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- Use of Duty Cycles or Measured Torque
- Tooth Load Capacity of Additive Manufactured Gears

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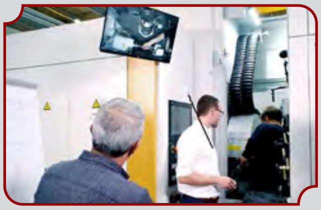
GT Videos

Liebherr Machine Training Center

The Machine Training Center (MTC) of Liebherr-Verzahntechnik GmbH in Kempten offers bright training rooms equipped with the latest technology the world of gear making has to offer including an LC 280 gear cutting machine with ChamferCut device, an LGG 280 gear grinding machine and a WGT measuring machine.



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Helios Solves Gear Cutting Tool Challenges with Delta Gear

The Helios Gear team recently delivered custom gear cutting tools to Delta Research in Livonia, Mich. This video examines what Delta Research had to say about the process.

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Remote Monitoring of Girth Gear Performance

Inadequate lubrication conditions lead to excessive displacement. Vibration and temperature can reveal cracks and misalignment. Profile deformation leads to worsening conditions, and wear speed diagnoses current gear protection while predicting critical wear. But a monitoring partnership that understands that integrated system will get you the best at all stages of your gear. Learn more about Kluber and DALOG's remote monitoring of girth gear performance.

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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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Education and Training

Publisher & Editor-in-Chief
Randy Stott

Almost every time I have the opportunity to meet with professionals in the gear industry, the topic of training and education comes up. Maintaining a stable workforce continues to be one of the chief struggles of manufacturing companies.

For some, that means attracting talent: finding and hiring the people—especially young people—with the aptitude and attitude for doing manufacturing work. For others, it means retaining that talent: keeping those workers engaged and interested.

In some ways, the answers lie in education and training. It's hard to find employees who are ready and able to step onto the shop floor and be productive from day one. It's also hard to get employees who are set in their ways to learn new skills that would help the enterprise.

Fortunately, there are many options for helping those employees, from online courses to hands-on training to in-plant seminars. This issue we take a close look at some of these options.

The article "Reigniting the Educational Infrastructure" by Senior Editor Matthew Jaster explores how new technologies and ways of thinking are changing the way manufacturing education is being taught (p. 18). Examples include data-driven education, a sociological approach and virtual reality.

The discussion continues with Senior Editor Aaron Fagan's article on AGMA's programs for professional development of the gear-manufacturing workforce (p. 24). Fagan describes how AGMA's IACET-accredited training programs help professional engineers keep up to date with continuing education credits. The article also includes an in-depth interview with AGMA's Education Manager, Stephanie Smialek, about all the options AGMA offers.

Of course, one of the best ways you can stay on top of your continuing education is by continuing to read *Gear Technology*. This issue we have two top-notch technical articles that are extremely relevant. "Use of Duty Cycles or Measured Torque—Time Data with AGMA Ratings" by Dr.-Ing. Ulrich Kissling explores how duty cycles are used in conjunction with gear rating. "Tooth Root Load Capacity of Additive Manufactured Gears," from the team at WZL-RWTH Aachen details the testing of gears made by both the binder jetting process and the laser powder bed fusion process.

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Helping Electric Vehicle Manufacturers Compete

GEAR SKIVING IS THE FASTEST-GROWING METHOD OF GEAR MACHINING

Electric vehicles (EVs) are responsible for considerably lower emissions over their lifetime than internal combustion engine vehicles (all photos courtesy of Sandvik Coromant).

"It's competition," said the American businessman John Mackey, "that forces companies to get out of their complacency." We are seeing this in the global electric vehicle (EV) markets. Manufacturers must produce lighter and more compact EV transmissions from tough materials such as low-alloy steels—and those that rely on traditional manufacturing processes risk falling behind. Mats Wennmo, global automotive transmission manager at the metal cutting specialist Sandvik Coromant, explains why gear skiving is crucial for competitive manufacturing.

Sales of EVs have taken a major leap forward in recent years. According to *EV-Volumes*, 541,780 new plug-in electric cars were registered globally in February 2022—twice as many as in February of the previous year. Meanwhile, Virta reports that 1.06 million new EVs were registered in Europe in the first six months of 2021, compared to 413 during the first half of 2020.

From these figures, it's clear that the global EV markets are growing fast—but what is driving these sales? One factor is the ambitious zero-emission targets pledged by the European Union (EU), Asia, and the U.S. The EU has committed to reducing its greenhouse gases to at least 40 percent below 1990's levels, and China to reduce its levels to 60–65 percent below those of 2005, by 2030. The U.S., meanwhile, has pledged a reduction of 26–28 percent below 2005's levels by 2025.

What role can EVs play in helping these countries achieve their goals? In truth, comparisons between the environmental advantages of EVs versus internal combustion engine vehicles aren't straightforward. According to *Carbon Brief*, it depends on the size of the vehicles, the accuracy of the fuel economy estimates used, how electricity emissions are calculated, the driving patterns used, and even the weather in regions where the vehicles are used. There is no single estimate that applies everywhere. Nevertheless, *Carbon Brief*'s report concludes that, overall, EVs are responsible for considerably lower emissions over their lifetime than internal combustion engine vehicles.

E-mobility technologies can also support the other two major factors that will drive EV sales. First, is a global move toward the use of more efficient and renewable energy sources, as outlined recently by European Commission President Ursula von der Leyen, for instance. Second, changing attitudes among consumers: half of those surveyed in PwC's December 2021 Global Consumer Insights Pulse Survey said their perceptions had become more eco-friendly.

Planetary gears

For carmakers and original equipment manufacturers (OEMs), the above factors all underline the need to move away from traditional combustion engines, and China and Europe will take the lead on these developments. These EV markets will also form a diverse and competitive playing field as larger established companies like Porsche compete with smaller, globally expanding manufacturers such as Polestar.

At the same time, the manufacturing of EVs will also present extra challenges, with a risk that manufacturers relying on traditional production processes will find themselves left behind. To examine these challenges, let's focus on the manufacture of gear components.

The ability to control a gear's revolutions per minute (rpm) is essential for all kinds of vehicles, including EVs. All EV transmissions are reduction transmissions, designed to reduce the vehicle's speed so that it can be controlled and driven economically. Because there is no combustion engine noise in an EV, any noise from the transmission will be noticed. The main objective is therefore to prevent noise. This is where the quality of the machining setup plays a decisive role in making the transmission as compact, light, and quiet as possible.

EV transmissions usually have a planetary design, with the planetary gears and the sun gear assembled inside the peripheral ring gear for a compact, lightweight assembly. The ring gear is the most difficult component to produce due to its thin walls and strict roundness tolerances. Unfortunately, traditional manufacturing processes can compound these issues with negative impacts on both time and cost.


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Traditional manufacturing

Traditional manufacturing processes typically rely on single-purpose machines. Each machine is limited to a certain area of machining, and the workpiece is passed from one to the next. This makes production lines inflexible in terms of responding to necessary changes in the component design.

Moving the workpiece from machine to machine can also worsen the component quality by creating run-out and center deviations. The after-heat treatment is harder to control, and traditional soft machining methods followed by grinding processes are very expensive. These processes also require additional oil-based machining to improve the machining and chip evacuation processes.

These disadvantages will only become more pronounced over the coming years, given the anticipated major manufacturing trends for EVs. We can also expect to see a demand for increased speeds in the development of new transmissions, a need for higher productivity and flexibility, and a demand for a shorter return on investment (ROI). Inflexible single-purpose machines will become less advantageous as flexibility, productivity and profitability become more important for manufacturing EV parts.

This is why manufacturers need to upgrade their traditional manufacturing processes. So, how can they do this? One way is by investing in multitask machines. The grinding equipment

Power skiving is emerging as the fastest-growing method for gear machining for EVs.

EV transmissions usually have a planetary design.

commonly used in traditional manufacturing can be an expensive investment. A good way to sidestep this is to divide the machining of gear components into two processes: soft and hard machining. These methods can be implemented in a single, multitasking machine setup.

Multitask machines can eliminate machining processes and their associated time and cost, and also improve part quality. The machines also offer benefits for customers. Along with improvements in product quality, the process cycle times are better than—or at least the same as—existing production solutions. In fact, Sandvik Coromant has seen minimum cost reductions of 30 percent for the end user.

Finally, manufacturers can achieve greater flexibility in producing future components for e-mobility. The process enables downsizing and weight reductions in transmission components. Gear skiving can be applied to both internal and external gears and splines, but it is especially productive when it comes to internal machining. The method works particularly well in mass production, where short lead times are vital.

Single, continuous process

As mentioned, the ring gear is the most difficult component to produce in a planetary gear assembly, but the concept of gear skiving—which has actually been around for over a century—is emerging as the most

efficient way to achieve this. Gear skiving is a process that combines shaping and hobbing (a machining process for gear cutting) into a single, continuous cutting process.

This has several significant advantages over traditional machining methods. Instead of relying on a single-purpose machine, with gear skiving a complete component can be machined in one multitask machine for higher productivity and flexibility. There is no need for specialized machines, and quality restrictions due to machine changes can be eliminated entirely. This significantly reduces the total production time compared to processes with broaching, shaping, and hobbing, for more manageable and predictable component machining.

Gear skiving is becoming more popular, with over 700 gear skiving machine tools delivered since 2014. The majority of these—over 60 percent—are multitask machines. That means the main machining processes happen within the same, single setup. This improves the quality of the component and enables more efficient machining.

Sandvik Coromant has developed its own high-quality tools for gear skiving that are optimized to support its customers for accurate machining of EV transmissions, such as the CoroMill 178, a solid gear skiving cutter that can be ordered as powder metallurgical high-speed steel (PM-HSS) or solid carbide. In addition, the CoroMill 180 is an indexable insert cutter with railed insert seats designed for excellent and repeatable accuracy. The tools can be optimized in terms of stiffness and overhang, coolant supply, and maximum tool life. These combined factors offer reliable, round-the-clock production.

Reduced machining time

In one example, when a manufacturer of main gears in low-alloy steel wanted to replace their time-consuming shaping process, they turned to Sandvik Coromant. The customer replaced their existing processes with gear skiving and was also able to replace the four dedicated machines they used previously with just two multitask machines.

In the end, the customer's machining time was reduced by 90 percent, with considerably increased tool life. In other instances, gear skiving was shown to be two to three times faster than traditional processes.

EV transmission producers and contractors are able to machine their own components at Sandvik Coromant centers with gear skiving on modern multitask machines. Skilled and experienced staff are ready to support customers' future investments to achieve productive, efficient, and flexible gear machining for EVs—all in a single setup.

These are just some of the reasons why gear skiving is emerging as the fastest-growing method for gear machining, offering both time and cost savings. It is accessible to both smaller manufacturers, helping them compete at a higher level, and larger manufacturers, to help them, in the words of John Mackey, "get out of their complacency."

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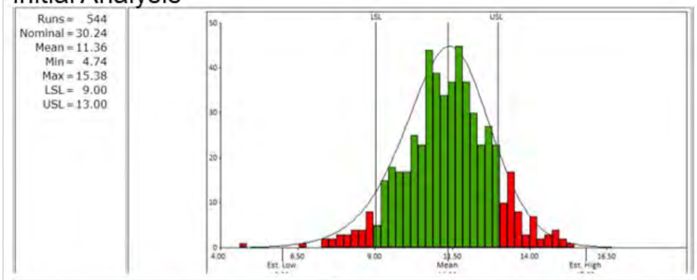
Dimensional Control Systems

EXAMINES E-POWERTRAIN ELECTRIC MOTOR GEARTRAIN SIMULATED TESTING WITH THE DIGITAL TWIN

Thomas Oetjens, Senior Dimensional Engineer-Gear Specialist, DCS

The performance of an Electric Vehicle Power Unit is directly connected with critical tolerances. Tolerances drive opportunities for performance enhancement with cost reduction. The tests normally used to determine and validate tolerances are both expensive and time consuming with prototype parts. By replacing the initial tests with Digital Twin simulations, results can be obtained quickly, and at a much lower cost. This article discusses one of these tests and the results.

Initial Analysis



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3	Surface Profile0.100A|B_0-18	EV_Motor_V10-GearsG4	0.100	0.180	3.28%
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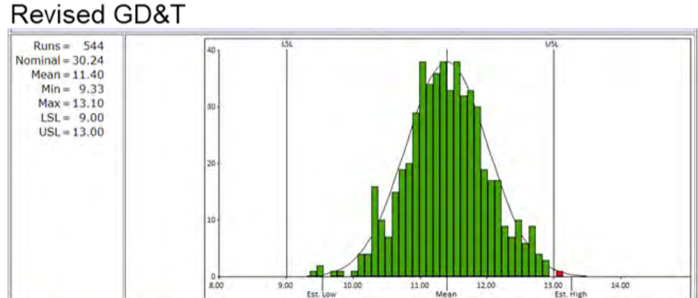

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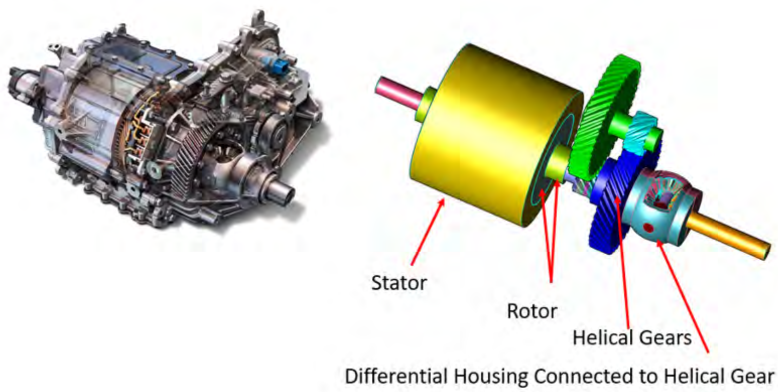
2	Surface Profile0.030Profile	EV_Motor_V8-Diff001SG4	0.030	0.100	19.00%
3	Surface Profile0.100A|B_0-18	EV_Motor_V10-GearsG4	0.100	0.180	16.08%
4	Surface Profile0.100A|B_0-18	EV_Motor_V10-GearsG3	0.100	0.180	16.08%

System angle backlash statistical reports.



Electric vehicle power unit.

This upfront simulation method illustrates the use of digital technology to create a parametric family of designs with statistical tolerances as the parameter. The result is a digital validation of the design variation to reduce prototype builds or solve build issues while increasing innovation.

Once an adjustable statistical tolerance has been established, the tolerances can be split into the individual components. For example, in the concept design phase, the bearing may represent the combination of the gear grade, bearing specifications, and the housing specifications. Dividing the tolerance up using statistical cost analysis can balance the design tolerances at the lowest cost.

Gear micro geometry in the form of gear crowning, gear backlash, or tooth clearance is another example of the method. Adjusting the tolerance as a parameter provides the geometric information to ensure the gear system backlash meets the required specifications.

For this study, tolerance analysis software integrated into CAD software was used to simulate both part and process variation. In this case, *3DCS Variation Analyst* software was used. This enables engineers to analyze their manufacturing process and determine how it affects both the assembly and final product functionality. The part tolerances, assembly process, and product measures are functionally transformed into the ability to predict and fix quality issues before the builds of concept, prototype, preproduction, and production.

Dimensional Analysis of Geartrains with the *3DCS Gear Modeler* includes a high accuracy tooth microgeometry contact mechanism. The analysis also includes complex gear and mechanism dynamics with bearings, shims, and housing systems.

The simulation output includes Contributors, the sources and primary cause of variation for a measurement. The Contributor list includes several statistics to show the influence of each Contributor, which can be an assembly process, tolerance, or other input. These are used to validate that the results are within the measurements Upper and Lower Specification Limits.

The Contributors with the higher percentage of contribution are candidates for tighter tolerances to meet the specification. The percentage of contribution estimated by the listed contribution percentage can be changed by adjusting the tolerance and running the model with the change.

The Angle Backlash is one simulated test that can be done with this Digital Twin model. The Electric Vehicle Power Unit Angle Backlash is the change in angle of the rotor while rotating back and forth with the wheels locked. In the illustration, the Angle Backlash, the wheel rotation gears, PG1 and PG2 are fixed. G2 and G3 are connected and rotate together in a Gear Stage. G4 Rotates with SG3 and SG4 in the connected Differential, along the same axis as PG1. The Gear Ratio for G1 to PG1 and PG2 is 12:1.

The 12:1 Gear Ratio from PG2 to G1 is the source of the dominant contribution of the PG2 and SG4 Gears, 44 and 43 percent. This indicates that to reduce the System Angle Backlash, the backlash between these two gears should be reduced.

This reduction is accomplished by reducing the Tolerance Range of the tooth microgeometry from 0.1 to 0.03 mm. This statistical adjustment in the Digital Twin is parametric.

The contributions of the PG2 and SG4 Gears have been both reduced to 19 percent and down from 44 and 43 percent respectively. In addition, the System Axial Backlash Range has been reduced to 3.77 degrees, down from 10.64 degrees.

The overall goal of this analysis is to reduce lead and launch time by eliminating or minimizing the sources of variation. By determining the corrective action in the simulation, users can find opportunities for innovation, quality improvements, capability, and lower costs.

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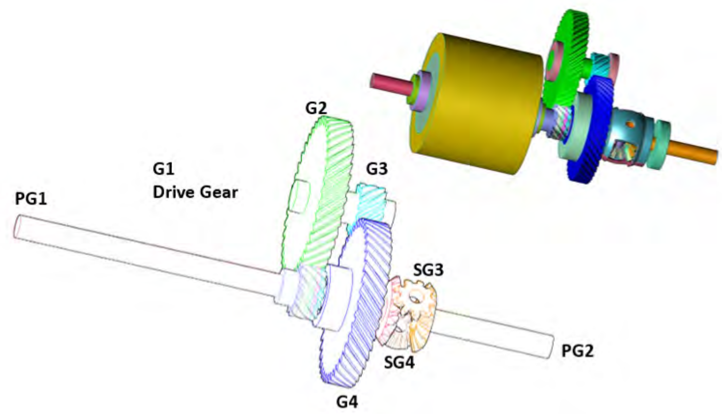
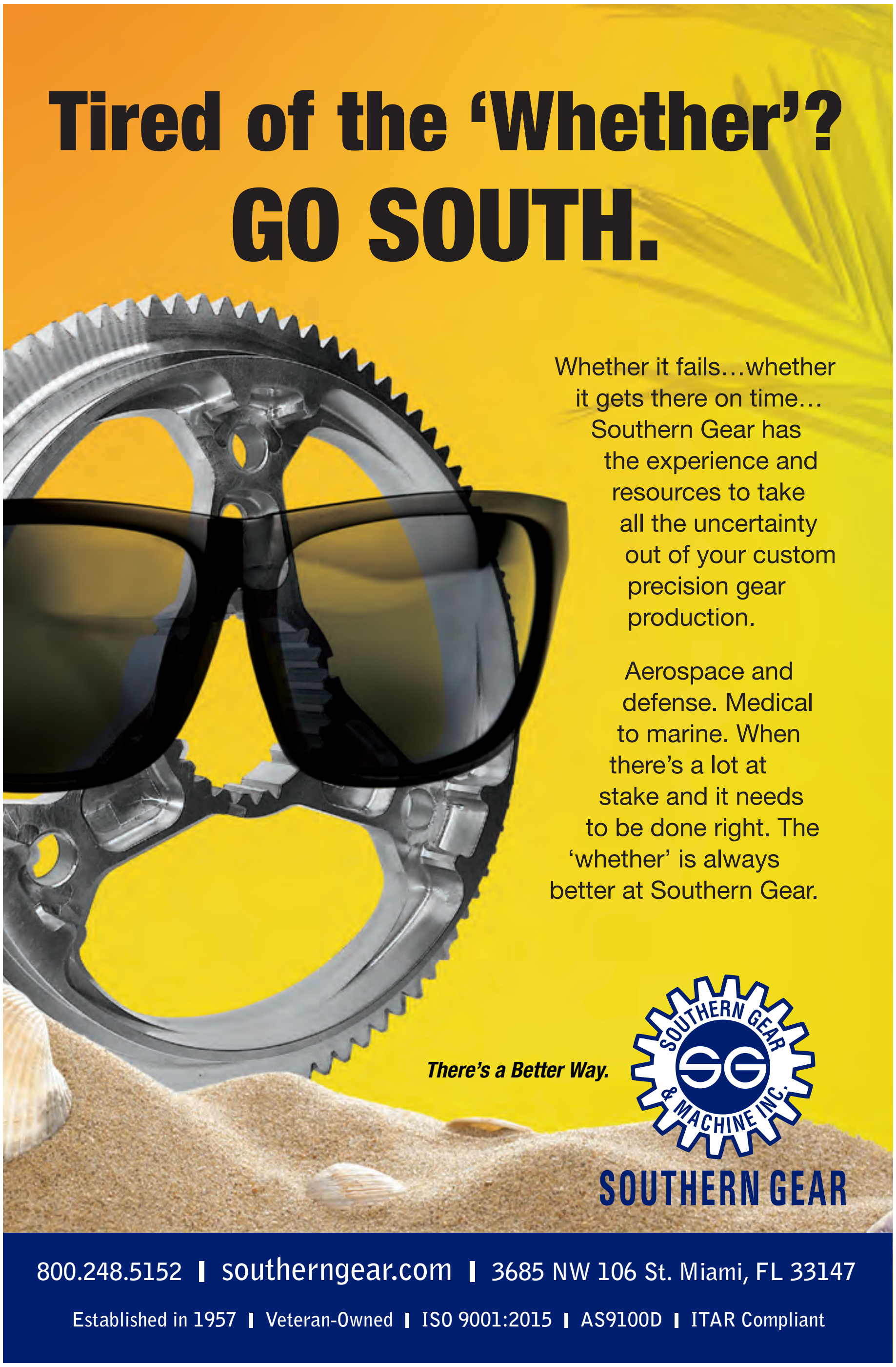


Electric vehicle power unit gears.



Reigniting the Educational Infrastructure

How data-driven education, virtual reality, and sociology can assist the skilled workers crisis

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Matthew Jaster, Senior Editor

Students learn about NASA technologies during the Smartforce Student Summit at IMTS 2022. Photo courtesy of IMTS.

For an industry that prides itself on cutting-edge technologies, manufacturing doesn't always practice what it preaches in terms of education and training initiatives.

"Manufacturing is one of the most technology-rich industries, right? They love talking about the Industrial Internet of Things (IIoT), automation, robotics, additive manufacturing, etc., yet you go to the training aspect and it's much more archaic than that," said Jeannine Kunz, chief workforce development officer at SME. "We do ourselves a disservice with these technology advancements when we don't take advantage of them."

The story of finding—and keeping—skilled workers in manufacturing has been told for decades. It's always the "next-generation," that's going to swoop-in and create a manufacturing renaissance both here and abroad. Yet, the conversation remains largely unchanged since as far back as the 1980s.

"This conversation is a bit like the movie *Groundhog Day* in the sense that we keep having the same discussion over and over again about addressing the needs of the skilled workforce," said Chad Schron, senior director for Tooling U-SME. "Unfortunately, there's such a pressing need to get parts out the door that many organizations can't justify taking the time needed to learn the skillsets to remain competitive."

Leadership has the best intentions when it comes to training and education, but the reality is that many shop floors are understaffed, underpaid, and have a difficult time developing in-house talent. Companies have looked at early education recruitment, mentorships/internships, technical schools, job fairs, trade shows, the list goes on and on, but the crisis remains as prevalent as ever.

"Everyone says the lack of skilled workers is still the number one challenge across manufacturing, but it doesn't get treated like the number one challenge," Schron added.

Those involved in manufacturing, however, saw optimistic signs during The Smartforce Student Summit at IMTS 2018 where broken attendance records followed a growing national conversation around STEM education. As the Smartforce Student Summit reconvened in September 2022, signs continue pointing toward advanced education and training strategies.

"Our content is answering the biggest needs of our manufacturing customers. They are looking to bring in new hires that can utilize some of these skills and enhance productivity on the shop floor," Schron said. "We're hearing these great stories from different age groups about how e-learning, hands-on training and virtual reality (VR) can benefit everybody."

Expanding the Toolbox

The average job shop can ill-afford to shutdown a portion of the workspace for training today. After COVID hit, it's clearly an "all-hands-on-deck" situation where product is moving out the door at an accelerated rate for many manufacturers. How can you justify sending three of your best machine operators away for training for a week or two? Organizations like Tooling-U SME, THORS, and Tulip are taking a closer look at adapting training resources for today's manufacturing challenges.

Classroom work, for example, is being supplemented by hands-on training workshops. Online learning tools are expanding to give today's trainees scheduling flexibility. Remote VR sessions are replacing machine tool demonstrations to offer cost, safety, and time benefits. These resources are supporting the fact that the old way of conducting business—Monday thru Friday, 9:00 am to 5:00 pm—is no longer a viable option in today's business climate.

"I think the greatest challenges to finding and retaining manufacturing employees include reaching students who are ready to transition from school to employment and finding potential employees who are trained on the latest manufacturing technologies," said Christine Walker, general manager, THORS eLearning Solutions.

THORS (The Helpful Online Resources Site) was envisioned by Senthil Kumar. The story goes that Kumar had many questions that his managers had very little time to answer at the beginning of his manufacturing career. His quest for more knowledge led him to create an online resource that captured decades of manufacturing and engineering experience on a single platform. Today, THORS has grown into THORS eLearning Solutions, offering a growing library of online courses and productivity tools and looks at education and training from different perspectives.

"Training today includes interactive elements like animations, AR/VR, which allow people to train even if they can't make it into the shop. Training can be continuous no matter where the employee is located," Walker said.

THORS eLearning is providing a variety of educational options to engage the next generation of skilled workers. This includes interactive, cloud-based learning solutions, industry-specific content that mirrors real manufacturing methods and courses developed by combining industry knowledge with theoretical insights presented with graphics, animations, and interactives.

The idea is to replace textbooks, enhance lectures and provide learning tools that appeal to the "YouTube generation,"

Tooling-U-SME's booth at IMTS 2022 featured virtual reality demonstrations as part of the company's Virtual Labs. Photo courtesy of Tooling-U-SME.

according to Darren Spotz, account executive at THORS. Spotz spoke with college educators and learned that most engineering courses are information driven. This traditional lecturing structure fails to engage student interest and motivation.

THORS meets these challenges by providing a baseline comprehension of the terminology as well as a focused understanding of the various manufacturing processes before a lecture takes place. Self-paced online assignments allow students to dive deeper into the content outside of the classroom giving more time for hands-on lab activities and exercises. This 'Show versus Tell' method allows students to gain a better understanding of manufacturing procedures using videos and animations. Spotz said—in many cases—these interactive assignments can give the students a better understanding of the manufacturing process than they would standing in front of the machine.

"The future skilled workforce may know how to use technology, but they may not know the fundamentals of how that technology came to be. The foundational understanding of why materials behave as they do, or what processes can lead to what results, or how to recognize defects to troubleshoot an issue are not typical topics taught in school," said Leslee Sambor, head of custom course development, THORS eLearning Solutions. "We need to assist these students with a background in manufacturing topics so that they can be better prepared to be problem solvers in a world where manufacturing meets technology."

More importantly, many of these resources are creating learning tools that appeal to a wide range of potential employees.

"Our training is enjoyable, we present the fundamentals of manufacturing with colorful graphics and dynamic interactives, that make it fun to learn. Manufacturing is presented in a way that is exciting and engaging because our own staff is passionate about creating learning materials that are visually appealing and relatable. We believe that when you enjoy what you are learning, you have better learning retention," Sambor added.

The State of Talent in Manufacturing

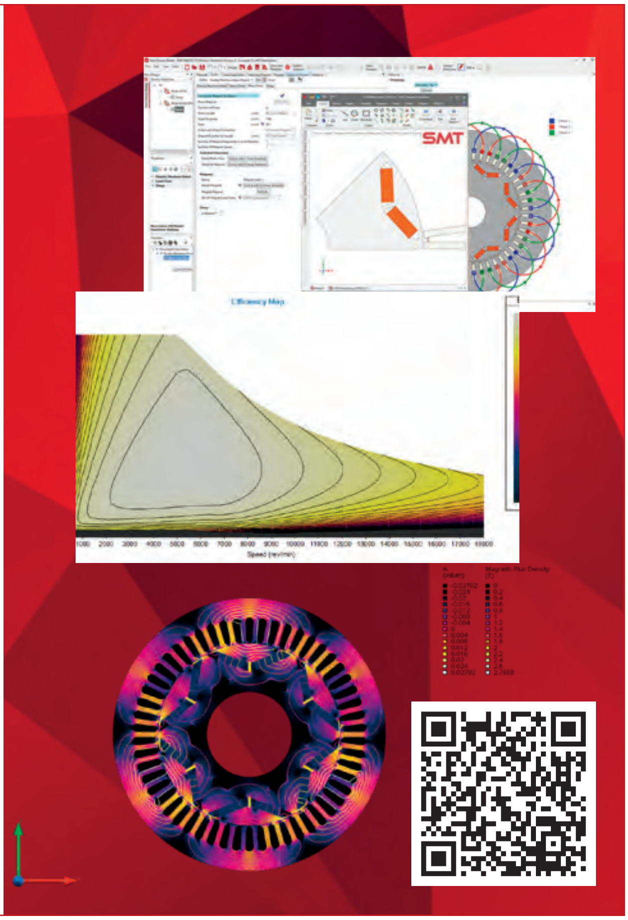
Perhaps one of the greatest mistakes in manufacturing education in the past was not paying close enough attention to the opinions of the workers on the shop floor.

Madilynn Angel, head of marketing, Tulip Interfaces, discussed skilled worker challenges in her presentation, "Why Upskilling and Digital Augmentation are Key to Winning the War for Talent," during IMTS 2022.

Angel described how a technology tradeshow like IMTS boast lots of vendors and showcases the latest and greatest in machine technology, but rarely focuses on the women and men on the frontlines that are thinking about the usability and design of these technologies.

"The frontline workers, historically, have been the most underserved by innovation and technology," Angel said. "Operators need to be more a priority from a performance, training, and support point of view."

Angel said this could be achieved by digitally training workers quicker, accepting feedback and making their general workflow higher quality. "Other industries, have already adopted



this approach and it's making it more difficult for manufacturing to stay competitive from a talent perspective."

There's a need to fill many important positions in the job market, but these are not excusively manufacturing and engineering careers.

"The war for talent is still prevalent in manufacturing. A competitive labor market, coupled with a wave of generational turnover is increasing pressure on manufacturers to retain workers more effectively. To be able to do that, manufacturers need to understand what workers are looking for and how to build a system that can service them," Angel said.

It's no surprise Angel's background in sociology comes into play when discussing the human elements of training and education. She described a workforce that is competing on a much larger stage in 2022 than in the past.

No matter what field we're talking about—big tech, healthcare, manufacturing, etc.—Angel still expects 25 percent of a company's workforce to leave for a new opportunity within a year.

"40 percent of manufacturing workers left their jobs for other opportunities in 2021. A 60 percent higher rate than other industries. This is particularly challenging for an industry that is trying to ramp up as well as respond to increase business and consumer demands," Angel said.

Many job descriptions in manufacturing, for example, require an average of four years of experience. "After four years of school, they won't consider certain applicants unless they've had an additional four years of field experience. So, you're looking at eight years in some cases to meet the basic requirements for these manufacturing positions."

Smartforce Student Summit, IMTS 2022. Photo courtesy of IMTS.

Angel said this problem will continue to grow if thought leaders can't come up with new ways of retaining manufacturing workers and developing a talent pipeline.

"Engineers are naturally inclined to solve problems, they like building things, they're excited about technology and they're invested in the manufacturing and engineering fields," she said. I believe the focus needs to be on the individuals and less on the companies trying to attract them."

Tulip was started by a team of engineers out of the MIT Media Lab. The platform is based on over ten years of research

Meta Quest 2 headsets were used at the Tooling-U-SME booth to showcase how VR can provide training and educational benefits. Photo courtesy of Tooling-U-SME.

in frontline operations, led by experts on the Internet of Things (IoT), machine vision, human-computer interaction, augmented reality, and machine learning. The company understands that automation has done so much for frontline operations, but the most complex tasks still need to be run by people.

Ready Player One: Manufacturing Edition

In addition to digital resources, VR is not just for gaming or traveling the world from the comforts of your living room anymore. It's a multigenerational tool being used to serve training and education platforms. Tooling U-SME showcased its new Virtual Labs during IMTS 2022. This innovative, immersive virtual reality training curriculum bridges the gap between *learning and doing* to enhance productivity, increase safety, lower costs, and engage a younger workforce.

Using a Meta Quest 2 headset or through their desktop or laptop computer, trainees tap into applied learning through virtual reality. By providing realistic, immersive experiences for learners to work with simulated equipment, Tooling U-SME Virtual Labs accelerate competency for real-world manufacturing situations.

"We're always looking at new ways to create and deliver content," said Schron. "Equally important is the way this content is delivered. It used to be lectures, VHS tapes, DVDs, e-Learning and now VR is the next step in engaging the manufacturing workforce. VR has been around forever, but now we're able to leverage this technology much more cost-effectively."

Gone are the days of $20,000 VR headsets that worked only half the time and forced participants to be plugged into a computer station with cords restricting movement. Today, anyone can purchase a VR headset for a couple hundred dollars and roam freely across rooms with minimal restrictions.

"We don't think it's going replace our e-learning or instruction-led training, but it's just another tool in the toolkit for us to deliver new content," Schron added.

During beta-testing of the VR tools, Schron found that the stereotype that VR headsets are for the younger generation is highly misleading.

"I can't tell you how many older people love this technology. We have this great photo from IMTS where there's a 10-year-old kid using the VR headset right next to an 85-year-old guy using one and they're both engaged in the technology. It's really a great educational tool for all generations," Schron said.

Schron added that everything is technology-driven today. Machine operators are utilizing 5- and 7-axis machines, but they don't know how to use the latest controls. The kids coming out of college know the software and technology but might not be as comfortable standing in front of the machine tool.

"We're hearing these great stories from across generations about how VR training can become a part of their educational development," Schron added.

Another key component is the safety benefits.

"When we think about schools, they don't get access to a lot of manufacturing equipment because it's so expensive and there's also a variety of safety issues," Kunz said. "It's a lot cheaper to break a tool in the virtual world or in a classroom than on the shop floor."

Virtual reality gives students the ability to get as close to the machine shop as possible without worrying about costs, time or safety issues that might occur.

"Additionally, workers can practice different skills and gain exposure to new technologies without having to shut down a portion of the manufacturing floor for training purposes. These are kind of the added benefits of creating a virtual training environment," Schron said.

At the end of the day, VR is about establishing the competencies and knowledge a new worker will need to be successful on the shop floor.

Based on the concept of Learn-Practice-Perform, the Virtual Labs are an efficient way to safely build knowledge that contributes to confidence and proficiency by learning new

Students learn more about the ARTEMIS project during IMTS 2022. Courtesy of IMTS.

information through standard instruction, practicing skills in a safe, virtual environment, and performing tasks and applying knowledge on the job or in the classroom.

"Welding is a great example of this. First, you must know a lot to be a great welder, then you need the skills and muscle memory to do the welding required for the job. You're not going to learn to be a welder by taking e-learning classes. VR allows you to learn about welding, practice welding techniques in a virtual environment and then demonstrate those skills in a real-world application," Schron said.

Embracing the Art of Engineering & Manufacturing

The future of training and education in manufacturing starts and ends with the trainees.

"The next generation of workers grew up with technology as no other generation has. They are accustomed to visual learning, understanding digital media, coding, and all things internet-related, and they are used to turning to technology for problem-solving," Walker said. "The leap from their childhood experience with screens to technology in the workplace is virtually seamless."

As we embrace this new technology, it's important to understand that these resources must continue to evolve. Sambor is excited by the notion of a blended approach utilizing online, e-learning, visual elements and AR/VR tools to change the curriculum. The human element, however, is still the most important aspect of workforce training.

The manufacturing industry needs to much more transparent, "a guidance counselor of sorts." It's important for a CEO to share their story and life advice. This allows the people of an organization to become more accessible and tangible so that manufacturing isn't always about materials and products.

"Building and fostering a culture of being a great place to work is one very important thing but going beyond that to help those employees feel a sense of pride and accomplishment in how they contribute to their communities and the overall state of the economy is important," Sambor added. "Showing valuable employees that their personal growth and worth mean something to your organization speaks volumes."

Profile: Continuing Education and Training with the AGMA

Programs for professional development of the gear-manufacturing workforce

Aaron Fagan, Senior Editor

The American Gear Manufacturers Association (AGMA) recently applied for and received reaccreditation from the International Accreditors for Continuing Education and Training (IACET) organization for its educational courses. An IACET accreditation allows gear industry professionals to earn Continuing Education Units (CEUs) for attending AGMA courses.

CEUs are an integral aspect of employment in the gear industry for many professionals, as numerous positions within the gear industry are required to earn a certain amount of CEUs per year. The amount required varies depending on the state of residence and employment.

Students who have taken IACET-accredited courses have shared that earning CEUs can be an essential factor in their company choosing AGMA educational offerings. It also assures AGMA instructors that their curriculum has undergone a rigorous evaluation process that ensures the lessons will enrich the gear industry.

Each year's educational offerings include a variety of instructor-led in-person and virtual course offerings, asynchronous online courses, webinars, and on-site training bespoke to your team's needs. The sidebars "AGMA Education Resources" on page 25 and "2023 AGMA Courses" on page 26 will help you get started.

AGMA's renewed accreditation is valid for a period of five years, through November 2027. "I am thrilled that we have been reaccredited and am excited to continue to offer the high-quality training that we do," stated Stephanie Smialek, Education Manager, AGMA. "The feedback that we receive from our participants helps us continually improve the courses we offer and are considering for the future. This, in turn, helps us provide a needs analysis to enhance our courses and topics for accreditation compliance." To celebrate, *Gear Technology* caught up with Smialek to discuss the full breadth of AGMA's professional development programs.

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***Aaron Fagan:* What is a concise overview of the AGMA educational offerings?**

Stephanie Smialek: We want to be the premier educational source companies turn to for training. We are constantly looking to refine our existing courses and develop new ones both for in-person and online.

I think the slowdown of the pandemic presented an opportunity for us to do a lot of shorter courses and those continue to be well received. They are constantly filling up. I hope to include more short programs and things like that in the future because it seems like they manage to convey a lot of valuable information in a short period.

We have quite a bit of educational material online that is free to AGMA members. Even the older webinars garner a lot of use from members and nonmembers alike. Webinars are useful because they offer short insights on a topic someone is trying to get more information about. And then our on-demand classes also do well, and I've found they are especially helpful to our international participants who want to work towards a certificate but don't necessarily have the means to fly to the US for one of our in-person courses. I know with the expansion of our online offerings, we have had a considerable number of international participants join us, and that's something we want to see continue into next year.

Any countries in particular? I know India, Italy, and Germany are big gear countries.

You know what, it's great, they come from all over the world. I've had a couple of people from Vietnam and Singapore, and quite a few from the UK. Canada sends a lot of people. Mexico has been increasingly sending more and more. If we can increase international participation in education, that would be great, because then we're bringing in new people with new ideas.

There are courses that would appeal to designers right through to process engineers and machinists and everybody in between. Closed-loop training if you will. What's the student profile?

We have a wide range of backgrounds and all levels of education. We see quite a few machinists in our operator classes, on-site training, basics of gearing classes, and on-demand classes like our workforce training series. In terms of our more advanced courses, it heavily leans towards design or technical applications engineers. The overarching course list is a comprehensive mix. We've even had some executives take the courses before just to see what it's about and brush up on their information.

Are classes held all over the place or do they tend to be in one place?

We hold them all over. We tend to return to places like Clearwater Beach, Florida. That's a very popular destination. But we do try to move some things around. There's always going to be something on the east coast, but this coming year I wanted to go to somewhere on the west coast, so we're going to go to San Diego. We might do somewhere in the middle—maybe we'll do Denver or Texas, something like that. That allows more people the opportunity to participate. We also try to think about what classes are going to be appropriate to industries in the regions we choose. San Diego, for example, is near Silicon Valley and a lot of tech areas. And

AGMA EDUCATION RESOURCES

Archived webinars free to AGMA members:
agma.org/education/online/webinars/

Video trainings:
agma.org/education/online/video-training/

Workforce training series trainings:
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In August, AGMA President Matt Croson held a ribbon-cutting ceremony for National Training Center (NTC), in partnership with Richard J. Daley College, in Chicago. The AGMA NTC provides industry-focused events and training for gear manufacturing professionals and year-round classes for novices and experts alike.

for the most part, the classes that are at the AGMA National Training Center (NTC) at Daley College in Chicago are the ones that utilize the machines in some way, but we are hoping to expand to do a few others that don't necessarily involve the machines but utilize the space that we have.

The NTC just had the ribbon cutting back in August. Can you give a little bit of the back story?

Daley College has these buildings in one part of their campus, and we lease out a building. At the ribbon cutting, we showcased the new signs we had put up both outside and inside the building. We want to house a lot of our classes here because Chicago is an ideal, centralized hub and many of the classes utilize the machines we have here.

Can you speak to on-site training?

Yes! It's expanding. We got quite a few inquiries this past year alone. From what I see, if they have a large enough group, they want to reach out and try to do training on their own terms. And that's where a lot of that on-site training comes into play.

Let's say they have this group of 10 to 20 people, and they want to get them all trained on this one specific topic—companies inquire for us to bring an instructor to them instead of them paying to send all their employees to us. Ten registrations, for example, to come to a class, plus then all the travel and whatnot for each of those individuals can add up quickly. They can save some money by having that training at their facility, and then the nice beneficial thing about it is we can make it directly applicable to the people who are in the class.

What makes it nice with on-site training is you can address detailed questions. And a lot of that information is often proprietary. In a regular class context, you wouldn't be able to share that kind of information where 20 different organizations might be represented. On-site training holds a lot of value for the companies they serve. We've already scheduled four for next year and we haven't even finished the month of November.

That's fantastic!

Yeah, there's definitely a lot of interest in it, which is really great because of that customizability.

How does that side of it work? This is a service that can be developed regardless of whether the company is an AGMA member.

Correct. We don't care if they're a member or nonmember. The pricing will change, so that does play a factor, but that also applies to all of our other classes. We have member rates and then our nonmember rates. For example, we have a group through the government that is in a couple of classes now. They're not members, but they reached out to us because they know we can provide the good training that they're looking for.

2023 AGMA Courses

Registration for all 2023 AGMA Education courses is now open. Topics include gear manufacturing, gear inspection, design basics, gear failure, gear chart interpretation, gear systems, and much more. Online and in-person courses on offer this year include:

- ANALYTICAL GEAR CHART INTERPRETATION**
- BASIC GEAR INSPECTION FOR OPERATORS
- BASIC TRAINING FOR GEAR MANUFACTURING**
- BEVEL GEAR SYSTEMS
- DESIGN BASICS FOR SPUR & HELICAL GEARS**
- DETAILED GEAR DESIGN
- EPICYCLIC GEAR SYSTEMS
- FUNDAMENTALS OF GEAR DESIGN & ANALYSIS
- GEAR FAILURE ANALYSIS**
- GEAR MANUFACTURING & INSPECTION
- GEAR SYSTEMS DESIGN FOR MINIMUM NOISE
- GEARBOX CSI
- GEARBOX SYSTEMS DESIGN
- HOW TO READ & INTERPRET A GEAR INSPECTION REPORT
- INVOLUTE SPLINE DESIGN & RATING
- LOADED TOOTH CONTACT ANALYSIS
- OPERATOR HOBBING & SHAPER CUTTING
- OPERATOR PRECISION GEAR GRINDING
- REVERSE ENGINEERING
- STEELS FOR GEAR MANUFACTURING
- WORM GEAR

agma.org/education/advanced-courses/

****COURSE IS OFFERED MORE THAN ONCE A YEAR.**

To get the specifics for each course, visit AGMA's course catalogue. There, you'll find course outlines, learning objectives, instructor details, deals on hotel rooms for in-person courses, and more. If you have any trouble signing up for courses or have any questions, email *education@agma.org*.

Why don't they hire their own consultants?

They could easily reach out to the consultant themselves if they wanted to—and I'm sure we've had some companies who have gone directly to the consultant instead—but one of the benefits of doing it through AGMA is that you obviously get the certificates of completion, and if an AGMA representative goes, we are also accredited to offer the Continuing Education Units (CEUs) which is something some states require on an annual basis for those with professional licenses.

We just went through the reaccreditation process and have officially been reaccredited for another five years to offer CEUs, so that's exciting.

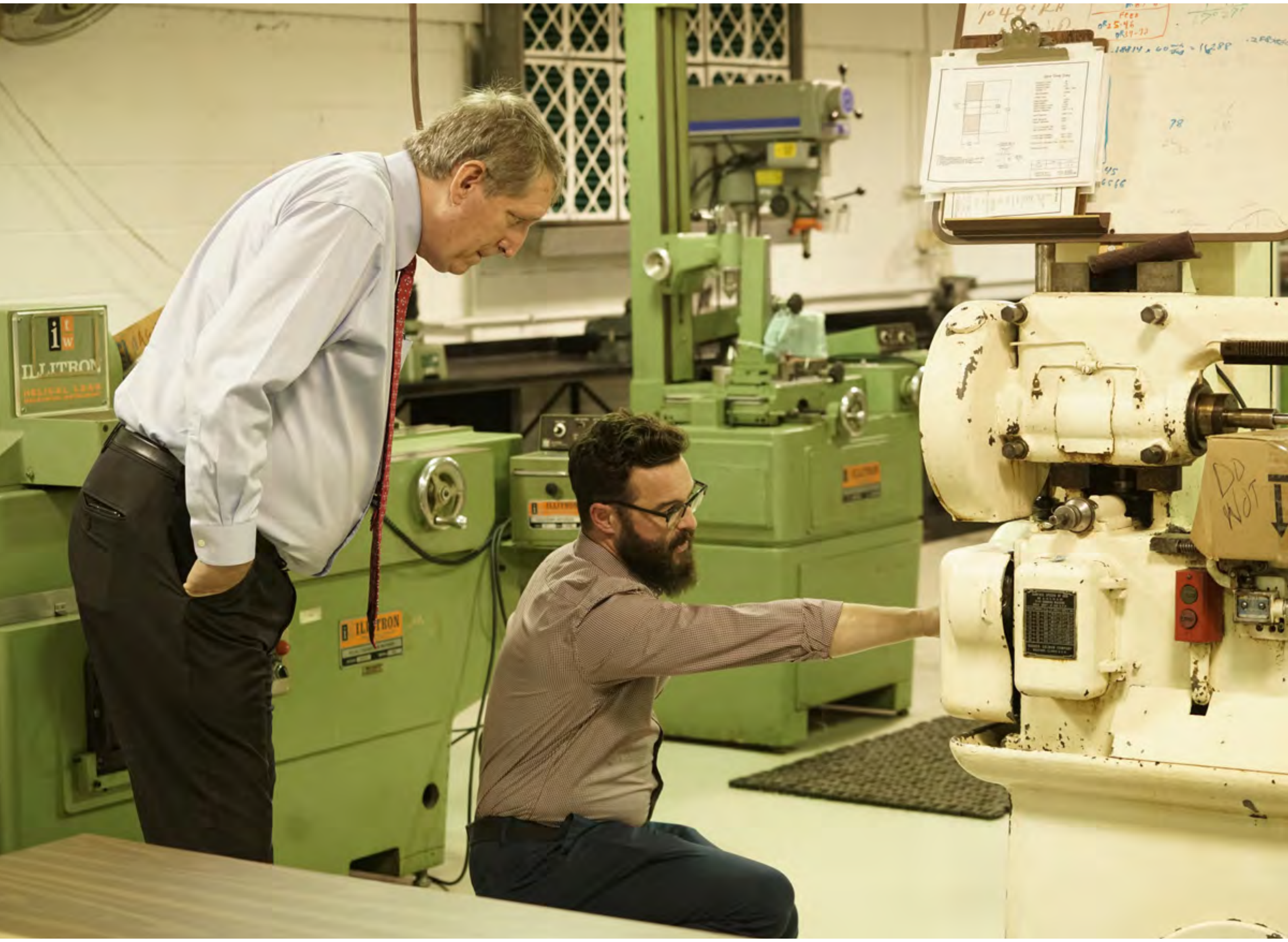
Are there any closing thoughts?

We offer a ton of different things for members and non-members alike. We want to continue to offer and improve the great classes that we currently have and continue to offer additional courses on topics that are of interest to our constituents. The AGMA is constantly trying to expand and investigate where we can move and introduce new topics and new ideas to make sure that we're staying up to date on topics just as everybody else is.

Gear standards don't play a huge part in the classes, but they do come up, especially when we're talking about design and all those specifications. AGMA education ties into each different piece at AGMA from the standards to membership as well. We can encourage people to get membership if they like our courses and continue to bring and send people to our courses.

The closed loop.

Closed loop, yeah. It's fun getting to meet all these great people. I enjoy getting to know each person and getting to know the instructors.



The outfitting of the facility has been made possible by generous donations of time, dollars, machinery, and materials to the AGMA Foundation. It is an incredible industry resource to train and upskill new and experienced workers within the gear industry.

About This Directory

The 2022 *Gear Technology* Buyer's Guide was compiled to provide you with a handy resource containing the contact information for significant suppliers of machinery, tooling, supplies and services used in gear manufacturing.

BOLD LISTINGS throughout the Buyer's Guide indicate that a company has an advertisement in this issue of *Gear Technology*.

But Wait! Where are the Gear Manufacturers Listed?

If you are looking for suppliers of gears, splines, sprockets, gear drives or other power transmission components, see our listing of this issue's power transmission component advertisers on page 43. In addition, you will find our comprehensive directory in the December 2022 issue of *Power Transmission Engineering* as well as in our online directory at *powertransmission.com.*

Handy Online Resources

The *Gear Technology* Buyer's Guide—The listings printed here are just the basics. For a more comprehensive directory of products and services, please visit our website, where you'll find each of the categories here broken down into sub-categories:

geartechnology.com/dir/

The *Power Transmission Engineering* Buyer's Guide—The most comprehensive online directory of suppliers of gears, bearings, motors, clutches, couplings, gear drives and other mechanical power transmission components, broken down into sub-category by type of product manufactured:

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Page 45

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Page 19, Inside Back Cover

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SEE AD
Page 44

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Back Cover

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Page 9, 29, 31, 38, 40, 42

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Inside Front Cover, Page 1, 45

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SEE AD
Page 7

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SEE AD Page 13

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Patriot Forge
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www.blackboxtech.in

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SEE AD *Page 44*

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PLYMOUTH, MI 48170
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SEE AD *Page 3*

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us.index-traub.com

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SEE AD *Page 14*

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Ohio Broach & Machine Co.
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pentagear.com

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Sichuan Mighty Machinery Co. Ltd.
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Star Cutter Co. India
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www.drkaiser.de

DTR Corp. (formerly Dragon Precision Tools)
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1261 WILEY ROAD, UNIT K
SCHAUMBURG IL 60173
Phone: (847) 375-8892
Fax: (224) 220-1311
www.dragon.co.kr

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ravjeet.com

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SEE AD
Inside Front Cover, Page 1, 45

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SEE AD
Page 19, Inside Back Cover

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SEE AD
Page 32, 46

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www.solarmfg.com

SEE AD
Page 4, 33, 34

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TM Induction Heating
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Zion Industries
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ZRIME
www.zrime.com.cn

ZZN Transmission Plant
www.zzn-transmissions.com

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Agnee Transmissions (I) Pvt Ltd
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Applied Thermal Technologies
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SEE AD
Page 19, Inside Back Cover

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IMT Forge Group including Clifford-Jacobs Forge
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SEE AD
Back Cover

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SEE AD
Page 4, 33, 34

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Sun Steel Treating Inc.
www.sunsteeltreating.com

SWD Inc.
www.swdinc.com

Thermetco Inc.
www.thermetco.com

Thermtech
www.thermtech.net

Thyssenkrupp Rothe Erde USA Inc.
www.thyssenkrupp-rotheerde.com

TimkenSteel Corporation
www.timkensteel.com

Titanium Coating Services Inc.
www.pvdamerica.com

Treat All Metals, Inc.
www.treatallmetals.com

United Gear and Assembly, Inc.
www.ugaco.com

VaporKote
www.vaporkote.com

Varitron Engineering (Taiwan) Co., Ltd.
www.c-var.com

Whitmore
www.whitemores.com

Wickert USA
www.wickert-usa.com

Willman Industries Inc.
www.willmanind.com

Zion Industries
www.zioninduction.com

ZRIME
www.zrime.com.cn

INSPECTION EQUIPMENT

AB Dynamics
www.abd.uk.com

ABM Drives Inc.
www.abm-drives.us/

ABTech Inc.
www.abtechmfg.com

Accu-Cut Diamond Tool Co.
www.accucutdiamond.com

Accurate Engineering Company Pvt. Ltd.
www.accurategauging.com

Advent Tool and Manufacturing Inc.
www.advent-threadmill.com

AIS Technologies Group
www.aistechgroup.com

Aksan Steel Forging
www.aksanforging.com

Arnold Magnetic Technologies
www.arnoldmagnetics.com

Ash Gear & Supply
www.ashgear.com

Becker GearMeisters, Inc.
www.maagmachines.com

Beyta Gear Service
www.beytagear.com

BK Power Systems—An Integrated Corrosion Co.
www.bkpowersystems.com

Blackbox Technologies
www.blackboxtech.in

Bonfiglioli USA Inc.
www.bonfiglioli.com/usa/en

Broach Masters / Universal Gear Co.
www.broachmasters.com

Buehler—An ITW Company
www.buehler.com

Capital Tool Industries
www.capital-tool.com

Celanese
www.celanese.com

Certified Comparator Products (CCP)
www.certifiedcomparator.com

CN Technical Services Ltd (CN Tech)
www.cntech.co.uk

CNC Center
www.cnccenter.com

Comtorgage Corporation
www.comtorgage.com

Dino-Lite
www.dinolite.us

Drewco Workholding
www.drewco.com

Empire Machine Tools—MFTM Division
www.emtmftm.com

Emuge-Franken USA
www.emuge.com

Ever Sharp Tools (EST) America
10138 RADIANCE DR
IRA TOWNSHIP, MI 48023
Phone: 810-824-3323
www.est-us.com
SEE AD *Page 45*

FHUSA-TSA
www.fhusa-tsa.com

Flexbar Machine Corporation
www.flexbar.com

Foerster Instruments Incorporated
www.foerstergroup.com

Frenco GmbH
www.frenco.de

Fuji Machine America Corp.
www.fujimachine.com

Furnaces, Ovens & Baths Inc.
www.fobinc.com

Gage Assembly Company
www.gageassembly.com

Galaxy Sourcing Inc.
www.galaxysourcing.com

Gearspect s.r.o.
www.gearspect.com

Gleason Corporation
1000 UNIVERSITY AVENUE
ROCHESTER, NY 14607
Phone: (585) 473-1000
www.gleason.com
SEE AD *Page 19, Inside Back Cover*

Global DriveTrain Inc.
www.globaldrivetraininc.com

Goldstein Gear Machinery LLC
www.goldsteingearmachinery.com

Greg Allen Company
www.gallenco.com

Hanik Corporation
www.hanikcorp.com

Hansford Sensors
www.hansfordsensors.com/us/

Helios Gear Products
www.heliosgearproducts.com

HobSource Inc.
834 E. RAND RD, SUITE 2
MOUNT PROSPECT, IL 60056
Phone: (847) 398-8320
Fax: (847) 398-8326
www.hobsource.com
SEE AD *Page 44*

HVH Industrial Solutions
www.hvhindustrial.com

Innovative Analytical Solutions
www.steelanalyzer.com

Interstate Tool Corp.
www.itctoolcorp.com

Juncera Automations
www.junceraautomations.com

KAPP NILES GmbH & Co. KG
2870 WILDERNESS PLACE
BOULDER, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
www.kapp-niles.com/en
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Klingelnberg
PETERSTRASSE 45
HUECKESWAGEN 42499
GERMANY
Phone: +(49) 2192-810
Fax: +(49) 2192-81200
www.klingelnberg.com
SEE AD *Back Cover*

Kudale Instruments Pvt. Ltd.
www.kudaleinstruments.com

L.S. Starrett Co.
www.starrett.com

Lambda Technologies
www.lambdatechs.com

Liebherr America
www.liebherr.com

Maheen Enterprises
www.maheenbroaches.com

Mahr Inc.
www.mahr.com

Marposs Corporation
www.marposs.com

Miller Broach
www.millerbroach.com

Mitutoyo America Corporation
www.mitutoyo.com

Mitutoyo South Asia Pvt. Ltd.
www.mitutoyoindia.com

Modern Gearing
www.moderngearing.com

Motherson Advanced Tooling Solutions LTD
www.matsltd.com

MRO Electric and Supply
www.mroelectric.com

Musashi AI
www.musashiamericas.com/ai-project

Mutschler Edge Technologies
www.mutschleredgetech.com

Nachi America Inc.
www.nachiamerica.com

Nemade Engineers Pvt. Ltd.
www.nemade.in

Newage Testing Instruments
www.hardnesstesters.com

Ono Sokki Technology, Inc.
www.onosokki.net

Parker Industries Inc.
parkerindustriesinc.com

Penta Gear Metrology LLC (Kapp Niles)
6161 WEBSTER STREET
DAYTON, OH 45414
Phone: (937) 660-8182
pentagear.com
SEE AD *Page 32, 46*

Phase II
www.phase2plus.com

Pioneer Broach Co.
www.pioneerbroach.com

Precision Gage Co., Inc.
www.precisiongageco.com

Prime Technologies
www.gear-testers.com

Proto Manufacturing
12350 UNIVERSAL DRIVE
TAYLOR, MI 48180
Phone: (734) 946-0974
www.protoxrd.com
SEE AD *Page 21*

QMS Inc.
qms-ky.com

Qua-Tech Industries
www.qua-tech.com

Quality Vision Services (QVS)
www.qvsi.com

RAM Optical Instrumentation
www.ramoptical.com

Ravjeet Engineering Specialty Ltd.
ravjeet.com

Reska Spline Gage
www.reskasplinegauge.com

Russell Holbrook & Henderson
www.tru-volute.com

SAMP India Pvt. Ltd.
www.samputensili.com

Samputensili S.p.A.
www.samputensili.com

Sandvik Asia Pvt. Ltd.
www.sandvik.coromant.com

Schnyder SA
www.schnyder.com

Sensor Products Inc.
www.sensorprod.com

SerWeMa GmbH & Co. KG
www.serwema.de

SMS Elotherm North America
www.sms-elotherm.com/en/

Spline Gage Solutions
splinegagesolutions.com

Star Cutter Co. India
www.starcutter.com

Star SU LLC
5200 PRAIRIE STONE PKWY.
STE. 100
HOFFMAN ESTATES, IL 60192
Phone: (847) 649-1450
www.star-su.com

SEE AD
Inside Front Cover, Page 1, 45

Stone Tucker Instruments Inc.
www.stone-tucker.com

Stotz Gaging Co.
www.stotz-usa.com

Stresstech Oy
www.stresstech.com

Surplex GmbH
www.surplex.com/en/

Techcellence
www.broachindia.com

TechnoMax, Inc.
www.technomax-j.com

Tokyo Technical Instruments Inc.
www.tti-geartec.jp

United Gear Works
unitedgearworks.com

United Tool Supply
united-tool.com

USA Borescopes
www.usaborescopes.com

View Micro-Metrology
www.viewmm.com

VL Motion Systems Inc.
www.vlmotion.com

Wenzel America
www.wenzelamerica.com

Westport Gage
www.westportcorp.com

Willrich Precision Instrument Company
willrich.com

Yilmaz Reduktor Sanayi ve Tic A.S.
www.yr.com.tr

Zoller Inc.
www.zoller-usa.com

ZRIME
www.zrime.com.cn

LUBRICANTS

A.W. Chesterton Company
www.chestertonlubricants.chesterton.com/en-us

ABM Drives Inc.
www.abm-drives.us/

American Refining Group, Inc.
www.amref.com

B&B Manufacturing Inc.
www.bbman.com

Bearings Limited
www.bearingslimited.com

BFK Solutions LLC
www.bfksolutions.com

Blaser Swisslube Inc.
www.blaser.com

Bodycote Thermal Processing
www.bodycote.com

Brighton Laboratories
www.brightonlabs.com

Carborundum Universal Ltd.
www.cumiabrasives.com

Castrol Industrial North America Inc.
www.castrol.com/industrial

D-A Lubricant Company Inc.
www.dalube.com

Des-Case Corporation
www.descase.com

Dillon Chuck Jaws
www.dillonmfg.com

Etna Products, Inc.
www.etna.com

Evolvent Design
www.evolventdesign.com

Forest City Gear Co.
11715 MAIN STREET
ROSCOE, IL 61073
Phone: (815) 623-2168
Fax: (815) 623-6620
www.forestcitygear.com

SEE AD
Page 11

Fuchs Lubricants Company
www.fuchs.com

General Magnaplate
www.magnaplate.com

Hoffmann Filter Corporation
www.hoffmannfilter.com

HVH Industrial Solutions
www.hvhindustrial.com

Hydrotex
www.hydrotexlube.com

Industrial Speciality Lubricants Co. (ISLUB)
www.islub.com

Isel Inc.
www.iselinc.com

Klüber Lubrication North America L.P.
www.klueber.com

Lubriplate Lubricants Co.
www.lubriplate.com

Microsurface Corporation
www.ws2coating.com

ML Lubrication Inc.
www.ml-lubrication.com

MMT Productivity
www.mmtproductivity.com

Motultech
www.motul.com

Nye Lubricants
www.nyelubricants.com

Oelheld U.S., Inc.
1100 Wesemann Dr.
West Dundee, IL 60118
www.oelheld.com

Paras Lubricants Ltd.
www.palco.co.in

Particular Technology, Inc.
www.particulartechnology.com

Petro Lubes Inc.
www.petrolubesinc.com

Petronomics Mfg. Group, Inc.
www.petronomics.com

RedLine Tools
www.redlinetools.com

Shell Lubricants
www.shellus.com

SWD Inc.
www.swdinc.com

Syn-Tech Ltd.
www.syn-techlube.com

United Gear Works
unitedgearworks.com

United Tool Supply Ltd.
unitedtoolsupply.com

Voelker Sensors, Inc.
www.vsi-oil.com

Whitmore
www.whitemores.com

Yantai Bonway Manufacturer
www.bonwaygroup.com

MACHINE TOOLS

A&A Coatings
www.thermalspray.com

Accu-Cut Diamond Tool Co.
www.accucutdiamond.com

AccuBrass
www.accubrass.com

Aksan Steel Forging
www.aksanforging.com

Ampere Metal Finishing
www.amperemetal.com

ANCA, Inc.
www.anca.com

AquaEase Infinity System
www.hubbardhall.com/aquaease-infinity-system

Artec Machine Systems
www.artec-machine.com

AX Control, Inc
www.axcontrol.com

Baart Industrial Group
www.baartgroup.com

Balanstar Corp.
www.balanstar.com

Becker GearMeisters, Inc.
www.maagmachines.com

Best Technology Inc.
www.besttechnologyinc.com

Beyta Gear Service
www.beytagear.com

BFK Solutions LLC
www.bfksolutions.com

Blackbox Technologies
www.blackboxtech.in

Bohle Machine Tools, Inc.
www.bmtbohle.com

Brighton Laboratories
www.brightonlabs.com

Broaching Machine Specialties
www.broachingmachine.com

BUDERUS Schleiftechnik GmbH
www.buderus-schleiftechnik.de

Buehler—An ITW Company
www.buehler.com

C&B Machinery
www.cbmachinery.com

Capital Tool Industries
www.capital-tool.com

Carborundum Universal Ltd.
www.cumiabrasives.com

Castrol Industrial North America Inc.
www.castrol.com/industrial

Cattini North America Corp.
1690 OPPORTUNITY AVENUE
CHAMBERSBURG, PA 17201
Phone: (717) 262-2120
www.cattinina.com

SEE AD
Page 44

Cleveland Deburring Machine Co.
www.cdmcmachine.com

CNC Center
www.cnccenter.com

Cosen Saws
www.cosensaws.com

Creative Automation, Inc.
www.cautomation.com

D.C. Morrison Company
www.dcmorrison.com

Danobat Machine Tool Co. Inc.
www.danobatusa.com

Des-Case Corporation
www.descase.com

DISKUS WERKE Schleiftechnik GmbH
www.diskus-werke.de

DMG MORI USA
www.dmgmori-usa.com

Drake Manufacturing
www.drakemfg.com

Drive Lines Technologies Ltd
www.drivelines.co.uk

The Duffy Company
www.duffycompany.com

DVS Technology America, Inc.
44099 PLYMOUTH OAKS BLVD.
PLYMOUTH, MI 48170
Phone: (734) 656-2073
Fax: (734) 656-2091
www.dvs-technology.com/en/dvs-group
SEE AD Page 3

DVS Universal Grinding GmbH
www.dvs-technology.com/en/dvs-universal-grinding

ElectroHeat Induction
www.electroheatinduction.com

Empire Machine Tools—MFTM Division
www.emtmftm.com

Felsomat USA Inc.
www.felsomat.com

Fixtureworks
www.fixtureworks.net

Flexbar Machine Corporation
www.flexbar.com

Foerster Instruments Incorporated
www.foerstergroup.com

Fuji Machine America Corp.
www.fujimachine.com

Furnaces, Ovens & Baths Inc.
www.fobinc.com

Galomb Inc.
www.injectionmolder.net

Gasbarre Thermal Processing Systems
www.gasbarre.com

Gehring L.P.
www.gehring.de

General Broach Company
www.generalbroach.com

General Magnaplate
www.magnaplate.com

GH Induction Atmospheres
www.gh-ia.com

Gleason Corporation
1000 UNIVERSITY AVENUE
ROCHESTER, NY 14607
Phone: (585) 473-1000
www.gleason.com
SEE AD Page 19, Inside Back Cover

GMTA German Machine Tools of America
www.gmtamerica.com

Goldstein Gear Machinery LLC
www.goldsteingearmachinery.com

Haas Multigrind LLC
www.multigrind.com

Havlik Gear
www.havlikgear.com

Heiko Machine Tools
www.heikomachine.com

Hines Industries
www.hinesindustries.com

HobSource Inc.
834 E. RAND RD, SUITE 2
MOUNT PROSPECT, IL 60056
Phone: (847) 398-8320
Fax: (847) 398-8326
www.hobsource.com
SEE AD Page 44

Hoffmann Filter Corporation
www.hoffmannfilter.com

HPB Motion Control Co. Ltd.
www.hpb-industry.com

HPI Processes Inc.
www.hpipro.com

Hy-Pro Filtration
www.hyprofiltration.com

Hydrotex
www.hydrotexlube.com

I-MAK Reduktor
www.imakreduktor.com

IMPCO Microfinishng
www.impco.com

IMT Group India
www.imtgrindinggroup.com

Index Corporation
us.index-traub.com

Industrial Hard Carbon LLC
www.industrialhardcarbon.com

Inovatec Machinery
www.inovatecmachinery.com

Integrated Components Inc.
www.integratedcomponentsinc.com

Interstate Tool Corp.
www.itctoolcorp.com

Ion Vacuum (IVAC) Technologies Corp.
www.ivactech.com

ISC Companies
www.isccompanies.com

Jenfab
www.jenfab.com

Jones Metal Products Company
www.jmpforming.com

Juncera Automations
www.junceraautomations.com

Kachelmann Getriebe GmbH
www.kachelmann.de

KAPP NILES GmbH & Co. KG
2870 WILDERNESS PLACE
BOULDER, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
www.kapp-niles.com/en
SEE AD Page 19, 23, 31, 37

Kennametal Inc.
www.kennametal.com

KGK International Corp.
www.kgki.com

Kiesler Machine Inc.
www.kieslermachine.com

Kinefac Corporation
www.kinefac.com

Klingelnberg
PETERSTRASSE 45
HUECKESWAGEN 42499
GERMANY
Phone: +(49) 2192-810
Fax: +(49) 2192-81200
www.klingelnberg.com
SEE AD Back Cover

Knuth Machine Tools USA, Inc.
www.knuth-usa.com

Kushal Udhyog
www.kushaludhyog.com

Kwikmark Inc.
www.kwikmark.com

Lafert North America
www.lafertna.com

Lambda Technologies
www.lambdatechs.com

Laser Tools Co.
www.lasertoolsco.com

Leistritz Advanced Technology Corp.
www.leistritzcorp.com

Liebherr America
www.liebherr.com

Machine Tool Builders—MTB
7723 BURDEN ROAD
MACHESNEY PARK IL, 61115
Phone: (815) 636-7502
Fax (815) 636-5912
www.machinetoolbuilders.com
SEE AD Page 5

Maguire Technologies
www.maguiretech.com

Matrix Precision Co. Ltd.
www.matrix-machine.tw

Mazak Corporation
www.mazakusa.com

Meccanica Nova Corporation
www.novagrinders.com

Metallurgical Processing, Inc.
www.mpimetaltreating.com

Miller Broach
www.millerbroach.com

MMR Precision Gears
www.mastermachinerepair.com

MMT Productivity
www.mmtproductivity.com

Modern Gearing
www.moderngearing.com

MRO Electric and Supply
www.mroelectric.com

Mutschler Edge Technologies
www.mutschleredgetech.com

Nachi America Inc.
www.nachiamerica.com

Nagel Precision
www.nagelusa.com

Nemade Engineers Pvt. Ltd.
www.nemade.in

Nidec Machine Tool America
46992 LIBERTY DRIVE
WIXOM, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
www.nidec-machinetoolamerica.com
SEE AD Page 9, 29, 31, 38, 40, 42

Normac, Inc.
www.normac.com

NTC America Corporation
www.ntcmc.com

Oerlikon Balzers USA
www.oerlikon.com/balzers/us/en/

Ohio Broach & Machine Co.
www.ohiobroach.com

Penna Flame Industries
www.pennaflame.com

Penta Gear Metrology LLC (Kapp Niles)
6161 WEBSTER STREET
DAYTON, OH 45414
Phone: (937) 660-8182
pentagear.com
SEE AD Page 32, 46

Pioneer Broach Co.
www.pioneerbroach.com

Pittler T&S
www.pittler.de

PRAEWEMA
www.dvs-technology.com/praewema-antrieb-stechnik

Precision Finishing Inc.
www.precisionfinishinginc.com

Precision Spindle & Accessories Inc.
https://precisionspindleinc.com

Precision Surfacing Solutions
www.pss-atd.com

Preco, LLC
www.precollc.com

PTG Holroyd
www.holroyd.com

QC American
www.qcamerican.com

QMS Inc.
qms-ky.com

R.A. Heller Co.
raheller.com

RAM Optical Instrumentation
www.ramoptical.com

Reade Advanced Materials
www.reade.com

Redin Production Machine
www.redinmachine.com

Renegade Parts Washers and Detergents
www.renegadepartswashers.com

Rewitec GmbH
www.rewitec.com

Riten Industries, Inc.
www.riten.com

Roders GmbH
www.roeders.de

Russell Holbrook & Henderson
www.tru-volute.com

Samputensili S.p.A.
www.samputensili.com

Sandvik Asia Pvt. Ltd.
www.sandvik.coromant.com

Schunk
www.schunk.com

Schutte LLC
www.schutteusa.com

SerWeMa GmbH & Co. KG
www.serwema.de

Setco Precision Spindles
www.setco.com

Shibaura Machine
shibaura-machine.com

Shivam Autotech Ltd.
www.shivamautotech.com

Shreecon Gear
shreecongear.com

Sichuan Mighty Machinery Co. Ltd.
www.sc-mighty.com

Sinto America
www.sintoamerica.com

Slater Tools Inc.
www.slatertools.com

SMS Elotherm North America
www.sms-elotherm.com/en/

Somers Forge
www.somersforge.com

Star SU LLC
5200 PRAIRIE STONE PKWY. STE. 100
HOFFMAN ESTATES, IL 60192
Phone: (847) 649-1450
www.star-su.com
SEE AD Inside Front Cover, Page 1, 45

Stotz Gaging Co.
www.stotz-usa.com

Stresstech Oy
www.stresstech.com

Surplex GmbH
www.surplex.com/en/

SWD Inc.
www.swdinc.com

Titanium Coating Services Inc.
www.pvdamerica.com

Toolink Engineering
www.toolink-eng.com

Tribo Surface Engineering LLC
www.tribosurfaceengineering.com

Trishul Machine Tools Pvt. Ltd.
www.trishulmachine.com

Ty Miles, Inc.
www.tymiles.com

U.S. Equipment
www.usequipment.com

Ultramatic Equipment
ultramatic-equipment.com

Ultrasonic LLC
www.ultrasonicllc.com

United Grinding
grinding.com

VaporKote
www.vaporkote.com

View Micro-Metrology
www.viewmm.com

Voelker Sensors, Inc.
www.vsi-oil.com

WardJet
www.wardjet.com

Watkins Mfg. Inc.
watkinssaw.com

Wendt (India) Ltd.
Wendtindia.com

Westfalia Technologies
www.westfaliausa.com

ZRIME
www.zrime.com.cn

RESOURCES

AGMA
1001 N. Fairfax Street, Suite 500
ALEXANDRIA, VA 22314
Phone: (703) 684-0211
www.agma.org
SEE AD Page 24

AGMA Media
1001 N. Fairfax Street, Suite 500
ALEXANDRIA, VA 22314
Phone: (847) 437-6604
www.geartechnology.com
SEE AD Page 55, 67, 71

American Bearing Manufacturers Association
www.americanbearings.org

American Wind Energy Association
www.cleanpower.org

AMT—The Association for Manufacturing Technology
www.amtonline.org

ASM International
www.asminternational.org

Gear Research Institute
APPLIED RESEARCH LAB
PENN STATE UNIVERSITY
UNIVERSITY PARK, PA 16802
Phone: (814) 865-5832
www.gearresearch.org
SEE AD Page 44

Metal Powder Industries Federation (MPIF)
www.mpif.org

Metal Powder Products
www.mppinnovation.com

Noria Corporation
www.noria.com

Thors, LLC
www.thors.com

VDI
www.vdi.de

Virgo Communications & Exhibitions Pvt. Ltd.
www.virgo-comm.com

ZRIME
www.zrime.com.cn

SERVICES

2 Channel Transmission
www.2channeltransmission.com

A&A Coatings
www.thermalspray.com

AB Dynamics
www.abd.uk.com

Accurate Engineering Company Pvt. Ltd.
www.accurategauging.com

Acorn Industrial Services Ltd.
www.acorn-ind.co.uk

Advanced Coating Technologies
www.actechnol.com

Affiliated Distributors
www.adhq.com

Agnee Transmissions (I) Pvt Ltd
www.agneetransmissions.com

Airflow Sciences Corporation
www.airflowsciences.com

Aksan Steel Forging
www.aksanforging.com

Ampere Metal Finishing
www.amperemetal.com

AmTech OEM
www.amtechinternational.com

Andec Mfg. Ltd.
www.andec.ca

Apex Broaching Systems
www.apexbroach.com

Applied Dynamics
www.applied-dynamics.com

Artec Machine Systems
www.artec-machine.com

Artemis Vision
www.artemisvision.com

Atlanta Gear Works
www.atlantagear.com

Avers Machine and Gear dba Innovative Rack & Gear
www.gearacks.com

AX Control, Inc
www.axcontrol.com

Baart Industrial Group
www.baartgroup.com

Balanstar Corp.
www.balanstar.com

Bartlett Bearing Company, Inc.
www.bartlettbearing.com

Bearing Engineering Company
www.bearingengineering.com

Bearing Headquarters
www.bearingheadquarters.com

Bearings and Industrial Supply Company, Inc.
www.bearingsnow.com

Becker GearMeisters, Inc.
www.maagmachines.com

Best Technology Inc.
www.besttechnologyinc.com

Beyta Gear Service
www.beytagear.com

Bharat Gears Ltd.
www.bharatgears.com

Blackbox Technologies
www.blackboxtech.in

Bodine Electric Company
www.bodine-electric.com

Bosch Rexroth
www.boschrexroth-us.com

Broach Masters / Universal Gear Co.
www.broachmasters.com

Broaching Technologies, LLC
www.keyway-spline-broaching.com

Brother Gearmotors
www.brother-usa.com/gearmotors

Buehler—An ITW Company
www.buehler.com

C&B Machinery
www.cbmachinery.com

Capital Tool Industries
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CHAMBERSBURG, PA 17201
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www.cattinina.com

SEE AD *Page 44*

Cincinnati Gearing Systems
www.cincinnatigearingsystems.com

Cleveland Gear Co.
www.clevelandgear.com

CNC Center
www.cnccenter.com

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SEE AD *Page 45*

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SEE AD *Page 44*

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SEE AD Page 9, 29, 31, 38, 40, 42

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Inside Front Cover, Page 1, 45

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Page 19, Inside Back Cover

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SEE AD
Page 19

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SEE AD
Page 32, 46

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SEE AD Page 44

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SEE AD Page 9, 29, 31, 38, 40, 42

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SEE AD Page 32, 46

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SEE AD Inside Front Cover, Page 1, 45

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Three New AGMA Publications

Phillip Olson, Director, AGMA Technical Services

AGMA is pleased to announce the publication of three new documents: AGMA 923-C22, Metallurgical Specifications for Steel and Cast Iron Gearing, written by the AGMA Metallurgy and Materials Committee, AGMA 929-B22, Calculation of Bevel Gear Top Land, Slot Widths and Cutter Edge Radii, written by the AGMA Bevel Gearing Committee, and AGMA 955-A22, Guidance for Industrial Gear Lubrication written by the AGMA Lubrication Committee.

AGMA 923-C22

AGMA 923-C22 begins with an extensive definitions clause specific to gear metallurgy, then defines acceptance criteria for various metallurgical characteristics to meet three quality grades. These quality grades are used in multiple other AGMA standards to define gear performance.

Work on the first edition of AGMA 923 began in 1993 with the goal of consolidating AGMA metallurgical specifications into one document. Through much discussion and consensus building the first edition was published in the year 2000. A second edition with only minor changes was published in 2005. In 2013 the work on this current, third edition, began. This current "C" edition of AGMA 923 has extensive updates from previous editions that took hard work and many meetings for the committee to hash out. It has been developed to be consistent with ISO 6336-5:2016. It has an expanded reduction ratio calculation methodology. Metallurgical tables have been updated to list requirements sequentially, add chemistry and cleanliness requirements, footnotes were reworded and renumbered for uniformity, and new metallurgical tables were added for gray cast iron, ductile iron, and austempered ductile iron.

AGMA 929-B22

AGMA 929-C22 provides a set of equations, integrated from various publications, to calculate bevel gear top land, slot widths, and cuter edge radii. It is intended to aid in completing calculations for gear capacity in ANSI/AGMA 2003, Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Teeth.

The first edition of AGMA 929 was published in 2006. Work on this second, "B" edition began in 2010, but the bulk of the work was completed in the last couple years. This new edition includes calculations anywhere along the face width instead of just toe, mean, and heel. The expanded calculations are largely based on the paper, 14FTM13, A Practical Approach for Modeling a Bevel Gear, by Brendan Bijonowski.

AGMA 955-A22

AGMA 955-A22 is a guide for gear designers and manufacturers in the selection of suitable commercially available liquid lubricants for open and enclosed gear drives. Work on AGMA 955-A22 began in 2016 after the AGMA Lubrication committee wrapped up the publication of ANSI/AGMA 9005-F16. AGMA 955-A22, was created as the first step of separating ANSI/AGMA 9005-F16 into two documents. AGMA 955-A22 provides fundamental, generalized lubrication information, whereas the future edition of ANSI/AGMA 9005 is planned to cover only information on lubricants. The first working draft of AGMA 955 was copied text from ANSI/AGMA 9005, but through the course of editing, this was greatly added to and expanded upon to produce the published version.

On behalf of the gearing industry, AGMA would like to extend a sincere appreciation for the participation and valuable contributions of the following experts. In addition, AGMA would like to especially thank the companies of these experts whose foresight and generosity made their participation possible.

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Use of Duty Cycles or Measured Torque—Time Data with AGMA Ratings

Dr. Ing. Ulrich Kissling, ETH

Introduction

Variable loads resulting from a working process, starting process, or operation near a critical speed will cause varying stresses at the gear teeth of a drive system. The magnitude and frequency of these loads depend upon the driven machine, the motor, the dynamic mass elastic properties of the system, and other effects (Ref. 1).

These variable loads (stresses) may be determined by such procedures as:

- experimental measurement of the operating loads at the machine in question.
- calculation, using known external excitation and a mass elastic simulation of the drive system, preferably accompanied by experimental testing to validate the calculation.

In the automotive area torque and speed over time are usually measured on test rigs. Also, for industrial gearboxes, a measurement of torque over time is often used, for example in wind turbines. As measurement equipment and the transmission and storing of such data become less expensive, the tendency to measure torque/speed on gear drives is growing. Based on such data the service intervals can be adapted due to the analysis of the accumulated damage over time.

The scientific term for such data is "time series." In gear drives, a time series (time/torque/speed data)—normally measured at the input or output of the gearbox—must be in the first step of the process to get the load on a specific tooth of every gear. Then in a second step, the load spectrum (also called "duty cycle") for fatigue damage calculation must be obtained. With the load spectrum the service life of a gear can then be calculated according to the rules as described in ISO 6336-6 (Ref. 1). As main formulas for the load capacity calculation, the methods according to AGMA 2001-D4 (Ref. 3) and ISO 6336-1,2,3 (Ref. 2) can be used.

If the torque and speed in a time series is always positive, the conversion of such data in a load spectrum is carried out using a process called the "simple-count method." However, the process is more complicated when the torque and/or speed is alternating (having positive and negative values). For the other elements in a gearbox such as bearings and—with some restriction—shafts, the simple count method, extended by the consideration of speed information, can always be used to generate a load spectrum.

The flowchart (Figure 3) explains the calculation process. The time series must be filtered to obtain the load on an individual tooth (see "Extract of the load on a particular tooth from a time series"). Then, depending on if the torque is alternating or not, the simple count method can be applied (no alternating torque, see "Generation of a load spectrum with the simple count method") or the more demanding rainflow method (see "Generation of a load spectrum with the rainflow-counting algorithm") must be used.

Notes:

- The term load spectra as used in ISO 6336 (Ref. 1) or AGMA 2001 (Ref. 3) is identical to a load duration distribution (LDD) as used in the standard IEC 61400-4 (Ref. 4) for wind turbines.
- A method to calculate load spectra is not explained in AGMA rating methods (such as AGMA 2001, 2101, 2003) but a reference is given to ISO/TR 10495 (nowadays replaced by ISO 6336-6 {Ref. 1}). The procedure, based on ISO 6336-6, as discussed in this paper is applicable to AGMA ratings.

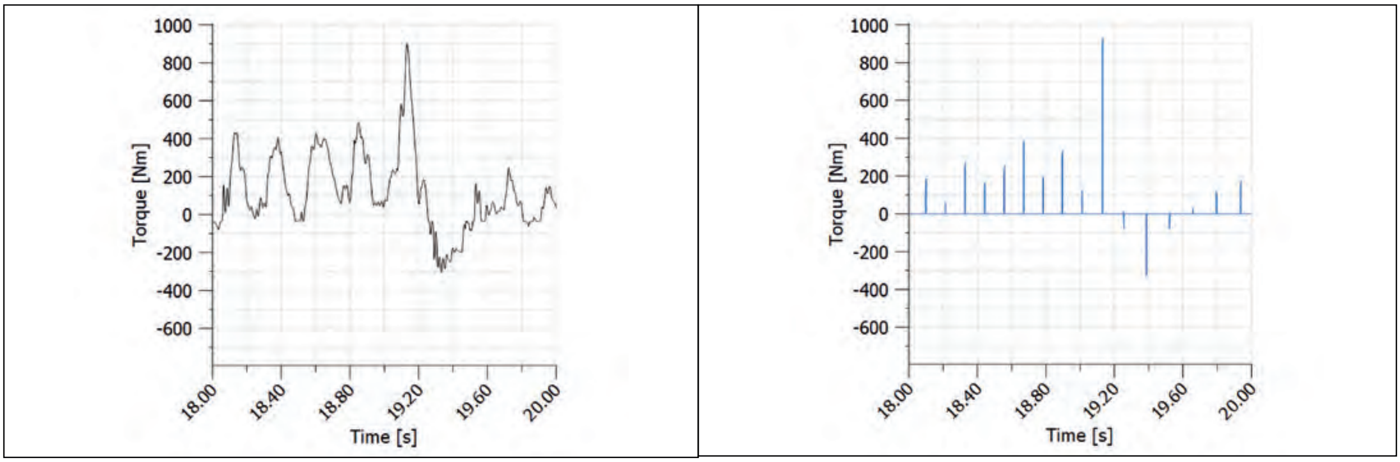


Figure 1—Torque over time in the time series (left). Torque on the tooth of the pinion at angular position 215 degrees (right).

Extract of the load on a particular tooth from a time series

The process to generate a load spectrum is complex (Figure 3). As the first step, it must be considered, that a tooth experiences load only once per revolution of the gear. The time series signal must therefore be modified before it can be used for further processing. This is shown in Figure 1.

Generation of a load spectrum with the "simple count method"

If the signs of torque and speed in a time series are in such a way that always the same flank is in contact, then for gears the so-called simple counting method can be used. Since there is only one flank in contact the respective side of the tooth root sees only pulsating tensile stress. In addition, the Hertzian pressure on the flank is always applied on the same flank. A matrix with torque intervals and speed intervals is formed and each measuring point is classified into the corresponding category, also called "bin." Then the number of measuring points is counted. This results in a load spectrum of bins with different torque and speed (extended simple count method).

The counting method is also documented in ISO 6336-6, Table 4 (Ref. 1). To obtain the load spectra for fatigue damage calculation, the range of the measured (or calculated) loads is divided into bins or classes. Each bin contains the number of load occurrences recorded in its load range. A widely-used number of bins—according to ISO 6336-6—is 64 (Figure 2). These bins can be of an equal size, but it is usually better to use larger bin sizes at the lower loads and smaller bin sizes at the upper loads in the range. In this way, the resolution for the most damaging loads is higher and the result is more accurate regarding the effective load (see "Generating the load spectra according to ISO 6336-6").

Generation of a load spectrum with the rainflow-counting algorithm

Generation of the matrix with the frequency of high to low torque

If torque and/or speed have alternating signs so that the loaded flank is changing, for the assessment of the Hertzian pressure on the considered tooth flank (left or right) only the positive values on this flank are considered. For the bending stress this simple calculation procedure cannot be applied. The considered tooth root side is subjected to an alternating load, getting tensile stress with positive torque and compression stress by negative torque. And all significant alternating load cases must be extracted from the torque curve. For that, the so-called rainflow method is used (Refs. 5, 6, 8). Rainflow analysis provides a matrix that shows how often the torque changes from T_{high} to T_{low}. The matrix, therefore, has two torque bin series, in Y-axis for T_{high} and in X-axis for T_{low} (Figure 5).

The rainflow method is usually carried out with stresses, not with torques. Because tooth root bending stress and torque are proportional, torque can also be used. In addition, the negative torques are multiplied by 1.2 since the compressive stress on the non-loaded flank is approximately 20% higher than the tensile stress on the loaded flank. Factor 1.2 is used in ISO 6336-3 and can be confirmed with FEM calculations (Fig. 4). A further challenge to get correct results: The torque must be multiplied by the dynamic factor K_V and the face load factor $K_{F\beta}$. The rainflow method does not conserve the speed information of a time series. As K_V depends on the speed, which is no longer considered in the subsequent rainflow calculation, for every data point of the time series K_V is determined and multiplied to the torque. Also, $K_{F\beta}$ must be multiplied to the torque of every point because $K_{F\beta}$ is not proportional to the torque and will therefore be different for T_{high} and T_{low}.

Conversion of rainflow T_{high} and T_{low} result to T_{ISO} and Y_M for ISO or AGMA ratings

AGMA and ISO are designed for pulsating load on the tooth; so, the nominal torque and the allowable bending stress numbers are intended for the pulsating load case. For alternate bending (reverse loading) AGMA just mentions that the allowable stress number must be multiplied by a factor 0.7. This factor coincides with older versions of ISO. In the current edition of ISO 6336-3, annex B (Ref. 2), a more precise rule is given for the alternating bending factor Y_M.

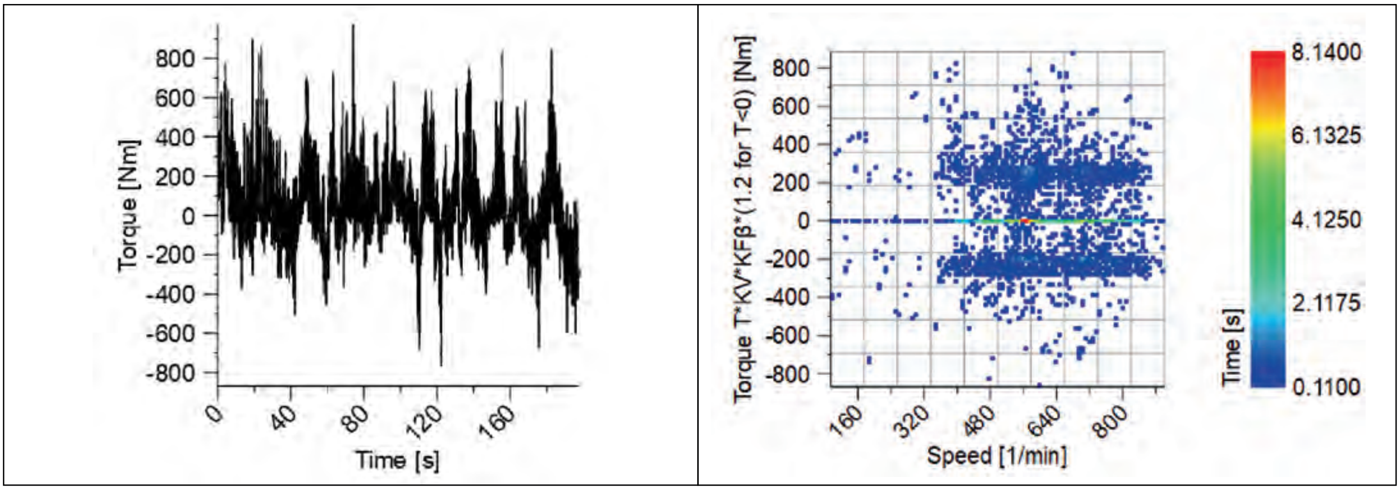


Figure 2—Torque measurement on a test run of a military car (left). Speed/Torque frequency result by simple count (right).

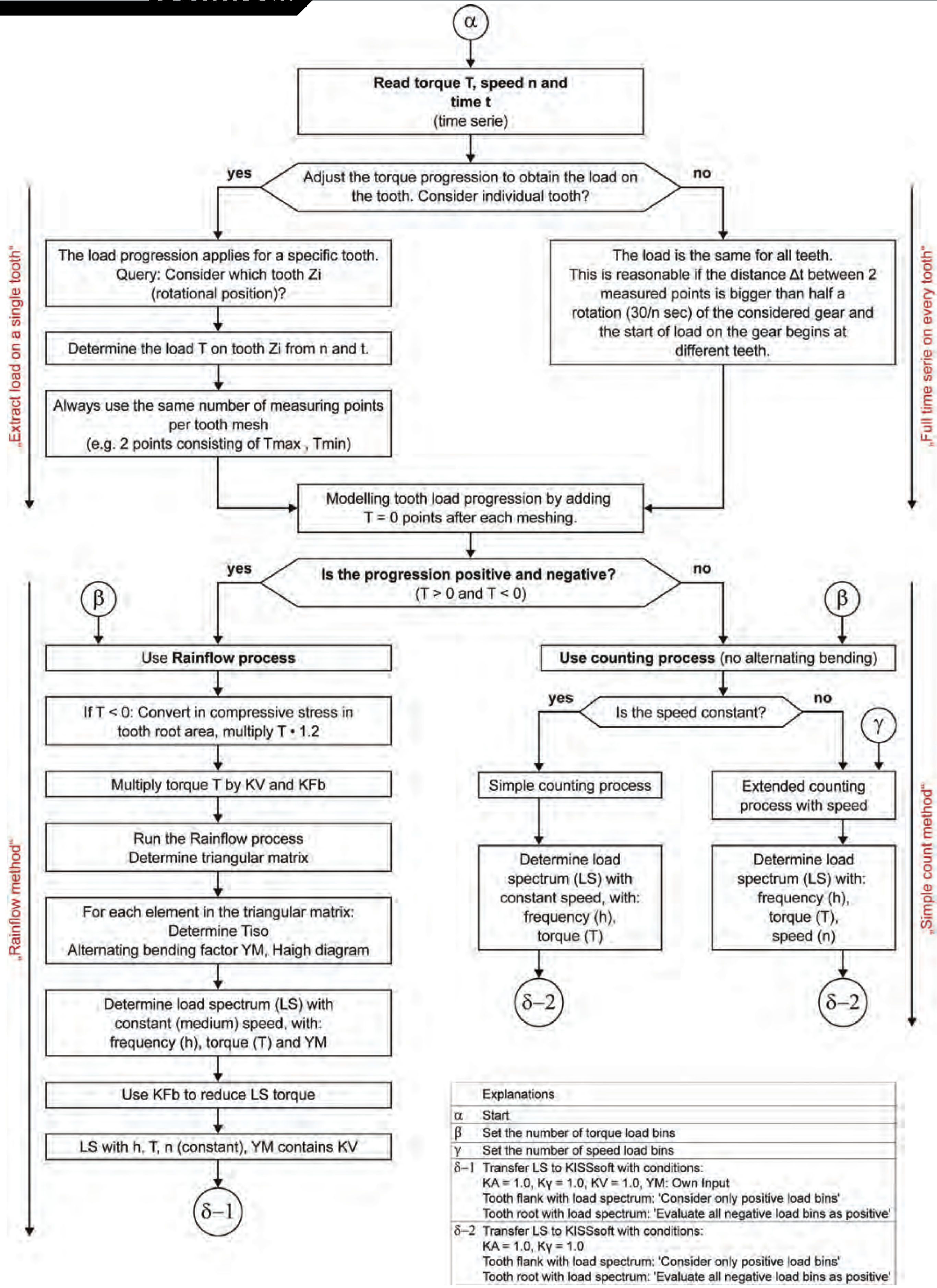


Figure 3—Flowchart to generate a load spectrum for gears from time series data.

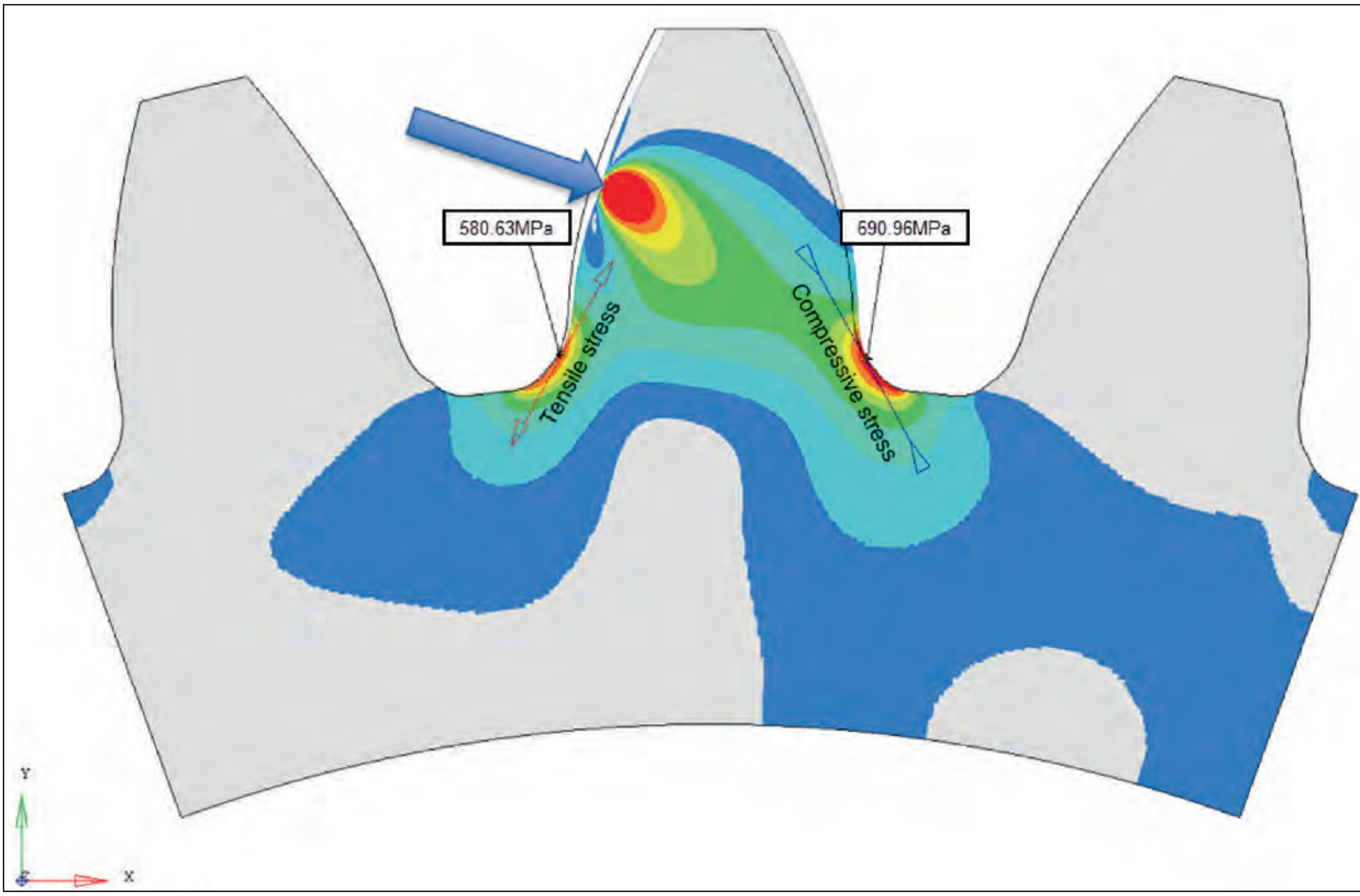


Figure 4—Stresses on the loaded and non-loaded side of a tooth by FEM analysis.

		T_{low}				
		-796.70 -778.60	-778.60 -760.49	-760.49 -742.38	-742.38 -724.28	...
T_{high}	-796.70 -778.60	01				
	-778.60 -760.49	0	2			
	-760.49 -742.38	0	0	3		
	-742.38 -724.28	01	4	0	1	
	...	...	...	...	...	...

Figure 5—Extract of a rainflow half-matrix with 100 bins.

The equation for Y_M is:

$$Y_M = \frac{1}{1 - R \cdot \frac{(1-M)}{(1+M)}} \quad (1)$$

Where:

R stress ratio. $R = -\sigma_{low} / \sigma_{high}$; and as here σ is proportional to T, $R = -T_{low} / T_{high}$

M considers the mean stress influence on the endurance strength amplitudes; the values are listed in Table 1.

Case hardened	0.8 – 0.15 YS
Case hardened and shot peened	0.4
Nitrided	0.3
Induction or flame hardened	0.4
Not surface hardened steels	0.3
Cast steels	0.4

Table 1—Mean stress ratio M according ISO 6336-3, Table B.1 (Ref. 2).

Equation 1 according to ISO may be used within a stress ratio $1 \geq R \geq 0$. Therefore Equation 1 is only valid if the following conditions apply: $T_{high} > 0$; $T_{low} < 0$ and $-T_{low} \leq T_{high}$. As the general case R may be in the range from -∞ … to +1, Equation 1 must be extended. For the definition of the allowable stress in mechanics the Haigh diagram is appropriate (Figure 6). The construction of the Haigh diagram requires the tensile strength R_m, the yield strength R_{p02}, the tooth root fatigue strength for pulsating loads (sat according to AGMA, or σ_{Flim} according to ISO 6336) and the mean stress ratio M.

Basically, the alternating bending factor Y_M is a factor that considers the change in the admitted amplitude σ_{admAmp} and the occurring amplitude $\sigma_{LoadAmp}$ of the general case "Gen" compared to the pulsating load case "Puls."

$$\frac{\sigma_{admAmpPuls}}{\sigma_{LoadAmpPuls}} = Y_M \cdot \frac{\sigma_{admAmpGen}}{\sigma_{LoadAmp\ Gen}} \quad (2)$$

The permissible amplitude $\sigma_{admAmpGen}$ results from the intersection of the R_{Gen} line with the Haigh diagram. With the high stress σ_{high}, the amplitude $\sigma_{LoadAmpGen}$ results in the general case from:

$$\sigma_{LoadAmpGen} = \frac{(\sigma_{high} - \sigma_{low})}{2} = \frac{(\sigma_{high} - R_{Gen} \cdot \sigma_{high})}{2} = (1 - R_{Gen}) \cdot \frac{\sigma_{high}}{2} \quad (3)$$

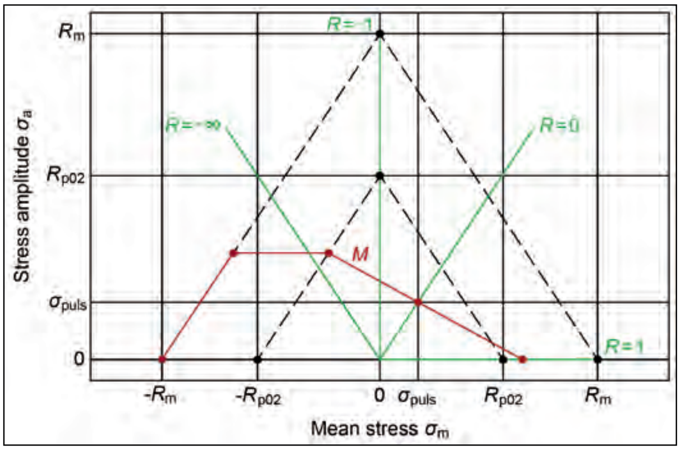


Figure 6—Haigh diagram with mean stress influence M according ISO 6336-3. (Note: The red line "M" is defined by the point $\{\sigma_{admAmpPuls}, \sigma_{admAmpPuls}\}$ and gradient M.)

For the pulsating case "Puls" with $R_{Puls} = 0$ the following applies:

$$\sigma_{LoadAmpPuls} = \frac{(\sigma_{high} - \sigma_{low})}{2} = \frac{(\sigma_{high} - R_{Puls} \cdot \sigma_{max})}{2} = \frac{\sigma_{high}}{2} \quad (4)$$

Whereas the admitted stress for pulsating bending is:

$$\sigma_{admAmpPuls} = s_{at}/2 \quad (5)$$

Finally, when Equations 3, 4 and 5 are inserted in Equation 2; then rearranged, we get Y_M for the general case:

$$Y_M = \frac{2}{s_{at}} \cdot \frac{\sigma_{admAmpGen}}{(1 - R_{Gen})} \quad (6)$$

Where:

s_{at} Allowable bending stress number (bending) in AGMA 2101 (Ref. 3)

$\sigma_{admAmpGen}$ The permissible amplitude from Haigh diagram

It must be noted, that with this general definition of Y_M all load cases on the tooth root can be considered; also pulsating compressive stress. In such cases, Y_M will be bigger than one, because the admitted amplitudes in the compressive domain of the Haigh diagram are bigger than the amplitudes in the tension domain.

T_{max}	T_{min}	$T_{ISOorAGMA}$
Positive	Positive	$+T_{max}$
Positive	Zero	$+T_{max}$
Positive	Negative	$+T_{max}$
Zero	Negative	$-T_{min}$
Negative	Negative	$-T_{min}$

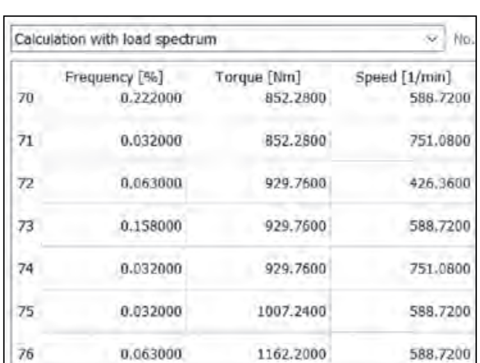
Table 2—Determination of the nominal torque to be used as nominal load in AGMA or ISO.

Generating the load spectra according to ISO 6336-6

With the nominal torque from Table 2 and the alternating bending factor Y_M from Equation 6, every element of the rainflow matrix can now be converted in a bin of the load spectrum. A bin according to ISO 6336-6 (Ref. 1) consists of only two elements, frequency, and torque. The frequency is a percent value of the number of load cycles of the bin versus the total number of cycles. The torque is the $T_{ISO\ or\ AGMA}$ value according to Table 2. For more general use, this definition must be extended. Generally, it is good practice to add speed as the third element of the bin. This definition of a bin (frequency, torque, and speed) is the most used case for gear and bearing calculations, appropriate to the simple-count method (see "Generation of a load spectrum with the simple count method"). When the rainflow method is used, then for every bin in addition the values Y_M, one for every gear, must be added (Figure 7).

Application of load spectra in AGMA ratings

A method to calculate load spectra is not explained in AGMA rating methods (such as AGMA 2001, 2101, 2003) but a reference is given to use Miner's rule as presented in ISO/TR 10495. This norm was replaced in 2006 by ISO 6336-6; the current version is from 2019 (Ref. 1). Gear rating methods according to AGMA and ratings according to ISO have the same basic structure, using general factors and bending and pitting ratings. Both methods use stress cycle factors (as called in AGMA) or


Calculation with load spectrum | No.

	Frequency [%]	Torque [Nm]	Speed [1/min]
70	0.222000	852.2800	588.7200
71	0.032000	852.2800	751.0800
72	0.063000	929.7600	426.3600
73	0.158000	929.7600	588.7200
74	0.032000	929.7600	751.0800
75	0.032000	1007.2400	588.7200
76	0.063000	1162.2000	588.7200


Calculation with load spectrum | No. 1 | Own Input

	Frequency [%]	Torque [Nm]	Speed [1/min]	K_{HB}	Y_{M1}	Y_{M2}
57	0.069000	861.2500	479.1600	1.0381	0.8912	0.8928
58	0.069000	861.2500	479.1600	1.0381	1.0000	1.0000
59	0.069000	949.6500	479.1600	1.0346	0.8573	0.8593
60	0.139000	949.6500	479.1600	1.0346	1.0000	1.0000
61	0.069000	1037.8550	479.1600	1.0316	0.7516	0.7547
62	0.069000	1037.8550	479.1600	1.0316	0.7814	0.7843
63	0.069000	1037.8550	479.1600	1.0316	1.0000	1.0000

Figure 7—Load spectra examples. Typical simple count method format (left) with frequency, torque, and speed. Typical rainflow method format (right) includes alternating bending factors Y_M.

life factors (as called in ISO) representing the SN-curves of gear materials. Otherwise, the factors to calculate the stress values and the allowable stresses are sometimes significantly different. The calculation of service life under variable load, as prescribed by ISO 6336-6 (Ref. 1), is using the Palmgren Miner rule, which is a widely used linear damage accumulation method. The method is absolutely "neutral," which means, that individual factors of the rating method used, are not involved. Therefore, the combination of the ISO 6336-6 method with an AGMA rating is possible and well suitable.

The alternate bending factor Y_M, as discussed in "Conversion of Rainflow T_{high} and T_{low} result to T_{ISO} and Y_M for ISO or AGMA ratings," is only marginally treated in AGMA, only "Use 70 percent of the sat values for … gears where the teeth are completely reverse loaded on every cycle" is mentioned in AGMA 2001, clause 16.2. As this factor in ISO 6336-3 is based on the Haigh diagram, which is a widely accepted concept in material mechanics, it can be assumed, that the factor is also applicable for AGMA ratings.

Gear rating calculation example

A load spectrum can be treated in a gear software package. Usually, a spectrum is introduced manually bin by bin or may be read in from an Excel file. If the spectrum is generated from a time series some additional inputs are needed (Figure 8).

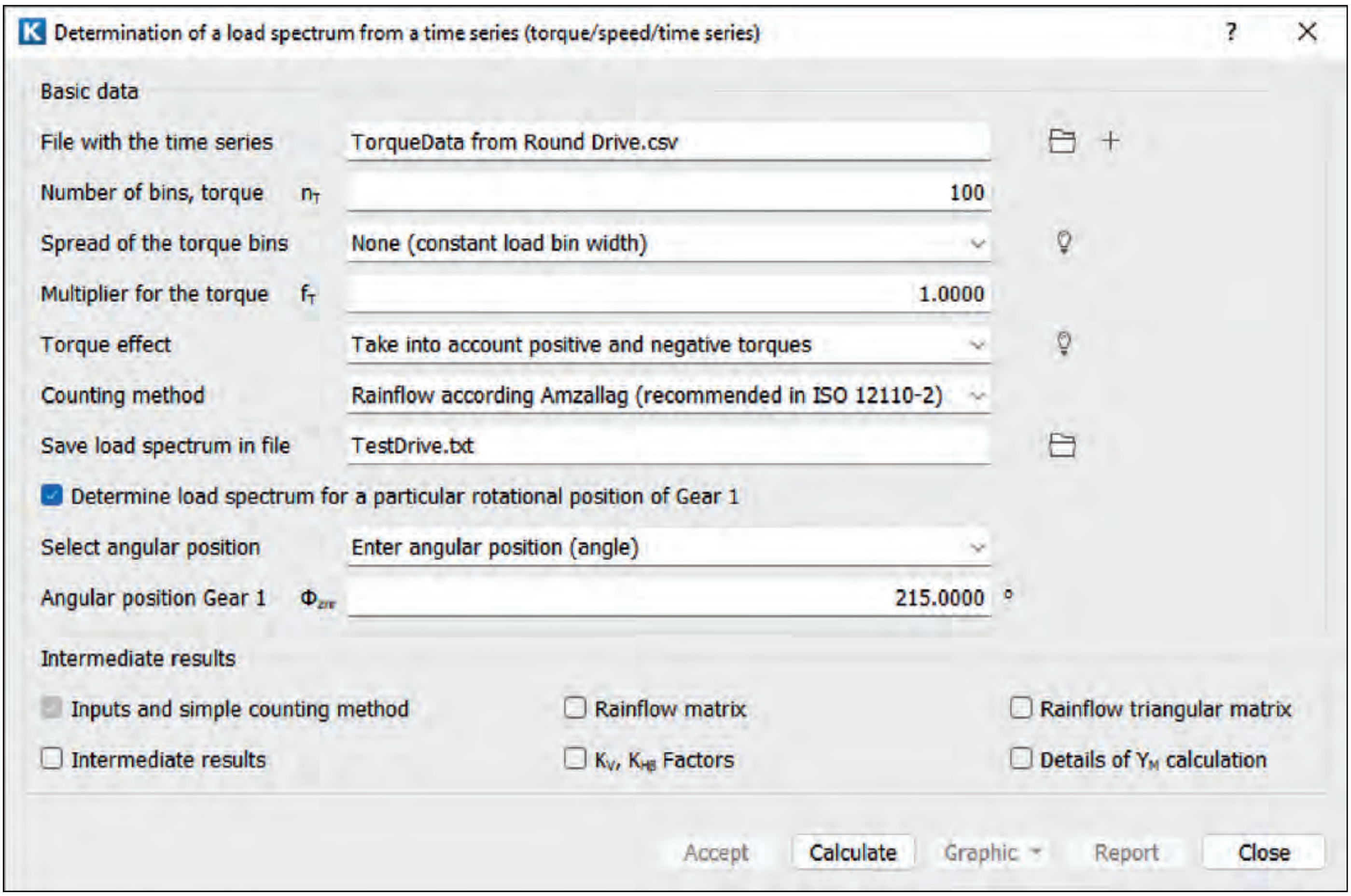
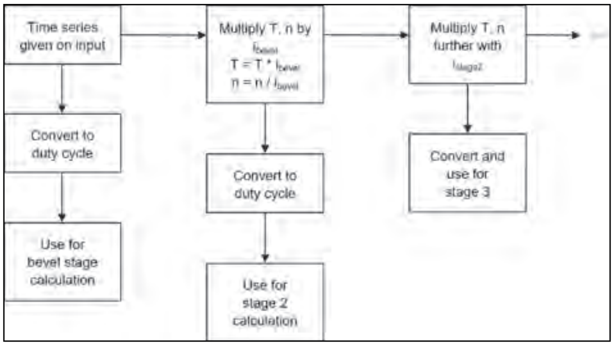


Figure 8—Input window in KISSsoft *(Ref. 7) for a duty cycle determination from a time series.*

	Tooth No. 5 Maximum damage		Tooth No. 1 Mean damage		Tooth No. 17 Minimum damage	
Safety Bending SF1, SF2	1.441	1.455	1.472	1.491	1.525	1.540
Safety Pitting SH1, SH2	1.173	1.277	1.179	1.283	1.189	1.254
Damage bending of gear 1, gear 2 (%)	86.47	78.99	71.63	64.17	49.60	46.36
Damage pitting of gear 1, gear 2 (%)	11.27	3.79	9-23	3.36	9.41	3.17
Lifetime of gear 1, gear 2 (h)	6938	7596	8376	9351	12100	12940

Table 3—Safety, damage, and lifetime, calculated with the time series on different teeth.



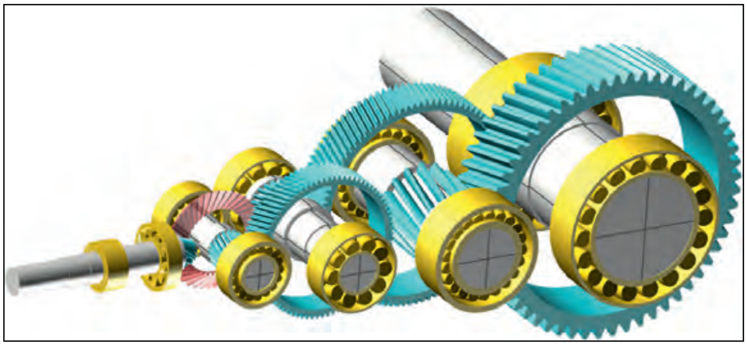


Figure 9—Industrial gearbox in KISSsys *(Ref. 7), flow chart for the load spectrum determination.*

One of the interesting results is the dependency of the considered tooth. As the torque in the time series in Figure 3 is strongly varying, the extract of the load on a particular tooth (Figure 1) gives different safety or lifetime results, see Table 3. But in this example, the duration of the time series is only 190 seconds (short test run). The test run will be repeated several times, the tooth in contact, when starting, will always be different—so the tooth getting the biggest damage will change. Therefore, it is a better practice to consider the results on a tooth having mean damage.

Application of time series in drive train calculations

Today the analysis of drive trains is performed with appropriate software as *KISSsys* (Ref. 7), which models the complete drive with all the main elements such as gears, shafts, and bearings. Normally the time series is given for the input or the output coupling. A load spectrum can be defined at this position and being used all over the drive system. A problem arises when time series with positive and negative torques are used. Then, because of the different frequency of alternating load changes, for every gear stage, an appropriate load spectrum must be used (Figure 9).

To motivate this statement, suppose that a tooth on the pinion of the input stage is submitted during 60 rotations to a positive torque, then for additional 60 rotations to a negative torque, and so on. If the input stage reduction is i = 4.0, then the pinion of Stage 2 will rotate four times lower; therefore, getting a torque change after 15 rotations. So, the frequency of alternate bending cycles is four times higher on Stage 2, and so on for the next stages.

Conclusion

AGMA and ISO gear ratings can be executed with load spectra (duty cycles)—based on Miner's rule—as explained in ISO 6336-6 (Ref. 1). Load spectra may be defined by different methods. In this paper, the ability to generate a duty cycle from a time series (time-torque-speed data) is explained. Such a time series can be obtained by measurements of the operating loads on an application or by computer simulation.

If the torque and speed in such a time series are so, where the same flank is always in contact, a simple-count method can be used to generate the duty cycle. However, if the loaded flank is alternating, the considered tooth root is not only submitted to pulsating tensile stress (bending) but additionally to alternating bending and pulsating compressive stress. As the first step, all the significant torque changes must be extracted from the time series. For this, the rainflow method is used. As the second step, the result of rainflow must be converted into a definition fitting AGMA or ISO gear ratings. This means that for a bin of the load spectrum the nominal torque and the alternate bending factor must be determined.

Finally, the application of the method in gear calculations and in drive train analysis is discussed with an example.

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As a gear expert Dr. Kissling is actively participating in different Work Groups of ISO for the development of international standards.

Tooth Root Load Capacity of Additive Manufactured Gears

Lukas Klee, Dr. Jens Brimmers, Prof. Dr. Thomas Bergs

Introduction and Motivation

Due to near-net shape production, additive-manufactured (AM) gears have a high potential to decrease costs and increase resource efficiency. The decreasing product life cycles as well as the increasing individualization of components demand high flexibility in manufacturing processes (Ref 4). The production of powder metal (PM) gears by die pressing is only economical for large batch sizes or in series production due to the plant technology (Ref. 3). An advantage of PM produced gears is the component density that can be adjusted through the sintering process compared to conventional machining. The porosity is accompanied by a reduction in weight and possible optimization of the noise vibration harshness (NVH) behavior of the gears. Due to the expected future shift of the automotive industry from combustion engines to electrified powertrains, the optimization of the noise behavior of transmission components is becoming increasingly important (Ref. 25). Compared to conventional subtractive manufacturing processes, the required tool operations are reduced, and resource efficiency is increased. Both, binder jetting (BJT) and laser powder bed fusion (LPBF) are generative manufacturing processes that can provide a solution to the conflicting aims of near-net-shape economic production and adjustable density in the component for small batch sizes in gear manufacturing (Ref. 3). For small batches, both additive manufacturing technologies offer an approach to manufacture gears that meet the requirements in terms of quality, strength, acoustics, and economy.

This report analyzes the tooth root load capacity of BJT gears made of stainless steel 17-4PH (X5CrN-CuNb16-4) and LPBF gears using the case hardening steel 16MnCr5. The BJT gears have a specific density of $\rho_{0,rel} \approx 98$ percent and the LPBF gears of $\rho_{0,rel} \approx 99.9$ percent. The fatigue strength of the BJT gears is determined in screening tests and classified by comparison with the tooth root load capacity results of gears made of 316L (stainless steel, X2CrNiMo17 12 2). After the discussion and analysis of the influences of different process parameters during the production of BJT gears made of 17-4PH, the manufacturing process is adapted along the entire process chain.

Process Chain Additive Gear Manufacturing

Additively manufactured products contribute to an increasing individualization and diversity of variants, since, for example, undercuts and functional elements can be integrated directly into the component. These can only be integrated into the design using additive manufacturing processes due to the additional degrees of freedom. The achievable geometric complexity in the design offers new possibilities for use and optimization. The conventional production of components is limited in complexity and functional integration. The following chapter gives an overview of the powder bedbased AM processes of BJT and LPBF in gear technology, that can be used for metal processing.

Binder Jetting

Binder Jetting of gears is a multistage additive manufacturing process. The possible process steps of BJT are shown in Figure 1. In

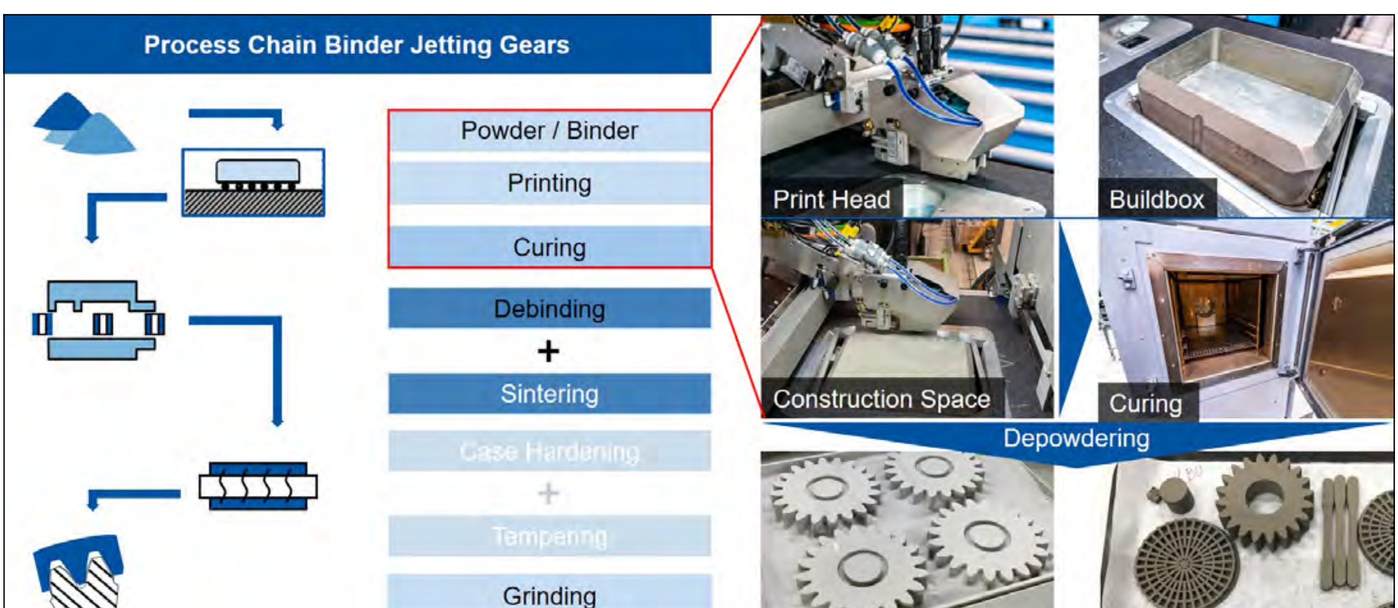

Figure 1—Process chain of binder jetting gears.

addition, images of the used Binder Jetting machine DM P2500 from Digital Metal AB are shown. The BJT process produces green compacts of gears which are sintered by secondary heat treatment processes. Both the powder mixture and the binder are prepared according to the defined recipe. Then the printing—the layer-by-layer generation of the gear green compact—takes place by applying the liquid organic binder locally to the powder bed and bonding both the powder particles and the existing layers together in this way. The BJT process produces green compacts of gears which are sintered by secondary heat treatment processes. An inert gas atmosphere in the construction space is not necessary. Since no additional heat is generated during the production process, it does not have to be dissipated via specific constructions. After the printing process, the binder is cured. For this purpose, the entire build box is moved into the curing oven with the printed gears and the unused, recyclable powder after printing, see Figure 1 right hand.

Subsequently the gears are removed from the powder bed. Afterwards, the binder is removed from the produced green gears by a thermal treatment. The following sintering and heat treatment process produces the final strength and densifies the green gears by shrinkage. After the heat treatment steps, the gear is transformed into a purely metallic state Ref. 1). During the sintering process, the diffusion of closely spaced powder particles results in compaction to form a compact component (Ref. 2). Due to the layer-by-layer component production, there is a risk of anisotropic properties in the component. The anisotropy influences the stability of the gear. The degree of anisotropy depends on the generation process as well as the orientation of the component in the construction space (Ref. 12). In principle, all sinterable metallic powders can be used for BJT (Ref. 1). The material powder used for additive manufacturing must have good flowability as well as a high filling density (Ref. 2). So far, commercial systems mainly process stainless steels (316L, knife steel 420, 17-4 PH) as well as titanium alloys such as Ti6A14V and copper (Refs. 1, 3, 10, 14). The accuracy that can be achieved in production using BJT depends on the machine and the mounting direction. In the x and y directions, the achievable accuracy depends on the resolution of the print head, and in the z direction on the adjustable layer thickness (Ref. 1). The resolutions of various commercial systems in the x-y level are in the range of 30 μm to approx. 65 μm, layer thicknesses in the interval of D_s = 30 μm to 200 μm (Refs. 1, 14).

Laser Powder Bed Fusion

LPBF of gears is a single-stage additive manufacturing process (Ref. 7). Both the basic geometric shape and the material properties of the final component are produced in a single operation without the use of shaping tools (Refs. 7, 22). The component is generated layer by layer. The process cycle of the LPBF process is shown schematically in Figure 2.

The construction space of the machine consists of the material powder storage container, the inertized construction chamber with lowerable construction platform and protective gas flow as well as a powder distribution unit. Both the storage chamber and the construction chamber have a movable floor. A scanner is installed above the construction space, which guides the laser beam according to the specified component geometry in x and y direction and at a defined speed on the powder bed. The heat application—the selective fusion (diffusion) of the powder particles to form a compact component—is performed by means of the laser beam source immediately after the layer-by-layer powder application in the construction space. The solidification of the molten bath leads to the creation of a further layer of the component (Ref. 11). Support structures must be built in the same process step in order to fix the component in the construction space and to dissipate the temperature peaks from the component (Ref. 12). The removal of the support structures is not to be considered as a separate process step (Ref. 7). After generating a layer of the component, the construction platform is lowered by one layer and the storage container is raised (Ref. 18). Subsequently, a new powder layer (layer thicknesses typically D_s = 30-50 μm) is applied

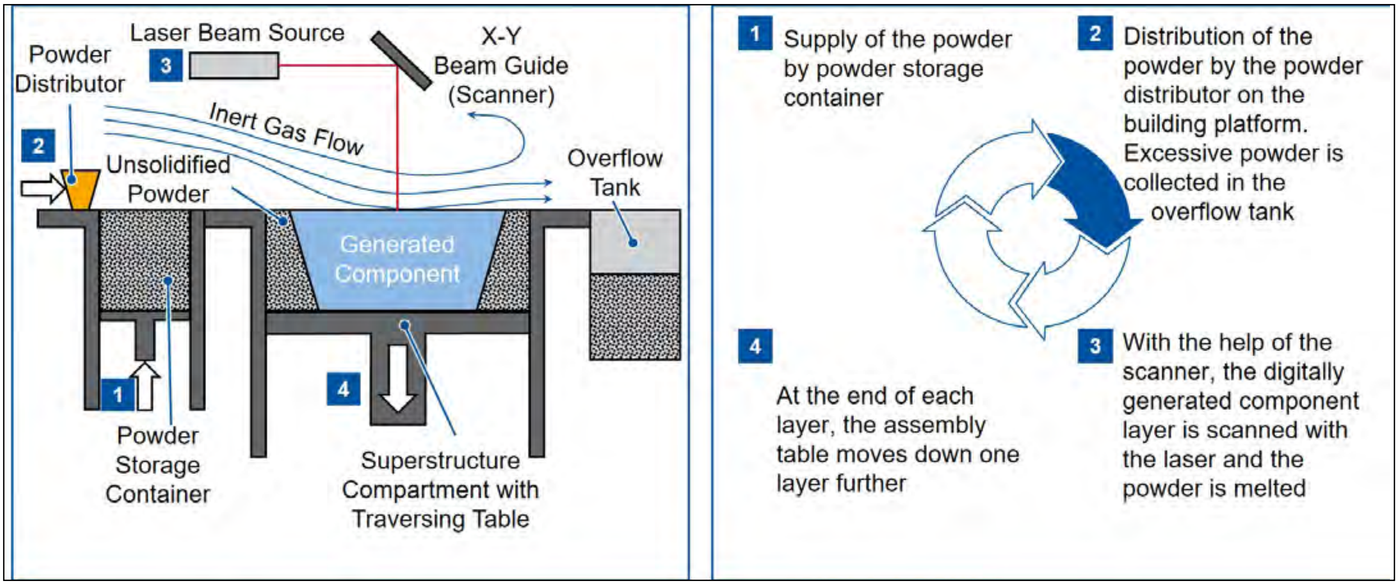

Figure 2—Schematic representation of the LPBF process according to Gebhardt (Ref. 12).

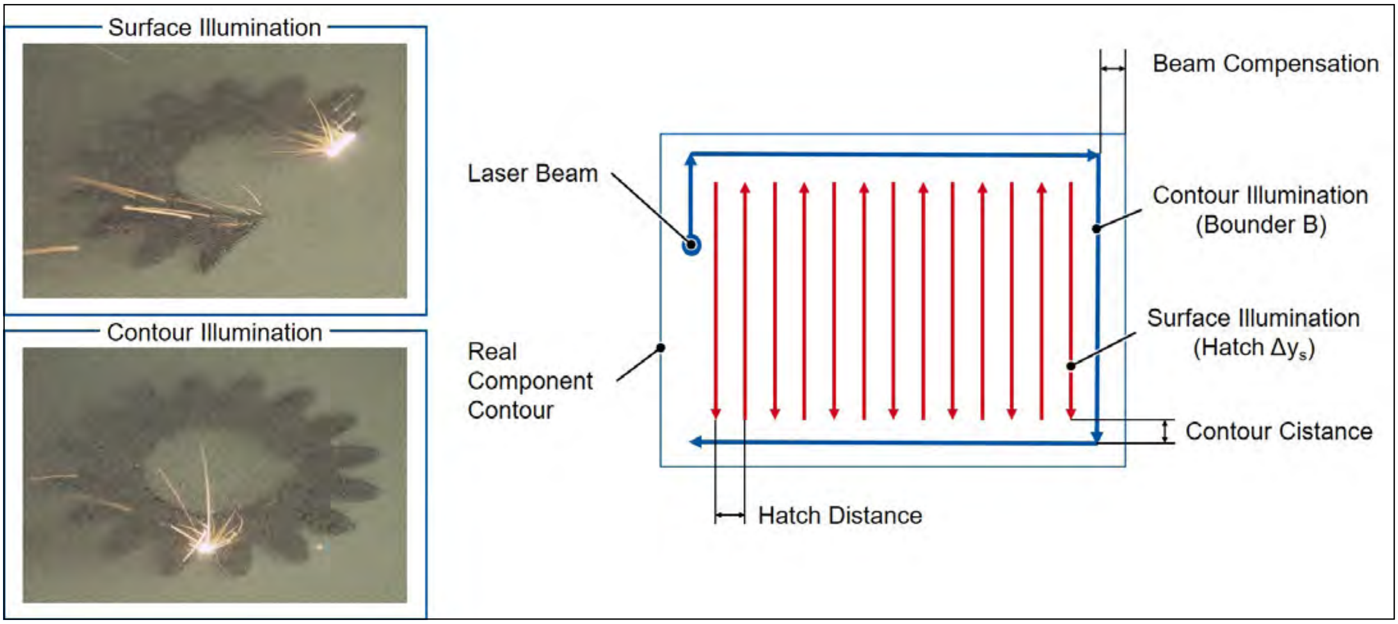

Figure 3—Exposure strategies in the installation space based on Gebhardt (Ref. 12).

evenly in the construction space by means of a leveling system and the generation of the next layer takes place again (Ref. 5). The generation cycle is repeated until the physical metallic component is manufactured. The bulk metal powder unused for the construction process is drained after the process, sieved to remove weld spatter and can be reused for the following component generations (Ref. 22). The high process temperatures can cause the formation of cracks and component distortions as well as the unintentional introduction of stresses into the component. Therefore, when generating each layer, the smallest possible areas should be produced in order to prevent thermal stress and the associated local distortion of the component, the curl effect (Ref. 11). Thus, an adapted process design and control is indispensable. During illumination in the construction space, a distinction is made between the areas of the component's outer contour (contour illumination) and the internal volume area (hatch illumination), see Figure 2 3. As an illustration, two photos were taken during the production of gears with the SLM Solutions SLM 280 HL machine, which show the construction of the internal volume area (hatch illumination) and the sharpening of the component contour (contour illumination), Figure 3 right.

To avoid edge elevation on the outer sides of the component, the inner volume surface (Hatch) should be exposed first before the contour run (Bounder). The resulting edge elevations can cause mechanical contact with the coating mechanism and thus cause an uneven powder application of a subsequent layer (Ref. 21). Both surface and contour illumination can be conducted with separate parameters. Variable illumination parameters are the scanning speed, the laser power and the distances between the individual welding tracks (track distances). LPBF is conducted in a process

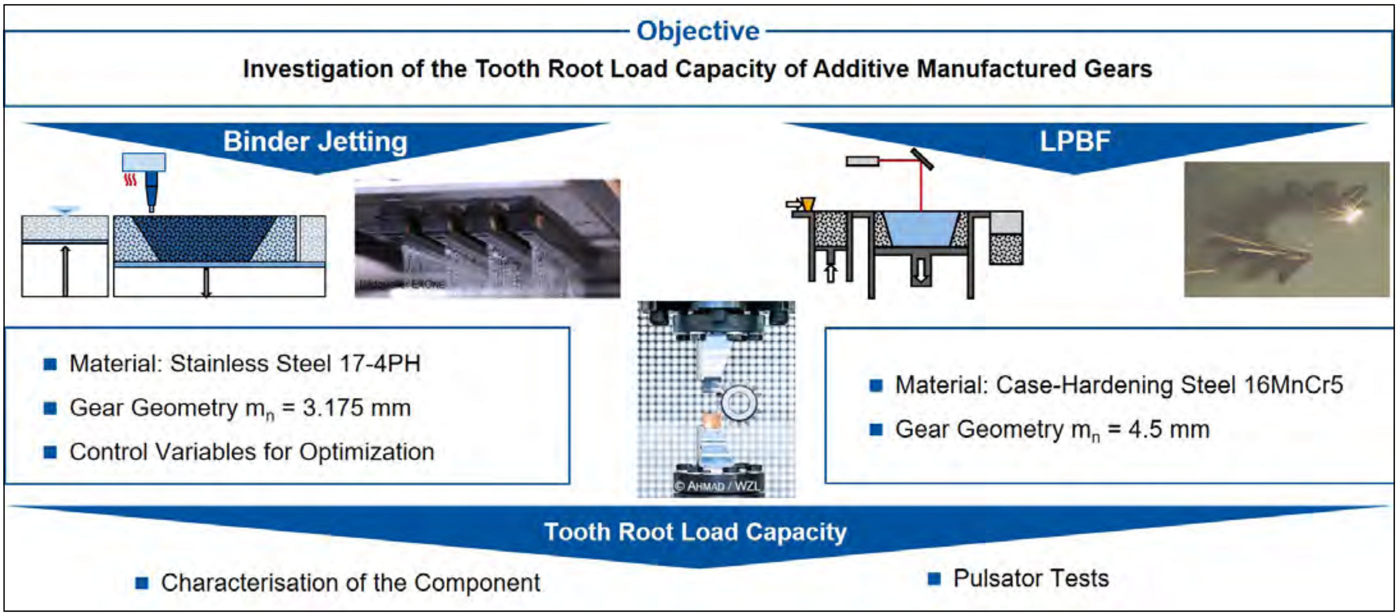

Figure 4—Objective and approach.

chamber through which inert gas (argon, helium or nitrogen) flows in order to avoid oxidation processes and to remove vaporized material from the process chamber. The conditions in the construction space must be kept constant throughout the entire production process.

Objective and Approach

The additive manufacturing processes of BJT and LPBF are intended to enable the production of individualized gears in small batch sizes, through which all requirements with regard to quality, strength, acoustics, and cost-effectiveness can be implemented. The long-term objective is thus to develop a process for the manufacture of highly stressed drive components. More research is still required for this. The objective of this report is to investigate the tooth root load capacity of additively manufactured gears. The BJT and LPBF processes and results are considered independently of each other due to different gear geometry and different material, see Figure 4.

For BJT, the influence of different process variations along the process chain on the tooth root load capacity of BJT gears made of material 17 4PH (stainless steel X5CrNiCuNb16-4) is investigated. The production of various constructive support structures as well as the benefits in the entire process chain are discussed. Various process setting options are explained using the DM P2500 machine from Digital Metal AB. Since an additional heat treatment of the material 17-4PH is not the subject of this work, the gears are ground after sintering, characterized and then examined in screening tests with regard to the tooth root load capacity on the pulsator test rig. The gears produced by LPBF are case-hardened before gear grinding to increase the load capacity. Afterwards, these gears were also ground and examined with regard to tooth root load capacity. The LPBF production process chain and process adjustments are not considered in this report. Only the results on the tooth root load capacity are shown. The BJT gears have a final relative gear density of $\rho_{0,rel} \approx 98$ percent, the LPBF gears of $\rho_{0,rel} \approx 99.9$ percent.

Control Variables for the Optimization of Binder Jetting Gears

The manufacturing process of BJT gears can be optimized by means of various parameters. In the following chapter, process variations of the powder and binder application are described and the resulting component properties are explained. Subsequently, support structures for gear manufacturing by means of BJT are discussed, which are particularly relevant for the subsequent process steps of heat treatment. Finally, adjustments in the process steps after the printing of the gear foundation are presented.

Powder and Binder Application

During the printing process of the gear green compact, the powder and binder application have been detected as the main influencing factors on the final print result. Since the numerous adjustment possibilities both directly influence the printing result and require an adaptation of the following process steps, knowledge of the respective influences is essential in the process design. Basically, all process information regarding the printing strategy is saved in a print recipe to be generated in advance. The most relevant variables for powder application are the layer thickness (D_s) as well as the application direction and speed as a function of the processed material powder. In addition to the amount of applied binder and the application speed, the application strategy is highly relevant for binder application. The print head must always be calibrated before each print run to minimize system-related errors. Before the powder is filled into the printer and can be applied layer by layer, the powder is mixed. The powder in the build box that is not printed during the BJT process will be recycled after a print and is thus available again for the next print. Typically, a powder mixture for printing consists of one-third new and two-thirds recycled material powder. Before the powder from previous printing processes can be recycled, a sieving process is essential to remove adhesions and larger powder particles. Subsequently, the powder particles are mixed and preheated to 80°C, dried, and filled into the powder magazine, which maintains the temperature at 80°C to ensure flowability.

The layer thickness of the gears made of 17-4PH was $D_s = 42$ µm. The influence of the layer thickness on the final geometry of the manufactured gears with a number of teeth $z_2 = 20$, a normal module of $m_{n2} = 3.125$ mm and a normal pressure angle of $\alpha_{n2} = 20°$ is negligible. In the case of helical gears, the occurrence of a stair-step effect resulting from the layered printing is possible. The mechanical properties of the gear are directly influenced by the layer thickness. If the layer thickness is too high, the binder cannot completely penetrate the layer and thus reduce the component stability.

The green part density is significantly influenced by the adjustment of the powder application direction and speed. This is an important parameter with regard to the sintering activity of the green compact. A higher green part density implies a lower shrinkage during sintering. This results in a reduction of the induced stresses and a decrease in crack formation, see "Design Support Structures in Gear Manufacturing." There are two different strategies for applying powder—application in only one direction of motion and application in two directions of motion (outward and backward path above the build box). When applying powder in two directions, a larger quantity of powder is inserted into the powder bed with the same layer thickness and the green part density increases. If the speed is also reduced during powder application, the green part density increases further, but productivity decreases.

In addition to the optimizations in powder application, the part quality can be further increased by adjusting the control variables for binder application. Basically, the binder is applied to the BJT system DM P2500 via two cartridges. The control variables consist of the amount of binder applied to the powder bed and the application speed and strategy. The amount of binder applied can be adjusted by controlling a different number of nozzles (number of pixels) of the respective cartridge. The green part geometry is described in the layer by pixels. Thus, pixels can be eliminated from the binder application based on defined patterns, similar to that of a chessboard.

The image of the drop geometry is shown in chronological order. The spherical drop head is followed by a longer, thin tail

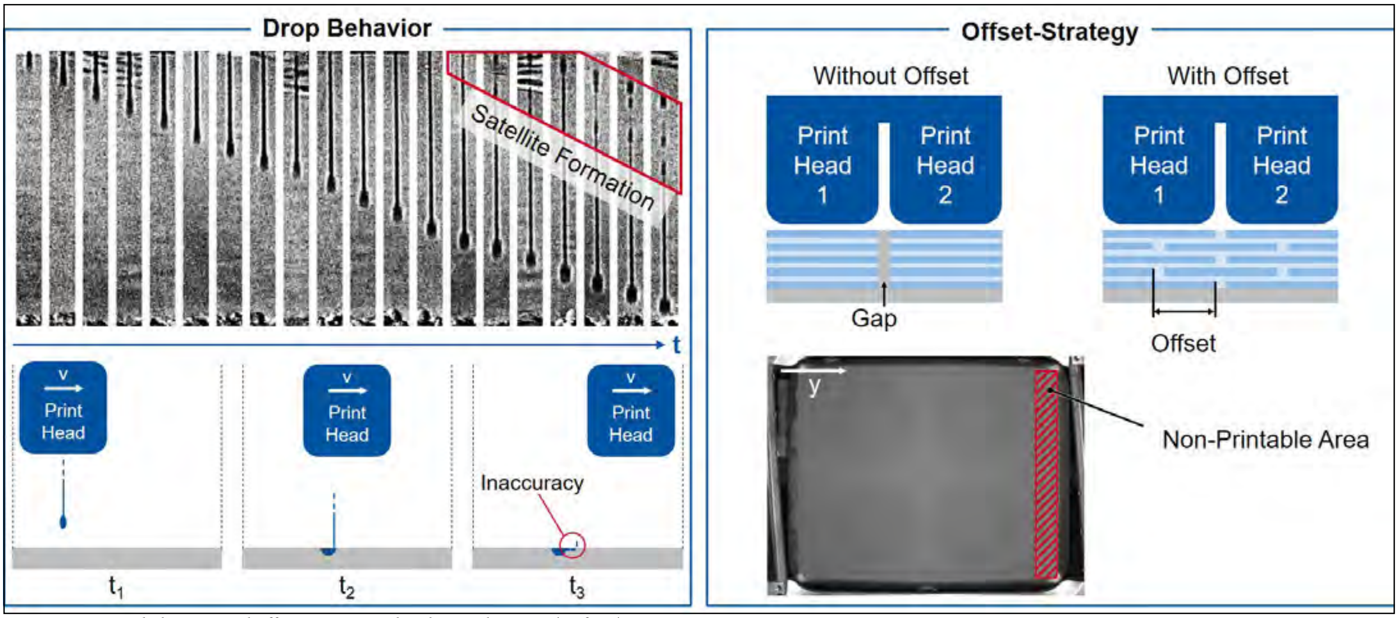

Figure 5—Drop behavior and offset strategy in binder application (Ref. 23).

at the end of which several smaller drops, so-called satellites, are separated from the main drop. Due to the break in the tail, the satellites drift away from the main drop in the direction of movement of the print head. With increasing horizontal print-head speed, the drift also increases, and the geometric inaccuracy rises (Ref. 23). In order to increase the green part density, the offset strategy is applied when printing the green gear. By overlapping the binder application areas, gaps between the individual print lines are avoided due to the intermediate area of both print heads. Since the offset of the print heads takes place in different powder layers, binder application-related weak points in the component are avoided and the binder is evenly distributed in the green part. The offset is compensated vertically to the direction of movement during binder application. The application of the offset strategy minimizes the print area in the build box due to the risk of component breakage in this area. Furthermore, the starting point of the print head's movement is varied at regular intervals when printing the gears in order to optimize the binder distribution over the entire component height.

Design Support Structures in Gear Manufacturing

Structural support structures during BJT of gears correspond to small components that are additionally produced with the gear in a printing process. These elements primarily provide support during the post-treatment processes of hardening the binder, known as curing, and sintering. Especially during the two process steps mentioned above, stresses are caused which are reduced by the use of support structures. During curing, the buildbox with the printed gears and the unused, recyclable powder is heated from ambient temperature to the curing temperature T_C = 200°C over a defined period of time (t_R) immediately after printing. Afterwards the gears remain in the oven at the temperature (T_C) for a calculated holding time (t_H). The process times in the oven can be calculated by the amount of binder used during printing and the number of layers. Thus, the times are varying for each print. When simultaneously printing four gears made of material 17-4PH, the ramp time is approximately t_R = 9 hours and the holding time at T_C is approximately t_H = 6 hours. The stresses during curing are caused by the static and dynamic interactions of the powder. While the dry pure powder has static characteristics, the printed green compacts have dynamic properties due to the wetting of the powder with the binder. The evaporation of moisture in the green compact causes it to shrink slightly. This results in an increasing pressure of the powder on the bore of the gear, which counteracts the dynamic behavior of the green part. In this manner, stresses can potentially be introduced into the component, which can lead to the formation and propagation of cracks in the green part of the gear. Due to the constructive insertion of a cylindrical green compact in the gear bore, the critical transition area between the statically behaving powder and the dynamic component green compact is reduced and the risk of crack formation during curing is minimized, compare left in Figure 6.

The cylinder height corresponds to the tooth width (b_2), the diameter is slightly smaller than the bore diameter (d_i) of the gear. This ensures the separation of both elements after curing. The visible gap formation in the outer area of the gear is negligible, as it has no effect on the component and thus to the component quality. After the curing process, the printed green gears are manually depowdered and inspected for component damage before being forwarded to the debinding and sintering process. As shown in Figure 6, support structures are designed and printed for the sintering process as well. During the sintering process, significantly higher stresses can occur compared to curing due to the shrinkage of the gear caused by diffusion processes. If the green gear is sintered directly on the ceramic plate, the area of contact in the sintering furnace, without a support structure, the frictional force between the ceramic plate and the gear counteracts the sintering shrinkage of the gear despite the use of friction-reducing materials. This can lead to cracks on the face surfaces of the gear. The cracks can completely rupture during debinding and sintering and thus lead to the rejection of the gear. In order to prevent this effect,

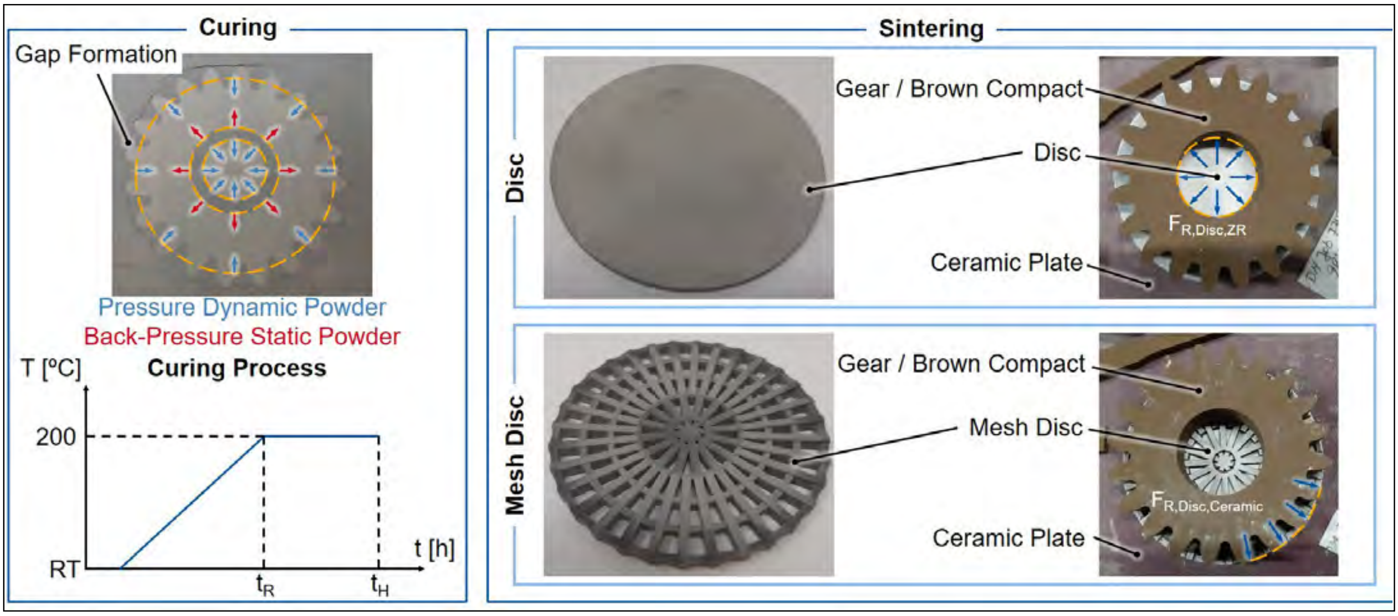

Figure 6—Support structures of the gear for the process steps of curing and sintering.

a disc made of the same material and thus with similar shrinkage properties as the gear was constructed on the one hand and a mesh disc on the other, cf. Figure 6. The disc diameter corresponds to the outer diameter of the gear and the thickness is s = 2 mm. The disc does not have a hole in its center and shrinks almost congruently with the gear, which implies a reduction in the frictional force between the gear and the base. A disadvantage due to the continuous disc design is the lack of free spaces, for example a hole, in the radial direction. Thus, at a certain moment during the sintering process, the disc cannot shrink any further and the sintering distortion of the disc begins. At the same time, the shrinkage of the gear continues due to the significantly higher amount of binder. Furthermore, the high weight of the gear causes additional friction between the disc and the ceramic plate. In the worst case, the disc shrinks unevenly, cracks and no longer performs its function as a support structure. For this reason, the disc has been further developed into a mesh disc by means of constructive adaptation following a failure analysis. The outer diameter also corresponds to that of the gear, but the thickness has been increased to s = 5 mm. The design adjustments in the structure resulted in radial free spaces, which considerably increase the deformability in the planar dimension. The contact area is smaller and material no longer counteracts shrinkage. Stress cracks in the gear due to the sintering process are thus avoidable. A further advantage of the mesh disc compared to a disc is on the one hand the increased resource efficiency and on the other hand the possibility of heat dissipation from the gear during the sintering process as well. Convective ambient properties also prevail in the furnace on the bottom side of the gear and the contact surface is smaller.

Post Treatment of Printed Gears

After printing the gears, the applied binder is hardened in the curing process and the gears can be removed from the powder bed, cf. "Design Support Structures in Gear Manufacturing." Subsequently, the debinding and sintering of the gears is performed. Debinding was conducted in a muffle furnace and sintering in a retort furnace. Due to the size of the furnace chamber, four gears could be fed to the debinding and sintering processes simultaneously. Each gear was positioned upon a ceramic plate including the support structure. A zirconium based lubricant was applied between the support disk and the ceramic plate before debinding. This prevents the gears from sticking to the support structure and the ceramic plate after sintering. Due to the fragility of the gear, it is not possible to apply the lubricant after debinding. Two ceramic plates are stacked on top of each other in the furnaces. Since minor temperature variations can occur in a chamber furnace depending on the location, the positioning in the furnace also influences the gear quality. The temperature variations induce stresses into the gears, which already lead to minimal cracks in the component during debinding and are intensified by the downstream sintering process. In addition, the amount of binder to be evaporated during debinding, analogous to the gear print (see "Power and Binder Application"), influences the component quality. A reduced amount of binder decreases the pressure during evaporation. For gears, which were manufactured with a higher amount of binder than for the final gear print (56.26 percent of the pixels), cracks occurred after debinding depending on the position. The cracks only occurred within the gears positioned at the top. After reducing the amount of binder used in the print and extending the heating ramp (analogous to curing) to approximately T_D = 350°C holding temperature, no more component cracks were detected. Further process adjustments of the debinding were not necessary.

During sintering, the required density of the gear is adjusted by the maximum sintering temperature at a constant sintering time. The sintering process is divided into three phases: heating to the final sintering temperature using various holding ramps, holding at the sintering temperature (T_S) and defined cooling. The target density of $\rho_{0,rel}$ = 98 percent was iteratively approximated in sintering tests with gears. Externally visible

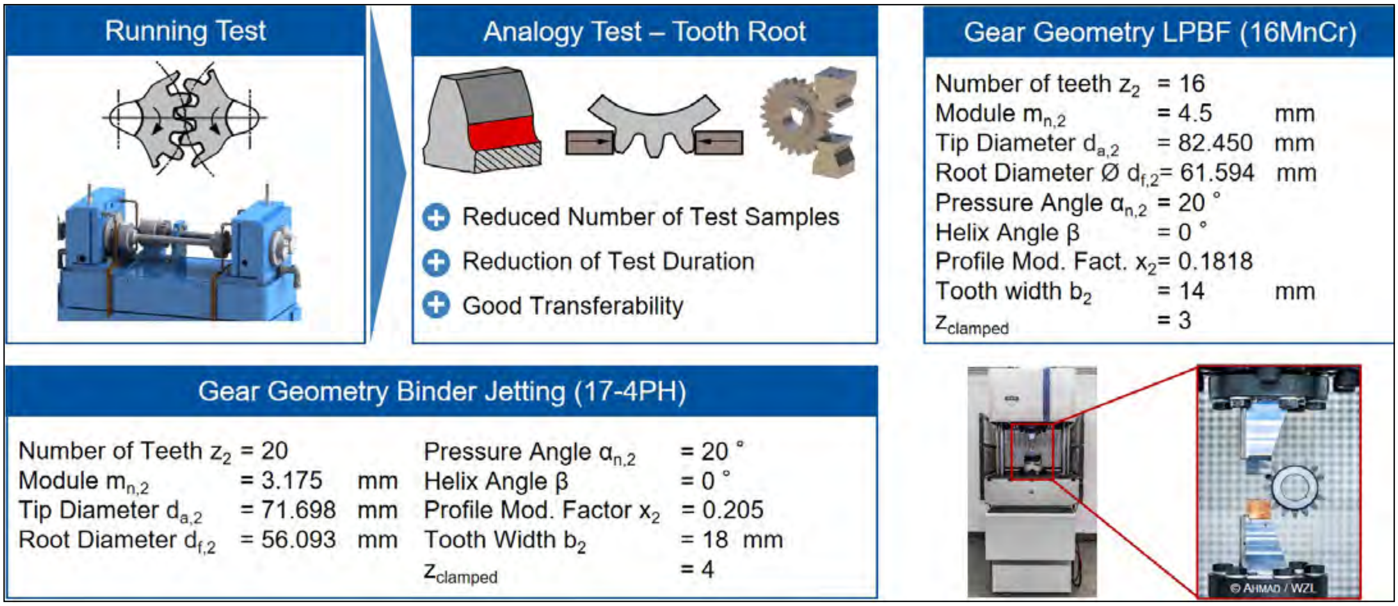

Figure 7—Pulsator test to investigate the tooth root load capacity (Ref. 19).

cracking was avoided by the design of the support structure, cf. "Design and Support Structures in Gear Manufacturing." The respective density was determined by using Archimedean measurements of reference cubes. The maximum sintering temperature of the 17-4PH gears is approximately T_S = 1300 °C. Sintering was performed in a pure hydrogen atmosphere to prevent oxidation of the gears during the process.

Tooth Root Load Capacity of Additive Manufactured Gears

The following chapter describes the results of the tooth root load capacity tests of the additively manufactured BJT and LPBF gears. For this purpose, the fatigue strength of BJT gears made of the material 17-4PH was investigated and classified in the state of the art by comparison with cold rolled gears made of 316L. In addition, the fatigue strength of LPBF gears made of the material 16MnCr5 was determined. Before testing, the gear quality and the surface roughness of the BJT and LPBF gears were measured. Due to different materials and gear geometries, the tooth root load capacity results of both processes are not comparable.

Experimental Design and Description

Gear-critical load types are stresses on the tooth flank due to rolling and bending fatigue in the tooth root (Refs. 13, 20, 24). The experimental investigations of the ground gears with regard to the tooth root load capacity were performed at a pulsator test rig. The pulsator is an analogy test rig which approximates a part of the stress curve occurring in tooth meshing with an alternative concept of load application, Figure 7. According to the definition of the ISO 6336 3 standard, the tensile and compressive stresses σ_Z and σ_D resulting from the mechanical load reach the maximum at the tooth root in the area of the 30° tangent (Ref. 16).

The major advantage of the pulsator test compared to the running test is the possibility of multiple use of a gear. In addition, no counter gear is required. The number of possible test points depends on the contact line to be examined and the number of teeth z_2 of the gear. Both the BJT and the LPBF gear contain four test points. The gear is clamped over several teeth between two plane-parallel pulsator clamps four teeth are clamped at the BJT gear and three teeth are clamped at the LPBF gear. In this way, the tooth normal force from the running test is applied to the gear. One clamp performs a pulsating movement and, in this way, introduces a sine-shaped force curve into the tooth. The other stationary clamp absorbs the applied force. This enables automated control of the pulsator test rig and evaluation of the tooth root load capacity.

Characterization of the Additive Manufactured Gears

Both, the BJT and LPBF gears were profile ground using a Kapp KX 500 Flex gear grinding machine. The Binder Jetting gears made of 174PH were not heat treated, while the LPBF gears made of 16MnCr5 were case hardened before grinding. The gear quality was measured on a Klingelnberg P65 gear measuring machine. Figure 8 shows an example of the results of the gear measurement of the Binder Jetting gears after hard finishing. The results of the LPBF gear measurements are similar, and thus not shown in this report. The measurement was conducted on all available gears in order to achieve the best possible statistical validation of the evaluation. In addition to the profile and helix deviation, the single and accumulated pitch errors f_p as well as the radial runout error F_R were measured. The measured values were evaluated by using a boxplot diagram. All measured values, both of the BJT and LPBF gears, averaged minimum within IT5 according to DIN EN ISO 1328 (Ref. 6).

The surface roughness of the respective tooth profiles of the BJT gears was measured after sintering and grinding using the tactile roughness measuring device Hommel etamic nanoscan 855. The roughness of the LPBF gears was measured after heat treatment and grinding. The evaluation of the roughness

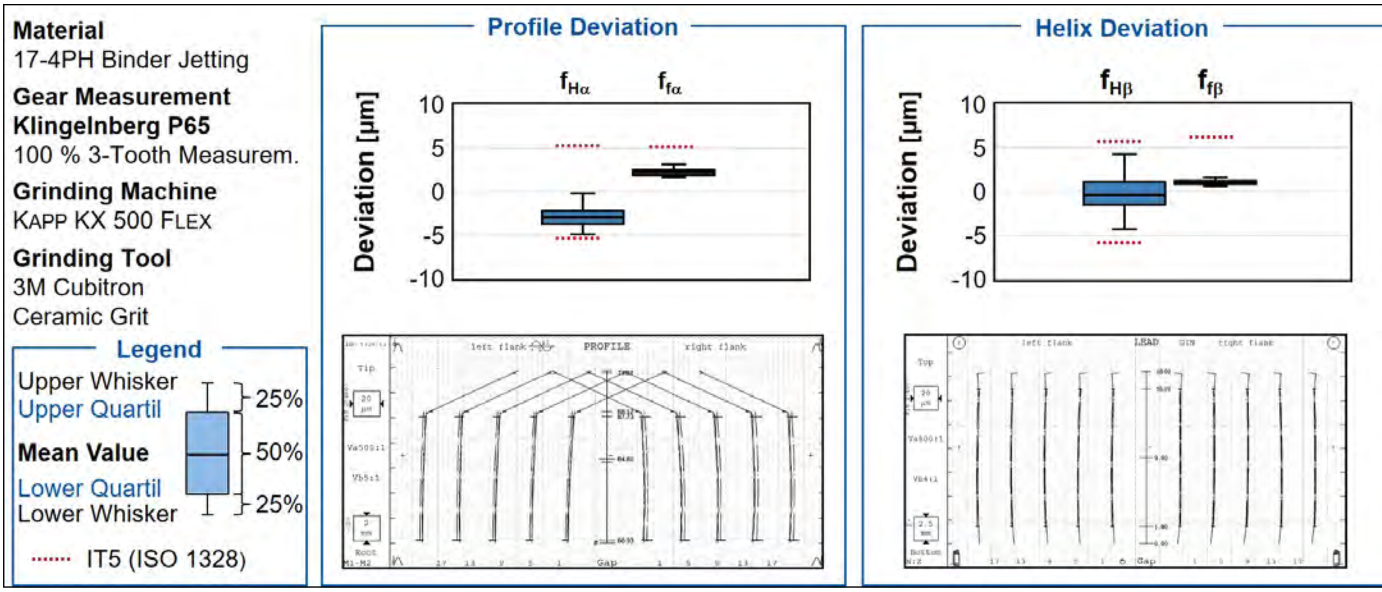

Figure 8—Gear measurements after hard machining of the BJT gears made of 17-4PH.

values and measurement reports was performed in accordance with DIN EN ISO 4288 in the direction of the profile (Ref. 8). In total, eight roughness measurements were performed for each gear. Of four teeth evenly distributed over the circumference, a roughness measurement was taken on both the right and the left flank of the respective tooth. The mean value of all Rz measurements was Rz = 35.8 µm for BJT gears after sintering, and the arithmetic average roughness value Ra = 6.6 µm. Hard finishing achieved a roughness to Rz = 2.3 µm and Ra = 0.3 µm. The mean value of all Rz measurements was Rz = 26.5 µm for LPBF gears after heat treatment, and the arithmetic average roughness value Ra = 4.7 µm. Hard finishing achieved a roughness as well of Rz = 1.47 µm and Ra = 0.2 µm. The roughness of the ground tooth roots of all the gears examined was within this range as well.

Investigation of the Tooth Root Load Capacity of Binder Jetting Gears

In order to describe the tooth root load capacity, 14 tests were performed at the transition to the fatigue strength load range using the stair-step method (Ref. 9). The staircase method was evaluated according to Hück (Ref. 15). The load step of the fatigue strength range of the BJT gears is shown in Figure 9. The fictitious point formed the 15th test point. The load step increase per double amplitude was $\Delta F_A = 1$ kN. The ratio of step jump and standard deviation was calculated according to Hück (Ref. 15). The limiting number of oscillations for the tooth root load capacity is set to $N_G = 3 \cdot 10^6$ load cycles (LC) according to DIN ISO 6336 part 3 (Ref. 16).

This also ensures comparability with the results of other projects and materials. Termination criteria during the

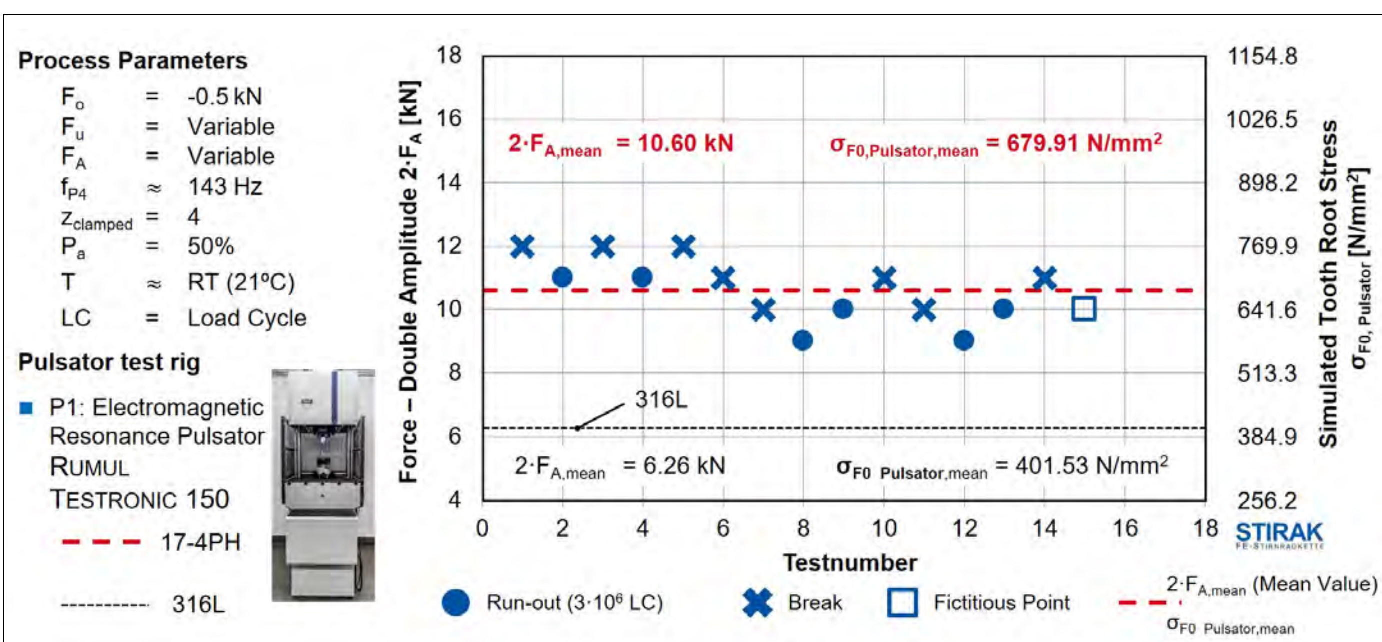

Figure 9—Fatigue limit for BJT gears according to Hück (Ref. 15).

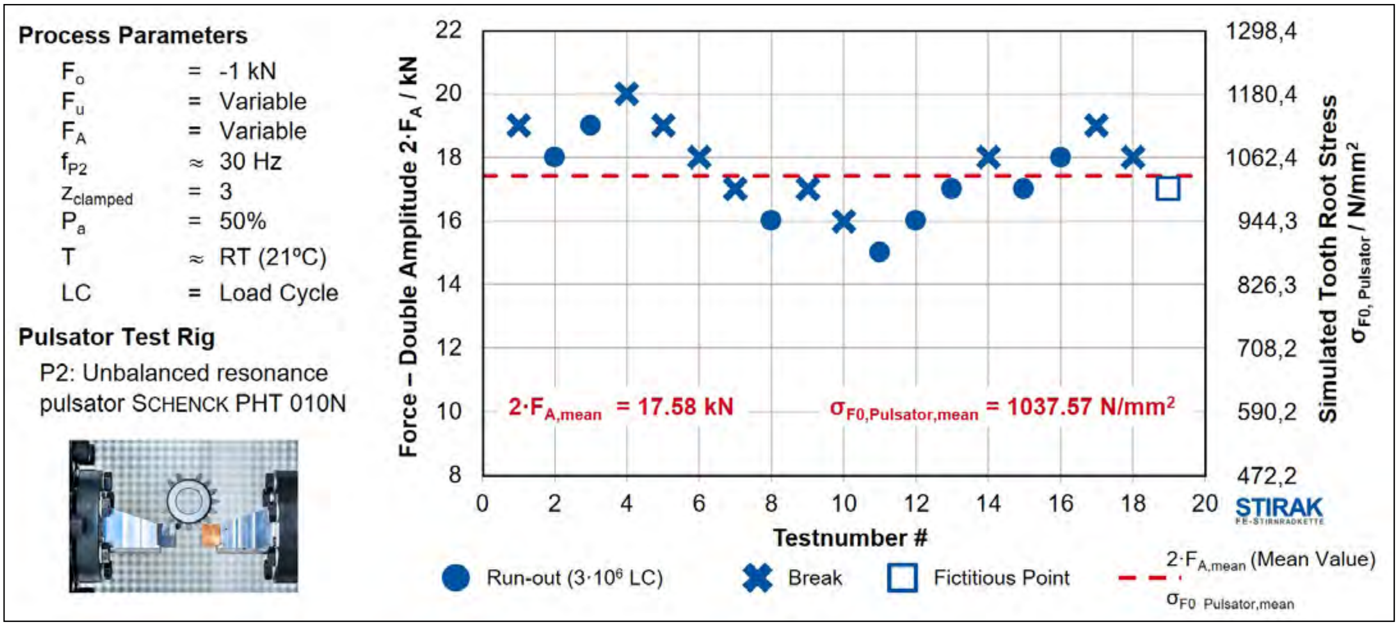

Figure 10—Fatigue limit for LPBF gears according to Hück (Ref. 15).

pulsator test are, on the one hand, reaching the limit number of load cycles and, on the other hand, tooth root fracture (Ref. 19). According to the Hück stair-case method, the following test depends on the previous test result. In the case of a tooth root fracture before reaching the limit number of load cycles N_G, the load or the stress is reduced by one step ($\Delta F_A = 1$ kN) and in the case of a run-out, it is increased by one step (Ref. 15). The y-axis shows on the one hand the force F_A of the double amplitude, which indicates the stress range, and on the other hand the tooth root stress σ_{F0} calculated by Stirak. The tooth root stress describes the local load in the tooth root. The test frequency of the pulsator test rig was $f_{P1} = 143$ Hz. Mean value of the endurable double amplitude (fatigue strength, $N_G = 3{\cdot}10^6$ LC) was $2{\cdot}F_{A,mean} = 10.60$ kN, corresponding to an endurable tooth root stress of $\sigma_{F0} = 679.91$ N/mm^2. The mean value of the double amplitude corresponds to the fatigue strength characteristic value for a failure probability of $P_a = 50$ percent. The standard deviation was $\sigma = 2$ percent. In addition, the average mean value of the double amplitude and the calculated tooth root stress of the fatigue strength tests of gears made of 316L are shown as a reference. Due to the material characteristics and sintering cycles deviating from 17-4PH, these gears were recompacted at a relative core density $\rho_{0,rel,2} \approx 92$ percent by means of external transverse rolling to compact the highly loaded surface zone. For this purpose, the rolling machine Profiroll PR 15HP was used. The average mean value of the endurable double amplitude was $2{\cdot}F_{A,mean} = 6.26$ kN, corresponding to an endurable tooth root stress of $\sigma_{F0} = 401.53$ N/mm^2. The comparison of the load capacity results of not densified gears made of 17-4PH with load capacity results of densified gears made of 316L (stainless steel X2CrNiMo17-12-2) showed an increase of almost 70 percent. Furthermore, no pores were recognizable on the microscopic images of the fracture surfaces. Basically, the crack initiation was causally related to the failure in the tooth root area at the surface of the 30-degree tangent. Within the BJT batch, minor scattering of results and achieved load changes occurred depending on the furnace position during sintering. Gears placed in the rear part of the furnace achieved higher load levels. It was notable that some tooth root fractures only occurred after more than two million load cycles.

Investigation of the Tooth Root Load Capacity of LPBF Gears

The investigation of the tooth root load capacity of the LPBF gears was done similarly to that of the BJT gears, see "Investigation of the Tooth Root Load Capacity of Binder Jetting Gears." 18 tests were performed at the transition to the fatigue strength load range using the staircase method (Ref. 9). The fictitious point formed the 19th test point. As with the BJT gears the load step increase per double amplitude was $\Delta F_A = 1$ kN. The stair step of the fatigue strength range of the BJT gears is shown in Figure10. The test frequency of the pulsator test rig was $f_{P2} = 30$ Hz. The different test frequencies of the pulsators $f_{P1} = 143$ Hz at BJT and $f_{P2} = 30$ Hz at LPBF do not influence the results, as both f_{P1} and f_{P2} are below 200 Hz (Ref. 17). Mean value of the endurable double amplitude (fatigue strength, $N_G = 3{\cdot}10^6$ LC) was $2{\cdot}F_{A,mean} = 17.58$ kN, corresponding to an endurable tooth root stress of $\sigma_{F0} = 1037.57$ N/mm^2. The mean value of the double amplitude corresponds to the fatigue strength characteristic value for a failure probability of $P_a = 50$ percent. The standard deviation was $\sigma = 2$ percent.

Summary and Outlook

In this report, the potential of gears manufactured by both BJT, using the material 17-4PH (stainless steel X5CrNiCuNb16-4), and LPBF, using the case hardened steel 16MnCr5, was analyzed with regard to the tooth root load capacity at a relative density of $\rho_{0,rel} \approx 98$ percent (BJT) and $\rho_{0,rel} \approx 99.9$ percent (LPBF). Since an additional heat treatment of the material 17-4PH was not the purpose of this work, the gears were ground after sintering, characterized and subsequently investigated in screening tests on the pulsator test rig. The manufacturing of various support structures as well as their benefits were discussed. These elements primarily provide support during the post-treatment processes of curing, as well as debinding and sintering and minimize the risk of fracturing. During curing, the stresses are induced by the static and dynamic interactions of the powder. The process stability of debinding and sintering was significantly increased by the use of a mesh disk between the gear and the ceramic sintering base. Effects of the sintering furnace on the printing result, especially if a retort furnace is used, also have to be considered. During the printing process of the green part, the powder and binder application have been identified as the main influencing factors on the final print result. In addition to the amount of binder applied and the application speed, the application strategy is highly relevant. The green part density is significantly influenced by the setting of the powder application direction and speed. The reduction of the binder amount shortens the process times and decreases the risk of cracking. The production parameters of LPBF gears were not considered in detail in this report.

The quality of the gears was measured after grinding using a gear measuring machine. All measured values averaged within quality class IT5 according to DIN EN ISO 1328 (Ref. 6). Mean value of the endurable double amplitude (fatigue strength, $N_G = 3 \cdot 10^6$ LC) of the BJT gears was $2 \cdot F_{A,mean} = 10.60$ kN, corresponding to an endurable tooth root stress of $\sigma_{F0} = 679.91$ N/mm². The comparison with load capacity results of densified gears made of 316L (stainless steel X2CrNiMo17-12-2) showed an increase of almost 70 percent. Within the BJT batch, minor scattering of results and achieved load changes occurred depending on the furnace position during sintering. Gears placed in the rear part of the furnace achieved higher load levels. The mean value of the endurable double amplitude (fatigue strength, $N_G = 3 \cdot 10^6$ LC) of the LPBF gears was $2 \cdot F_{A,mean} = 17.58$ kN, corresponding to an endurable tooth root stress of $\sigma_{F0} = 1037.57$ N/mm². Due to different materials and gear geometries, the tooth root load capacity results of both processes are not comparable.

The long-term objective is to reduce and optimize support structures in Binder Jetting gear manufacturing. The influences of the position dependency during sintering in the retort furnace on the load capacity of each individual gear can be reduced to a minimum by using a continuous furnace. In short term, comparable investigations with regard to creep strength and fatigue strength has to be repeated in a continuous furnace in order to be able to provide a well-founded statement about the tooth root load capacity of BJT gears made of 17-4PH. Furthermore, an additional heat treatment shall be tested in order to further increase the tooth root load capacity. The influence of variable binder moistening and different layer thicknesses on the mechanical properties will be investigated on bending and compressive specimens. Furthermore, the development and certification of further materials, especially common gear steels such as 16MnCr5, is planned for the BJT. These can already be processed with the LPBF. The aim of the LPBF developments is to significantly increase process quality and stability by using process monitoring methods.

Acknowledgement

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Mr. Lukas Klee concluded his bachelor's degree in mechanical engineering at the FH Aachen in 2016 with a focus on energy technology. In parallel, he completed an apprenticeship as an industrial mechanic, which he finished in 2015. Between 2016 and 2018, he successfully conducted his master's degree in the field of production technology at FH Aachen University of Applied Sciences. Since 2018, Mr. Klee is a research assistant at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University in the gear department. There, he is team leader of the gear soft machining group and focuses on the additive manufacturing of gears.

Dr.-Ing. Jens Brimmers is the head of the gear department at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University since June 2019. He graduated from RWTH Aachen University with master's degrees in mechanical engineering and business administration. His Ph.D. thesis focused on beveloid gears and topological tooth flank modifications.

Pro. Dr.-Ing. Thomas Bergs, in his capacity as a member of the board of directors of the Fraunhofer Institute for Production Technology IPT, leads the Process Technology Division and is the Chair of Manufacturing Technology at the Laboratory for Machine Tools and Production Engineering WZL at the RWTH Aachen University. For the main part of his academic qualification, Thomas Bergs studied design engineering at the Rheinisch-Westfälische Technical University, Aachen. He graduated in 1995 having written his diploma thesis at the Engineering Research Center for Net Shape Manufacturing in Columbus, Ohio. In 2001 he went on to earn a doctorate in engineering at the RWTH Aachen University for which he was awarded the Borchers Plaque. He also graduated as an Executive Master of Business Administration in 2011. Thomas Bergs was a research associate in the Process Technology Section at the Fraunhofer Institute for Production Technology IPT in Aachen from 1995 to 2000. In the year 2000, he was appointed Manager of the Laser Engineering Group and of the Business Unit Aachen Tool and Die Making. Since 2001 he has also held the position of Managing Director under Professor Fritz Klocke as institute head. Thomas Bergs has additionally founded the company Aixtooling in 2005, where he became Managing Director until 2018. Core area of the expertise at Aixtooling was tool making for precision glass molding as well as advanced glass optics manufacturing. In 2018 Thomas Bergs was appointed as Professor at the Chair of Manufacturing Technology at the Laboratory for Machine Tools and Production Engineering WZL of the RWTH Aachen University and as Director of the Process Technology Division at the Fraunhofer Institute for Production Technology IPT. As the successor to Professor Fritz Klocke, he is also a member of the Board of Directors of both production engineering institutes. Main focus of his ongoing research activities comply the digital transformation of manufacturing technologies—so called networked adaptive production.

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APPOINTS NICK FALGIATANO AS MARKETING MANAGER, SALES AREA AMERICAS

As of Dec. 1, U.S. Central Regional Sales Manager Nick Falgiatano will be the new marketing manager, Sales Area Americas, for Sandvik Coromant. In his new role, Falgiatano will be accountable for establishing and reaching the strategic objectives of Sales Area Americas.

Falgiatano will also be responsible for ensuring the use of appropriate marketing channels and efficient methods to promote Sandvik Coromant's growth strategy, as well as supporting the sales team by developing and implementing marketing activities. He will be responsible for the Sandvik Coromant Centers in Sales Area Americas, securing certification and maximum utilization for the centers. In addition, Falgiatano will execute launches of new Sandvik Coromant offers, as well as lead a balanced and efficient mix of marketing, communication, and brand activities.

Falgiatano has been with Sandvik Coromant for 10 years as a sales engineer and, most recently, as a regional sales manager based in the Chicago market. He has a bachelor's degree in Business Management and Leadership, as well as a master's degree in Organizational Leadership and Management. Falgiatano has made substantial contributions to the company and the U.S. Central Management team over the years.

"We look forward to welcoming Nick into our Marketing Management team, where he will bring his sales perspective to the role," said Virginie Geoffrion, head of field marketing at Sandvik Coromant. "In this new position, Nick will develop our Sales Area Americas Marketing team with a new, fresh perspective based on his customer knowledge."

Falgiatano will relocate to Mebane, N.C., in 2023 to be based out of the U.S. headquarters. He will report to Virginie Geoffrion, Sandvik Coromant Head of Field Marketing, and will be a member of the Marketing Management team, as well as the Sales Area America Management team.

sandvik.coromant.com

Shell

SIGNS AGREEMENT TO ACQUIRE ECL BUSINESS OF PANOLIN

Wholly-owned subsidiaries of Shell plc ("Shell") in Switzerland, the UK, US and Sweden (Shell (Switzerland) AG, Shell U.K. Limited, Pennzoil-Quaker State Company and Shell Aviation Sweden AB) have entered into agreements to acquire the Environmentally Considerate Lubricants (ECLs) business of the PANOLIN Group.

The transaction includes the PANOLIN brand, ECL product formulations, intellectual property, technical expertise and technology, international customer base and portfolio of products – for hydraulics, gears, universal tractor transmission oils, biodegradable engine oils (HDEO), turbine oils, chainsaw oils and greases for machine lubrication, including leading OEM-approved products.

ECLs are biodegradable lubricants and can help contribute to a more sustainable future, offering greater protection for wildlife and ecosystems in the event that they come into contact with the environment, in comparison to conventional lubricants. They enable customers to reduce the risks of operating in sensitive environments. The global market for ECLs is expected to grow significantly over the coming years.

Following completion of the transaction, Shell will manufacture, distribute and market the PANOLIN portfolio of ECL products alongside its established Shell Naturelle branded products. The acquisition will strengthen Shell's presence in the mining, construction, agriculture, renewable power, hydropower and offshore wind sectors.

Shell expects to fully integrate the business into its global lubricants business within two years after completion, aligning with Shell's Powering Progress strategy to accelerate the transition to a net-zero emissions energy business by 2050.

Machteld de Haan, Global Executive Vice President of Shell Lubricants, said: "We are entering into this strategic acquisition to grow our presence in the global industrial lubricants market, through differentiated, value-added propositions for our customers. Once completed, the acquisition will enable us to complement our existing range of sustainable products in response to increasing customer demand."

All PANOLIN staff who currently support the ECL business in Switzerland, the UK, US and Sweden are expected to join Shell.

Subject to regulatory clearance and the satisfaction of closing conditions, the deal is expected to be completed by early 2023.

shell.com

Parminder Kohli, SVP Shell Lubricants, (left) and Christian Lämmle, PANOLIN (right).

January 19–25—IMTEX 2023

IMTEX is a flagship event for the Indian metal cutting industry. It is South Asia's apex exhibition showcasing the latest trends as well as technological refinements from India and other global players. The event attracts visitors from a wide spectrum of manufacturing and ancillary industries including key decision and policy makers as well as industry captains who are keen to source latest technologies and manufacturing solutions for their product lines. IMTEX is co-located with Tooltech and Digital Manufacturing. Tooltech showcases machine tool accessories, metrology and CAD/CAM cutting tools, tooling systems and trends. Digital Manufacturing offers the latest products in Additive Manufacturing and Industry 4.0.

geartechnology.com/events/5047-imtex-2023

January 23–27—SciTech 2023

Spanning over 70 technical discipline areas, AIAA's conferences provide scientists, engineers, and technologists the opportunity to present and disseminate their work in structured technical paper and poster sessions, learn about new technologies and advances from other presenters, further their professional development, and expand their professional networks that furthers their work. Focus areas include science and technology, aviation, space, propulsion and energy/defense.

geartechnology.com/events/5040-scitech-2023

January 24–26—IPPE 2023

The International Production & Processing Expo (Atlanta) is the world's largest annual poultry, meat, and feed industry event of its kind. A wide range of international decision-makers attend this annual event to network and become informed on the latest technological developments and issues facing the industry. Previous shows featured more than 8,018 international visitors from over 129 countries. Mexico and Latin American/Caribbean countries represent the largest region of international visitors, but there has been continued growth in numbers coming from Europe. Canada represents the largest single country outside the United States with regards to number of attendees.

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February 21–23—PowerGen International

PowerGen is the largest network and business hub for electricity generators and solution providers engaged in power generation. Power producers, utilities, EPCs, consultants, OEMs, and large-scale energy users gather at PowerGen International (Orlando, Florida) to discover new solutions as large, centralized power generation business models evolve into cleaner and more sustainable energy sources. This year-round platform of digital education, current and breaking industry news, thought leadership articles, quality matched meetings, and industry-leading live events provide a hub for power generation professionals to learn and network.

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February 21–23—Houstex 2023

SME's Manufacturing Technology Series in Houston, Texas brings together key decision makers, major tool and technology suppliers and thought leaders from across a broad spectrum of manufacturing disciplines. Hands-on equipment demonstrations, keynotes and panel discussions, emerging manufacturing technology showcases and networking activities offer attendees an opportunity to learn about the latest manufacturing trends. Regional industries include oil and gas, aerospace, automotive, transportation, energy, military, plastics, research and development and more. Houstex is an interactive experience, dedicated to showcasing advanced technologies and processes that help manufacturers innovate and create industry transformation.

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Beers and Gears

Dontyne Entices Trade Show Attendees with In-House Nanobrewery

Matthew Jaster, Senior Editor

Trade show swag. It's everywhere on the show floor—chocolates, plastic toys, T-shirts, free popcorn. As a frequent attendee to manufacturing and engineering events, most industrial professionals would agree we don't need additional fountain pens. If you really want to grab attention at your trade show booth, why not offer beer?

Backlash Brewery, located in Prudhoe in sight of the castle on the hill and close to the River Tyne, is a part of Dontyne Property and Leisure, the third Dontyne company. Dontyne Systems formed in 2006, followed by Dontyne Gears in 2013, were both set up to supply gearbox design software and services to a range of industries. These companies now have more than 200 customers worldwide. The logical next step in the company's evolution from gear design software was obviously beer.

"I noticed on our trips in the UK and internationally, beer seemed to be a ubiquitous business tool," said Mike Fish, director of Backlash Brewery. "Although there are some excellent micro-breweries locally, I felt we would have an additional 'hook' if we could make the beer ourselves. We formed Backlash in 2017 with the idea of funding the brewing from a retainer from the two Dontyne companies and offering the product in 330 ml or 500 ml bottles free at exhibitions and other industry-based events. We have already used the product at exhibitions in Germany and Japan."

In 2021, Dontyne was offered investment to expand the brewery so other companies could use it to promote their products. Dontyne needed to hire an experienced professional to help with the requirements of an increased customer base. Adam Brewer—yes, this is his real name—joined Backlash as head of brewing in January 2022.

"Adam has worked for Tyne Bank Brewery and Blackstorm Brewery so he's familiar with the local industry and has many contacts that have helped us to develop our range and capability. As a result, we offer some other formats such as casks and kegs and are starting a gluten-free range. Brewer has gone on to produce some of his own recipes for lagers and IPAs," Fish said.

Beers include Backlash Lager, Big in Japan (red ale), Proud Hill (blonde ale), Mucky Dog (brown ale), Self-Made Maniac (bitter). Fish believes the brewery should be classed more as a 'nano ' or even 'pico' brewery, but he still wants a profitable model.

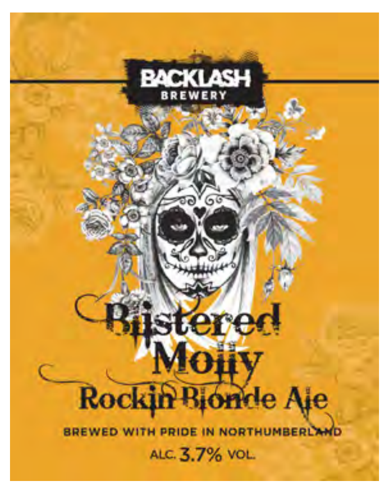
"We are looking to make batches as small as 50L at a time for specific occasions but could work up to 200L a day, if necessary," he added.

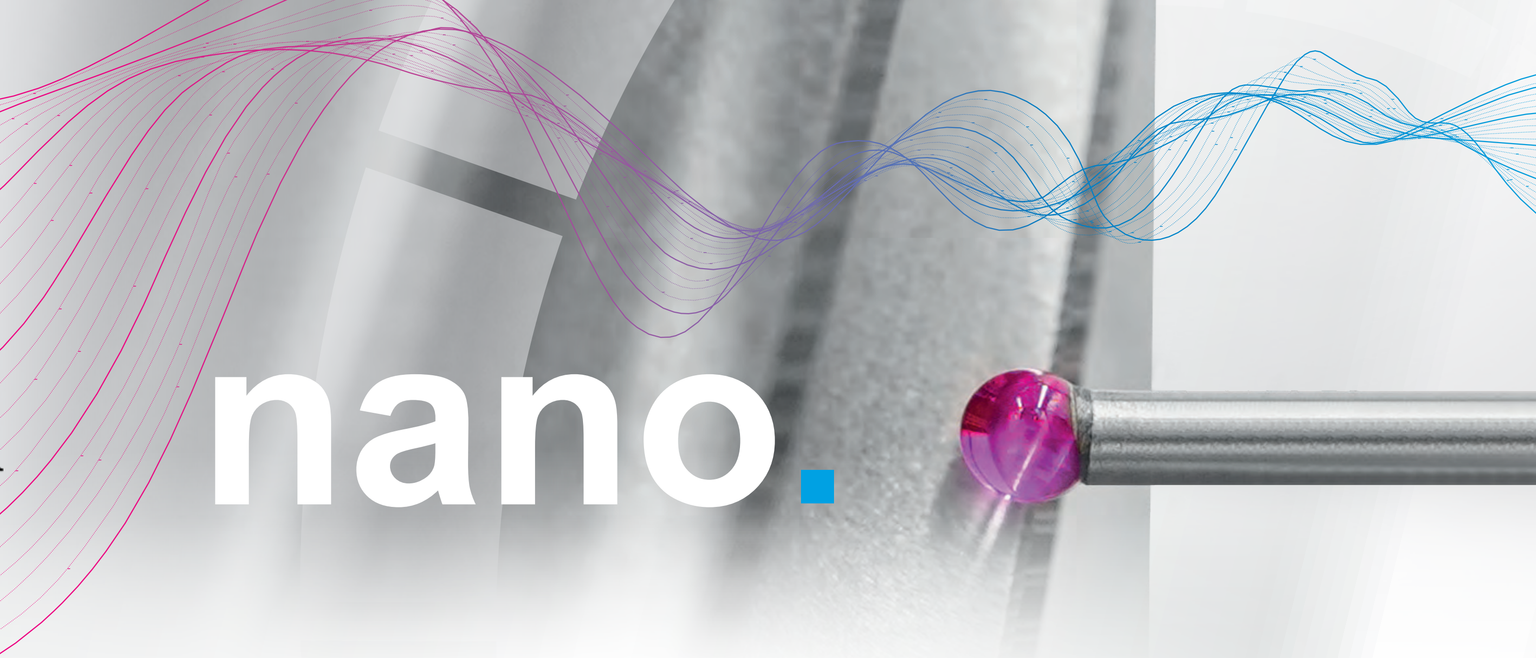
Customers can come to the Backlash site and work on something with Brewer to meet their requirements. Dontyne can also host small groups at their site to offer Brew Days, very popular for team building. "Those opting for brew sessions have often chosen to have a custom label too which we can create and apply before we deliver the finished beer," Fish said.

Backlash was one of the main sponsors of the Tynedale Beer and Cider Festival 2022 this year. The festival site at Corbridge is only a few miles from Backlash and this has helped to promote marketing opportunities and membership locally to the festival goers.

As for IMTS 2022, Backlash Brewery was discussed, but bottles were not brought to the American trade show—something Fish hopes to remedy for the 2024 event.

Contact *backlash@dontynepal.com* for additional information.

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