and n_c), see Figure 2, with additional abrasive machining movements consisting of an infeed X, vertical feed Z, and lateral shift movement Y. The interaction of parameters creates a "contact zone." The contact zone comprises a contact length l_k, contact width a_p, and contact depth a_e.

Polish grinding is performed as a final machining sequence, with the workpiece remaining clamped on the same workpiece carrier during both grinding and polish grinding. Also, most importantly, polish grinding does not aim to impart the surface with a mirror finish. First and foremost, polish grinding must produce a functional surface, a surface that features reduced friction while still capable of retaining an oil film during gear meshing.

Polish grinding follows immediately after conventional generating grinding, typically consisting of a rough and finish grinding pass. For this purpose, the grinding worm is divided into the grinding and polishing zones.

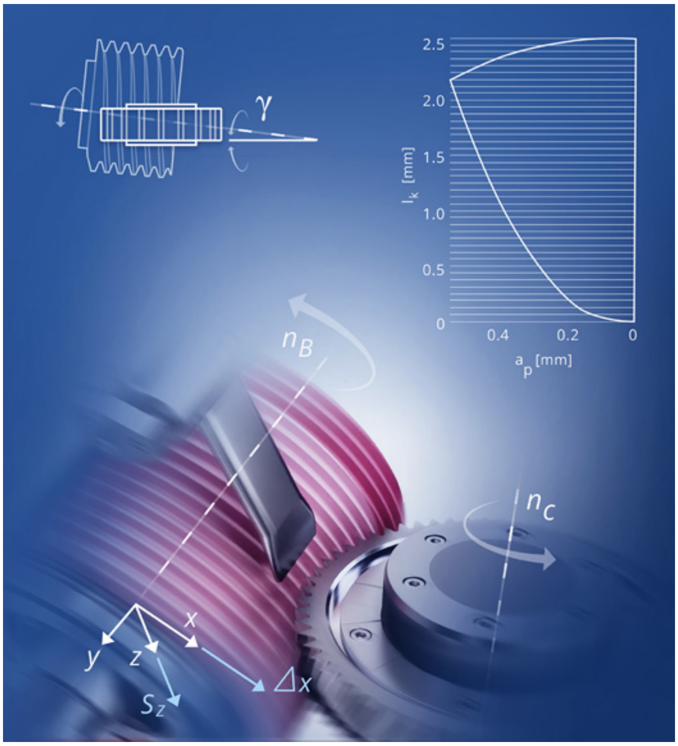


Figure 2—Principle of continuous generating grinding.

This final sequence is a polish grinding pass using the elastic, resin-bonded section of the grinding worm. There are some fundamental differences between grinding and polish grinding. Simply put, grinding uses larger grain sizes and more rigid bond structures. For grinding, a grain size of 80 is used, with an average grain diameter of 185 µm. For polish grinding, a grain size of 800 is used, with an average grain diameter of 7 µm. When polish grinding ICE gears, the selection and combination of grinding and polishing zone was easy as most combinations worked immediately. However, combining the right grinding wheel and polish wheel section for EV gears requires much experience. For example, using the same polishing section but two different grinding sections results in very different polished surfaces. The right grinding section must be selected initially for the polish wheel to deliver the right final surface requirements.

Grinding aims to achieve perfect geometry, a "good" surface quality, gear flanks free of waviness, form accuracy, and high material removal rates. As a subsequent step to grinding, polish grinding should not alter the geometry created by grinding. However, it increases the load-bearing capacity of the tooth flanks by removing surface peaks. Moreover, for technical purposes, polish grinding should only remove the peaks of surface roughness and leave the roughness of the surface valleys intact so that an oil film can adhere to the polished surface. The increase in the load-bearing portion of the gear tooth flanks allows gear designers to boost the power density of the gearboxes.

After the roughing and finishing grinding passes, the grinding worm shifts via a jump from the vitrified bonded zone to the polishing zone for the final machining pass, as shown in Figure 3.

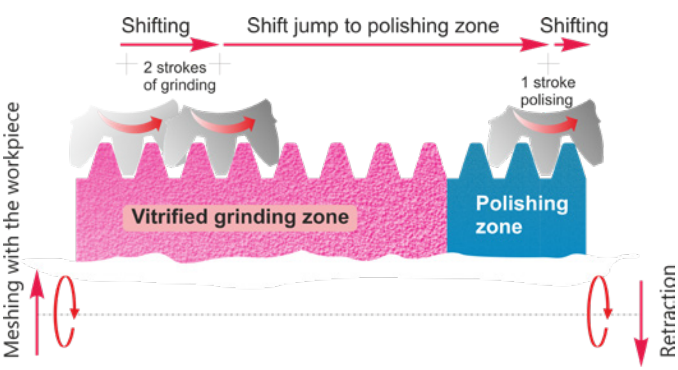


Figure 3—Principle of continuous generating polishing grinding.

Using a combined grinding and polishing wheel offers a significant advantage over alternative methods, such as vibratory finishing, which requires a prior grinding process and, thus, two different machine tools and more complex material handling. Continuous generating grinding requires only one machine tool. It grinds and polishes the component in one clamping, making it economically viable for mass production. In the combined process, polish grinding perfectly follows the gear profile and flank line's precision-ground micro and macro geometries.

Scientific Basis

A research project by NASA's research center confirmed as early as 2002 that superfinish-ground (polished) gears have a fourfold lifespan compared to conventionally ground gears (Ref. 2). In this case, the polishing finish was achieved by immersing the gear parts in an abrasive medium and subjecting them to vibratory finishing. Polished surfaces increase the service life of gears as they reduce micro-pitting and lead to lower friction in the gear meshing process and, hence, higher transmission efficiency.

Surface Characterization

One such number would be R_a, the arithmetic average of the profile height deviations from the mean line, the most common value for describing ground surfaces. However, this is mostly for historical reasons, as early roughness gauges were limited to this particular parameter. However, R_a is not very useful for polish grinding as the same R_a value can have various surface characteristics. The problem of why R_a is not useful for polish grinding is given by its definition: The average deviations from the mean line. In other words, the average is taken from the valleys' depth and peaks' heights along a defined distance. According to this definition, two very different surfaces could be identical: one with high and low valleys and the other with low and deep valleys. Furthermore, R_a does not differentiate between narrow and wide spacing between peaks and valleys, although the spacing may significantly influence gear noise generation. Hence, while different measured surfaces may have identical R_a values, the resulting performance of meshing gear flanks, although of identical R_a values, may be worlds apart regarding gear noise and vibrations.

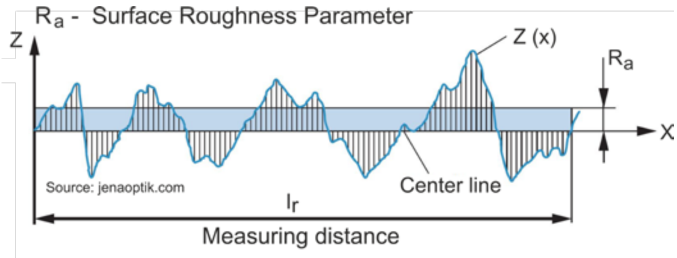


Figure 4—Ra surface roughness parameter.

As M. Stewart writes in an SME paper from 1990:

> "Tribology studies have shown that the ideal sliding surface is smooth with relatively deep valleys to hold and distribute the lubricant. However, quantifying and specifying these surfaces has always been a problem. Since its introduction, the bearing area curve - the Abbott curve - has been recognized as the only effective method for characterizing these surfaces but is rarely used in specifications." (Ref. 3)

The Abbott curve, Figure 5, is a much better indicator for predicting the load-bearing wear behavior of gear flanks than the roughness value R_a. The arithmetic mean deviation R_a does not differentiate between peaks and valleys and, therefore, has a relatively weak informational character. Furthermore, it should be highlighted here that, to date, there are no common standards for polishing grinding, and users have different ideas concerning the polishing characteristics they aim for. Thus, an identical R_a value can describe a surface with high peaks and shallow valleys or a surface with low peaks and deep valleys. For this reason, users today prefer the R_{vk} value, which describes the reduced groove depth. This parameter is used to characterize valleys that retain lubricant. During the polishing process, the R_{pk} value (the peaks) is altered more than the R_{vk} value (the valleys). The goal of polish grinding should be to reduce the R_{pk} and leave the R_{vk} as much as possible intact, with the further goal that the R_{pk} value remains identical on both flanks.

While one must be careful to declare absolute surface characterization values for polish grinding, the following values may serve as a guideline:

R_{pk} 0.15 µm, R_k 0.4 µm, R_{vk} 0.25 µm, R_a 0.1 µm

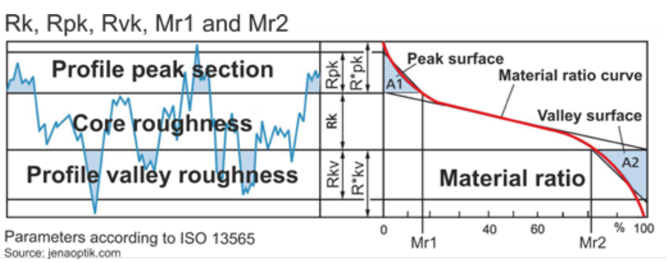


Figure 5—Abbott material ratio curve.

Figures 6 and 7 show the typical results of polish grinding, profile, lead, and surface roughness on a typical automotive ring gear.

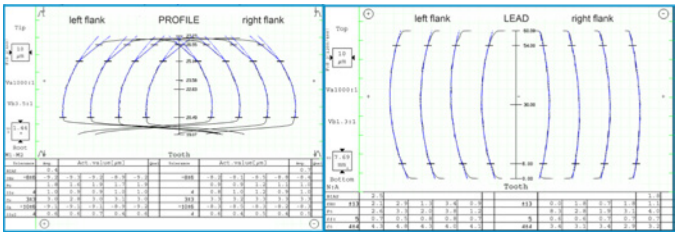
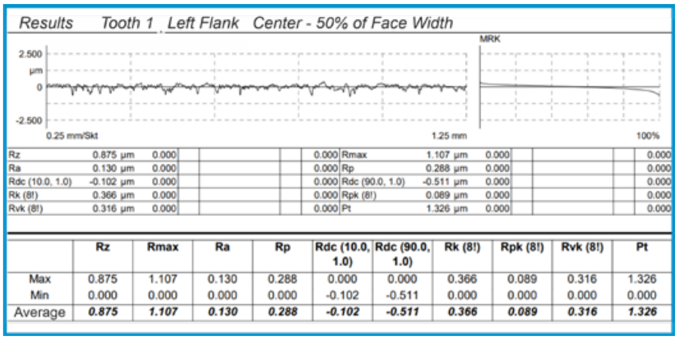


Figure 6—Profile and lead measuring chart of ring gear, module 2.4.



Rz	0.875 µm	0.000	0.000	Rmax	1.107 µm	0.000	0.000
Ra	0.130 µm	0.000	0.000	Rp	0.288 µm	0.000	0.000
Rdc (10.0, 1.0)	-0.102 µm	0.000	0.000	Rdc (90.0, 1.0)	-0.511 µm	0.000	0.000
Rk (8!)	0.366 µm	0.000	0.000	Rpk (8!)	0.089 µm	0.000	0.000
Rvk (8!)	0.316 µm	0.000	0.000	Pt	1.326 µm	0.000	0.000

	Rz	Rmax	Ra	Rp	Rdc (10.0, 1.0)	Rdc (90.0, 1.0)	Rk (8!)	Rpk (8!)	Rvk (8!)	Pt
Max	0.875	1.107	0.130	0.288	0.000	0.000	0.366	0.089	0.316	1.326
Min	0.000	0.000	0.000	0.000	-0.102	-0.511	0.000	0.000	0.000	0.000
Average	***0.875***	***1.107***	***0.130***	***0.288***	***-0.102***	***-0.511***	***0.366***	***0.089***	***0.316***	***1.326***

Figure 7—Surface roughness measurement of ring gear, module 2.4.

Economic Considerations and Conclusion

The direct integration of polish grinding as a subsequent step in the conventional generating grinding process results in minimal investment costs if customers already have Reishauer generating grinding machines. Moreover, the diamond dressing tools remain the same as with conventional methods. Polish grinding also requires only minimal additional operator training. Although the cycle time increases slightly due to the additional polishing stroke, this is offset by the gain in product quality.

Additional costs arise from purchasing special grinding wheels with two different areas for grinding and polishing. The higher process costs compared to conventional gear grinding are more than offset by the benefits of reduced torque loss, higher load-bearing capacity of polished ground gears, and higher power density in the gearboxes.

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FTM 2024 Call for Papers

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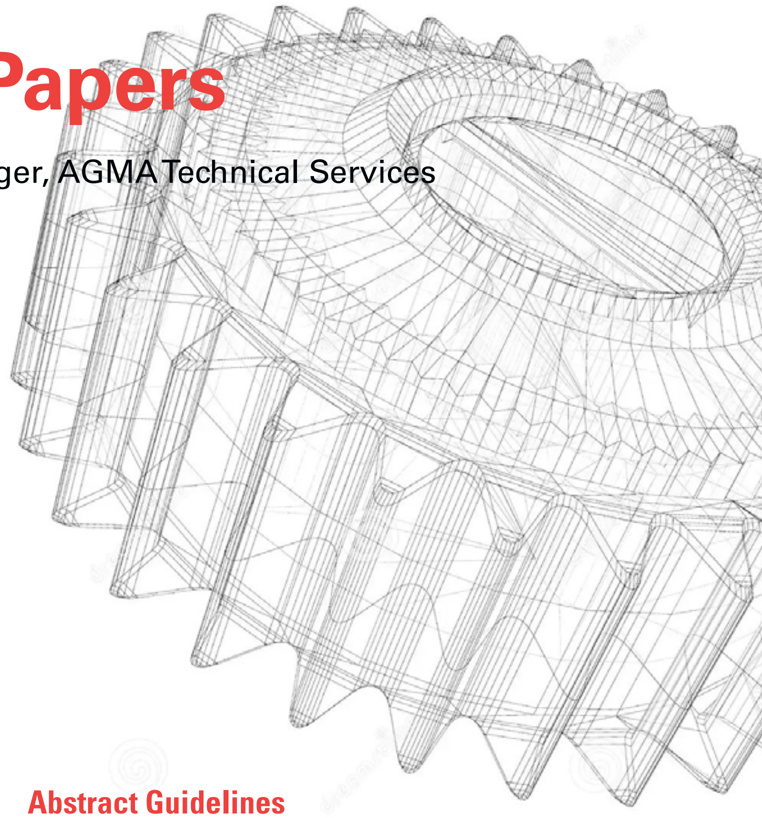

For each FTM, AGMA selects abstracts submitted by authors for development into technical papers. Subject matter may include topics relevant to the gear industry, such as design and analysis; manufacturing and quality; materials, metallurgy, and heat treatment; operation, maintenance, and efficiency; and gear failure. The papers then go through a double-blind peer review process to ensure the efficacy of the research. The authors then present the results of their work at the FTM. We encourage industry experts and professionals to submit an abstract. Abstracts that are selected to become papers should be on relevant technical subjects, original to the AGMA audience (not a paper that has been previously published in its submitted form), technically accurate, and free of commercialism. All papers presented at FTM will be indexed in Scopus, the international database of peer-reviewed literature. AGMA will waive the FTM registration fee for ONE presenter per paper accepted for presentation. Full registrations will include all FTM events. All Fall Technical Meeting questions should be sent to: *FTM@agma.org*

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Abstracts should be between 200 and 300 words.

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Investigation of the Manufacturability of Topological Modifications Using Adapted Kinematics for Gear Skiving

Christopher Janßen, Stylianos Tsakiris, Mareike Solf, Thomas Bergs

Nomenclature

a	axial distance
b_2	gear width
c_β	crowning
d_{a0}	tool tip diameter
d_{a2}	gear tip diameter
f_a	axial feed rate
m_i	polynomial coefficient
m_{n0}	tool module
m_{n2}	gear module
NC	Numerical Control
z_0	number of teeth of the tool
z_2	number of teeth of the gear
α_{n0}	tool profile angle
α_{n2}	gear profile angle
β_0	tool helix angle
β_2	gear helix angle
Δ	difference between modifications
Σ	axis crossing angle
φ	twist angle

Introduction

Gears that are provided with tooth flank modifications have advantages over unmodified variants (Ref. 1). These advantages include improved acoustic excitation behavior, improved load-carrying capacity, or an increase in efficiency (Refs. 2, 3). The degree of optimization can be increased by using topological modifications, compared to the standard modifications known by the standard (Refs. 2, 3, 4, 5).

The increasing industrial relevance of tooth flank modifications can be traced back to a radical change in the automotive industry. Increasing environmental awareness is presenting car manufacturers with new challenges. One of these challenges is to make automobiles more efficient and thus more resource-efficient in their consumption. The transmission is one component that can be optimized in terms of weight and noise emissions (Ref. 6). Tooth flank modifications are usually applied to the gears in the last step of the gear manufacturing process chain, hard finishing (Ref. 7). For the manufacturing of this modification, established manufacturing processes such as profile or generating grinding are generally used (Ref. 7).

A manufacturing process that has received little attention in this respect is gear skiving. It is only recently that gear skiving has become a focus of gear manufacturing (Refs. 8, 9). With gear skiving, a process is available that is suitable for the machining of gears in soft and hard conditions (Ref. 10). Gear skiving can be combined with the production of tooth flank modifications. However, the application possibilities and limits have hardly been investigated so far.

This paper was first presented at the 17th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 12–14 July 2023, Gulf of Naples, Italy.

State of the Art

According to ISO 21771, topological modifications are described as a freely definable modification amount on the grid of a tooth flank (Ref. 11). In contrast to standard modifications, which require at most two defining parameters, a definition with three parameters is necessary (Refs. 4, 11). Two of the parameters describe the location on the grid using coordinates in lead and profile direction. The third parameter represents the amount of modification at the previously defined location. Topological modifications can thus have gradients that go beyond the linear and quadratic gradients of standard modifications (Ref. 4). A description of the courses by a polynomial of higher order (with a degree greater than two) is possible, as well as a periodic modification in the form of a wave (Ref. 2), see left side of Fig. 1. For the manufacturing of topological modifications, generating grinding or profile grinding was mainly used (Refs. 12, 13). The manufacturing of topological modifications by gear skiving has not been investigated so far.

Gear skiving is a manufacturing process with a defined cutting edge for machining periodic profiles (Ref. 14). It is suitable to produce both internal and external gears as well as worm gears (Ref. 15). The process is mainly used when gear hobbing is not possible (Ref. 10). This is especially the case for producing internal gears and gear shafts with interfering contours (Ref. 8). Due to progressive developments in the field of CNC control of machine tools, series production with gear skiving is possible (Ref. 8). Hard skiving is an additional process variant that allows hard fine machining of the tooth flanks (Ref. 16).

The kinematics of gear skiving are shown graphically on the right side of Figure 1. The rotational axes of the workpiece and the tool are inclined to each other by the axis crossing angle Σ. The axis crossing angle results from the sum of the helix angles of the tool β_0 and the workpiece β_2, cf. Fig. 1 (Ref. 14). If the axis cross angle Σ is increased starting from 0 degrees, the rolling motion becomes a screw rolling motion (Ref. 15). The screwing motion results in a cutting speed v_c, which leads to chip removal if the axis crossing angle Σ is sufficiently large.

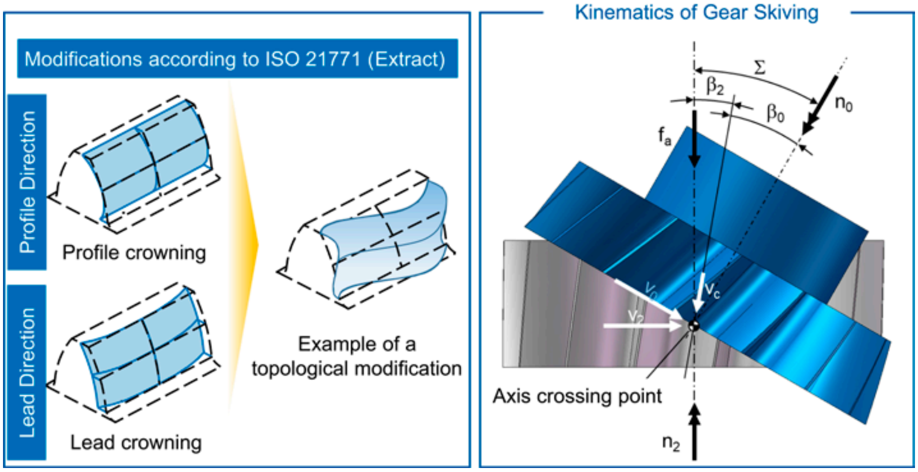

Figure 1—Flank modifications and gear skiving kinematics (Refs. 14, 11).

Objective and Approach

By applying topological modifications, a gear can be improved in terms of acoustic excitation behavior, efficiency or load-carrying capacity compared to standard modifications. The manufacturing of such modifications has been researched for established manufacturing processes such as generating or profile grinding. These processes are however not suitable for internal gears, whereas the gear skiving process is suitable for internal and external gears. Investigations into the manufacturability of topological modifications utilizing gear skiving are not available.

In the first step of this research, the kinematics of the tool and the workpiece required for producing the modifications are derived. The modifications are varied for the flank lines starting from a linear and a quadratic deviation up to a polynomial deviation of a higher degree. Based on these kinematics, an *NC* code is created for the machine control. For the derivation of the necessary kinematics, the knowledge about the positioning of the axes in the machine coordinate system is relevant. In the next step, external gears are manufactured using the previously defined kinematics in a gear skiving process. Finally, the lead deviations and the topography are measured. Based on the available results, it can be evaluated to what extent topological modifications can be applied by gear skiving.

Design of Experiments and Test Setup

Trials to investigate the manufacturability of topological modifications were carried out on a Gleason Pfauter 300 PS gear-skiving machine. A two-flank machining strategy in the soft state was selected for the application of the lead modifications. The material used was a 20 MnCr5 steel commonly used for gears. A gear skiving process with 25 cuts was designed for cutting the gears. The infeed over all cuts was defined with a degressive strategy based on a maximum chip thickness of $h_{cu,max}$ = 0.15 mm. The modified kinematics were applied exclusively in the last quality-critical cut. A cutting speed of v_c = 60 m/s was kept constant for all cuts. An axial feed rate of f_a = 0.05 mm was selected for the final shape-forming cut. A low feed rate of this magnitude results in minimal process-related flank deviations, such as feed marks.

At an increased feed rate f_a, there is a possibility that process-related deviations will override the modifications applied by the adapted kinematics. Based on the tool and workpiece data, an axis crossing angle of Σ = -20 degrees was specified. For the investigations, a right-handed tool with an outer diameter of d_{a0} = 160 mm and a number of teeth of z_0 = 29 was used. Both the pressure angle an0 and the helix angle β_0 were 20 degrees. The cutting material used was PM high-speed steel coated with AlCrN. Table 1 shows the most important gear and tool data.

The general procedure for varying the kinematics is shown in Figure 2. When varying the center distance along the tooth width b_2, the kinematic parameters axis crossing angle Σ and twist angle φ remain constant. In addition to the center distance variations, which can be described by a polynomial of any degree, a gear with an end relief was manufactured. To produce an end relief, the specification of a discontinuous differentiable axis motion is mandatory. A possible discontinuous axis motion is shown in purple Figure 2 on the left. In addition to the center distance, the axis crossing angle Σ and the twist angle φ can also be varied, see Figure 2 center and right. Varying the twist angle φ causes a shift of the cut from one flank side to the opposite flank side. The change in position of the workpiece relative to the tool due to a twist angle variation is shown as an example in Figure 2. A variation of the axis crossing angle Σ leads to a change of the tool profile projected into the tooth gap. An example illustration of the variation is shown in the center of Figure 2. Depending on the selected axis crossing angle Σ, the additional tilting around the y-axis results in an increase or decrease of the tool profile projected into the cutting plane of the tooth gap. Due to the tilting of the tool profile, uneven material removal in profile and flank direction is to be expected during manufacturing.

Transfer of the Kinematics into the Machine Control

The use of simulations enables the optimization and testing of processes in advance of their execution in the manufacturing environment. The translation of the simulated motions into a machine-readable language, such as *NC* code, is necessary to take advantage of the simulations in practice. This chapter describes the development of a converter capable of translating discrete-time kinematics from a simulation into *NC* code for a machine control system.

Development of an *NC* Converter

To transfer the kinematics, a converter was developed that can translate discretized time kinematics from a simulation into *NC* code for machine control.

	Value	Unit
Gear		
z_2	21	
m_{n2}	5	mm
β_2	0	°
d_{a2}	116.2	mm
b_2	44	mm
Tool		
z_0	32	
m_{n0}	5	mm
β_0	20	°
α_{n0}	20	°
d_{a0}	160	mm
Process		
Σ	-20	°
a	120.6	mm
f_a	0.05	mm

Table 1—Gear, tool, and process data.

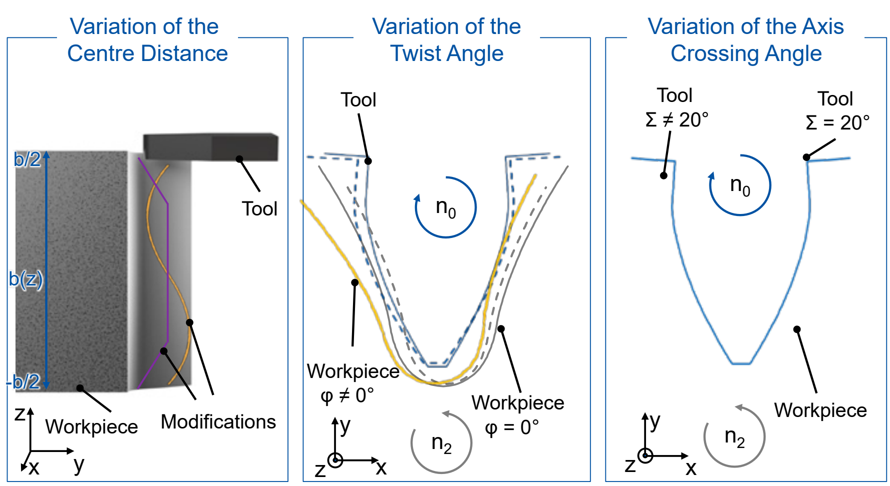

Figure 2—Overview of kinematic adjustments.

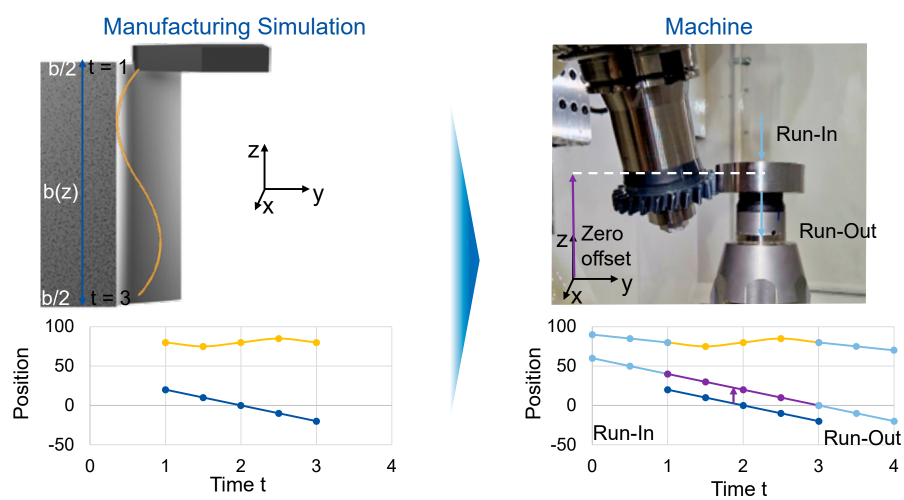

Figure 3—Method for converting kinematic data.

The kinematics derived in a .MPF file were read in and processed by the *Sinumerik* 840D SL machine control from Siemens. Discretized time kinematics refers to the movements of a system that calculates the axis movements of the tool and workpiece in time steps. For the development of an *NC* converter, the understanding of the working area and the axis positioning was of fundamental importance. The required axis positions in the machine coordinate system were derived from existing data and taken into account.

The simulation used to generate the kinematics had a different origin in the coordinate system to the machine coordinate system itself. Therefore, the axes for the machine control had to be shifted to generate accurate kinematics. The machine coordinate system refers to the area in which the machine actually operates, while the simulation coordinate system represents a virtual area in which the kinematics are generated. The differences between the two systems could induce faulty machine control if the axis positions were not correctly considered. An example of the procedure for transferring the kinematics to the machine control system is shown in Figure 3. Starting from a manufacturing simulation, kinematics was defined which describes a variation of the center distance a along the gear width b_2. In addition to the center distance variation, the traverse path in the z-direction is also displayed. The kinematics are described discretely in time in a period from $t = 1$ to $t = 3$. Due to a shift in the coordinate system in the working area, it is necessary to perform a zero-point shift. In this example, the shift of the z axis is necessary. In addition, the run-in and run-out defined by the machine are taken into account and coupled with the previously derived kinematics. This is illustrated by an extension of the machining period, cf. Figure 3.

Knowledge of the working area and axis positioning enabled the *NC* converter to generate accurate and effective kinematics. By using the correct axis positioning in the machine coordinate system, the accuracy of the conversion was maximized. Then, the path curve was discretized. Here, the time-location information was divided into discrete steps to ensure a smooth transfer of the motions to the *NC* code. The velocity was kept constant by explicitly specifying the feed rate. A special feature of the converter is that it recognizes which axis has been modified and adjusts the path curve for the corresponding *NC* code. This meant that the simulated movements could also be accurately implemented using the machine control. Absolute specifications were used for changing the axis distance parameter as well as for varying the twist angle. For a variation of the twist angle, the converter enabled the generation of an *NC* code with relative position specification to execute the movements of the machine correctly even with changes in the twist angle φ. To transfer the kinematics, a converter was developed that can translate discretized time kinematics from a simulation.

Validation of the *NC* Converter

To validate the functionality and accuracy of the converter concerning the transmission of the kinematics, two reference gears were manufactured. The first reference component was manufactured without modifications. The kinematics were calculated using the machine control's dialog program, considering the tool and workpiece parameters, cf. Figure 4. The second reference gear was also manufactured without modifications using kinematics specified by the converter. First, the kinematics were derived simulatively. The discretized time kinematics, which describes the movements of the tool and the workpiece over time, were calculated. These kinematics were then converted to an *NC* code using the converter. The two reference gears were measured for their IT quality and examined for the precision of the transferred kinematics. In Figure 4, the comparison of the results of the gear measurement for the left and right lead lines of three tooth gaps each, distributed over the circumference of the two reference gears is shown. Comparing the lead lines reveals that the *NC* code was able to manufacture a gear that is qualitatively equivalent to the gear produced using the skiving machine's dialogue program. A maximum difference of $\Delta = 3.6$ µm is found between the two reference gears. Based on the available results, it can be concluded that the deviations detected are in the order of magnitude of the usual manufacturing deviations due to the concentricity of the tool and the workpiece. Sufficient agreement can therefore be assumed. Thus, the functionality and accuracy of the converter could be validated.

Manufacturing of Topological Modifications Using Gear Skiving

After successful validation, the converter can be used to produce topological modifications. For this purpose, modifications are created by varying the axis crossing angle Σ, the center distance a, and the twist angle φ.

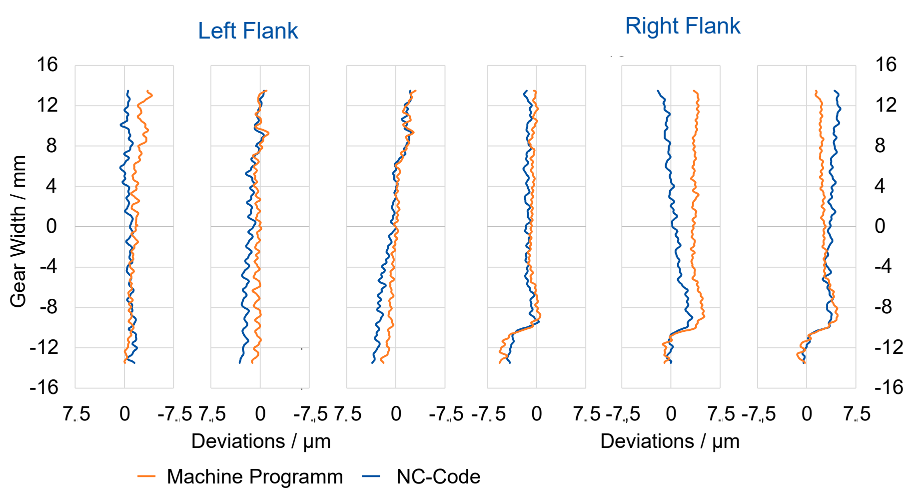

Figure 4—Comparison of the lead lines of the two reference gears.

Variation of the Center Distance

The results of changing the center distance based on a polynomial with degree 4 are shown in Figure 5. The course of the specified polynomial could be applied to both flank sides. However, there are deviations between the specified and the manufactured modification in terms of the amount obtained over the entire width of the tooth.

On the left flank side, a deviation of Δ = 2.5 µm was detected between the specified and the achieved amount of modification. On the right flank side, this amounts to Δ = 3.4 µm. However, an analysis of the topography of both flank sides reveals a good agreement between the specified course of the modification over the tooth flank and the obtained course of the flank line modification. A high degree of agreement was achieved concerning the course and magnitude of the modifications. The course of the flank lines in the form of a polynomial of degree 4 is clearly recognizable.

The specification of a discontinuous path movement in processes such as generating grinding is used to produce end relief. This procedure could be applied to gear skiving, cf. Figure 6. The desired amount of modification for the left flank in the positive and negative areas of the gear could not be achieved exactly. A difference of Δ = 7.6 µm was determined between the specified modification amount and the amount achieved. Due to the constant center distance setting during cutting in the center of the gear (b_2 = 0 mm), no differences resulted between the actual and the nominal values. However, when the center distance is changed to a linear infeed, deviations in the modification amount and the course can be detected.

The course of the measured flank line shows that the tool was fed into the workpiece before the desired point for the start of the center distance modification. In the center of the gear (b_2 = 8 mm to -8 mm) there are almost no deviations. In radial direction towards the tip radius in the direction of the outer radius, however, deviations between the specification and the manufactured topography become apparent. On the outer sides of the tooth flanks, the change in the center distance to a linear infeed is evident. The start of the linear infeed varies for both flank sides in the radial direction. The deviations at the beginning of the infeed show a linear course along the profile direction of the gear. The shape of the present deviations is similar to a twist, which in principle occurs in modified helical gears (Ref. 14).

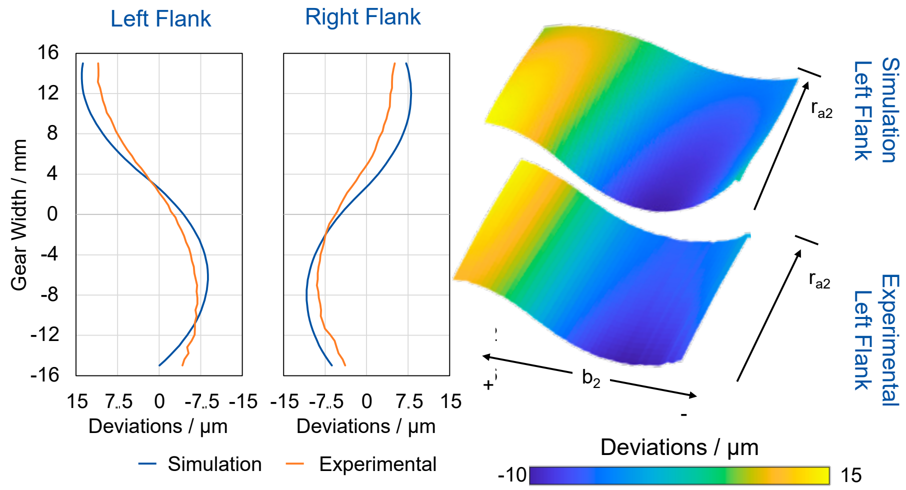

Figure 5—Results of the application of a polynomial degree 4.

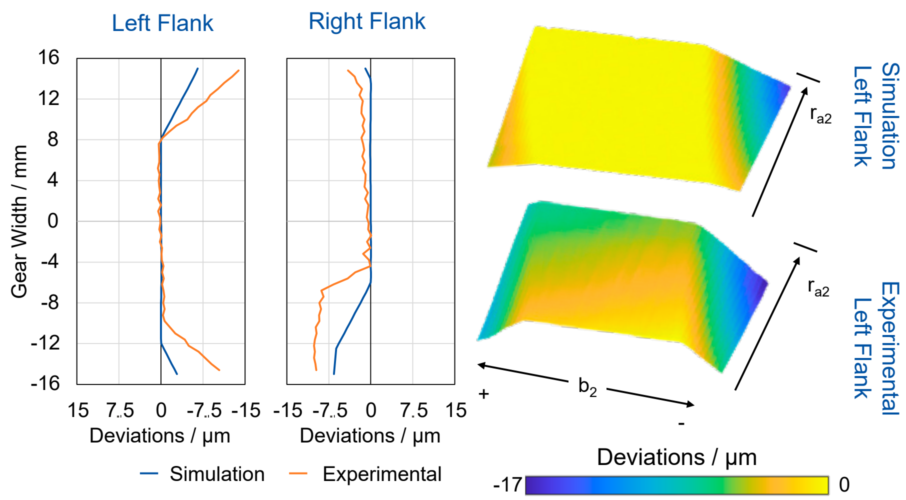

Figure 6—Results of a discontinuous change of the axial distance.

Manufacturing of Modifications by Changing the Twist Angle

The twist angle φ was varied in the range between 0.0° ≤ φ ≤ 0.2°. A qualitative agreement was achieved between the simulatively defined specification and the actually manufactured flank line concerning the amount and the course, cf. Figure 7. For the left flank side, the largest deviation in terms of amount is identified in the positive area of the tooth width with Δ = 1.0 µm. Due to the two-sided machining, a modification mirrored in amount is obtained for the right flank side. A qualitative agreement was also reached between the specification and the achieved modification. However, deviations can be seen on the right flank in both the positive and negative areas of the tooth width b_2, with a difference between the specified and the achieved modification amount of Δ = 4.5 µm. Further deviations on the left flank side become apparent when analyzing the topography. Contrary to the simulation, the amount of modification changes in the profile direction for the manufactured gear. However, it should be noted that a quadratic modification could be applied by adjusting the twist angle φ.

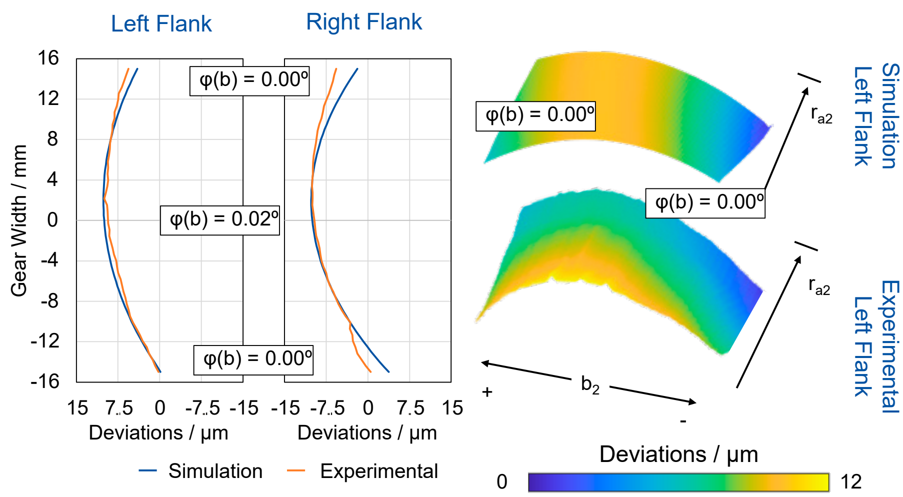

Figure 7—Results of a quadratic change of the twist angle φ.

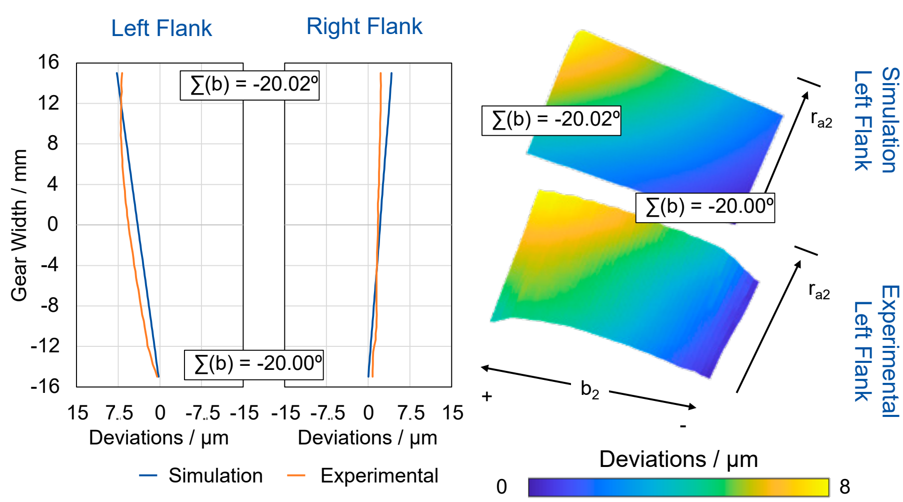

Figure 8—Results of a linear change of the axis crossing angle Σ.

Manufacturing of Modifications by Adjusting the Axis Crossing Angle

The influence of a variation of the axis crossing angle Σ on the tooth flank topography was investigated in the following. For the investigation, a linear variation of the axis crossing angle Σ was applied along the tooth width b_2. The variation of the axis crossing angle Σ was carried out in a range of between -20.02° ≤ Σ ≤ -20.0°. The results are shown in Figure 8 and demonstrate that a specific modification of the tooth flank topography is possible by varying the axis crossing angle. The specified linear variation of the axis crossing angle Σ could not be fully implemented on the left flank. Instead, a parabolic course of the manufactured flank line could be measured. Nevertheless, the specified amount of modification could be maintained, which means that only a maximum difference of Δ = 2.3 µm between the specified and the actual amount was detected. On the right flank side, a linear progression of the measured flank line could be observed. When considering the topography for the left flank side, an analogous picture emerges. Instead of the specified linear course, a quadratic modification of the topography was measured. However, apart from the lack of linearity, an equivalent modification curve is obtained between the simulated and the specified topography. These results show that the specific modification of the tooth flank topography by varying the axis crossing angle Σ is possible. Precise implementation of this technique is challenging and requires further investigation to improve the accuracy of the transferred kinematics.

Summary and Outlook

Gear skiving is used for both soft and hard finishing. As a quality critical final step in hard finishing, the process can be used to create modifications to the tooth flank. At present there is no knowledge of the extent to which topological modifications can be applied by gear skiving. In this report, the feasibility of manufacturing topological modifications on an external gear through adapted kinematics for gear skiving has been investigated. The first step was to develop an NC converter. The kinematics derived from a manufacturing simulation had to be transferred to the machine control. Considering the characteristics of the skiving machine, such as the infeed and outfeed paths or the zero offset, the simulated kinematics are converted into *NC* code that can be executed by the machine controller. A comparison between a gear produced by the dialogue program and a gear produced by the predefined kinematics showed very good agreement between the lead measurements.

The *NC* converter was used to derive the adapted kinematics for the modifications. The parameters of the center distance a, the axis crossing angle Σ, and the twist angle φ were varied. Due to the two-flank machining, partially offset modifications were generated on the right flank. The specified modifications due to a center distance modification could be kinematically implemented and determined on the tooth flank with small deviations. It was also possible to generate the specification of a discontinuous modification in the form of an end relief. A constant change in the twist angle φ results in a helix angle deviation $f_{H\beta}$. An extension of the adjustment of the twist angle φ to generate further modifications is therefore a logical conclusion. A quadratic variation of the twist angle φ led to the generation of a crowning and can therefore be considered as an alternative to the application of a width crowning by changing the axis distance. A linear variation of the axis crossing angle Σ resulted in a parabolic twist, which could be used to compensate for the natural twist caused by lead crowning.

In addition to the derivation of adapted kinematics and the development of a converter, it is necessary to adapt the tool profile to generate topological profile modifications. A realization of the corresponding manufacturing process and thus a superposition of adapted kinematics and tool profile is the next step. An investigation of the transferability to internal gears is also required.

Acknowledgements

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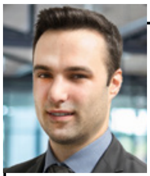

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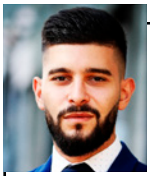

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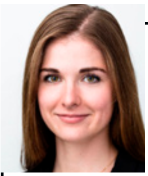

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Finding the Right Task for Optical Gear Metrology

Markus Finkeldey and Dr. Christof Gorgels

Modern Sensor Systems on Coordinate Measurement Machines (CMM)

Tactile or contact probes are the most common metrology technique in the coordinate measurement world, including the more specialized gear measurement community. Tactile probes can be active or passive, scanning or touch only, and may vary in cost and performance depending on the system itself. They are offered by multiple industrial companies as standalone OEM products (e.g., Renishaw) or only included in their coordinate measuring machines (e.g., Zeiss, Klingelnberg, and Hexagon). Their overall performance, especially their robustness and flexibility, have led to a gold standard for most metrology tasks.

Multiple companies (e.g., Wenzel, Gleason, Klingelnberg, Zeiss, Hexagon) offer different optical metrology updates as an add-on or included in a hybrid measurement concept for their coordinate measurement machines. The main idea is to increase measurement speed compared to tactile metrology. For some applications, the benefit of a noncontact optical system, the negligible influence on the sample's surface itself, may also be beneficial to reduce damage on coatings or other fragile surfaces. Further approaches include the use of additional information given by optical systems, for example, to analyze color, material absorption, or information about the surface roughness.

Optical metrology on CMM uses multiple techniques with different benefits. Common sensor systems include structured-light scanner, laser triangulation with different laser colors in point or line configuration, and white-light sensor systems using interferometric or confocal chromatic approaches. Most of these systems are commercially available from OEM companies or are directly included in their metrology systems (e.g., Keyence, Mitutoyo, Zeiss/GOM). Less common but commercially available systems include confocal laser sensors, laser time-to-flight systems, and the use of the frequency comb.

Optical Gear Metrology

With the growing impact of optical metrology in the coordinate metrology community and optical technologies like LEDs, Lasers, digital cameras, and optical sensors joining the mass market with increasing performance at decreasing prices, the idea of fast and precise gear metrology using optical technology increases over the last two decades. The paper gives a brief overview of the history of optical technology in gear metrology and describes an approach with practical results for a hybrid (optical and tactile) gear measurement.

In the academic field, optical gear metrology started to get more attention around the year 2000. In 1997, a publication tried to sell the idea of the use of optical gratings in gear metrology (Ref. 1). In 2003 new approaches of gear metrology and analysis, including optical metrology, were discussed (Ref. 2). In 2005 and 2006, fringe projection (structured-light) for gear metrology was demonstrated (Refs. 3, 4). A technology used and optimized by GOM (Zeiss) for a fast 3D acquisition of rather large parts, like for example car parts (e.g., doors) or even complete cars. In 2011, an interferometric system was shown (Ref. 5). Slowly the industry started to join the process with Nikon filing a patent for their optical profile measuring apparatus in 2012 (Ref. 6). Gleason was demonstrating their laser technology for their multi-sensor gear inspection system in 2017, showing a Gear Rolling system with integrated laser technology in 2019 (Ref. 7). In addition, in 2019 a sophisticated method using advanced interferometric techniques, digital multi-wavelength holography, was demonstrated by the academic community (Ref. 8). DWFritz receives the Fest & Sullivan Best Practices Award in 2020 for their noncontact metrology technology ZeroTouch using multiple laser triangulation sensors (Ref. 9).

Klingelnberg showed academic and industry-grade prototypes starting from 1992 with laser triangulation, fringe pattern projection in 2004, a white light sensor in 2011, and an interferometric fiber-optic sensor in 2015 (Ref. 10). These resulted in a custom-made laser triangulation system presented to the market in 2017 and a custom white light sensor was shown in 2018. The first white light sensor system fully integrated with a P 26 gear-measuring machine and used in Klingelnberg's hybrid metrology concept was delivered to a customer shortly afterward.

It should be mentioned that the term hybrid metrology does lack a clear definition. Hybrid metrology is used to characterize hybrid sensors using a direct combination of optical and tactile elements (s. notable mentions), as well as for approaches using a separated tactile and an optical sensor in a serial or parallel way. The approach, described in more detail in this publication, uses a combination of a tactile system and a separate optical sensor.

Optical Sensors for Gear Metrology

While a couple of different sensors were used in the metrology industry as well as in the scientific community, the three main sensor types for optical gear metrology are laser triangulation, structured-light projection, and white light sensors.

Laser Triangulation

Laser triangulation is the most common system for gear metrology and is frequently used for other industrial applications as well. Laser triangulation allows compact, fast, and affordable systems, which are available from different OEM manufacturers. Depending on the application, single-point systems and line sensors can be used. Typical laser colors are in the red (around 655 nm) or blue wavelength range (455 nm), each with different impacts on the surface scattering process. The power of the laser system is typically class 3R or lower, resulting in visible light with less than 5 mW output power. Lasers with a higher output power or a nonvisible beam can be dangerous and may need special protection and safety features on the metrology system. While commercially available systems can reach acquisition rates around 50 kHz (Keyence, Micro-Epsilon, and others) at a fair price rate, it is known that there is a fundamental limitation for the achievable accuracy (Ref. 11). The topic was discussed for gear shape measurements in 2021 and compared to the confocal-chromatic principle as well (Ref. 12). For long time measurements, the temperature behavior of the compact sensor must be carefully controlled.

Structured Light Projection

The idea of structured light projection or fringe pattern projection is based on the knowledge of the different behavior of different, well-known patterns, projected on a target and imaged with a stereo camera setup. The used software algorithm, the pattern structure, the number of used patterns, and even the wavelength of the used light may vary depending on the manufacturer or scientist. However, the sensor system is suited for the fast and complete digitalization of rather larger parts. Therefore, the technology is well-established and can be purchased from different manufacturers (GOM Metrology, Keyence, and others). The accuracy and potential to increase the accuracy have been discussed in the academic community since about 2005 (Refs. 13, 14). Depending on the surface type of specimen, like gears, a coating is quite frequently applied to optimize the optical performance of such systems.

White-Light Sensor

The term white light sensor is unspecific and can be applied to multiple sensor technologies. In most cases, either confocal chromatic sensors or interferometric sensors are described with the term white light sensor. A confocal chromatic sensor is an advanced version of a confocal sensor, replacing the monochromatic light source with a broadband light source and the simple intensity-based point detector with a more complex spectrometer (Ref. 15, 16). This modification of the confocal setup gains the ability to get distance information over line area in space, via a smart interpretation of the spectrometer's spectral information, but loses the lateral resolution and simplicity of the original setup. OEM and standalone systems are available from different suppliers (e.g., Micro-Epsilon, Precitec, Keyence). An interferometric sensor uses the low temporal coherence of the broadband light source and either a spectrometer or a tunable light source combined with a simpler intensity detector to generate distance information. A more detailed explanation can be found in a review paper about optical coherence tomography (OCT), a technology widely used in the medical and biological community (Ref. 17). Both technologies allow easy separation of the different optical components (e.g., sensor head, electronics, and light source) with the use of optical fibers, which allow easier thermal management.

Notable Mentions

There are combined tactile/optical measuring systems, e.g., the Werth Fiber Probe or the Renishaw SP25M (Refs. 18, 19). While interesting technology-wise, they seem to have a limited influence on the gear metrology community. This is comparably true for other methods, such as the use of the optical frequency comb or pure laser confocal sensors (Ref. 20). For small features of gears or very small gears (micro-gears), the focus variation technology or advanced scattering light techniques (Refs. 21, 22) can be used. Both methods are commercially available from different companies including Confovis, Keyence, Alicona, and Optosurf. However, even for small gears or features like roughness, tactile systems still are the gold standard. The phase unwrapping problem, which appears for different technologies (e.g., interferometry), is discussed for gear tooth flanks by Wang et al. in 2020 (Ref. 23).

Resolution, Accuracy, and Reproducibility

In the optical metrology field, the term resolution is used to describe the performance of a system. Lateral and axial resolutions, with different criteria (e.g., Rayleigh, Sparrow, and Abbe) and cases for coherent and noncoherent illumination are discussed in detail (Ref. 24). For gear metrology in the industrial context, this discussion is less important. Nevertheless, it is worth pointing out a few of the aspects with more precision.

Optical Spot Size vs. Tactile Touching Size

It is known that the size (diameter) of the used orb of the tactile measurement system influences the measurement results. The influence can be described using a mathematical morphological filter to describe or simulate the mechanical filter of the stylus, as standardized in the DIN EN ISO 16610-41. It is even discussed if multiscale morphological filters can be used directly for gear fault detection, however with noise data instead of geometry data (Ref. 25). The crucial point is that there is a difference between the actual surface of the specimen (gear) and data points of features seen on the measurement sheet. In general, this difference depends on the size and physical behavior of the measurement point as well as additional filters used by the measurement software. A typical result is shown in Figure 1.

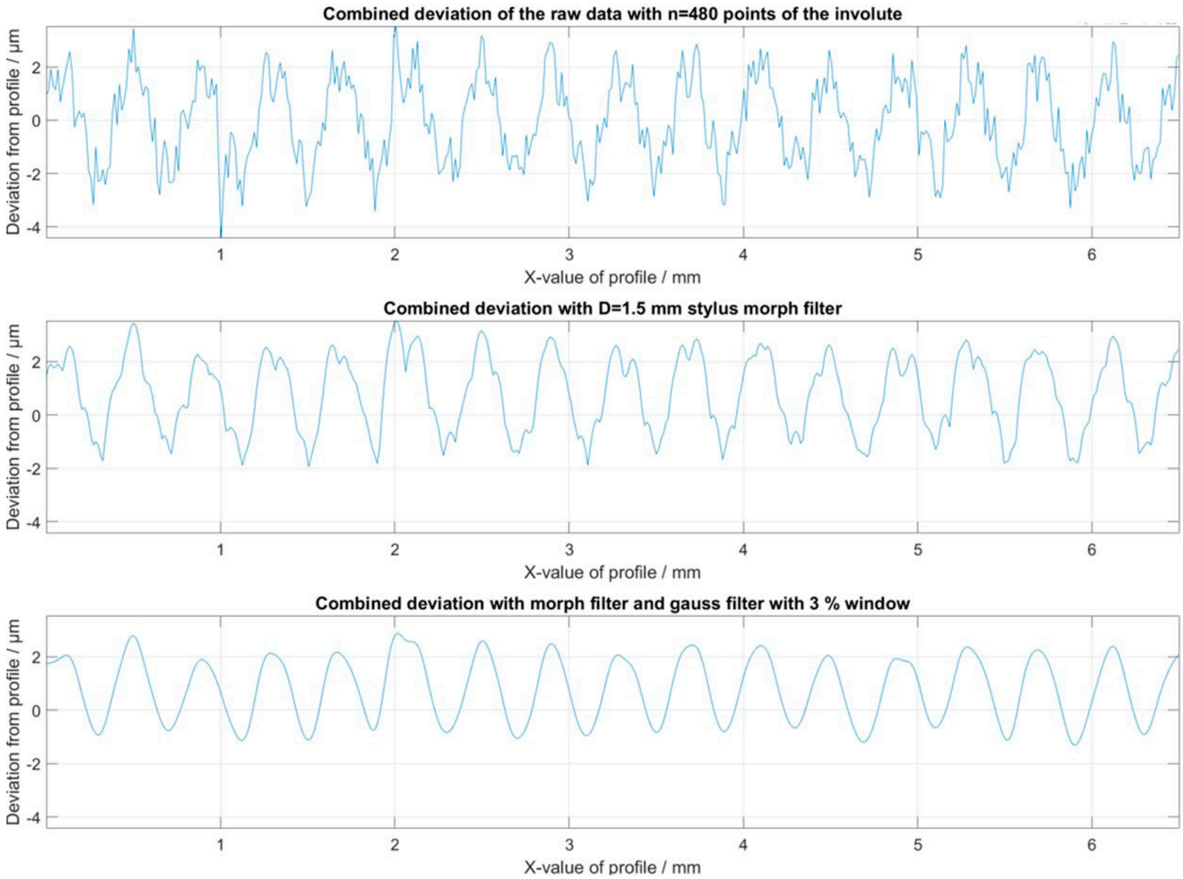

Figure 1—The row on top shows a simulated profile deviation with 480 data points over a 6.5 mm rolling path of a gear profile. The row in the middle shows the influence of a morphological filter with a 1.5 mm stylus. The row at the bottom shows the data with a Gaussian filter (3 percent window) applied.

By interpreting the results, the reader must keep in mind that the data is a simulation, with the sole purpose of demonstrating the influence of the mechanical filter of the stylus (illustrated by a morphological filter) and a Gaussian filter as seen on a typical gear measurement sheet. What can be seen from this example is that while the high-frequency component may change drastically, the low-frequency component of the signal (profile deviation) is mostly unchanged. Therefore, depending on the type of feature of the gear, the data may change depending on the stylus size as well as on the measuring technology. The reason for this is that most optical systems have a smaller spot size or touching area on a gear flank compared to a tactile stylus on technical surfaces. In addition, it is a fact that the "touching" physics or interaction between measurement systems and objects is different between mechanical and optical systems. In other words, the accuracy of the data is related to the feature type (low or high frequency) on the gear and the used metrology technique (touching size and physics). To enable the highest accuracy, some kind of expert knowledge, possibly provided by intelligent software algorithms developed by the metrology manufacturer or the science community is needed.

Accuracy and Reproducibility

A method commonly used for a measurement system analysis is a type 1 study, which will result in *Cg* and *Cgk* values acquired from a series of at least $n = 25$ measurements (Refs. 26, 27). The Cg value gives information about the reproducibility, mainly indicated by the standard deviation (sigma) of the measurement process, and the *Cgk* value adds information about the accuracy (the difference between the measure value and the actual value) of the study.

The *Cg* value is defined as:

$$Cg = \frac{dt * T}{si * \sigma}$$

where dt is the drawing tolerance factor with a default value of 20 percent (0.2), T is the drawing tolerance itself, si is a sigma interval factor (typically four, sometimes six) and σ is the standard deviation. The target value commonly used for Cg as well as Cgk is 1.33. The standard deviation σ is given by:

$$\sigma \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

With n (25 or more) indicating the number of measurements, x_i the measurement with the index i and $\bar{x}$ the mean value of all n measurements.

A quick example of the needed standard deviation for given tolerances from a customer with a target Cg of 1.33, dt of 0.2 and a si of six is shown in Figure 2.

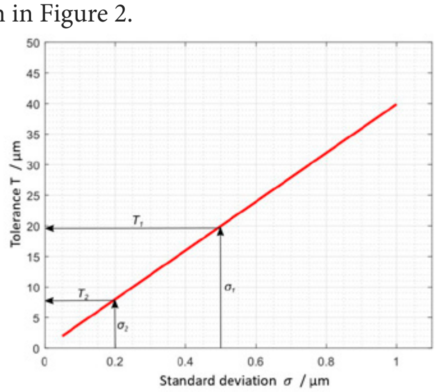

Figure 2—Drawing tolerances and needed standard deviation for an example with a target Cg of 1.33.

While the reproducibility required is given by the drawing tolerances and depends on the application, a good value for most gear features in the automotive industry is a standard deviation around 0.1 µm.

Setup

For the experiment, a sixth-generation Klingelnberg P26 metrology system configured for hybrid metrology with the optical sensor package together with the corresponding September 2021 software release was used. The tactile system applied was the Klingelnberg proprietary 3D Nanoscan tactile probing system. The optical system is the proprietary, contactless HISPEED OPTOSCAN, based on a custom white light sensor with an approximate spot size of about 12 µm.

Basic Accuracy and Reproducibility of an Optical Sensor on a CMM

The fundamental limit in terms of accuracy and reproducibility of a CMM is given by its capability to define and retrieve its center / zero position, or in other words defined by the calibration. While this limit is influenced by the capabilities (e.g., resolution) of the optical sensor itself, it is also affected by the mechanical and thermal stability of the CMM chassis, the quality of the translation stages, the motor control units, the temperature control, filters applied by the software and multiple other impacts.

A study to define the reproducibility of this calibration process is normally done under well-defined conditions in a highly controlled environment, for example in a vibration-isolated climate chamber with minimal user influence. A Klingelnberg hybrid P26 was used under these conditions and analyzed in a study with a sample size of $n = 100$. The results are shown in Figure 3.

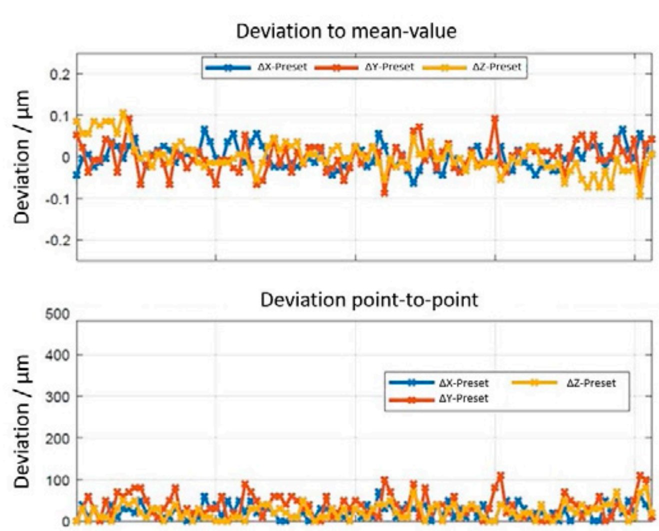

Figure 3—Preset study with n = 100 measurements under controlled conditions. The diagram on the top shows the deviation for every axis (x-y-z) to the mean value, and the diagram at the bottom shows the measurement-to-measurement variation.

The results indicate a maximum error of around 200 nm with a standard deviation of 28 nm for the x-axis component, 35 nm for the y-axis component, and 38 nm for the z-axis component under near-perfect conditions. In terms of a measurement systems analysis, this would lead to process-ready tolerance, for a rather challenging target of Cg = 1.33 with a six σ interval and 0.2 drawing tolerance of 1.6 μm.

Physical Limitations

While optical metrology is commonly used in different industrial, medical, and biological fields, the gear community is notoriously skeptical about its performance and behavior and there are limitations for optical gear metrology given by the physical interaction between light and matter.

Absorption and Reflection

The major limitation of this method is the fact that every optical metrology system needs light that gets back to some type of detector unit. Two physical processes may limit this path: Absorption and reflection. A target with a rather high light absorption, a mat black one, for example, will never be a good target for optical metrology. This is also true for targets with very high reflectivity, e.g., mirror-like objects, because the light will follow the laws of reflection, which in cases of gear metrology normally means that the reflecting light does not reach the sensor again. While both cases are possible in the gear industry, they are very unlikely to appear in the automotive industry and even in the whole industry itself. A similar, albeit uncommon case is transparent (plastic) gears, which will lead to a superposition of optical depth information and thus to a rather high need for data post-processing.

Dirt, Dust, Rust, and Oil

Unlike a tactile stylus, which has limited influence of dirt on the measurement results, the contactless optical technology will measure every obstacle in the light path as part of the object. A clean and dry object is required to achieve the highest quality levels. If the standard cleaning process of gears during production—centrifuging and the use of air pressure—is carefully executed, this is considered to not have a significant influence on the results. However, this needs to be checked in advance.

Shadowing and Probing Angle

Depending on the sensor technology used, for example, if the illumination and detection light beam is separated, the typical geometry of gears may lead to shadowing. This means that a part of the gear is blocked by other parts, which leads to dead spaces on the gear. This can be partly avoided by a sophisticated calculation of the measurement movement, often in combination with an additional rotation and/or translation stage for the sensor head.

In comparison to a tactile probe, where the touching process is always orthogonal to the surface, this is not the case for most optical sensor systems. If an optical sensor head would follow the gear's geometry, a major part of its speed advantage would be diminished. The influence of this process needs to be considered. However, this is mostly relevant for high-frequency features, like roughness.

In the next section, a real-world example of an optical/hybrid metrology task for gear analysis will be provided. This example focuses on the pitch measurement of gears. This is an industry standard metrology task for gears, which causes a major part of measurement time, compared to other metrology tasks. The goal is to demonstrate the improvement of the hybrid metrology concept compared to a tactile-only approach to measurement speed. In addition, the general accuracy of the system is demonstrated by carrying out a calibration study.

Example of a Hybrid Metrology Use Case

While the results measured in a very controlled environment are a demonstration of the best-case scenario, experienced engineers will ask about a real-world scenario.

The following results were received during the standard pre-acceptance of a Klingelnberg hybrid P 26. The measuring conditions are comparable to a temperature-controlled shop floor. This means it was definitely not a high-class metrology room, but also not a worst-case shop floor scenario. For the first part of the acceptance procedure, a calibration (preset) study with n = 25 was performed. The results are shown in Figure 4.

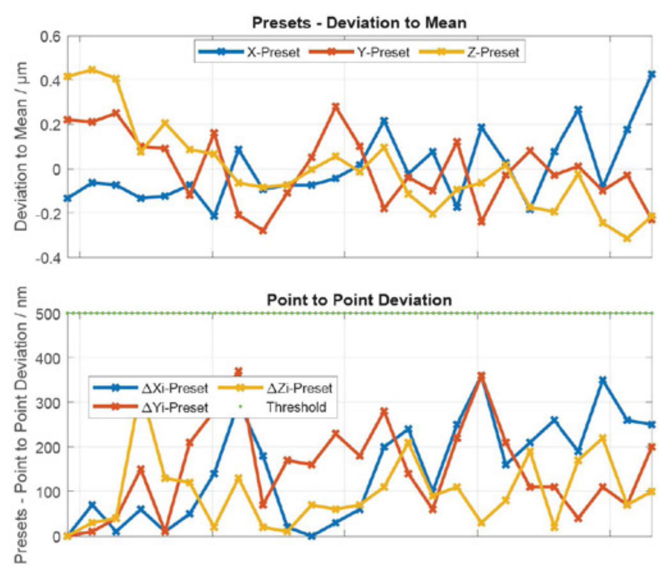

Figure 4—Preset study with n = 100 measurements in a production hall using the optical sensor of a Klingelnberg hybrid P 26. The diagram at the top shows the deviation for every axis (x-y-z) to the mean value, and the diagram at the bottom shows the measurement-to-measurement variation.

The results indicate a maximum error of around 640 nm with standard deviations of 156 nm for the x-axis component, 161 nm for the y-axis component, and 200 nm for the z-axis component.

For the second part, a DAkkS certified gear with z = 63 teeth, a normal module of m_n = 1.52 mm, a pressure angle of 17 degrees and a helix angle of 31.5 degrees was used in a type 1 study with n = 25 measurements. The tolerances for a gear in quality class 4 based on DIN ISO 1328 as needed for a measuring machine of class A based on VDI/VDE 2612 / 2613 were used. According to the pre-acceptance procedure, the drawing tolerance factor was 0.2 and a four-sigma interval was used. The results are shown in Figure 5.

Parameter	$fpMax_l$	$fpMax_r$	Fp_l	Fp_r	Fr	mdK
Statistic (25 Measurements)						
Average [µm]	0.672	0.892	2.772	3.460	3.336	115608.324
Min [µm]	0.600	0.700	2.600	3.300	3.100	115607.500
Max [µm]	0.700	1.100	2.900	3.700	3.500	115609.400
PtP [µm]	0.100	0.400	0.300	0.400	0.400	1.900
Std [µm]	0.046	0.086	0.079	0.104	0.119	0.461
References & Tolerances						
Reference [µm]	0.820	1.040	2.620	3.470	3.030	115605.500
Tolerance [µm]	4.000	4.000	14.000	14.000	12.000	100.000
MPE [µm]	1.039	1.039	3.637	3.637	3.118	-
Drawing Values						
x_s + 0.1T [µm]	1.220	1.440	4.020	4.870	4.230	115615.500
x_s [µm]	0.820	1.040	2.620	3.470	3.030	115605.500
x_s - 0.1T [µm]	0.420	0.640	1.220	2.070	1.830	115595.500
0.2T [µm]	0.800	0.800	2.800	2.800	2.400	20.000
T [µm]	4.000	4.000	14.000	14.000	12.000	100.000
σ	4.0	4.0	4.0	4.0	4.0	4.0
Capability Parameters						
cg	4.364	2.320	8.843	6.725	5.059	10.841
cgk	2.750	1.461	7.883	6.677	3.769	7.779
In Tolerance	✔	✔	✔	✔	✔	✔

Figure 5—Statistical analysis of the type 1 study with n = 25 measurements showing Cg and Cgk values significantly larger than target of 1.33 for all index features, indicating a capable measuring tool. Measurement performed using the optical sensor of a Klingelnberg hybrid P 26 in a production environment.

The used parameters for the pitch deviation analysis are described in ISO 1328, *fpMax* is the largest value of the single pitch deviation, *Fp* is the total cumulative pitch deviation in µm, *Fr* is the runout in µm and *mdK* is the diametral dimension over balls in µm. The index l indicates the left flank of a gear, and *r* is the right flank of a gear.

The speed improvement of the optical index measuring method compared to the tactile (point) method is about 70 percent for the used gear and even larger for the tactile flank method. It depends on the normal module of the gear as well as the pressure angle. Compared to a gear with a pressure angle of 17 degrees, a slightly larger pressure angle (e.g., 20 degrees) would lead to an even larger speed benefit, typically reaching around 80 percent speed gain. Speaking about relative values, the absolute gain in measurement time also depends on the number of teeth. More teeth will in general lead to a larger time benefit for the optical method.

Discussion

The practical results of the optical index measuring method performed on a Klingelnberg hybrid P 26 indicate a couple of conclusions:

The optical metrology for index measuring is a capable tool to speed up gear measuring even for high-quality gears based on the type 1 study results with some headroom left.

The relative speedup for the index measuring can be rather high (80 percent) which has an impact on the overall measuring time since the index measuring is the most time-consuming measurement. The general time improvement or better daily gain in throughput of gears depends on the number of other tasks performed for the complete quality control process, as well as the gears geometry. A typical process of measuring the profile and lead on four teeth, a torsion check on the first tooth, index measuring, run-out and tip- and root-diameter with workpiece axis position detection can still benefit from an optical index measurement indication between 15 percent to 30 percent gain in gear per day throughput.

The preset measurement in a normal production environment shows a small drift of preset values according to temperature changes, as seen in Figure 4. This drift of preset values is related to the expansion of material (e.g., used to hold optical components) based on the temperature change. With additional adjustments of the temperature compensation model to include the optical system, this drift can be minimized in the future. The goal is to achieve an optimized standard deviation in a standard production environment.

Optical metrology for gears is only accepted if the speed improvement does not come with losses in accuracy or reproducibility. Both need to be checked with studies using a certified master part in a real-life environment. The gear measuring community is challenged by rather low tolerances for modern gears, especially in e-mobility, in the tactile and optical metrology world.

The results of this study indicate a strong benefit for hybrid pitch measurements compared to a tactile-only approach. The future will show whether this technology will find wide acceptance in the industry. However, from our perspective this technology is promising.

Summary and Outlook

Based on today's technology, optical metrology is a capable tool if embedded in a hybrid metrology concept to enhance users' gear metrology experience. It can improve measurement speed for specific tasks (e.g., for index measuring), and thus can reduce quality costs.

In addition, optical metrology will be beneficial for future measuring tasks, if they have rather large complexity. All future quality control strategies, like topographic measurements, 100 percent Industry 4.0, closed loop, or holistic approaches, will require sophisticated measurement strategies. Therefore, modern quality control will benefit from fast optical metrology. If the optical metrology has a similar or better accuracy compared to the tactile gold standard.

We think the hybrid approach, while still needing some fine tuning and a broader set of features, is the future of gear metrology.

Disclaimer

The authors are employees of Klingelnberg GmbH, Germany. Both are directly responsible for the R&D of the hybrid metrology concept demonstrated and discussed in this publication.

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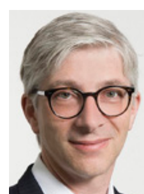

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A36 CARBON STEEL BLANKS NOW AVAILABLE ONLINE

TCI Precision Metals announces that its A36 Carbon Steel, Ready-to-Ship blanks are now available from OnlineMetals.com, an e-commerce metal and plastics supplier. The pre-machined blanks allow customers to order flat, square, and parallel materials to close tolerance specifications.

ASTM A36 steel plate is a grade of steel commonly used in structural applications. This mild steel contains alloys that give it properties such as machinability, ductility, and strength that are ideal for building applications. Due to its high strength, many bridges and other structures are made with A36 steel. It is also used for components in automotive, heavy equipment, and oil and gas applications, including frames, bearing plates, tanks, gears, and base plates.

"A36 Ready to Ship Blanks help shops shorten setup time, reduce scrap, and increase overall throughput up to 25 percent or more by eliminating material prep. Blanks arrive machine-ready for production," said Ben Belzer, president, and CEO of TCI Precision Metals.

Precision blanks eliminate the need for in-house sawing, grinding, flattening, squaring operations, and outside processing. Blanks are consistent, part-to-part, which reduces setup time. In the case of flat blanks, the production process alleviates the material's residual stress, resulting in reduced part movement during finish machining. A36 Ready-to-Ship blanks are available in sizes ranging from .250"-2" thickness, 6"–36" width, and 12"–48" in length. Each blank is deburred, cleaned, and individually packaged to avoid damage during shipping. Ready-to-Ship Blanks arrive square, flat, and parallel within ±.002" of specified thickness and +.125"–0" of specified length and width.

"At OnlineMetals.com, we specialize in cut-to-size, small to medium quantity orders shipped direct to any location. Pre-machined A36 carbon steel blanks that are Ready-to-Ship provide that extra processing value that lets customers order materials that arrive ready to go directly from receiving to machining. Customers can use the time they previously spent in setup and prep for more productive use of CNC machining centers," said Matt Holzhauer, marketplace manager at *OnlineMetals.com*

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Sandvik Coromant

NET-ZERO TARGET VALIDATED BY SCIENCE BASED TARGETS INITIATIVE

Through the wider Sandvik Group, Sandvik Coromant has committed to near-term, companywide emission reductions in line with climate science with the Science Based Target initiative (SBTi). Aligned with the goals of the Paris Agreement and the United Nations Sustainable Development Goals (SDG), Sandvik Coromant's own sustainable business targets have been set in line with the SBTi's criteria as part of the organization's commitment to reducing its greenhouse gas emissions and practicing responsible manufacturing.

A collaboration between global nonprofit CDP, the United Nations Compact, World Resources Institute (WRI) and the WorldWide Fund for Nature (WWF), SBTi defines and promotes best practice in emissions reduction and net-zero targets in line with climate science. The initiative works alongside businesses to help them take the necessary steps to reduce their carbon emissions and seize the environmental, financial and business benefits that science-based climate goals can bring. The SBTi Net-Zero Standard also ensures that companies' net-zero targets translate into action that is consistent with achieving a net-zero world by 2050.

Alongside the wider Sandvik group, Sandvik Coromant first committed to set targets in line with the SBTi's criteria in December 2021, beginning a rigorous validation process during which the SBTi worked with the team to help update its targets. Now, following validation from the SBTi, Sandvik Coromant is working toward several revised sustainability goals.

First, the organization is committed to reaching net-zero. When considering net-zero, greenhouse gas emissions are split into three scopes. Sandvik Coromant plans to reach net-zero for scopes one and two—which include emissions produced directly within Sandvik Coromant's operations and those produced indirectly through heating and power—by 2035. It aims to reach net-zero for scope three emissions—those that result from activity that takes place beyond facility walls, such as the production of raw material and emissions generated through the supplier network—by 2050.

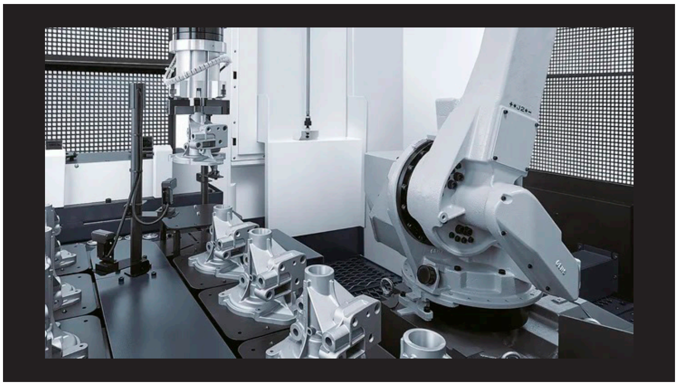
Sandvik Coromant is also working to become more than 90 percent circular by 2030, with its buy-back scheme for recycling used carbide tools forming an important part of its circularity strategy. The company's third sustainable business goal relates directly to people, with a pledge for women to make up a third of Sandvik Coromant's management team by 2030.

"Committing to science-based targets is a crucial part of our sustainability strategy," said Patrik Eurenius, head of sustainability and EHS at Sandvik Coromant. "Recognition of the SBTi initiative has grown exponentially in recent years. When we first signed up, around 3,000 other businesses did so at the same time. Now, that figure is almost double. As more businesses wake up to the reality our planet faces and act to make a difference, validation from the SBTi will become even more vital."

Sandvik Coromant has already made significant progress toward its sustainability goals and has already halved its scope one and scope two carbon emissions compared to 2019 levels. "We've encompassed sustainability goals into our practices for some time," added Eurenius. "With SBTi validation, we can evidence our commitment to leading the manufacturing shift even further. We want to support everyone—our customers, colleagues, partners and stakeholders—in the transition toward sustainable manufacturing. Now, we have the science behind us to help make that happen."

sandvik.coromant.com

January 22–February 2—DMG Mori Open House Pfronten 2024



Visit DMG Mori's "Home of Innovation" showroom and find out how to optimize your processes with MX—Machining Transformation (Pfronten, Germany). Experience solutions for process integration, automation as well as digital and green transformation. The open house includes 45+ high-tech machines and more than 20 automation solutions, including a world premiere and innovations from various sectors: the DMF 400|11, a new traveling column machine with 4,000 mm travel, and the new PH Cell 500, a modular pallet handling system with a transfer weight of 500 kg. Attendees can also view CELOS X, the holistic digital and data-based ecosystem for optimizing production processes.

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

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IPTEX 2024 (Pune, India) is an important event for all relevant stakeholders in automobile, aerospace, or energy as well as manufacturers, buyers, partners, and consultants. Focus industries include mechanical power transmission, electrical power transmission, linear motion drives, fluid power and IoT/smart technology. IPTEX will provide a consistent channel of communication to the members of this industry to come together under one roof and participate in technical seminars, share knowledge and expertise with industry leaders and to be a part of discussion on policy codes, standards and challenges faced by the industry. Grindex 2024 is the co-located event.

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February 27–29—Gearbox CSI

This AGMA live online course examines individual failure modes and the failure scenarios that lead to actual system failure, an essential skill to designing gear/bearing systems that will operate properly for their full design life. In this course, AGMA will define and explain the nature of many gear and bearing failures and discuss and describe various actual failure scenarios. In addition, a detailed primer on bearing technology prefaces the failure scenario discussions. Attendees will gain a better understanding of various types of gears and bearings. Learn about the limitation and capabilities of rolling element bearings and the gears that they support. Grasp an understanding of how to properly apply the best gear-bearing combination to any gearbox from simple to complex.

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March 2–9—IEEE Aerospace Conference 2024

The International IEEE Aerospace Conference, with AIAA and PHM Society as technical cosponsors, is organized to promote interdisciplinary understanding of aerospace systems, their underlying science and technology, and their applications to government and commercial endeavors. The annual, week-long conference (Big Sky, Montana) is set in a stimulating and thought-provoking environment. The 2024 conference will be the 45th in the series. Plenary sessions feature internationally prominent researchers working on frontiers of science and engineering that may significantly impact the world we live in. Registrants are briefed on cutting edge technologies emerging from and intersecting with their disciplines. Each year, a large number of presentations are given by professionals distinguished in their fields and by high-ranking members of the government and military.

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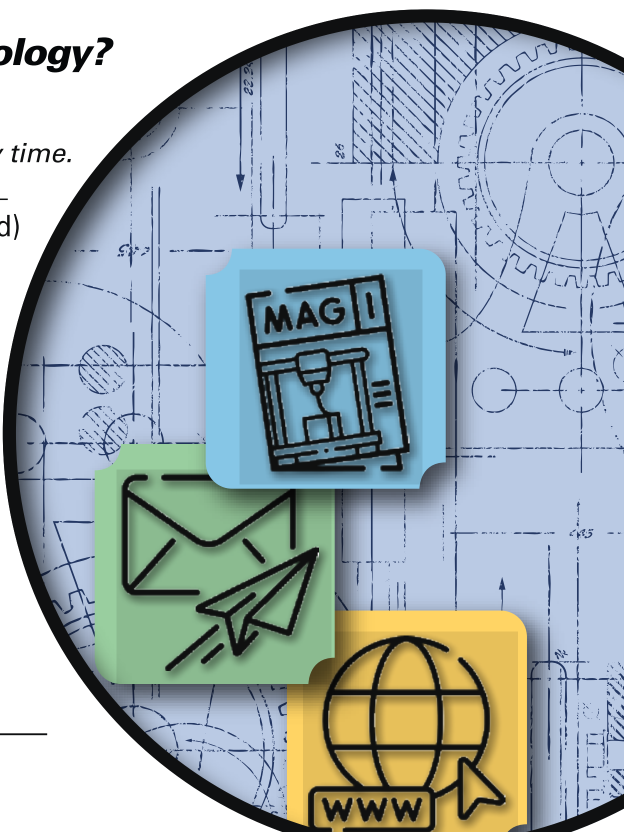

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Workforce Development: The Video Game

Influencers, Innovators and Gamers Collaborate to Bolster STEM Initiatives

Matthew Jaster, Senior Editor

I grew up playing video games in the 1980s/1990s. Today, my kids not only play video games, but could discuss coding, designing, and marketing at length on their YouTube channel. This generation is growing up with technology no other generation has ever had.

It's no surprise that academic institutions are starting to see the value in tapping into this generation's experience from a workforce development perspective. If we train enough coders, software developers and content creators, how many of these students might use these skills on a manufacturing floor after high school?

According to the Space Foundation, one of the most important components of STEM academics and careers in STEM is the ability to learn by trial and error; confidently theorize certain solutions; put them to the test; and record and process results. Students who engage with robotics can learn these important elements of STEM, which will benefit them in future projects.

It's suggested that robotics, automation, and software careers will draw kids that have put the hours into technology and science from an early age whether its LEGOs, video games, board games or engineering puzzles.

But can all that "button-mashing" experience with an Xbox or Nintendo provide real value down the road?

In a medical study conducted by the National Library of Medicine, 30 medical students between the ages of 24 to 26 were divided into two groups (gamers vs. non-gamers) and performed a simulated surgery using VR equipment. The gamers significantly outperformed the non-gamers in many of the metrics needed to successfully perform robotic surgery.

Future First Gaming at an event in Las Vegas.

The National Science Foundation provided LEGO robotics kits to summer campers that included game design software and motion control capabilities. The purpose of the two-week summer program was to field test the double effect of teaching both gaming and robotics to improve students' spatial visualization and computational thinking skills.

Future First Gaming (FFG) is a *stem.org* accredited company that convenes esports enthusiasts to engage in competitive and recreational gaming events, fosters a gaming community and presents opportunities for participants to explore educational and career development pathways in science, technology, art, and relevant esports disciplines. The company offers technical training in areas like coding, business management, game design and content creation.

The *Ready or Not* manufacturing simulation game developed by the Oregon Manufacturing Extension Partnership (OMEP) is a live, interactive experience set in a hypothetical manufacturing business that you control. The game teaches critical skills and lessons in an engaging, exciting format that delivers valuable training, team building, and insights.

Finally, the College of Professional and Continuing Education in Long Beach, CA, reported that the US federal government has also taken an interest in the use of simulation to build job readiness in a future workforce. In recent years, these games incorporated virtual reality technology to create life-like simulations of high stress events to practice for situations that can be difficult or costly to practice in a hands-on manner.

We do not need to raise a generation of kids glued to their smartphones, tablets, or gaming computers, but research suggests a couple hours of *Minecraft* a week may not be such a bad thing for the future of manufacturing.

Resources

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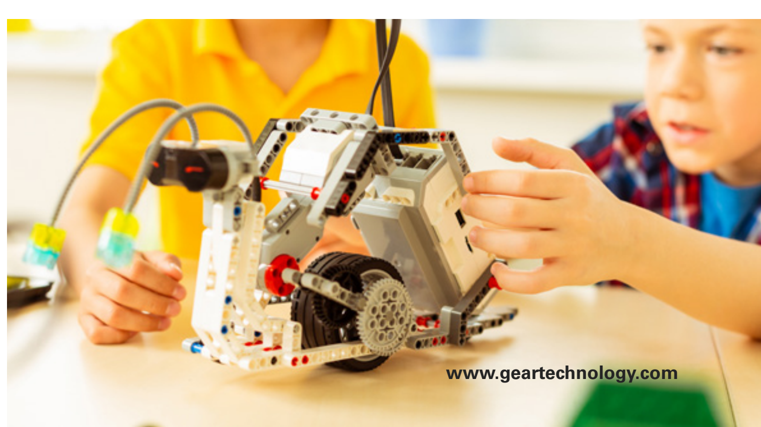

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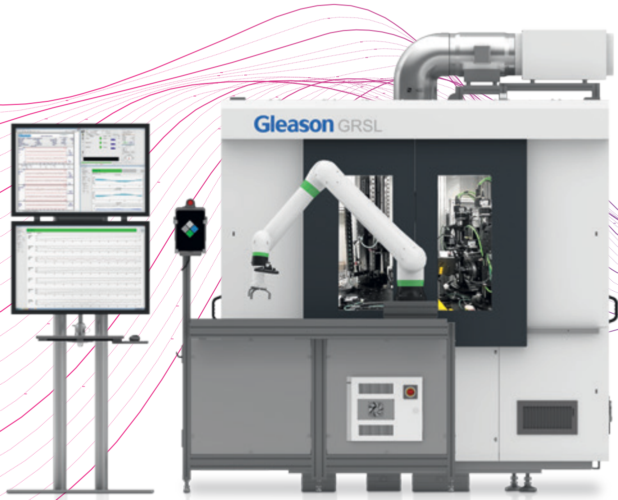

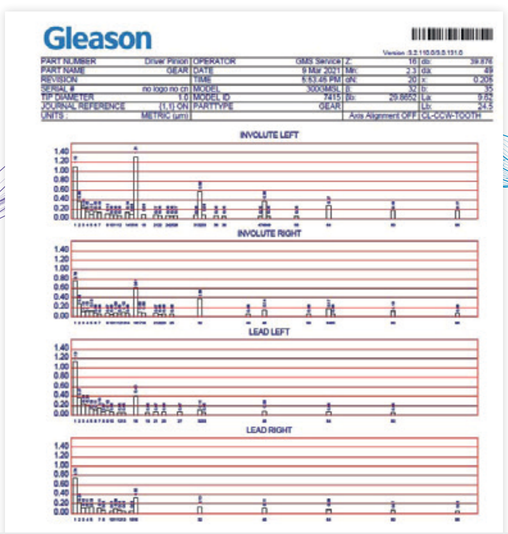

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