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JANUARY/FEBRUARY 2023

State of the Gear Industry

2023 State of the Gear Industry
- Survey Results
- Insights from the Industry

Cutting Tools
Skiving
Grinding

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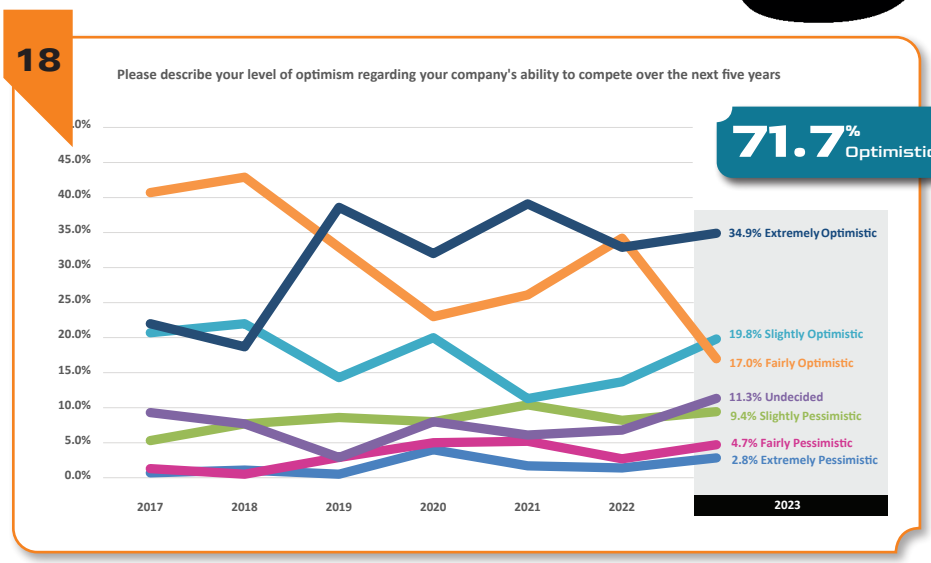

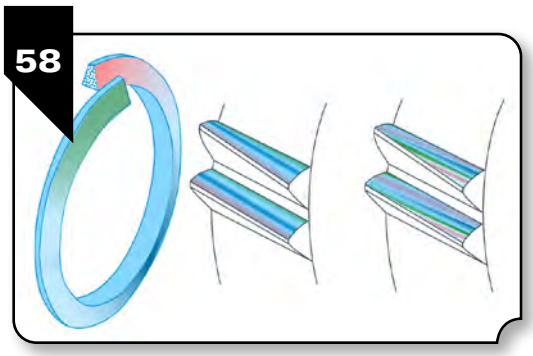

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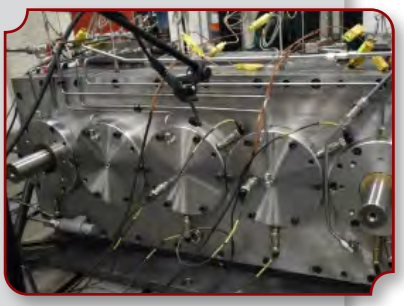

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FCG Taps Helios Gear for Custom Cutting Tools

The Helios team delivered custom gear cutting tools to Forest City Gear in Roscoe, Ill. See what Forest City Gear had to say about the process.

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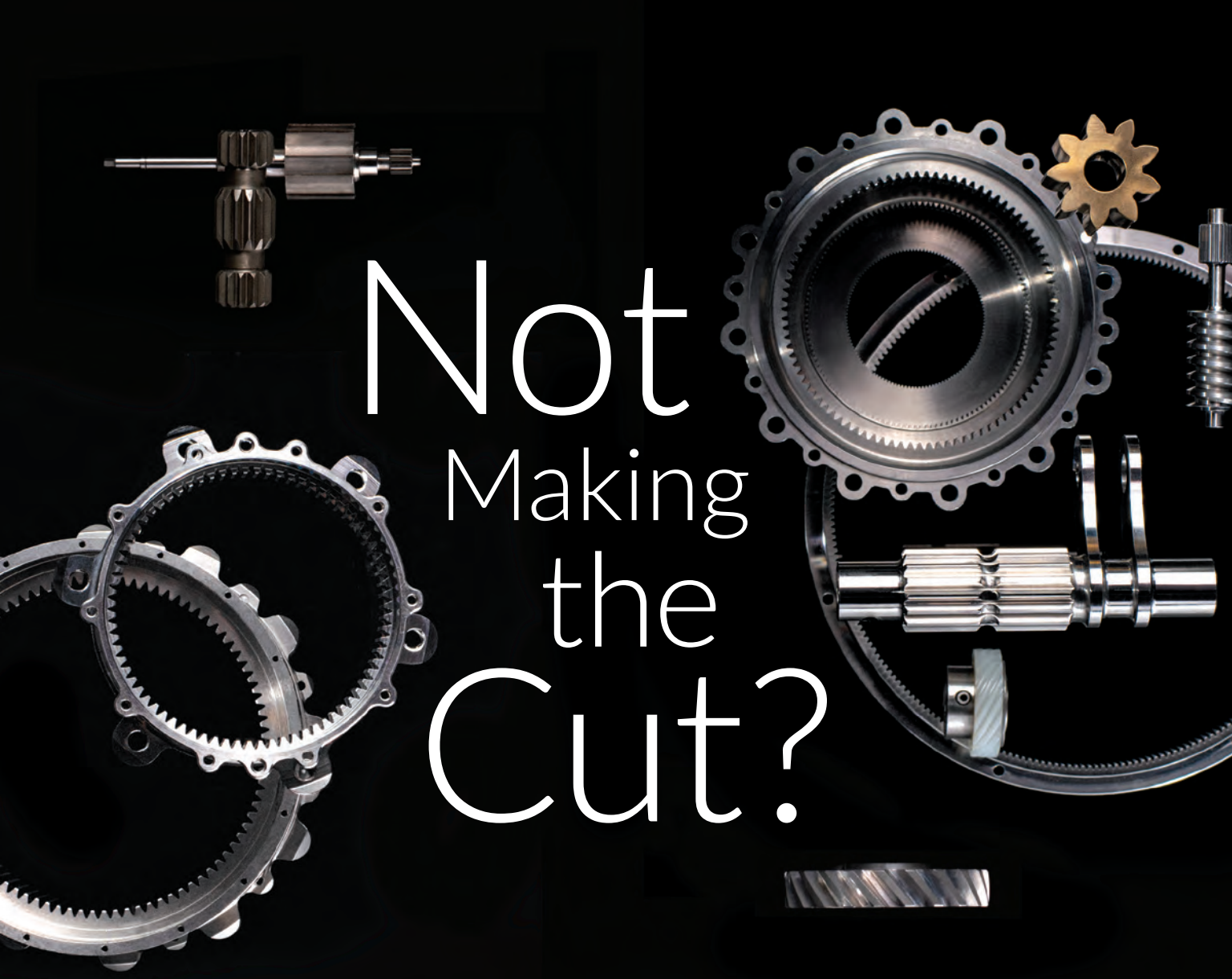
Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein *Gear Technology* Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear 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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All Over the Board

Publisher & Editor-in-Chief
Randy Stott

This year's State-of-the-Gear-Industry survey generated a wide variety of responses. The industry doesn't seem to be moving in just one direction, but rather, in multiple. In some cases, this is a story of the haves and the have-nots. Depending on what's going on the world, companies serving one industry will outperform companies serving another. But overall, companies that are well positioned—those that have invested in technology, found ways to hire and maintain a skilled workforce and who have anticipated and prepared for paradigm shifts like the electrification movement—seem to have a much more positive outlook.

Unfortunately, as I review the results, it seems clear to me that not enough are in that position. You can see it in the downward trend of most of the statistics. Last year, more than 80 percent of our respondents expressed some level of optimism about the future. This year it was only 71 percent. By the way, that's the lowest level of overall optimism we've seen since we started doing this survey in 2006.

This year we added historical data to the charts, so that you can see not only this year's results, but also how they compare with previous years. For most measures, there's been a visible downward trend over the years. Overall, as each year passes, a smaller proportion of gear manufacturers are expecting increases in sales, employment, production and capital spending.

Now might be a really good time to ask yourself if you're working for one of those companies that's been paying attention.

You can get a good idea of the disparity in outlook by reviewing some of the responses to our open-ended questions. This year we asked people how their companies are dealing with some of the most significant trends affecting our business: the shift toward electrification, the difficulty in maintaining a skilled workforce, the challenges of today's supply chain, and implementation of emerging technologies.

Clearly, these challenges don't affect everyone equally. I'll grant that some are feeling the supply chain pinch worse than others. Some aren't experiencing a workforce shortage. Some are in industries not directly affected by electrification (yet). But the number of respondents who think these issues don't affect them seems way too high. They think that electrification is a hoax, or that automation is impossible in a high-mix, low-volume environment, or that emerging technologies will never affect their business.

I get the sense that too many gear manufacturers are unwilling to face reality.

I suspect that many of these are industry veterans who have seen their share of boom and bust cycles. They've been successful in their careers by staying the course and keeping the attitude of "This too shall pass." Most of them have survived numerous crises over their careers.

But that doesn't mean they'll survive the next ones—especially when the crises come simultaneously. I expect that many of those companies won't be included in our survey results in coming years—not because we won't include them, but because they'll cease to exist.

Fortunately, it's not all bad news. I also see in our results many clear examples of gear manufacturing companies who are progressive, proactive and prepared for tomorrow. They are doing the things necessary to adapt, survive and even thrive in the coming years. Those companies give me hope.

Gear manufacturing isn't going away. In fact, I'm confident that the ones who are still around 10 years from now will be among the most technologically advanced, best managed companies in all of manufacturing.

If you're working for one of those companies, congratulations. If not, you've got some work to do.

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AGMA STRIVES TO CONNECT & ENGAGE

By Greg Schulte, AGMA Chair and President, Bonfiglioli USA

From 2020 to 2022 I had the honor of serving as the AGMA Chair. As I close the two-year service commitment, I have been asked by several people: What has AGMA accomplished recently, and where is the 107-year-old trade association heading?

This question is easy and difficult to answer all at the same time. There are so many avenues the conversation can take. Across media, education, emerging technology, standards, market intelligence, meetings and networking, there is so much to talk about. We literally have more than 600 AGMA members actively engaged in these broad efforts, delivering value to our industry in a collaborative manner.

However, as Chair, and looking at the bigger picture, I can identify six areas that I think are of critical importance to note:

1. AGMA is delivering programs that connect more people in our industry together, allowing the larger network the ability to problem solve and gain creative ideas and solutions in a short period of time. Attend our Annual Meeting, Strategic Network Leadership Forums or the Women in Gearing and Future Leaders network that is being created to understand how you can build a stronger network of industry resources.

2. AGMA built out and is executing on the AGMA National Training Center at Daley College and obtaining more intellectual property to aid in the building of the industry's succession plan. AGMA is ensuring future machine operators, engineers and managers have the training they need to design, manufacture and inspect your company's innovative systems. Your leadership should consider requiring employees to earn the AGMA Gear Manufacturing Certificate or the AGMA Advanced Gear Engineering Certificate.

3. AGMA pivoted to an online presence following the pandemic, creating more opportunities for learning and connecting online. This will continue as our efforts will focus on expanding this globally in 2023 and beyond. Everyone understands money is tight, but don't let that deter you from world-class education. Send your team to the online courses and save time and money.

4. AGMA has also been evolving and updating its programming at the Annual Meeting, attracting new attendees that are looking for personal engagement or workshops on business issues facing the fast-paced industry in which we work. Bring your rising stars to this event and invest in their leadership development.

5. AGMA continues to grow globally and expand its product offerings to emerging markets that are relevant to members for both sales growth opportunities and supply chain management. Pay attention to our efforts with Gear Technology India—your marketing team may want to partner with us as we begin in earnest this month at IMTEX 2023 in Bangalore.

6. AGMA moved to an e-publishing platform and designed new digital connection opportunities—with more to come as we work on the new agma.org website. Overall, AGMA is the ONLY organization that can reach the entire supply chain, face to face, online and via events. This gives your business sponsorship and marketing opportunities in growing markets.

We are seeing a new generation of industry leaders emerge along with the traditional business changes because of automation and robotics in our manufacturing process, but also technology with electrification. Yet, in all of this, we can't forget our technical history, and how AGMA standards continue to stay relevant and focused.

There is a lot going on at AGMA, and if you are a business leader in our space, and NOT an AGMA member—you are missing out, both proverbially and in reality. Leaders lead, and that takes active involvement.

Being an active and engaged leader at AGMA has made me a better leader while developing a stronger business, and the privilege to create new ways of thinking and ways of executing more effectively.

I will continue to be engaged in AGMA because it's now a primary business partner for me and my team. I hope to see you all at a future meeting or online at an AGMA event.

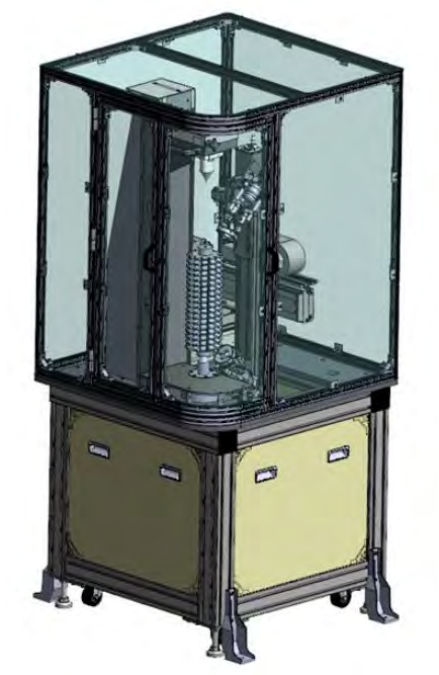
P.S. **For more information about the scope of everything AGMA does, and to learn more about becoming a member, see our ad on pp. 34–35.**

Greg Schulte
Chairman of the Board, AGMA
and
President, Bonfiglioli USA

Nidec Machine Tool Corporation

LAUNCHES ROBOT CAMERAS FOR HOBBING AND BROACHING MACHINES

Nidec Machine Tool Corporation has launched Robot Camera SPEED, visual inspection equipment for cutting tools (hobbing machines) to process gears and other components, and Robot Camera MAX, visual inspection equipment for broaching machines. These Robot Cameras use a digital camera to automatically shoot images of cutting tools' edges at a high speed and with high accuracy and save the graphic data of those images. By entering a tool's specifications into a Robot Camera, the user can have it determine what images to shoot of tools of different shapes and identify any missing part on the edge of a cutting edge and any detached portion of coating, while judging if any problem exists with a tool's visual appearance, including its wear status. The Robot Cameras were both developed for the automation of Nidec's cutting tool manufacturing and regrinding. This improves their quality and can reduce inspection time by 90 percent.



Robot Camera SPEED, Nidec's latest inspection equipment for hobbing machines, can capture images of hob cutters with a straight or spiral tooth depth with an external diameter of 20–130 mm, a total length of 50–350 mm, and a weight of up to 20 kg. With the images of all blades taken from four different directions with high accuracy, Robot Camera SPEED can determine if there is any problem with the cutting tool. Robot Camera MAX can accommodate a large and long tool with a maximum diameter of 200 mm, a length of 2,300 mm, and a weight of 30 kg. It can capture images of any blade alignment, such as straight, helical, and spline.

Both "SPEED" and "MAX" are now available as part of Nidec Machine Tool's strategy to improve its cutting tool-related services. Nidec Machine Tool is committed to actively working to solve its customer's problems.

nidec.com

JTEKT

OFFERS NEW HMC SERIES

JTEKT Toyoda Americas Corporation has recently introduced its FH5000 series of three high-speed horizontal machining centers (HMC), including the FH5000S HMC with 800 x 800 x 880 mm (x, y, z) strokes, 900 mm workpiece diameter, and 1,100 mm workpiece height capacity. The FH5000 series machines include a 500 mm table capable of handling 1,000 kg loads.

"With this series, Toyoda meets the growing demand for producing components with high metal removal rates, short cycle times and superior surface finishes," said a company spokesperson.

Toyoda's FH5000S HMCs with 60-tool ATC capacity are designed for speed and production reliability, featuring a 15,000 rpm, 50 hp (37 kW), 303 Nm (223 ft-lbs.) high acceleration spindle. The 40-taper spindle is designed with four ceramic bearings at the front of the spindle for increased rigidity and reduced vibration. Its patented hydraulic preload system brings the spindle up to 15,000 rpm less than one second without spindle warm-up, ideal for aluminum processing. The larger machines

in the FH5000 series are equipped with a 50-taper spindle, 45 tools, and a longer x-axis travel.

This machine is equipped with a direct drive b-axis table featuring an index time (90°) of 0.7 seconds. The FH5000 machining centers with the spindle design, preload system and high torque features, allows machine shops to take advantage of more aggressive, high-volume machining in a compact footprint, according to the company.

Easily programmed, the H5000 series features the TOYOPUC-Touch panel through which the operator can monitor the machine, see operating data including energy consumption, and edit as required.

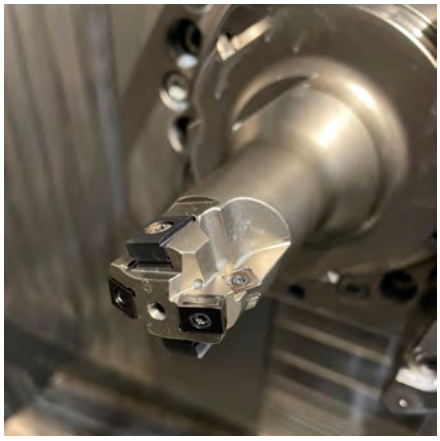
jtektmachinery.com

Ceratizit

OFFERS COMBINATION TOOL FOR VEHICLE WATER PLUG BORING

As a newly developed custom solution, a combination tool for heavy goods vehicle (HGV) freeze plug/water plug boring from Ceratizit dramatically reduces cost and increases performance when producing the holes in cylinder blocks and heads. Such results are possible because the tool roughs, chamfers and reams/fine finishes holes in a single operation—even in grey cast iron with EN-GJV450 vermicular graphite.

The tool's Ceratizit R84 fine boring indexable inserts feature a brand-new reaming geometry specifically designed for exceptional hole finishing. The new positive geometry generates extremely low cutting forces and includes a new chip breaker that improves chip control. All of which



allows for higher feed speeds while at the same time producing a better surface quality. Plus, the new inserts provide a much longer tool life as compared to their predecessors.

Compared with the conventional machining approach using two tools (one for roughing and chamfering, one for finishing), the Ceratizit solution reduces tool changes down to one, shortening the cycle time by at least 20 percent. As Alfred Briegel, application manager at Ceratizit, stresses: "The savings potential of our new water plug drilling tool is huge. The shorter cycle time saves around 25 seconds on a component with 12 holes."

He also points out the lower cost per part. Tool costs also drop by about 20 percent, as only one tool holder is required. The single-tool strategy also means that having to adjust the different tools precisely in relation to each other is now eliminated.

Additionally, he stressed the advantages of the four-edge indexable inserts. "Many users will also benefit from getting the tool for the entire machining process from a single source," reflected Briegel. "Plus, a separate cutting insert for chamfering is already integrated. Previously used roughing inserts can be used for this purpose, as only up to about 45 percent of their cutting-edge length is used when roughing."

Plug and play for easy tool settings

When it comes to tool setting, the plug and play system of the new water plug machining makes reconditioning of a worn tool much easier than with the previous two-tool approach. While users still must remove the cutting inserts and clean the base body, the highly accurate insert seat and the equally precise indexable insert mean that no resetting is required. Users simply rotate the four-edge insert and screw it back in position, recalculate the length dimensions and print the label or download the latest tool dimensions to the (optional) integrated chip.

The new HGV water plug machining tool from Ceratizit is available in diameters ranging from 25 to 65 mm. The tool holder is designed and manufactured as a special tool in line with the customer's length and diameter requirements. The indexable inserts for roughing and fine boring are standard stock products.

ceratizit.com

Index

LAUNCHES CENTERMASTER ACCESSORY FOR MULTI-SPINDLE CNCS

Index has announced the launch of its new CenterMaster accessory. As part of the company's sustained investment in R&D focused on streamlining the setup and changeover process for CNC multi-spindle lathes, CenterMaster reduces the time needed to align a drill by up to 90 percent.

Previously, center alignment of a drill required specialized knowledge by the operator and a challenging, manual process that could take up to 30 minutes per holder. With CenterMaster, the user simply clamps a radio dial gauge into the workspace and sets it to the quill. The gauge and machine wirelessly communicate, automatically adjusting the holder along the x axis. The system then guides the operator through adjusting the y axis via the machine's touchscreen display.

The CenterMaster system allows operators with no specialized knowledge or experience to set up a drill in two to three minutes. Additionally, it provides a repeatable accuracy of <5 µm.

"Over the past several years, we have introduced multiple innovations to make CNC multi-spindles more flexible," says Cris Taylor, president and CEO of Index. "We had already taken a lot of the time out of setups and changeovers via presetting and our quick clamping system with W-serration locating. CenterMaster eliminates another time-consuming aspect of setups, so that customers can truly optimize their machine utilization."

us.index-traub.com

Siemens

SINUMERIK ONE REDUCES PRODUCT DEVELOPMENT AND TIME TO MARKET

With Sinumerik One, the first digital native CNC, Siemens is driving forward digital transformation in the machine tool industry. The new controller works with software to create the machine controller and the associated digital twin from one engineering system and thus contributes to the seamless integration of hardware and software. Thanks to its seamless interaction between the virtual and the real world, including high-performance hardware, Sinumerik One is setting new standards in terms of productivity, performance, and digitalization. It is the future-proof machine tool controller in the increasingly digital world of manufacturing. Both machine tool builders and CNC machine users benefit from the universal digital twin for the product, production, and performance.

With Sinumerik One, machine tool builders can virtually map their entire development processes—significantly reducing the product development phase and time-to-market for new machines. The virtual preparation of machine commissioning can also reduce the duration of actual commissioning considerably. The virtual model of the machine opens new possibilities

for builders and users alike. Machine concepts and functions can be discussed and planned even before real hardware is available. Realistic simulation enables CNC machine users to simulate the programming of workpieces and the setup and operation of machine tools completely on the PC. Even training can be carried out using the digital twin instead of training on the actual machine.

Software and hardware innovations, including the possibility of creating a universal digital twin for product and production, significantly reduces machining time. The CNC system with integrated Simatic S7-1500F PLC is available in both a control cabinet-based and panel-based version. Sinumerik One fits into the Totally Integrated Automation (TIA) Portal and makes a highly efficient engineering framework available for machine tool builders. With Safety Integrated, the new Sinumerik One supports the consistent Siemens industry standard for safety. With IT security integrated in the CNC by design, Sinumerik One implements the multilayer Defense-in-Depth-Concept.

With *Create MyVirtual Machine* and *Run MyVirtual Machine*, the new CNC comes with software to create the machine controller and its digital twin from one engineering system. As a result, the universal digital concept of the digital twin, powerful hardware and integrated IT security make Sinymerik One a forward-looking CNC, which is driving digital transformation in the machine tool industry.

usa.siemens.com/sinumerik-one

PTG Holroyd

RELEASES DUAL ROTOR MILLING TECHNOLOGY

A recently developed dual-purpose CNC rotor milling machine from PTG Holroyd aims to increase the manufacturing capabilities of a leading German maker of compressed air, gas, and vacuum technologies. Currently in build at PTG Holroyd's Rochdale-based machine tool technology center, the machine, a PTG-Holroyd 4EX-R-BL (BL = blower) model, will be used to precision-mill both helical rotors and Roots-type blower air ends. In doing so, it will equip the German manufacturer with exceptional levels of speed, flexibility, and efficiency.

Transforming the manufacture of straight-fluted rotors

"We have long been aware of a gap in the market for a rotor milling machine that can fulfil the needs of manufacturers who wish to produce both traditional compressor rotors and low-pressure output displacement compressors, such as Roots-type, rotary lobe blowers," comments PTG Holroyd Sales Director, Mark Curran. "It is for that reason we developed the 4EX-R-BL—a machine tool that applies the high speed, precision, and performance of PTG Holroyd EX Series milling machines to the production of Roots-type blowers. Fully appreciating the attributes of the 4EX-R-BL, our German customer believes the machine will transform the way in which their straight-fluted, infinitive lead rotors are milled, significantly reducing manufacturing time and increasing the accuracy of the production process."

Incorporating Siemens' Sinumerik One CNC

In line with PTG Holroyd's objective of simplifying the production of even the most complex of helical components, the company's new 4EX-R-BL model utilizes Siemens' Sinumerik One future-proof CNC. PTG Holroyd is believed to be the first UK manufacturer to offer the Sinumerik One control with its machine tool technologies and, only last year chose the automation system for its new range of HG Series gear and rotor grinding machines.

"We selected the Sinumerik One CNC for its ease of use, ability to accommodate each customer's Industry 4.0 strategy, rich, real-time reporting of machine health and performance data, and uncompromising levels of industrial security," adds Curran. "We also embraced the 'Create my virtual machine' and 'Run my virtual machine' capabilities of the Sinumerik One software suite to build and run a virtual 'digital twin' of the 4EX-R-BL on the desktop. This proved invaluable throughout the development stages of the new machine."

30-minute milling time, floor-to-floor

Although sitting within PTG Holroyd's EX range of rotor milling machines, the 4EX-R-BL is a new concept designed from the ground up. Equipped to mill helical rotors of up to 450 mm in diameter, the 4EX-R-BL will also rough mill blower blanks of around 320 mm in diameter and 900 mm body length, into straight fluted rotors in 30 minutes floor-to-floor, ready for finish profile milling to

absolute size. This represents a significant time saving when compared to the one-and-a-half to two hours typically required to cut individual Roots-type blower rotor flutes using traditional milling techniques.

Improving the manufacturing process

"Traditionally, manufacturers producing rotors for Roots-type blowers have relied on NC flatbed milling machines or machining centers that have been retrofitted to absorb the considerable vibrations that occur during the flute milling process," continues Curran. "When you consider that with either one of these production methods each flute must be milled in a separate operation, it is easy to see why the machining process for Roots-type rotors has historically been labor-intensive. By comparison, the technology offered by the 4EX-R-BL moves the manufacture of Roots-type rotors away from traditional flatbed milling [where the component would be manually turned after each flute was cut], to a fully automated, programmable process, able to machine both two- and three-flute blowers in one sequence."

No manual intervention

Removing the need for manual intervention or indexing during the milling of each flute, the Holroyd 4EX-R-BL features a bespoke steadying system that has been designed to withstand the additional forces that are generated during the milling of straight flutes. Specially developed 'finger clamps' ensure the workpiece is held securely while a flute is being milled, then release to enable automatic rotation and positioning ready for milling of the next flute.

Considerable versatility

"In what has been a genuine 'from the ground up' development of a completely new kind of machining center, in the 4EX-R-BL we have designed a model that is able to produce all helixes from horizontal to vertical, for helical rotors, infinitive lead blowers, helical blowers, compressor rotors and vacuum pumps. This significant level of versatility makes the 4EX-R-BL well suited to manufacturers, such as our German customer, who make different rotor types and therefore need considerable flexibility in their machining technologies."

holroyd.com

Exact Metrology

INCREASES CAPABILITY OF ARTEC 3D SCANNERS

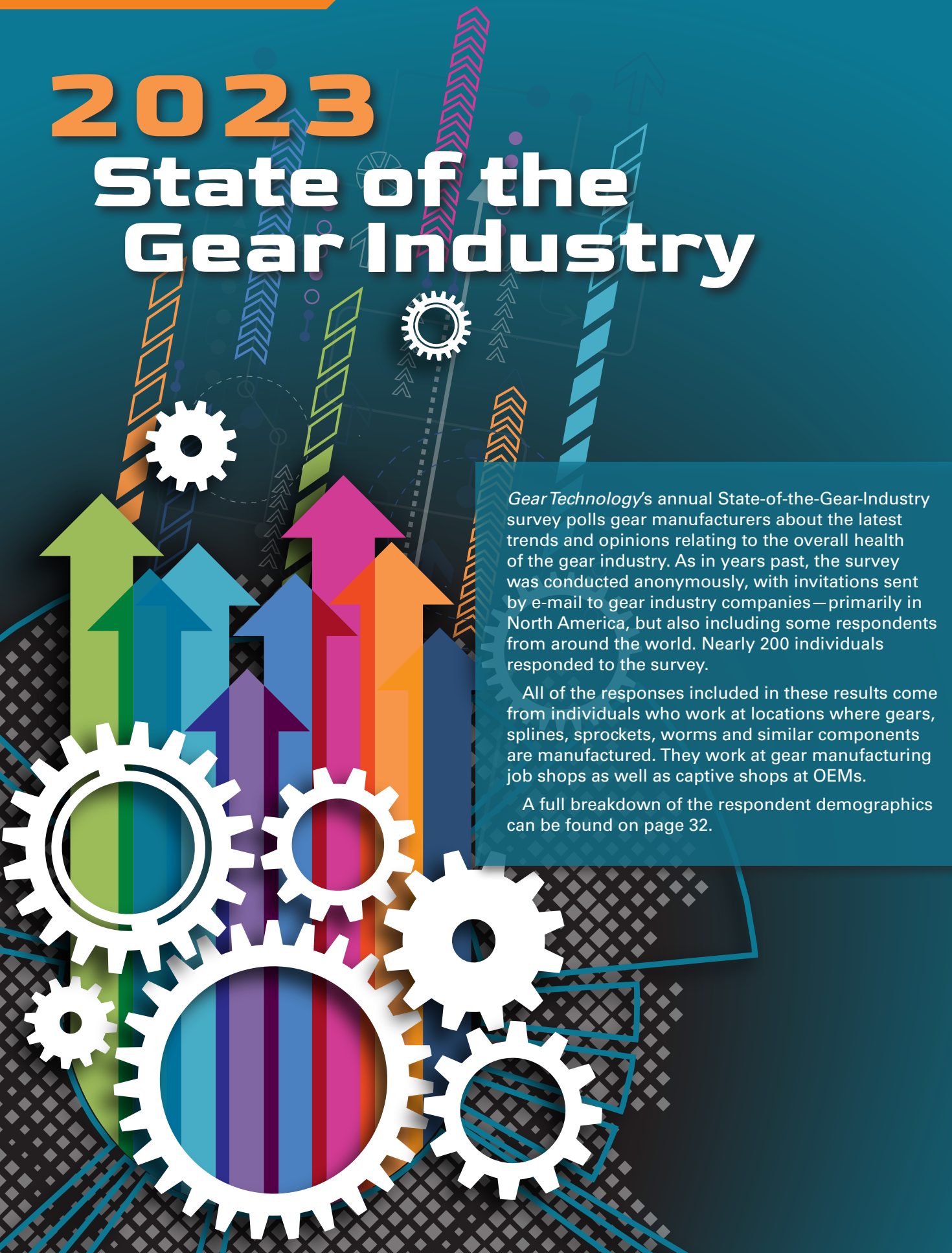
Exact Metrology: A Division of In-Place Machining Company and a comprehensive 3D metrology service provider and hardware sales company, has increased the capability of their Artec 3D handheld scanners with the new HD mode. This Artificial Intelligence-powered scanning technology provides ultra-sharp, clean and detail-rich scans for Artec Leo and Artec Eva.

Powered by Artec 3D's AI neural engine, users can obtain sharp 3D scans with a resolution of up to 0.2 mm. Trained on hundreds of thousands of carefully selected samples, the engine's neural network detects familiar patterns, surface details and shapes. This allows the 3D scanner to reconstruct a higher number of polygons per frame, resulting in 3D data that's both denser and higher quality. Now, the desired HD density can be selected from a standard 1X density up to 36X for Eva (~3 mln polygons per frame) and 64X for Leo (~5 mln polygons per frame). HD mode makes it possible to capture smaller, thinner elements with the 3D scanner while also considerably reducing noise. With these Artec scanners, fine edges can be captured in high definition, faithful to their original shape. It's easy to capture hard-to-reach areas as the scans are reconstructed with every detail, giving users complete surface geometry.

Handheld Eva and Leo scanners can easily scan dark or shiny surfaces in high resolution and capture the full range of their geometries, without additional steps. Using the Artec AI engine, little to no noise in the raw scan data results in cleaner processed data and saves time when producing the final 3D model. Once difficult to capture, now short hair, even separate strands, are fully within reach when scanning with HD mode. Furthermore, these scanners can capture a broad range of objects flawlessly and in high detail: from smaller, intricate parts such as thin pipes or valve handles, to larger objects with multiple high-detail sections, including car engines and skeletons. A perfect fit for reverse engineering and quality control due to clean, comprehensive data, scans can be easily fitted with primitive shapes and exported to the most popular CAD solutions for development.

exactmetrology.com

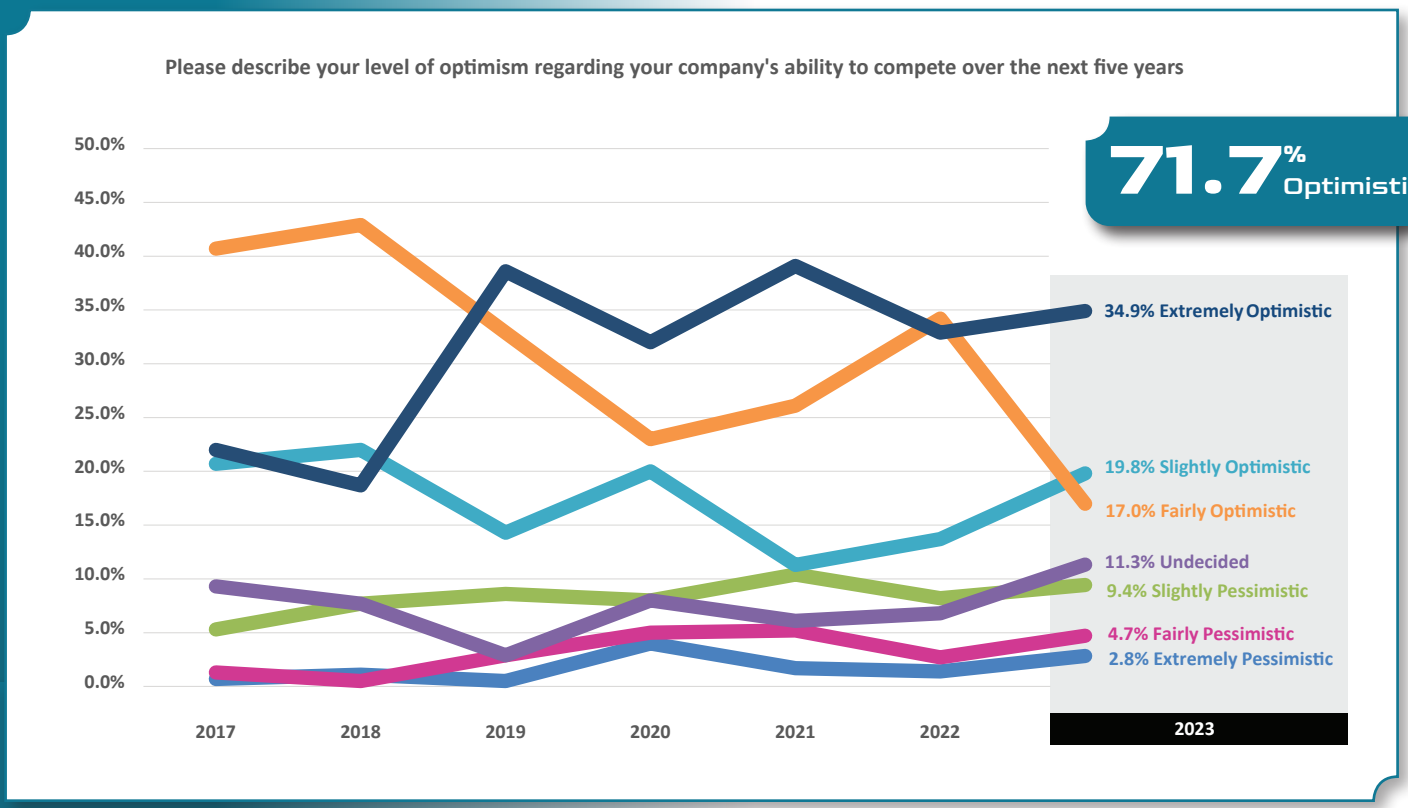
2023 State of the Gear Industry



Gear Technology's annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry. As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear industry companies—primarily in North America, but also including some respondents from around the world. Nearly 200 individuals responded to the survey.

All of the responses included in these results come from individuals who work at locations where gears, splines, sprockets, worms and similar components are manufactured. They work at gear manufacturing job shops as well as captive shops at OEMs.

A full breakdown of the respondent demographics can be found on page 32.



Describe the most important trends affecting your business and the gear industry in 2023. What should our readers know about these trends?

"Electrical mobility."

"Russian War COVID´s effects in the production chain."

"Automation growth."

"Cost efficiency, supply chain, the Build America Buy America Act, supplying solutions instead of products, factory automation."

"Reduced income by European inflation on the global market."

"e-mobility."

"Stock-outs for spare parts for machinery repair."

"The overall gear manufacturing industry is still maintaining extremely long lead times. This helps us since we are able to offer expedited production services."

"Government mandated electric automobiles."

"New products."

"Continued cost increases for alloy steel."

"We serve a wide range of industries with low volume/high mix products, subcontract manufacturing and repair. With inflation and the weaking economy, production volumes drop and repair becomes more cost effective. Having specialized in this type of work, we have developed equipment and methods that allow us to continue to expand our market reach at a very low cost."

"Recession."

"Staffing—especially industry specific positions—is very difficult. Bi-partisan emphasis on return to U.S.-based manufacturing is great. Increases in aerospace, outer space, industrial, defense and medical/instrumentation."

"Supply chains, if recovered at all, are hanging on by a thread. Inflation and cost increases are rampant. Business is good, costs are high. Bookings are up but shipped units are lower."

State of the Gear Industry Perspectives

Matthew Jaster, Senior Editor

There's optimism, there's pessimism and there's a little bit of old-fashioned indifference when it comes to the challenges and opportunities the gear market will bring in the coming years. Many contributors answering our State-of-the-Gear-Industry survey feel that manufacturing will ramp up in 2023–2024, creating a 'new normal' outside of pandemics, labor shortages and supply chain woes.

Gear Manufacturers Examine Changing Markets

Manufacturers are stabilizing costs and prices and continuing to assess raw material challenges, according to Michael Cinquemani, owner, Master Power Transmission.

"Our challenges have been focused on casting suppliers and probably reflect a capacity/manpower issue which grew out of the pandemic. We are dual sourcing and investing in new relationships."

"Rising costs and protecting our profitability to ensure we avoid eroding our profit margins is our greatest challenge," said Kika Young, president at Forest City Gear. "Specifically, this is affecting us in several ways. Human capital is

Most Important Trends (cont'd)

"Continued funding for government contracts. Continued stability in oil prices. Further development of EV gearing for automotive."

"Increasing supplies and availability of permanent magnet motors that may not require gear reducers."

"Car sales have changed. Lower production drives higher demand and higher profits. Make less cars but make more money. It's a good model for the OEMs but not the suppliers."

"Vehicle electrification and how it affects the gear demand."

"Stability of supply chain including gear materials."

"Advent of EV industry. Optimization of gearbox with the given package."

"Aging aerospace platforms becoming more competitive. Materials and labor are becoming more expensive."

"Lack of orders for lightweight, high power density new starts."

"Employment trends: It will continue to be hard finding good people."

"Demand for large gears for mining and bulk material handling projects remains solid. Smaller gear drives for unit material handling slowing down."

"Gearless drives on large conveyor belts. Lithium production South America geopolitical situation(s)."

"Raw materials lead-time is easing. Customer orders are less optimistic starting in the 3rd quarter of 2023."

"Increased material costs, energy costs, heat treatment costs and tooling costs. Worldwide competition."

"Uncertainty regarding worldwide business given geopolitical tensions."

"5-Axis machining, 3D Printing—new ways to make old products. Fewer people, quicker turnaround."

"Overseas and Mexican sourcing by competitors."

"Lack of raw material availability and shortage of skilled manpower."

"Tighter tolerances on every aspect of the gear while trying to maintain efficiency."

"Costs of living/inflation; recession; staffing shortages."

"Oil, off-highway and big truck business."

"Standardizing calculation methods for involute splines with straight or highly crowned teeth. Incorporating bearing manufacturers' proprietary data on internal geometry into computational models for gearboxes and shafts. Improving surface finishing methods for splines designed for low friction and high misalignments."

"Heat treatment issues."

"Service."

"Shortage of employees. Automation needs serious consideration by all."

"Worker availability and skill levels."

"Maintaining quality and speed in production, especially being a jobbing gear manufacturer and meeting customer expectations."

"Inflation."

"Green energy."

"Skilled trade. I think it is important to lead in training the next generation of skilled machinists. We are starting to see a turn in this country that it is OK not to go to college and that the skilled trades are a pathway for a lot of our younger generation to have a high paying, highly skilled job without a degree. We are finally seeing support from the local and state government as well. I think the companies that stay ahead on this front will be well set going forward."

"Raw material pricing, labor needs and inflation."

"Delivery capability."

"EV requirements. Safety."

"The invention of EVs has shifted the focus for us and many other companies involved with gear manufacturing. We are a gear cutting tool supplier, so we are now concentrating more on carbide hobs and skiving cutter development, as these products will be in high demand if EVs flourish in the future. With so many alternate technologies being experimented (hydrogen, etc.) eventually one thing is for sure that automobiles are not going anywhere and they will definitely need a powertrain in some form another. Maybe the products will become expensive in the beginning due to economies of scale not being present, but there will definitely be demand."

"EV powertrain."

"Getting the younger generation more excited about manufacturing. We have a few, but could use more."

"Low demand."

"Automation and e-mobility."

"Moving back productions from Asia to Europe."

"Supply chain issues and trying to replace retiring, skilled employees. A university degree (support staff) will not replace highly skilled tradespeople that are in such short supply as to be nonexistent (the ones that contribute to GDP)."

"Inflation impacts in the USA as compared to other world areas is a concern relative to competitiveness. U.S. wage growth and the strength of the dollar are concerns."

"Pandemic caused inflation. Labor pool for technical help. Long lead times for mold components. Program timing delays due to supply chain delays."

"Innovation and research."

"Lack of skilled help available."

"We are almost out of work. Everyone is going to electric cars."

"Improve efficiency (smaller losses) for all transmissions, especially for transmissions in mechatronic systems. That means transmission for high ratios with low number of elements. Transmission with very low weight for a referred ratio are in the focus of research and development. Low weight are the key for low cost (when you accept the same production quality and the same tolerances for all parts and elements for transmission)."

"Skiving."

"Grinding of ring and pinion gears for rear axles."

"Desire for increased revenue reduces personnel and drives higher usage of early optimization tools."

"Miniaturization of gears and gear train components seems to be the direction our customers are going in."

"Electric vehicles powertrain using less gearing."

"Electrification, not only on automotive."

"Powertrain electrification is currently a high priority among most automotive companies. The number of gears in electric drives is much lower. PHEV vehicles will have more gears in the drivetrain than current ICE vehicles. My belief is that the U.S. will most likely have 60% PHEV vehicles and only 20% BEVs."

"Continuity of supply of high quality steel."

"Demand for automation in all industries. Growth of distribution center supply model. Both have been positive for gearmotor business."

"Skiving tool application. Impact of future mobility (e-mobility) on the gear manufacturer industry. Business inquiries are good."

"e-drive technology, Ukraine crisis."

"Cost of capital equipment, manpower."

"With the economy slowing, low-volume manufacturing will become the driving force. Low volume is very difficult to automate and typically requires higher skill people to make one or two of a part number."

"EV madness. China recession. Global recession."

"New energy sources. How will these affect the transmissions and axles. New materials and heat treatments."

"New drive systems already under development."

"Reduced staff may cause delivery shortfalls."

becoming more expensive as the labor market tightens; there is a shortage of skilled technical workers and a shortage of workers overall. We are seeing our supply chain have growing issues with labor as well. Increased government oversight and regulations in areas like cybersecurity and CMMC are very expensive to implement and maintain. Orders remain strong and business is healthy, so it has become a matter of managing and mitigating these issues while growing."

Areas that FCG is keeping a close eye on include additive manufacturing, gears produced on non-dedicated equipment such as multitasking machines and automation/cobots.

"As a job shop with low volume and high mix applications, these resources are limited for our scope. We are looking at the intuitive cobots. Implementing these into our workflow is something we're getting creative about," Young said.

Supply chain challenges stem from customers' restrictions and approved supplier lists. This restricts FCG's ability to take control of the supply chain and vendor management to the extent they would like. "A few years ago, we made a conscious effort to exit from customer LTAs that had restrictive pricing pass-throughs and certain covenants. This has proven to be very fortuitous, as we have been able to pass through increased prices for materials and special processing to our customers," said Jared Lyford, director of manufacturing operations at FCG.

"Lead time is delicate and difficult with customers, oftentimes due to their own labor issues and shortages. We are as proactive as possible with our vendors regarding lead time, giving as much visibility as possible and providing POs to 'get in line.' Of course, the most advantageous way to navigate these issues is by simply fostering good relationships and providing good communication with both our customers and our vendors," Lyford added.

Internal training and workforce development is another focal point for FCG and Master Power Transmission.

"For decades, FCG has felt that investment in our workforce is a central tenet to our success. Through COVID shutdowns, we were unable to focus the resources we historically have on training. Mid-2022, we reinvigorated our approach to this," Young said.

The future of gear manufacturing will rely on new engineering talent to navigate areas like smart manufacturing, system integration, automation, and robotics.

"Mechatronics is the key," Cinquemani said. "Commercially, consolidation is going to limit customer's choices resulting in opportunities with potentially lowered barriers through new technology."

Young added, "From our perspective, the tolerances required from customers are trending higher. This places more pressure on supply chain and machine manufacturers themselves."

Meeting Today's Gear Industry Challenges

On the supplier side, machine tool companies are looking closely at e-mobility, energy, sustainability, electrification, Industry 4.0/IIoT to provide new technologies and solutions as gear manufacturing starts hitting pre-pandemic production figures.

"In the near term, we don´t envision significant major shifts in gear manufacturing technology," said Udo Stolz, vice president of sales and marketing at Gleason. "We are focused today on driving the continuous improvement of precision and productivity in existing processes. These efforts include meeting stringent quality and advanced surface roughness requirements and increased productivity today required by gear manufacturers (particularly EV) to minimize noise, vibration, and harshness (NVH). Hard fine finishing technologies like grinding and honing and, increasingly, skiving, will play an important role in achieving these goals."

There has been an increasing demand for automation products, in conjunction with gear machine offerings, according to Peter Wiedemann, managing director, Liebherr-Verzahntechnik GmbH. "For sure, even job-shop customers – as well as customers in low-cost labor countries – who did not in the past consider automation, are more-interested than ever. This is most-likely due to the overall global skilled labor shortage in manufacturing. For this reason, a close collaboration with our customers not only includes an automated system, but also the proper training and smart-factory solutions like Industry 4.0, to get started with these turn-key solutions from the onset of a new installation," he said.

"The greatest challenge is to fulfill the increasing demand for our machines and services. Klingelnberg is perfectly positioned to serve the growing markets for e-mobility and wind power and our production capacities are fully booked," said Christof Gorgels, vice president innovation and technology at Klingelnberg. "The trends we are paying close attention to are digitization and data driven optimization approaches as well as gear noise becoming a major quality criterion. Besides improved surface finish brings advantages in terms of efficiency which is interesting to improve renewable energy generation and especially wind power."

"We are going to be quite busy in 2023 with several new projects which is a good thing, but at the same time this brings on challenges that we have been facing the previous year that appear to not be going away," said Shane Hollingsworth, vice president of sales, Kapp Technologies.

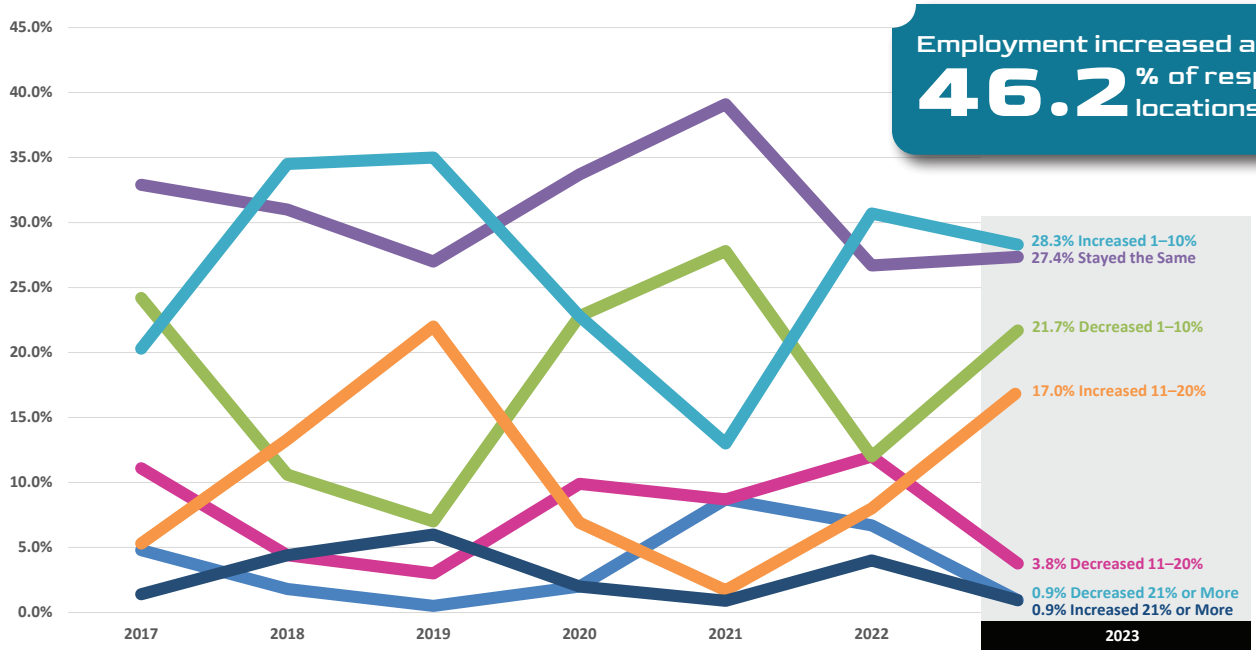
"Supply chains are still stretched out and at times unpredictable which makes scheduling difficult, it's no secret the industry is looking to solve a skilled labor shortage—mix in unreliable schedules adds to the complexity. We are not seeing one area that is affected, it's everything from bearings, electronics, controllers, and vessel delays to name a few."

—Shane Hollingsworth, Kapp Technologies

An area grabbing significant attention continues to be the EV market.

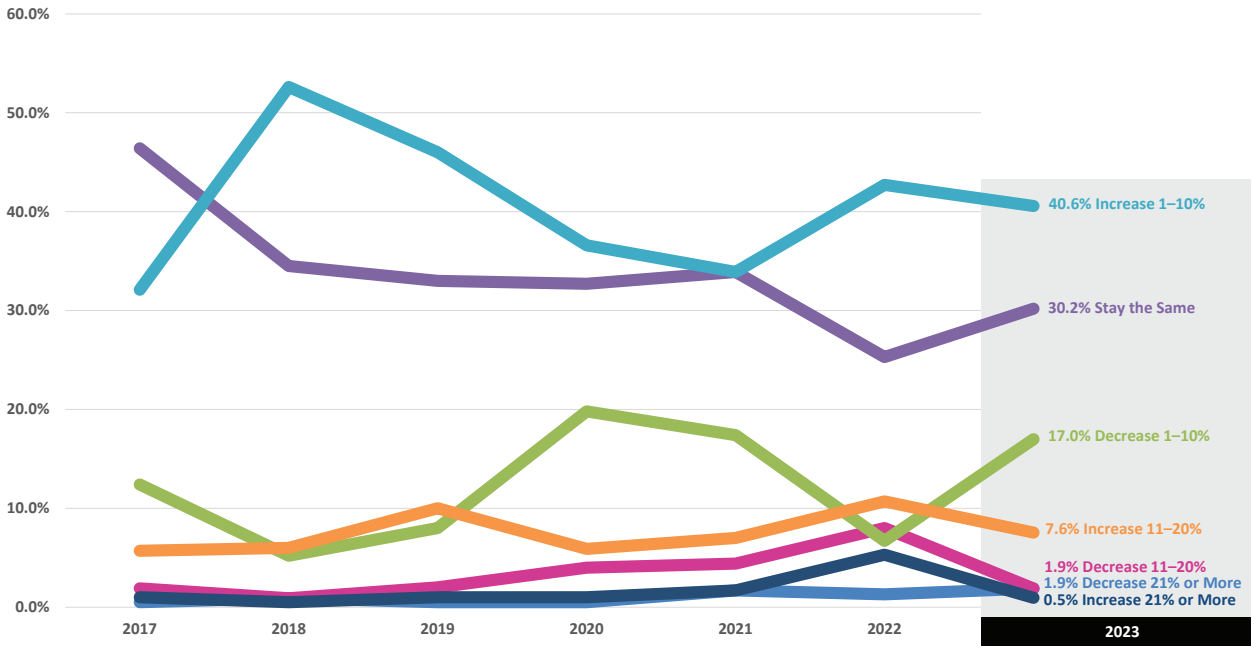
"We have seen in Europe along with China that this market is further along being accepted and introduced in the market.

How has your location's LEVEL OF EMPLOYMENT changed over the PAST 12 MONTHS?



Employment increased at 46.2% of respondent locations

How do you anticipate your location's LEVEL OF EMPLOYMENT will change in the NEXT 12 MONTHS?



48.7% expect employment to increase this year

North America has touched its toe in the water. We see more and more projects being introduced, but still at a much lower production scale. Future energy prices, infrastructure, and legislation will be major influencers for how this market continues to develop," Hollingsworth said.

Scott Knoy, vice president of sales at Nidec Machine Tool America said the core business of Nidec is electric motors.

"Part of the reason they acquired Mitsubishi Heavy Industries was it gave them a partner to help produce electric motors globally. We recently sent some machine tools down to a Mexico plant for this reason. We're moving into the market because that's where the business is headed. There's a big push for electrification across the board," Knoy said. "There are basically two types of EV transmissions. You have the external helical gearsets used most famously by Tesla. These are very easy to make the gears, but it's not as efficient as a planetary set. We've recently seen two-stage planetary sets where the weight and overall efficiency is much better. We think they're going to go in this direction as things progress," Knoy added.

Even though inflation cooled in the last two quarters of 2022, Helios Gear Products continues to pivot to address employee wages/benefits and product pricing — while keeping their ears to the ground regarding market competition.

"No one has perfect foresight, but the situation does not seem to be fully settled, so our planning (financial, sales, marketing, operations) needs to incorporate an element of flexibility for 2023," said Adam Gimpert, president, Helios Gear Products.

"Smart manufacturing trends continue to be very interesting, and they have the chance to transform gear manufacturing. I feel this will be a 'tipping point' change still years in the future, but I think it's worth following as it evolves," Gimpert said.

An Increase in Automation/Robotics

While automation cannot solve ALL manufacturing floor challenges, the opportunity to setup a machine and have it run all day/night unattended is appealing.

"We collaborated with a company at IMTS called AWR (Automation Within Reach) and they make CNC machine tending units. The baskets are a source of anxiety and high cost in many of these applications so they're moving away from baskets. The AWR unit at IMTS featured a reloadable shelf, two sides, and a robot would work on Side A while the operator is loading or unloading on Side B. This machine would run continuously and only need about five minutes of operator attention per hour. This is what AWR specializes in," said Knoy.

While automation is not going to help you with a shop's skilled operations, Knoy said it can take the grunt work out of the equation for activities such as loading, unloading, measuring, part washing, etc. anything that can be integrated into these machining cells. Now management can free up skilled technicians to handle the important challenges on the shop floor.

He believes automation is going to increase significantly in gear manufacturing especially in the Tier 2 suppliers and the job shops. "They're really starting to see the benefits of these

How is the push toward ELECTRIFICATION affecting your business?

"Not too much at this point. EV is not our direct sector. Our customers are slowly moving towards it, though more and more customers are asking about our environmental, social and governance (ESG) policy."

"New challanges by reduced tolerances."

"Decreasing quantities."

"It still doesn't affect us."

"Some negative effect."

"We are seeing an increase in business from ancillary industries such as mining and mineral processing."

"I believe electrification is a hoax, so what can it do but hurt everyone?"

"We are using the new motor technology in industrial drives."

"Minimal."

"Demand for repair and customization to reduce cost of purchasing electrified products will increase our sales."

"We have seen units for EVs in quoting much more. At this point it is not yet affecting us, but we do zero automotive."

"Little to no direct impact."

"Opens new opportunities in both automotive and genset applications."

"Increasing product demand in some markets."

"Awaiting orders that have been quoted. Changes in demand. Accelerating modernization of production. Changes in teeth size range."

"Our company began investigating opportunities to enter the EV market."

"It gives us the impetus to prepare for new challenges and thus invest in infrastructure."

"Zero."

"Huge, no need for gearing."

"It is not."

"Some impact in newer gear designs from OEMs."

"No effect at this time."

"Less power installed or divided power = smaller reducer, less money."

"No effect."

"Not much."

"Decrease or set to zero our business."

"We are not affected by it."

"No effect."

"More prototype work from various companies."

"No real effect at this point."

"Not at all."

"Higher costs are offset by less stringent safety requirements in steelmaking and rolling mill plants."

"Not affected."

"Too much."

"Not much."

"Minimal impact at this stage, but it is a journey that we have now started, and we are now working with small OEMs in development stages."

"Increase sales."

"Improving our downtime due to excessive load shedding."

"None."

"Not an urgent issue."

"A little bit."

"Not applicable. We serve industry markets like mining, cement, sugar, steel, power etc."

"Outsourcing of gearbox parts."

"We are finding and pursuing new opportunities by entering into horizontal expansion of our product line."

"Few new designs in progress. Appears that our customers' resources are invested in BEV technologies."

"It has not."

"Keep same."

"There are fewer gears in electrified cars, trucks and devices."

"None."

"As a supplier of more than just gears it is actually helping us from the standpoint of more business."

"Very important."

"Not applicable for us."

"We see a decrease in the gears we make for diesel engines."

"It is reducing gear demand in automotive sectors. It is requiring higher cost processing in other areas."

"Our business is not affected by the push towards electrification."

"Not impacted."

"High."

"Unknown."

"Negative."

"For the automotive industry, the mass and the volume of transmissions will become smaller than for cars with an ICE engine. That means the production of transmissions (in kg) will become smaller, the precision and quality will become higher. Research and development will become higher, the quantity will decrease."

"Massively."

"Very little."

"Electrification drives new business. The gears change but are still required and in some cases require additional changes to deal with electrification's shortcomings."

"Will cause some decrease in volume."

"Huge investments are being made in battery plants and electric drive systems."

"Completed strategic purchase of motor and VFD Companies to support existing gear business."

"Only slightly."

"Slightly negative impact."

"Some impact."

"Negatively in general, opportunities in specific fields."

"We are not involved in this segment, so it won't affect our business."

"No effect."

"Introducing a lot of new installations to change gas to electricity."

"New opportunities slightly beyond our capabilities."

How are you handling and navigating supply chain issues heading into 2023?

"Situation is getting better."

"2020 was tough. We were able to resolve our supply chain in 2021, thought with some delays in delivering."

"Reduced staff."

"Increased capacity in procurement and SQA."

"Looking for other alternatives."

"Trying to expand our vendor base."

"For certain types of raw materials that customers specify we can only offer quotes that are good or 48 to 72 hours."

"Very little problem."

"We are developing new local suppliers. to avoid dependence of imports."

"Working very closely with suppliers and customers."

"Acceptably."

"Living with them. Placing larger orders and stocking."

"We pay our suppliers and vendors in 30 days or less. This typically gives us preferential treatment."

"Brute force. Larger purchases, higher inventories, more vendors."

"Diversifying supply base for items which typically didn't need it prior to COVID. Trying to source all components domestically."

"Supply chain is vastly improved."

"It's tough, lead times are hurting our competitiveness."

smaller tending machines because they're very flexible, you can set them up quickly and they provide longer runs."

Hollingsworth said automation has a significance in Kapp Technologies current and future machine tools due to the diversity of the markets the organization serves. "Clearly, the automotive sector is the leader in automation/robotics utilization and for such we offer machines capable to interface with varying platforms and sizes," he said.

Liebherr has supplied its own automation—including robotics and other automated systems—for its gear machines since the early 1980s.

"Part of our division of Liebherr has been automating complete factories, and building our own gantry systems, palletizers, and providing robotic integration since the 1970s in fact, said Scott Yoders, vice president sales, Liebherr Gear Technology, Inc. "We see these automated solutions moving from their traditional gear-cutting markets like automotive and truck, into other areas like aerospace, construction, agriculture, and even larger gear cutting applications like wind-power, oil and gas, as well as mining products. We even have interest from some small job-shop customers for automation of even small batch sizes."

Helios Gear Products has always focused heavily on automated gear manufacturing processes. "Over the past four years, we have dramatically reduced the cost of these systems while keeping them simple and without a third-party integrator, which lowers the bar for manufacturers to benefit from them.

"Robots, cobots, new automation systems, and programming will also continue to evolve, meaning decreased costs and easier implementation. This will allow complete flexibility for manufacturers to easily re-tool cells and workflows to address changing market demands."

—Adam Gimpert,
Helios Gear Products

The shortage of skilled workforce in combination with more attractive robotics pricing on one hand, and increased capabilities on the other hand, offer some interesting opportunities, according to Stolz.

"By having our own automation division, Gleason can meet the automation needs of our internal manufacturing and offer integrated automation solutions for gear manufacturing machines as well as general machine tools for non-gear applications. In the future, the ease of integration, increased capabilities and improved collaboration will certainly increase the trend for agile production and the use of automation to perform even more complex tasks."

Gorgels at Klingelnberg is also seeing more automation in combination with the company's machine tools.

"Whereas this was a focus mainly for mass production such as automotive in the past, today we even see a growing need also for large gears e. g. in the wind industry. So, there is an increasing need for flexible automation systems and systems capable of handling big and heavy parts."

Supply Chain (cont'd)

"Looking for new suppliers."

"Our company is developing new business partners."

"Invest in supply chain to mitigate the drawbacks in delivery as well as quality."

"Pushing costs back to our customers."

"Looking at alt sources and automotive supply."

"Involving key customers more quickly and relying on their strength more often."

"Adding resources and attempting to utilize sources in same hemisphere as plants if possible."

"Beefing up inventory and keeping ahead of the curve."

"New vendor sources brought online in 2022 will significantly decrease supply chain issues."

"Difficulties to find reliable partners."

"Adding new suppliers as needed."

Broadening supply base, sourcing more product from reliable overseas vendors."

"Lack of components."

"We are developing alternative suppliers."

"With support from our customers."

"Specifically looking into forgings rather than bar stock."

"Carefully...not sure how to answer this question. The best way is to say adding inventory and ordering earlier to address the longer lead times."

"Not been a factor."

"Much longer lead times especially for larger size bearings. Trying to make structural designs more modular and flexible, not constrained to one kind of bearing."

"By strong SCM strategies."

"Planning."

"Supply chain issues are settling down but can't be ignored."

"Diversification."

"We are ordering more and carrying more stock to avoid delays."

"We are working on it."

"Finding additional sources."

"Raw material is the biggest issue."

"Having more than one partner."

"Do not see any supply chain issue."

"Don't have much issue there."

"We are not seeing issues."

"Better now than during COVID, but still a few supply issues."

"We have been minimally affected. We are a job shop with some room to be flexible."

"There is no rhyme or reason to some of these issues. Handling it is like an oxymoron."

"Good."

"More automation."

"Trying to move to reshoring supply chains. Offshore has way too many pitfalls."

"We are making changes internally to better serve our industry and our clients moving forward. We will be vertically integrating more and building up internally held stock so we can control more of our supply base. We are here to support those companies that also wish to become American made and lessen their dependency on foreign products."

"At the moment we don't have problems in our supply chain."

"Supply chain issues are improving."

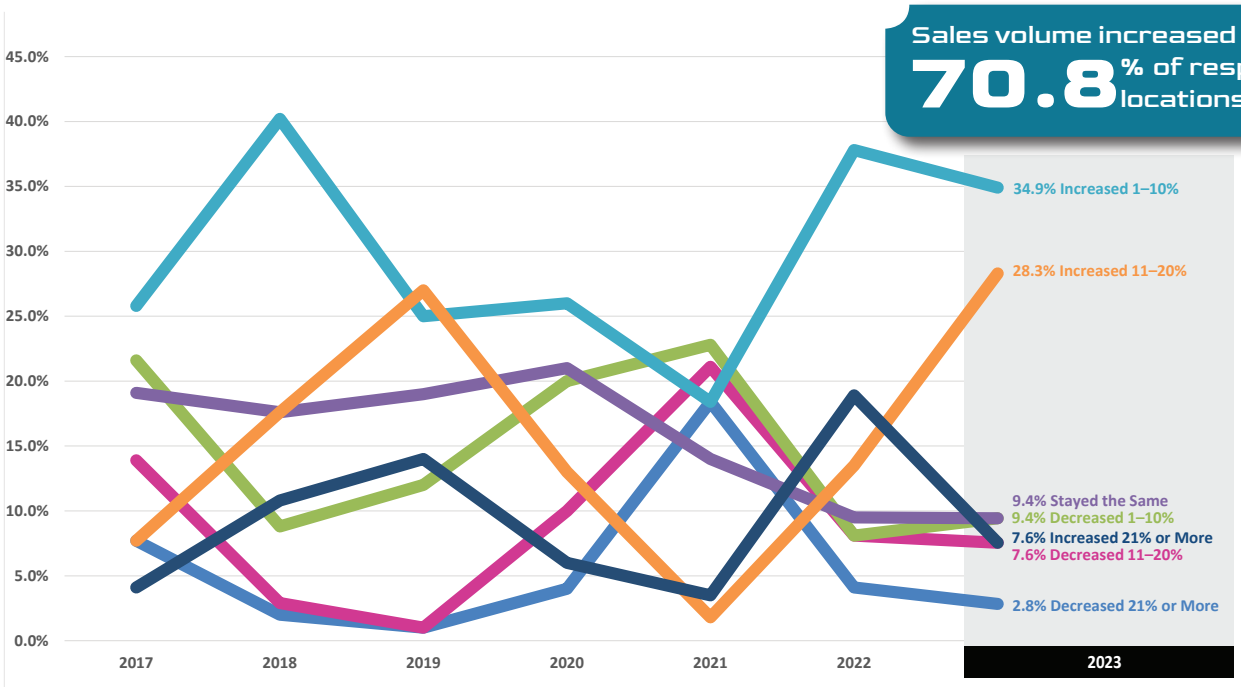
"Supply chain management remains a critical component in our ability to not just survive but to thrive in 2023. Multiple sourcing, logistics and attentive inventory control will be the key to insuring material stocks are in house at the right time and quantity to meet our customers' requirements.

"Purchasing ahead at first sign of issues."

"No change."

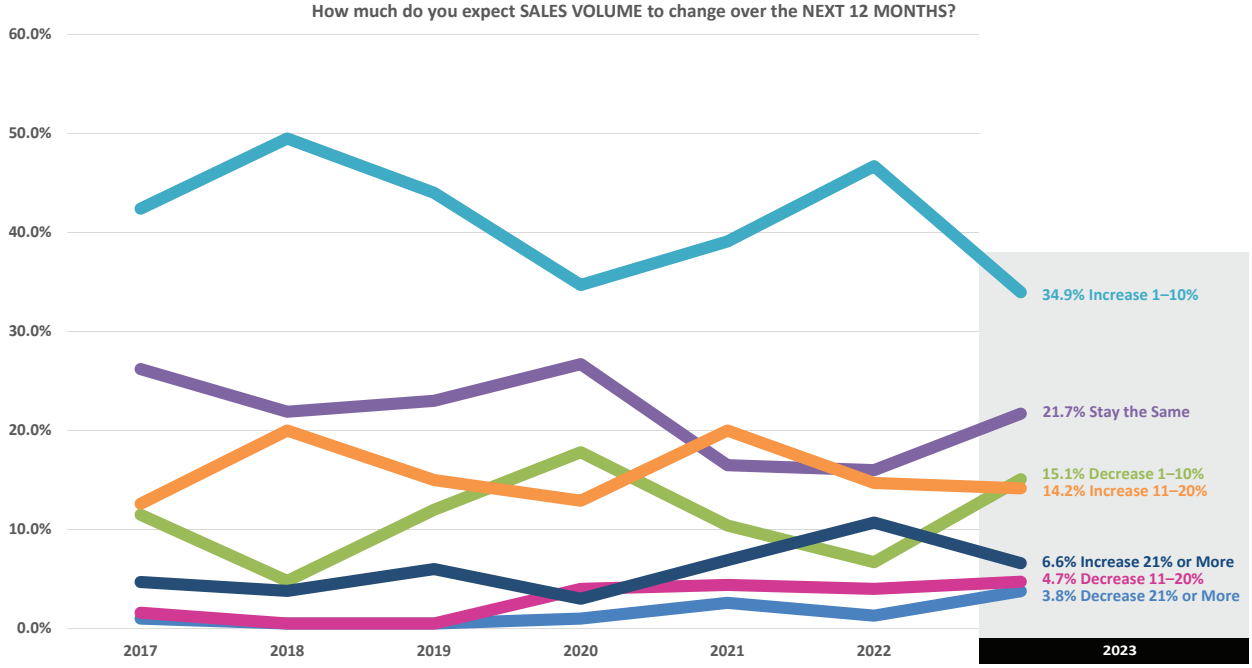
"Not really a problem."

How has total SALES VOLUME changed over the LAST 12 MONTHS?



Sales volume increased at 70.8% of respondent locations

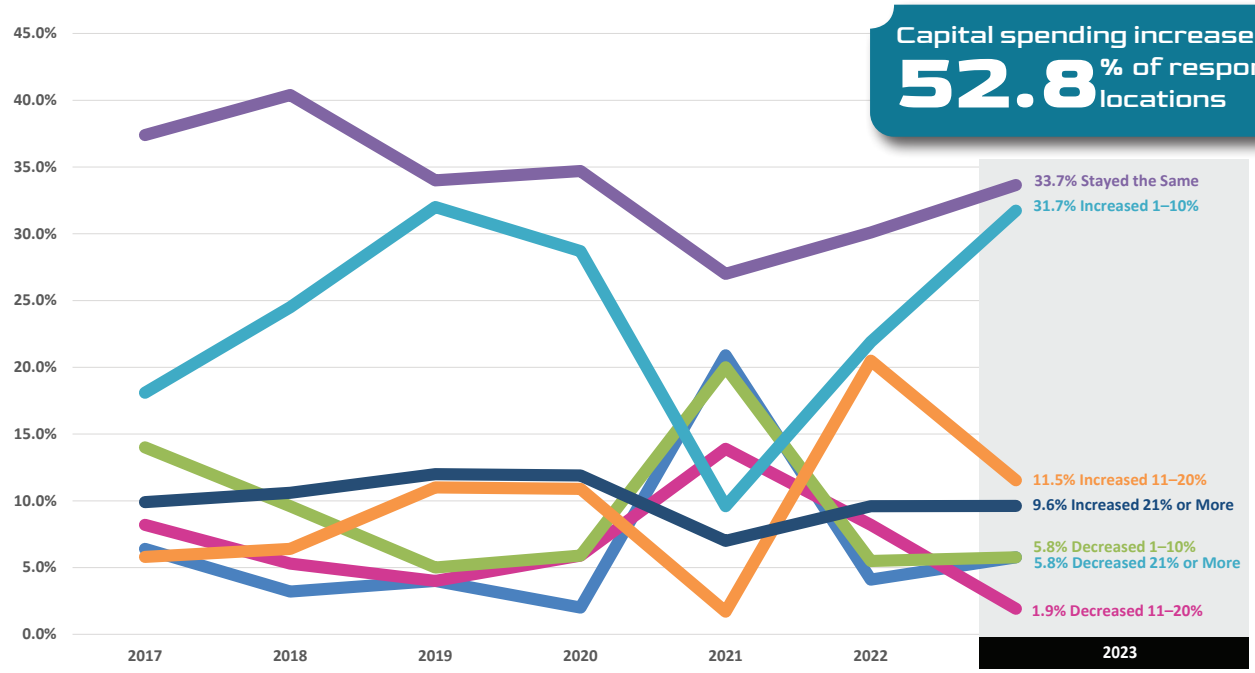
How much do you expect SALES VOLUME to change over the NEXT 12 MONTHS?



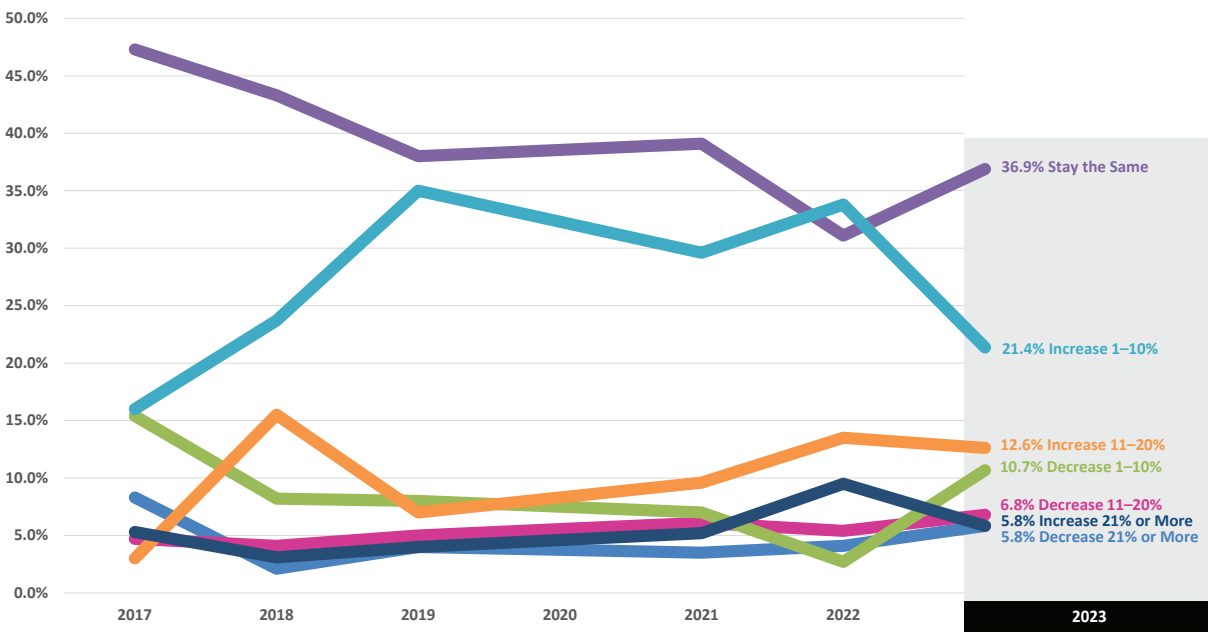
55.7% expect sales volume to increase this year

How did your location's CAPITAL SPENDING in 2022 compare with 2021?

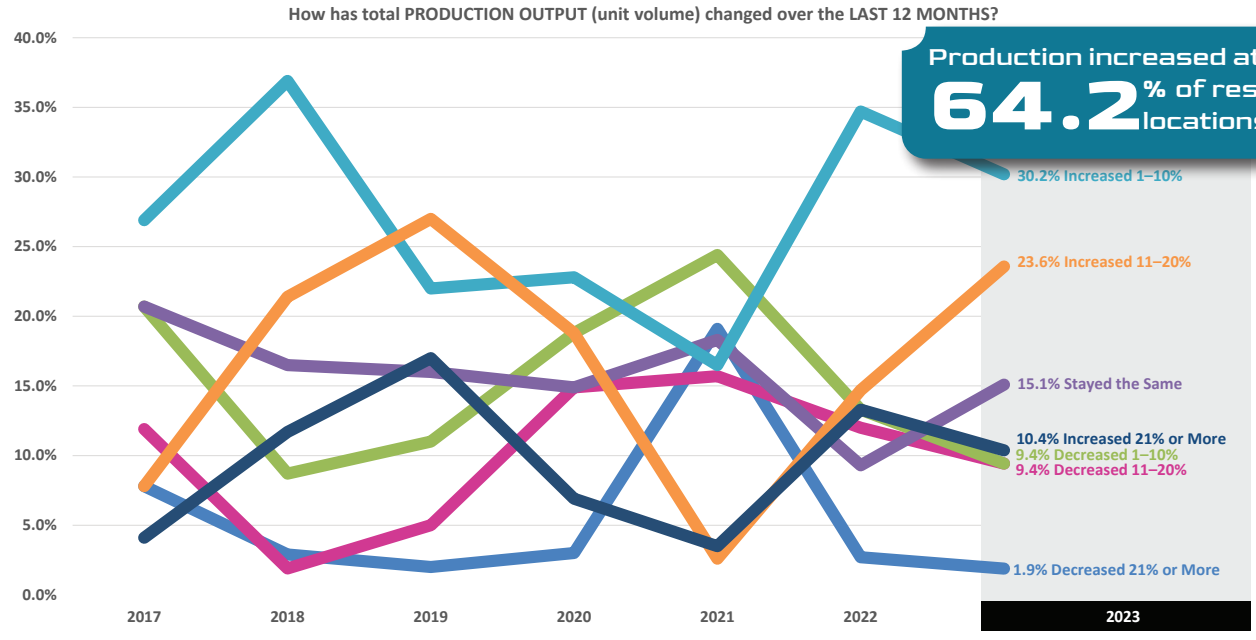
Capital spending increased at 52.8% of respondent locations



How do you anticipate your location's CAPITAL SPENDING will change over the NEXT 12 MONTHS?



39.8% expect capital spending to increase this year



What role will emerging technologies (including, but not limited to IIoT,additive manufacturing, robotics and automation) play in your organizationin the coming years?

"More automation in production."

"It's slowly move towards it, but is definitively here, especially robotics and automation. It helps to get more efficient and productive, particularly when it is hard to hire qualified people for a particular task.

"Increased smart manufacturing technologies (process control). work simulation by digital twins."

"Big role."

"We are about to start in automation."

"Not much as we use conventional machine tools and don't have many CNC machines."

"We are presently doing extensive research and development using additive manufacturing for tooling and inspection."

"I will be surprised if we are changed from any of these things but we have purchased machines that can be automated."

"Will be phased in as customer demand requires."

"IIoT, robotics and automation have limitations when making 10 or less of a part number. 3D printing has a way to go in reducing costs for producing parts for logging, construction and farming equipment manufacturing, modification and repair."

"Not much."

"We're optimistic it will help us from a staffing perspective in particular."

"Large capital expenditure ideas are still difficult to get approved."

"Automation will play a role in increased high-volume gearing production. Additive manufacturing already being used for certain non-critical parts and may eventually be used for structural but non-rotating parts."

"More emphasis and investment."

"Part of our strategy rests on our inspection products replacing personnel. This should be seen as a positive in the market."

"They greatly influence and contribute to manufacturing process improvement and target customer change."

"Not thought much in this line yet."

"Increased productivity."

"None."

"A more significant role."

"Could be significant with more cost-effective predictive maintenance tools available."

"Virtual production skills."

"Increase of competitiveness."

"Limited effect for now."

"It will be significant especially as it becomes more cost competitive."

"Useful for flexibility and energy saving."

"Not sure at this time."

"None in the immediate future."

"Significant."

"Robotics only chance to compete."

"Simplify online wear monitoring of difficult to access components and gearboxes. Measurement of torques and loads in scenarios that are difficult to estimate or simulate beforehand to improve existing designs by reducing unnecessary safety margins."

"Should go for automation."

"Increasing levels of Industry 4.0/IoT refining databases and statistical analysis. Opportunities to increase automation, add robotic handling is now high on the wish list."

"We are looking at all options to deal with worker shortages."

"We are a small jobbing gear manufacturer and cannot possibly afford the new innovative trends but will implement what becomes more useful to our needs."

"More automation in our product."

"Zero."

"Very little to our industry."

"A small role."

"Will Support shift of business model from supply chain to demand chain."

"Extensive digitalization."

"Not sure, but should be for the better."

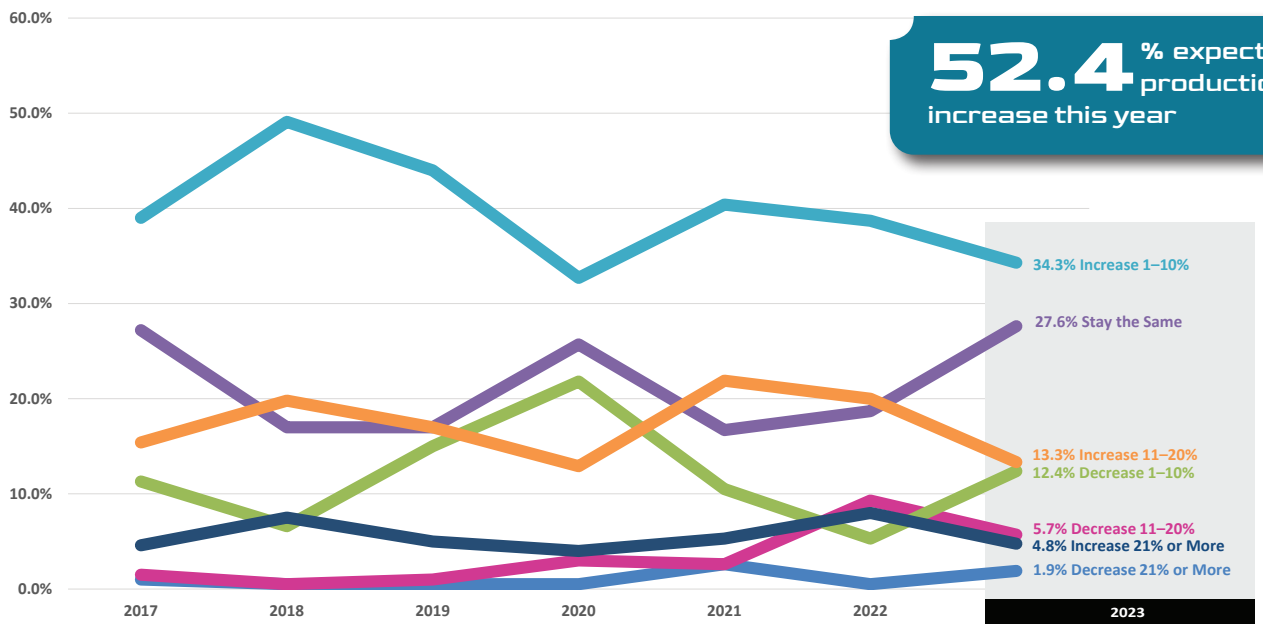
"None."

"COVID and post COVID have distracted us from innovating."

"None! Advanced technologies cannot put a machine together."

"It is my main focus this year to keep adding these types of tech."

How much do you expect PRODUCTION OUTPUT (unit volume) to change over the NEXT 12 MONTHS?



52.4% expect production to increase this year

Emerging Technologies (cont'd)

"Important."

"Additive manufacturing will be a possibility if costs can be decreased and speed improved."

"We will continue to advance our technology."

"Important role, especially robotics and automation."

"Automation needs to increase dramatically to fill the void from a lack of U.S. workers and the need to manage costs."

"Emerging technologies play a critical role in our ability to thrive in the coming years. Additive manufacturing has made huge strides over the last decade and promises to hit the tight tolerances needed for precision gears in the coming years. We are increasing our utilization of both robotics and automation to remain competitive on a global scale."

"We are a critical supplier to the robotics industry."

"Automation may be our only way forward."

"Robots will become more important."

"Quite important."

"Key role. Automation and machine learning will change the way we work and control our processes."

"Hopefully a significant help to reduce labor shortages."

"Some, but not a lot. Low per part volumes limit the ability to increase automation."

"Will require more automation."

"I believe that IIoT will play a greater role on how we manage our production on the shop floor."

"Additive manufacturing."

"Already adding IIoT capability to existing products. Much more to do. Automation of our factories already started and to increase in the years to come."

"Adding more automation."

"Only slightly playing into our facility."

"Focus is on digitalization."

"Minor."

"All emerging technologies are already installed, with important effects on the product offering and ROI."

"Not Much."

"With low volume manufacturing and repair for base industries, IIoT will not help much without an ISO language for sharing information. We already have robotic welding and find it does not help much in lots smaller than four of a part number. We have done different forms of additive for years and it probably will never be a significant portion of our sales. We use CNC machines for lots of 1 to 10 for most of our production. Further automation does not seem cost effective at this time because of setups. We add several new part numbers per week in lots of one to 10. We are working on building machine tools for low volume part machining."

"Mainly robotics and automation. IIoT in a lower degree."

"Tooling increased outputs are sought after."

"Not sure."

How is your organization addressing the skilled worker shortage?

"Training program. Partnership with schools."

"Reaching out to universities and offering internships."

"Employing skilled workers takes longer, but we are able to hire people that we are looking for."

"In-house training."

"Incentives for applicants."

"Ongoing training of current staff."

"It is a challenge. The new generation of workers do not prefer shop floor jobs."

"We do not have a problem within our organization. However we hear about worker shortages from our suppliers."

"We have a few good people."

"We are buying more than producing."

"In-house training."

"Hiring young, inexperienced people. Looking for a diamond in the rough."

"Internal training."

"Participating heavily and sponsoring many different internships through local high schools and apprenticeships through local community colleges."

"Focus tasks requiring skilled work and allow low-value-added work to be performed by unskilled labor."

"Collaboration with local vocational programs, increased scope of co-op program, second chance employment in certain cases."

"Reaching out to community colleges and four-year universities."

"Suffering."

"We kept our workforce."

"Our company strives to hire new young people and at the same time spends time passing on skills."

"Tapping into industrial training institute."

"Hire in advance."

"Grow talent inside our business."

"Importing workers from other regions."

"Job fairs, tapping into trade schools, hiring more in-house HR support."

"Shower them with amazing benefits as we have done in the past. Best way to keep skilled/good workers is to invest in them."

"More modern machine to counter lack of know-how or intelligence."

"In-house training of new machinists."

"Using recruiters, more classroom training, apprenticeship program."

"Not addressing due to reduction of production."

"We are not affected by the skilled worker shortage."

"Hiring offshore."

"Increased starting pay, going to job fairs."

"Hiring unskilled and training, partnerships."

"By retaining skilled laborers."

"Hope."

"Always shortage."

"Constantly on a recruiting campaign for young technicians and skilled workers."

"Automation."

"We are doing on-the-job in-house training."

"We are fortunate to have a good labor pool."

"Hiring and training in house."

"Working as best as possible to get new employees into the mix. So often, they do not like working in a volatile manufacturing environment."

"We train and educate."

"Automation."

"We have permanent employees and have a very strong training team to bring unskilled workers to skilled level in no time."

"Longer lead times."

"Not Well!"

"Always looking and willing to hire young talent, we work with the local college."

"We are letting the dust settle on this one."

"I have a rotating internship and apprenticeship program I have year round with local high schools with manufacturing programs."

"Training young people."

"Going to have to try in-house training before all the skilled workers are retired."

"Our systems are easy to operate and able to be entirely automated, which allows companies to increase productivity despite labor shortages or lower experience labor."

A Focus on Training and Workforce Development

Workforce development and training continues to make headlines—not just in gear manufacturing but the entire industrial sector.

Gimpert plans to focus even more time and energy on internal training in 2023.

"Maintaining existing strong personnel is key to successfully weathering any future industry disruptions, and I feel training must be part of the solution. Interestingly, online training resources continue to expand, so connecting the dots between these resources and employees who could benefit is the work to be done," he said.

Klingelnberg's main goal is to ensure skills to support customers with local personnel in the different time zones and without experts travelling.

"We have increased our online training and support efforts for customers and our own colleagues," Gorgels said. "We keep a wide network with universities, innovation hubs and local organizations. In combination with our apprenticeship program, we can attract talent even in a challenging environment.

The key in the future will be the increasing need for data collection not only for measuring machines but more and more with our machine tools also. "This goes very much in line with an increasing focus on software development for digitization to support our customers moving forward. This increases the need for data handling and evaluation so the need for new skills in the workforce on the shop floor comes naturally," he added.

Workforce development is a win-win situation, according to Stolz at Gleason.

"It helps Gleason to continue its many years of industry leadership, while at the same time ensuring career development opportunities, productive new skills and, ultimately, a successful career path for all our employees. The challenge is finding people with the right skills and qualification. Our internal qualification programs, including apprenticeships, training on the job, digital and on-site learning and/or leadership development programs, all contribute to a better and more qualified workforce."

The Gleason Gear Trainer concept (started as Home Trainer during the pandemic) is providing high-level education for thousands of participants every year free of charge.

"With Gleason`s unique expertise in 'design-manufacturing-inspection' we have the bandwidth to provide in-depth know-how during seminars, on-site courses or through the highly regarded Gear School. Our employees greatly benefit as well from these programs," Stolz said.

Liebherr has invested heavily in its Training Center in Kempten, Germany, to formally train operators, technicians, as well as mechanical and electrical maintenance personnel, with both in-person and online formats.

"We believe it's necessary to help the introduction of these new skillsets in the gear machining workforce," Wiedemann said. "For that very reason, Liebherr has invested heavily in our Training Center to formally train operators, technicians, as well mechanical and electrical maintenance personnel, with both in-person and online formats."

Field service is an area where Nidec is focusing its development efforts.

"Right now, we have 16 field service engineers so we're well staffed for what we do, but we'd like to get a couple younger people on staff and train them up. We're partnering with some of the local colleges here in Michigan to find new talent but it's still a huge challenge."

—Scott Knoy, Nidec

"Mechatronics is the area of study that is most appealing, however, we're not seeing the interest in our line of work. They typically want to work at GM or Ford. The travel is another issue. Many of these field service engineers are road warriors and they travel more than the sales team, it takes a certain breed to be on the road across North America this much," Knoy said.

Hollingsworth believes there's no short-term solution for the skilled workers crisis.

"States and local municipalities are making more and more investments which is a good start, but these need to grow on a

Skilled Workforce (cont'd)

"We make internal training."

"Continued hiring, cross training and employee development."

"The skilled labor shortage remains in the forefront of our efforts to grow in 2023. First, addressing our current workforce to minimize poaching from a competitor and second, increasing our efforts to train from within. By improving pathways to advance within ourorganization we provide an environment that retains our skilled labor force and attracts talentfrom outside."

"More training internally."

"We can't find any."

"Engage more old people (with high know-how!) to work longer than normal."

"Reinforced benefits for retainment and new employees."

"Not very well. Trying to find trainable workers, which is difficult."

"Additional training of our unskilled workers through the local community college."

"A big problem."

"Apprentice programs for skilled trades have been re-started in the last four years due to the shortage of skilled tradespeople in the area."

"Continually hiring due to turnover. Recruiting for and providing apprentice program for skilled trades with local community college."

Automation."

"Being more flexible on working hours and in-house training."

"Struggle at this time."

"More efforts in job opportunity promotion."

"Training and selecting manpower interested in the gear industry."

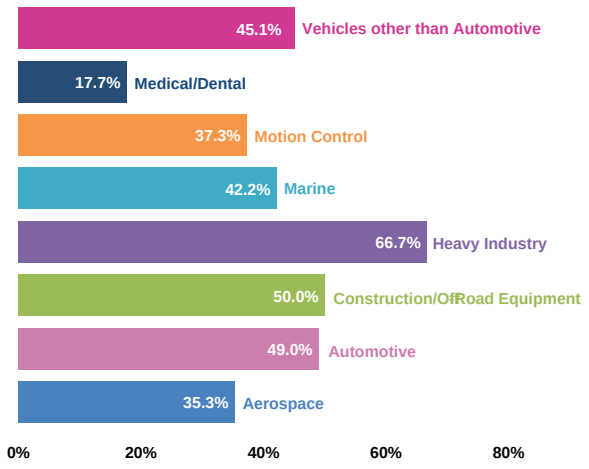
"We are increasing on-the-job training."

"Training internally."

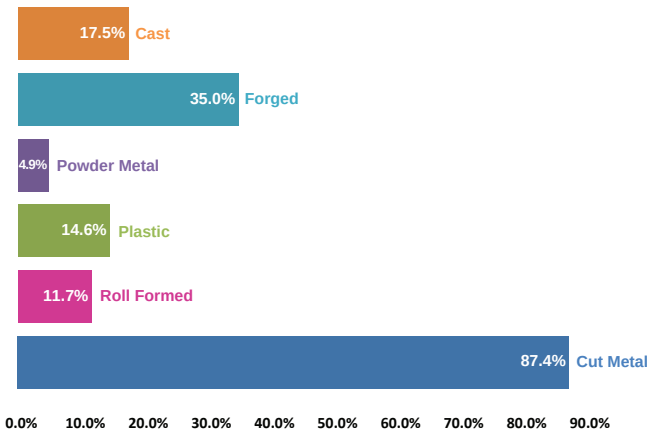
"Haven't seen any changes. Still hoping for better results."

"We're not."

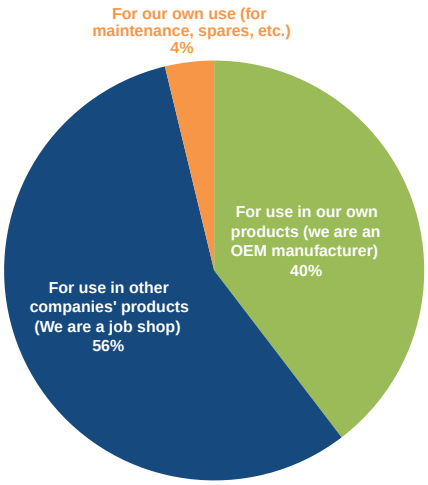
The gears (including sprockets, splines, worms and similar components) made at this facility are used for (check all that apply):



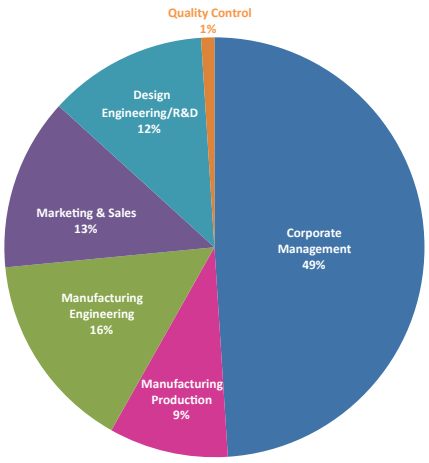
The gears manufactured at this location are (Check all that apply):



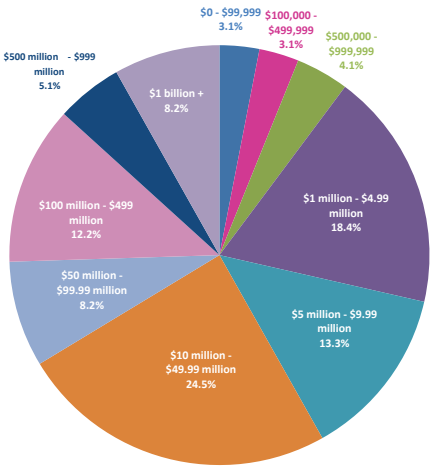
Gears (including splines, sprockets, worms and similar components) are manufactured at this location:



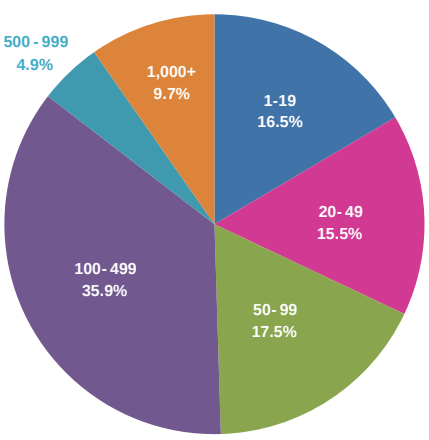
Which category best describes your job title/function?



What is the approximate annual revenue for your company?



How many employees work at your location?



larger scale to address the larger problem. The machines being built today are being tasked more to help alleviate this pressure, time will tell how far this evolves the controller's and software's of the future," Hollingsworth said.

Kapp headquarters offers a nice apprenticeship program and the company has started offering summer internships where future employees are brought to the United States for eight weeks.

How Will Things Change Moving Forward?

The gear industry will clearly have an increased level of automation moving forward, and data-driven Industry 4.0 will have a profound impact on machine tool digitization.

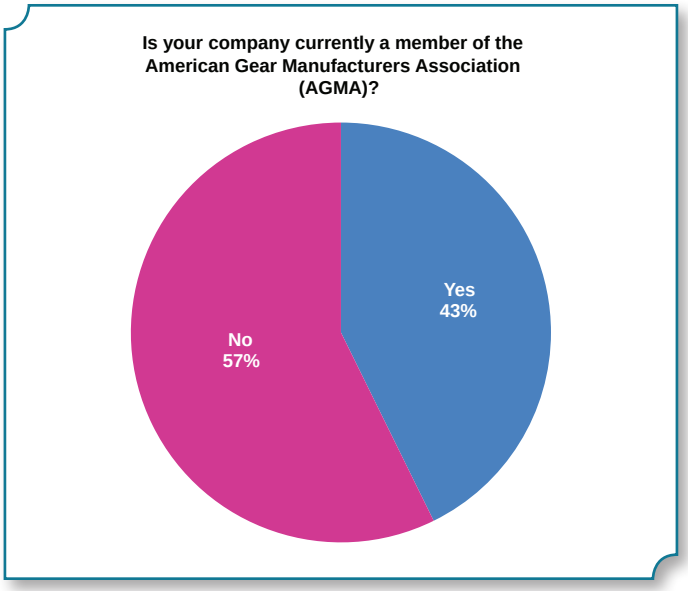
"We will also see a trend toward larger gear cutting demand, owing to a worldwide energy crisis developing since the past 1.5 years (wind, oil, gas)," said Wiedemann.

"Furthermore, the electrification trend will see increased demand in our high-end gear machining solutions like Hobbing with ChamferCut and DFT Gear Grinding. We see this automotive segment continuing to increase the demand for sophisticated solutions... Not just tooling, clamping, and automation, but also the software, mathematics, and know-how for the topological modifications required for noise reduction in gearboxes," Yoders said.

Quality requirements and cost per piece are still going to drive future gear design and manufacturing strategies, according to Stolz, adding that the tailored solution which fits best to achieve the task will succeed.

"Due to the electrification strategies in automotive, the overall number of gears will be lower, but more sophisticated and complex. Since manufacturing solutions alone will not be able to guarantee success, integrated design, manufacturing, and inspection solutions in a Closed Loop system will be important keys for future success."

—Udo Stolz,
Gleason Corporation



"As the design parameters and the cost per piece for specific manufacturing processes are already set during the design phase, it will be mandatory to provide gear and transmission designers with some substantial manufacturing know-how," Stolz said.

"With the increasing need for electric vehicles, gear noise becomes a big focus. This increases not only the quality requirements for gears but also the need to understand gear noise as a new quality criterion. We will see an increasing number of roll testing systems in the industry within the next years," Gorgels said.

The smart factory floor, according to all the participants interviewed, is coming and will offer wholesale changes in terms of technology and utilization.

"Smart manufacturing will continue to trickle into the industry while automation remains a leading solution, albeit with more "intelligence" (IIoT) than in the past," said Gimpert. "20th century manufacturers will slowly die away, and 21st century manufacturers (clean, digital, human-centric) will lead new business, acquisitions, and hiring."

Editor's note: Read more in-depth analysis on the State-of-the-Gear-Industry at ***geartechnology.com***

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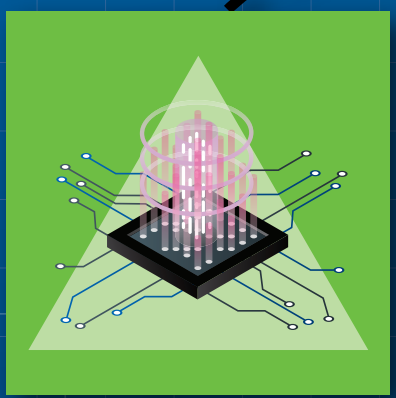

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Polished Up!

Tool systems for grinding and honing today's most challenging gears

Dr.-Ing. Nicolas Bleil, Gleason-Hurth Tooling GmbH

The trend towards hard fine finishing of gears for automotive transmissions is accelerating. In recent years, the focus has been on increasing the efficiency of gears in order to make optimum use of the narrow gear ratio range, gear by gear, and to reduce fuel consumption. Surface finish, in particular, is under increased scrutiny since it plays such a decisive role in achieving the noise and efficiency requirements of gear units for today's EV applications.

These higher gear quality standards are driving significant innovation in the grinding and honing manufacturing processes required to achieve them. Fine finishing and, in particular, polishing machining, offer a tailor-made approach to meet these objectives. Inherent in these processes is the fact that two machining steps (roughing and fine finishing) are performed sequentially, in a single setup. Alternatively, different processes can be combined to achieve the same end result, such as grinding with gear honing. The disadvantage of this approach, however, is that the workpiece must be loaded into a machine tool twice. What all these processes have in common is that they offer a wide range of tool specifications, including variations in grit size and bond type, to achieve the desired result in the finished workpiece.

For fine finishing in one clamping, two zones of combination tools are used in generating grinding, both of which are ceramic-bonded, but with different grit types and, above all, grit sizes. Zone 1 is identical to a conventional, standard generating grinding worm, which performs the main cutting action during roughing. Finishing is performed exclusively in zone 2 with a finer grit size in order to achieve the required surface roughness and material contact ratio.

The procedure for gear honing is analogous, whereby a Gleason honing machine can accommodate two honing tools in the same, single honing head in a process called Combi Honing. It should be noted that zone 2 (i.e., honing wheel number 2) can also be produced using a resin bond.

Two-zone wheel for polish grinding—zone 1 right (ceramic zone), zone 2 left (polish zone).

Polishing is also carried out with a combination tool, although the polishing effect can only be achieved with a more elastic type of bond (polyurethane) and even finer grit.

Development of this highly productive new generation of combination tools has also required that the bar be raised on the tools used to dress them. Whereas in gear honing the diamond-coated dressing tools are typically designed for a specific workpiece, generating grinding addresses a wider variety of applications. For prototypes, a universal shape dresser (GDU) can be used, which operates in point contact and thus maps any type of profile modification via machine kinematics. For smaller batch sizes, flexible tools (GDF) with a specific pressure angle and module range are used, which dress the grinding tool with a single flank. Workpiece-specific dressing systems (GDW) have an integrated tip dresser with a defined radius to avoid a step in the tooth root area or even to grind the full root radius.

All of the above dressing systems can also be used to perform Gleason's twist-controlled grinding process without any further modifications.

Gleason Combi Honing with two honing tools in one set-up, seen here as a polishing application.

Dressing tools for gear honing and gear grinding. From left to right: Diamond dressing gear for gear honing; workpiece-specific dressing disc system (GDW); and flexible dressing roll system (GDF) for generating grinding.

As one might expect, the performance requirements for dressing tools are significant, necessitating the use of a complete array of grain types and sizes and different bond systems, for applications ranging from an electroplated diamond dressing gear in gear honing to a dressing disc in generating grinding.

At the same time, today's dressing tools must also consider the greatly increased demands on surface finish, but without sacrificing the best possible performance inherent in standard machining processes. This is an enormous challenge for the diamonds used by the diamond dressing tool, one of the essential system variables in the dressing processes.

To reliably maintain a maximum form error of < 2 μm, manufacturers of dressing tools have to consider many factors. Shape and position tolerances of the basic body must be maintained with extreme precision. The smallest deviations in the axial runout of the tool can cause the µm limit to be exceeded when checking the gear quality. Analyses of noise, vibrations (NVH test), and the surface structure help to check the requirements in all areas with great precision. A homogeneous grain distribution and a clean coating must be ensured before the grinding/finishing of the electroplated coating can take place. In this process two tasks have to be performed equally well: grinding the exact shape of the rotational dressing disc shape as well as the correct treatment of the diamond grits to ensure their shape retention over repeated use and thus the longest possible service life.

Additionally, the dressing of different grain materials and sizes as well as different bonding systems are critically important. Ideally, these tasks should be performed using the same tool. In generating grinding, two-zone grinding wheels with Gleason dressing discs can be used without compromise. No adjustment of dressing parameters or speeds is required. Gleason dressing discs are designed to provide the required cutting capability for roughing as well as to fully meet the requirements for finishing or polishing.

In gear honing, the approach is congruent; only the degrees of freedom are greater since there are two separate honing tools without a connection. In this case, if necessary, a special diamond dressing gear per honing ring can also be executed to utilize the full potential in fine and polishing machining. In addition, for gear honing it is of course also possible to design a dressing tool (diamond dressing gear) for both honing tools, e.g., for Combi Honing.

Through the use of this new generation of dressing tools, the latest grinding wheels and honing tools are well-positioned to meet the increased demands placed on them. The "splitting of micrometers" is a great challenge, one that meshes well with our area of expertise and passion for the work we do.

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Two examples of polished ground gears: Left: polished disc-type gear Right: polished shaft from an e-drive application

Can Gear Skiving Be the Game-Changer I Need for My Business?

Kenneth Sundberg, esco

Why Gear Skiving?

Why is the industry considering changing from well-established gear manufacturing processes to something that is much more complex at first glance?

Gear manufacturing has been its own "world" in metal cutting, dominated by companies with very specific expertise around gear technology. Production output has been high, but flexibility is limited. The technicians running these machines are highly skilled, but recruiting new staff with these skill sets has become more and more difficult.

Over time, the production philosophy has changed, and the industry is looking at manufacturing systems that are more flexible to better manage just-in-time demand. Very large batch sizes are—for most manufacturers—no longer the case.

Modern multitask machines have gained a high market share in metal cutting in the last 30 years. The concept of machining as many operations as possible in one set-up has many benefits.

The quality and lead-time reduction that can be reached by complete machining is a very attractive option. This is also the case for manufacturing components with gear and spline features.

As multitask machine tools were developed to be suitable for gear skiving, the concept of flexibility could be combined with high productivity. This triggered a fundamental change in the gear manufacturing industry. The implementation of mill-turn centers started about 15 years ago and has been going on ever since. Initially, some skepticism was expressed, but quite soon the doubts were eliminated, and the concept of multitask machining has since then had a very positive development. This technology shift has had a strong impact on how gears are produced today—and how gears will be produced in the future.

Motivating Factors for ChangingTechnology

The big question for the gear industry is now how to validate gear skiving versus the well-established machining methods which have been used for decades. The tremendous growth in e-mobility has increased the need to validate and decide on future manufacturing technologies, accurately and rapidly. The machining equipment used in the past is probably not generating the desired results needed for high-precision gear components used in e-mobility transmission systems. How can I, with reasonable precision, determine whether I will benefit from implementing gear skiving for my business?

A change to skiving means in most cases that investments in new machine tools are needed, which represent a significant cost. The production or technology manager needs to have a good business case with trustworthy arguments to justify the investment.

Looking at the Options When Considering Implementing Skiving

- Convert internal broaching of splines, and change to multitask machining.
- Convert shaping for internal and external machining of splines and gears.
- Change from single-purpose hobbing and shaping machines to multitask machines.
  - Partly replace hobbing with skiving.

The conversion to skiving should preferably be taken stepwise to generate and spread know-how in the organization over time. Most companies that have implemented skiving see no point of return and most of them are striving to expand the technology once the first processes have been established.

Implementation of skiving is giving users a competitive edge, which can result in gains in lowered component costs that are outstanding. Correctly implemented, also excellent quality and surface conditions can be reached. Skiving does not mean any compromise versus the traditional technologies; many applications show rather the opposite.

The Need for Qualified Software Tools to Support Decision-Making

There is a need to identify the possibility to implement skiving from a technical and commercial perspective. Software that can give answers to the fundamental questions in the decision-making process for, or against, skiving is crucial.

1. Can I use gear skiving for a certain process?
2. Which conditions should I apply for reaching the best result?
3. What is the level of productivity that I can reach?
4. What is the total commercial impact of changing the process?
5. How can I define and specify what I need for my cutting tool supplier?

The new esco software module, *eSkiving.FS* is developed to guide the industry toward correct decision-making based on facts, exact simulation, and visualization.

esco-aachen.de/en/

Validation and Estimation of Commercial Impact

» **New Projects**

Detailed analysis of technical and commercial aspects already in the gear design and manufacturing planning phase

- Secure design suitable for machining and define ideal machining conditions

» **Existing portfolio**

Review component portfolio suitable for skiving

- Determine impact of changing technology and future capacity requirements

» **Improve the knowledge of specifying high-performing cutting tools and thereby:**

- Reduce time-to-market
- Reduce risk for error.

The esco Gear Skiving Platform, ePP

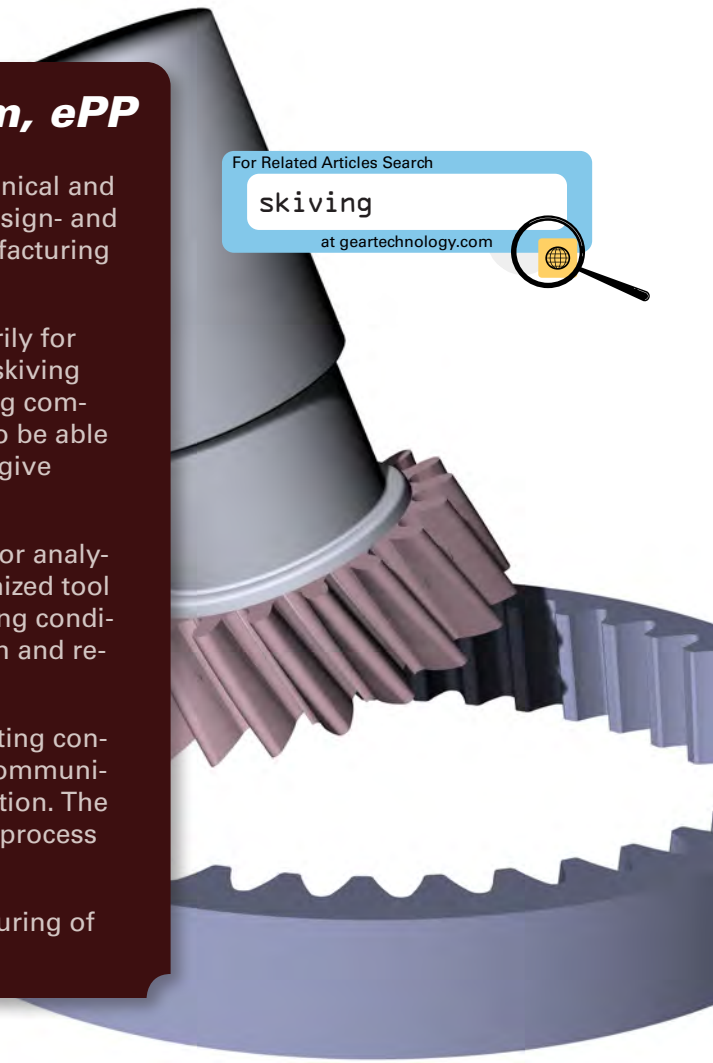
eSkiving.FS Comprehensive evaluation of technical and commercial feasibility studies. Intended for gear design- and manufacturing companies within design and manufacturing engineering / manufacturing planning.

eSkiving.TD Advanced design software, primarily for the cutting tool industry. Tool design based on the skiving kinematics. (Can be an alternative for manufacturing companies aiming at having very high skills and want to be able to develop own design / manufacture own tools or give detailed information to their cutting tool supplier)

eSkiving.TA Important add-on to eSkiving.TD for analysis of technologically relevant parameters for optimized tool design and definition of optimum geometrical cutting conditions as well as giving output for usable tooth width and re-grinding setting data.

eSkiving.AS Software to support optimized cutting conditions based on input from TD. Enable seamless communication between cutting tool design and tool application. The software is intended for application specialists and process technology engineers.

eSkiving.TM Software configured for manufacturing of skiving cutters.



Remaining Competitive

Don't Let Technology Pass You By

Joe Arvin

In manufacturing, there are many aspects of a company that contribute to success. However, there is one characteristic that rises to the very top of the prioritized list. This is the ability to be competitive.

While the importance of being competitive is as old as commercial transactions, the dynamic of remaining competitive in the manufacturing industry has experienced profound changes in the past decades. Fifty years ago, most manufacturers could get by with investing in new capital equipment every twenty years or so. Later, approximately twenty-five years ago, new equipment was required every twelve years. Today, the necessity of purchasing new equipment for remaining competitive is closer to every three to five years.

Advances in technology have washed over the landscape of manufacturing in past years like a tsunami. The ability to produce products faster and with higher levels of quality is the direct result. And if you can produce more accurate and less costly parts than the other guy, you win the competition game.

Now you might be thinking, "What are you telling me, Joe? Are you saying that I have to replace all my equipment every three years or go out of business?" The short answer is both yes and no. Let me explain.

In reality, most companies are in the same boat when it comes to adding the latest technology. It can be an overwhelming expense, so your competitors probably won't be refitting their entire operation every few years, either. So, in this regard, you have some time to implement new equipment. However, it is essential to keep your eye on the ball. You need a carefully crafted and cost-justifiable plan on replacing equipment. In other words, you need to add new equipment and technology that will have the best bang for your buck in terms of improvements in quality, cycle times, opportunities for automation, and ultimately, your bottom line.

Don't start sweating just yet, as there are other considerations to take into account as you evaluate new technology. For example, you may not have to keep up with the latest tech if you have a product line that has minimal competition. In this case, new acquisitions can be made when it is most comfortable in order to improve when there is the opportunity to increase profitability or when something is simply worn out.

Still, the ongoing need for reinvestment to remain competitive in the future cannot be ignored for long. Here are a couple of stories highlighting why CapEx is so important to staying competitive.

After World War II, the U.S. auto and machine tool Industries were kings of the world. But as we all know, that did not last forever. With the early post-war reconstruction assistance from the U.S., there were billions of dollars

channeled to rebuilding the industrial bases in war-torn Japan and Germany. At first, the industrial capacities of these countries were no match for the might of American manufacturing. In fact, for many years, products from Japan were laughed at. But within a couple of decades, these industrial bases began to mature as heavy investment in new capital equipment took place, in many cases facilitated by their governments. In addition, innovative concepts such as continuous improvement, Quality Circles, and Just-In-Time (JIT) were being adapted, particularly by Japan. Speaking of JIT, I have some interesting stories behind JIT, but I'll save that for another time.

Nevertheless, by the late 1970s Japan was emerging as a strong competitor and I had begun feeling the pinch from my vantage point at Arrow Gear Company. Wishing to get a first-hand look at this transformation, I set up a two-week tour of the Japanese auto and machine tool industries in 1980. Joining me were twenty-four executives who were my fellow members of the American Gear Manufacturers Association. All of us were very curious about what we would find.

To our surprise, the auto assembly plants were completely automated, using hundreds of robots with only a few people in view. The finely choreographed union of subassemblies being dropped into place looked nothing like the plants we had back in Detroit.

What we witnessed from the Japanese machine tool industry was a very similar scenario. We saw new and modern facilities fully equipped with the latest technology. Thinking about our plant back at Arrow Gear, we only had a few CNC machines. Obviously, this gave me a very uneasy feeling—not just for my company, but for all of the others in the United States that would need to compete with this streamlined and well-equipped industrial base in Japan.

Not long after my return to the states, Jack, an executive from Warner & Swasey (W&S), had heard of my tour and asked if I would meet with him at their headquarters in Cleveland.

I'm sure all of us in the power transmission industry have heard of W&S. The fact is they were one of the world's largest machine tool builders in the post-war era.

My visit with Jack at W&S began with a tour. What I witnessed was quite disturbing. There were only a few CNC machines and NC SC Chuckers, but there was an overwhelming amount of manual machine tools, even a line of lathes powered by an overhead belt drive. This was very depressing due to what I saw in Japan.

After our tour, Jack and I went back to his office. As I sat down, he asked, "So what do you think of our operation?"

Without hesitating, I said, "I'm afraid that you're going out of business." I continued by pointing out that they were making CNC machine tools with mostly manual machines. In contrast, their Japanese competitors were making their machines with all CNC machines. Needless to say, the Japanese productivity and quality would be extremely difficult to compete with head-to-head, not to mention their lower labor costs.

My comments and candor obviously ruffled Jack. In response he said, "Well, Joe, maybe you can tell me where in the world I'm going to get the $100 million plus, to replace all our manual machines?"

"Unfortunately," I replied, "I'm afraid that is an answer that I don't have."

That meeting took place in 1981. By 1988, W&S had closed their main factory doors.

There are many reasons why some companies fail, but it is clear to me that the root cause of their decline involved the inability to adapt to the changes in technology. This is a story I have never forgotten about the direct connection between reinvestment of the latest technology and the ability to compete.

So, right now you might be thinking, "Joe, how do I reinvest without overleveraging?" That's the million dollar question. Let me share some ideas on ways to save considerable money while purchasing new equipment.

Obviously, there are several machine tool OEMs with similar quality, cycle times, and competitive pricing. However, actual list prices can vary. Here are some points to keep in mind that I have found to be helpful. Also, thank you to Ron Kauzlarich, Arrow Gear Director of Facilities (retired) for his contributions to this list.

ROI Calculations

This is a critical first step in the process of acquiring new equipment. Perform the due diligence up front to justify the purchase. This is not the time for relying on gut feelings.

Your calculations should include the total cost of the purchase, offset by all the anticipated savings in the future, such as reduced setup times, reduced cycle times, less scrap and rework, more up-time, and less maintenance. You will also need to know all installation requirements, such as voltage, pneumatic air, network connections, and foundation requirements, taking these expenses into account.

Negotiation

I've heard it said that everything is negotiable. This is also true with machine tools, which are quite expensive. Negotiations can include pretending to walk away to look at other brands, even if this is the machine you really want. You can also try having them include options at no cost, such as a longer warranty, additional training and support, and free shipping.

Excess Inventory

In some cases, OEMs may have excess inventory just sitting in a warehouse. These machines can typically be had at a reduced price.

Demo Units

It is common for OEMs to have demo units that are no longer needed for demonstration purposes. This is a great opportunity for savings.

Year-End Inventory Sale

The end of the year is a good time to look for discounts from the OEMs, as they may be feeling pressure to hit their quotas for the year, especially when a new model will soon be introduced.

Machines from Trade Shows

When OEMs bring a machine to a trade show, they are motivated to avoid the costs of sending the equipment back to a warehouse. Their desire to avoid the cost of rigging and shipping the machine back to storage can translate into savings. Consider negotiating prior to the show. If an advance sale can be arranged, you can get some free advertising with your name displayed on the machine as the purchaser.

The Retrofit Option

When looking at new equipment, don't forget that the real goal is improved productivity and quality. Sometimes this can be accommodated by retrofitting existing equipment, costing only a small percentage of a new machine's price tag.

Here are some other considerations to keep in mind.

Sample Parts

When purchasing any new equipment, consider it mandatory to have some of your sample parts run in their machine to verify cycle times and quality before signing a firm purchase order.

Verified Performance

Sometimes the rosy projections of a salesperson may not be based in your version of reality. If their representative makes a relevant verbal claim, make sure it is on the purchase order, which avoids the "but you told me," scenario.

Payments

Hold back some money until the machine is on your shop floor and running as expected and being productive. You might consider spelling out in the purchase order that once the machine is on-site, if it does not meet specific requirements, the machine will be returned with full return rights—specifying FOB Destination.

Training

Be sure that sufficient training by the OEM is included in the deal and specified in writing on the purchase order. Remember that a trained operator is an essential part of the machine being productive. Here is another important training consideration: As new capabilities are introduced to your organization, it's a good idea to be sure that more than one person is trained on the equipment. If it is only one and they become out of the picture, you can avoid some real problems, let alone finding yourself having to deal with a prima-donna situation.

Support

If the machine involves a significant new technology, be sure you have the engineering, programming and maintenance resources to make the most of the equipment.

Team Approach

Supervisors and shop floor operators should be involved in the selection process as appropriate. Being involved and having their opinions noted goes far to promote a positive team atmosphere. At the very least, keep them informed of the new addition, emphasizing the importance of the new capabilities as it pertains to being competitive and staying in business. If this results in some operators being moved, the advance notice will make

the transition a little easier for them to adapt.

Here is an example of this concept: Five years ago, there was a company who purchased their first five-axis machining center, which was capable of replacing four different operations. While on-site, the trainer instructed the operator on how to set up and run all four operations in the same machine. One month later, they were only machining two of the operations. The trainer came back and within a few hours all operations were running. Two weeks later, it was back to running only two operations. Can you guess what was wrong? Neither the department supervisor nor the operator(s) were involved or informed of the machine purchase and why it had been added. In addition, this contributed to concerns that someone might get laid off.

The Importance of a Project Leader for Changes

With any new addition or change, it is essential that there is a project leader. Someone must be responsible for keeping the new capability on track and ensuring the equipment functions as anticipated. New technology will often require an operator or others in the organization to work beyond their comfort zone. It should be the role of the project leader to be sure optimal results are achieved and maintained. If not, the barrier, be it specific machine problem, operator training, or tooling, must be identified and addressed immediately.

Conclusion

As long as you are in pursuit of customers and other organizations offer the same product or service, you will need to keep being competitive at the forefront of your focus. And in view of this era of rapidly advancing technology, having the latest equipment will factor into the formula for success. Since the financial resources for getting everything on your wish list will likely not be available, careful planning and innovation will be essential.

In the end, remember that becoming comfortable with the status quo is very risky because when it comes to manufacturing technology, dormancy is death.

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Joe Arvin is a veteran of the gear manufacturing industry. After 40 years at Arrow Gear Company, Joe Arvin is now president of Arvin Global Solutions (AGS). AGS offers a full range of consulting services to the manufacturing industry. His website is *ArvinGlobalSolutions.com* and he can be reached by email at *ArvinGlobal@Gmail.com*.

A Final Word

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

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- **It doesn't matter how efficient your plant is! What matters is the accuracy of your quote?**
  Mar/April 2017—Page 54
- **Can Lean Manufacturing Kill Your Job Shop? A Tale of Two Companies**
  May 2017—Page 42
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2022 AGMA Technical Committee Activity

Phillip Olson, Director, AGMA Technical Services

Thanks to our many hardworking volunteer committee members, 2022 was a productive year for the AGMA Technical Division with the publication of two new and three revised information sheets. The AGMA Metallurgy & Materials committee finally published their long awaited revision of AGMA 923-C22, Metallurgical Specifications for Steel and Cast Iron Gearing, which defines metallurgical acceptance criteria for three quality grades used in multiple other AGMA standards. AGMA 925-B22, Effect of Tribology and Lubrication on Gear Surface Distress, published by the AGMA Helical Gear Rating committee, took seven years to publish and has more than double the content from the previous edition. The AGMA Bevel Gearing committee followed with their revised AGMA 929-C22, Calculation of Bevel Gear Top Land and Guidance on Cutter Edge Radius, which has expanded calculations to anywhere along the face width instead of just the toe, mean, and heel. The AGMA Gear Accuracy committee finally closed the book on their long awaited the new document, AGMA 943-A22, Tolerances for Spur and Helical Racks, which fills a gap in the AGMA catalog, being the first document to cover spur and helical rack tolerancing since the withdrawal of AGMA 390.03a in 1999. And last, but certainly not least, AGMA 955-A22, Guidance for Industrial Gear Lubrication, published by AGMA Lubrication committee, was created as the first step of separating ANSI/AGMA 9005-F16 into two documents addressing "lubricants" and "lubrication."

Looking ahead to 2023, many AGMA technical committees plan to meet face to face for the first time since 2019, and they will continue work on ten projects.

The current list of active AGMA projects is:

- AGMA 919-2, Condition Monitoring and Diagnostics of Gear Units and Open Gears: Part 2—Applications and Advanced Analysis
- AGMA 926, Recommended Practice for Carburized Aerospace Gearing
- AGMA 947, Gear Reducers—Thermal Capacity Based on ISO/TR 14179-1
- ANSI/AGMA 1012, Gear Nomenclature, Definitions of Terms with Symbols
- ANSI/AGMA 2101, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth
- ANSI/AGMA 2116, Evaluation of Double Flank Testers for Radial Composite Measurement of Gears
- ANSI/AGMA 6008, Specifications for Powder Metallurgy Gears
- ANSI/AGMA 6011, Specification for High-Speed Helical Gear Units
- ANSI/AGMA 9000, Flexible Couplings—Potential Unbalance and Mass Elastic Properties (and its metric version ANSI/AGMA 9110)

AGMA technical committees are also the vehicle through which U.S. companies can be involved in international ISO gear standards.

ISO published five new documents in 2022:

- ISO 10825-1:2022, Gears—Wear and damage to gear teeth—Part 1: Nomenclature and characteristics
- ISO/TR 10825-2:2022, Gears—Wear and damage to gear teeth—Part 2: Supplementary information
- ISO/TS 6336-20:2022, Calculation of load capacity of spur and helical gears—Part 20: Calculation of scuffing load capacity—Flash temperature method
- ISO/TS 6336-21:2022, Calculation of load capacity of spur and helical gears—Part 21: Calculation of scuffing load capacity—Integral temperature method
- ISO/TR 6336-30:2022, Calculation of load capacity of spur and helical gears—Part 30: Calculation examples for the application of ISO 6336 parts 1,2,3,5

ISO working groups also recently began meeting face to face again, which should speed up their document development.

In 2023 ISO working groups will continue work on the following twelve documents:

- ISO/DTR 10064-2, Code of inspection practice—Part 2: Double Flank Radial Composite Measurements
- ISO/DIS 10300-1, Calculation of load capacity of bevel gears—Part 1: Introduction and general influence factors
- ISO/DIS 10300-2, Calculation of load capacity of bevel gears—Part 2: Calculation of surface durability (pitting)
- ISO/DIS 10300-3, Calculation of load capacity of bevel gears—Part 3: Calculation of tooth root strength
- ISO/AWI TR 10300-30, Calculation of load capacity of bevel gears—Part 30: ISO rating system for bevel and hypoid gears—Sample calculations
- ISO/DIS 10828, Worm gears—Worm profiles and gear mesh geometry
- ISO/NP 14635-2, Gears—FZG test procedures—Part 2: FZG step load test A10/16, 6R/120 for relative scuffing load-carrying capacity of high EP oils
- ISO/NP 18792, Lubrication of industrial gear drives
- ISO/DIS 21771-1, Gears—Cylindrical involute gears and gear pairs—Part 1: Concepts and geometry
- ISO/CD 21771-2, Cylindrical involute gears and gear pairs—Part 2—Part 2: Calculation and Measurement of Tooth Thickness and Backlash
- ISO/AWI 23509-1, Bevel and hypoid gear geometry—Part 1: Basics principles
- IEC/AWI 61400-4, Wind turbines—Part 4: Design requirements for wind turbine gearboxes

The expert knowledge, meticulous attention to detail, and consensus-building skills of our volunteer members who work hard to develop the standards often go unnoticed in the background. The benefits of their work, however, are front and center to the gear industry and gear users every day. For all the valuable contributions of our committee members to help, the gear industry, and gear users everywhere, we thank you!

Mechanical Power Loss of Spur Gears Subject to Various Surface Finish Pairings

Isaac Hong, Emily Aneshansley, David Talbot

Introduction

Mechanical power loss in gears is generated through sliding and rolling of the contact resulting in frictional work and elastic hysteresis generation of heat. This action is both a parasitic loss of energy from the drivetrain and a source of engineering costs to control system temperature to avoid heat-related failures of the gearbox components. Therefore, from both a cost and durability standpoint it is of great interest to minimize the frictional losses at the gear tooth contact interface.

Lubricated gear contacts typically operate in a mixed Elastohydrodynamic (EHL) regime defined by loaded solid-to-solid contact between the asperities as well as contact where the load is supported by a fluid film. Presenting different surface finishes to the contact directly influences the amount of asperity interaction. Gear designers and manufacturers must carefully balance costs associated with surface finish processes while achieving target goals for transmission design. This study utilizes a closed-form model combining a gear load distribution model, a statistical microcontact model, and a lubrication rheological model to predict friction in mixed lubrication contact conditions well as gear mechanical power loss. Profilometer roughness measurements from a wide variety of manufacturing processes are collected and input into the model to predict friction coefficient and mechanical power loss under a wide variety of surface finish pairings for several operating conditions consistent with automotive applications.

Model to Predict Gear Mechanical Power Loss

The model used to predict average gear mechanical power loss was developed by Ref. 1. This model predicts the gear load conditions using the gear load distribution model Windows LDP (Ref. 2). Film thickness in the contact is estimated using the formulation of Dowson and Toyoda (Ref. 3). This film thickness is used as a separation parameter in the microcontact model of Greenwood and Williamson (Ref. 4) known as the GW model. This model predicts the asperity contact area between two rough surfaces given a known average separation. Roughness is parameterized by a constant asperity density and tip radius as well as a stochastic distribution on Roughness heights. This parameterization is estimated from measured 2D roughness profiles using the methods of McCool (Ref. 5). McCool also provides a transformation between the profile mean plane separation which correlates to film thickness and the summit mean plane needed for the GW model. With the asperity area contact ratio defined by the GW model, the friction coefficient is estimated by the method of Tallian (Ref. 6) such that

$$\mu = \mu_E P_E + \mu_B P_B \tag{1}$$

where

μ is the effective friction coefficient of the contact
μ_B is the boundary friction coefficient
μ_E is the EHL (Couette) friction coefficient
P_B is the boundary friction area of contact
P_E is the EHL friction area of contact

Boundary friction coefficient is taken from empirical measurement (Ref. 7) and set at μ_B=0.1. The EHL friction coefficient is assumed to be dominated by the sliding loss component (Couette) flow and rolling loss and elastic hysteresis is assumed to be negligible. EHL friction coefficient is then defined as:

$$\mu_{E=}\frac{1}{P_c}\left(\frac{\eta^* V_S}{h_{min}}\right) \tag{2}$$

where

P_c is the Hertzian contact pressure
η^* is the Ree-Eyring effective viscosity
V_s is the sliding velocity
h_{min} is the Dowson & Toyoda minimum film thickness

With the effective friction coefficient defined the power loss can then be described at the work due to sliding across the two surfaces. For a gear, the sliding velocities vary linearly with the contact roll angle. Average sliding velocity can therefore be defined as

$$\hat{V_s} = \frac{V_s(\phi_{p,o}) + V_s(\phi_{g,o})}{4} \tag{3}$$

where

$\phi_{(p,o)}$ is the roll angle at the end of active profile of the pinion
$\phi_{(g,o)}$ is the roll angle at the end of active profile of the gear

The average work done due to friction in the gear mesh can then be described as the average work done in one mesh cycle of the gear.

$$P_L = \hat{\mu}\hat{V}_s F_m \quad (4)$$

where

$\hat{\mu}$ is the average friction coefficient
$\hat{V}_s$ is the average sliding velocity
F_m is the mesh force

Validation of the model was done using measured gear mechanical power loss data taken from various surface roughness pinion-gear pairings including equivalent surface pairings (surfaces machined the same) and dissimilar surface pairings (surfaces finished differently). Predictions matched the measured mechanical power loss closely for all pairings and conditions. Figure 1 shows the results of this comparison as adapted from (Ref. 1).

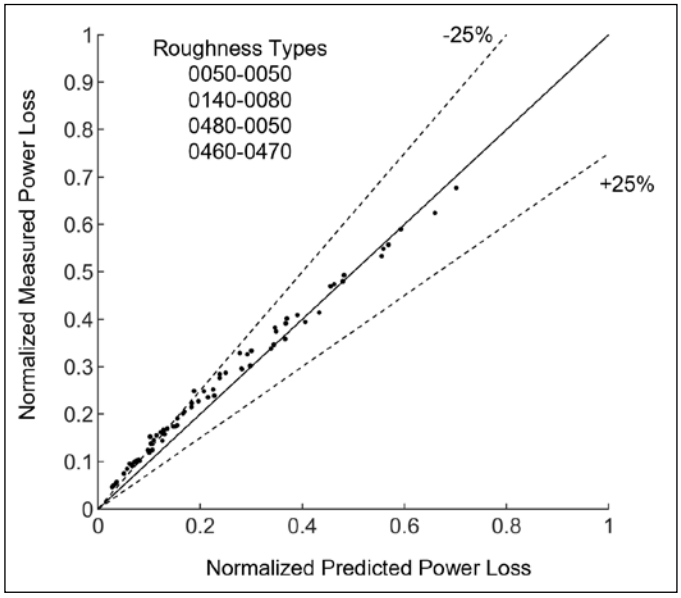

Figure 1—Model predicted power loss as compared to measured mechanical power loss. Adapted from Ref. 1.

Simulation Matrix and Roughness Profile Analysis

The gear mechanical power loss model is used to help understand how average gear mechanical power loss is affected by both pairings of like surfaces (ex: ground pinion and gear flanks from the same grinder) but also pairs of unlike roughnesses (e.g., ground pinion mated with a polished gear). Gears finished from various processes were measured off a Talysurf I-20 profilometer to extract the 2D roughness profile. Measurements and filters were made to conform to ISO 4288:1996 (Ref. 8). Six different traces covering a span of Ra=0.036 µm to Ra=0.450 µm. These profiles are listed in Table 1.

Trace Name	Ra	Rq	Rz
0036	0.036	0.046	0.275
0122	0.122	0.151	0.510
0219	0.219	0.274	1.400
0258	0.258	0.321	1.643
0302	0.302	0.374	1.777
0450	0.450	0.579	3.4

Table 1—Gear profile roughness trace list.

Figure 2 shows a visual comparison of the magnified roughness profiles. The scale is consistent between all measurements. A 1.5 mm segment has been extracted from the full measurement for display purposes. Full measurements were used in all calculations.

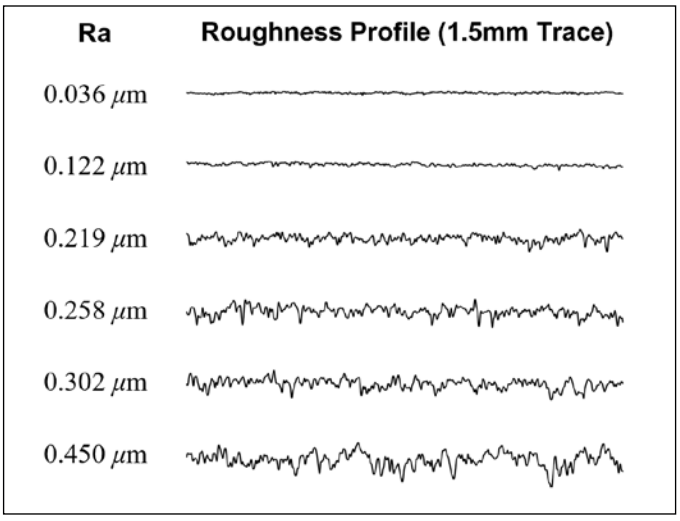

Figure 2—Magnified roughness profiles.

It is important to note that McCool's parameterization of the measured roughness amplitudes assumes the roughness amplitudes are Gaussian in nature and that the asperity tip radii are equal for all asperities and density is constant. This at minimum precludes the model from comprehending the effects of local surface defects on gear mechanical power loss such as from scratches or from irregular machining patterns. The surfaces used for validation of the model all had roughness amplitudes that conformed reasonably well to a Gaussian distribution with some exceptions at the extreme valleys and peaks of the material. Goodness-of-fit can be checked visually by plotting the surface heights on a Normal Probability Plot. If the data conforms to the normal distribution, then it shall follow a straight line. Deviations from the normal distribution are shown as deviations from a straight line. Normal Probability Plots are shown in Figure 3 for each of the six roughness profiles.

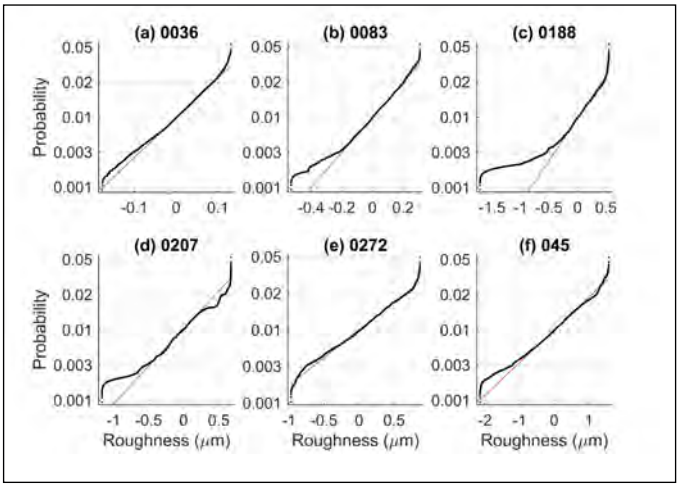

Figure 3—Normal probability plots for the roughness profiles.

The bulk of the material for all traces conforms closely to a Gaussian distribution. For all profiles, material at the extreme valleys and peaks exhibits several outliers consistent with roughness profiles used in the model validation of Ref. 1. The roughness profiles do not exhibit any significant deviation from the normal distribution in between the extreme peaks and valleys which would indicate surface defects or non-repetitive surface asperity characteristics.

A full factorial of simulations is performed using the previously described mechanical power loss model and the six shown surfaces. This results in 21 unique parings of surfaces and simulations according to Table 2.

Trace Name	0036	0122	0219	0258	0302	0450
0036	x	x	x	x	x	x
0122		x	x	x	x	x
0219			x	x	x	x
0258				x	x	x
0302					x	x
0450						x

Table 2—Surface pairing for simulation runs.

Simulations were done using gear specifications according to Table 3.

Gear Parameters	
# of Teeth	17–26
Module	4.23
Pressure Angle	22.5
Face Width	14–20
Pitch Diameter	71.97–110.07
Base Diameter	66.49–101.69

Table 3—Gear parameters used for power loss simulations.

Simulated operating conditions are typical of automotive applications. Oil viscosity parameters belong to a typical automotive transmission fluid. For each of the 21 surface paring combinations, a full factorial of three torques (50, 100 and 150 Nm) and six speeds (500, 1000, 1500, 2000, 2500 and 3000 rpm) as shown in Table 4 were used for a total of 18 predictions per surface pairing combination. In total, 378 different conditions were simulated as part of this study. The computing time required to run these simulations was less than 1 minute.

Torque (Nm)	Rotational Speed (rpm)					
	500	1000	1500	2000	2500	3000
50	x	x	x	x	x	x
100	x	x	x	x	x	x
150	x	x	x	x	x	x

Table 4—Simulation operating conditions.

Effect of Various Surface Roughness Parings

The results of the modeling are shown for equivalent surface pairings (0036-0036, 0122-0122, 0219-0219, 0258-0258, 0302-0302, 0450-0450) in Figure 4. Power loss magnitudes have been normalized such that the focus of this study is correlation and trend rather than magnitudes of the arbitrary gear design simulated. The general correlation of power loss to operating torque and speed is the same in all pairings. Peak power loss occurs at the highest speed and torque condition for all pairings. As the roughness increases power loss is seen to increase.

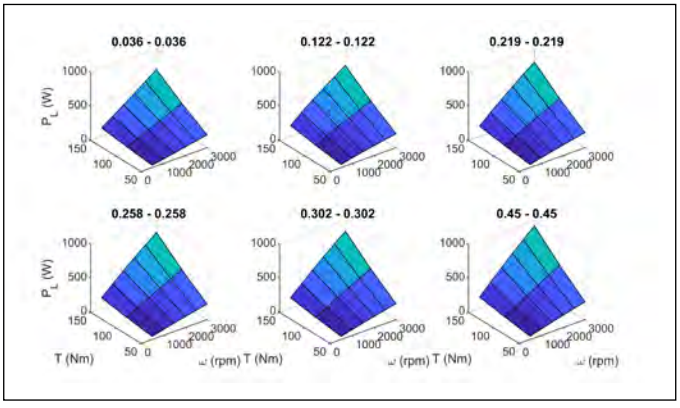

Figure 4—Predicted mechanical power loss for equivalent surface parings.

Similarly, mechanical power loss predictions for all surfaces paired with the smoothed surface (0036) are shown in Figure 5. This compares the correlation of mechanical power loss to torque and speed against similar surface parings and dissimilar surface pairings. Again, power loss correlates in a similar manor as torque and speed are changed.

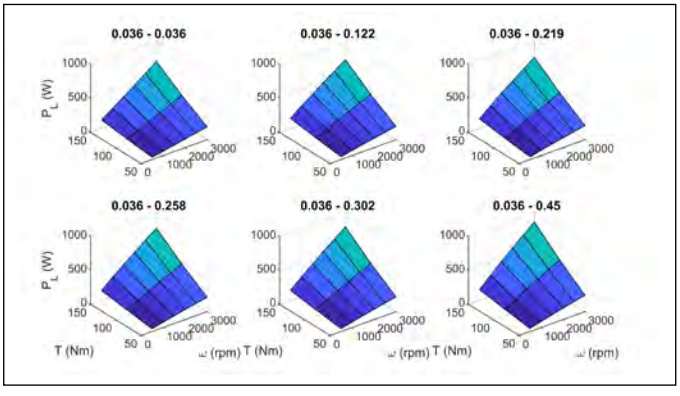

Figure 5—Predicted mechanical power loss for 0036 surface parings.

The primary variable of interest from the model predictions, besides mechanical power loss itself is the prediction of the area asperity contact ratio. This alone weights the effective friction coefficient between boundary friction μ_B=0.1 and EHL friction (approximated as Couette Flow) and describes the relative contributions of each to the effective friction coefficient. Extreme operating conditions in terms of fluid film thickness will be at high torque, low speed for low film thickness and high speed, low torque for high film thickness. This is observed in the boundary area contact ratio for both equivalent surface pairings and dissimilar surface pairings from the model as shown in Figure 6 and Figure 7, respectively.

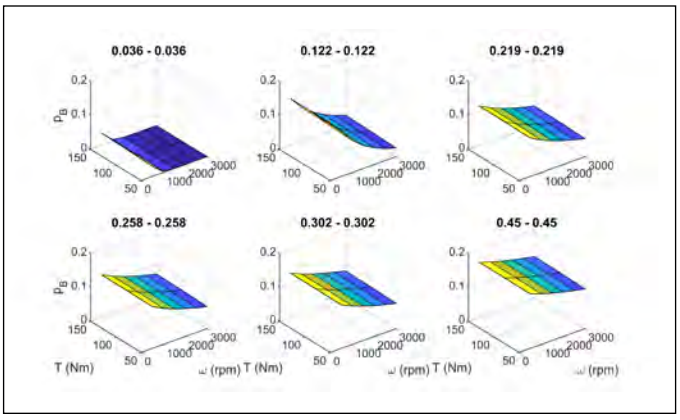

Figure 6—Boundary area contact ratio for equivalent surface pairings.

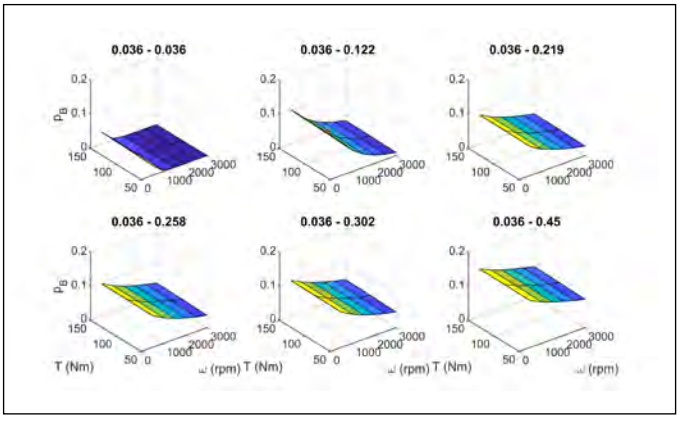

Figure 7—Boundary area contact ratio for 0036 surface pairings.

For surface parings in which a smoother surface is paired with a rough surface, the boundary area contact ratio is lower as compared to paring two of the rough surfaces as expected. It is also noted that within the operating conditions explored in this study only the smoothest surface pairing of 0036-0036 exhibits no boundary asperity contact at the higher speeds although it is expected that the 0036-0122 pairing would display this property if operating speeds were extended.

Composite roughness is an often-cited metric of roughness conditions in EHL contact, particularly when used as part of the film parameter λ. Composite roughness is defined as

$$\hat{R}_q = \sqrt{R_{q1}^2 + R_{q2}^2} \tag{5}$$

Composite Roughness metrics for the 21 surface pairings are shown in Table 5.

Trace Name	0036	0122	0219	0258	0302	0450
0036	0.065	0.158	0.278	0.324	0.377	0.581
0122		0.214	0.313	0.355	0.403	0.598
0219			0.387	0.422	0.464	0.641
0258				0.454	0.493	0.662
0302					0.529	0.689
0450						0.819

Table 5—Composite roughness ($\hat{R}_q$).

The film parameter λ is defined as

$$\lambda = \frac{\hat{h}_{min}}{\hat{R}_q} \tag{5}$$

where

$\hat{h}_{min}$ is the average minimum film thickness across the gear tooth contact

Normalized power loss vs composite roughness is shown for each of the 378 simulation conditions in Figure 8 at (a) 50 Nm, (b) 100 Nm and (c) 150 Nm 17T pinion torque. At any given operating condition (torque and speed) there is an approximate linear relationship between the composite roughness and mechanical power loss within the range of operating conditions used here. From a design standpoint this means that if operating conditions on the transmission are fixed, the transmission designer may approximate changes to mechanical loss if the mechanical loss at two different composite roughness values are known. This helps to avoid unnecessary costs in efficiency testing. However, composite roughness does not provide any information on how mechanical power loss will vary with torque and speed.

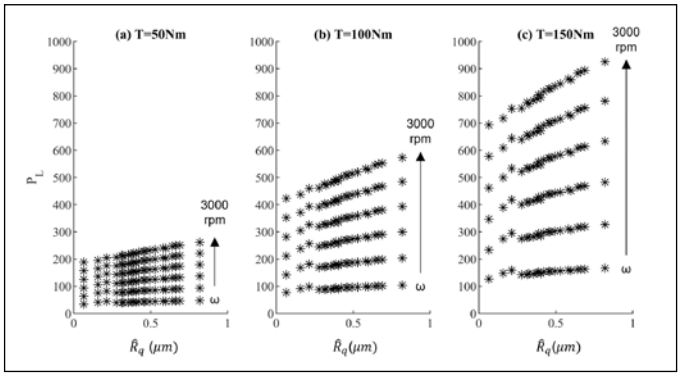

Figure 8—Predicted power loss vs. composite roughness.

Predicted mechanical power loss is plotted against the film parameter λ in Figure 9. Mechanical power loss shows similar bands corresponding to the simulated torque and speed conditions. At any given torque and speed condition the Dowson and Toyoda predicted average minimum film thickness is equal for all roughness pairings as it is assumed independent of roughness. This means that at any given operating condition λ is solely a function of the composite roughness and increases as composite roughness decreases. At any given operating condition in which film thickness is high enough to present film parameters of >1, predicted mechanical power loss shows a very little decrease with a further increase of the film parameter. This indicates there is little gain from an efficiency standpoint from further smoothening of the surfaces once the film parameter is equal to or greater than one for the operating conditions used in this study. There is, however, a speed dependence on the precise λ corresponding to equivalent slopes in the power loss vs film parameter plots. Higher operating speeds will result in higher film parameter values for equal diminishing returns in efficiency gains.

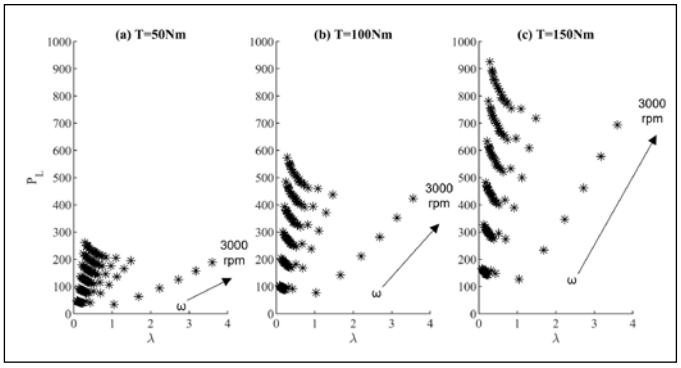

Figure 9—Predicted power loss vs. film parameter.

The same deficiency exists with the film parameter as with the composite roughness for the prediction of mechanical power loss. This is because the film parameter itself still provides no correlation to the magnitude of power loss with changes in torque and speed and only correlates to roughness conditions at a single operating condition. This is even though the film parameter accounts for the changes in film thickness due to operating conditions.

The observed boundary area contact ratios for the operating conditions and roughness amplitudes were well away from both 0 (no asperity contact) and 1 (purely asperity contact) indicating the gear teeth would be operating in mixed lubrication conditions. When considering the linear trend discussed in Figure 8 of power loss vs composite roughness it must be annotated that this is true only in the mixed lubrication condition. If roughness were to continue to increase well past $\hat{R}_q = 1$, the film parameter would approach zero ($\lambda \to 0$), and eventually, the boundary area contact ratio would approach 1 ($P_B \to 1$) indicating almost pure asperity contact. At this point, the effective friction coefficient is almost purely dependent on the boundary friction coefficient. Furthermore, increasing the roughness amplitudes even more would not affect that friction coefficient in a way comprehendible by this model approach. This means that at some large composite roughness value, the trend of a linear increase in power loss with composite roughness would break, and predicted power loss would be equivalent even as composite roughness is increased.

Similarly, as roughness is dropped the film parameter will approach infinity ($\lambda \to \infty$), and the boundary area contact ratio will go to zero ($P_B \to 0$) indicating that the effective friction coefficient will be purely dominated by fluid shear (within the assumptions of this model). This friction coefficient will also be constant for each operating condition and further reductions in roughness will not result in significant changes to mechanical power loss. Again, the linear trend of power loss with composite roughness will break at very low roughness values and the predicted power loss would be equivalent even as composite roughness is decreased.

This discussion suggests that mechanical power loss will have a purely linear relationship with the boundary area contact ratio. This is shown in Figure 10 and that trend is observed. It is again seen that most of the contacts operate in a mixed lubrication condition with few conditions having no asperity contact. This condition with no asperity contact is the 0036-0036 condition at 1500 rpm and above for all torque levels.

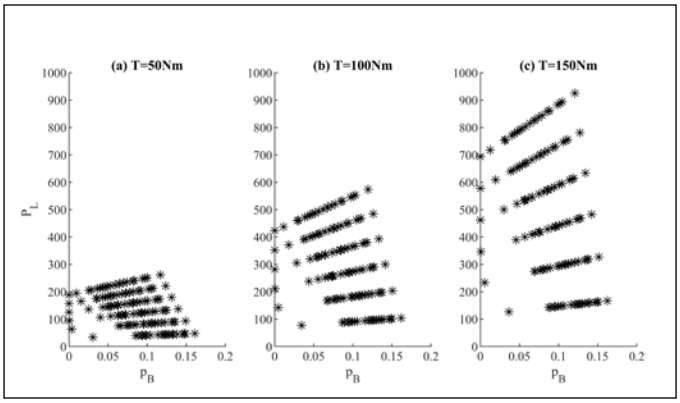

Figure 10—Predicted power loss vs. boundary area contact ratio.

Summary and Conclusions

A model developed by Ref. 1 for the prediction of gear mechanical power loss was used to investigate 378 unique gear operating conditions consisting of 21 different pairings of gear surface roughness. Applied torque varied from 50 to 150 Nm and operating speed varied from 500 to 3000 rpm. Surface roughness profiles varied from R_a=0.036 μ_m (R_q=0.046 μ_m) to R_a=0.450 μ_m (R_q=0.579 μ_m). All roughness profile amplitudes were shown to conform to a Gaussian distribution for the bulk of the material surface heights consistent with the requirements for the power loss model.

Power loss was shown to increase almost linearly with composite roughness at any given torque and speed operating condition. However composite roughness alone does not describe the relationship between power loss to torque and speed. This does allow for reduced experimental need with respect to high-resolution increments in surface roughness amplitude and shifts the focus to experimental testing of a wide range of operating torque and speeds.

With respect to the film parameter, it is observed that past $\lambda=1$ at any given operating condition, and very little reduction in mechanical power loss takes place. This in turn means that further smoothening of the surfaces will not result in a substantial gain in mechanical efficiency. However, the correlation between power loss and operating conditions cannot be determined from the film parameter, and experimentation or modeling is required.

Simple metrics such as the composite roughness or film parameter can be useful when determining relative mechanical power loss at a fixed operating condition. However, they require experimentation or modeling to understand the effect of operating conditions. The model presented performs well with roughness profiles conforming to a normal distribution, but caution is urged when presented with problems arising from the presence of surface defects or irregularities. Under regular circumstances, the model can provide results for thousands of operating conditions and roughness profile pairing with minimal computational overhead making it useful for early design phase decision-making.

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Aspects of Gear Noise, Quality, and Manufacturing Technologies for Electromobility

Hartmuth Müller and Christof Gorgels

In modern automotive vehicles, gear noise becomes more and more of an issue. The main reason is the reduced masking noise of the engine, which vanishes completely in the case of an electric driveline. Improved gear quality unfortunately does not correlate with a better noise performance in any case. High gear quality makes sure that the gear flanks are inside tight tolerances and that all teeth are nearly identical. Even if the running behavior of such gear sets shows a very low sound pressure level, the noise perception for human ears may be annoying.

The Root Cause for Gear Noise Excitation

Campbell Diagram

Gear noise is an airborne sound. Components of the vehicle vibrate and emit airborne sounds. To minimize the airborne sound primary and secondary measures are available. Primary measures focus on minimizing the root cause of a vibration whereas secondary measures deal with optimizing the acoustic transfer path from the vibration source to the human ear.

This paper handles primary measures by focusing on tooth mesh excitation.

Not every kind of tooth mesh excitation becomes critical in terms of transmission noise. Only when the tooth mesh stimulates a residual mode of the assembly, structure-borne noise (SBN) will emerge. Whether SBN will convert into airborne noise or not depends on the acoustic transfer path.

The interaction of tooth mesh excitation and eigenmodes of the transmission assembly can be seen in the Campbell diagram shown in Figure 1.

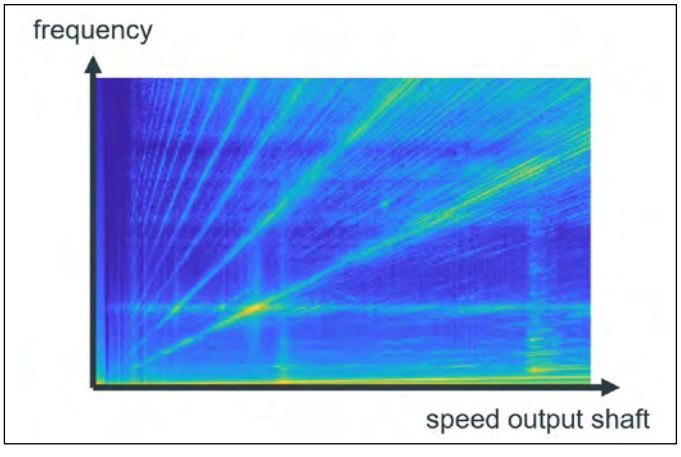

Figure 1—Campbell diagram.

The diagram in Figure 1 shows the speed scan of SBN in a transmission. The horizontal axis represents the speed of the output shaft, and the vertical axis shows the frequency of the SBN. The lighter the colors become, the higher the amplitude of the structure-born noise will become.

The horizontal lines in the Campbell diagram are eigenmodes of the assembly. Their frequency is constant and independent of the speed of the transmission. The ascending lines are tooth mesh effects. The slightly inclining line is the first harmonic of the tooth mesh and the more inclined lines are higher harmonics or ghost frequencies of the tooth mesh.

Critical tooth mesh excitations are only those, where an inclined line crosses a horizontal line. Here the tooth mesh excitation stimulates an eigenmode of the transmission and depending on the acoustic transfer path, the SBN will convert into audible airborne noise.

Flank Form Modifications and Imperfections

What is the reason for tooth mesh excitation? In the case of a perfect involute tooth profile, the mesh transmission error will be zero, i.e., no excitation exists. Because of manufacturing tolerances and load-induced deflections an unmodified involute profile and an unmodified lead shape will immediately show up with edge contact. Applying flank form modifications shown in Figure 2 can guarantee favorable tooth contact under all conditions.

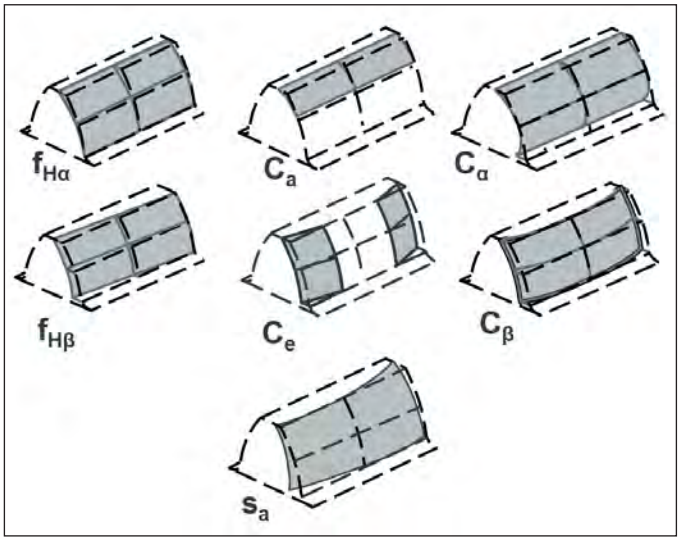

Figure 2—Flank form modifications.

In particular tip relief C_a and end reliefs C_e are widely used for optimization purposes. Profile crown C_α and lead crown C_β have a significant influence on the mesh transmission error and should be kept small.

It is obvious that a gear design engineer has to compromise the mesh transmission error and the amount and type of flank form modifications required by the load-carrying capacity of the gears. Gears being highly insensitive to displacements and load-induced deflections require larger modification amounts. Hence, they provide a larger mesh transmission error with higher excitations to the transmission assembly.

Detecting Gear Noise

Unloaded Tooth Mesh

It often happens in series production that gears are inside their geometrical tolerance limits but some of them do not perform acceptably in noise behavior. In case such a phenomenon occurs in the End-of-Line test, expensive disassembly, and root cause analysis needs to be done. Avoiding fault repair in gearbox assembly a method of fishing out critical gears before assembly is desirable. Figure 3 shows the different influences on the running behavior of mating gears.

Three groups of influencing parameters can be distinguished:

- flank from modifications including machining imperfections
- load-induced displacements and deflections
- damping characteristics of the transmission assembly

When addressing the phenomena of some gears of a batch performing not acceptable in noise, considering effectual alternations in manufacturing and assembly is required. Damping characteristics and material specifications will not show a substantial effect, but flank form modifications and additional machining imperfections will occur in gear machining.

The good news is that the unloaded tooth mesh is sufficient to forecasting the noise. All variations in flank geometry are detectable in the unloaded tooth mesh. Figure 3 shows in red color the critical influences on noise excitation caused by tooth mesh (Ref. 1).

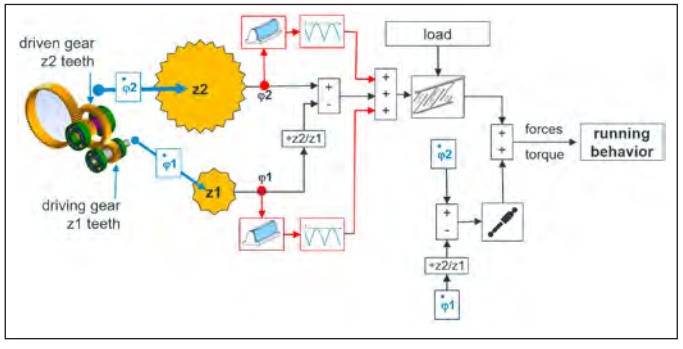

Figure 3—Influences on the running behavior of mating gears.

Waviness Analysis

Gear metrology and Closed-Loop applications control nowadays flank form modifications in a perfect manner. Nevertheless, small surface defects are not the focus of gear metrology. In particular, regular surface defects are critical in terms of noise excitation. Profile and lead form errors in metrology evaluation standards are only a rudimentary approach to detecting regular surface defects like waviness.

Gear metrology must be capable of checking waviness with amplitudes down to 100 nanometer. In case a capable measuring device exists, waviness analysis is an appropriate tool for detecting noise-critical gears. As a matter of course a correlation between transmission noise and waviness amplitudes of orders must be given.

Roll Testing

Two-Dimensional Analysis of Gear Flanks

Waviness analysis is limited to checking in one dimension in profile as well as in lead direction whereas roll testing allows checking the flank surface in two dimensions by means of meshing teeth. Several roll test methods for detecting noise are applicable.

SFT–Single Flank Test

In SFT the gear and a master gear are in quasi-static tooth mesh. High-resolution encoders capture the rotational positions of gear and master gear. The SFT result is the difference of the rotational position given by the number of teeth and the captured angular positions. SFT shows the quality of the mesh transmission precision. The advantage of this quasi-static measurement principle is the high repeatability and results in consistency on different test equipment.

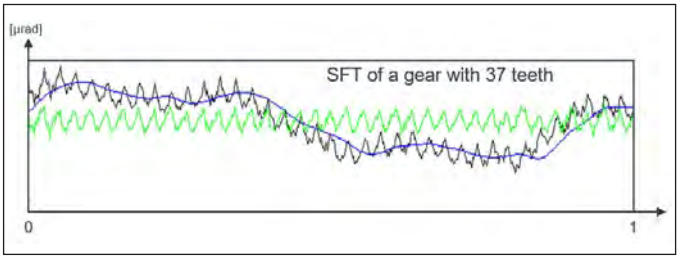

Figure 4—SFT with mesh transmission error.

Figure 4 shows the SFT result of a gear with 37 teeth. The mesh transmission error is the black graph. For better understanding, the mesh transmission error is decomposed into the blue long-wave content and the green short-wave content.

SFT allows detecting precisely the tooth mesh deviation. However, SFT only works with reduced rotational speed since no parasitic effects are allowed in order to avoid an influence of the test equipment in the mesh transmission error results. Even SFT is significantly faster than a waviness analysis on a gear inspection machine. Still, SFT is in most cases not able to support a 100% check of all gears in a 1:1 ratio of gear processing machine and SFT tester.

SBN–Structure-Borne Noise

In contrast to SFT SBN is a very fast method. The rotational speed for testing is from 500 to 2,000 rpm. Instead of rotational encoders, a vibration sensor records the vibration of the SBN test equipment. Even though this test principle focuses on exciting eigenmodes of the gear environment there is a difference to the real gearbox. Instead of exciting the eigenmodes of the gearbox assembly, SBN excites the eigenmodes of the test equipment. Nevertheless, SFT gives a clear indication about tooth mesh exciting eigenmodes, especially for higher frequency ranges.

TAT–Torsional Acceleration Test

The torsional acceleration test runs at the same speed, like SBN. The difference to SBN is the type of sensor equipment used to capture the vibration. SBN processes the signals of a three-axis acceleration sensor, whereas TAT uses rotational accelerometers in the workpiece and master gear spindle. TAT only records the rotational acceleration caused by the tooth mesh. Therefore, the dynamic impact of the test equipment comes much less into effect. For getting the torsional acceleration without any influence of the test equipment the second derivative of SFT results needs to be computed—with the disadvantage of a longer measuring time due to the quasi-static condition of SFT.

Describing Gear Noise

Order Spectrum

SFT, SBN, and TAT results show the respective sensor data over the rotational position of the workpiece and the master gear. For getting quantitative numerical values, a Fourier-transform is applied to result in an order spectrum. Instead of looking at deviations in each rotational position, the order spectrum tells, how often per revolution an incident happens and how big this incident is. Figure 5 shows the order spectrum of the SFT result shown in Figure 4.

The order spectrum gives a detailed look into the tooth mesh operation. In the example of Figure 5, the peaks in order 37 and multiples of it are tooth mesh orders. The amplitudes of these orders mainly arise from flank form modifications. The orders between the tooth mesh orders are so-called ghost orders. Only machining imperfections cause ghost orders.

The first order for example originates from the workpiece runout. This incident happens once per revolution. The orders close to tooth mesh orders are so-called sidebands caused by indexing errors. The ghost orders between 148 and 185 are provoked by parasitic machine dynamics or from external environmental influences on the machine-like foundation vibrations.

Order spectra of gears in general show a multitonal characteristic and create an annoying noise experience. The task is to design an order spectrum with lower amplitudes in tooth mesh orders and a higher number of sidebands and ghost orders with rather low amplitudes taking a certain share of the vibration energy induced by the tooth mesh.

Psychoacoustic Metrics

The vibration energy excited by the tooth mesh spreads over all orders of a spectrum. A gear without any machining imperfections shows an order spectrum without sidebands and without ghost orders. Here the vibration energy can only distribute on tooth mesh orders. Even a low sound pressure level of such a gear may give an annoying acoustic experience due to high tonality. An order spectrum with side bands and ghost orders creates a higher sound pressure level but the sound perception might be less unpleasant to the ear.

Gearbox noise is significantly quieter than most all other vehicle sounds. Nevertheless, it is an annoying noise due to its tonal character. The aim of applying psychoacoustic properties is to objectify the subjective impression of an assessor by using mathematical methods matching subjective evaluation with objective measurable variables (Ref. 2).

The annoyance of gear noise is whining, humming, and rattling. When applying psychoacoustic principles, only those properties are relevant correlating with typical gear noise. Therefore, the focus is on the following four psychoacoustic properties (Ref. 3).

- Loudness: Is the perceived intensity of a sound, measured in Sone. Calculating Loudness in Sone considers frequency, bandwidth, length of time, and sound pressure level. The Loudness in Sone is proportional to the perception of the sound intensity of a human ear.

- Tonality: Is a measure for the existence of singular tones calculated in Mel. Tonality becomes high when single frequencies or narrow-band noises obtrude in relation to

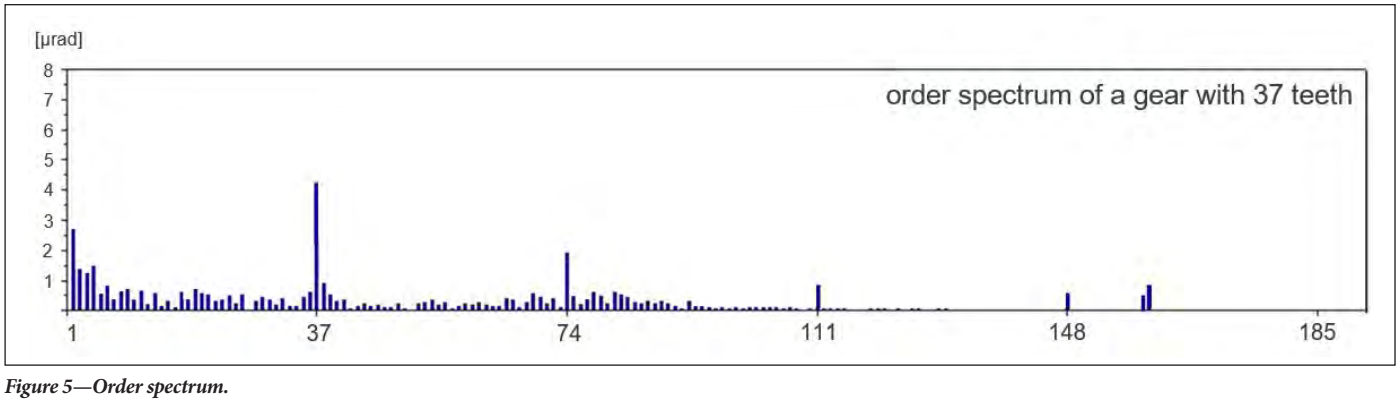

Figure 5—Order spectrum.

the remaining noise. Tonality correlates with the annoyance of subjective sound perception.

- Fluctuation strength: Describes the decrease and increase of sound in case frequencies of a sound are close together. This effect is perceived as a pulsating or humming noise and causes alertness. The unit of fluctuation strength is Vacil.

- Sharpness: In case a noise excitation changes rapidly and contains high frequencies, a rough sound impression is perceived. Calculating the sharpness is based on the spectral concentration of the loudness. The unit of Sharpness is Acum.

Computing these properties is not possible with simple formulas. Complex algorithms are needed (Refs. 4, 5, and 6). Besides the mathematical evaluation of these four psychoacoustic parameters based on the order spectrum, there is an easy-to-understand correlation.

- The level of amplitudes correlates to the loudness.

- If single orders are prominent in the spectrum, the tonality becomes high.

- A high fluctuation strength indicates that low orders have a high amplitude causing a humming noise.

- A high sharpness value is a clear hint that amplitudes of sidebands are too high.

Psychoacoustic properties help to interpret an order spectrum of SFT, SBN, or TAT with regard to the expected subjective human noise perception.

Influencing Gear Noise

Loudness in the Design Phase

The basic noise behavior of a transmission is defined in the design stage. Macrogeometry and flank form modifications determine the amplitudes of the tooth mesh orders. Improving the psychoacoustic property of loudness the mesh transmission error must be minimized in the design stage. Counteracting flank form modifications are needed to cope with load-induced and tolerance-caused displacements and deflections.

Before flank form modifications are applied the gear macrogeometry needs to be designed properly. A high contact ratio takes care of a high number of teeth being engaged simultaneously. This provides load sharing leading to an improved load-carrying capacity and a lower mesh transmission error. Influencing design parameters of the contact ratio are tooth height, helix angle, and module.

If the macro design is not well done, noise optimization in a later stage will not be successful.

Tonality, Fluctuation Strength, and Sharpness in the Manufacturing Phase

In the case of noise-sensitive gears like in e-mobility, it often happens that all gears are in tolerance but some of them fail at the end-of-line test of the assembled gearbox. Since the majority of gears perform as expected, the root cause must somehow originate in the manufacturing process.

A gear corresponding exactly to the design will only show tooth mesh orders with a low sound pressure level and a high tonality. Minimizing the amplitude of a tooth mesh order is not possible in manufacturing but masking a tonal noise will help to improve the subjective hearing impression. Partial masking reduces the loudness of a tonal noise but does not mask it completely (Ref. 7).

Adding low amplitude ghost orders and low amplitude sidebands contribute to partial masking. In case of a large runout of the gear, amplitudes of the tooth mesh orders will be reduced substantially but side band orders with high amplitudes will pop up. Such order spectra have high sharpness and will be annoying. As a secondary effect, the fluctuation strength is highly audible in a humming noise.

Influencing the order spectrum will only work when affecting the flank geometry. Since flank geometry and gear quality correlate directly, the challenge is finding measures not downgrading the gear quality but improving the partial masking effect.

In the following paragraphs, the manufacturing technology focuses on generating grinding.

Influencing the surface structure of gear flanks requires a special dressing operation of the grinding worm. When modulating the ratio of the circumferential speed ratio of the dressing roll and grinding worm during the dressing cycle, a surface effect on the grinding worm flanks is induced by devolving to the gear flanks. Some sections of the grinding worm have a higher cutting ability, some a lower. The geometrical effect on the gear flanks will be in the range of less than a micrometer and therefore not affect quality parameters.

Figure 6 shows how the modulated grinding worm surface affects the gear flanks.

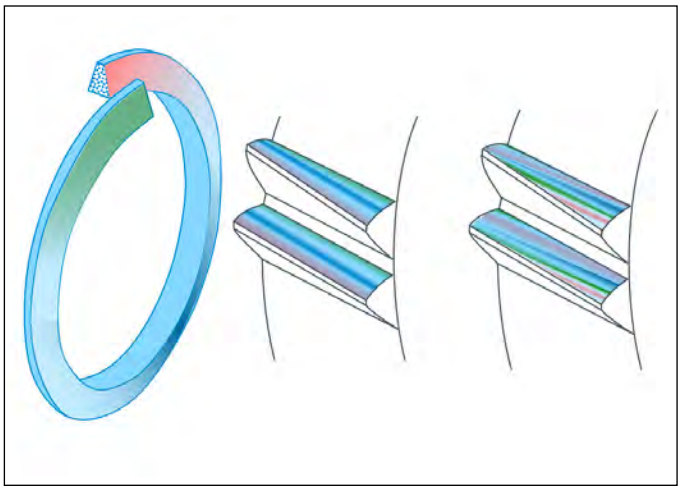

Figure 6—Flank surface modulation.

The left picture in Figure 6 shows one thread of a single-start grinding worm. The colors represent the surface modulation of the grinding worm. The middle picture shows a flank surface texture with a structure parallel to the root and tip. The right picture shows a flank surface inclined texture.

There are only some parameters influencing the texture of the gear flanks.

- The magnitude of the texture will increase with a higher change of speed ratio of the dressing roll and grinding worm during the dressing cycle.
- The density of the texture structure becomes more subtle when the speed ratio changes more often during the dressing cycle.
- The inclination angle of the texture increases with the shift amount per workpiece revolution.

Up to now, this method will create identical teeth and therefore just affect the tooth mesh orders. Big magnitudes and a high density of the structure will increase the amplitudes of high tooth mesh orders. A fuzzy texture spreading over all the teeth will create ghost orders. Creating a fuzzy texture with a three-start grinding worm shows Figure 7.

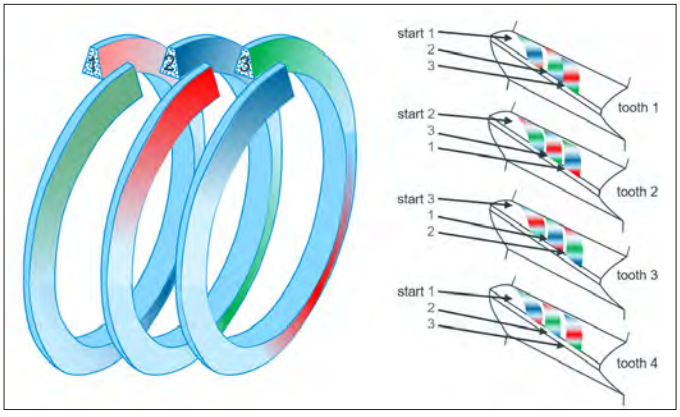

Figure 7—Flank surface modulation.

Start 1 of the grinding worm will devolve its characteristic on tooth 1, start 2 on tooth 2, start 3 on tooth 3, and so on. After one revolution of the workpiece, the grinding worm operates due to the stroke motion along the face width on a position next to the last contact of the worm and flank. Now start 2 devolves its characteristic on tooth 1, start 3 on tooth 2, start 1 on tooth 3, and so on. When grinding the gear is finished, each flank has a slightly different surface texture and therefore the ghost orders and side bands with low amplitudes are induced in the order spectrum.

With this grinding technology called Quiet Surface Shifting (QSS), it is possible to produce gears of the highest quality and improved psychoacoustic values in loudness, tonality, fluctuation strength, and sharpness resulting in less noise annoyance of transmissions.

Summary

Physical measures like sound pressure level are not suitable for forecasting the subjective hearing experience. Psychoacoustic principles allow objectifying the subjective impression by using mathematical methods matching subjective evaluation with objective measurable variables. Roll testing provides objective measurable values represented by the order spectrum. The Quiet Surface Shifting (QSS) technology allows for improving the relevant psychoacoustic parameters loudness, tonality, fluctuation strength, and sharpness without compromising gear quality.

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Dr. Christof Gorgels is currently vice president of technology and innovation at Klingelnberg. Before he served as director of metrology and as head of the application department. He has a university diploma and a Ph.D. from Aachen University in Germany in mechanical engineering specializing in gear manufacturing. Dr. Gorgels also served as head of the gear group at WZL in Aachen University and presented two papers at the AGMA fall technical meeting.

Dr. Hartmuth Müller is currently head of technology and innovation at Klingelnberg GmbH. He studied electrical engineering at University Karlsruhe. His career with Klingelnberg began in 1990 as software developer and from 2001–2016 he served as CTO. Since 2022, he has been a gear technology consultant.

Verisurf Software and Wenzel America

ANNOUNCE OEM RESELLER AGREEMENT

Verisurf Software, Inc., and Wenzel America Ltd have entered into an OEM reseller agreement. Under the agreement, Wenzel customers now have the option to select Verisurf measurement and inspection software for all new and legacy CMM devices directly from Wenzel.

"Customers can now order complete Wenzel metrology solutions powered by Verisurf software for CMM programming, inspection, quality reporting, reverse engineering, tool building, and guided assembly," said Pat Bass, director of sales at Verisurf Software, Inc. "We are proud to be associated with an industry-leading, quality brand like Wenzel."

Each complete measurement solution is based on Verisurf Coordinate Measuring Machine (CMM) software, with an emphasis on its popular CMM Programming and Inspection Suites, bundled with a Wenzel Programmable CMM or Portable CMM Probing and Scanning Arm. Each solution includes installation, training, and support services through collaboration between Wenzel and Verisurf.

Verisurf software provides repeatable process control while increasing efficiency and effectiveness, from CMM plan creation through execution and reporting, especially when it comes to getting the most out of 5-axis CMMs that use Renishaw PH20 5-axis touch-trigger, or REVO-2 5-axis scanning probes.

Verisurf is the only inspection and measurement software built on a full-featured 3D CAD/CAM platform with intelligent Model-Based Definition (MBD). This ensures data integrity and lets users perform measurement and inspection workflows in a seamless CAD/CAM environment while maintaining model-based digital continuity. Verisurf software is compatible with all CAD file formats, and the Verisurf Device Interface (VDI) communicates with and drives all programmable and portable CMMs for universal compatibility.

"We are very excited to add Verisurf to our offerings. Its unique CAD/CAM platform and modern object-oriented approach to CMM programming bring a lot of efficiency to the table for customers, particularly for the growing 5-axis CMM market," said Drew Shemenski, president of Wenzel America Ltd.

wenzelamerica.com

verisurf.com

Auto Gear

JOINS GEAR MOTIONS

Gear Motions is proud to announce that Auto Gear Inc. has joined the Gear Motion's family. Auto Gear located in Syracuse, N.Y., specializes in efficient and economical low-volume gearbox production, from design to delivery. George Sollish, president of Auto Gear, stated that gearbox design and manufacture is a Syracuse tradition. "As the last of our respective breed, gears by Gear Motions and gearboxes by Auto Gear are a natural partnership. I am delighted to commit my energy, my creativity, and my family's legacy to our combination. My mission, and Auto Gear's—To Be the Best Today, and Better Tomorrow—is in good hands."

Gear Motions President Dean Burrows added "having been partners with Auto Gear for decades, having them join the Gear Motion's family of companies adds to the capabilities of Gear Motions through gearbox design and assembly. This acquisition complements our existing businesses while allowing us to provide more services and capabilities. It enables Gear Motions to offer custom gearbox applications to its current customer base."

gearmotions.com

Solar Atmospheres of Michigan

SET TO OPEN NEW FACILITY

Solar Atmospheres of Michigan, formerly Vac-Met, has recently purchased 18,000 square feet of plant space on four plus acres in Chesterfield Michigan. The new building is 20 miles Northeast of the two existing Vac-Met facilities which are currently located in Warren and Fraser Michigan.

Bob Hill, President of Solar Atmospheres of Michigan Inc states, "We are working feverishly in 2023 to prepare and equip this new facility to make it our fifth state of the art vacuum heat treating and brazing facility in the United States. Once all of the electrical, water cooling and specialty gas utilities are installed, we will strategically relocate the nine existing vacuum furnaces to their new home. Additionally, two new vacuum furnaces were purchased from Solar Manufacturing." Hill continues, "This investment of over $5 Million dollars gives Solar Atmospheres of Michigan the space to locate our valuable employees and equipment under one roof while continuing to

grow the Michigan vacuum thermal processing needs."

solaratm.com

KISSsoft

RELEASES TRAINING SCHEDULE THROUGH SUMMER 2023

In the KISSsoft training program until summer 2023, you will find introductory training courses, advanced training courses and special training courses on selected topics.

KISSsoft will be offering training in Bubikon, Switzerland and live streams, which will allow you flexibility and planning security, as well as the opportunity to interactively ask questions and participate in discussions in a virtual setting.

February 21–22
Live Stream, Basic: Gear Calculation

February 28–March 1
Live Stream, Basic: Shaft and Bearing Calculation

March 14–16
Live Stream, Basic: KISSsys—Modeling Gearboxes

March 21–22
Live Stream, Advanced: KISSsys—System Calculations

March 23
Live Stream, Special: KISSsys—Model Customization

May 8–11
Live Stream, Special: Fine Pitch Gears in Plastic and Sintered Material

June 20–22
Bubikon, Advanced: Cylindrical Gear Design, Analysis and Optimization

kisssoft.com/en/products/training/upcoming-seminars

MPIF

ANNOUNCES DISTINGUISHED SERVICE AWARD RECIPIENTS

The Metal Powder Industries Federation's (MPIF) Awards Committee has announced the recipients of the 2023 MPIF Distinguished Service to Powder Metallurgy (PM) Award that recognizes individuals who have actively served the North American PM industry for at least 25 years and, in the minds of their peers, deserve special recognition.

2023 Award Recipients

(Company name in parenthesis indicates employer at time of retirement)

- Christopher T. Adam, PMT, VALIMET Inc.
- Carl Blais, Laval University
- Shelton R. Clisby. Hoeganaes Corporation
- Thomas K. Houck, Nichols Portland Inc
- Bo Hu, North American Höganäs Co.
- Edmond Ilia, (AAM Powertrain)
- Todd A. Leonhardt, Rhenium Alloys, Inc.
- Eric J. Reinert, Bronson & Bratton, Inc.
- Mark Saline, Gasbarre Products, Inc.
- Rajiv Tandon, Luxfer Magtech Inc.
- Juan R. L. Trasorras, Global Tungsten & Powders Corporation
- Barton White, Kymera International

The awards ceremony will take place during PowderMet2023, June 18–21, Las Vegas, Nevada.

mpif.org

Velo3D

HIRES DR. ROBIN STAMP AS DIRECTOR OF SOLUTIONS ENGINEERING

Dr. Robin Stamp

Velo3D, Inc. has appointed Dr. Robin Stamp as director of solutions engineering to help grow the adoption of Velo3D's metal additive manufacturing technology with new customers and in new industries. In his role, Dr. Stamp will oversee the development of new standards with regulatory agencies, qualification of new metal alloys for use in the Sapphire family of printers, and the collaboration with partners and agencies.

Dr. Stamp has extensive experience leading teams in the research and development of additive manufacturing technology, which includes operating Velo3D's fully integrated solution in production environments. He was previously a principal engineer at SpaceX, where he worked on developing technology for space applications. Dr. Stamp also spent more than a decade at Stryker, a medical technology company with more than $17 billion in sales, leading the research and development team responsible for creating new additive manufacturing processes for medical implants.

"In our industry, there aren't many people with more experience using metal additive manufacturing technology in production environments than Robin," said Dr. Greg Brown, Velo3D vice president of technology. "His creativity solving problems through additive manufacturing will be very beneficial to our solutions engineering team and his experience operating Velo3D's

technology in real-world environments will help our customers maximize the use of their Sapphire printers."

With extensive experience across a variety of industries and in production environments, Dr. Stamp will be well equipped to support the development of Velo3D's technology. Dr. Stamp will work with customers to understand their needs, expand the manufacturing capabilities of Velo3D's solutions, and educate customers on how to fully leverage various technology improvements. This continuous delivery of new capabilities to customers operating existing systems helps ensure the longevity of Velo3D's solutions and the success of its customers.

"Since I first operated a Velo3D Sapphire printer, I realized the technology was a cut above the rest in terms of its print capabilities," said Dr. Stamp. "I'm looking forward to working more closely with Velo3D's innovative technology, helping improve and develop products, and enabling new customers."

Dr. Stamp has a Ph.D. in additive manufacturing for medical devices from University of Liverpool. He also has a Bachelors in Aeronautical and Astronautical Engineering from University of Southampton.

velo3d.com

Interact Analysis

SEES GEARED PRODUCTS MARKET GROWTH IN 2022

Updated research from Interact Analysis shows the geared motors and industrial gears market experienced strong growth in 2021. The market expanded by 16 percent last year, with the sharp rise driven by price increases. On average, the selling price for geared motors and gearboxes increased by 7.8 percent in 2021, with further price rises forecast in 2022.

Steady growth has also been seen in 2022, with sales expected to increase by 7.2 percent. Following a slowdown in sales this year from 2021's rapid growth rate, 2023 is expected to see sales decline by 0.9 percent. This fall in sales is likely to be due to a price decrease and a slight downward trend in the number of units sold from the previous year(s). Steep drops in commodity and freight costs in 2023 are expected to push down prices significantly. Regionally, APAC is expected to maintain its lead in the geared products market out to 2027 with a CAGR of 4.5 percent. The main driving forces behind this are the growing demand for industrial automation in emerging Asian countries, as well as increasing growth rates of manufacturing industries. Following behind the APAC region, the Americas market is predicted to experience a CAGR of 4.1 percent from 2021 to 2027, while the EMEA region is forecast growth of 3.8 percent over the period in question.

In terms of application, machinery manufacturers are the major consumers of geared products. They accounted for 74 percent of sales in 2021 alone, a market share that is anticipated to remain stable throughout the forecast period. Food and beverage industries are particularly heavy users of the technology, while demand for geared products from the conveyor segment is rising, accounting for 25 percent of sales to the machinery sector in 2021 and anticipated to grow at the fastest pace of all market segments due to rising demand for factory automation.

"When it comes to the company leading the global market for geared products—SEW retains its top position. Overall, the market share tables remained very stable in our research with little room for maneuver. Although four of the top five vendors are based in Europe, they have a strong global presence. In EMEA and Japan, local vendors appear to be performing the best, while SEW and Guomao are very much leaders in the rest of the APAC region. Elsewhere, Sumitomo has a significant market share, particularly in the United States, and Regal Rexnord is also one to watch out for," said Shirly Zhu, principal analyst at Interact Analysis.

interactanalysis.com

ZF and Beep

ANNOUNCE E-MOBILITY PARTNERSHIP

ZF unveiled its next generation shuttle for autonomous driving in urban environments and mixed traffic at the 2023 Consumer Electronics Show (CES) in Las Vegas. The next generation complements the established model, which is primarily designed for use in segregated lanes. For the new shuttle generation ZF announced a strategic partnership with U.S. mobility services provider Beep, Inc. The agreement aims to deliver several thousand shuttles to customers over the coming years, combining ZF's ATS with Beep's mobility services and service management platform into a single-source autonomous mobility solution.

"In order to reduce traffic-related emissions in metropolitan areas, a reduction in motorized individual transport and a simultaneous expansion of more sustainable, efficient, comfortable, and affordable mobility options are required," says Torsten Gollewski, executive vice president, Autonomous Mobility Systems at ZF.

With its Autonomous Transport Systems, ZF is driving a mobility transformation, while offering a solution to the serious driver shortage in local public transport. As further proof of its progress on the road to "Next Generation Mobility NOW," ZF is presenting a new, autonomous Level 4 Shuttle. The new shuttle complements the already established autonomous shuttle model. Soon, ZF can offer two shuttle types—one primarily for use in segregated lanes and the new model, which will be used primarily in urban environments and in mixed traffic.

The new shuttle is equipped with state-of-the-art sensor technology consisting of lidar, radar, camera, and audio systems that provide precise environmental detection. This is complemented by other technology such as the ZF ProConnect connectivity platform, which enables communication with the infrastructure and the cloud, as well as the ZF ProAI supercomputer, where data converge.

The Virtual Driver—ZF's AD software—processes these expansive volumes of information, derives safe driving strategies using artificial intelligence, and passes them on as input to the on-board actuators. The Virtual Driver replaces the human driver and thus makes the steering wheel and brake pedal superfluous. The system is designed with redundancies so that the full functionality and operability of the vehicles are highly reliable. Thus, ProConnect and ProAI units in the shuttle work together to operate the ZF Virtual Driver. All ZF components and systems are Automotive Grade certified, meeting both the high safety and quality requirements of the automotive industry and applicable cyber security standards.

With selectable battery capacities between 50 and 100 kWh, the next-generation shuttle can cover up to 80 miles in pure electric mode—at a maximum speed of initially 25 mph, in further development of 50 mph. The Shuttle offers a total passenger capacity of 22 with up to 15 seated. The vehicle conforms to requirements of the Americans with Disabilities Act and includes an automatic ramp and wheelchair restraints. The interior is customizable in layout and trim level. With front- and rear-wheel steer and kneeling functions, distance to the sidewalk is reduced to a minimum when approaching a stop. This enables the shuttle to dock precisely and provide barrier-free boarding and disembarking.

Autonomous, emission-free ZF Shuttles can operate on defined routes 24 hours a day, 7 days a week. Public transport operators can provide passengers with a mobility service even when demand is low and expand routes to meet increased demand despite an acute shortage of drivers.

With the US mobility provider Beep, ZF has already established a partnership for its new shuttle generation: ZF and Beep have signed an agreement to bring the shuttle to market in the United States.

Headquartered in Lake Nona, Fla., Beep delivers the next generation of shared mobility services. Specializing in planning, deploying and managing advanced autonomous shuttles for both private and public communities, Beep safely connects people, places and services in first-mile, last-mile mobility networks across the United States. The company has been safely testing autonomous shuttles for more than three years, with more than 100,000 road hours, and operates the largest and longest-tenured private-sector autonomous mobility network in the U.S.

"We are excited to partner with ZF to bring their next shuttle generation to market in the United States," said Joe Moye, chief executive officer for Beep. "ZF's full suite of shuttle services, its U.S. partner network and its automotive-grade vehicle complement our turnkey mobility networks and autonomous services technology platform. This shuttle will allow us to continue to pursue our vision of extending mobility equity and reducing carbon emissions, expanding our use cases while meeting industrial requirements for vehicle service life, performance and safety."

Beep is evaluating several possible sites and routes with both new and existing customers. "Our offer of clean, efficient and affordable mobility is convincing, and has found a partner and major customer in Beep," says Torsten Gollewski.

zf.com
ridebeep.com

Klingelnberg

HONORS 32 EMPLOYEES FOR COMPANY LOYALTY

In 2022, machine manufacturer Klingelnberg again honored its employees with longstanding service to the company. This year's honorees included 16 colleagues celebrating 40 years of service and 14 employees looking back on 25 years with the company. Two employees are even marking a full 50 years of service.

As Christoph Küster, CFO of the Klingelnberg Group, enthusiastically stated: "We are extremely proud to be honoring two employees in 2022 – Peter Kaehler (toolmaking) and Petra Schmidt (application development) – who have spent half a century with Klingelnberg." "In today's fast-paced times, we see this as an outstanding commitment, and one that shows just how much we can rely on our employees."

Kaehler can look back on a long and varied professional path with a single employer. He first dipped his toes in the water as an intern before starting his training as a machine toolmaker in the "Bevel Gear Machine Tools" department in Remscheid on August 7, 1972, and completed his training in Hückeswagen in 1976. Until he began his part-time paid release in 2021, he exercised a number of functions in the Production/Toolmaking department, including toolmaker, milling cutter, grinder, welder, spark erosion grinder, foreman, and inspection agent.

After 50 years, Kaehler had this to say of his overall experience: "What I really appreciate about Klingelnberg is that the company has always been a reliable employer over the years, despite any crises that came up. I also thoroughly enjoyed the camaraderie with my coworkers and the pleasant working environment."

Schmidt also began her training as a part draftsman on August 7, 1972, and even attended the same school as her anniversary colleague Kaehler, in the same class. Schmidt has fond memories of her time at Klingelnberg: "We had a wonderful training director at Klingelnberg back in the day, with a wealth of technical expertise. His wife was also one of our teachers in our school. Schmidt also made her mark as a vocational training representative for young people from 1973 to 1975. Since 2000, she has been working as a technician in Application Development, where she focuses primarily on the documentation for Klingelnberg Precision Measuring Centers. She has also been a shop steward since 2000; she is actively engaged in working with the Council of Employees with Disabilities. Schmidt summed up her time at Klingelnberg with these words: "It has always been a pleasure to work at Klingelnberg."

klingelnberg.com

Helios

GEAR SCHOOL 2023 OPEN REGISTRATION

After 33 years, over 1,500 educated attendees, and 68 facility tours the Helios team is excited to continue to help manufacturers build shops full of gear experts by hosting the 2023 Helios Gear School on May 16, 17, and 18 in Elgin, Ill. The seminar course is designed for entry-level gear manufacturing personnel including manufacturing management, industrial engineers, supervisors, set-up technicians, operators, and quality control. This intensive three-day program covers the basics of gear manufacturing from cutting to finishing, then through final inspection. With a limited class size of 35, this course provides the optimum learning environment for attendees new to the industry and those with experience in need of a refresher.

Nathan from General Motors describes the course as an excellent experience, mentioning that the "instructors were very friendly, and it was nice to see a wide variety of equipment and processes." Beyond the classroom the course features machine demonstrations at Helios Gear Products, and immersive plant tours at Forest City Gear and Overton Chicago Gear. "They did a great job including everyone, making it an interactive class, and the tours were a great addition" says Harrison of Amarillo Gear. The 2023 course features six industry-expert instructors including Adam Gimpert, David Harroun, Jason Spitzer, and Michael Weas of Helios, and Shane Hollingsworth of Kapp-Niles to offer a wide variety of perspectives and operational experiences.

heliosgearproducts.com/education

February 28-March 2–AGMA Gearbox CSI

A good understanding of individual failure modes and the failure scenarios that led to the actual system failure is an essential skill to designing gear/bearing systems that will operate properly for their full design life. In this course (Philadelphia, Pa.), we will define and explain the nature of many gear and bearing failures and we will also discuss and describe various actual failure scenarios. In addition, a detailed primer on bearing technology prefaces the failure scenario discussions. You 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.

geartechnology.com/events/5056-agma-gearbox-csi

March 4-11–IEEE Aerospace Conference 2023

The International IEEE Aerospace Conference, with AIAA and PHM Society as technical cosponsors, is organized to promote interdisciplinary understanding of aerospace systems, their underlying science and technology, and their applications to government and commercial endeavors. The annual, weeklong conference (Big Sky, Mo.) is set in a stimulating and thought-provoking environment. The 2023 conference will be the 44th 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, many presentations are given by professionals distinguished in their fields and by high-ranking members of the government and military.

geartechnology.com/events/5055-ieee-aerospace-conference-2023

April 10-15–CIMT 2023

Since founding in 1989, the China International Machine Tool Show (CIMT) held in every odd year has successfully organized 17 sessions. s CIMT (Beijing) is the most prestigious, largest scale and most influential professional machine tool exhibition in China, regarded by the global machine tool industry as with the same popularity of EMO in Europe, IMTS in the United States, and JIMTOF in Japan. CIMT has become an important place for exchange and trade of advanced global manufacturing technology, and a display platform for the latest achievement of modern equipment manufacturing technology, and vane and barometer of machinery manufacturing technology progress and machine tool industry development in China.

geartechnology.com/events/5048-cimt-2023

April 17-21–Hannover Messe 2023

Hannover Messe picks up on the current trends and provides everyone involved with orientation in times of energy shortages, climate change and supply chain problems. How do you install intelligent energy management and thus create an environment for CO_2-neutral production? What are the latest developments surrounding Industry 4.0 and artificial intelligence? And how about the mega-topic hydrogen? From drive and fluid technology to digital platforms and IT security to industrial internet and robotics, the huge variety reflects the manufacturing industry's broad scope and provides important economic and social impulses every year. Additional 2023 topics include 5G technology, additive manufacturing, automation, sensors, e-mobility, linear technology, material handling and more.

geartechnology.com/events/5058-hannover-messe-2023

May 2-4–AGMA Gear Manufacturing and Inspection

While function and rating are important factors in a successful gear design, to be truly optimal and successful, the gear designer must also design the gears to be manufactured and inspected. In this course (Cincinnati, Ohio), therefore, we will address key factors in a wide variety of manufacturing and inspection processes to enable the gear designer to better design optimal gears considering both rating and the necessary manufacturing and inspection processes to produce the gears as designed. We will also help the designer to understand how to interpret inspection data so that they can ensure that the gears meet the design.

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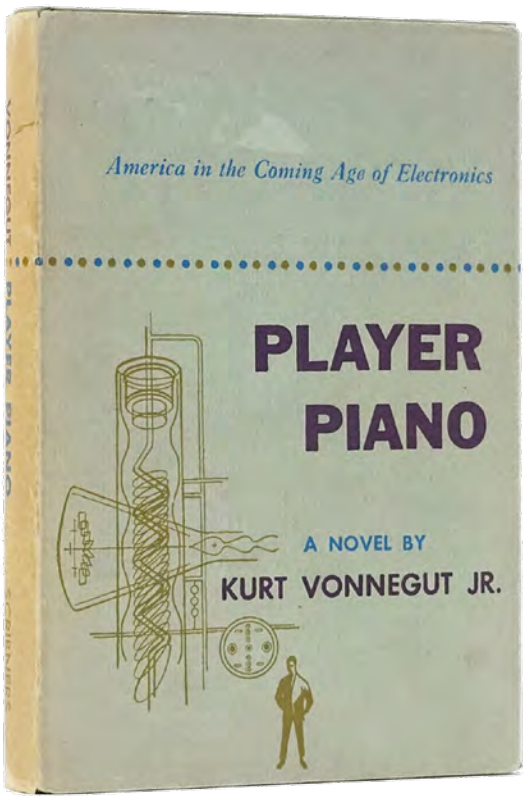
The Relevance of Kurt Vonnegut's *Player Piano* in the Age of Automation

Aaron Fagan, Senior Editor



In 1952, Kurt Vonnegut published his first novel, *Player Piano*, a dystopian story set in a future where automation has taken over most jobs, including manual labor and white-collar work, leaving many people unemployed and feeling purposeless. The protagonist, Dr. Paul Proteus, is a top engineer working for Ilium Works, which produces most of the country's automated machines. The Ilium Works symbolizes the power of the industrial complex and its ability to shape society through its control over technology, and as a result, Proteus struggles to come to terms with the consequences of widespread automation.

The story explores the theme of dehumanization and the impact of technological progress on society, as well as the power struggles between the ruling class and the unemployed masses. In the novel's imagined future, the government and corporations have adopted a caste system where people are assigned jobs based on their abilities and intelligence scores. Those at the top of the hierarchy are the engineers and managers who control the machines, while the rest of the population is relegated to menial, low-skilled jobs or unemployed.

This narrative of technology leading to mass unemployment and social unrest still holds relevance in the 21st century as the debate over automation and its impact on jobs and society continues. With the rise of AI and robotics, there is growing concern that machines will replace human labor, leading to vast economic inequality. To quote from *Player Piano*, "Reality is that which, when you stop believing in it, doesn't go away," and the impact of automation on society is a reality we must confront and manage in a responsible and proactive manner.

Automation has significantly impacted the gear industry by increasing production efficiency and accuracy, reducing labor costs, and improving product quality. Automated gear manufacturing processes such as computer-controlled gear cutting, grinding, and inspection has become more common, leading to improved consistency and reduced production time. Additionally, the use of robotics in gear assembly and inspection has also increased. These advancements have enabled the gear industry to keep pace with the growing demand for high-precision gears used in a variety of industries.

While automation has brought many benefits to the gear industry, it has also resulted in labor issues similar to those portrayed in *Player Piano*, and it has been addressed with a shift in the job market towards high-skilled workers. There is also an ongoing debate about the ethics of automation and its impact on the workforce.

Some argue that automation is a necessary step forward in our technological development, while others see it as a threat to jobs and livelihoods. Many also worry about the potential for automation to exacerbate social inequality, as the benefits of automation tend to accrue to those who own and control the technology. The need for a rethinking of education and training systems has become increasingly important to prepare the workforce for technological advancements and to address the impact on employment.

Player Piano serves as a cautionary tale and remains relevant in the age of automation as it addresses the issues of technological progress and the impact of replacing human labor and the resulting loss of purpose and meaning in life. It highlights the consequences of relying too heavily on machines and the need to find a balance between progress and preserving the human spirit. The novel remains relevant as discussions around the future of work, job loss due to automation, and the ethics of artificial intelligence continue to be important topics in today's society.

Despite these challenges, the trend toward automation is likely to continue as technology continues to advance and companies seek to remain competitive in a rapidly changing global economy. As such, it is important for policymakers, businesses, and individuals to work together to ensure that the benefits of automation are widely shared and that workers are supported as they adapt to the changing landscape of work.

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