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JANUARY-FEBRUARY 2024

2024 State of the Gear Industry
—Survey Results
—Industry Insights

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Hydraulic Workholding

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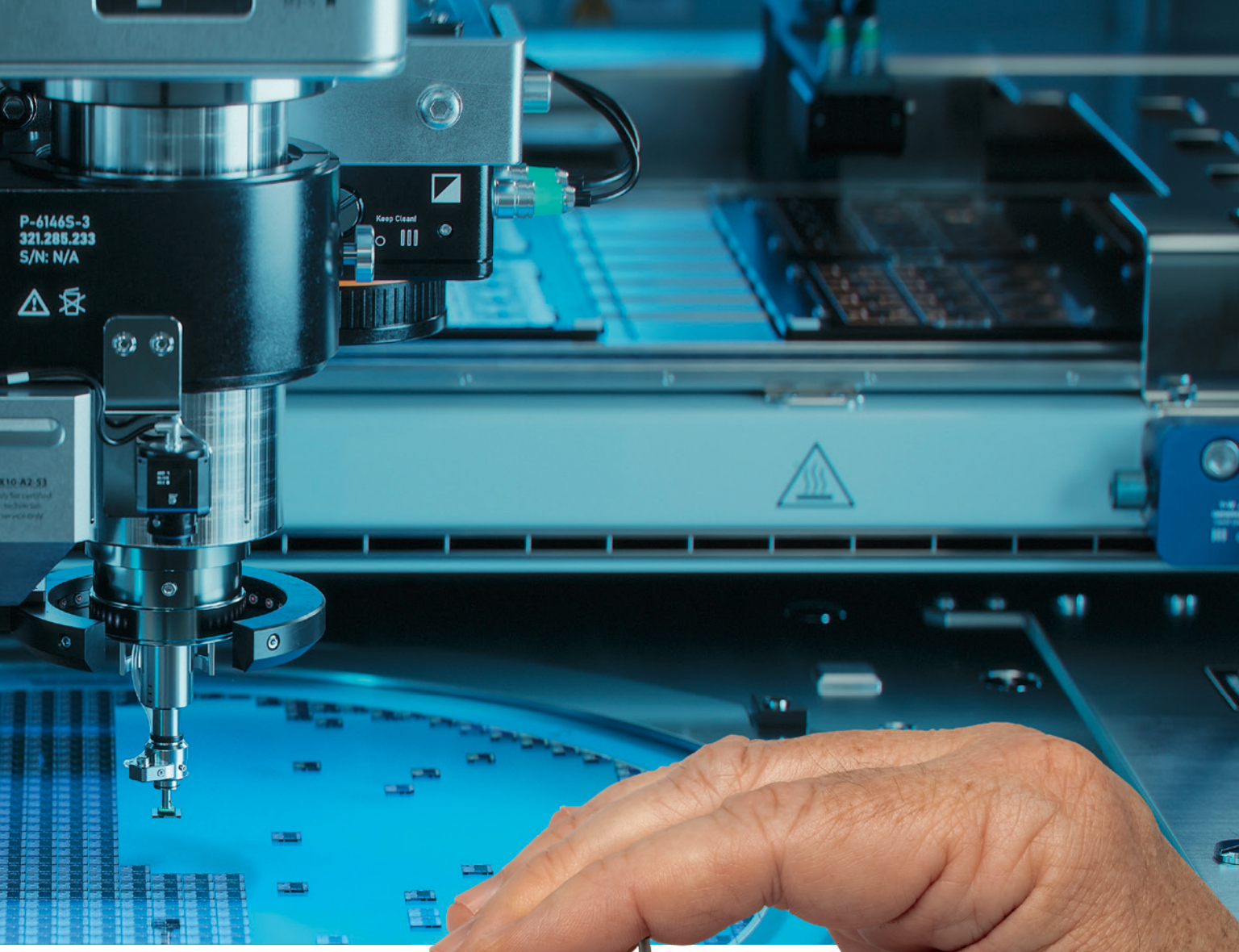

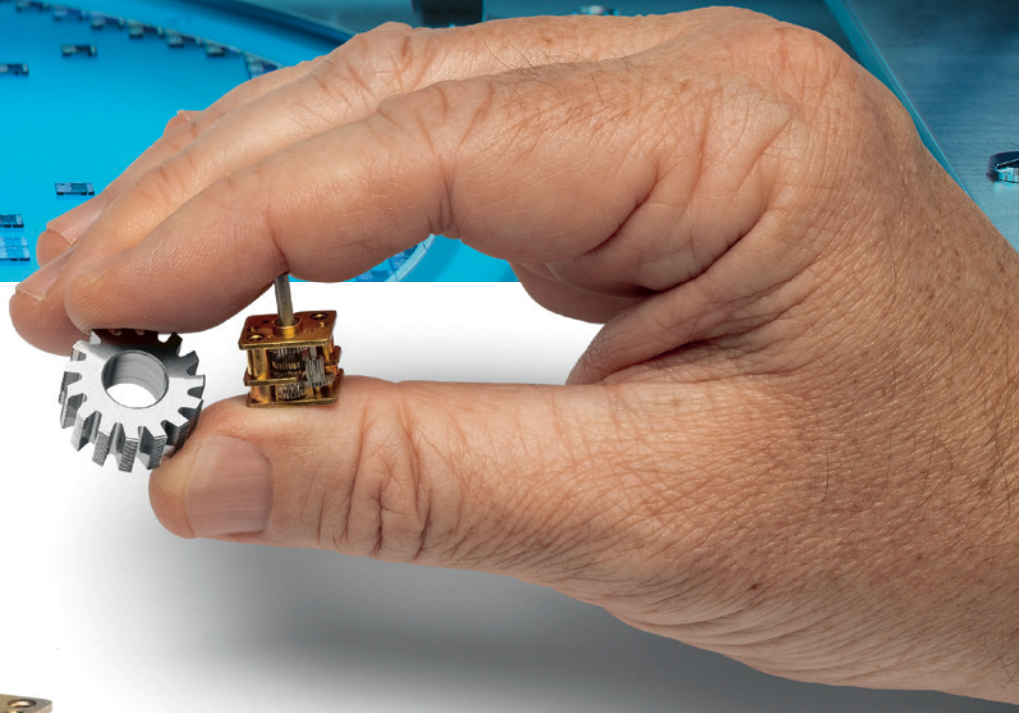

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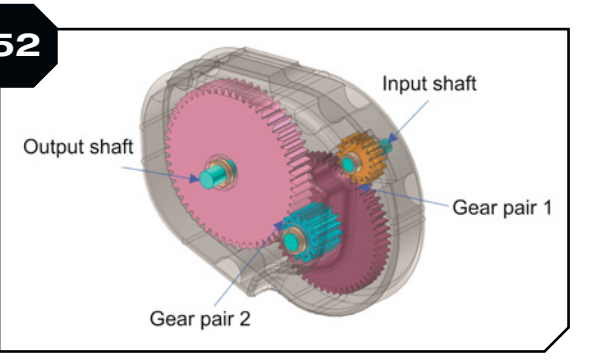

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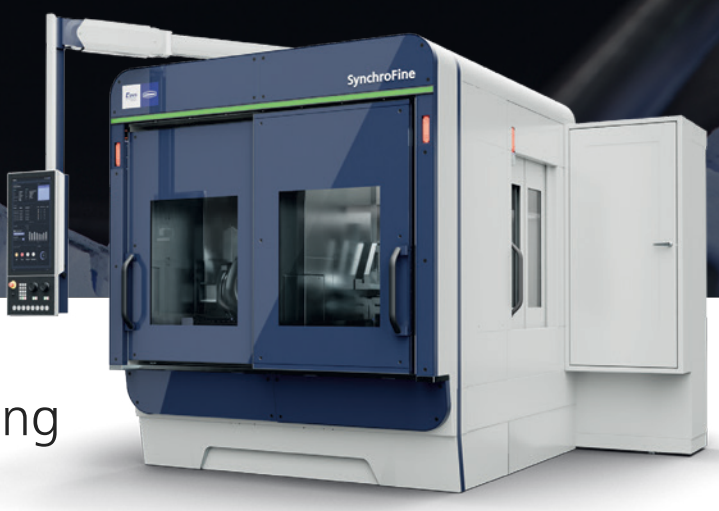

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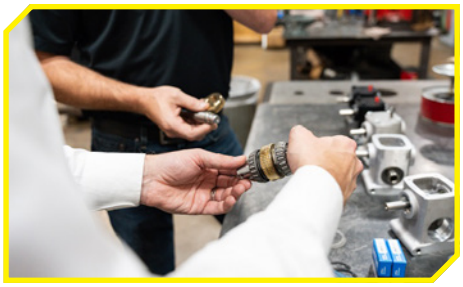
GT VIDEOS

Dayton Gear Doubling Down on Hera Hobbing

The Helios team recently installed a Hera 200 and Hera 500 at Dayton Gear in Dayton, OH. Learn more on page 14 of Product News and hear feedback from the Dayton Gear team at:

geartechnology.com/media/videos/play/273



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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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Holding Pattern

Last year, when I wrote this column about our annual State-of-the-Gear-Industry survey, I urged most of you to consider whether you were working for one of those gear industry companies engaged with the future or one of those ignoring it. I feel like I could run the same words again, and they would still apply.

Clearly there are some very progressive, thoughtful gear industry leaders out there, who are working to solve challenges, understand the threats to their business model and embrace and prepare for change (you can read about one of them, Forest City Gear, on page 33). But there are others who don't seem to fit that mold. They've survived decades in the industry. They have a solid customer base and back orders that will keep their machines running through the next two years. They don't think their old-school business will ever be affected by global trends like electrification or new-fangled concepts like additive manufacturing or IIoT.

The results of this year's survey look much like last year's. Considering that this year is also a U.S. election year, I get the sense that we're in even more of a holding pattern than usual.

The thing about holding patterns, though, is that you need to have enough fuel to keep circling. It's likely that a lot of these old-school gear industry companies will continue to exist. They're cranking out gears, after all, and somebody needs them. That should keep them fueled up and circling for some time. But consider this: Over the past decade, how many similar old-school gear manufacturers have dropped out of the sky—because their owners died, or their business dried up, or they could no longer produce parts as cost-effectively or as quickly as competitors? How many will drop over the next decade?

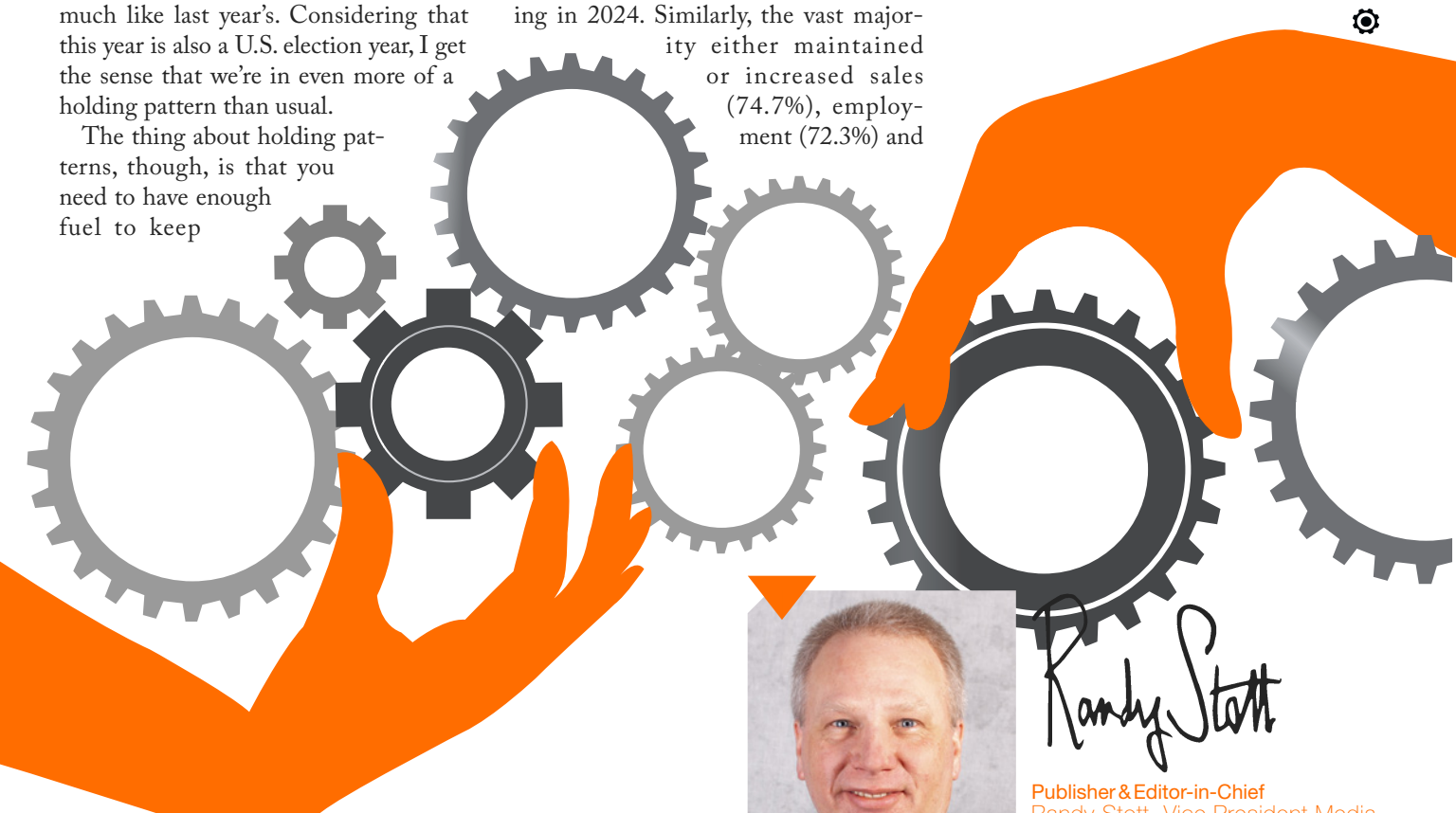
Like I said, I wrote a similar message last year, but my goal here is not to be a pessimist. There is much to be encouraged by regarding the state of the gear industry.

For example, 74% of respondents are optimistic about their companies' ability to compete over the next five years, and this is an uptick from last year's 71%. As AGMA Chair Michael Cinquemani points out in his Voices column (page 10), the vast majority of respondents expect their companies either to maintain or increase their capital spending in 2024. Similarly, the vast majority either maintained or increased sales (74.7%), employment (72.3%) and production levels (69.8%) in 2023—all signs of a healthy overall industry.

It looks like three-quarters of you are doing okay.

The rest might still need some help. My job, and our magazine's job, is to make sure you have all the information you need to improve your operations. It's not called "Gear Technology" for nothing. We focus on the technology, including things like electrification, which might not at first seem to be strictly gear-related, but which could potentially have a profound effect on your business. You might notice a new column in this issue called "Frontiers," written by Mary Ellen Doran, who is Director of Emerging Technology for AGMA. It's just one example of the type of thing we're doing (both as a magazine and an association) to keep you informed and help you navigate these incredible technology changes that are coming.

You see, we don't want to see any of you just circling forever. It's not a winning long-term plan. We'd much rather help you find a safe place to land.



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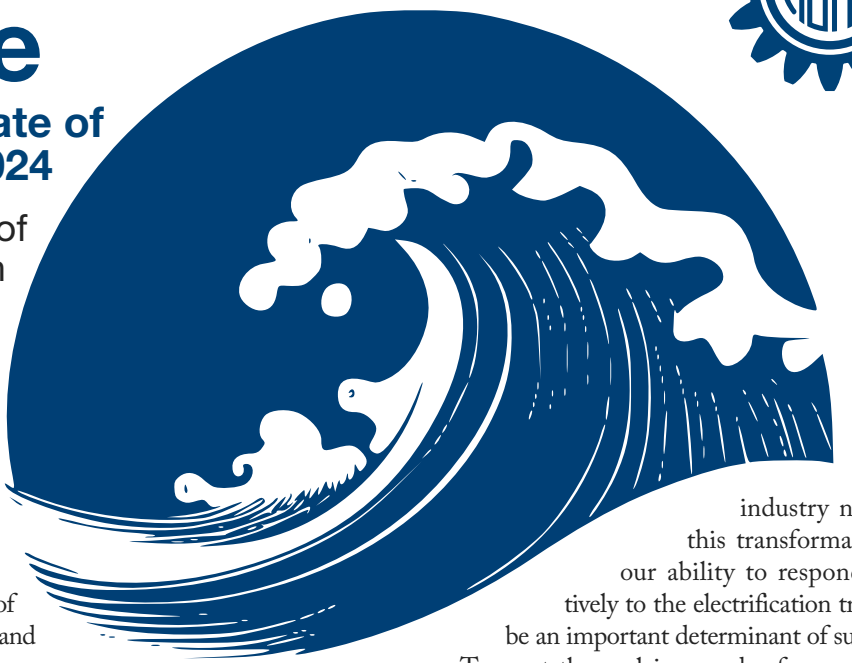
Navigating the Currents of Change

A Reflection on the State of the Gear Industry in 2024

Michael Cinquemani, CEO of Master Power Transmission and Chair of the American Gear Manufacturers Association



As we embark on a new year, let's review the current state of the gear industry, and how the changes of the past several years will shape our path forward. The insights garnered from *Gear Technology*'s annual survey offer a glimpse into the collective mindset of professionals in the field and help us understand how to plan for an ever-changing future.

Gear manufacturers face a lot of challenges, like how to find and retain qualified employees, how to deal with disruptions to the supply chain that are beyond our control, and how to adapt to sweeping industry changes like electrification. It's no surprise that some 15% of respondents expressed some level of pessimism about their companies' ability to compete over the coming years.

But the good news is that most of you are either weathering the storm or even thriving. According to the survey, 47% of respondents are expecting growth in production output this year. When combined with another 40% who expect their production levels to remain stable, the survey indicates a prevailing confidence in the future of the gear industry.

An encouraging 38% of participants expressed their intention to increase capital expenditures in 2024. Furthermore, 44% of the respondents indicated that they plan to maintain their capital spending at 2023 levels, indicating continued strong capital investment in gear manufacturing as we go forward. In total, gear manufacturers are optimistic about growth and plan to invest to support that growth!

One of the more interesting aspects of the survey is industry professionals' description of the prevalent industry trends. A resounding theme echoed throughout the results is the emphasis on "electrification," "EV," and "e-mobility." This aligns with the broader global shift towards electrification. As reported by the EV committee within AGMA's Emerging Technology initiative, this sea change in how transportation is driven, and the innovation required to meet the new challenges are top of the mind for much of the gear industry.

The surge in interest and investment in electrification is not merely a passing fad; it represents a paradigm shift in the automotive and industrial landscape. The increasing demand for electric vehicles (EVs) and the broader adoption of electrified transport solutions are reshaping the requirements for gears. As the gear industry navigates this transformative era, our ability to respond effectively to the electrification trend will be an important determinant of success.

To meet the evolving needs of our members, AGMA is committed to aligning our product development and innovation support with the trend towards electrification. AGMA recognizes that the gear industry's role in supporting the growth of electric vehicles, renewable energy and sustainable transportation is pivotal.

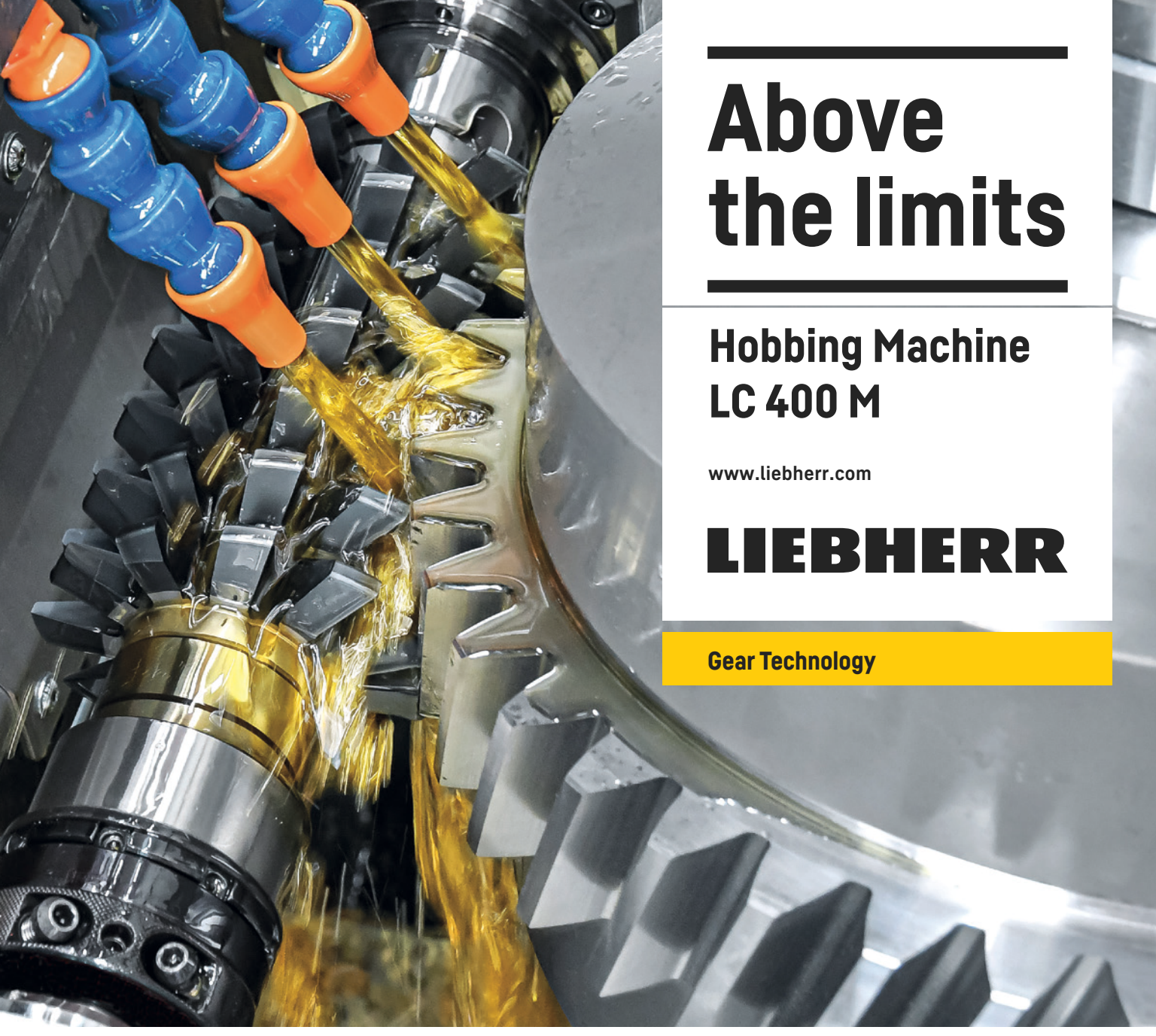
AGMA will launch its first Gear and Gearbox for EV Design class in the first quarter, and an Information Sheet focused on EV in development within our Technical Division is being commissioned in 2024.

It is also noteworthy that the survey reflects a forward-looking approach among gear industry professionals. Rather than merely reacting to market forces, a substantial portion of respondents are proactively "gearing up" for the future, embracing change and innovation and exploring concepts like "automation," "IIoT," "additive manufacturing" and many others. This mindset is a testament to the resilience and adaptability ingrained in the DNA of the gear industry.

In conclusion, the state of the gear industry in 2024 is marked by optimism, strong capital spending, and a collective commitment to addressing the challenges and opportunities presented by electrification. I am confident that by staying attuned to industry trends, fostering innovation, and embracing change, we can not only navigate the currents of change but also emerge as leaders in shaping the future of the gear industry.

Together, let us embark on this transformative journey, driving progress and innovation in the years to come.

Michael Cinquemani
CEO Master Power Transmission and AGMA Chair



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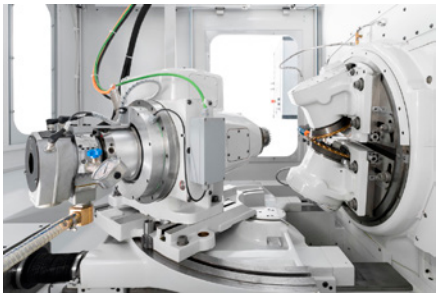
NUM and Lanzi

COLLABORATE ON RETROFITTING A GEAR HOBBING MACHINE



If the cost difference is small, the customer will always choose to purchase a new model machine rather than a retrofitted one. However, when the price difference becomes greater, the conversation changes dramatically.

This is exactly why thirty years ago the company Lanzi—Manutenzioni e Retrofit from Emilia in Italy began offering retrofits on machines, and specifically on gear-cutting machines thanks to an ingenious idea of Gian Luigi Lanzi, from the second generation of the family. The retrofit challenge is far from simple, but one which has evolved over the years relying on a technological partnership with NUM. Retrofitting a gear hobbing machine, including changing the operating concept, is a very complex operation that requires specific know-how and technical skills at the highest level.

Lanzi—Manutenzioni e Retrofit was founded over fifty years ago in 1964 by Francesco Lanzi who specialized in the maintenance of traditional machines like lathes and milling machines. About twenty years later, Luigi Lanzi, from the second generation of the family, recognized a new and untapped market niche, and gradually shifted the company's core business from the original segment to the field of modernizing gear cutting machines. This is when the company first began collaborating with NUM. The new focus of the company, based in Ozzano dell'Emilia (province of Bologna), is still the same today: retrofitting gear cutting machines, with particular attention to the bevel gear sector, and including spiral and spur gears.

"There is a significant difference between the purchase price of a new machine and the retrofit of a hobbing machine," said Federico Lanzi, who has been managing the company alongside his father in the third generation since 2007. "Of course, the retrofitted machines have a slightly lower output, typically a production deficit of about 30 percent, but that doesn't change the fact that the end user can buy three [or], four hobbing machines [for the same budget] instead of just one. So, if the customer does not have space problems in his plant, it is much more advantageous to buy a retrofitted hobbing machine."

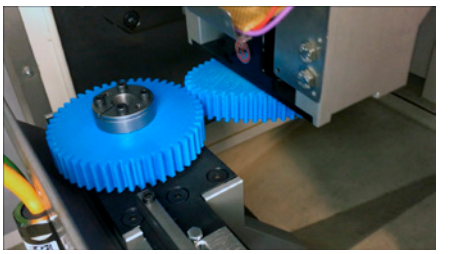
It is also interesting to ask about the service life of a retrofitted gear hobbing machine. This is almost as long as that of a new machine, if not longer, due to the rather large cast iron machine beds with which the original machines are equipped in most cases. Today, when a hobbing machine leaves the Lanzi factory after a retrofit, it is basically a new Lanzi brand machine, CE certified and equipped with Industry 4.0 functions. This means that anyone who decides to buy such a machine can benefit from all the advantages they would get if they had bought a new machine.

There are many key performance gains when retrofitting a gear cutting machine originating from the 1960s and 1970s. First, it can be noted that the new retrofitted CNC machine performs the same machining operations as the conventional mechanical machine, but—quite clearly—with an exponentially higher output. This is thanks to a reduction in set-up and production time, and with a significantly higher quality of the finished gear.

"Compared to a conventional machine," said Marco Battistotti, managing director of NUM NTC Italy, "the CNC machine is also much more flexible in terms of programming. This is because Lanzi has developed their own HMI (operator interface) using functions from our system. This makes it much easier for the specialist to create the machining program."

The retrofit of a hobbing machine always starts with an initial evaluation phase to understand whether it makes sense to carry out the retrofit at all from a technical/economic point of view. "After an initial analysis, the machine is completely disassembled and repainted," said Federico Lanzi, "so that we can then move on to the next phase, which is one of the most important. It consists in fitting the latest generation motors—NUM in our case—to the old mechanics." The machine is then connected to the new electrical cabinet, which houses the numerical control system that controls the machine's three axes.

The long-standing collaboration between NUM and Lanzi has deepened over the years through various projects. The most recent project was the retrofit of an old bevel gear hobbing machine for straight-toothed work pieces. For this, NUM supplied the complete CNC system NUM Flexium+ 8 with all safety functions, MDLUX drives and BPX motors.



"Originally this machine consisted of two milling heads where the cutting edges were synchronized so that the two sides of the workpiece's teeth could be machined simultaneously. The focus of our project was to design the two heads with direct drives inside, to be able to achieve a higher cutting speed and eliminate the mechanical backlash, which is usually the main cause of machining errors," Lanzi said. "With this implementation, we were very optimistic that in the future we will be able to work with carbide cutters, a modification already used in the spiral bevel gear hobbing machines. The special feature of tungsten carbide is that it can significantly increase the cutting speed and thus the machining feed rates, which shortens production times. One challenge in implementing this project was to keep the two cutting heads synchronized. Originally, they moved synchronously because they were mechanically connected and driven by a single motor. However, once they were electronically controlled, they became two completely separate heads, and NUM's support was critical to keeping them synchronized."

To this end, NUM has developed a special function—Electronic Gearbox. It ensures that the two heads remain fully synchronized so they don't collide or misalign with each other which would eventually cause a malfunction.

Much of Lanzi's energy went into increasing machine performance, for example by replacing the crown wheel spindle with a direct-drive ball screw for moving the carriage. It also added optional extras that the conventional machine did not have, such as the connection of robots for loading and unloading the work pieces, and programmable work piece clamping and cutting force controls.

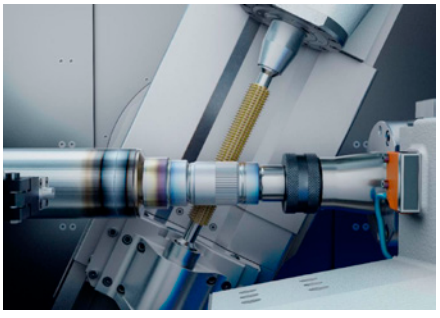
Moreover, is the issue of sustainability.

"Today we are trying to make people aware of the importance of retrofitting also from the point of view of sustainability," Lanzi said. "Upgrading an older machine instead of scrapping it is undoubtedly a much more sustainable decision rather than buying a new one."

num.com

EMAG Koepfer

PRESENTS GEAR HOBBING MACHINE



The fact that electric cars don't have any transmissions (apart from the sometimes-indispensable differential) is just a legend—but one that persists quite stubbornly in the public eye. It assumes that the electric motor does not require any gear ratio given its stable torque. In practice, however, it is usually the case that a so-called 1-speed gearbox is used, which helps reduce the speed of the electric motor by a certain factor. As a result, there are numerous gearing elements on components such as the drive shaft, rotor shaft or axle drive, and their component quality must be exceptional so that, for example, there are no loud running noises—these would be audible given the quiet electric motor.

High Gear Quality Scores

In this context, the technology of EMAG Koepfer is grabbing the attention of production planners. For many years, the specialists have been developing highly versatile mechanical engineering solutions for machining a huge range of workpieces, from gear shafts to steering pinions and worm gears to planetary gears—an ideal experience base for providing highly efficient solutions for the gear cutting of rotor shafts as well. The HLC 150 H gear hobbing machine is one of the focal points here, offering a high level of productivity for components with a maximum length of 500 millimeters and a weight of 10 kilograms. First, the milling head ensures this. It is very rigidly suspended and moves completely during machining. The shift axis is made up of the interpolation of two axes. In this way, a large milling head swiveling angle is realized with a large shift path at the same time. As a result, gear hobbing is very smooth and the gear quality is high. The horizontal arrangement of the workpiece also prevents chip clusters from forming. In the end, this technology ensures enormous performance

figures in the machining of rotor shafts with cycle times of only 35 seconds at a gear quality of DIN Q7.

Can Be Integrated into the Line

On this basis, the machine builders plan and develop complete lines for the rotor shaft in which all machining processes are perfectly linked one after the other—from the soft machining of the blanks to the final hard machining, including the tooth flank grinding processes or skiving hobbing. The HLC 150 H is also used here, which is no problem in view of its integrated high-speed gantry loader. It picks up the components from EMAG's own TrackMotion system, which in a sense, drives through the machines on the line.

K 160 in Use with Two-Piece Rotor Shafts

Incidentally, EMAG Koepfer has the K 160 gear hobbing machine—a solution for components with a maximum length of 300 millimeters and a weight of 2.5 kilograms, which is particularly interesting for assembled rotor shafts, because their individual parts are relatively small and light (before joining). At the same time, this machine can also be integrated into EMAG lines or largely automated. In any case, the high vibration damping ensures long tool life and high surface finishes. Maximum motor speeds at the milling head and main spindle result in high cutting speeds even for shafts with small numbers of teeth.

Overall, EMAG Koepfer sees itself well equipped for the growing e-car boom. When it comes to setting up high-volume production in this area, the gear experts offer highly efficient solutions that can be integrated into the manufacturing flow in very different ways. This approach is highly interesting for any production planner—and not just with a view to the rotor shaft.

emag.com

Dayton Gear

INSTALLS HERA GEAR HOBBERS FROM HELIOS GEAR PRODUCTS

Dayton Gear partnered with Helios Gear Products to install a new Hera 200 CNC gear hobber, followed shortly after by a Hera 500 CNC gear hobber. Helios had a chance to check-in with Adam Baird and Brian Baird, 3rd generation at Dayton Gear, to see how their production has changed since the installation, and how they're planning and looking forward to the future.

"The productivity those things put out is insane... say a part took 30 minutes on one of our old machines, the Hera 200 is cutting the part in 2 minutes; it's that big of a difference." After experiencing the productivity gains of the Hera 200, "it just proved the point even more to go with the Hera 500," explains Brian.

Dayton Gear specializes in gear cutting, and gearbox repair and rebuilding services. Brian Baird reflects on his vision for Dayton's future as "everybody's dream is to have their shop function as a well-oiled machine, and every single year we're making the right strides to get to that dream." Helios continues to support gear manufacturers like Dayton Gear with expert applications engineering support for machines, consumable tools, and automation systems.

heliosgearproducts.com

Zeiss

RELEASES INSPECT 3D METROLOGY SOFTWARE

With the release of the new *Zeiss Inspect* 3D metrology software, Zeiss offers its Industrial Quality Solutions customers numerous new functions. *Zeiss Inspect Optical 3D* is the solution for the inspection and evaluation of 3D measurement data. With this release, data acquisition is further accelerated and evaluation functions are further improved. The new Autosurfacing app also automatically converts scan data into a high-precision CAD model.

Customers master their daily metrological challenges with software from Zeiss. Zeiss Inspect combines various technologies and applications for this purpose. Data evaluation is possible independently of the system. Since its market launch, *Zeiss Inspect* has become the industry standard for optical metrological inspection and evaluation. Today, it includes CT-based quality inspection in addition to optical inspection.

For the analysis of CT data, *Zeiss Inspect X-Ray* offers all the necessary functions. This year, defect analysis will become even easier. The new Multiview function makes it possible to display and analyze multiple workspaces with different perspectives of the component in parallel. Also new: the feature Region of Interest helps to analyze individual parts of a component with different tolerances.

With *Zeiss Inspect*, Zeiss Industrial Quality Solutions lays the foundation for a logical further development of its software landscape. The vision is software that can solve all 3D quality and metrology tasks. Zeiss Inspect thus becomes the 3D metrology software for a wide range of challenges.

Zeiss Inspect forms the core of the *Zeiss Quality Suite* - the one central touchpoint for the user. The platform offers software products and complementary services. Direct access to trainings, updates, news and apps simplifies daily work in metrology. With this year's release, customers can purchase license subscriptions in the Zeiss Quality Software Store in an automated self-service, initially offered in Germany only. Metrologists also have the option of further customizing their software: many apps for solving specific measurement tasks are available in the store, some of them free of charge. The *Zeiss Quality Suite* enables a seamless, cross-product workflow, e.g. combining *Zeiss Inspect* with

Zeiss PiWeb for comprehensive statistics and reporting options. "The *Zeiss Quality Suite* is a holistic, digital control center for metrology," says Christoph Grieser, head of global software sales at IQS.

zeiss.com

Schunk

EXPANDS JAW PORTFOLIO FOR WORKHOLDING

With its new adapter jaw, Schunk has established compatibility between machine vises and the world's broadest portfolio of top jaws from Schunk/Gressel. These useful connecting elements offer new and flexible clamping options for any machining task.

The interface between the machine vise and the top jaws for the specific clamping task depends on the manufacturer. Until now, users have been bound to the respective vise manufacturer's jaw portfolio for this reason. This is now a thing of the past with the new Schunk adapter jaws. They enable Schunk to create compatibility between the vise and its top jaw portfolio, which is the most extensive on the market worldwide. Therefore, users are no longer tied to a specific system, but can now significantly expand their clamping options.

The potential of the adapter jaws for machine vises with a jaw width of 125 mm is considerable. This is because they offer concrete advantages for stationary workpiece clamping on vises, especially in milling machines:

The Schunk adapter jaws open up any top jaw variation for virtually infinite clamping possibilities. Due to this flexibility, many different clamping options can be achieved—not to mention the cost advantages. After the initial investment for the adapter jaws, this expenditure can be amortized very quickly by using the top jaws from the Schunk portfolio, since the top jaws are less expensive than comparable competitor products. Another advantage is the set-up time savings and process optimization due to the quick-change function on some variants of the top jaws from the Schunk portfolio. Screws only must be loosened slightly instead of completely, and the jaw can be easily removed upwards along the grooves.

Depending on the workpiece and application, different top jaws are mounted on the adapter jaws for the respective clamping task. The customer can continue to use its original system jaws, which results in greater cost-effectiveness. Logistics and process planning also become easier—another plus point for users, because thanks to the adapter jaws, the same top jaws can be used on different vises. But there is also a sustainability benefit, as existing products can be reused. And finally, the short delivery times will certainly impress users, as they can access the standard portfolio of Schunk top jaws instead of having to wait for products in special design.

This is how the Schunk adapter jaws turn third-party vises into "partners" for any clamping application, as they create a useful and flexible connection. Now the extensive range of adapter jaws fits vises from market players such as Allmatic, Roemheld or Röhm, for example. Replacing previous system jaws in the vise is done quick and easy—the new Schunk adapter jaws can be replaced one-to-one and are instantly ready to use due to the easy handling—just mount them and get started. No other interfaces are required.

schunk.com

GF Machining Solutions

EXPANDS CUSTOMER DIGITAL ASSISTANCE WITH NEW MY RCONNECT PLATFORM

To ensure all customers and their machines benefit from digital assistance, GF Machining Solutions (GFMS) has launched their new My rConnect platform engineered for the company's EDM, milling, and laser texturing machines. The all-encompassing platform allows shops to connect any model of GFMS machine for fast, responsive, and easily accessible service and support while also providing expanded digital capabilities.

Prior to My rConnect, shops were required to have a connection between a machine and the rConnect software. Additionally, a separate dedicated PC—other than the machine's—was needed to run the software and to access the internet to connect with GFMS technicians.

Now, My rConnect is completely cloud-based, so as long as a computer is connected to the same network as their current GFMS machine, that machine is connected to My rConnect. However, GFMS machines that don't have network access and are connected to the internet can also use My rConnect.

With My rConnect, machines are connected without having them connected, per se. As such, shops gain the ability to contact GFMS for service calls for machines that previously weren't connected by the older PC version of rConnect software. With this capability, they can update a machine's profile with any service information, record repair issues, obtain updated machine documentation, and much more.

A key benefit of bypassing the need for a direct connection is security. My rConnect is password protected and includes an extended level of protection where the system verifies user identity via text message or email code.

The GFMS My rConnect provides a virtual link between a machine and the company's service and support team, often eliminating the need for a technician to travel to a customer's shop. When problems occur with those machines that are networkable, shops create an event for that issue, and a service engineer will log in and ask for permission to access and view the

machine via the live Remote Assist function to diagnose problems at the machine level.

For nonnetworkable GFMS machines, the process is basically the same. However, once a GFMS service engineer connects using Remote Assist, the operator and GFMS service engineer can use the My rConnect audio/video/chat/ and whiteboard to communicate and resolve the problem.

From these types of service calls, GFMS can record data on how a particular service problem was resolved. If that same problem occurs but with a different customer, this database of information allows the service engineer to quickly fix and/or diagnose the problem.

Within My rConnect, users can create groups, such as for the machines in various production facility locations. Once done, they can request any related documentation, such as manuals, for a particular machine. Instead of service having to send it, customers with My rConnect-connected machines can simply download needed documentation.

With a machine network connected to My rConnect, shops gain more digital capability. This includes access to current and future developed applications (apps) that enhance the capabilities of customer machines, and the platform makes new or updated apps easy to acquire. GFMS can push the new apps or application update directly to a customer's machines, notifying them when they log into a particular machine.

One such app is a new version of the company's Job Recorder now for Wire EDMs and a version for its milling machines. The app lets shops record all the jobs they've done to generate efficiency reports based on how much time during a day a machine worked on certain jobs.

Another extremely useful app is the Machine Dashboard. It shows real-time machine status—whether it's running, paused or off.

Central communications platforms such as My rConnect provide fast and comprehensive IIoT connectivity, and according to Chris Jones, president of GF Machining Solutions North America and Mexico, systems such as My rConnect have special appeal in industries such as aerospace, defense and medical part production in particular, that are under constant pressure to record information and validate machining processes.

"Direct internet connectivity," he said, "represents the future of end user-machine builder relationships, and the goal of platforms such as My rConnect is to ensure that a shop's machine is running, cutting parts and generating profit for the maximum amount of time available."

gfms.com

Customize Gear Skiving for Precise, Efficient Gear Cutting

The advantages of gear skiving on machining centers

Evan Duncanson, Milling Application Specialist, Emuge-Franken USA

Emuge-Franken offers complete gear-skiving solutions including tooling, clamping, and process optimization. (All images courtesy of Emuge-Franken.)

Producing many slots on a gear is a challenging process that requires high accuracy. Manufacturers need to achieve high accuracy while being as productive as possible, cutting slots fast. Traditional gear-cutting processes include broaching, shaping, hobbing, or using a specialized end mill. Although effective, each of these methods has disadvantages.

Broaching requires special broaching machines that are very expensive and difficult to set up. Each part must be set up individually, which can take multiple hours. Depending on the complexity of the part, each broach can cost thousands of dollars.

Shaping is an older method of skiving without spindle or part rotation. Shaping is essentially broaching but using a circular tool. As with broaching, shaping requires a specialized shaping machine.

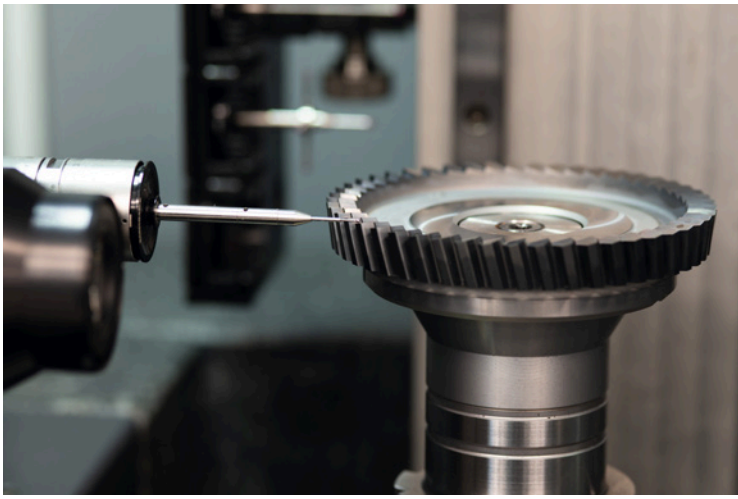
Once again, hobbing requires a special hobbing machine. Hobbing is a very efficient way of machining gear teeth, but the main downside is having to use a specific hobbing machine. Also, the hobbing cutter can be very expensive.

In addition, gear manufacturers may use a special form end mill to cut gears for applications where skiving cannot be applied because it is not involving the ID or OD of the teeth, but this strategy can only cut one tooth at a time. When using an end mill, you can use the same machine and setup for other features on the part. One advantage of this strategy is that it can be used on gear teeth that cannot be machined in other ways. An example of this is a Hirth spline application, where two Emuge special form end mills are efficiently cutting the gear teeth on the face of a cylinder in just one operation.

Gear Skiving Optimizes Slot Cutting

Now manufacturers have a relatively new option that offers several key advantages—Gear Skiving on Machining Centers. Gear skiving on a mill-turn machining center with fully synchronous spindles is highly efficient, fast, and accurate. In some cases when producing small and medium-sized volumes, gear skiving will gradually replace established gear-cutting processes.

To implement gear skiving, the right tooling is required. To begin, work with a cutting tool manufacturer with the expertise to custom design the solution for your specific application needs. For example, Emuge-Franken USA (West Boylston, MA) offers complete skiving technology solutions, and after the design and manufacture of the gear skiving tooling, a datasheet for each tool. The data sheet includes all the necessary machining parameters including recommended rotational



Manufacturing skiving tools is demanding, requiring stringent quality control. A sensor probe may be used to measure dimensional geometry.

speeds, machining time, infeed strategy, and cutting coordinates for each cut. This data sheet essentially provides manufacturers with a tested process to follow for optimal results.

A gear skiving wheel should work on internal and external gears. This can be either a shell tool or a shank tool comprised of HSS or carbide. After the skiving wheel has been designed based on a 3D drawing and the part, the skiving process can be simulated to show the wheel passing through a tooth gap in the gear. In this first step, penetration occurs and results in interlocking and cutting. Then the adjusting screws can be turned until the skiving wheel is geometrically defined.

During the design process, collision checks are performed to produce a tool drawing with all the required parameters ranging from the number of teeth to the axis cross angle, to the recommended machining speeds and feeds. It is important to adhere to these specifications because while deviations from the specified machine speed may not immediately lead to a collision, the gear-cutting quality and result would surely degrade.

Once the tool design has been determined, the skiving tool can be produced. Manufacturing the skiving tool to integrate it into a demanding gear-cutting process requires tactile measurement technology. In addition to optical measurement, your cutting tool manufacturer may use a special sensor probe to measure with high accuracy the proper gear geometry. The sensor probe is a precise, safe, and repeatable method for inspecting the gear skiving wheels, and for scanning and evaluating the complete gear profile.

Skiving Application Success

In a planetary gear carrier application at a large automotive supplier, tool life was quadrupled using an Emuge-Franken skiving tool setup when compared with using competitive specialized end mills. Note that a planetary gear carrier is an essential component of an automatic transmission because it carries the planetary gears, which are needed to couple the sun and ring gears. The central point of an automatic gearbox is the sun wheel, which is orbited by several shafts. These shafts have gear wheels, the so-called planetary gears, and the movement which is similar to that of planets orbiting a central sun. This structure is surrounded by a ring gear. As the name suggests, the planetary gear carrier carries the planetary gears. By changing gears in the gearbox, the interaction of the various gears previously mentioned changes so that the drive operates at the optimal speed and load range.

The automotive supplier tested the skiving solution for the external and internal gearing of planetary gear carriers, and due to the application success, has put the solution into production on an ongoing basis for increased tool life and productivity.

Clamping the Skiving Tool and Gear

It is useful to know about clamping options for both the tool and the gear. Skiving tools can be clamped in several ways. For example, tools with shanks can be held with Emuge FPC Chucks. High Precision/Performance FPC Chucks provide unprecedented rigidity, vibration dampening, concentricity, machining speed, and tool life over conventional chuck technologies for milling and drilling applications. Featuring the world's only chuck with a 1:16 worm gear, the Emuge FPC Chuck's patented design delivers three tons of traction force. The unique design and body provide 100 percent holding power for maximum rigidity, and the collet-cone assembly absorbs virtually all vibration for maximum dampening.

Since the concentricity of the FPC collets is very good, this chuck is recommended for holding the skiving tool versus

Skiving tool with bore is held by a diaphragm milling holder.

using a shrink-type chuck. A tool holder such as FPC ensures less chatter, minimal vibration, and increased process stability and tool life.

However, a different clamping approach is necessary for bell-type roller wheels with a bore. An optimal clamping solution is based on an expanding mechanical element. For example, Emuge-Franken offers an "SG Expanding Bushing" design which is a mechanical solution utilizing a buttress-type thread. The SG Bushing is designed to expand and contract evenly over the entire length of the cutter bore, as well as pull the cutter toward the end stop which increases the rigidity and transferable torque values, resulting in better tooling life. It can be designed with thin walls allowing for a more robust and stable base body. Additionally, the tightly toleranced clamping bolt provides stability, and axial tightening ensures that vibrations can be dissipated into the stop, which is diamond-coated to increase the torque.

When clamping the gear, a diaphragm chuck can achieve superior concentricity and roundness, even on filigree parts. This clamping solution adapts very well to the part contour. It also protects against contamination from coolant and swarf. In roughing operations, the clamping force can be further increased by the pulling force of the machine tool. In addition, due to the integrated centrifugal force compensation of the diaphragm, the part is tightly held even at higher machining speeds.

With the variety of parts that are "roller peeled" today, the diaphragm chuck is commonly tailored to ring gears or similar designs. However, custom clamping solutions featuring mandrels or chucks of other designs can serve a range of part geometries.

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Diaphragm chuck adapts well to the contours of the gear.

Four Tips to Optimize Quality and Reduce Cycle Time in Gear Tooth Profile Grinding

Choosing the right wheel can reduce cycle time and optimize quality.

By Dennis Brown, technical sales manager, Weiler Abrasives

Gear tooth profile grinding, also known as form grinding, is a finishing method used in gear manufacturing. It involves the use of vitrified bonded grinding wheels to modify or correct the profile of gear teeth, often after heat treatment. The grinding wheel runs between two opposing teeth, grinding both surfaces at the same time.

Compared to gear cutting, this process is known to provide a more accurate tooth finish and offers more versatility because of its ability to make a specific, unique profile or to make profile corrections by dressing the wheel with the required corrections or modifications. In most applications, a type 1 or type 4 wheel is used. The machine and gear geometry will determine the size of the wheel.

Profile grinding is used to grind internal and external gears and allows for unique versatility. It can be used on gears that have clearance issues that do not allow for other grinding processes like continuous generating gear grinding. Typically, profile grinding is used to finish larger gear teeth, such as those greater than module 5. This type of grinding is used to produce many types of gears across a variety of industries—from automotive and aerospace to agriculture and energy. The gears can be quite large for some applications, such as those for mining and rock crushing that measure over 30 feet in diameter. However, this method has proven successful on smaller modules as well, especially when gear quality is critical or when special R&D, small-production batches are made.

Because of the quality requirements involved, profile grinding can be a very labor- and cost-intensive process—making it a critical part of overall gear production for a manufacturer. Therefore, it's important to choose the right wheel and to follow best practices that will help reduce cycle time, reduce burn risk, and optimize quality in these operations.

Profile grinding offers versatility and can be used on gears with clearance issues that do not allow for other grinding processes.

Profile Grinding Basics

Gear tooth profile grinding is a discontinuous process that grinds both the right and left gear tooth flanks at the same time, gap by gap. The grinding wheel is dressed in with the exact dimensions of the gear being ground. Most machines use a rotary diamond dresser mounted in, either behind the grinding wheel, on top of the wheel or below it. During the process, the dresser and grinding wheel (or a combination of both) move in multiple axis to achieve the desired gear tooth profile. Compared to continuous generating gear grinding, where the profile is produced by the generating movement, in this process the profile is generated by the profile form that is dressed in the grinding wheel. This helps provide greater profile accuracy.

Most of the time, gear grinding is the last step in the manufacturing process. After grinding, the gear is typically prepared for assembly. The machines used in this process vary by manufacturer and size. Some machines are capable of grinding gears up to 20 feet in diameter inside an enclosure. Other machines are built for larger production batches and can be equipped with automated loading and unloading capabilities, although most material handling in and out of the grinder is typically done manually with hoists.

A high performance profile grinding wheel from Weiler Abrasives, showing the high porosity of the wheel. These high performance wheels offer better form holding and longer wheel life.

Challenges of Profile Grinding

There are several challenges that can affect the cycle time and quality produced in profile grinding. These include:

- **Grinding burns:** Burning is usually the most crucial quality element in profile grinding. When not managed correctly, burning can cause scrap and increased cycle times.
- **Form holding:** The grinding wheel's ability to hold form is the next most-important quality element, and it has a direct impact on cycle time and gear geometry.
- **Operator skill level:** It's crucial that the operator has gear knowledge and machine training in profile grinding. Finding, training and retaining these operators can be challenging.
- **Grinding wheel life:** It's important to choose a wheel that can achieve all the quality requirements while also providing the most tool life. Using the correct grinding strategy can help extend wheel life. This makes application training for profile grinding operators especially key to ensure they are using proper grinding strategies.
- **Incorrect parameters:** The overall grinding strategy must be determined first, then machine parameters can be programmed or adjusted. Using incorrect programming parameters in the profile grinding process can result in increased cycle time, poor gear quality, burning and increased scrap in gear production. Consulting with an application engineer, such as from an abrasives manufacturer like Weiler Abrasives, can improve results.
- **Production bottlenecks:** The profile grinding process can be a source of bottlenecks. For example, very large gears or a grind-from-solid operation may have a two-to-12-hour cycle time. A strategic change to the grinding wheel itself or perhaps a parameter adjustment can potentially cut that time in half or more.

Abrasive Product Options

When choosing a grinding wheel, many formulations are available. Depending on gear hardness, size and finishing method, different wheels will have different results. Other factors to consider include wheel size (width and diameter) as well as rated speed. Different types of wheels can provide varied cutting properties, durability and product life.

Typically, profile grinding operations select an open porosity, vitrified bonded wheel that uses either aluminum oxide grains or high-performance ceramic grains. This differs from the

An example of the profile grinding wheel with the profile dressed in.

Some profile grinding wheels come pre-formed from the manufacturer, as shown in this example of a high performance profile grinding wheel from Weiler Abrasives.

wheels used in continuous generating gear grinding, which typically uses a normal or non-induced porosity wheel. For profile grinding, it's preferred to use a wheel with induced porosity, or very large pores, to reduce the risk of damaging or scrapping the part—which can add considerable cost to the operation—it's important to use the correct wheel for the job. Even if the operation is not running the wheel at its maximum capacity, choosing the right wheel can help avoid disastrous results. One wrong grinding wheel can potentially cost a company thousands of dollars or more if the gear fails after it is installed and in use.

Look for an abrasives manufacturer that can assess your application requirements and produce a wheel for profile grinding that will deliver optimized performance. A quality manufacturer can engineer customized grinding wheels in a variety of grit sizes and abrasive grain types that are adapted for use with a wide range of CNC machines.

Four Tips for Profile Grinding

Optimizing quality and reducing cycle time in profile grinding requires attention to some important best practices. Grinding strategy also plays a pivotal role, so be sure to consider factors such as "how many teeth can we grind before we need to dress?" Keep in mind these four tips for profile grinding:

1. Better form holding:

There are two elements in the grinding cycle to consider: grind time and dress time. The in-cycle dress time can be between three to eight minutes or more. Therefore, the better you can hold the form, the longer you can cut between dress cycles and the faster your cycle time will be. This makes application training for profile grinding operators especially key to ensure they are using proper grinding strategies. Consult with an abrasives manufacturer to formulate a wheel with optimal grain and bond technology to maximize form holding.

2. Cooler cutting:

The most crucial quality element in profile grinding is the risk of burning. Burning, or tempering, is when the tooth surface has been exposed to very high temperatures from the grinding process. This can decrease hardness and cause stress to the

gear material, resulting in cracking that will lead to gear failure. Most machines have high-volume coolant systems that allow for adequate flooding properties to wash away metal chips created by the grinding wheel as well as high-pressure nozzles to clean the wheel. Before a grinding wheel can be chosen, these conditions must be met or the wheel will not perform as designed. A wheel that cuts cooler can provide numerous benefits. As you increase performance and wheel aggression, it's important to choose a cooler cutting wheel to avoid burning the part and possible wheel failure. A wheel grinds cooler by maximizing the exact timing of the grain releasing from the bond and by having the proper grain technology for the job. When a high-performance grinding wheel can cut cooler, it may be possible to cut faster. In addition, having the gear blank roughing process as accurate as possible or of optimal geometry and size before grind will lower the risk for quality failures and help stabilize the grinding operation.

3.Increase wheel life with higher cutting volumes ($V'w$):

Cutting volume is the measure of how much gear tooth material can be removed before the geometry must be corrected, also known as when form loss occurs. When a machine is set up, the form is dressed into the wheel and the gear is ground—so the form is on the gear. The same form on the wheel is copied onto the gear. How many times this can be done before the form is out of tolerance or unacceptable is known as the achievable cutting volume, which is a volumetric calculation. Remember, the in-cycle dress time can be several minutes; therefore, cycle time reduction can be achieved by optimal grinding and dressing strategy. Different grinding wheels have different cutting volumes. Generally, economical grinding wheels have a lower cutting volume, while high-performance wheels have a very high cutting volume. Higher cutting volumes will equate to longer wheel life and lower cycle time. A lower cycle time is achieved by reducing the amount of dress intervals. When the grinding strategy is correct and optimized, you will get the best result from a high-performance wheel.

4. Reduce cycle time with high material removal rates ($Q'w$):

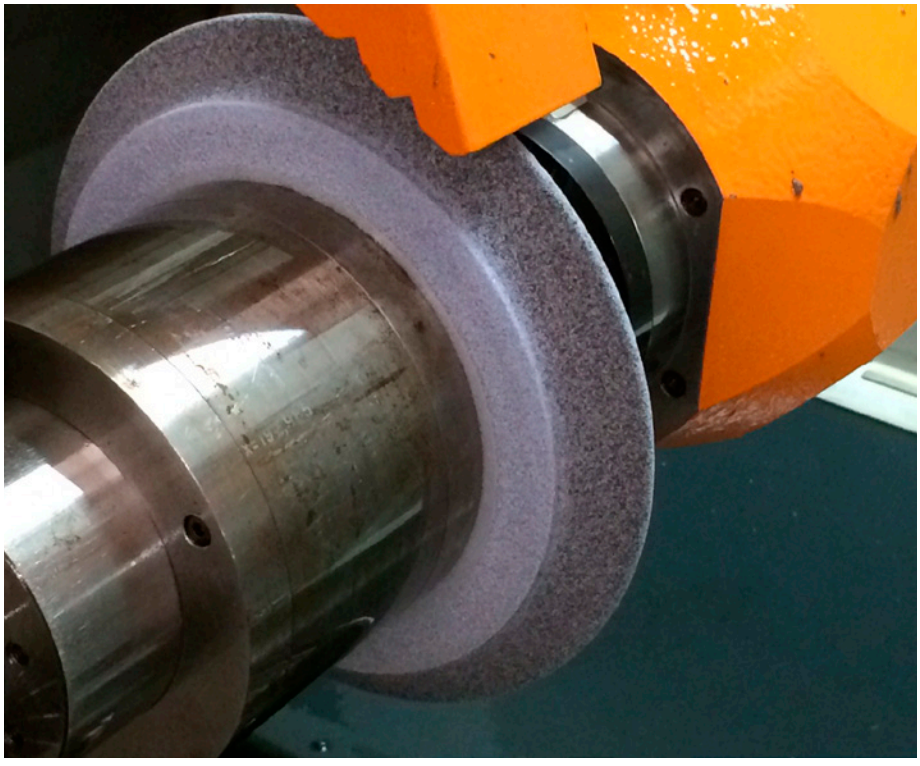
Improving the material removal rate (MRR) will decrease cycle time. Material removal rate is a metric used to understand how fast workpiece material is removed by the grinding wheel. The higher the value, the higher the rate of removal. A higher MRR can be achieved by either increasing the amount of stock or increasing the wheel feed rate—or a combination of both. The formula for $Q'w$ is:

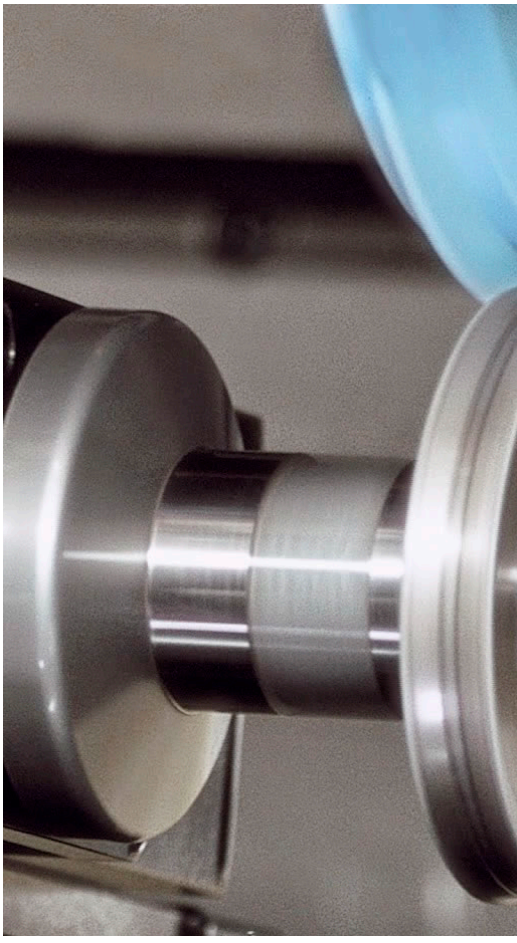
$$Q'w = (a_e * v_w)/60$$

where,

a_e = amount of material, units in volume

v_w = feed rate, units in distance/time





Profile grinding with the wrong wheel can add considerable cost to an operation. This example shows extreme loading on a profile grinding wheel because it was the wrong wheel choice for the job. Working with an applications engineer can help avoid this issue.

Depending on the grinding wheel technology used, a high feed rate may be preferred instead of a low feed rate and high stock removal amount. This is a common factor used in grinding and is usually one of the first questions asked by operators. The $Q'w$ formula shows you can adjust the material removal rate by understanding how to apply the correct grinding wheel technology to optimize stock amount, feed rate or both. It is important to note that gears with a low number of teeth have a variable $Q'w$ along the profile from root to tip. Because the profile angle varies from root to tip on medium- to large-pitch gears, this type of gear will require a different grind strategy to achieve quality and prevent burn. As with other elements of the grind process, $Q'w$ is impacted by the coolant system, gear geometry and other factors. Consider also that as you increase the removal rate in terms of feed rate, it can put added stress on the machine and cause premature machine failures, adding maintenance and downtime.

Improve Profile Grinding

Quality and efficiency are critical in profile grinding. A gear application engineer can design a grinding strategy for a specific gear before taking the machine offline and set-up begins. Working with an application engineer from a grinding wheel manufacturer will give the operator or tooling engineer valuable data to design the grind program with optimal grinding rates and cutting volumes for the specific wheel technology being proposed. They can also determine if the grinding wheel technology is correct or if it needs to be redesigned or changed. Manufacturers want to be cost-effective and reduce cycle time in profile grinding, but first and foremost they must maintain extremely high quality, making cycle prediction with programming crucial. The right grinding wheel manufacturer understands these challenges and can work with operators and engineers to formulate a wheel that is the best fit—to help save costs and optimize cycle time without sacrificing quality.

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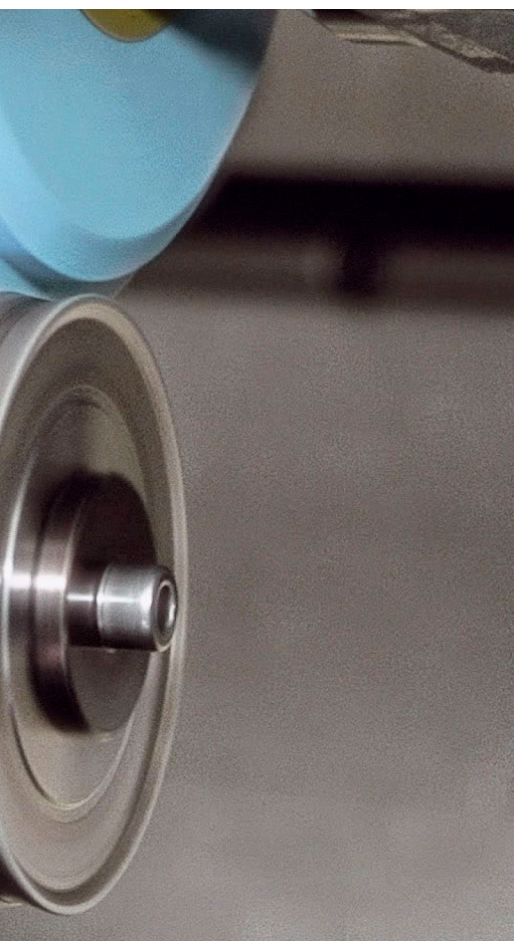


Action of a profile grinding wheel being dressed to demonstrate the method used.

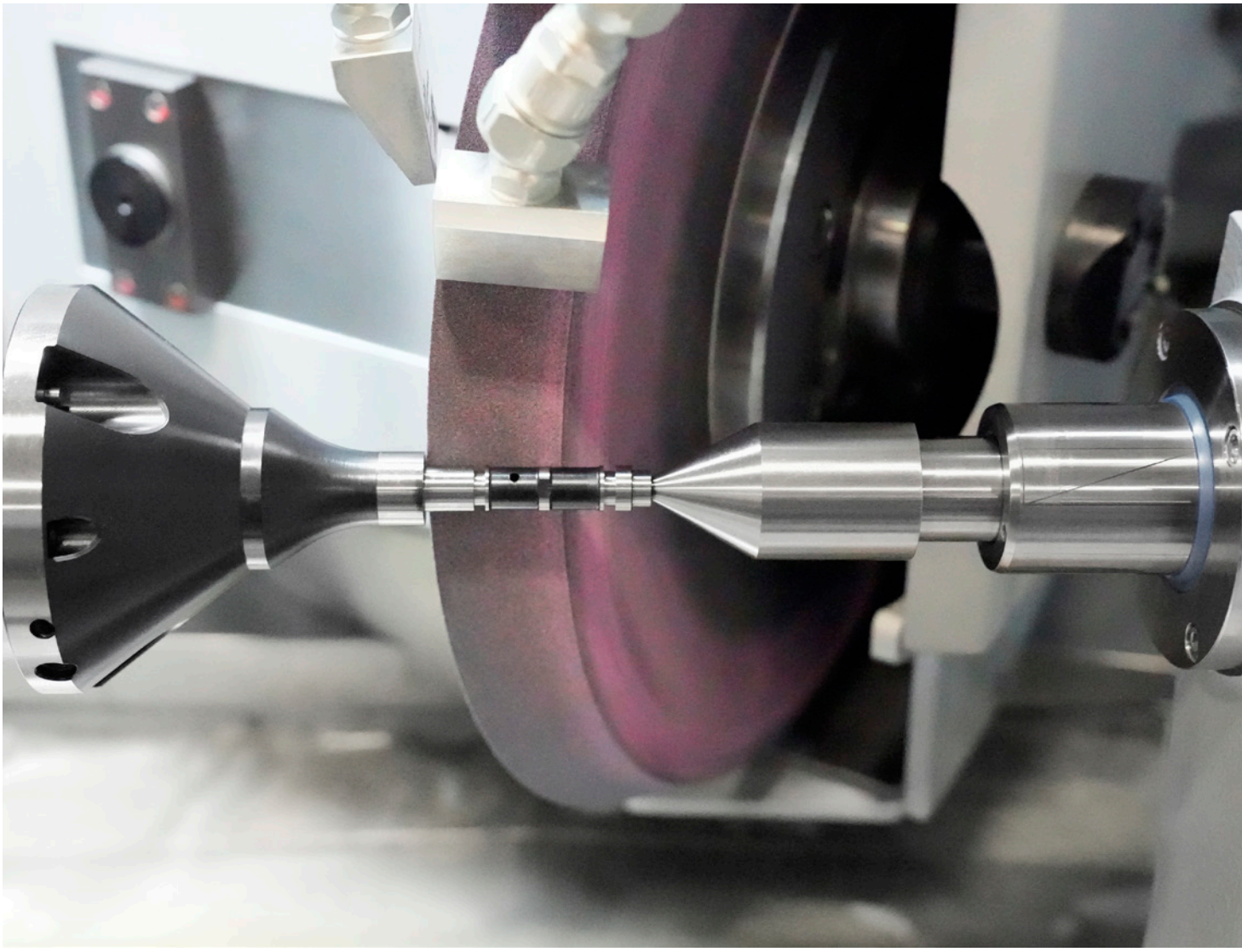
An open porosity, vitrified bonded wheel uses either aluminum oxide grains or high-performance ceramic grains. For profile grinding, it's preferred to use a wheel with induced porosity, or very large pores, to reduce the risk of damaging or scrapping the part. This image shows an open porosity wheel after grinding with no sign of loading.

Hydraulic Workholding Expands Its Horizons

Extremely accurate and impervious to contamination, hydraulic clamping is ideal for e-drive and other applications where producing high-precision gears is paramount.

Robert Peyr, Director Product Management, Global Services & Workholding
Gleason Corporation

In a world where hard finishing operations are now commonplace and high precision is the rule rather than the exception, many gear manufacturers are taking a closer look at workholding. Manufacturers have come to realize that workholding, long under-appreciated and over-looked, can play an important role in squeezing precious seconds out of idle time, help reduce costly runout on precision gear teeth to just a few microns, and cut the high cost of maintenance and repair.



New manufacturing cell, dedicated to hydraulic workholding, gives Gleason total product quality control throughout the entire value stream. This includes the final hard finish grinding before the workholding is assembled, tested, and inspected.

A Bright Future for "Fluids"

But not all workholding is created equal—and your tried-and-true mechanical device may, or may not, be the perfect fit. A new generation of hydraulically actuated workholding solutions can outperform their traditional mechanical counterparts in many of the high precision gear production applications that are increasingly common today—like hard finish grinding, honing, power skiving, and even downstream in the other non-gear machining operations.

The latest improvements in design and manufacturing have resulted in a new generation of hydraulic production expanding arbors available for, but not limited to, the 12 mm to 100 mm diameter size range common to today's e-drive transmission gears. These arbors deliver an extremely precise and repeatable clamping force when hydraulic fluid pressure is applied to a thin-walled, precision-machined expansion sleeve. The sleeve expands as required by the application uniformly across the entire chucking length of bore ID or shaft OD, ultimately guaranteeing a runout below 3 µm TIR or better, as compared to the 5 µm (or below) runout that can be expected from its mechanical equivalent. The hydraulic arbor expands into the bore to clamp, leaving zero clearance, whereas a mechanical system requires a small clearance, thus compromising accuracy. Mechanical systems also require an axial clamping element; the hydraulic system's inherently high bore clamping forces eliminate this need. Note that the automatic chucking system is designed with a pressure balance feature to prevent over-expansion. It can also be expanded without a workpiece with no risk of damage, since its maximum expansion range can't be exceeded. This makes hydraulic clamping much more consistent and repeatable part to part and helps reduce workpiece non-conformities to the "near-perfect" levels that are quickly becoming the norm—not only e-drive gears, but in countless other applications where quiet, long-running gear precision is now so critical. Hydraulic systems can be a particularly good, highly

New generation of high-precision hydraulic workholding, ready to meet demand driven by e-drive and other high precision applications.

economical alternative for clamping parts with very small-bore diameters too, since they eliminate the challenges of producing small, high-precision collets of various diameters required for mechanical systems.

Additionally, hydraulic workholding, with its completely enclosed system, seems almost tailor-made for the hard finishing operations that are increasingly in use to raise the workpiece quality bar, whether fine finish grinding or honing of e-drive gears, or hard power skiving of larger parts. The swarf produced as a by-product of these operations, particularly when producing smaller parts dry and in higher volumes (and larger internal gears as well where chip evacuation can be difficult) can play havoc with mechanical workholding and cause frequent and costly downtime for maintenance, cleaning, and lubrication. Hydraulic workholding is by design completely sealed, and impervious to contamination of the type that greatly affects more exposed mechanical components.

But the many benefits of hydraulic clamping don't end there. The thin-walled, high precision expansion sleeve at the heart of these systems delivers a powerful, consistent clamping force uniformly across its entire length. This makes it particularly well-suited as a clamping solution for both thin-walled parts and multiple-stacked parts production. The sleeve can even be designed with multiple expansion zones to accommodate the stacking together of parts with different diameters. It can also be more easily applied to complex gear designs that include internal bore features with varying diameters.

That's not to suggest, however, that hydraulic workholding is a "one size fits all" solution. A strong case can be made for mechanical workholding in applications where a hydraulic system's more limited expansion range makes it impractical, or where the benefits of the latest modular mechanical systems outweigh those of a hydraulic system. Ultimately, a cost benefit analysis must show that the initial higher price of a high-precision hydraulic device will be more than offset—whether by reduced maintenance downstream, improved part quality, or by reducing the cost and lead times for the multiple mechanical collets that a single hydraulic device can replace. Gear manufacturers are, by nature, wary of change and what worked in the past can seem good enough. Naturally, questions arise: Will hydraulic workholding be harder to source on time? And thousands of duty cycles later, can the user be assured of responsive maintenance and service when a seal leaks and hydraulics need to be replenished, or when the expansion sleeve or high-pressure piston experiences wear?

Best of Both Worlds

Gleason has embarked on a multimillion-dollar capital investment program to build out our workholding resources in the United States, Europe, and Asia. With e-drive applications and hard finishing processes expected to drive demand for hydraulic workholding even higher, the objective is to offer the best of both the workholding "worlds," whether mechanical or hydraulic. This includes Gleason and non-Gleason gear and non-gear machines. At its Rochester, NY, production facility, Gleason has invested in a dedicated manufacturing cell for the most critically important components found in a typical hydraulic workholding system. It's where new designs that result from the vast experiential knowledge base and the application of powerful software design tools converge with highly productive manufacturing resources to bring these products to life. Long-range capital investment in Rochester, as well as in parallel projects at the Munich and Suzhou, China, facilities, will give Gleason total product quality control throughout the entire value stream.

These new manufacturing cells not only add capacity to existing manufacturing resources used to produce more basic components for workholding but enable the production of those components requiring the highest precision and the most diverse and specialized designs. In the case of the critically important expansion sleeve, for example, Gleason can respond more quickly to any wear or repair issues that might result downstream. The Gleason design allows for this component to be easily repaired or replaced, as compared to competitive designs where this component is soldered in, making it difficult or impossible to repair. The cells will also help accommodate an extremely wide application for hydraulic workholding: from a 50 mm bore diameter on an e-drive transmission gear, to a 500 mm diameter hard-power-skived internal gear, to non-gear, small to large part machining operations such as turning. Most importantly, Gleason will now be able to build longer service life into all the wear components of these latest hydraulic systems, and react faster when service is required, anywhere in the world.

gleason.com/workholding

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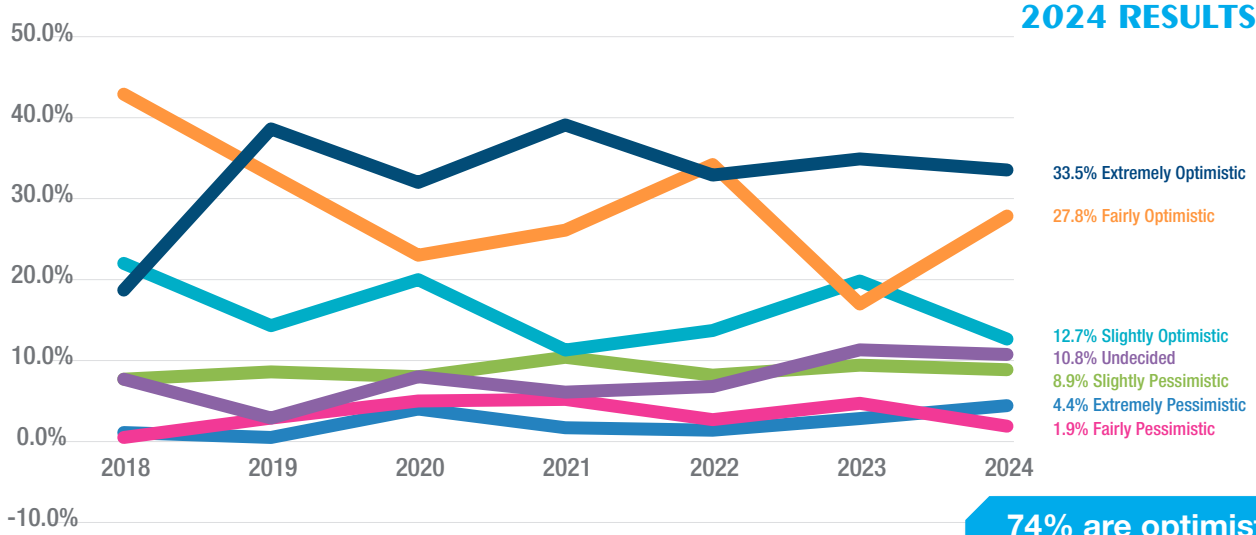
2024 State of the Gear Industry

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 email to our subscribers, AGMA members and others in the gear industry. Primarily, our responses come from North America, but they also include responses from around the world. Nearly 200 individuals responded to the survey.

Please describe your level of optimism regarding your company's ability to compete over the next five years.

2024 RESULTS



74% are optimistic about the future

Describe the most important trends affecting your business and the gear industry in 2024. What should our readers know about these trends?

"Expansion of the automotive EV market and the Defense Industry."

"The EV vehicle's entry is a big challenge to gear industry productivity."

"The readers should know that the United States Government has allowed the Chinese to flood the American Oilfield Market with inferior gear reducers. They should have concentrated on helping American Manufacturers promote their products in China like the Chinese Government help their manufacturers. It is also a National Security concern when the United States has to depend on China for replacement parts to keep the crude oil producing equipment in operation."

"The electrification of vehicles."

"Since EV gears in the auto industry is picking up, the need for focusing gear finishing at required surface roughness is necessary. A few gear machine manufacturers have come up with some grinding solutions, but the trend will demand the finish from design stage."

"Automation in general—robotics—use of precision gears."

"Small module gear grinding."

"New gear technologies related to EV, microgeometry of gear manufacturing and inspection methods."

"Requirements for gearboxes which are operating with high pitch line velocities and power."

"Rising costs."

"Expansion of acceptance for epicyclic gearing in use for the oil and gas industry to lower pitch line velocities for higher power and speeds."

"Automation and the need for an expert to observe the automated process. The expert will be using AI for

Forest City Gear Examines 2024 Machine and Personnel Investments

Kika Young, president, and Jared Lyford, director of operations at Forest City Gear recently discussed the state-of-the-gear industry from the job shop perspective. The greatest challenges facing the custom gear manufacturer includes the rising costs of perishables, consumables, etc. as well as the ability to find skilled labor. Three priorities FCG will focus on includes:

a. Utilization of its direct labor force to be monitored and measured through more advanced tracking technology.

b. Investment in new equipment (this will be further vertical integration and will include a mill-turn as well as inspection technology) this helps to consolidate the vendor base and therefore lower the risk of outside suppliers.

c. Managing rising customer sophistication and the costs that come with it.

"As our customers get more sophisticated and have higher inspection requirements, higher program requirements, demands for export control and cyber security—keeping up with pricing to capture these overhead costs can be difficult."

–Young

In terms of machine technology and utilization, the gear manufacturing community is evolving.

"From the perspective of a job shop, you see alternate solutions for gear manufacturing, such as multitasking machines, coming into play for the lower volume prototype opportunities—thus making it less advantageous for a higher margin loose gearing manufacturing to capitalize on these smaller run opportunities. One aspect to secure new customers is providing front-end value and this type of machine capability has cut out some of this value-add from a DFM perspective," Lyford said.

In addition, Lyford explained that the power of engineering software (*SolidWorks, Inventor,* etc.), has allowed a younger/less experienced generation of engineers to design parts which are more complex and therefore much more difficult to produce—thus creating even more need for the expertise of the custom gear manufacturer. Overly complicated designs due to more capable software and less experienced design engineers are causing this overall lack of design for manufacturability.

FCG will continue to focus on building its own workforce and training/promoting from within the organization. Young discussed the importance of getting new employees in front of machine tools to enhance their technical skillsets.

"There are several different aspects to this the first of which would be learning style. It is helpful and advantageous for many visual and hands-on learners to see a task in person and complete it themselves to fully understand the mechanical concept. There is a great deal of opportunity when you're focused on hands-on training where theory is in practice. Conceptualizing an idea out of a textbook is a lot easier when it is physically happening in front of you. It is easier to synthesize the information in front of you when you understand the practical (and not just theoretical) application," Young added.

FCG is planning to expand its presence in manufacturing through organizations such as the National Tooling & Machining Association, AGMA, IMEC and the local chamber of commerce.

Both Young and Lyford see several emerging technologies influencing gear manufacturing:

"As far as additive manufacturing there is an opportunity in 3D printing primarily for workholding and tooling from our perspective," Lyford said. "Additionally, we see it as an advantage to create protypes models for our engineers as they begin to do process planning for new and complicated parts."

FCG was an early adopter of robotics and automation on its gear cutting equipment.

"Within our business we see the ability to leverage robotics and cobots to offload some of the basic part loading and material handling operations which today are primarily done by our direct labor force. Cobots would allow us to train our operators to focus on more delicate and/or feature critical activities."

–Young

forestcitygear.com

the context recognition of errors in manufacturing or procedural errors."

"Electrification of drive systems."

"Foreign competition buying market share. Management adversity against risk. Long lead times for bearings, forgings."

"Competent machinists or lack of them."

"Impact of coatings on gears and how they affect the performance of lubricants is a growing concern. The use of different coatings can have different performance results, resulting in different formulations, which could lead to a need for more specialized lubricants."

"EV push and market acceptance, mining expansion in North America, political support for mining given EV push."

"Customers are developing applications that will require gearing that has a smaller footprint, requires less energy/has better efficiency, and has greater precision."

"Ongoing shortage of factory replacement gears and long lead times."

"Lack of skilled gearing engineers knowledgeable in both design and efficient/effective manufacturing of gears. Transition from ICE to electric drives requiring a different gear and gearbox design (higher input speeds). Conventional gears are commodities and will be produced by low-cost countries due to higher steel and labor costs in the U.S. (except for prototypes and repairs)."

"Electrification of cars."

"Electrification."

"China/Asia competition. Low cost of production."

"Vehicle electrification."

"We should stop making the parts we lose money on and be more selective about the new parts we take on. Currently grasping to make anything."

"The new technical developments of my company will support our market position and will help us to grow more in the following years."

"Improvements in powdered metal options."

"Gear manufacturing for e-vehicles worldwide."

"Economy ups and downs, electrification, materials change, heat treatment advances."

"Materials cost. processing innovations."

"Torque density (increased torque in smaller packages) and overall weight."

"Finish hobbing and gear grinding will be the focus. Gear shaving is going to reduce a lot."

"Gear train in both transmission and engine are reducing as EV is taking over, but ICE will continue to be dominant with hybrids competing with EV."

"The lack of capabilities in the U.S. and on-time delivery across the board is only showing minimal improvement."

"Competitiveness arising from China and India."

"No new people coming into the business as technicians, engineers or on the shop floor. The so-called CEO/Operations Manager/CFO would rather ship the work and knowledge overseas or across borders than keep home."

"Automotive: Electric cars mean fewer gears are required per car."

"Cost and overseas competitors."

"Gears for electric drive units without noise."

"China."

"Employees & cybersecurity, healthcare."

"Change in technology to hybrid and EV."

"Global uncertainty, disruption of supply chains, economic recession."

"New workers and financing."

"Lack of personnel and lack of resources to train them."

"Waviness on the gear tooth originating at the hard finishing operation resulting in NVH topics at EoL or in the field."

"Ever-increasing demands on tool precision while not allowing for appropriate price increases, among others."

"Continued investment in new plant and equipment, experienced employees."

"EV transmission shift from IC segment. Less noisy gears, gear microgeometry evolution."

"Upgrading in machine and tooling technologies, the volatile alloy steel markets."

"Energy change in vehicles."

"Upgrading equipment/CNC gear equipment."

"Electrification of the drivetrain."

"Electrification in agricultural implements."

"Cost competitive gear manufacturing, low noise gear design, high power density gears."

"Continuing supply chain issues for raw materials."

"Geopolitical unrest in the world."

"Constant pressure to keep prices low. The whining from customers is incessant."

"Integration of sensors in gears."

"Silence, reliability, availability, delivery, cost."

"Fully automated drives with self-locking gears."

"Transport electrification."

"General lack of knowledge by most of our customers in the way they treat gearboxes in their plant. Overloading and lubrication issues."

"EV gear boxes including differentials."

"EV gear systems."

"Power skiving, scudding process is getting momentum over shaping, broaching and penetration will increase with increasing mobility volumes."

"Inspection and various evaluation techniques."

"Design optimization of gears and gearbox components for minimal global competitive cost, having higher torque rating without compromising the quality, ensuring the reliability and durability of the gearbox."

"International relations and geopolitics."

"Becoming carbon neutral."

"Hardening methods to address material distortion. Hardened material machining for better gear accuracy. Functional and manufacturability vs encompassing requirements that tend to be interpreted in many different ways."

"Aerospace is very busy."

"Customers want more data, faster lead times and lower price points."

"Improvements in manufacturing gears, especially surface condition."

"High quality gears will be the trend, and the metrology aspect will be relevant."

"Big influence of IT."

"The main trend that is positively affecting our business is the trend towards electrification in the automotive industry. Great opportunities are opening up for new technologies for the manufacture of electric cars."

"The electrification trend."

"Offshoring of gears due to labor costs. Cost of running a manufacturing company in California is just too expensive to continue in this state."

"Rising steel costs, lack of skilled manpower, increased material costs, etc."

"Continued strong oil and gas market."

"EV."

"Increasing E-mobility for bikes, cars, trucks."

"Automation is becoming a very important consideration in gear manufacturing. 3D printing is going mainstream and will be utilized in gearing. EV market is evaporating due to poor performance and lack of interest."

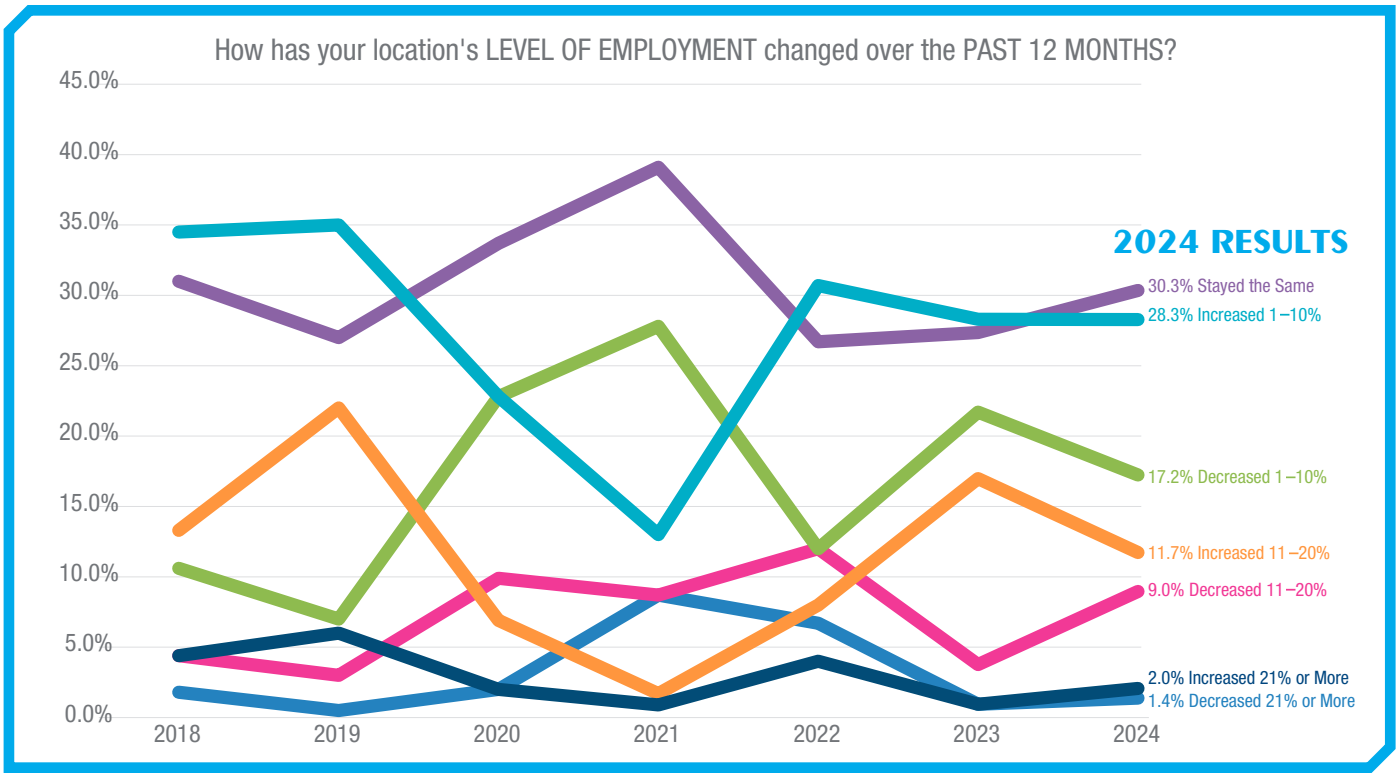
"We are not state-of-the-art. We are unaffected [by most trends]."

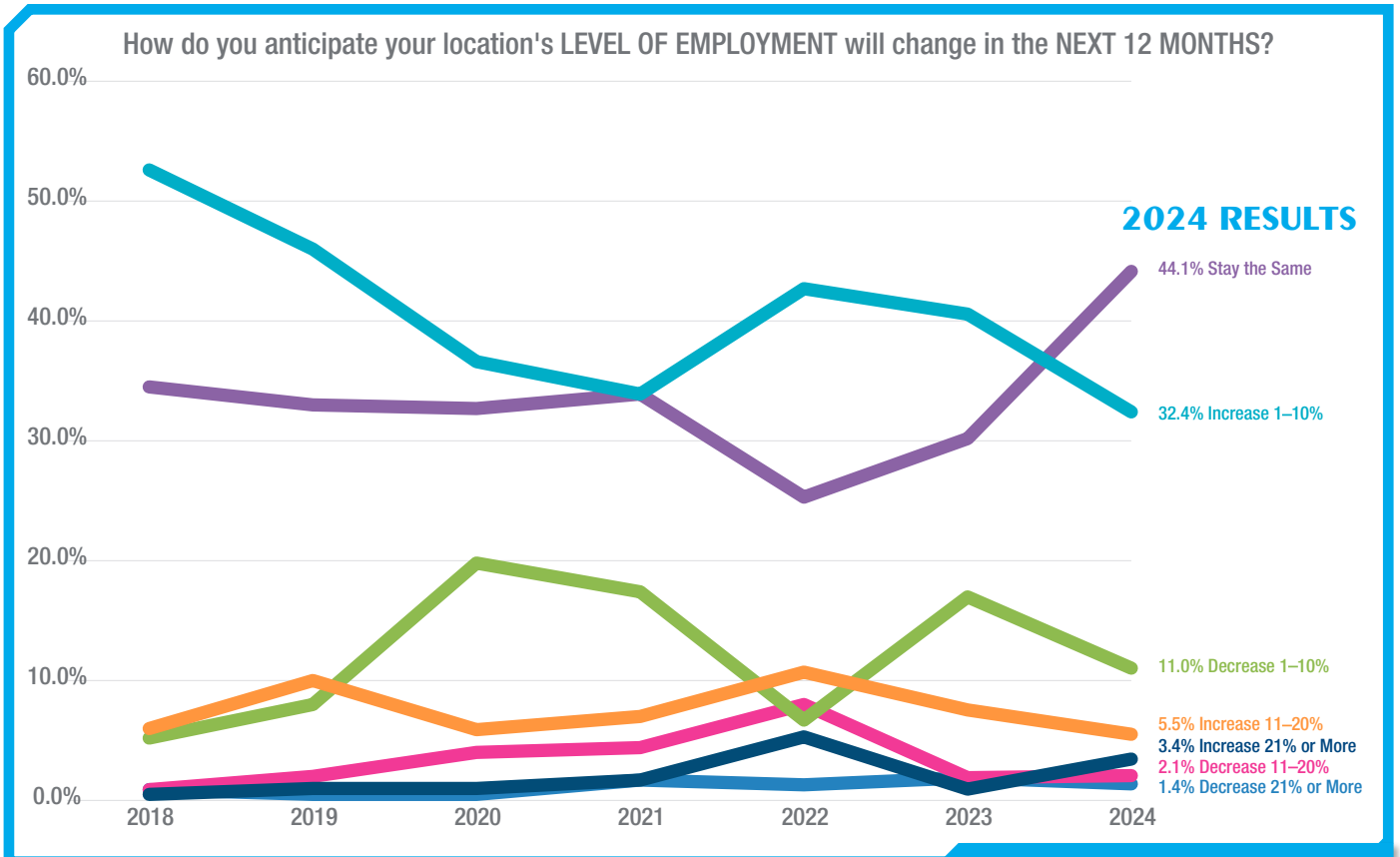
"Additive manufacturing of gears and polish grinding of gears."

"Health of automotive industry."

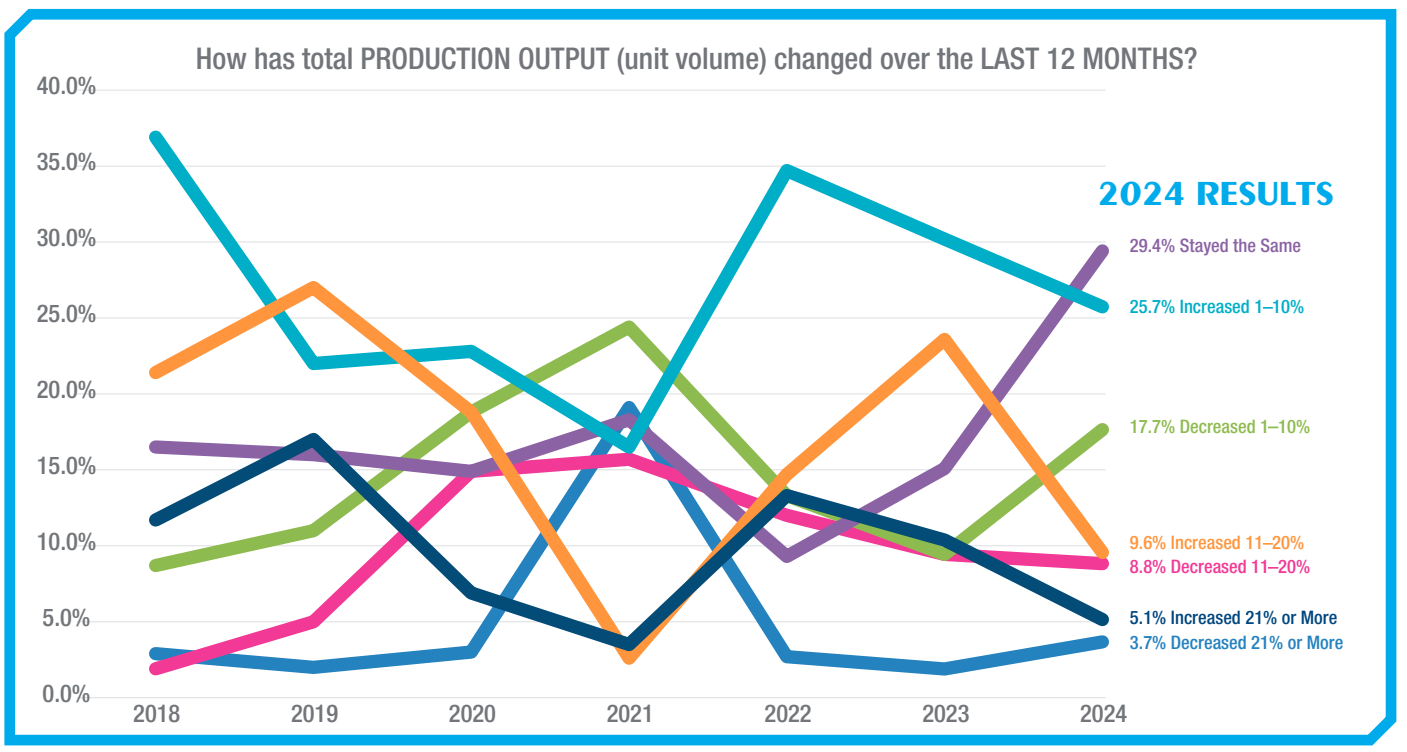
"The use of 3D printing and how gears could be produced with it."

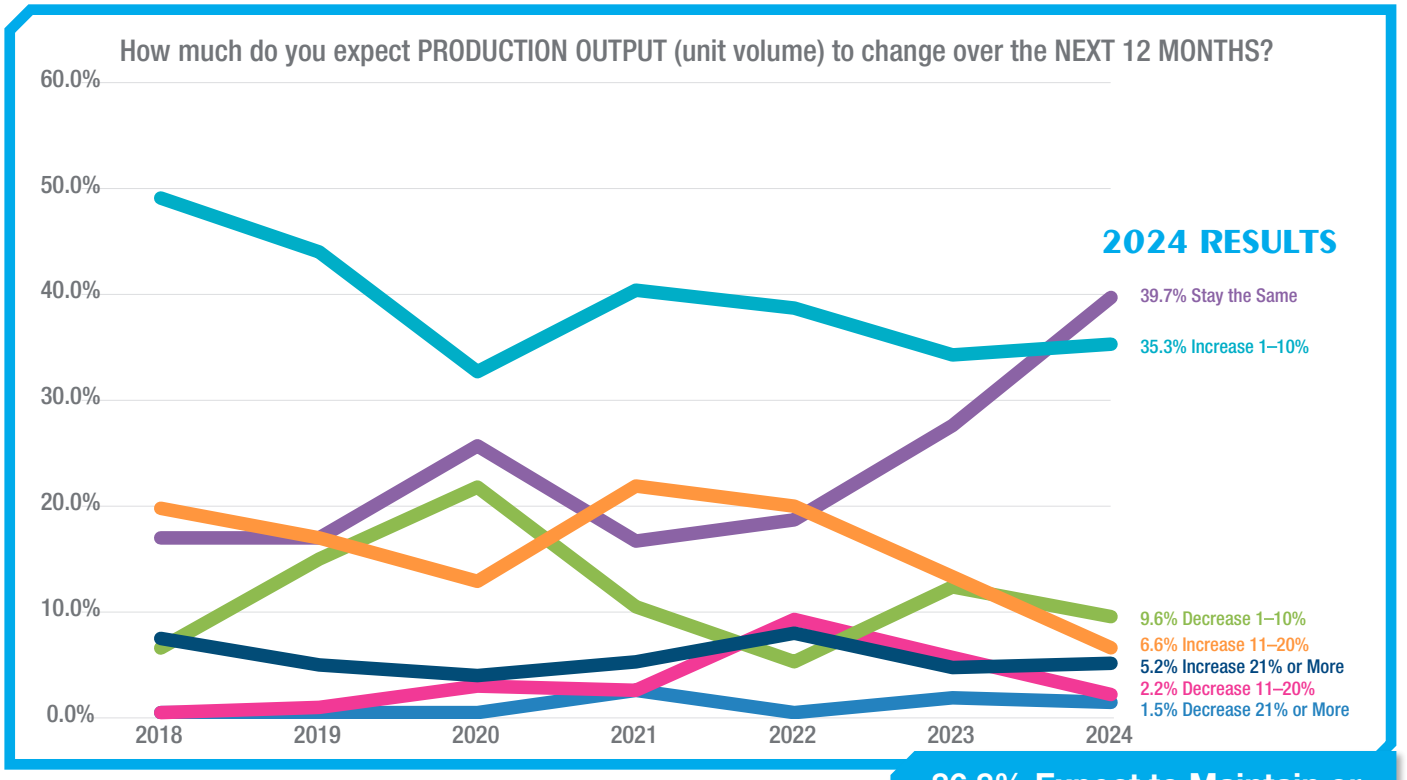
"More of our customers are purchasing from outside of the USA."



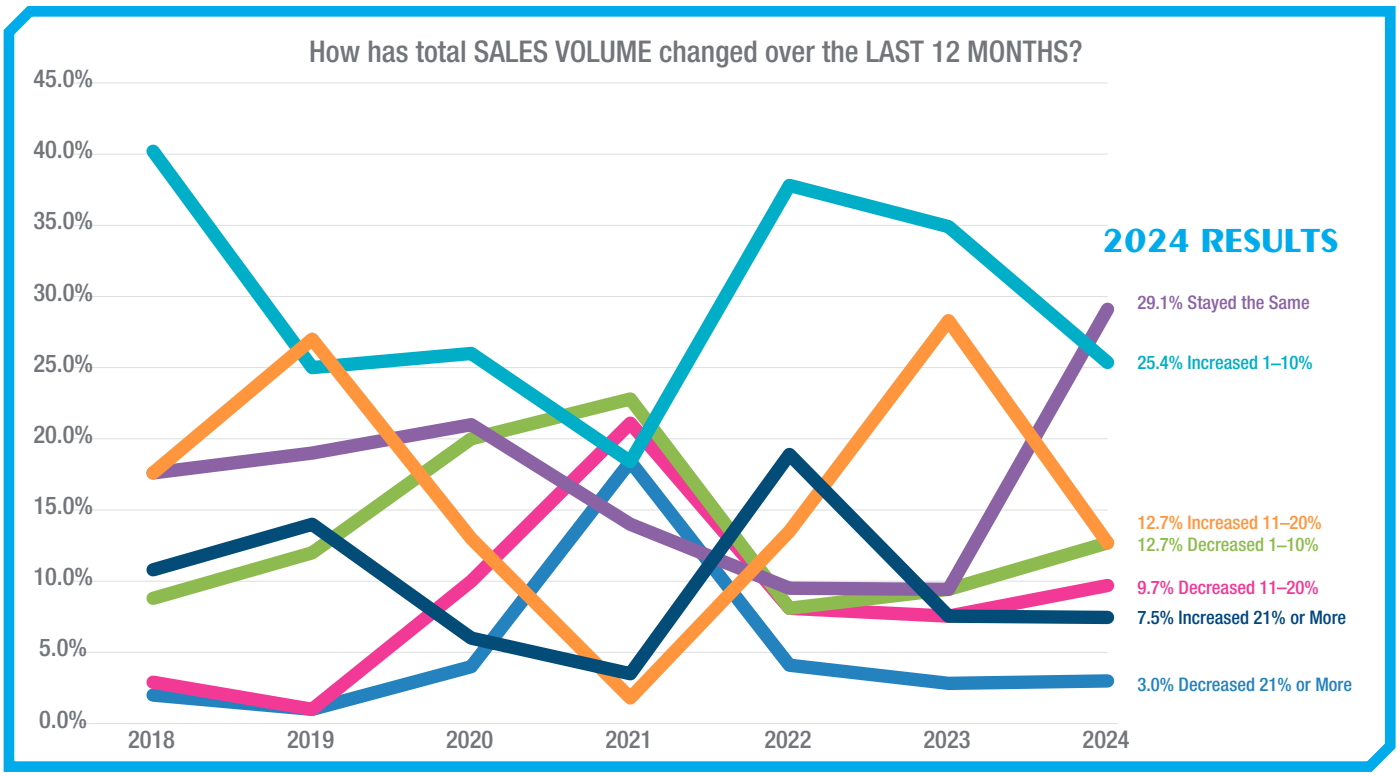


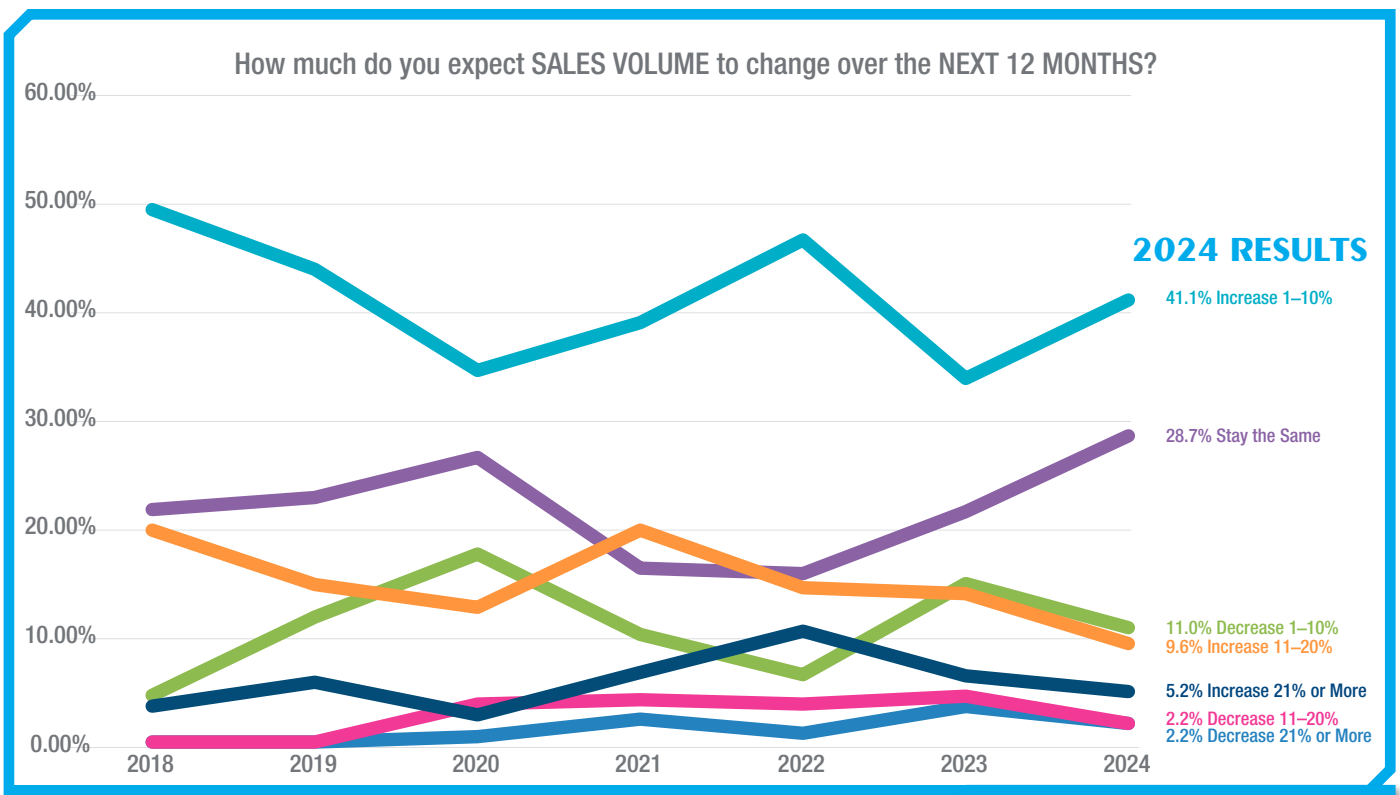
85.4% Plan to Maintain or Increase Employment



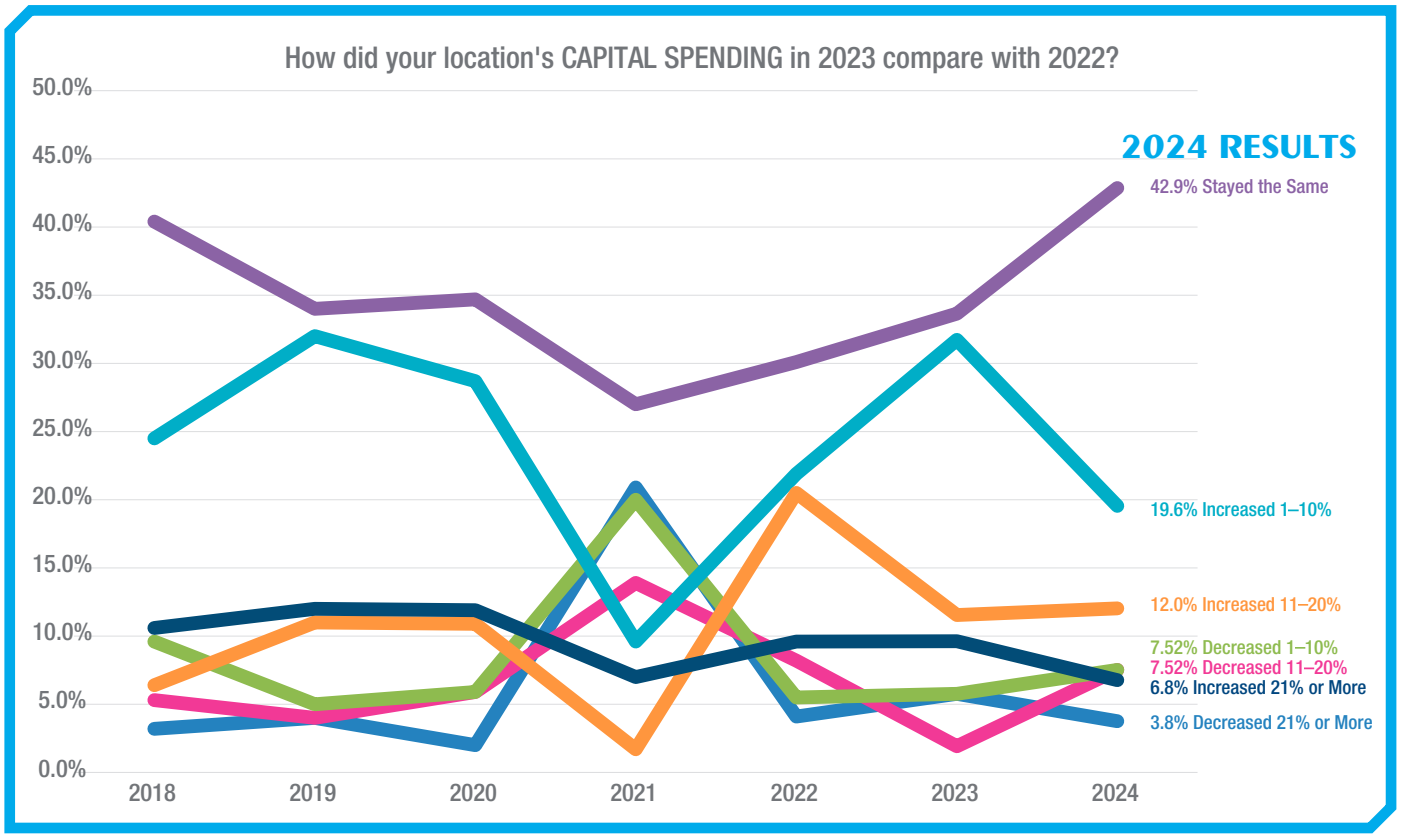


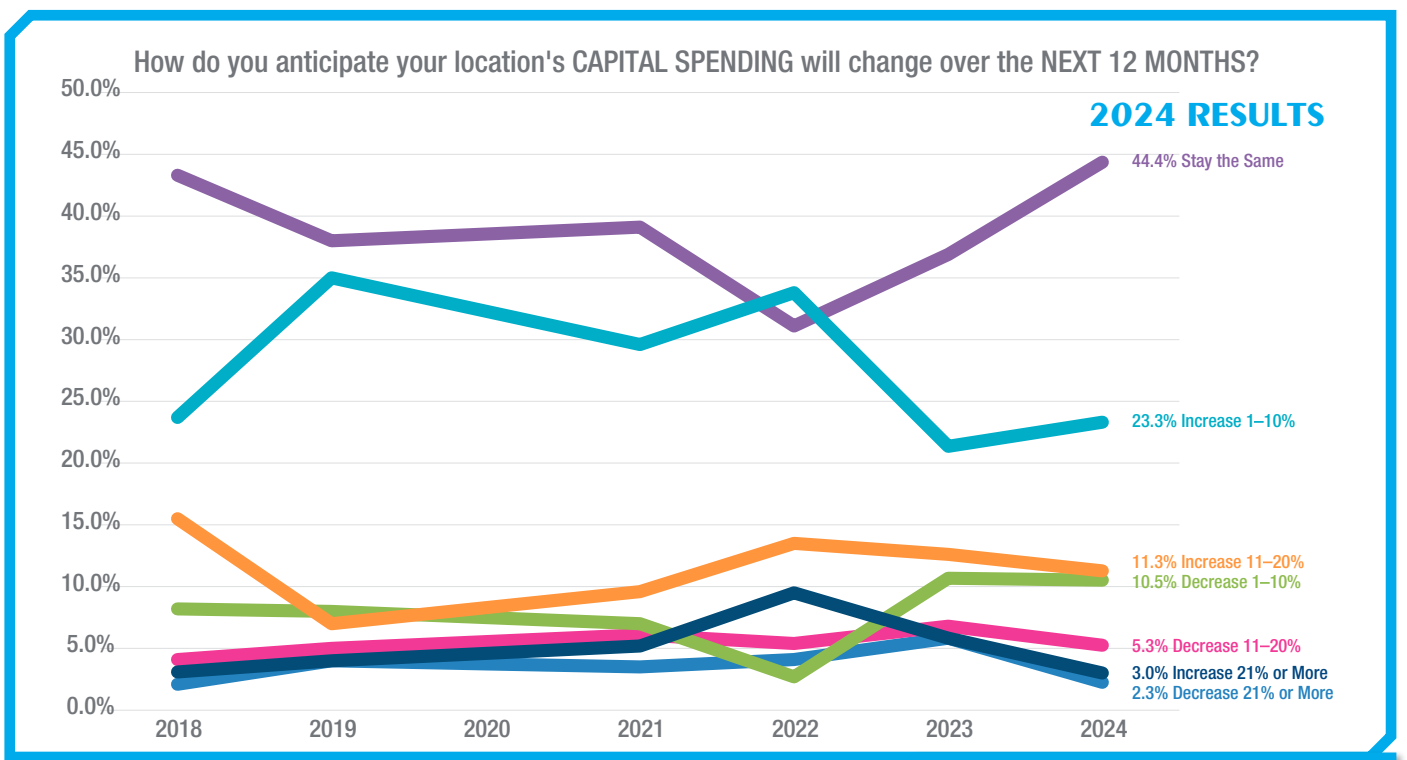
86.8% Expect to Maintain or Increase Production Levels





84.6% Expect to Maintain or Increase Sales





82% Expect to Maintain or Increase Capital Spending

The View from Here

Aaron Fagan, Senior Editor

In 2024, machine tool companies anticipate challenges such as global insecurity, supply chain disruptions, and adapting to the electric vehicle market. Gleason, GMTA, Kapp Niles, Helios Gear Products, MTB, Nidec Machine Tool America, and Star SU express concerns about geopolitical issues, EV market adaptation, balancing current orders and new projects, softening demand, and communication challenges. Optimistically, they foresee opportunities in stable industries, economic growth, onshoring, and increased demand for gear manufacturing. Training programs focus on gear education and apprenticeships, while IIoT and Industry 4.0/5.0 remain significant. Workforce development solutions aim to bridge the skills gap. E-mobility's trajectory varies, and companies emphasize minimizing carbon footprint and evaluating sustainable practices. Concerns include the aging workforce, political landscapes, and ongoing challenges like overregulation and declining production. Nidec highlights involvement in additive manufacturing and strategic acquisitions for continued growth in 2024. Overall, the industry faces a mix of challenges and opportunities, with a keen eye on global, technological, and political dynamics.

What are the most significant challenges 2024 will present to your machine tool company?

Global insecurity with the continuing crisis in Ukraine and the Middle East, potential crisis and dangers to global supply chain, US elections may also bear risks and opportunities. Chinese economic development continues to drive/influence world demand.

—Christian Albrecht, Chief Marketing Officer, Gleason Corporation; *gleason.com*

The most significant challenges for GMTA in 2024 include adapting our product portfolio to the EV market, addressing continued supply-chain disruptions (long lead times), and understanding how AI and other technological advancements can be incorporated into our business model.

—Claudia Hambleton, Office Manager/ Corporate Treasurer, GMTA; *gmtamerica.com*

From a global perspective, the most significant challenge will be managing deliveries from a strong order backlog, similarly the follow-up on installation requirements with the ability to support ongoing field requirements. It is a balancing act that we must support the current installation base with the demand on our organization to install and successfully launch new projects.

—Shane Holllingsworth, Vice President Sales, Kapp Niles; *kapp-niles.com*

2023 was a very strong year for us, so I expect some rebound from our customer base, meaning a softening of machine tool demand. As a machine tool distributor, we continue to be challenged by keeping our manufacturing customers up to speed with the latest technological options available to them. There's just a lot of communication noise that every individual must combat in today's always-connected world, so communicating technical update information to manufacturers can be challenging.

—Adam Gimpert, President, Helios Gear Products; *heliosgearproducts.com*

Keeping up with the global demand for gear-cutting machines and metrology, as well as automation solutions, remains the biggest challenge for our Liebherr production program. Over the past few years, the industry has seen delivery times elongated due to supply chain issues, but also due to the increasing market demand for our gear machines and technology. 2024 will continue with strong demand—and we are ready for that challenge. A further challenge is always trying to apply some of the new ideas and gear technology developments into the new customers workpieces (EV) and applications, due to their high-quality demands and sometimes unique features (special chamfers, for example).

—Bernd Rösch, Head of Testing, Gear Technology, Liebherr; *liebherr.com*

I can't help but sense "a disturbance in the force." While the economy has withstood a lot over the last few years, one must wonder about the impact deficits, wars, and borders will have going forward. It doesn't take much to throw a monkey wrench into even our great, very resilient economy. One has only to look at how supply chains seized up and inflation went through the roof. Much is riding on the outcome of the elections this year, and how our nation goes forward in the face of mounting threats overseas.

—Kenneth Flowers, Owner and President, Machine Tool Builders (MTB); *machinetoolbuilders.com*

The market continues to demand higher quality parts, shorter cycle times, and, as always, higher efficiency/lower costs. Nidec Machine Tool America (NMTA), as part of the dynamic and fast-growing Nidec group of companies, will continue bringing innovative new solutions to the high-volume gear production market, such as the new CF26A cut chamfer machine. Getting the word out about our advanced solutions is a welcome challenge.

—Dwight Smith, Vice President, Nidec Machine Tool America (NMTA); *nidec-machinetoolamerica.com*

For our machine tools, we see continuous demand for e-mobility applications driving larger, higher speed gears, tighter tolerances, and an impact on noise reduction as part of a growing emphasis on gear face chamfering applications.

—Andreas Blind, President, Star SU LLC & John O'Neill, Engineering Manager, Gear Tools, Star SU LLC; *star-su.com*

How is the push toward ELECTRIFICATION affecting your business?

"No effect."

"New machine purchased for delivery in March 2025 has full automation. Seeking to add automation to hobbing machines."

"Quantity of gears will reduced because numbers of gears have reduced in EV vehicles."

"We are adjusting our product line to accommodate electric vehicles."

"As an oilfield service provider, our customers depend on their volume of production sales. Electrifying vehicles reduces the demand for fuel. It puts a strain on oilfield equipment repairs. The same applies to the auto mechanics. We find it hard to support our families."

"It's given us new opportunities to explore."

"The trend is there but due to product mix it did not impact last year."

"Very positive."

"Higher roughness requirement."

"Need to make more investments related to new technology and slowly reduce old business."

"Positive."

"None."

"Has not affected our business."

"More motors means more gearboxes to rebuild."

"It is not affecting our business in any meaningful way."

"No change."

"Substantially, with a level of uncertainty."

"Has not been affected at all."

"Not."

"Impact of stray current is a growing concern."

"Increasing customer investments."

"No change yet, but expect it to augment growth for gearing technology as motor adoption continues to grow."

"It's terrible. Nobody wants electric vehicles except the garbage truck buyers..."

"Minor. Our industry is too remote to make full electrification feasible. Higher interest in hybrid solutions."

"Don't know."

"In some applications, electric drives require higher input speeds, which changes the design of the products resulting from noise/vibration."

"Slowing it down."

"Making us consider new directions."

"To some extent it's affecting us negatively—approximately 4–5%."

"Reducing target clients."

"We are the last to make a change and not forward looking."

"It is a really good opportunity."

"Providing new opportunities for product creation."

"We are now producing gears for e-transaxles for electrified vehicles."

"Not applicable at this time."

"Very little."

"Increasing."

"Yes, it does affect...but getting compensated by tractor and construction equipment volumes."

"Big ."

"It has impacted certain customers completely, but as we provide complete drive systems, we are still able to compete."

"None."

"Nothing."

"More EVs = Less Gears."

"None."

"Getting ready for electrification components."

"Not much."

"No effect."

"Not at all."

"High."

"It is not (so far)."

"Not—we are not involved in automotive."

"We are into EV transmission mainly."

"The requirement for more precision and silently operating gears has increased exponentially to be attained at very high costs."

"Hurting ."

"Until 2024 nothing."

"Slow."

"No effect at this time."

"Not very much."

"Negatively."

"Not at all."

"Increased opportunities and adoption of new technology."

"Medium."

"Market trend is not clear, affecting the investment plan for the next years."

"Big effect on design requirements."

"No major effect."

"Gears are not needed in some applications anymore."

"Business will increase for precision gears."

"Electric vehicles usage is increased. The new startup companies in the electric sector are growing much faster than earlier."

"Is not affecting ."

"It typically has little impact."

"Have not seen any major impacts."

"This impacts us with the mining trucks sold, which has been very strong and looks great over the next 5 years and beyond."

"Not much as yet but expect that it will in the near future as we see more applications at higher load/speed combinations."

"Electrification requires high quality gears. Gear metrology is more important."

"Bad influence."

"This affects us very positively."

"There is no effect."

"We're in the process of converting most forklifts and tug carts."

"Very little impact as of yet."

"Non existent and losing steam."

"No effect."

"Not significantly at this point."

"Only that our concern for how this electricity will be produced."

"Not applicable."

"Was strong, now focusing on other core industries."

"It's forced us to improve of the use of simulations in development stages."

"More interest in hybridization. Pure electric operation is not currently feasible for our industry."

"This is the main reason for our increases in business levels."

"Massively."

"N/A yet."

"Huge. As long as we can keep up with demand."

"We are ready and involved."

"None."

"Minimal, although keeping an eye on market trends."

"Not at all."

"We have added electrical and automation engineers to our staff and products to our portfolio."

What are you optimistic about for 2024?

While e-drive growth continues, some manufacturers reconsider options including rather classic approaches. Strong aerospace industry, stable construction, agricultural, and transportation markets. Although production is forecasted to decline in many markets, we believe that we are well-positioned to overcome these looming challenges.

—Christian Albrecht, Gleason

The possibilities introduced by AI and bringing new partners to the US market.

—Claudia Hambleton, GMTA

Onshoring continues to be a common thread as supply chains adjust in a post-pandemic world. Helios is uniquely situated to bring world-class machine tool solutions to North American and European manufacturers.

—Adam Gimpert, Helios

With the introduction of several series of gear machines, including FlexChamfer for gear hobbing, and ChamferCut IG for the skiving process, and further process monitoring (out of our digitization packages) for gear grinding we've several new developments for increasing productivity in gear machine shops.

—Scott Yoders, Vice President Sales, Liebherr Gear and Automation Technologies; *liebherr.com*

While the global economic conditions are uncertain, and seemingly one crisis after another around the world leads off the nightly news every day, I remain stubbornly optimistic. If current economic conditions, particularly supply chain issues, have told us anything post-pandemic, it's that we've got to start producing more here at home. We're expecting more robust demand as a result—perhaps not this year, but certainly in the years to come.

—Kenneth Flowers, MTB

The economic trends are encouraging; inflation is moderating, and businesses have cash for capital projects. Re-shoring continues to bring more gear-making to the US, and NMTA is well-positioned to serve the market. I expect 2024 to surpass 2023 in economic growth and sales for NMTA.

—Dwight Smith, NMTA

While we foresee a softening in the overall manufacturing industry, we feel optimistic that gear-tool demand will continue to remain strong driven by reshoring and e-mobility applications.

—Andreas Blind & John O'Neill, Star SU

What will 2024 training programs look like from the machine tool industry?

Gleason continues to educate the industry with the broadest program of basic and advanced gear design, manufacturing, and metrology topics, including the latest gear technology trends. In May 2024, Gleason will present its yearly webinar highlight "E-Drive Days," and offer in-person gear technology seminars in specific markets throughout the year. In addition, Gleason will continue to run its highly acclaimed live Gear Trainer Series and has introduced more Gear School Classes in the US and Germany, extending to customers' areas—we call it the "Gear School on the Road."

—Christian Albrecht, Gleason

I see further implementation of apprenticeship-style opportunities. Due to the skills gap and the expected increase in employment, companies will need to take on the task of bridging education with real-world needs.

—Claudia Hambleton, GMTA

Helios has expanded its education and training offerings to supplement its 33-year-old Chicago-based "gear school," so manufacturers can now send personnel to regional, in-person schools in Anaheim, Boulder, Hartford, and Charlotte. Online courses also continue to be a convenient solution for on-demand training. Nothing can replace real experience, but today, manufacturers really have no excuse for not connecting personnel with gear manufacturing knowledge.

—Adam Gimpert, Helios Gear Products

We must continue to plan further and further out in advance, the required skill set is not immediately available in the marketplace. We have seen success in hiring young employees and providing them with the time to learn the technology properly. Of course, this launch period is closer to two years instead of six months, but the employees see our investment in them and in return reward us with loyalty. Each summer we host apprentices in the States for 4 weeks, we take them to customers and provide them the opportunity to experience what the US has to offer, the hope is in three to five years they will be interested in relocating here if/when an opportunity arises.

—Shane Hollingsworth, Kapp Niles

Liebherr made a huge investment in our training academy—a separate section within our factory in Kempten, Germany—back in 2021. Called the "Machine Training Center," nowadays this academy is used for our workforce development (for example training our service technicians and application engineers), but also used by our customers and end-users of Liebherr gear machines all over the globe. Both hands-on and in-person training programs take place, on actual gear machines, but also via online and digital training (live as well), further enhanced using the equipment found at our academy.

—Scott Yoders, Liebherr

We do not see any significant changes from 2023; hands-on training, particularly in the application, service, and support of today's most modern gear machines, along with similar training for the "legacy" machines, is mandatory.

—Kenneth Flowers, MTB

NMTA continues to offer Gear Basics training. This has been very popular, and many companies bring me in to train new team members. Despite the popularity and efficiency of online training, live, in-person training is still relevant and valuable.

—Dwight Smith, NMTA

How are you handling and navigating supply chain issues heading into 2024?

"Day to day."

"ID/OD grinding support continues to be a capacity issue with our vendor base."

"By diversifying business to suspension and steering."

"Carefully."

"We are doing our best to promote 'Made in America,' even if it requires Americanizing Chinese Reducers. We are replacing Chinese gears with specialty-designed American gears and converting the Chinese reducers."

"Getting everything we can out of China."

"Depending on need. No big issue now."

"Long term contracts with suppliers—increasing our stock."

"Evaluating different countries for changing the supply chain."

"By making alternate sources, and in-house capabilities."

"Expanding search for more partnerships in supply chain relationships."

"More inventory."

"There are no significant problems at this time."

"With greater ease than 18 months ago."

"With a certain level of frustration."

"We have no supply chain issues."

"Prayer. Long lead times!"

"No problems with supply chain."

"Diversification and better management tools."

"Terribly."

"Diversification, continuing to reduce reliance on China and developing alternate sourcing for U.S.-based suppliers."

"Freight rates are being passed on."

"No major issues."

"No worries."

"We are tapping other additional opportunities."

"Struggling and sending parts late."

"We see no problems on this topic so far."

"Supply chain has settled down and is returning to normal."

"Conflicts between countries are directly affecting us."

"Improved planning, partnering, and communication."

"Our supply chain has been surprisingly easy to navigate other than increased cost. Quantity hasn't really been an issue."

"Not an issue."

"Challenging, as there was some dependency on long-distance suppliers, which are being navigated through strategic sourcing from within 100 km distance. It is proving effective but challenges on quality remain."

"More direct contact and follow up with suppliers."

"Holding steady/same."

"Double- checking long lead items with machine suppliers."

"So far no major issues."

"Increasing inventories on material."

"All is good now."

"Finding new suppliers out of state."

"Not really an issue for us."

"Mainly suppliers all located in Japan, so at the moment no severe problems with material supply."

"Working with vendors to better communicate trends, being selective on who we deal with."

"More on predictive buying and cooperation of suppliers."

"By planning in advance, by maintaining expected requirements from customers."

"We can´t see problem to our planning in 2024."

"New ERP system."

"Ordering more, stocking material, trying to get volume pricing."

"Using more help from freight forwarders."

"Digitization ."

"Have a shorter and nearer supply chain."

"Sourcing of special steels is still a problem and also the unfortunate price increases on a daily basis."

"Better than last year."

"Sourcing from close and reliable origins."

"Input costs have gone up. Price revision, value added services to customer to compensate for the increased cost."

"Localization and increasing the quantity of suppliers."

"As normal."

"In-region strategic transfers. In-load to our facility."

"Patience and prayers at this point. Communicating issues with customers as best as possible. Buying future material runs."

"Lead times are coming down, so this seems to be fine. Aerospace material grades don't have many options. Pricing is very high and lead times are very long."

"Much better than the last three years where electronic components were so difficult to get, and delivery times unstable and unforeseeable. Now we feel and see that this problem is much less acute."

"Shift the delivery."

"Working with suppliers to prevent any future supply chain issues."

"We have adjusted well and have very few issues in our supply chain.."

"Planning and forecasting improved."

"Not a problem."

"Supply chain is flowing well."

"We need to search around the world for better conditions for the supply chain. We are investing in supplier qualification."

"Continuing to expand presence in Europe, divesting from the United States and China."

"We are struggling with vendor lead-times. Many times the lead-times for very small parts is greater than the lead-time for one of our multi-1K ton machines."

"Increasing the level of engagement of most important suppliers."

"Cautiously."

"We've been lucky."

"Was challenging, but is smoothing out."

"No change."

"Watching closely to catch trends before they get bad like 2020/2021."

"We don't have a problem."

"Starting to see shipping issues again, but nowhere near to 2021 levels. We are looking into alternative routes."

How is your organization addressing the skilled worker shortage?

"Training staff and middle management."

"Better equipment and adding automation."

"Regular new trainees and training them as per our requirement."

"We have relationships with multiple universities. "

"In the gear industry, we have to spend years training our technicians."

"Training and working with local schools."

"Training new and young people."

"Difficult topic. Til now we are finding the right people—but it takes longer time."

"Not much."

"Try to retain old employes. Upskill junior level employees."

"Automation wherever possible."

"Hiring younger."

Star SU continues to place an importance on the education of our customers, from the aspect of our specific machining applications and a general understanding of gear industry knowledge.

—Andreas Blind & John O'Neill, Star SU

What level of focus is on IIoT and Industry 4.0 or 5.0?

IoT/4.0/5.0 solutions are already part of our regular development tasks and daily production life with design to manufacture solutions, Closed Loop and Smart Loop Manufacture with in-process quality inspection, as well as digital twins that allow to forecast feasibility of manufacture to avoid costly errors and scrap production. The highest precision and maximum efficiency must be built into today's products, whether we offer design and simulation solutions or manufacturing cells with integrated quality inspection systems. It is something customers expect, and we continuously challenge ourselves to take fresh and new approaches to these requirements throughout the complete process chain.

—Christian Albrecht, Gleason

I feel the level of focus is much the same as the previous year, where mostly large companies are devoting relatively modest resources to develop technologies that fall under the banners of IIoT or Industry 4.0. Most manufacturing companies, which largely include small- to medium-sized operations, might have a few "pet projects," but when simple automation (for example) is a "big step" for these manufacturers, the benefits of IIoT are still on the horizon.

—Adam Gimpert, Helios

Liebherr dedicated a huge number of resources to the IoT realm already starting six years ago, and nowadays we offer a complete suite of products to link, and collect data from Liebherr machines, other machine tools from industry, gear metrology equipment, and even automation. Our LHWebPlatform is the perfect basis to collect data in a standardized format (as well as offering the possibility to customize it to a specific need) with our LHSignalInfo, LHMachineInfo, and LHReportInfo system tools. We have enhanced these offerings recently on LHSignalInfo, to be able to complete adaptive process monitoring—often being able to detect problems in the production of gears—before they arise.

—Florian Schuon, Head of Digital Solutions, Liebherr; *liebherr.com*

This is most important for the OEMs that we support. Investment in the factories of the future is impacting how competitive the machines we represent are, relative to their designs, delivery, and cost. Our OEM partners recognize that—and we've picked some good ones to represent.

—Kenneth Flowers, MTB

I'm surprised by the relatively slow implementation of IIoT. This is especially true in the job shops where they need a concrete ROI in a short time. Many of the larger companies struggle with analyzing and transforming the data into actionable knowledge.

—Dwight Smith, NMTA

Our continued focus is to utilize IOT and Industry 4.0/5.0 where applicable.

—Andreas Blind & John O'Neill, Star SU

Do you have new workforce development solutions for 2024?

Like the whole industry, we face labor shortages of different levels depending on the geographic area we operate in. In some countries, we develop our workforce through apprenticeship and trainee programs. In others, we attract talent by a more diversified approach. Nonetheless, the topic remains a challenge and we are optimistic about the further development at Gleason.

—Christian Albrecht, Gleason

We are focused on making the seamless transition from an older generation of highly experienced technicians and professionals to a younger generation of less experienced, but very capable, individuals—and then training them to succeed. The labor pool is short, alarmingly so, of the skilled technicians, machine operators, engineers, and the others that we took for granted some 35 to 40 years ago. There is simply no alternative to establishing robust training programs in-house since there are very few technical schools or formal education available anywhere in the US for machine tool technology/design and manufacturing.

—Kenneth Flowers, MTB

Yes, we have implemented additional training for our service technicians to ensure they have the advanced skill set needed. For example, our mechanical specialists are receiving electrical/electronic training to broaden their abilities for machine repair.

—Dwight Smith, NMTA

As a global company, Star SU faces the same challenges that our customers and competitors face. Measures are in place to further training, education, and promotion of our internal resources.

—Andreas Blind & John O'Neill, Star SU

Is e-mobility heating up or cooling down in 2024?

While significant investments have been made in the past years, we believe that e-mobility still bears interesting opportunities regarding program extensions and ongoing investments in the automotive sector. We also see the upscaling trend for vehicles with larger drives and similar applications which join the general electrification trend. Electrification is not over—by all means.

—Christian Albrecht, Gleason

E-mobility is cooling down a bit. I just don't see the infrastructure to support it yet.

—Claudia Hambleton, GMTA

Heating up! We're at the cusp of the electrification of so many types of vehicles, and gears will be critical to these new systems. We continue to address the gear manufacturing needs of both startups, established EV makers, and their subsuppliers.

—Adam Gimpert, Helios

Worker shortage (continued)

"Increased internal training resources to create the skills. Also investing in technology to reduce reliance on skilled labor into the future."

"We are trying to keep our current quality workers. But it's taking longer to get new talent on board."

"Using a partial non-migrant workforce."

"Not very well. Recognition is slow in coming."

"We are retaining our employees ."

"Much prayer, but maybe not to the correct deity. I've been in gears for 50 years. The biggest hurdle is management, because to bring a young engineer up to a level to be competent in gear unit design and engineering is five years with proper mentoring. A competent machinist about two years. A competent service man 3–5 years. The management philosophy is: Go hire someone today, they can start in two months, if they pass the hiring process, then they will be ready to go. The new people needed to be hired five years ago. Oh yes, pay!"

"We are not having a skilled worker shortage in the Greater Toronto area."

"Investing in community development programs, investing in more job training programs, and automating what makes sense."

"Increased compensation and benefits, increased internal training and opportunities to move within the company."

"Hire and train and pay enough. Nobody thinks they can compete on compensation."

"Trying to automate as much as possible."

"Workers are being trained or reimbursed for college classes."

"Training like crazy."

"Training new employees."

"We are not. We have a lot of old employees and no good way to fill the gaps."

"We make people grow from the bottom. Nevertheless certain positions are difficult to cover."

"Hiring bonuses."

"Keeping talent motivated and rewarded. Generational changes are now more drastic with actual centennial people vs millennials and X, Y generations."

"In-house training."

"Recruiting heavily and attempting to automate wherever possible to reduce requirement of workers."

"In-house training team with amazing capabilities."

"Poaching is there to stay, and we are treating skilled workers as our own assets."

"We have partnered and suggested our supply chain also partner with local schools and universities, basically bringing the apprentice program back."

"Outsourcing."

"Hope and a prayer. Refuse to develop or bring in young people. Keep holding on to "a hope and a prayer" to find experienced gear machinists. Need to bring back apprenticeships!!!"

"Training in house."

"People are stable in their jobs, so far."

"Still struggling."

"Internal training programs."

"In-house training."

"Trying to do in-house training."

"Continuously conducting interviews with possible candidates and improving the skills of unlearned workers through on-the-job training."

"Poorly—we are having trouble retaining good people and finding replacements."

"More on automation and de-skilling. For skilled worker, giving more opportunities and upgrading semi-skilled by training."

"By adding fewer but people skilled in multiple areas and by training not-so-skilled ones in house under the guidance of the skilled workers."

"With much difficulty because entrants to the metal industries are less available."

"Internal training. Training local workforce."

"Own internal school."

"Upgrading equipment."

"Society offerings of training, local junior college or trade school."

"Training."

"Training by using VR/AR/MR platforms."

"Work in partnership with technical schools."

"Automation."

"I don´t know."

"We have employed a new machinist in the gear cutting department to train and upgrade our output and quality."

"Increasing the ability of current ones."

"Training. Employees work in various positions. Promotion in universities and schools."

"Training new candidates."

"Training and skill development."

"Increasing the trainees and providing the on-the-job training to them after systematic training courses."

"Using CNC equipment."

"There's no way."

"IT support."

"Resource pooling, tie up with universities."

"Apply new technology."

"Push towards automating properties."

"Working to improve our culture to keep people longer."

"No problem as we are a small group who have all worked together for more than 55 years!"

"Apprentices (dual study)."

"No skilled young people available. Old people are still useful!"

"Offering competitive salaries and benefits in the market and a pleasant work environment to retain our staff."

"In-house training programs."

"Looking to sponsor out-of-country candidates, looking to education system for apprentice opportunities."

"Junior colleges, recent military separations."

"More focused hiring."

"Reaching out to community partners for help in identifying and hiring employees."

"Not a problem for us."

"Focusing on internal skill-based training program and versatility training as well for longer term employees."

"Exchanging skilled workers of the company located in different plants."

"Internal training, women in trades, coop programs, increased compensation and benefits."

"Working with local tech centers and colleges for their upcoming graduates. We are hosting many manufacturing visits from the local high schools."

"Increase internal training capacity and attitude, expand company's benefits to create employee loyalty."

"Training."

"Automating more, hiring less and upskilling."

"Lots of interviewing."

"It is extremely difficult to find professional help these days. We are on a constant look for a proper fit to our company."

"No major issues this year after a rough 2023. Wages and extra recruitment efforts were needed in 2023."

"Very hard to get young talent to do this type of work."

"Looking to launch a formal apprenticeship program."

We still this as the main driver for automotive investment activity, projects are quite regular, and requests for future programs are consistent. Development demands are still very high considering we are almost 10 years from the initial technology that was developed. Our customers continue to push for methods of control and data collection, not only from grinding applications but connecting that information and analyzing it with various forms of inspection. This topic can feel like looking at an iceberg, the possibilities below the surface are many, and prioritizing these to meet customer expectations. As soon as you feel one step has been taken, we see another three or four to enhance the solutions further.

—Shane Hollingsworth, Kapp Niles

We suspect it will cool down in 2024. The unbridled enthusiasm and increase in sales and production in 2023 is now being tempered by the realities of the marketplace. Huge problems with infrastructure, sourcing materials, and the natural resistance of the consumer to high cost and impracticality are the current EV landscape. The ambitious plans and projections of the Big 3 for EV are already off the table. Closed plants and scaled back production are the reality near term.

—Kenneth Flowers, MTB

I see e-mobility cooling down slightly. We are seeing EV and hybrid projects in the planning stage. With the recent slowdown in EV sales, some of these may be delayed as the market adjusts.

—Dwight Smith, NMTA

E-mobility will continue to heat up, and we anticipate a steady growth of additional companies entering the prototype, installation, and development, along with established OEMS entering production phases.

—Andreas Blind & John O'Neill, Star SU

Where is the focus on energy and sustainability in 2024?

While we continue to maximize the efficiency in our operations, providing products with excellent productivity ratings and minimum carbon footprint, living up to ever-increasing official regulations and customer initiatives is challenging. To comply with such expectations, we improve supply chain management regarding its overall sustainability and minimize its footprint. It is a serious and tedious task.

—Christian Albrecht, Gleason

Sadly, lacking in every industry.

—Claudia Hambleton, GMTA

Despite what some might have us believe, it's becoming increasingly clear that the drive to replace fossil fuels with clean energy can't be achieved through electrification, wind and solar alone. The economic consequences would be ruinous. This will instead require a full court press, including hydrogen, nuclear, geothermal, bioenergy, and of course wind, solar and natural gas, along with a more gradual transition away from oil and gas.

—Kenneth Flowers, MTB

It is interesting that we read about this in the news and industry press, but don't see much actual impact on the day-to-day operations of our customers. The hype exceeds the reality.

—Dwight Smith, NMTA

We as a company are constantly evaluating our current practices and strive to reduce our global carbon footprint. Measures such as facility upgrades (i.e., lighting, mist extraction, and central cooling systems, etc.), recycling efforts, modernization of legacy equipment, and utilization of solar energy.

—Andreas Blind & John O'Neill, Star SU

What is something I may have overlooked that is of great importance to you in 2024?

2024 so far, has not been a bad year. As we have pointed out before, we may feel effects of global crisis, overregulation, weak markets, and declining production, nonetheless, we feel optimistic about 2024.

—Christian Albrecht, Gleason

What is the age of the respondents or workforce in the survey? Most were corporate management or design engineers. I'd be interested to know how close they are to retirement and what legacy/recruitment plans they have in place, if any.

—Claudia Hambleton, GMTA

Since coming out of the pandemic, it feels that timing to SOP has condensed. The tools that design engineers have today allow for significantly more analytics before a beta build, hence we see the time from design to SOP is accelerated. The new normal is not a 5-year launch, it's maybe 24 months and customers have 12 months or less from actual design release to production start requirements. The power of technological development can be seen in this area and many others. If I can add another point to this question, what is the future of re-shoring activity? We have seen in several areas, not a huge wave, but it is present and ongoing. I believe this topic ties into one of the survey questions about managing supply chains and government requirements. How long will this continue and to what extent is yet to be known.

—Shane Hollingsworth, Kapp Niles

The political landscape and the impending 2024 elections are of utmost importance. While the economy has seemingly weathered the short-term impact of the pandemic, serious longer-term challenges are mounting. The true economic state impacting purchasing labor and taxation, as well as the immigration situation and border crisis, will, if not remedied in Washington, weigh heavily on our jobs outlook and economic future.

—Kenneth Flowers, MTB

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

"We are introducing robot automation."

"Likely a much bigger role."

"Reduction of manpower due to increase of automation."

"Additive manufacturing of many of our lower stressed components."

"The CNC Microsoft new technology used in the Five Axis Machining Centers is revolutionary. But for the small business, it is priced at a level that only the prime contractors can easily afford. We (the small business) will continue with the conventional method."

"IIOT is an excellent tool, as is six-sigma. We use both."

"We are doing our best to work these trends toward our advantage."

"Automation for part handling and workholding changeover up to 100 kg."

"Important role."

"Robot, automation and IIoT."

"New software for documentation, gear calculation, online programing and auto correction makes process easier. And robots."

"Automation of design activities will be carried out."

"Little effect."

"Lots of automation will be brought to the work order system."

"We are investing now to understand the role...separate the hype from opportunity."

"About the same as now, slow and steady."

"Hopefully there will be a shift towards new and emerging technologies. But, that will require investments that are slow in coming."

"We continue to add robotics to our operations."

"We've got a lot of artificial intelligence. What we need is real, tangible intelligence, which takes a few years to have. LOL. That spark of creativity is very important."

"Will have to be implemented."

"Will be critical to help in reducing carbon foot print and increasing component life."

"Reasonable role—depending on customer demand to incorporate."

"A significant impact. Those who do not adopt emerging technologies will not be competitive."

"Nothing can replace a hard American worker, properly educated."

"Automation and autonomous systems will be a large part of both our manufacturing and products."

"We see technology playing out in many different ways from internal changes related to manufacturing efficiency improvements, speed to market, and reduced downtime (digital twin-maintenance). On the sales side, we see similar evolution in our products and the market needs, which encourages a higher level of design integration."

"We will be quicker to get products from design, through manufacturing, to the customer."

"Yet to make any significant impact."

"Low role."

"We already utilize robotics and will need to better utilize them."

"For sure the new technology will support us in growing."

"Very limited role for emerging technologies."

"Some in the near future, but likely more in the 10-year planning."

"Robotics and automation will be most significant to us as we struggle to automate worker tasks. We have utilized AM in work holding for many years and are still ramping this up."

"Robotics, small automation and single-piece flow are being implemented with focus on continuous improvement."

"Big."

"We have already begun additive manufacturing; robotics are starting to come into the field."

"No impact."

"No role."

"None."

"Low impact."

"Potentially big improvements."

"Need to stay informed."

"No effect."

"Probably not much effect in our markets."

"High."

"Not clearly statable so far. Probably noncritical to neglectable dimensions."

"IIoT is already present; we are looking at additive manufacturing."

"IIoT, AI, automation, robotics, machine learning."

"We can venture into automated loading and unloading assisted by robotic arms and increase use of semi-automated robotic arms to help operators load and unload larger and heavier jobs."

"None."

"Little relevance. As much as possible we will try to implement additive manufacturing. This is not the time for big investments."

"Some robotics are currently used and will add more if needed."

"Slowly increase productivity levels."

"Very little."

"Lean digital technology."

"A more automated factory using a sum of technologies. The factory will be able to work alone 100%."

"We are a jobbing plant and are slowly moving more of our production off the older manual gear machines to the new multi-axis CNC machines and are looking to upgrade our gear grinding equipment, but costs are high."

"Will have major effects."

"Selling price is always under pressure."

"Will have a positive influence and need to update the skill level."

"Smart sensors as condition monitoring devices and SCADA will be the key element in every automated factory."

"Do not affect us."

"Additive manufacturing and robotics may help."

"It will enhance our productivity and address our yield."

"Only way to manage growth with current labor market will be automation and data monitoring."

"Having the capex to invest in technology that many leaders do not see the importance in investment."

"Important role."

All this is already used since long time in our company. New tools are not always better. To do the same thing we were doing with 700 kilobytes now can't even be done with 700 megabytes!"

"New technologies are and will be playing a leading role in this industry."

"Robot and cobot implementation where possible."

"Will maintain status quo. No large capital output."

"Will most definitely increase and become more important over time."

"Zero."

"We'll explore best practices."

"We will be evaluating all these technologies and looking for the right fit."

"No plans at this time."

"Hopefully reduce the labor issue"

"We are doing partnership with universities to improve issues regarding technologies as IIoT, additive manufacturing, automation and artificial intelligence."

How will the gear market evolve in the NEXT FIVE TO 10 YEARS?

"It is going to grow."

"Capacity in the gear market has been tight and I don't see the demand for gears slowing up at all in the next 5–10 years."

"It will be reduced 20 to 50%."

"Geometrical precision and materials."

"It will all depend on the direction the USA goes."

"The need for new lubricants that are lower shearing."

"The suppliers who continue to invest in people and equipment will gain market share."

"Should grow."

"We are working in precision gear business. Because of increasing automation levels, the market will grow."

"Decreasing."

"Gear market has become more competitive, and OEMs need more reliable gear manufacturing partners. Manufacturers needs to change manufacturing technology to overcome new changes."

"The reduction in vehicle gearing due to electric automobile production will pressure gear companies focused only on industrial drives with more competition."

"Low noise, highly optimized contact gears will further penetrate all industries."

"More domestic purchases."

"Unsure of the future at this point."

"Most of the gear units will be made offshore, China, Korea, Germany, Brazil, Spain, India, maybe Mexico."

"Simple gears will leave..."

"Increasing demands for longer gear life, with lower carbon footprint."

"Decline in automotive sector, increase in heavy equipment."

"Good question. I hope we have the courage to learn, invest in and adopt emerging technologies. If we don't evolve, we will become obsolete."

"Automation will play a big part, unfortunately. AI, automation and robotics."

"Higher requirements: quiet gears for electric applications."

"Fewer shops willing to do what we do, giving us a larger customer base."

"High volume production of gears will be predominantly produced in low-cost countries. The U.S. and western world manufacturers will have to focus on technology to remain relevant as well as sourcing globally to remain competitive. While we will still see traditional machinery produced, we can anticipate no new development in traditional designs but a transition to electrification in every possible market."

"Don't know."

"Slowly components for gear train for electrical vehicles are getting manufactured locally and expect this to improve with time."

"I don't know."

"Fewer heat treating places to heat parts will create a bottleneck."

"Will decrease in number of gears but increase in the quality. Therefore, better equipment and strategies will be necessary."

"It will shrink slightly due to electrification, but will stay strong."

"Less components purchasing, more accuracy on actual ones. Quicker product delivery because changes are happening faster now."

"I would expect more advances in additive manufacturing, particularly in materials and property enhancement."

"We believe to achieve increased loading in continuously smaller packages, that a fair portion of the market will go from traditional rolling element bearings to oil lubricated journal bearings."

"Volumes might reduce, but accuracy and margins will increase."

"Stay the same with changing applications."

"That is the million dollar question that no one can truly answer."

"Unknown."

"I have real concerns companies will continue to try and offload gear manufacturing south of the border. Evolve is not the correct term, survive is."

"Market will decrease."

"Stronger quality for noiseless gears."

"Continue to shrink because of lack of interest by young people."

"Steady."

"More 3D printed parts, new heat treat, new materials."

"Lower volume of gears, but much higher requirements for NVH and tighter tolerances. Master gear quality for series production is the motto."

"We expect some growth with fewer players in the marketplace."

"More stringent on performance and noise level. More light weight and more torque with process improvement."

"There is going to be a slight shift in type of requirement of gears, but the constant requirements will remain and only increase as the other countries look for alternatives to China production. The market will turn towards India for the same to achieve same quality and similar costs."

"We don't know."

"Uncertain."

"Don't really know."

"More automation, freeing time for current staff to improve quality, etc."

"Immensely."

"We suppose that small gears will be done with additive manufacturing, the big ones no."

"I don´t know."

"I would suggest that there will be a move to additive manufacture for smaller gears and conventional subtractive manufacture for large gears."

"Less multi-speed gear boxes, more high-speed gear boxes."

"Slightly increase."

"Demand for precision gears will increase."

"30% growth."

"Improve 10% to 20%."

"Growth of 10 to 15 percent."

"For our specific products there is not much change, but on the processing side, we will definitely have changes that may help us in the next 5 to 10 years."

"Large push to automation. Smaller companies absorbed into larger ones."

"More automation and less importance on people and relationships. Developing new customers will get harder and harder."

"More attention to gear noise."

"No idea."

"Only high-quality gears will survive with large dimension gears."

"With each passing year, higher quality gears will be required to satisfy new quality requirements."

"Precision gear grinding and hobbing with automation."

"Not really certain..."

"More electric drives, hydrogen powered drives, greater automation requirements, more AI features and additive technology improvements."

"Decrease."

"Should increase."

"It will continue to get more complex in terms of the machinery and the training level to maximize the return on investments."

"Don't have a clue."

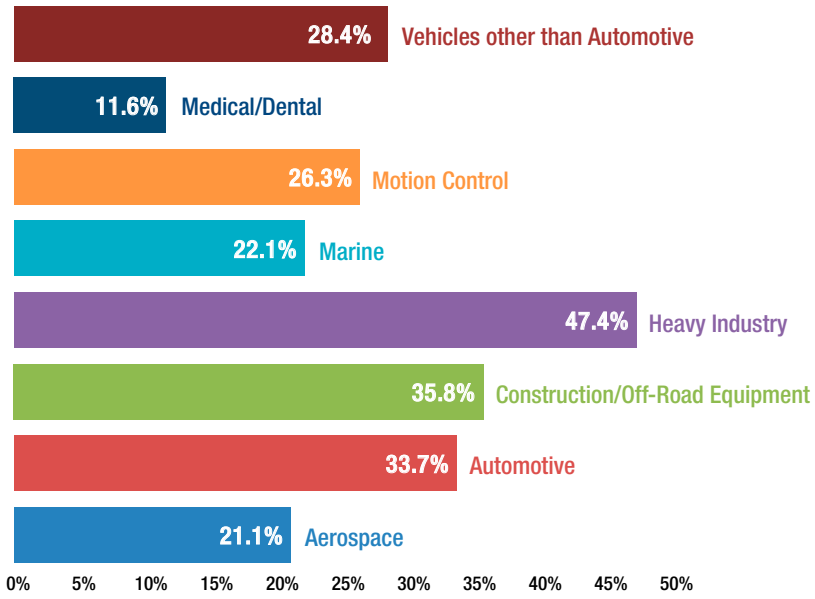
"Globally gear technology is getting stronger and will make it tougher for North American companies to survive."

"In my opinion the market regarding gears will grow maybe 40% next years, but new subjects will come around such as lubrication, heat dissipation, high speed, low weight and NVH."

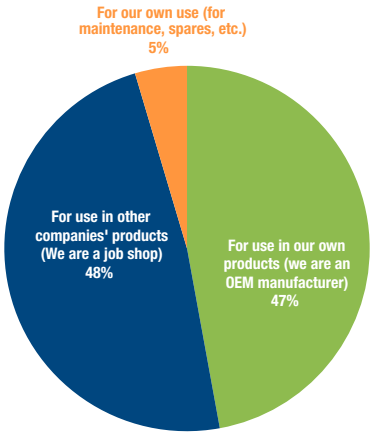
"It is likely that lower demand will create the opportunity for focusing on improving the gears quality."

"Room to grow."

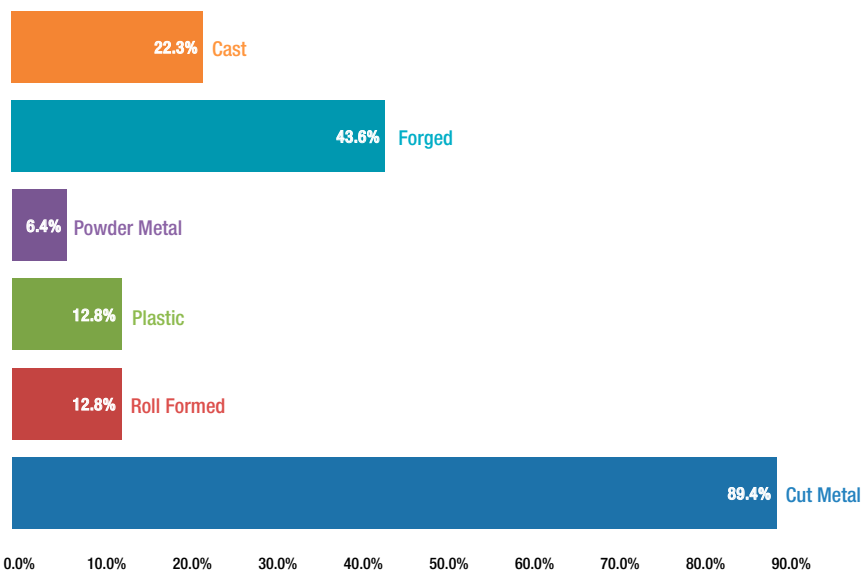
The gears (including sprockets, splines, worms and similar components) made at this facility are used for (check all that apply):



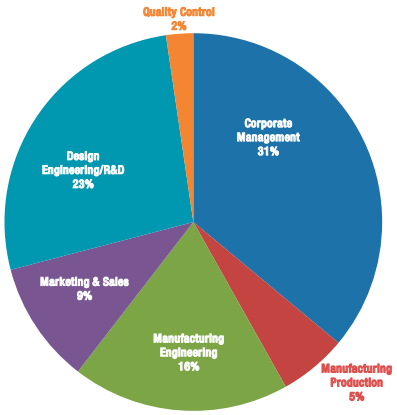
Gears (including splines, sprockets, worms and similar components) are manufactured at this location:



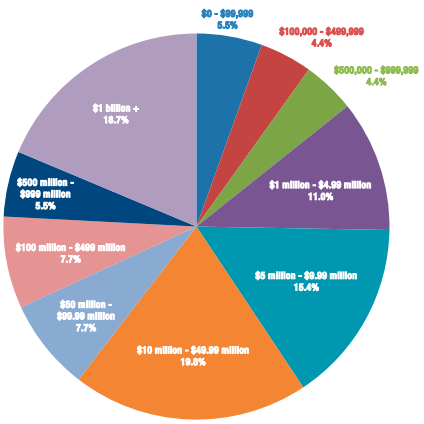
The gears manufactured at this location are (check all that apply):



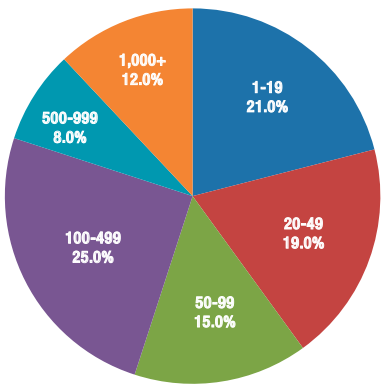
Which category best describes your job title/function?



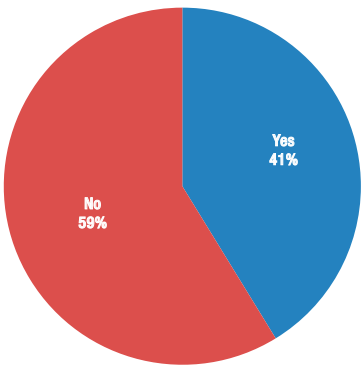
What is the approximate annual revenue for your company?



How many employees work at your location?



Is your company currently a member of the American Gear Manufacturers Association (AGMA)?



Notes Toward Emerging Technology

Welcome to the Inaugural "Frontiers" Column!

Mary Ellen Doran, AGMA Director, Emerging Technology

This new column is designed to provide information on the forward-thinking tech that is being reviewed and discussed in AGMA emerging technology committees. What should we be watching in the specific topic areas we cover? How will that impact the future of the gear industry? What are people discussing, specifically in the manufacturing space? I hope to be able to provide some of these answers in the coming issues.

The beginning of the year is always that unique time where you reflect on accomplishments from the past yet at the same time use those as a springboard for success in the future. Our emerging tech committees were very busy in 2023. We held more than 25 committee meetings. We hosted twelve webinars on topics that ran the gamut from blockchain to new techniques in additive forging, to major advances in technology on machine tools—all of these are available on-demand, for free, at *agma.org*. We hosted members at what is now our annual curated tour on the RAPID show floor. We tackled the topic of new standards at an EV Town Hall at the MPT Expo, and we worked hard on white papers that will be published in the coming months.

Using these great accomplishments as a starting point, we have much on the calendar already for 2024. Another busy monthly webinar series, including a special presentation on February 29th of the new updates to CMMC 2.0. If you do any government contracting, this is one not to miss.

Each of our committees will have a special focus in 2024. The IIoT committee will stay true to its cybersecurity roots (the December 2023 webinar on cybersecurity is another one to watch), but you can expect a lot of discussion on artificial intelligence (AI). AI may have gotten a lot of buzz in the last year, but we have been watching it for some time as it was utilized for digital twin technology and many more applications in manufacturing. We will bring you the latest as AI for manufacturing begins to be used for customer service and order-taking while keeping our eye on the power generation that is necessary for all this added computing.

Each committee will have at least four meetings this year; each meeting will have a topic of discussion and, in many cases, a special guest presentation. I welcome anyone with interest in these topics to join our committees. These are not committees for experts, they are committees for the curious. Joining is easy, please just send an email to: *doran@agma.org*.

The robotics committee is watching the projections of the industry moving from 590,000 units delivered in 2023 to estimates in the tens of millions by the 2030s. How will we get there? What technologies will be utilized for new robotic applications? And how will this directly impact the gear industry? We hope to tackle these tough questions this year.

The 3D printing committee understands that the place to watch in this space is materials development. We are always watching for more printed gears, but we are seeing movement in the development of materials for the cutting tool space that we would like to follow. Look for some updates here this year.

And finally, the electric vehicle committee will finalize its white paper at the beginning of 2024. All of us watched a transformation in the auto market in the last three years as major players announced the turn to electric vehicles, and new players emerged from some places we did not expect. We will be watching and discussing the trend lines in the EV committee this year. And we are putting a special focus on the supply chain with some discussions about steel and other natural resources much needed in this sector.

I am psyched for 2024 emerging tech work at AGMA! I hope to keep you updated, and maybe introduce something brand new to you through this column in coming issues.

Characterization of the Gear Meshing Damping of Gear Drives with Plastic Gears Using the Forced Response Analysis for NVH Prediction

Dr. Saeed Ebrahimi, Dr. Ulrich Kissling, and Sebastjan Matkovič

In powertrain systems, all deformable elements can dissipate energy when subjected to dynamic deformations. The internal damping of these elements including bearings and supports, shafts, and gears have an important impact on the energy dissipation. Consequently, damping plays an important role in the design of structures to minimize noise, structural instability, and fatigue failure of components. The gear meshing damping is known as an important determinative factor in the dynamic response of the system under specific running conditions. Without damping, undesirable induced vibrations create noise, increase dynamic loads, and potentially damage the gear teeth and bearings. It is well-known that plastic materials have higher damping values than steel. So, the main question discussed in this paper is, how noise, vibration, and harshness (NVH) are influenced by the presence of different viscous gear meshing damping. Here, some guidelines are presented to adjust the gear meshing damping for achieving the NVH characteristics of a powertrain system. In this regard, a dynamic calculation process called "forced response analysis tool" has been developed in *KISSsoft* to enable analysts and engineers to perform the dynamic analysis of the powertrain systems quickly and efficiently (Refs. 1, 2). To achieve this goal, gear body material with higher damping properties within the required torque ratio specifications can be chosen. Based on the static transmission error of the gears, shaft imbalances, etc., the bearing reaction forces are calculated by considering their mass and inertia.

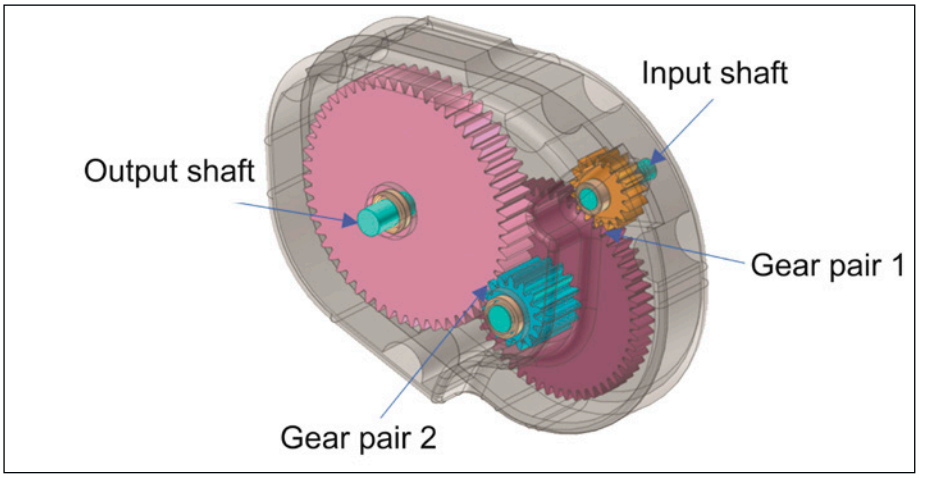


Figure 1—A two-stage gearbox model layout.

Forced Response Analysis

A two-stage gearbox model is considered in two variants with different gear materials, one with plastic gears and one with steel gears, see Figure 1. Both variants have the same input parameters (load, speed, number of cycles) and are designed to have similar root and flank safety. Therefore, the plastic gears are larger and have bigger diameters. The plastic gears' strength is calculated according to VDI 2736, while the steel gears' strength is calculated using ISO 6336. Both variants have the same housing material. Based on the load excitation imposed by the gears, the forced response analysis is conducted and at the bearing positions, the transient loads are evaluated.

In the first step of the forced response analysis, the dynamic factor K_v is evaluated. The dynamic factor is the ratio of the maximum dynamic excitation load between the meshing gears to the static contact force. K_v of the first gear pair of both models without gear meshing damping is shown in Figure 2. The dynamic factor characterizes the system behavior under dynamic loading at different shaft speeds and reveals the margins of the operational speeds for which the powertrain system can be significantly excited. The increase of the dynamic factor in the model with plastic gears is much higher than in the other model when no gear meshing damping is considered. The main reason behind this difference is the high transmission error due to the low meshing stiffness of the plastic gears compared to the steel gears, see Figure 3. In the example used, the dynamic meshing forces of the plastic gear model without damping consideration increased up to 550 percent (K_v=5.5); whereas in the steel gear model, the increase is only about 5.5 percent (K_v=1.055) (Fig. 2). When we first obtained these results, we were searching for errors in the calculation approach, as—from practice and test rigs—we know that gear drives with plastic gears have lower excitations. However, the results changed completely when we rerun the calculations considering damping.

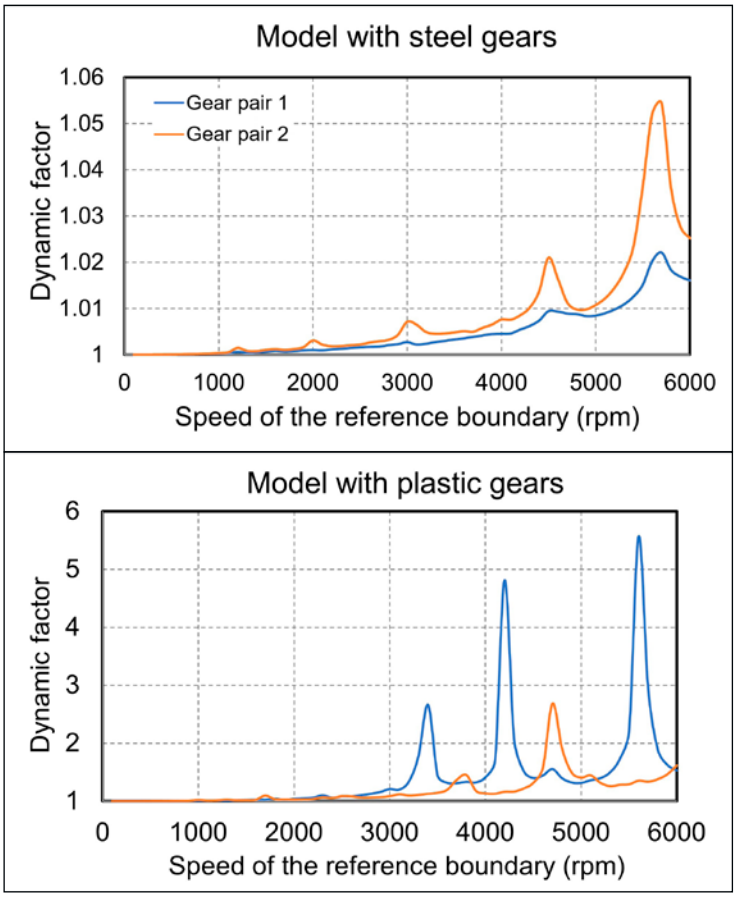


Figure 2—Dynamic factor without gear meshing damping, d=0 Ns/m.

When considering the damping effect in the meshing, the effect on the dynamic meshing contact forces for the gearbox with steel gears is noticeable, decreasing in our example K_v from 1.055 to 1.020, see Figure 4. Note that a damping factor d=1,000 Ns/m is a good approach for steel. In the model with plastic gears, the damping decreased the dynamic factors dramatically; in our example, K_v came down from 5.500 to 1.015 with a damping factor d=1,000 Ns/m (and to 1.004 with d=5,000 Ns/m). It is difficult to

obtain precise damping factors for plastic materials. After extensive research of the available literature, we determined the damping factor depends on the plastic type, temperature, and fiber reinforcement and that a damping factor of d=5,000 Ns/m is a conservative assumption to use.

It is interesting to notice that the effect of damping already at low values is dominant, which means that the reduction of the dynamic factor from d=0 Ns/m to 1,000 Ns/m is higher than the reduction from 1,000 Ns/m to 5,000 Ns/m. The same conclusion can be drawn by comparing the dynamic factor reduction from successive damping increases. As the main conclusion from the above analysis, it reveals that for plastic gears, an analysis without damping is useless. This implies that the damping should not be neglected even when a very approximate damping factor must be used, otherwise it would lead to an unrealistic response of the system.

NVH Analysis in *RecurDyn* Based on the Forced Response Analysis in *KISSsoft*

When executing an NVH evaluation, the gearbox housing is excited by the transient bearing forces at the bearing location points, and consequently, the noise emitted from the housing is evaluated. The bearing forces calculated in *KISSsoft* are imported to *RecurDyn* and applied directly to the housing of the powertrain model at bearing positions. As a major kinematic parameter required for the NVH analysis, the surface velocities at nodes of the meshed geometry are calculated. Finally, the equivalent radiated power (ERP), as the main factor for measuring the emitted noise level from the housing`s surface to the environment, is calculated. To demonstrate which parts of the housing's surface emit higher noise, the contour plot of the ERP is very helpful. It can subsequently be used to address demanded design modifications, such as local stiffening of the housing utilizing the ribs, to reduce the noise. Based on the bearing reaction forces calculated in the forced response at a speed of 5,600 rpm, the ERP contours of both models are shown. In both models, the region of the housing close to the output shaft has higher ERP values, and consequently, emits noise to the environment. The plastic gears model has

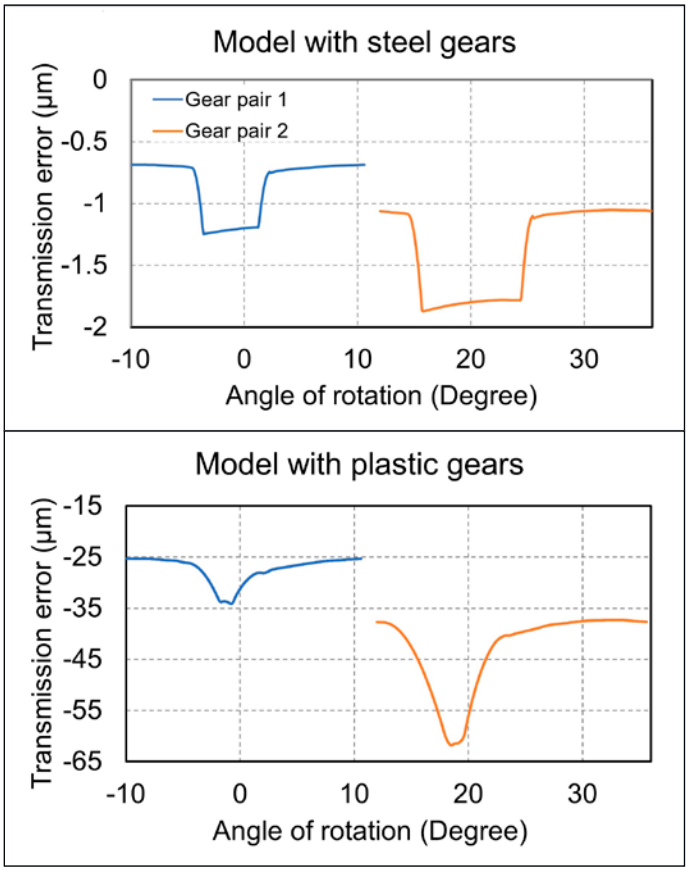


Figure 3—Transmission error of the gear pairs.

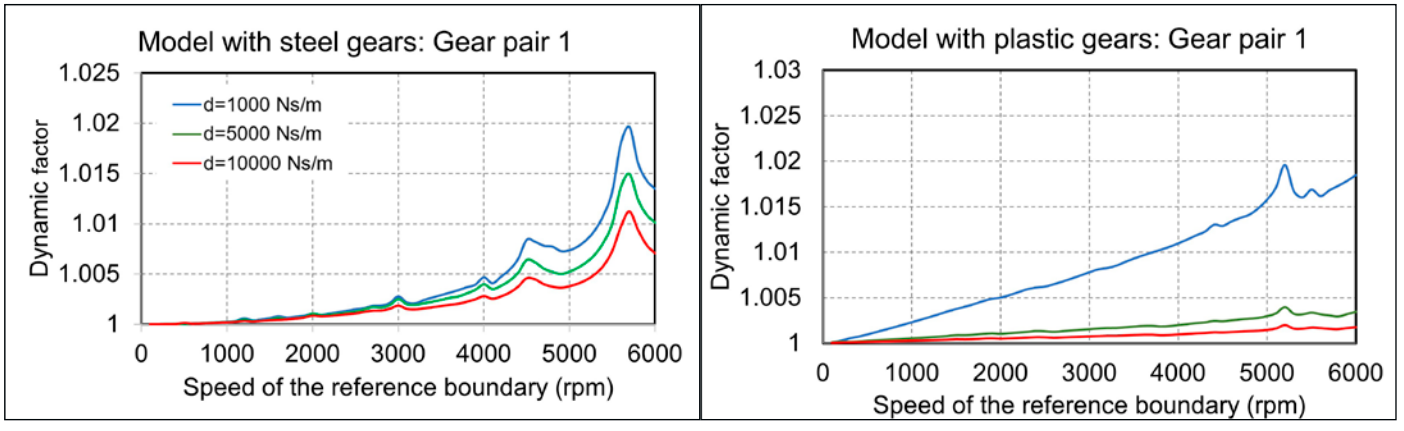


Figure 4—Dynamic factor of the models with different gear meshing damping.

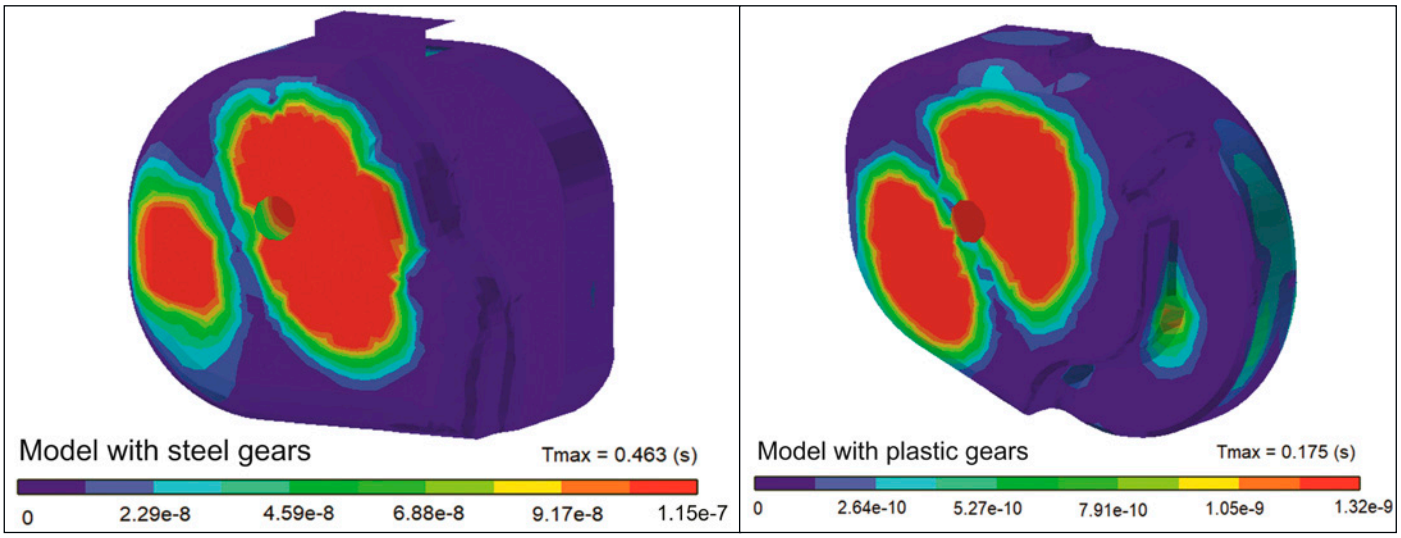


Figure 5—ERP contours at the time with maximum values at a speed of 5,600 rpm.

a much better performance concerning noise emission. The difference between the scales of the ERP of both models reveals this superiority (Figure 5). The maximum values of the color legends are adjusted to clearly show the noise distribution through the housing's surface. It is noticeable to mention that the variation of the ERP depends on the simulation time and the locally evaluated position on the housing.

Conclusion

This paper presented some steps to get more insight into the effect of meshing damping on the dynamic response and noise emission of a two-stage gearbox transmission system. For this purpose, two variants of the model with different gear materials, one with plastic gears and one with steel gears, were considered. Both variants were designed for the same number of cycles of operation with similar root and flank safeties. The forced response analysis of the models was carried out and the exciting reaction bearing forces were calculated to evaluate which model can achieve better NVH characteristics results with lower noise emission from the housing. It was observed that for plastic gears, the damping should not be neglected even when using an approximate damping value, otherwise it would lead to the unrealistic response of the system. Therefore, for plastic gears, consideration of meshing damping by selecting suitable gear material can be an efficient approach for damping undesirable induced vibrations. On the other hand, for steel gears, it is not as crucial as for plastic gears to use damping, since the results are less affected when compared to the plastic gears.

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2. KISSsoft *User Manual,* KISSsoft AG., Bubikon, Switzerland, 2023.

Dr. Saeed Ebrahimi has been the software developer at KISSsoft since 2019. He was previously an associate professor of mechanical engineering at Yazd University in Iran. He received his Ph.D. in mechanical engineering from Stuttgart University in Germany in 2007 and completed his post-doctoral fellowship at McGill University, in 2008.

Dr. Ulrich Kissling has been the president of KISSsoft since 1998. He studied Machine Engineering at the Swiss Technical University (ETH). In 1981, he started his professional career in a Gearbox Manufacturing Company. As a gear expert Dr. Kissling is participating in different Work Groups of ISO for international standards.

Sebastjan Matkovič is the software developer at KISSsoft, with extensive knowledge of polymer gears and gear tribology. In addition, he is a researcher and Ph.D. student in the Laboratory for Tribology and Interface Nanotechnology—TINT, University of Ljubljana.

Morphology of Wear on Tapered-Roller Bearing Roller Ends and Thrust Ribs

Robert Errichello, Rainer Eckert, and Andrew Milburn

Introduction

This report investigates the wear morphology on the large end of tapered rollers and the inner ring's large end rib on a planet carrier TRB from a multi-megawatt wind turbine gearbox. The literature (Ref. 1) on abrasive wear has many classifications, including 2-body abrasion, 3-body abrasion, scratches, grooving abrasion, rolling abrasion, cutting abrasion, and plowing abrasion. For this analysis, we have selected grooving abrasion, a common problem in wind turbine gearboxes and a prominent failure mode on many bearings, particularly planetary carrier bearings and planet bearings. Grooving abrasion is frequently observed on cylindrical roller bearings (CRB) and tapered roller bearings (TRB).

Fitzsimmons and Clevenger (Ref. 2) conducted tests on roller end/rib wear for TRBs with contaminated gear oil, and they provided an excellent explanation of the mechanism.

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

geartechnology.com/wear-morphology-figures

Nomenclature

BSE	Back Scattered Electrons
CRB	Cylindrical Roller Bearing
EDS	Energy Dispersive Spectroscopy
GS	Generator Side
GSC	Geometric Stress Concentration
IR	Inner Ring
LOM	Light Optical Microscopy
OR	Outer Ring
SEM	Scanning Electron Microscopy
TRB	Tapered Roller Bearing

Example Planet Carrier Bearing

Figure 1 shows a generator side (GS) planet carrier TRB. The image displays the inner ring (IR), outer ring (OR), and a few rollers. However, the cage has been removed. The IR, OR, and rollers have extensive micropitting. Moreover, a section of the IR has severe macropitting. See Figure 30 for the geometry and nomenclature of a TRB.

Figure 2 displays two rollers with micropitting on the larger end, indicating bearing misalignment.

In Figure 3, one can see a section of the IR. The raceway in this section is entirely affected by micropitting, and as a result, secondary macropitting occurs at both edges of the raceway due to geometric stress concentration (GSC). For more details about micropitting and GSC, refer to Ref. 3.

Figure 4 shows the section of the IR with severe macropitting.

Description of Figure 4

Macropitting is a type of failure that often occurs after micropitting. This is because micropitting can damage the accuracy of some components, such as the OR, IR, and rollers, and increase the internal clearance of the bearing. When the components lose their accuracy and the internal clearance increases, the bearing can become misaligned, leading to GSC. One can identify macropitting by looking for beach marks left by fatigue growth and fretting corrosion in the craters caused by rubbing between the faces of the subsurface macropitting cracks.

It is important to recognize that micropitting is the primary failure mode, with macropitting being a secondary failure mode that occurs due to micropitting.

Figure 1—GS planet carrier TRB.

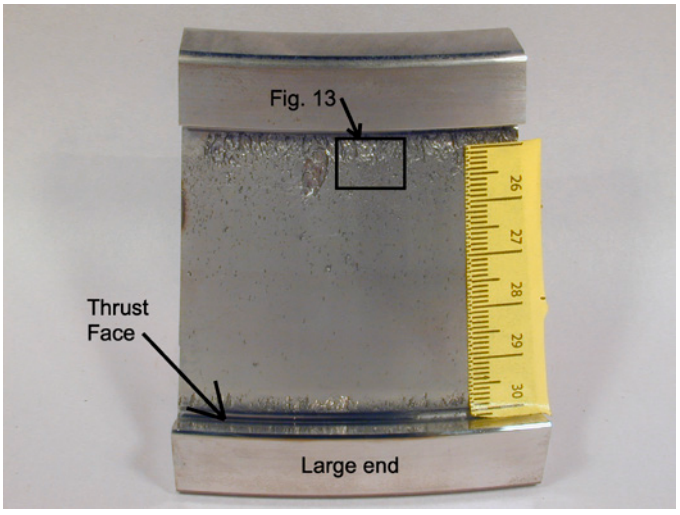

Figure 3—section of the IR with micropitting and macropitting.

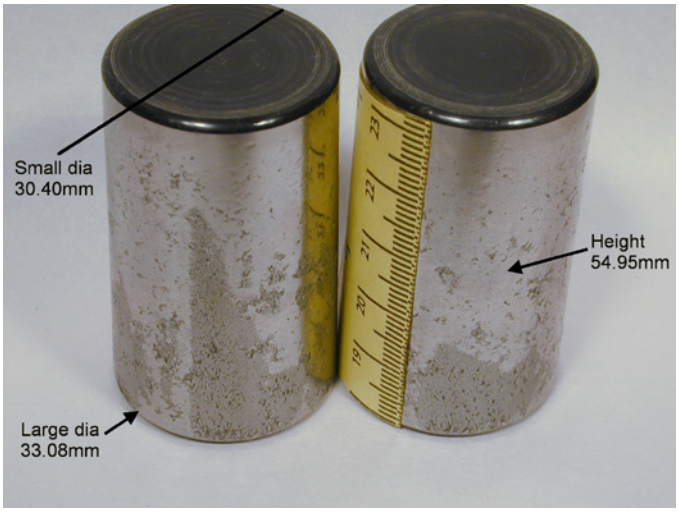

Figure 2—TRB rollers with micropitting toward large ends.

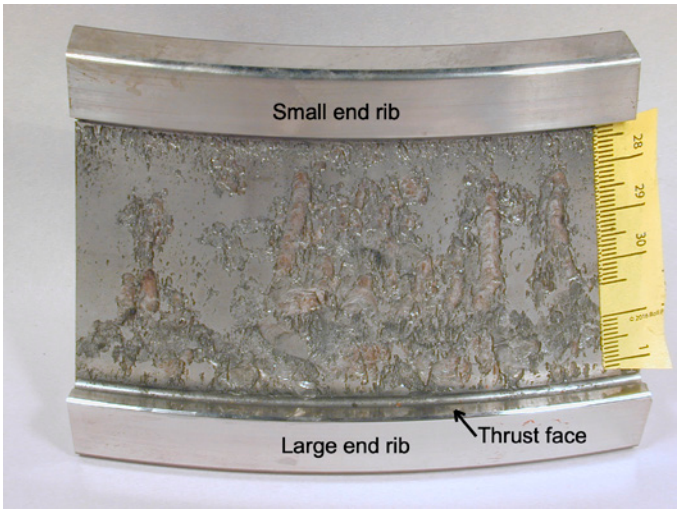

Figure 4—section of the IR with severe macropitting.

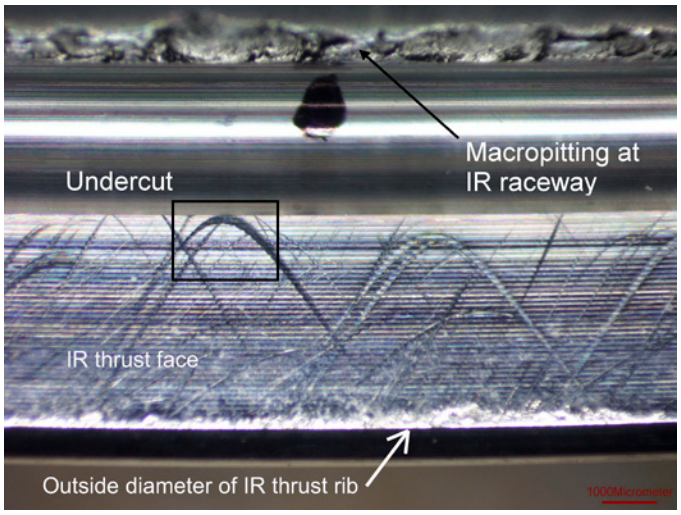

Figure 5—LOM image of the IR thrust rib.

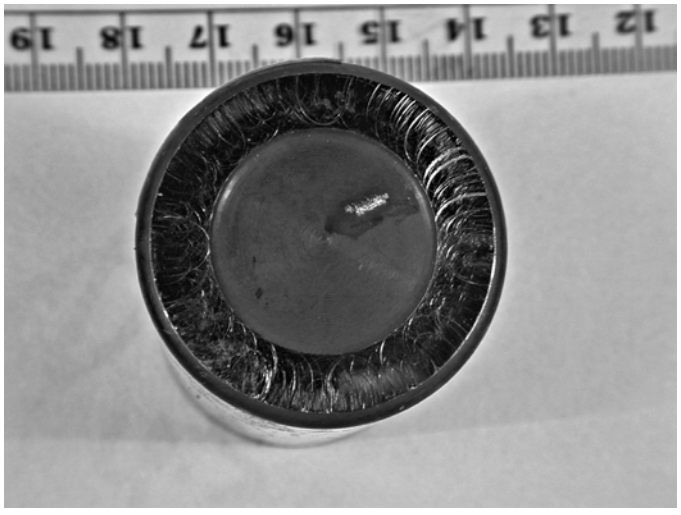

Figure 6—LOM image of the roller large end with a multitude of scratches.

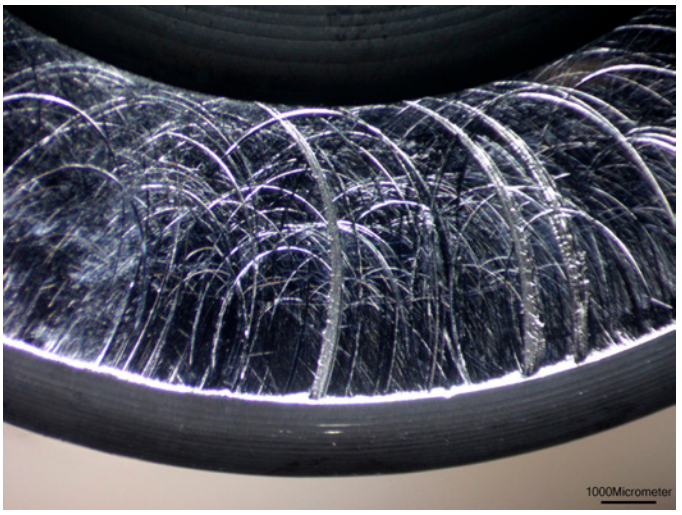

Figure 7—LOM image of an enlarged view of Figure 6.

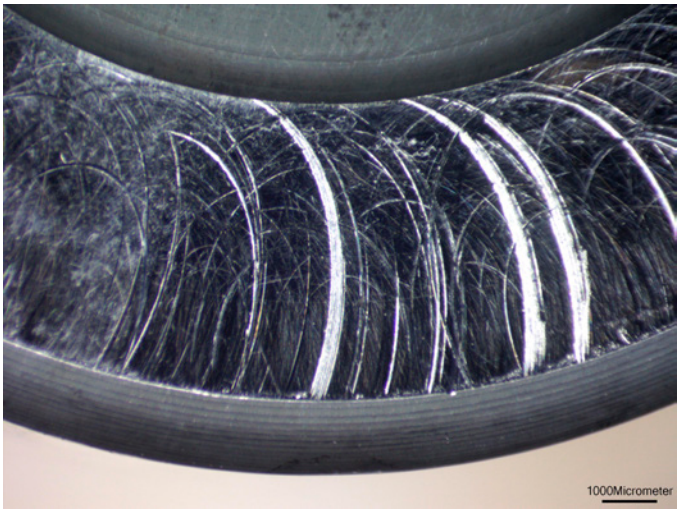

Figure 8—same as Figure 7 except with a different light direction.

Figure 5 is a light optical microscopy (LOM) image of the face of the IR thrust rib.

Description of Figure 5

The macropitting at the edge of the IR raceway is at the top of the image and the outside diameter of the IR thrust rib is at the bottom of the image. The undercut of the grinding relief is between the macropitting and the face of the IR thrust rib. See Figure 21 for an enlarged view of the area within the rectangle.

The arc-shaped marks on the face of the IR thrust rib are grooving abrasions that were caused by hard particles that were trapped between the roller ends and the IR thrust rib. Each arc-shaped mark was caused by a particle that got fixed on the end of a roller and forced to follow a specific path called a curate epitrochoid (see "Annex A" section for description of epitrochoids). The various positions of the arc-shaped marks were caused by separate particles that were fixed at various positions on the roller ends.

Figure 6 is a LOM image of the large end of a roller with a multitude of scratches.

Figure 7 is a LOM image that is an enlarged view of Figure 6.

Figure 8 is like Figure 7 except that a different lighting direction was used for the photo. LOM has an advantage over scanning electron microscopy (SEM) because scratches are emphasized by specular light reflection.

Description of Figure 8

The recess on the roller end is at the top of the image, and the outside diameter of the roller is at the bottom of the image.

There are marks on the roller end face that are shaped like an ellipse. These marks were caused by grooving abrasion, which was caused by hard particles that got trapped between the roller end and the IR thrust rib. A fixed particle on the IR thrust rib traces an ellipse-shaped curve called a prolate epitrochoid on the end of the roller. The positions of the ellipse-shaped marks varied because separate particles were fixed at different positions on the IR thrust rib. If you want to know more about epitrochoids, see Annex A for a detailed description.

Figure 9 is a LOM image of the bearing OR. It shows micropitting biased toward the large end of the OR raceway and small macropits starting at the edge of the OR raceway.

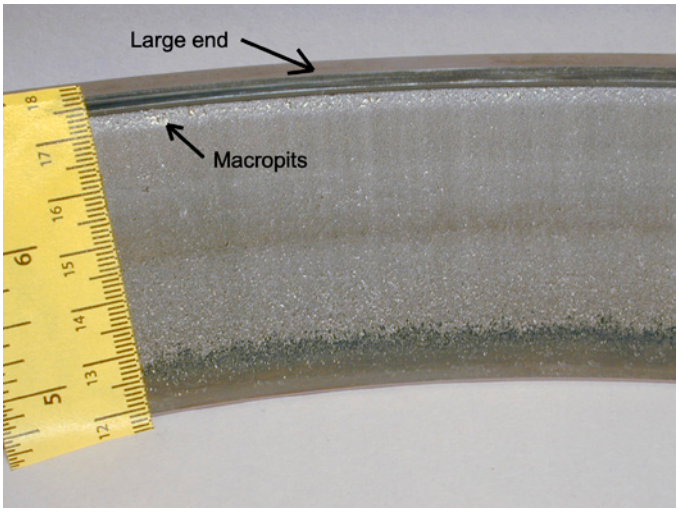

Figure 9—Micropitting biased toward the large end of the OR raceway.

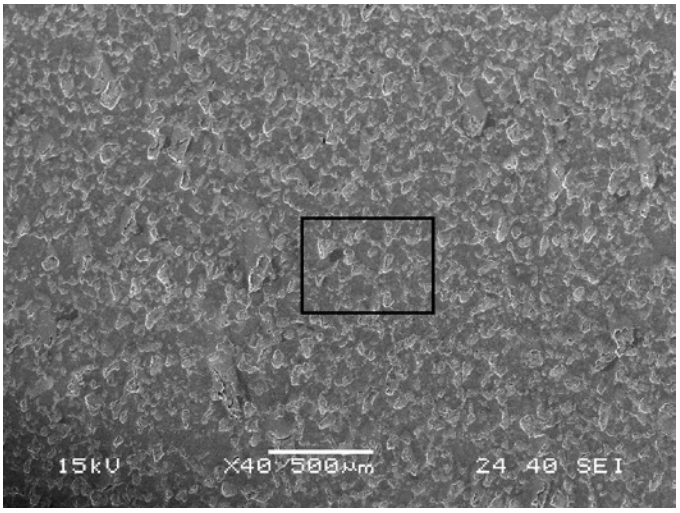

Figure 11—SEM image of the IR raceway at 40x magnification.

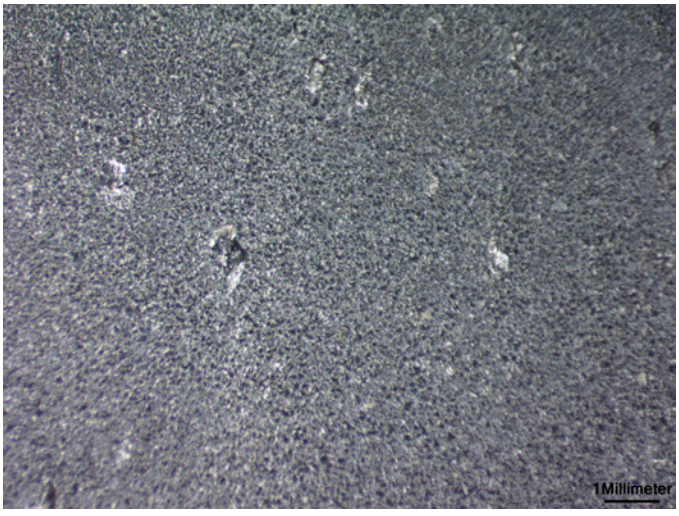

Figure 10—LOM image of the bearing IR raceway at 10x magnification.

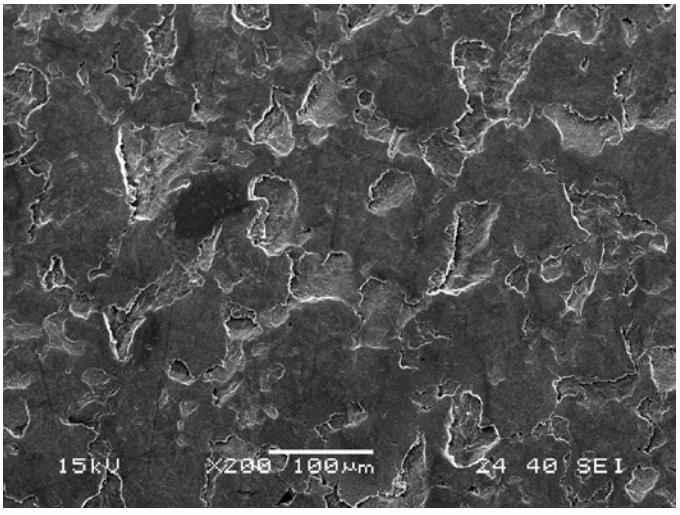

Figure 12—SEM image of the IR raceway at 200x magnification.

Figure 10 is a LOM image of the bearing IR raceway at 10x magnification.

Figure 11 is an SEM image of the IR raceway at 40x magnification.

Figure 12 is an SEM image of the IR raceway within the area of the rectangle in Figure 11 at 200x magnification.

Figure 13 is an SEM image of macropitting at the edge of the small end of the IR raceway.

Description of Figure 13

Macropitting was detected at both edges of the IR raceway. Figure 13 shows macropitting at the small end of the IR raceway. This area is just to the right of the large macropit shown in Figure 3. The macropitting was caused by GSC, which occurred due to the abrupt edge of the micropitting on the IR raceway. Furthermore, the micropitting increased the internal clearance of the bearing, leading to misalignment and further aggravating the GSC.

Macropitting is a secondary failure mode that often occurs at the edges of bearing raceways, following the primary failure mode of micropitting. This occurs because micropitting causes the IR raceway to conform to the rollers and eliminates

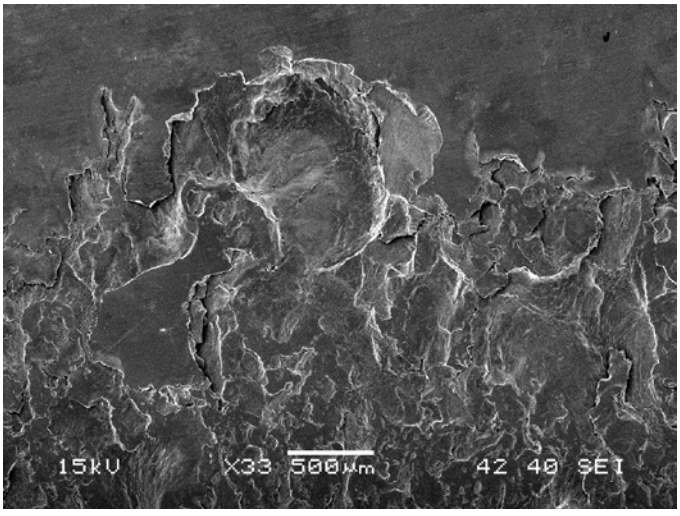

Figure 13—SEM image of macropitting at the edge of the small end of the IR raceway.

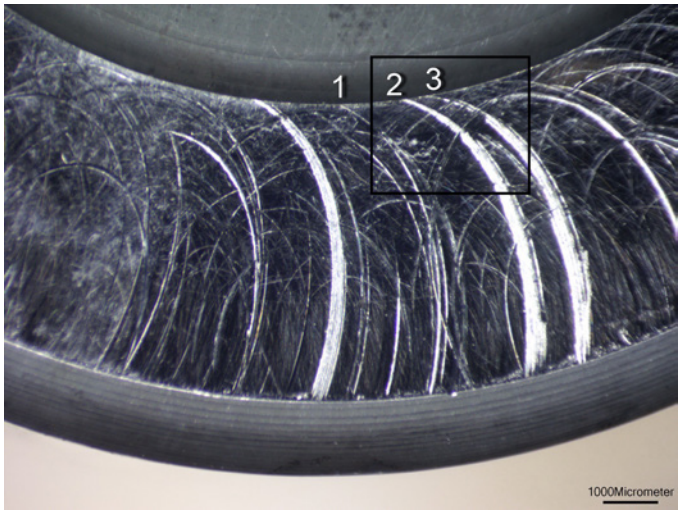

Fig 14—LOM image of roller end (same as Figure 8).

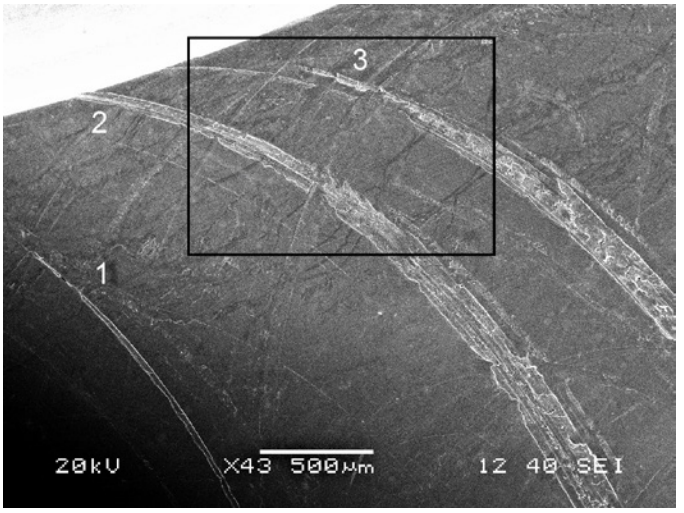

Figure 15—SEM image of the roller end at higher magnification.

the crown on the rollers, which creates GSC at the ends of the rollers. For more detailed information on this mechanism, please refer to Ref. 3.

Figure 14 is the same LOM image as Figure 8, repeated here for clarity.

Description of Figure 14

For discussion, we identify three prolate epitrochoid curves—Curve 1, Curve 2, and Curve 3. Curve 1 is narrower than 30 µm and is referred to as a scratch, while Curve 2 and Curve 3 are wider (up to 400 µm) and referred to as grooves. During the grooving abrasion process, hard particles on the IR thrust rib begin contact with the roller end at the bottom of Figure 14 and leave contact with the roller end at the recess near the top of Figure 14. See Figure 15 for an enlarged view of the area within the rectangle.

SEM and BSE Images of Roller End Wear

The following Figures 15–20 are SEM images and backscattered electrons (BSE) images of roller end and IR thrust rib grooving abrasion.

Figure 15 is an SEM image of the roller end within the area of the rectangle in Figure 14 at higher magnification.

Description of Figure 15

Curve 1 in Figure 15 is a smooth and clean scratch that ends near the number 1. The particle that created Curve 1 left contact with the roller end near the number 1. At its widest point, Curve 1 measures about 30 µm, which is close to the limit of detection for the naked eye. However, with intense directional light, the specular reflection makes the scratches easily detectable, as shown in Figure 14. See Figures 16 and 17 for enlarged views of the area within the rectangle at higher magnification.

On the other hand, Curves 2 and 3 are rough and plastically deformed grooves that are as wide as 180 µm near the bottom of Figure 15. The roughness of these curves causes light rays to scatter in all directions, resulting in diffuse reflection. This makes grooves 2 and 3 appear frosted, as shown in Figure 14.

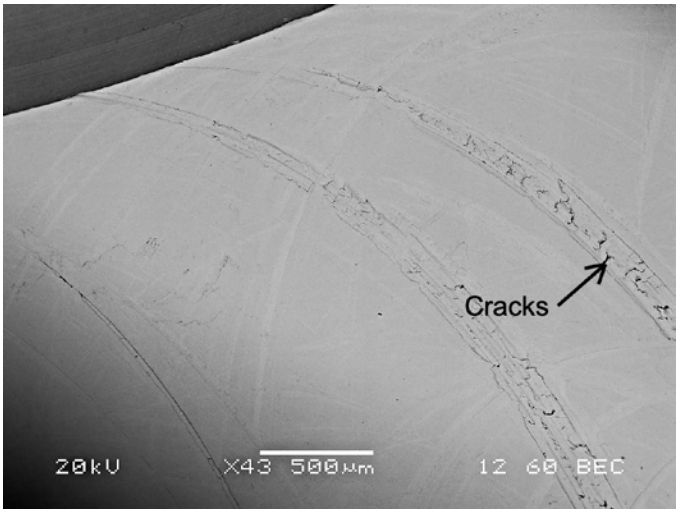

Figure 16—BSE image of Figure 15.

Figure 16 is a BSE image of the roller end within the area of the rectangle in Figure 15 at higher magnification.

Description of Figure 16

BSE images can easily detect foreign particles that may be embedded in a surface. Some common types of particles include grinding dust (such as aluminum oxide, cubic boron nitride, or silicon carbide), or environmental dust like silica sand. BSE images can distinguish between different elemental compositions based on their atomic weight. In a BSE image, aluminum and silicon appear dark as they have low atomic numbers of 13 and 14 respectively, while iron, which has a relatively high atomic number of 26, appears bright. By examining Figure 16, one can see that there are no dark particles present, indicating that there are no hard, foreign particles embedded in the roller end. Therefore, the abradants are likely to be debris particles from micropitting and macropitting of the bearing components that have been work-hardened by overrolling.

BSE images can aid in detecting cracks because carbon from hydrocarbon lubricant gets trapped within the cracks, making them appear dark in BSE images. Figure 16 displays multiple

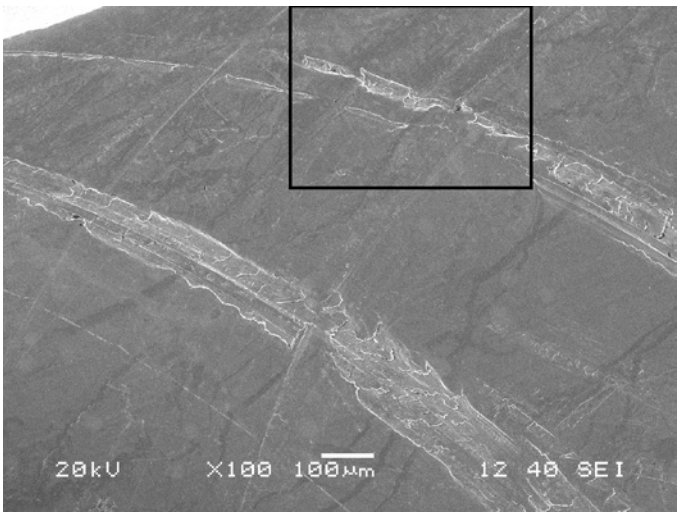

Figure 17—SEM image of roller end at higher magnification.

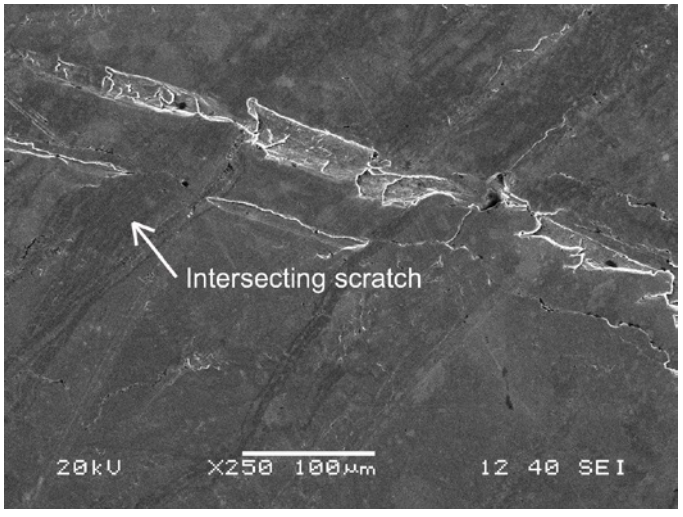

Figure 18—SEM image of roller end at higher magnification.

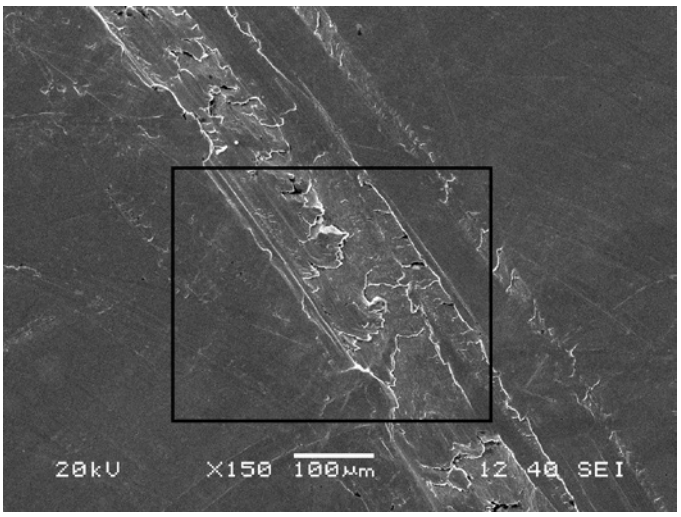

Figure 19—SEM image of roller end at higher magnification.

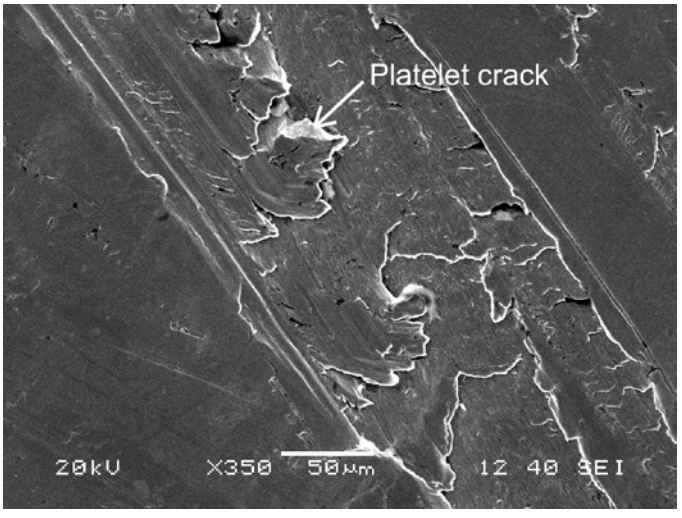

Figure 20—SEM image of the roller end at higher magnification.

cracks within two broad grooves. It's worth noting that these cracks are not noticeable in the SEM image shown in Figure 15.

Figure 17 is an SEM image of the roller end within the area of the rectangle in Figure 15 at higher magnification.

Description of Figure 17

The image displays the rough surfaces inside the grooves, with plastic material flowing into them due to intersecting scratches. See Figure 18 for an enlarged view of the area within the rectangle.

Figure 18 is an SEM image of the roller end within the area of the rectangle in Figure 17 at higher magnification.

Description of Figure 18

The upper rough groove is the groove labeled 3 in Figure 15. The lower smooth groove is a scratch that was interrupted by plastic deformation caused by intersecting scratches.

Figure 19 is an SEM image of the roller end at another area.

Description of Figure 19

This image shows a wide groove with flattened platelets due to plastic deformation in the groove, cracks on the upper shoulder, and plastic flow on the lower shoulder caused by intersecting scratches. See Figure 20 for an enlarged view of the area within the rectangle.

Figure 20 is an SEM of the roller end within the area of the rectangle in Figure 19 at higher magnification.

Description of Figure 20

Grooving abrasion creates raised shoulders on both edges of the grooves. When the raised shoulders encounter a mating surface, they get flattened, which we call ironing. As the roller rotates, it causes angular displacement and cracking of the thin platelets of plastically deformed surface material.

Figures 15–20 demonstrate that the shape of grooving abrasion in wide grooves is consistent with a process of plastic deformation that leads to the formation of thin platelets of material flow. These platelets are likely to contain cracks caused by tensile stress due to frictional force between the roller and a fixed particle on the IR thrust rib. It is probable that the wide groove width, which can be up to 400 µm, is produced by macropitting debris.

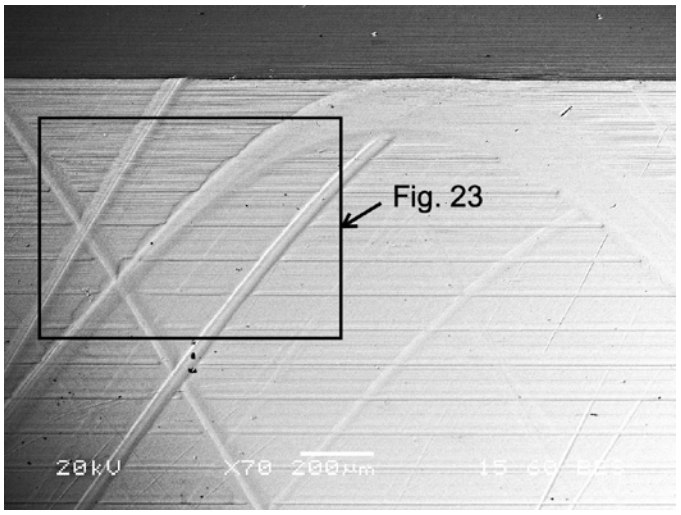

Figure 21—BSE image of the IR thrust rib.

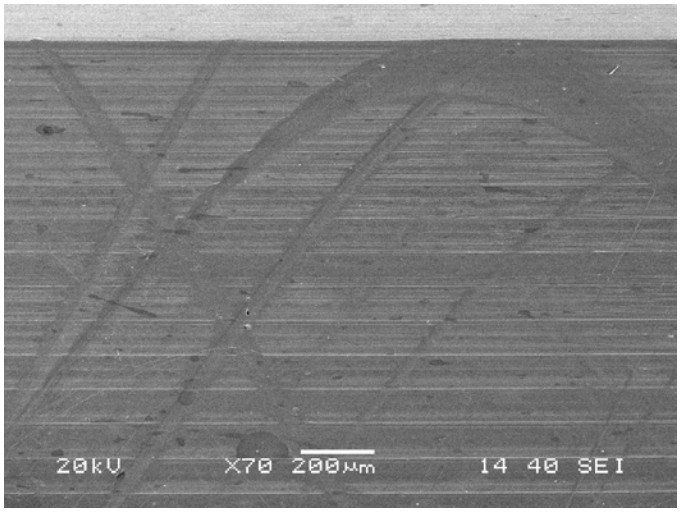

Figure 22—SEM image of the IR thrust rib.

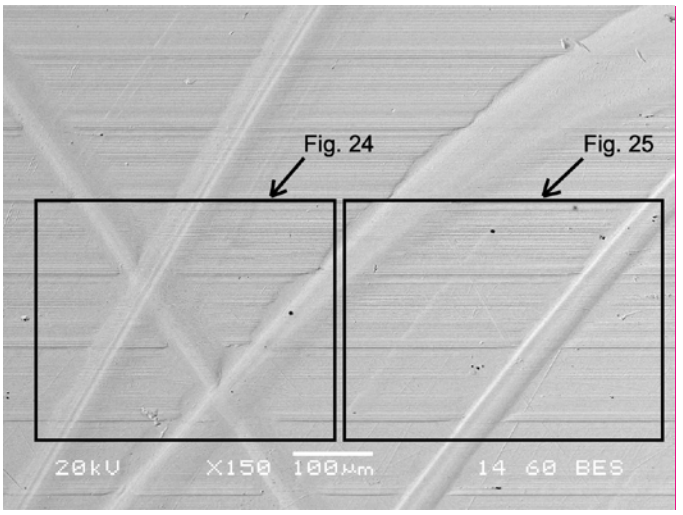

Figure 23—BSE image of the IR thrust rib at higher magnification.

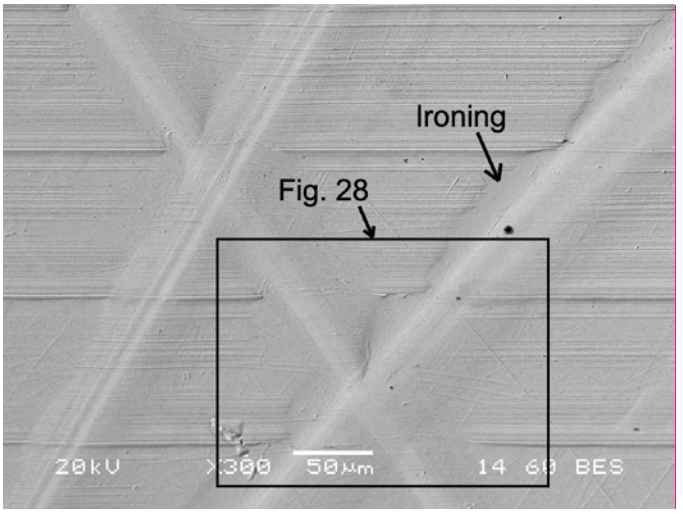

Figure 24—BSE image of the IR thrust rib at higher magnification.

SEM and BSE Images of Thrust Rib Wear

The following Figures 21–29 are SEM and BSE images of the wear on the IR thrust rib.

Figure 21 is a BSE image of the IR thrust rib within the area of the rectangle in Figure 5 at higher magnification.

Description of Figure 21

In the image, the top part shows the undercut of the grinding relief. The horizontal grooves that can be seen are a natural part of the surface topography that was created by grinding the face of the IR thrust rib. There are also finer grinding marks on the surface between the horizontal grooves. Below the rectangle, three black dots are believed to be from a fractured hard particle, which is a rare occurrence for the images in this report. See Figure 23 for an enlarged view of the area within the rectangle.

When comparing Figures 20 and 21, the IR thrust rib in Figure 21 appears more ductile than the roller end in Figure 20 because there were no cracks in the IR thrust rib.

Figure 22 is an SEM image of Figure 21.

Description of Figure 22

Comparing Figures 21 and 22, it is evident that BSE images provide a higher resolution of surface topography and are ideal for displaying grooving abrasion features compared to SEM images.

Figure 23 is a BSE image of the IR thrust rib within the area of the rectangle in Figure 21 at higher magnification.

Description of Figure 23

The curtate epitrochoid groove in the central part of the image displays ironing plastic deformation of the upper shoulder of the groove. The narrow groove at the right of the image has less plastic deformation of the upper shoulder. See Figure 24 for an enlarged view of the area within the left rectangle. See Figure 25 for an enlarged view of the area within the right rectangle.

Figure 24 is a BSE image of the IR thrust rib within the area of the left rectangle in Figure 23 at higher magnification.

Description of Figure 24

Ironing of the upper shoulder of the larger groove caused the material to flow on top of the original grinding marks on the

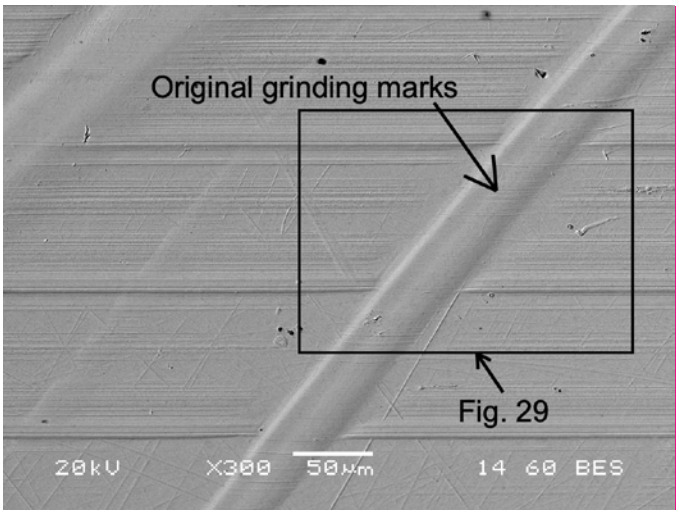

Figure 25—BSE image of the IR thrust rib at higher magnification.

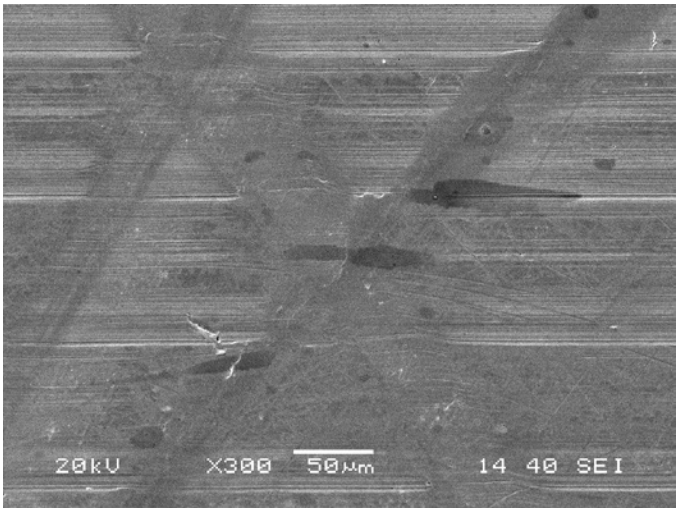

Figure 27—SEM image of Figure 24.

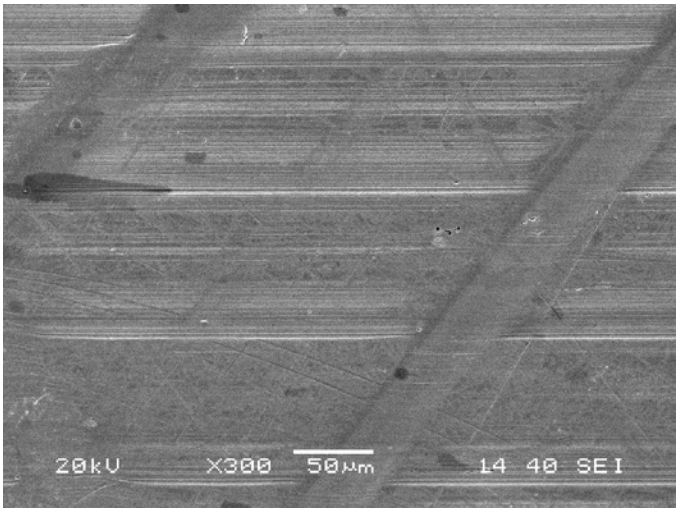

Figure 26—SEM image of Figure 25.

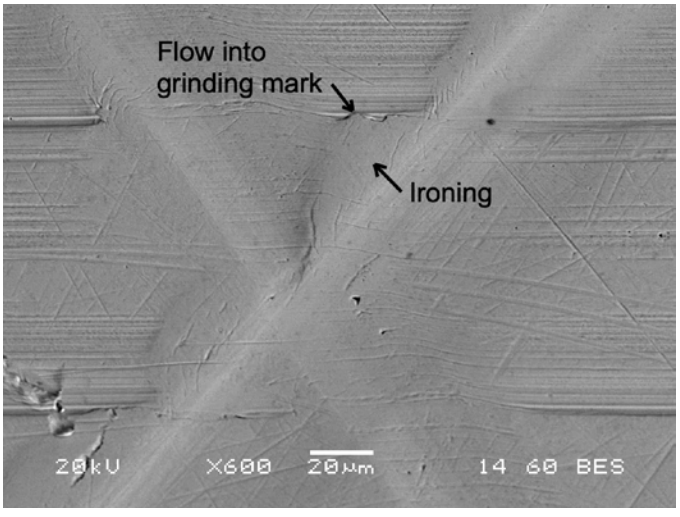

Figure 28—BSE image of the IR thrust rib at higher magnification.

face of the IR thrust rib. See Figure 28 for an enlarged view of the area within the rectangle.

Figure 25 is a BSE image of the IR thrust rib within the area of the right rectangle in Figure 23 at higher magnification.

Description of Figure 25

The groove on the right-hand side of the image is a common example of a narrow groove with a small upper shoulder and original grinding marks present within the groove. This shape is indicative of grooving abrasion, which occurs due to plastic deformation without any evidence of cutting abrasion. Additionally, since the width of the narrow groove is approximately 30 µm, the narrow grooves were likely produced by micropitting debris. See Figure 29 for an enlarged view of the area within the rectangle.

Figure 26 is an SEM image of Figure 25.

Description of Figure 26

In comparison to Figure 25, Figure 26 demonstrates that BSE images are ideal for displaying surface topography, while SEM images are better suited for displaying surface marks, films, and contamination. Although SEM only produces black-and-white images, when paired with energy dispersive spectroscopy (EDS), it can identify the chemical composition of surface films.

Figure 27 is an SEM image of Figure 24.

Description of Figure 27

Compared to Figure 24, Figure 27 shows that BSE images are best for showing surface topography, and SEM images are best for showing surface films. The black marks are artifacts created by a residual cleaning agent.

Figure 28 is a BSE image of the IR thrust rib within the area of the rectangle in Figure 24 at higher magnification.

Description of Figure 28

This image demonstrates an instance of plastic deformation caused by ironing the shoulders of grooving abrasion. It is apparent that the ironing process has resulted in the distortion of the original grinding marks, and in some cases, the material has flowed into sections of the deeper grinding marks.

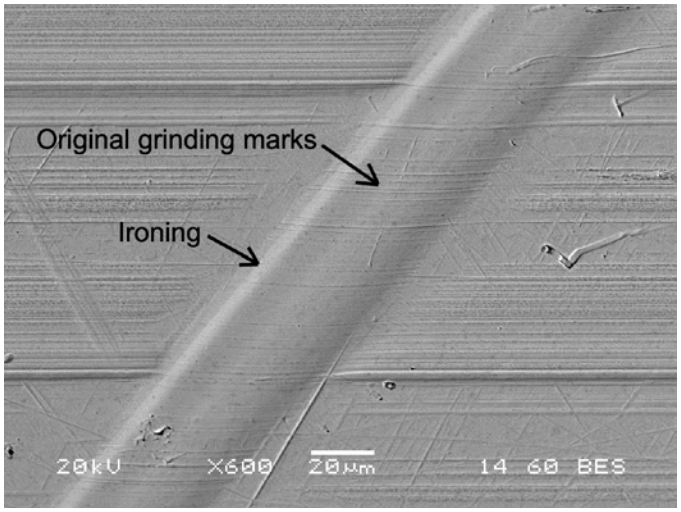

Figure 29—BSE image of the IR thrust rib at higher magnification.

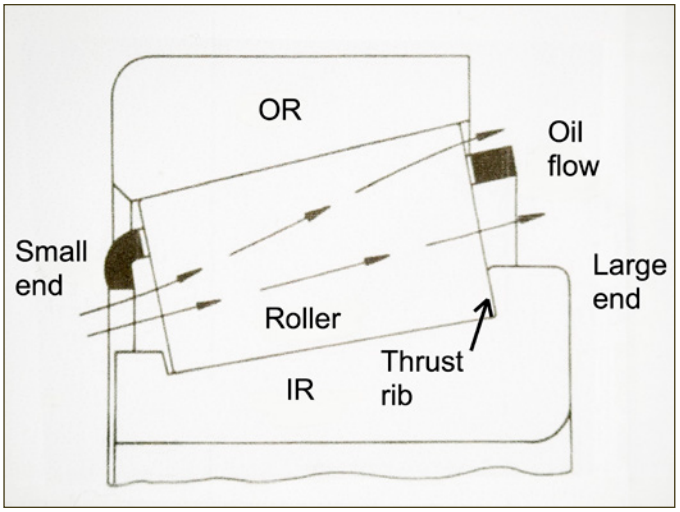

Figure 30—Lubricant flow in a TRB (Ref. 2).

Figure 29 is a BSE image of the IR thrust rib within the area of the rectangle in Figure 25 at higher magnification.

Description of Figure 29

This image displays the presence of original grinding marks inside the groove. This phenomenon is quite like the circular indentation formed by a tungsten ball of a Brinell tester. When the Brinell indentation is made, plastic deformation occurs below the surface and the original grinding marks remain preserved within the indentation because the surface stays elastic.

Figures 21-29 indicate that the wide and narrow grooves on the IR thrust rib have a ductile appearance, with no signs of cracking. However, Figures 15–20 reveal that the wide grooves on the rollers display a more brittle appearance, with evidence of plastic deformation and platelet cracking. The reason for the different morphology of grooves in the rollers and IR thrust rib is not due to a variation in hardness, as the hardness of the roller was 60.8 HRC, and that of the IR thrust rib was 61.6 HRC, which is not a significant difference.

Discussion

According to Fitzsimmons and Clevenger (Ref. 2), the lubrication process of TRBs involves the entry of lubricant at the small end of the rollers. The lubricant is then pumped towards the large end of the rollers because of the taper on the rollers. This movement may cause contaminants in the lubricant to be transported to the IR thrust rib, as shown in Figure 30.

To study the influence of metallic wear debris on TRBs, Fitzsimmons and Clevenger utilized particles that were typical of work-hardened bearing material with a Mohs hardness of 8. These particles were harder than carburized steel, which has a Mohs hardness of 7. They found that metallic particles ranging in size between 5–40 µm caused significant wear on both the TRB roller ends and IR thrust ribs. However, the elastohydrodynamic film thickness of the lubricant employed in their experiments was only 0.2 µm. Therefore, they concluded that the particles were significantly reduced in size as they were overrolled in contacts between the roller and the IR and OR raceways.

We found two types of wear debris - micropitting and macropitting. Micropitting debris was smaller than 10 µm, while macropitting debris was around ten times larger. Both types of debris were ductile and could be flattened, indicating they were hard but ductile.

Abradants experience a force normal to the groove plane, and a tangential force tangent to the path of the epitrochoid. Particles that are around 30 µm wide undergo low normal and tangential forces. This helps the groove maintain its smoothness and reflectivity. However, larger particles are subject to higher forces, causing the grooves to widen, and resulting in rough grooves with diffuse reflection.

The SEM and BSE images showed no evidence of cutting abrasion or transferred material. We conclude that cutting abrasion and adhesion played no role in the grooving abrasion found on the roller ends or the IR thrust rib.

Conclusions

1. The failure mode for roller ends and the IR thrust rib is 2-body grooving abrasion.
2. Grooving abrasion created narrow grooves less than 30 µm wide and wide grooves up to 400 µm wide.
3. Narrow grooves on the roller ends had smooth surfaces that exhibited specular reflection in LOM images and appeared as scratches.
4. Thin platelets of plastically deformed and cracked material on roller ends created wide grooves with rough surfaces. These grooves exhibited diffuse reflection in LOM images and appeared as frosted grooves.
5. Narrow grooves were probably caused by small, work-hardened particles from micropitting debris. Despite being about 30 µm wide, these narrow grooves could have been created by much smaller particles that were elongated by overrolling.
6. Wide grooves were probably caused by large, work-hardened particles from macropitting debris.
7. Particles creating narrow grooves experienced relatively small normal and tangential forces, which caused smooth grooves and specular reflection.
8. Particles creating wide grooves experienced relatively large normal and tangential forces, which caused rough grooves and diffuse reflection.
9. Roller end grooving abrasion followed prolate epitrochoid paths created by particles fixed on the IR thrust face.
10. IR thrust rib grooving abrasion followed curate epitrochoid paths created by particles fixed on roller ends.
11. No evidence of embedded foreign particles was found in any image associated with grooving abrasion.
12. No evidence of micropitting or macropitting fixed debris was found in any image. This indicates that only temporarily fixed debris created 2-body grooving abrasion.
13. Wide and narrow grooves on the IR thrust rib appeared ductile, while wide grooves on roller ends showed more brittle plastic deformation and platelet cracking. The different morphology is not due to hardness variation. Roller hardness was 60.8 HRC, and IR thrust rib hardness was 61.6 HRC, which is not significantly different.
14. IR thrust rib groove abrasion showed original grinding marks in narrow grooves, and ironing on the shoulders of wide grooves, indicating ductile deformation.
15. Cutting abrasion and adhesion played no role in the grooving abrasion found on the roller ends and the IR thrust rib.
16. BSE images are ideal for showing surface topography, while SEM images are better at displaying surface films.

Annex A

Epitrochoids

Figures A1 and A2 were produced by the Desmos graphing calculator available at the following links:

Link for Figure A1: ***desmos.com/calculator/fy72awovzl***
Input data for Figure A1:
a = 51 (number of rotations of rolling circle r)
R = 16.54 (R_{roller})
r = 280 ($R_{raceway}$)
d = 282.5 (distance of generating point from the center of rolling circle r)

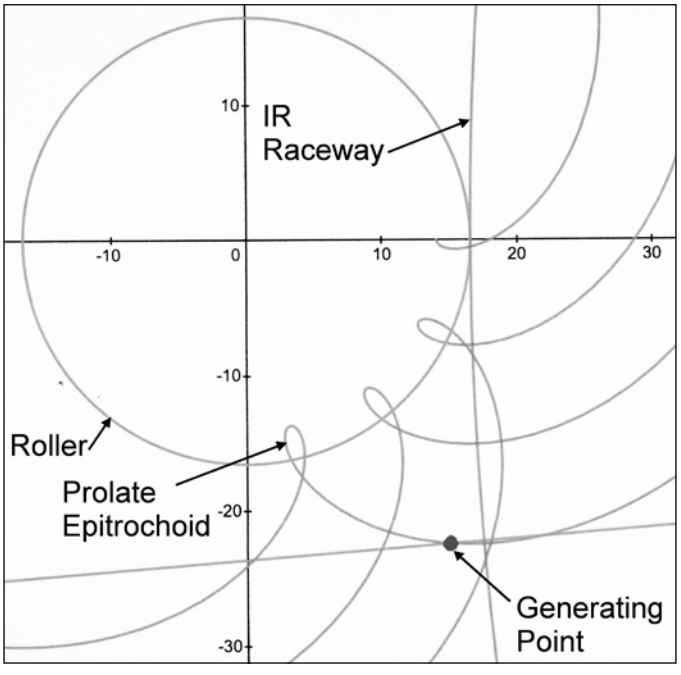

Figure A1—Prolate Epitrochoid.

Link for Figure A2: ***desmos.com/calculator/ug0hdi91w1***
Input data for Figure A2:
a = 1.5 (number of rotations of rolling circle r)
R = 280 ($R_{raceway}$)
r = 16.54 (R_{roller})
d = 13 (distance of generating point from the center of rolling circle r)

Definitions

R_{roller} = radius of the large end of the TRB roller

$R_{raceway}$ = radius of the large end of the TRB IR raceway

Epitrochoid: A geometric curve traced by a fixed point on a rolling circle that rolls around the perimeter of another fixed circle.

Curtate Epitrochoid: occurs when the fixed point on the rolling circle is inside the rolling circle.

Prolate Epitrochoid: occurs when the fixed point on the rolling circle is outside the rolling circle.

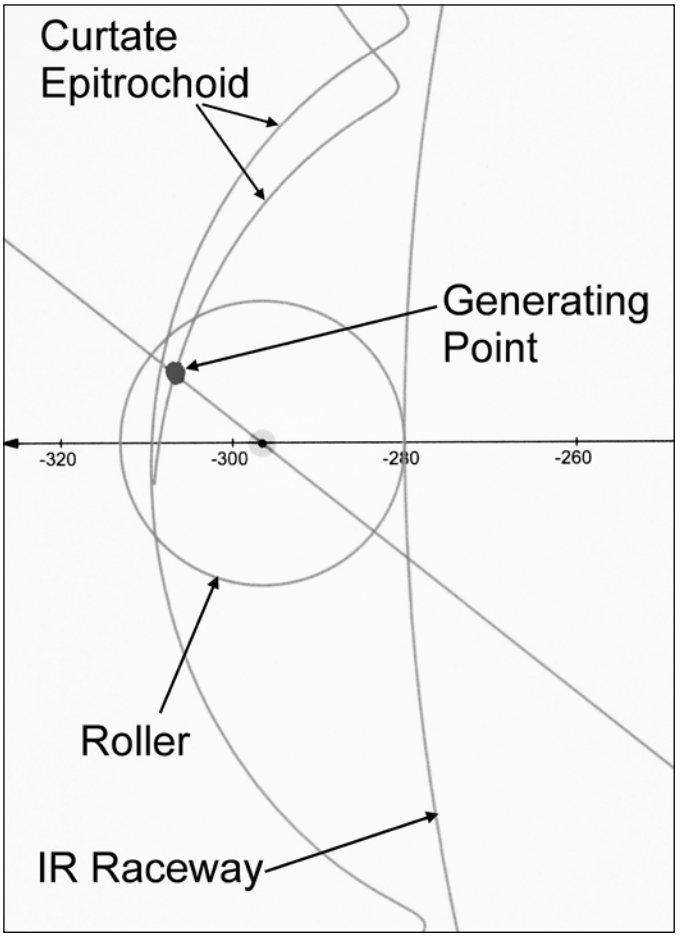

Figure A2—Curtate Epitrochoid.

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

Rainer Eckert is a forensic engineer and director of the metallurgical services department for Simon Forensic, LLC in Seattle. Eckert has assisted manufacturers in basic research, design improvement, quality control, and root cause failure analysis. He has authored technical papers for a variety of associations including AGMA and STLE.

Andrew Milburn is currently president of Milburn Engineering, Inc., a consulting firm located near Tacoma, WA, and has 45 years of experience in the design and analysis of gears and gearboxes. As a consultant, he has investigated numerous gear and bearing failures and helped clients improve their gear products.

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1. Blau, P.J., "Tribosystem Analysis- A Practical Approach to the Diagnosis of Wear Problems," CRC Press, 2016; pp. 1–192.
2. Fitzsimmons, B., and Clevenger, H.D., "Contaminated Lubricants and Tapered Roller Bearing Wear," *ASLE Trans.*, Vol 20, No. 2, 1977; pp. 97–107. *https://doi.org/10.1080/05698197708982822*
3. Errichello, R.L., "Morphology of Micropitting," AGMA Technical Paper 11FTM17, 2011; pp. 1–19.

Gleason

ANNOUNCES GEAR TRAINER PROGRAM 2024

The new Gleason Gear Trainer Program 2024 features new and exciting gear technology topics, including gear and transmission design, cutting and hard finishing processes, metrology and gear noise analysis, tools and workholding, as well as software updates and smart production systems. Gear Trainer Webinars take advantage of a mix of different media including live manufacturing and software demonstrations. Within 30 minutes, experts get to the bottom of typical industry challenges, addressing application-specific questions while maintaining a compact, time-efficient format. Participation in Gear Trainer Webinars is free of charge. The following Gear Trainers Webinars are now available for registration.

February 15: Involute Gears–Generation Process and Microgeometry (English)

February 27: Workholding Systems for Gear Manufacturers (Spanish)

April 25: Generating Grinding versus Honing (English)

May 16: Chamfer Cutting Update–Including Collision Gears (English)

June 13: State-of-the-Art Gear Shaping (English)

July 18: Gear Cutting Tools–The Basics (English)

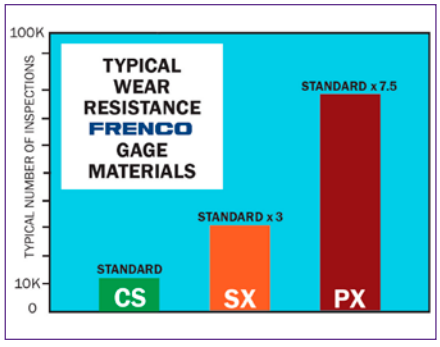
gleason.com/geartrainer

Frenco

OFFERS MATERIAL UPGRADE ON INO-SYSTEM SPLINE GAGES

Euro-Tech Corporation in cooperation with Frenco, the precision specialist in gear & spline metrology, is offering a Free Material Upgrade for quotes between now and March 31, 2024.

Euro-Tech is now quoting standard chromium steel (CS) but delivering the upgraded material of SX on INO-system spline gages. We are quoting the upgraded SX and delivering Frenco's strongest wear-resistant material of PX. For example: if the standard material is CS and it will measure 10,000 parts before reaching wear limit, the free upgrade to SX will now measure 30,000 parts. The upgrade to PX will now measure 75,000 parts. Get a much longer wearing gage for a small increase in price.



eurotechcorp.com

Forest City Gear's

LYFORD JOINS ROCK RIVER VALLEY TOOLING & MACHINING BOARD OF DIRECTORS

Forest City Gear is proud to announce that Director of Operations Jared Lyford has been elected to the Rock River Valley Tooling & Machining Association (RRVTMA) board of directors.

"It is an honor for me to join the Rock River Valley Tooling and Machining Association as member of the board of directors," says Lyford. "I am passionate about the apprenticeship program, as I credit the foundation of my career to the experience, education, and credentials it provides."

As the local chapter of the National Tooling and Machining Association, RRVTMA promotes setting world-class standards in machining and tooling solutions in northern Illinois and southern Wisconsin.

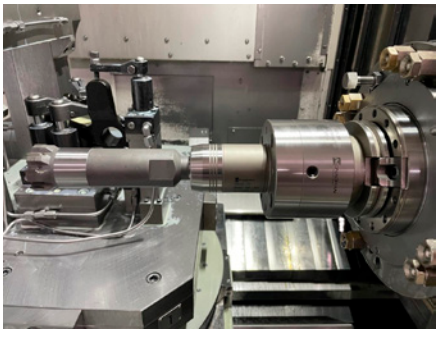
"I have had the pleasure of knowing Jared for several years and knew he would add a lot of value to our organization," says Casey Schwebke, president of RRVTMA. "I am excited for the fresh ideas and energy he brings to our organization."

"It is no secret that the labor market needs ambitious and skilled people," says Lyford. "As these people get involved with our industries, they need to have a robust place to get training and begin to build their respective networks locally. I look forward to collaborating with the team in place at the RRVTMA and working towards advancing the cause and effectiveness of an already great program."

forestcitygear.com

Monaghan Tooling Group

SHUFFLES LINE CARD TO FOCUSES SOLELY ON CUTTING TOOLS



To sharpen its focus on cutting tools, Monaghan Tooling Group has

recently shuffled its line card and transitioned the sales, marketing, and service for Elliot Tool Technologies Precision Metal Finishing back to Elliot, where they will be handled in-house by the manufacturer. Monaghan personnel will work with current metal finishing, burnishing, recessing, and mechanical joining customers to ensure a smooth transition.

"While we have enjoyed representing Elliot Tool Technologies in North America and appreciate the many relationships we've developed over the years, taking this step is best for both parties and most importantly for our customers," said Monaghan President Scott Monaghan. "Customers now have a single point of contact for all matters about Elliott, and it allows us to focus solely on cutting tools."

The company recently added Vergnano taps, hobs, and thread mills to its family of cutting tool products which include Diatool high-performance reaming, MK Tools Solid Carbide tools, PCD Tooling, and AXIS micro machining tooling.

monaghantooling.com

Walter Surface Technologies

ACQUIRES GREENFIELD INDUSTRIES

In its quest to become a global leader for productivity and safety solutions in the metalworking industry, Walter Surface Technologies is pleased to announce the acquisition of Greenfield Industries, a USA-based leading manufacturer of branded and private label cutting tools.

Walter and Greenfield Industries share a strong focus on providing solutions answering the needs and challenges facing industrial end-users. With the addition of Greenfield to Walter's portfolio, we can help our customers to be more productive with effective and durable cutting tool solutions for a broad subset of applications.

"We are very excited to welcome Greenfield Industries to the Walter family. Greenfield brings to Walter its premium U.S.-made brands (Cleveland, Chicago-Latrobe, Cle-Line, Greenfield Threading) and its robust manufacturing capabilities and infrastructure that will allow us to continue our mission to help our customers work better. Walter is always looking to provide solutions that answer the needs and challenges facing end-users in the metalworking industry. Now, with this acquisition, Walter is a primary supplier of tooling and drilling solutions in North America," said Marc-André Aubé, CEO of Walter. "This transaction is an unequaled opportunity to position Walter as a primary supplier of tooling and drilling solutions in North America as we continue to evaluate other growth strategies, namely through accretive acquisitions," he added.

Ty Taylor, president of Greenfield Industries, welcomes the new relationship: "We saw in this opportunity the perfect alignment of both products and values. We are proud to see Greenfield adding its tooling and drilling solutions to Walter's renowned and robust offering. We are confident this is a strong pathway to growth."

Following this transaction, Greenfield Industries will continue to operate under their own respective brands. The transaction is effective immediately, and activities for both customers and suppliers remain unchanged.

walter.com

Verisurf

ANNOUNCES NEW SALES PLATFORM

Verisurf Software, Inc. introduces a new sales platform where customers can source new and pre-owned CMMs powered by Verisurf software. All machines are calibrated and certified and include Verisurf CMM Programming and Inspection Suite software.

"Verisurf is committed to selling measurement and inspection solutions based on customer requirements. Though our preference is to provide new machines with the latest technology, if budget or application calls for pre-owned equipment, there are plenty of excellent CMMs available," said Terry Wear, director of CMM Integration for Verisurf Software, Inc. CMMs are made to last; many have heavy granite bases, rigid gantry designs, and frictionless air bearings, making them a good investment when paired with the right software. "Software is the key to realizing the full potential of any CMM, especially when it comes to 5-axis CNC CMMs," added Wear.

All CMMs, new and pre-owned, can be operated by Verisurf software. Verisurf is the only metrology software built on a full-featured 3D CAD/CAM platform with intelligent Model-Based Definition (MBD). This ensures data integrity and lets users perform metrology workflows in a seamless CAD environment while maintaining model-based digital continuity. Verisurf software supports all CAD file formats, and the Verisurf Device Interface (VDI), with virtual CMM display, communicates with and operates all programmable and portable CMMs for universal compatibility. The software's modular design, ease of CMM programming, and built-in productivity tools let users quickly create measurement routines using efficient and repeatable workflows for quality process control.

verisurf.com

FEBRUARY 13–15

Industrial IoT Conference

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

geartechnology.com/events/5084-industrial-iot-conference-2024

FEBRUARY 21–23

Operations, Maintenance & Safety Conference

Clean energy employees are the heart and soul of the industry and keeping them safe is a top priority. ACP's Operations, Maintenance and Safety Conference (OMS) is the place where leaders from headquarters to the field come together to talk about retention strategies, recruitment techniques and training best practices to make clean energy stronger and safer. Key exhibitors include Applied Industrial Technologies, ExxonMobil, Intertek AIM, ONYX Insight, Shell Lubricants, Vestas and more. The event takes place in San Diego at the Manchester Grand Hyatt.

geartechnology.com/events/5086-operations-maintenance-safety-conference

FEBRUARY 22–24

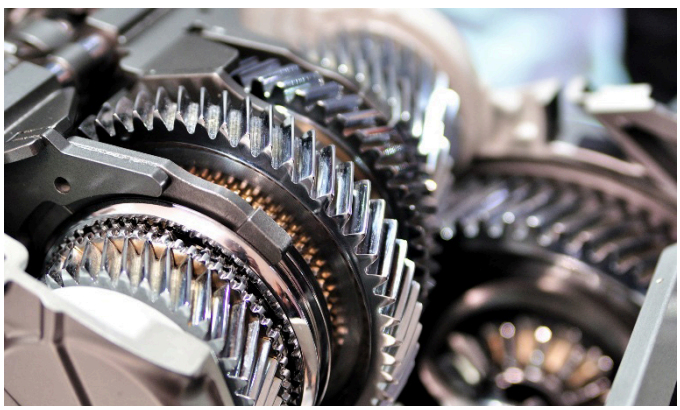
IPTEX 2024

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

geartechnology.com/events/5082-iptex-2024

FEBRUARY 27–29

Gearbox CSI



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

geartechnology.com/events/5083-agma-gearbox-csi

MARCH 2–9

IEEE Aerospace Conference 2024

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

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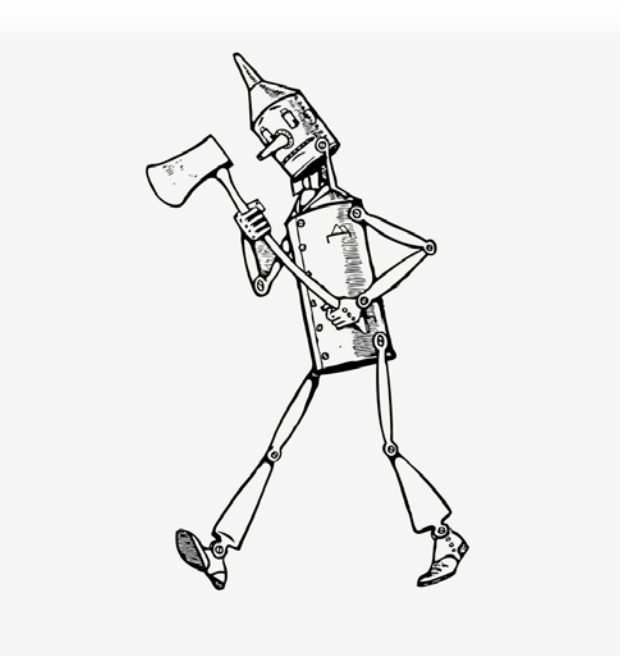
The Tin Woodman and Mother Machines

Aaron Fagan, Senior Editor

Isn't the Tin Woodman from *The Wizard of Oz* a kind of cutting machine? There is a great poem by the poet Gary Snyder titled "Axe Handles" about working with his son to create a new axe handle with an axe—the process reminds him of a line by another poet, Ezra Pound, "When making an axe handle the pattern is not far off." The poem reminds me of being trained on a Bridgeport mill, years ago, where the operator told me: "You can make a Bridgeport on a Bridgeport." Of course, that's not literal but mere shorthand for their versatility. *Gear Technology* regularly covers machine tools, often referred to as "mother machines" due to their role in producing other machines, which serve as the cornerstone of industrial civilization by cutting or shaping metal. Think of all the gears in the machine tools that not only cut and polish gears but are indispensable for manufacturing a wide range of goods, with nearly every product being created either directly using machine tools or through machines manufactured using these tools.



"The Tin Woodman knew very well he had no heart, and therefore he took great care never to be cruel or unkind to anything."
***—L. Frank Baum,* The Wonderful Wizard of Oz**

Anderson Ashburn, in *Is New Technology Enough?*, aptly captures the interconnectedness of machine tools with various industries, stating, "Thus an automobile is an assembly of metal parts made by machine tools, plastic parts produced by machines made by machine tools, fabric processed on textile machines made by machine tools, rubber processed and molded by equipment made on machine tools, and glass processed by equipment produced by machine tools."

The ability to produce machine tools is considered a crucial capability for industrialized nations. It not only grants access to the latest manufacturing technology but also ensures that the production of essential items—wartime or peacetime—is not hindered by a shortage of machine tools.

Historically, the United States held a dominant position in machine tool technology throughout much of the 20th century. However, a sudden and drastic decline occurred in the early 1980s, leading to a significant reduction in annual machine tool shipments, the closure of numerous companies, and a decline in global ranking.

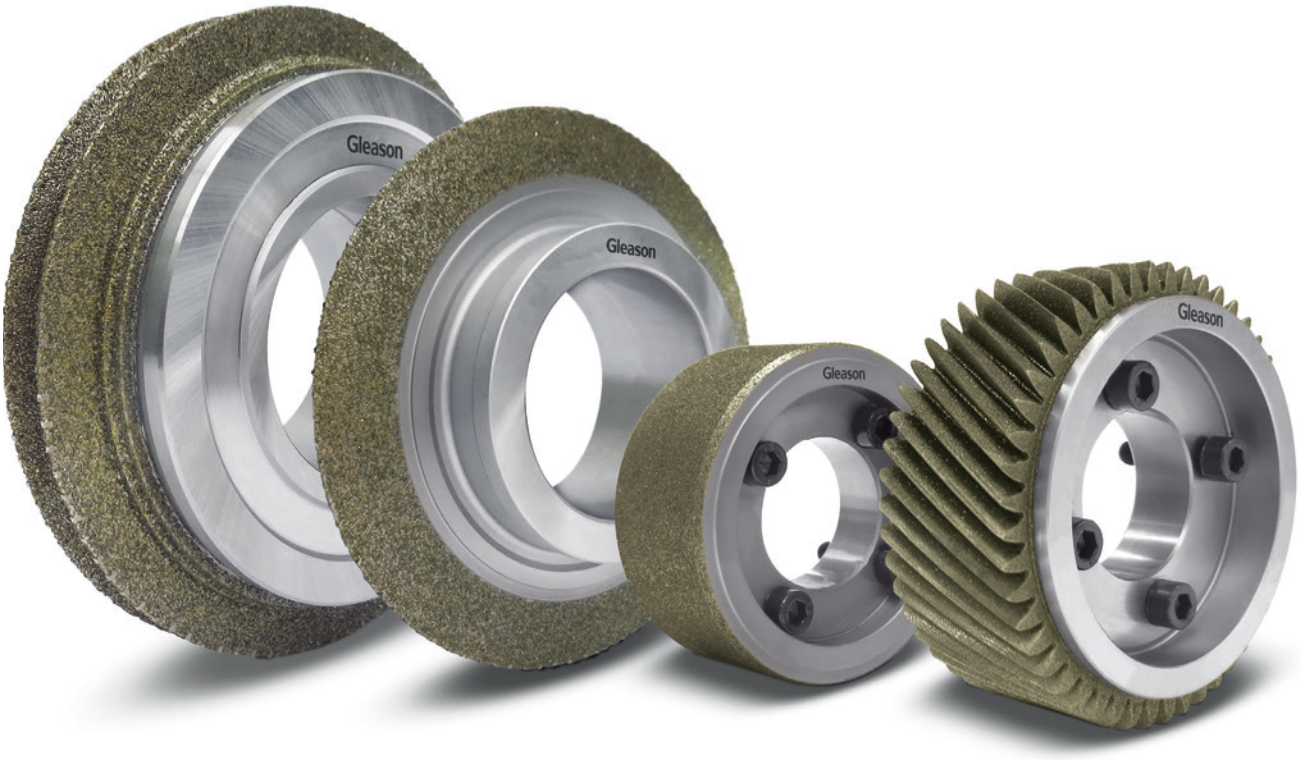
The early machine tool industry played a pivotal role in the American System of Manufactures, contributing to the birth of precision in standardized and interchangeable parts. The rise of the automobile industry further fueled the demand for advanced machine tools. The post-war era witnessed a surge in machine tool production driven by the demand for munitions during World War II.

In the 1960s, industry underwent transformative shifts, including the advent of numerical control (NC). While the U.S. had been a leader in machine tool technology, foreign competition, particularly from Japan, gained momentum. Japanese manufacturers excelled in producing reliable, cost-effective machine tools, outpacing the U.S. in technological adoption and delivery speed.

The ownership landscape of machine tool companies changed in the 1960s with conglomerates acquiring them. This change, coupled with the cyclical nature of the industry, led to a focus on short-term profits and a reluctance to invest in long-term competitiveness. Foreign competition, especially from Japan, further exacerbated the challenges faced by U.S. machine tool builders.

The recession of 1982 marked a critical turning point, and the U.S. machine tool industry faced a rapid decline. Employment in the sector plummeted, companies closed their doors, and the U.S. relinquished its position as the world's largest machine tool builder.

Today, the U.S. competes in a machine tool market where foreign companies—particularly from Japan, Germany, and China—dominate. But as efforts to re-shore and nearshore U.S. industry evolve, the pendulum is swinging again. The 20th-century decline of the U.S. machine tool industry stands as a complex historical phenomenon shaped by technological shifts, changes in ownership, and global competition, but as AI, robotics, and other automation solutions evolve in the 21st century, they will also transform the scope and utility of machine tools. From an axe making an axe to machines making machines to robots making robots, what will the future hold? What would the Tin Woodman have to say when this January, Elon Musk predicted one billion humanoid robots on Earth by the 2040s?



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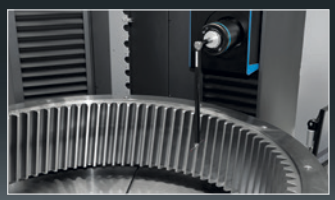

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