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GEAR TECHNOLOGY®

MAY 2024

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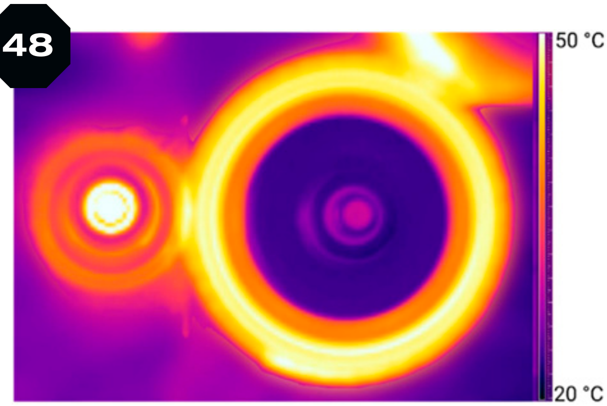

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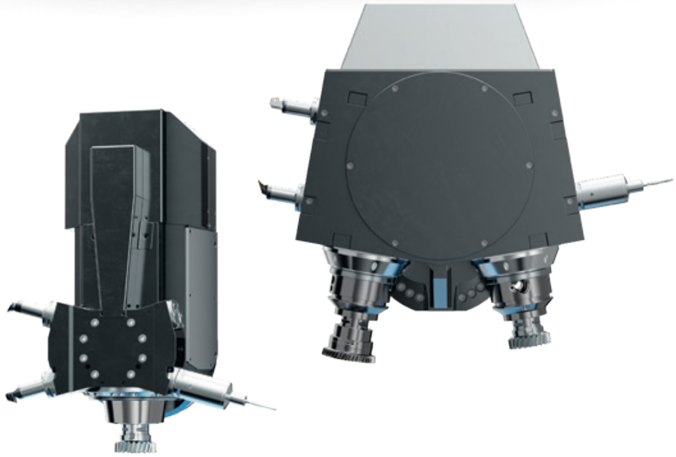

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Vol. 41. No. 3

gear TECHNOLOGY

GT SOCIAL MEDIA

Celebrate 40-Years of *Gear Technology* Online

We look back to the very first editorial from Michael Goldstein, founder and original editor-in-chief, at *Gear Technology*. "New manufacturing methods, materials, and machines were continuously being developed, but the technical information about them was not readily available to those that could best use it. There was no central source for disseminating this knowledge. Thus, the idea for *Gear Technology—The Journal of Gear Manufacturing*, was born."

linkedin.com/pulse/gear-technology-turning-40-agma-media-rs5be/?trackingId=BCBkrt6YEGqYcpObOeHzcA%3D%3D

GT VIDEOS

Klingelnberg Highlights Höfler Cylindrical Gear Roll Testing Machine R 300

The Höfler Cylindrical Gear Roll Testing Machine R 300 is the latest machine development from Klingelnberg in the area of cylindrical gear technology. Designed for all roll testing methods, this compact machine is the ideal solution for anyone who wants to combine inspection cycles and reduce disassembly costs while benefiting from a user-friendly design.

geartechnology.com/media/videos/play/275

AS SEEN IN *PTE*

The Benefits of Bevel Gear Technology

The Danish company FLSmidth wants to be in constant dialogue with their customers in the mining and minerals industry to develop individual and pioneering solutions for better productivity as well as the responsible and efficient use of natural resources. As the drive is the heart of the crusher, the bevel gear is one of its most important components, making gear quality crucial to the design and manufacture of reliable crushers.

powertransmission.com/blogs/1-revolutions/post/9772-the-benefits-of-bevel-gear-technology

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The Hats I've Worn

I joined the staff of *Gear Technology* 30 years ago, as a lowly editorial assistant. I had just moved back to the Chicago area after a brief stint working for a family business in Louisiana. The nice people at Randall Publications offered me an opportunity to put to good use my journalism degree as well as my enthusiasm for math and science.

"You'll be be writing and editing for a world-class magazine," they told me, "conducting interviews with CEOs in a vital industry. You'll be producing content that matters. Oh, and by the way, you'll also be in charge of data entry for our subscriptions department."

Wait, what?

The editors at that time (Peg Short and Nancy Bartels) sat me down and explained that to be successful in a small organization like this one, you have to learn how to wear multiple hats.

Huh, I thought. Maybe the job didn't have quite the glamour of a newsstand title published in New York City or the prestige of working for a major news organization. But I needed the job, and even though I knew nothing about gears or manufacturing, the idea of writing about technology really appealed to me. And the other part didn't bother me, either, because in addition to being a journalist, I've always been kind of a computer nerd.

So I took the job. And I learned to wear multiple hats.

And you know what? Peg and Nancy were right. As the data entry person, I personally saw every subscription that came into our office—which meant I knew better than anyone who the readers of *Gear Technology* were. That knowledge—that connection—has informed my writing ever since. Knowing your audience is key to creating good content, and I felt like I had the inside edge from the very beginning.

In 1996, we launched *geartechnology.com*. In the beginning it wasn't even my project, but my inner nerd couldn't resist it, so I picked up HTML and Perl programming, and before long I'd earned another hat. By the time we launched powertransmission.com in 1997, it really was my project, and I've been the main developer of our websites ever since, adding javascript and php programming to my repertoire along the way. And that early work I did with databases was sure paying off, too.

By this time, I'd moved up to "Associate Editor," and I'd been given the authority to hire an assistant to help with both the data entry and website work, so learning to manage a team became just another part of the journey.

Then in 1998, I became Managing Editor and Associate Publisher, and I had the opportunity to guide not just the editorial vision and the execution of the websites, but also the overall strategy of our business and all its aspects. Including marketing, sales, HR and whatever else came up.

Of course, I was fortunate to have worked all that time alongside Michael Goldstein. As I grew into the role, he always gave me plenty of free rein to manage the business, guide the team and make mistakes, which I appreciated as much as his insight and vision over the years. When he retired at the end of 2019, I was honored to take over as Publisher and Editor-in-Chief and help our team transition to being on the staff of the AGMA.

Today, *Gear Technology* is celebrating its 40th anniversary, and I'm proud to say I've been a big part of who and what *Gear Technology* is for 30 of those years. I'm extremely grateful to my team, whose contributions have honestly been a much bigger part of the success of this publication than mine: Dorothy Fiandaca (33 years of service), Carol Tratar (21 years), Matt Jaster (15 years), Dave Friedman (14 years), Megan Harrold (3 years), Aaron Fagan (2 years) and Jess Oglesby (1.5 years).

I'm also grateful to the gear community at large, including all the readers, advertisers and contributors I've gotten to know so well over the years. I look forward to serving all of you for many years to come as the steward of *Gear Technology*, the Gear Industry's Information Source.

But most of all, I'm grateful for that early advice. If any of you readers are at the early stages of your careers, don't be afraid to take on something new, especially if it's the kind of work nobody else wants to do. You might discover that the unique insights and skillsets you acquire will pay off in ways you didn't expect.

Publisher & Editor-in-Chief
Randy Stott, Vice President Media

How It All Started

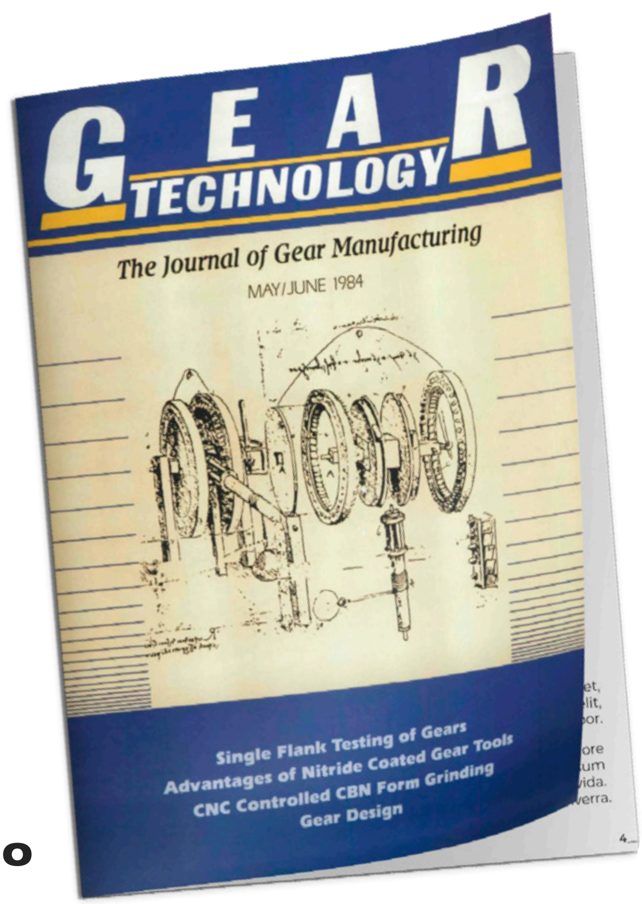
My family company, Cadillac Machinery, was a used machinery dealer specializing gear machinery, especially bevel gear equipment, so we knew first-hand how unique and sometimes insular the gear industry was. As a member of AGMA, I often attended AGMA events, including the Fall Technical Meeting, where tremendous knowledge was presented, year after year, about the latest research, technology and manufacturing approaches for gears.

And there were other technical conferences. Companies would send their top gear engineers to these conferences to learn as much as possible from technical experts around the world. They would hear the presentations and come home with a binder full of technical papers. The engineer would take that binder back to the office, put it up on a shelf, and catch up on all the work that accumulated while he was gone. He knew what was in those binders, but no one else did.

Back in the early 1980s it occurred to me that the information in those binders could benefit far more people if it were more widely disseminated. There were other trade publications at the time, of course—but nothing so highly focused or technically oriented as what the gear industry needed.

The original purpose of the magazine was nothing more than a mission to educate the community. If all we ever did was republish some of those technical papers and share them to a wider audience, we'd be doing a great service to the gear industry.

The idea was met with extreme enthusiasm. My good friend David Goodfellow, then president of American Pfauter, pledged his support on the spot and became our very first advertiser. Other suppliers were equally enthusiastic and eager to join the project, including Klingelnberg, Starcut Sales, Liebherr and Gleason, all of whom advertised in that very first issue, May/June 1984.



Clearly, there was a hunger for this type of information. From the beginning, response from our readers has been enthusiastic and supportive.

Over the years, our content grew beyond technical papers. We added news, back-to-basics, in-depth feature articles and analysis of trends. I'm not sure exactly when it happened, or when we took on the moniker, but we became "The Gear Industry's Information Source." All the while, though, our mission of being the industry's educational resource never changed.

I remember Marty Woodhouse, then sales manager at Star Cutter, telling me he was sitting in the lobby of a gear company in the middle of China, where no one spooke English. He happened to be there when the mail was delivered, and sure enough, there was a copy of *Gear Technology*. He told me then, for sure, that he knew *Gear Technology* could be found wherever gears were manufactured or engineered.

I can't tell you how many engineers have told me they have kept every single issue. In my time at Cadillac Machinery, and later Goldstein Gear Machinery, I had the opportunity to visit many gear plants, and they were often proud to open up a closet or point to the shelf where they kept their personal *Gear Technology* library.

In the old days, nothing was digitized. We printed the magazines using plates and film. So we hired a firm to scan everything. We employed the teenage children of some of our staff members to help us break up those scans into articles and import everything into a database. I remember spending my vacations—not just basking in the sun, but sitting on the beach with my laptop adding keywords to all those articles. Creating that digital library is one of the projects I'm most proud of from my career.

Of course, today that library is available online to anyone who needs it. Every issue and every article from 1984 until today is part of the Michael Goldstein *Gear Technology* Library. My vision of taking that information out of those binders on the shelf and spreading it out to the world has come true, and now the world's greatest collection of gear knowledge is available to anyone with an internet connection.

Gear Technology is unique: started by a gear industry insider, read by gear industry professionals around the world, now published by AGMA, the gear industry's association. Anything else is a poor example of a "wannabe."

Although I retired at the end of 2019, I am very happy to see that the legacy safely continues under the auspices of the AGMA. From what I can see, it looks like *Gear Technology* is in good hands for at least the next 40 years.

Michael Goldstein
Founder, Gear Technology

Escaping the Dark Ages

The inaugural issue of *Gear Technology* marked a significant change in the industry. I was 13 years into my career, working at my third company and in my fifth year on AGMA's Helical Gear Rating Committee. Back then, few engineers moved around; you started at a gear company, were indoctrinated in their way of doing things, and hoped to advance by making very incremental changes to the "old family recipe."

Commercial gear design software was almost unheard of. If you were lucky, your organization had an "expert" who could write a custom program that incorporated the lessons learned in its collective experience. Otherwise, you drew the "short straw" and attempted to create your own code from AGMA standards and whatever reference books that you could round-up. In 1984, "personal computers" were quite primitive. A big upgrade for me was moving from an HP-9810 to an HP-9825S because it had upper- and lower-case text! Both machines relied on "magnetic strip" for memory and those were quite limited in capacity.

The introduction of desktop computers created a demand for well-tested software. For an engineer to use commercial software, they had to break out of the "silo" thinking that caused every organization to think their "recipe" was the best way to design gears. My committee work and job transfers, along with hating to write software, positioned me to be an early adopter. I am forever grateful to my supervisor at Cone Drive in Traverse City, MI, for making me serve as their AGMA representative. In early 1979, I was by far the youngest member of that committee. Upon my "retirement" from committee work in 2016, I was one of the old timers. In many ways, this was like a graduate seminar with some of the greatest minds in the industry.

There is an old saying that 'You don't know what you don't know.' For me personally, my real education as a gear designer began on the Helical Gear Rating Committee. To avoid testing the patience of the sages, I had to find many obscure reference books and study them. This required opening my mind to methods and technology that did not line up with the old family recipe.

When that first issue of *Gear Technology* hit my desk, I devoured it cover to cover. If you were not careful, the magazine tended to disappear. Many offices had a distribution list for a circulating copy. Frequently, the ideas described were hotly debated by traditionalists. Not all the resistance was "commercially" related; American companies were highly invested in through hardened gearing and some early adopters of surface hardened gears were "burned" by a poor understanding of how different the designs had to be.

For example, the early 1980s were a boom time for the oil industry. Any gear shop that could make drill rig or pump jack gearboxes was running flat out. Imported product was viewed with skepticism; "hard gears" theoretically allowed for a massive reduction in size and weight. A typical API-320 pumpjack speed reducer was the size of an office desk; the case hardened "import" was the size of a suitcase. According to the ISO rating methods, they had the same "capacity." Unfortunately, the impact loading inherent with the application did not understand mathematical equivalency and teeth on the smaller drives quickly broke off. As late as 2015, I encountered oil patch veterans who remained uncomfortable with carburized gearing.

As Thomas Aquinas famously posited, things are right or wrong depending upon their circumstances. To understand those circumstances, the analyst must be fully informed. Our litigious society is reluctant to openly discuss failures. *Gear Technology* provided a peer reviewed forum where many of the best engineers published reports on sensitive topics. For many people in the gear world, this was a new experience.

Accredited engineering schools must spend more than a few hours teaching about gears. Until recently, post graduate gear education was confined to a handful of places around the world. The magazine should be credited with changing that when it began reprinting papers from the AGMA Fall Technical meeting and other important international seminars. Space was also allotted to basic gear education, reader questions, and the always enjoyable Addendum page. Who can forget the incredible Leonardo DaVinci sketches on the covers or the thought-provoking publisher notes?

I am proud to have been a contributor to this outstanding publication. It was a huge honor to serve as a volunteer technical editor, columnist, and blogger. Having all four of my FTM papers published resulted in a bit of "impostor syndrome" because of my respect for the giants of our craft who also wrote for the magazine. The online archive's author list is full of incredible people.

That searchable database is a wonderful monument to the founder's vision for a better-informed gear community. AGMA should be recognized for its continued stewardship of Michael Goldstein's vision and its wide offerings of continuing education classes. Between the magazine, the archives, the classes, and the internet, you no longer have an excuse for not knowing what you need to know about gears.

Charles D. Schultz has been a long-time contributor to *Gear Technology* magazine as a technical editor, author, and blogger. "Gear Talk with Chuck" ran from 2014–2021 on the GT website:

geartechnology.com/blogs/1-gear-talk-with-chuck

Charles D. Schultz
Technical Editor, Gear Technology

Liebherr

OFFERS ELECTRIC DRIVE SOLUTIONS FOR CONSTRUCTION MACHINERY

Compact and lightweight—such is the most common requirement for the gearboxes of emission-free, electric drives. With seven basic gearboxes, the LPI series by Liebherr fulfils exactly this need for high power density. With their low weight, reduced installation space and torque ranges from 20,000 Nm to 350,000 Nm, they are ideally suited as drives for crawler and crawler undercarriages. Customized large gearboxes are even available up to the maximum torque of 2,300,000 Nm.

High level of standardization, flexible configuration

"The advantages of electric construction machinery are not limited to cutting harmful greenhouse gases. The considerable reduction in noise, savings in fuel costs and advantages when awarding contracts are the advantages that raise customer interest. We respond to this trend with the standardized LPI gearbox series," explains Frowin Wack, head of development at Liebherr.

Despite its high cost-effectiveness, the LPI series has a wide range of options for flexible customization, depending on application requirements. The gearboxes can be designed with two, three or four stages, and their connections are suitable for all standard electric and hydraulic motors in the market. At the same time, the ratio range extends from 15 to 750, enabling the best possible drive combination of a gearbox and a motor. The brakes, seals and sensors also allow for optimal configuration to match the application.

Fully electric construction machines with Liebherr drives

In addition to Liebherr itself, other construction machinery manufacturers also rely on Liebherr's LPI gearbox solutions in their machines. And there are indeed many reasons for this. These encompass, for example, sustainability aspects, which influence the choice of electric machines for projects taking place near nature conservation areas. Construction companies that take this into account have clear advantages when it comes to awarding contracts. Liebherr-Components has positioned itself as a competent system supplier, offering not only special components, but also a wide standardized portfolio. This is important for subsequent support, spare parts logistics and the associated cost-effectiveness, especially when fast support is required for machines operating worldwide.

According to Frowin Wack, another important aspect is the lower noise emission of electric machines. "Noise means stress, and less noise at a construction site is an important contribution to occupational safety. At the same time, the range of possible operating time increases. Quieter machines can be used early in the morning, late in the evening and sometimes even at night. Especially in urban areas, this can be a selling point regarding quiet construction sites."

The development specialists at Liebherr are convinced that the future will see a variety of drive types, including electro-hydraulic, fully electric, and diesel-electric solutions. Customers require lower maintenance efforts for electric drives, which is a clear cost advantage. Regardless of a drive concept, construction machinery manufacturers are well equipped with Liebherr's LPI gearbox series.

liebherr.com

Horn USA Inc.

EXPANDS TOOL PORTFOLIO FOR GEAR CUTTING

Horn is expanding its tool portfolio for gear cutting to include types for milling PTO shafts. Manufacturers are increasingly focusing on the complete machining of drive shafts. Horn has standardized its own tool range for this purpose, which demonstrates high milling performance. The double-edged carbide insert S274 is used. The program includes tools for PTO shaft sizes 1 3/8" and 1 3/4". The portfolio also includes special milling cutters for restricted shaft clearances. The M274 tool holders are equipped with an internal coolant supply for targeted cooling. The carriers have a diameter of 63 mm (2.48") and 10 teeth.

Tractor attachments such as a mower or loader wagon do not have their own drive. To operate them, the mechanical drive energy of the tractor must be transferred to the attachment. This is done via the power take-off or PTO shaft. This drive, which can usually be switched on and off, is available at a secondary output of the tractor transmission. The energy can be utilized directly via a PTO shaft. A profiled shaft stub, which protrudes from the gearbox, is connected to the PTO shaft of the attachment by means of splined or involute gears. For operation, the user attaches the PTO shaft to the stub shaft in an axial direction. Rotationally symmetrical locks are used to secure the connection, which can be released easily and without tools.

horn-group.com/us/company/about-us

Ceratizit

DELIVERS SOLUTIONS FOR THREAD MILLING, CLAMPING AND QUICK TOOL CHANGES

Ceratizit's solid carbide MonoThread—SGF and MonoThread SFSE Performance Line shank thread milling cutters provide precision and process reliability when they count most. The MonoThread redesign increases the number of cutting edges for faster machining, optimizes core rounding and taper for improved accuracy and uses an advanced coating for higher wear resistance.

The solid carbide MonoThread—SGF and MonoThread—SFSE, with a chamfer facet, prevent material breakage with their axial coolant supply. They are well suited for cutting all standardized thread profiles in asymmetrical, thin-walled or very complex workpieces of virtually any material. Due to its low cutting pressure, Ceratizit's Performance Line thread milling cutters can process components at high speeds and feeds to cut production times. Thread milling reduces process costs by having a single tool that can produce left and right threads in addition to blind and through holes. The new MonoThreadSGF and MonoThreadSFSE can also be reground up to three times to keep tooling costs low.

Ceratizit's new mechanical MNG mini zero-point clamping system is the latest advance for precise machining of small workpieces. A standardized and universal system, the MNG mini can reduce setup times by at least 30 percent or more to maximize machine uptime.

The Ceratizit MNG mini uses weight-optimized consoles, pyramids, and clamping towers with an integrated zero-point clamping system for small clamping devices.

The MNG mini uses a modular design that is available in several different versions that allow towers, consoles, and pyramids to be added as needed. Affording tremendous flexibility, the system can be used for a variety of machining applications, including milling, turning, or grinding, and due to its 2.04 in. (52 mm) clamping bolt spacing, the MNG mini is compatible with systems from other manufacturers.

The time-tested Ceratizit MaxiChange exchangeable head system is known for providing quick tool changes in the processing of low- to medium-volume production of complex parts. Now, the MaxiChange GX adds a grooving function for internal and external machining as well as axial and radial machining to its repertoire.

Being a modular system, the wide range of MaxiChange heads and base holders are compatible with each other and can be used for a variety of applications. For internal and external machining, the MaxiChange GX is available for interfaces up to 1.5 in. in varying groove widths.

To improve tool life and counteract the negative impacts of chip jams and extreme temperatures at the cutting zone during the grooving process, the MaxiChange GX is equipped with an internal coolant supply. MaxiChange GX can also be used in combination with a vibration-damped boring bar for long overhang applications where high-quality surface finish is important.

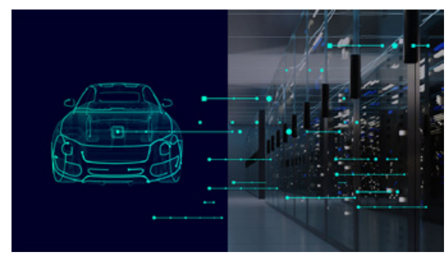
cuttingtools.ceratizit.com

Siemens Digital

EVOLVES TO MEET AUTOMOTIVE SOFTWARE AND HARDWARE DEMANDS

Siemens Digital Industries Software announced it is adding accelerated pre-silicon development in the cloud to its hardware assisted verification product offering with *PAVE360* software for Software Defined Vehicles (SDV). The solution is the first accelerated simulation environment to support the new Arm Cortex-A720AE CPU semiconductor IP, launched in March 2024.

Following the initial announcement of its collaboration with Arm and AWS in late 2023, Siemens is now supporting key Arm ecosystem partners. The integration of select partner enablement solutions to the cloud-based development platform will allow Tier One suppliers and OEMs to develop early software for Arm's new Cortex-A720AE IP, a break from the tradition of waiting for silicon before being able to develop software for the latest semiconductor IP. This empowers automotive software teams to shift-left, by providing extremely fast cloud-based simulation speeds for iterative pre-silicon software development, debug, and validation long before first silicon availability.



"The automotive industry's move to the software defined vehicle means that traditional software and hardware development processes are no longer valid and must evolve to meet the industry's demands," said Mike Ellow, executive vice president, electronic design automation, Siemens Digital Industries Software. "Our partnership with Arm, supporting an accelerated simulation environment with Cortex-A720AE CPU, is helping to address automotive industry challenges by reducing time-to-market for SDV software through the availability of accelerated automotive platforms well ahead of silicon."

By delivering a *PAVE360* cloud-based software development solution on AWS cloud services, developers can experience simulation speeds that rival those of evaluation boards and remove the reliance on conventional slow on-premises modeling and simulation infrastructures. The solution is available to select software ecosystem partners, Tier One suppliers and OEMs, with broad availability planned afterwards.

"The driver experience is being redefined by a surge of software requirements and AI advances, and as vehicle electronics become increasingly complex automakers have to continue to innovate at pace," said Dipti Vachani, senior vice president and general manager, automotive line of business, Arm. "By collaborating on new virtual platforms with industry leaders like Siemens, we're putting our latest Automotive Enhanced technologies into the hands of software developers' way ahead of silicon availability to dramatically accelerate time to market for the industry."

sw.siemens.com

Seco Nanojet Reamers

OPTIMIZE CHIP CONTROL TO ELIMINATE SCRAPPED PARTS

Seco Nanojet Solid Carbide Reamers enhance chip control with an innovative through-coolant outlet for optimal chip evacuation. This design eliminates costly scrapped parts, jamming and edge damage to increase safety, part quality and tool life.

Critical reaming operations require stable, secure, predictable tools. On blind and through bores, Seco Nanojet Solid Carbide Reamers extend the proven performance of Seco Nanofix products with innovative through-coolant outlets that stop chip jamming and enhance application stability. The unique design of these new tools delivers a powerful, precise stream of lubrication directly to the cut zone for optimal chip evacuation and tool life. Along with production stability, shops can rely on Seco Nanojet Solid Carbide Reamers to maintain cutting speeds as well as part quality.

This versatile range of multiflute reamers comes in eight grades and more than 10 geometries, along with custom sizes and tolerances. The tools work with any precision toolholder. They hold tolerances from 10 µm–15 µm (0.0004"–0.0006") and produce surface finishes from Ra 0.2 µm–Ra 1.2 µm (Ra 8 µ"–Ra 50 µ").

Seco inspects each Nanojet Solid Carbide Reamer and documents its measured diameter for consistent performance.

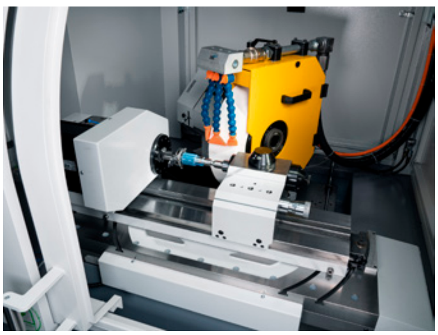
Many industries, including general engineering, automotive and aerospace rely on secure, reliable reaming to avoid costly scrap.

According to Jean-Bernard Hantin, product manager at Seco, manufacturers realize that poorly manufactured or incorrectly specified reamers can jeopardize high-value parts. "Nanojet Solid Carbide Reamers provide cost-efficient performance with much needed quality and stability," he said.

secotools.com

EMAG

OFFERS FLEXIBLE EXTERNAL GRINDING WITH WPG 7 CNC



In many areas of application, it is uneconomical to use oversized universal cylindrical grinding machines for the external machining of smaller components - a lot of floor space is lost and the functionality is not fully utilized. With the new WPG 7 CNC external grinding machine, EMAG Weiss demonstrates another way of grinding workpieces with a maximum length of 250 millimeters. The very small machine requires only a minimal footprint, but at the same time features a whole range of high-tech components for flexibility and productivity. What is important in detail?

If you want to finish small and medium-sized components, you may not need a large grinding machine, is the simple credo of EMAG Weiss regarding the WPG 7 CNC. The purely external cylindrical grinding machine fits on two Euro pallets and can be easily transported to its location by crane as an easy to set up machine. The grinding process can then be started immediately - without compromising on quality or process reliability, as the WPG 7 CNC has negligible heat build-up thanks to its rigid design. In addition, high-precision in-process measurement with proven Marposs technology, which works independently of the cycle time during the machining process, is available as an option.

Straight or angled external grinding wheels are used, which have a maximum diameter of 500 millimeters, and can of course also be profiled depending on the task. Conversely, this means that it is not possible to integrate an internal grinding wheel and there is no B-axis for swiveling the headstock. Instead, the rest of the WPG 7 CNC is a state-of-the-art solution including highly dynamic axes, a powerful and controllable grinding wheel drive and a workhead with stationary or live center (MK4/MK5 or W20/W25). The graphical dialog interface of the control panel is also important for the productivity of the solution. It is based on a Fanuc control system and considerably simplifies the input of technology parameters for certain cycles. The basic version of the control already includes all common grinding cycles.

Finally, many users are interested in the fact that EMAG Weiss offers this solution with automatic or manual loading. Many individual linkages can also be implemented around the machine because the specialists have developed their own linear gantry for the WPG 7 CNC, which is virtually integrated into the housing. It first removes the raw parts from an approximately two-meter-long chain conveyor belt, and then feeds them into the work area from the side at high speed. Once the process is complete, the finished parts are returned to the conveyor belt via a gantry. The whole process is controlled simply by a machine panel. Under these overall conditions, the WPG 7 CNC is an ideal solution for purely external grinding processes on smaller components with a maximum length of 250 millimeters and a maximum weight of 30 kilograms. Thanks to the existing automation solution, medium quantities can also be completed at high speed. Dynamic axes and drives ensure fast grinding processes and the intuitive dialog control ensures uncomplicated changeover processes. Current market successes show that this approach may interest many users since the machine is in frequent demand at EMAG Weiss and has a proven track record.

emag.com

Rego-Fix USA

WILL HIGHLIGHT TOOLHOLDING AND METROLOGY INNOVATIONS AT IMTS 2024

Rego-Fix USA will spotlight two new tool clamping/unclamping units for the company's powRgrip toolholding system and a new spindle drawbar force testing tool at IMTS 2024 in Booth 431822. The new units are the PGA (automatic) 9500 and the powRgrip Single, while the ForceMaster tool is the latest addition to the company's family of metrology products. The automation-ready PGA 9500 provides a simple way to automate the tool setup process when using the popular REGO-FIX powRgrip toolholding system. As such, it allows tools to be set up unmanned and around-the-clock.

For seamless integration, the PGA 9500 easily connects, via a robot, to other equipment as well as to tool storage areas. Its automatic door and easily controllable clamping device make the PGA 9500 well suited for working within existing automation systems. Its space-saving design, safe operation, and the fact that it generates no heat or hazardous fumes make the clamping unit the ideal solution even in limited spaces.

The powRgrip Single, like the other members of the powRgrip family of toolholding systems, is easy to use and provides fast, efficient, and safe operation. In fact, the powRgrip Single is the company's fastest powRgrip clamping device with a cycle time of less than five seconds. It's also smaller in size and manufactured with Swiss precision that ensures strong and stable gripping for longer tool life and cost effectiveness.

While existing powRgrip loading/unloading units accommodate several toolholding collet sizes, the powRgrip Single is designed for one holder size series. This is in direct response to shops requiring the use of only one series of PG holders.

Because of its size, the powRgrip Single requires less room and saves on valuable workbench/worktable space. This also allows the unit to be placed in tight areas close to point of use for added convenience.

To make machine tool spindle drawbar testing, tracking, and documenting easier than ever, especially for shops with a variety of machines, Rego-Fix developed its ForceMaster drawbar tool. It allows shops to quickly measure drawbar pull-force, and the tool adapts to virtually any machine tool spindle.

More than a dozen available adapters thread on to the tool to measure all popular spindle tapers, including HSK, SK, BT, CAT, and others. This flexibility makes the ForceMaster a universal metrology tool for the shop floor. With one rugged, robust measuring tool, operators can ensure spindle clamping force meets manufacturer recommendations to mitigate chatter, tool, and drawbar damage, while minimizing the risk of crashed spindles.

ForceMaster also integrates into digital production environments and is fully accessible via a mobile phone app available for Apple and Android devices. The device dashboard can be mirrored to perform measurements remotely, and all information is downloadable for analysis and tracking.

rego-usa.com

Anatomy of a Rebuild

Bringing older gear machines back to life

Tony Johnson, Director, Sales and Marketing,
Machine Tool Builders, Inc.

From the outside, Gallmar Industries, nestled into an Oshkosh, WI, neighborhood, looks like any unassuming, medium-sized gear shop. Then take a plant tour with Gallmar's VP of Operations Kenan Zolota—and prepare to be amazed. The facility stretches on like the Army's warehouse at the end of *Raiders of the Lost Ark*, with everything from gear cutting to heat treat, gear grinding to inspection, all under one roof. Gallmar's breadth of product line is in evidence too: defense-related transmission gears, 60-in. diameter internal gears for mining equipment, axle components for fire/rescue trucks five feet in length, right down to a bin of brass ammunition casings that Zolota says are a special order.

"Because lives are at stake!" Zolota exclaims when asked why his company has made the investment to control every process and eliminate outsourcing wherever possible. "Failure is not an option for the types of products we produce, and the vehicles they go into, whether an armored MRAP or rescue truck. We don't shy away from complex, demanding work; outsourcing adds an element of unacceptable risk. The buck stops here."

Machine Tool Builders' complete rebuild of a circa 1990s Pfauter P400G Form Grinding Machine adds years to its useful, productive life at Gallmar Industries.

New Life for an Old Grinder

Perhaps most amazing of all at Gallmar is the machine that Zolota says is one of his most important, and productive: a Pfauter P400G CNC Form Grinding Machine built sometime in the 1990s. If you're skeptical that a roughly 30-year-old grinding machine with outdated CNC could live up to the quality and AGMA 15 accuracy requirements demanded of the hard finishing, high-precision work that Gallmar specializes in, you'd be right. Zolota bought the machine just a few years ago in "like-new" condition from Machine Tool Builders (MTB), specialists in rebuilding, retooling, and recontroling gear machines of all makes and models. "We saved many thousands of dollars by buying this machine, and months on delivery," recalls Zolota. "The machine came with an extended warranty too, not unlike what you would expect for a new machine. Most importantly, MTB is there for us at the drop of a hat, whether for service, spare parts, or help with parts programming, just as if this was a new machine direct from the OEM."

The P400G's journey from *obsolete to awesome* started on the shop floors of MTB, where founder Ken Flowers and his team of technicians view each rebuild as an opportunity that's akin to restoring a classic Corvette. "If the framework, the 'iron' is sound then the restoration can proceed in similar fashion," Flowers explains. "Nothing is left untouched, every active component, including CNC, is upgraded, every mechanical piece meticulously inspected then repaired or replaced."

The MTB rebuild methodology has been refined for almost 30 years and hundreds of gear machines of all types, makes, and sizes. While no two machines are exactly alike, MTB's gear machine rebuild process has been efficient and effective in the industry—and unfolds for every gear production machine (whether hobber, shaper, or grinder) in similar steps in less than a year, once the machine is on MTB's shop floor:

1. Cleaning

The machine is completely disassembled, and each piece is thoroughly cleaned, either by hand-scraping (or -grinding) or by blast-freezing with CO_2 and blowing off the frozen oil, sludge, and debris. This process ensures a totally clean, dry surface. Meanwhile, engineering is already at work, designing the mechanical and control features, utilizing 3D modeling software.

2. General Mechanical

All way surfaces are refinished, either by hand scraping or grinding. Turcite material on the slide underside is used to restore proper alignment with the drive shaft and screw, plus to provide a low-friction slide.

3. Head and Spindle

The head and components are thoroughly cleaned and inspected, and the spindle, outboard, and internal bearings are replaced, along with seals and gaskets. Geometric alignments of spindle(s), axes, outboard bearings, and tooling are performed to ensure true square precision performance.

Recontrol to latest Siemens CNC, and MTB's new* Form Grinding Conversational Software*, combined to empower machine operators and simplify their daily tasks.

4. Worktable

The table is disassembled, and all parts are inspected for wear. Final drive parts are inspected for spacing errors and contact, and the table is then reassembled with the proper lash set. The column and machine base are assembled, radial/axial slide scraping is completed, and the table housing is readied for reassembly.

5. Hydraulics

Hydraulics is overhauled, including A) hydraulic pressure valves; and B) hydraulic pumps. MTB installs new or rebuilt hydraulic pumps, hoses, pressure switches, pressure-reducing valves, flow controls, and pressure regulators.

6. Lubrication

New lubrication valves, pumps, meter blocks, hoses, and feedback are installed.

7. Coolant

All coolant components, such as the pump, motor, hoses, and nozzle, are replaced or repaired.

8. Guarding

MTB's meticulous rebuild process leaves nothing untouched. Every component is upgraded, and every mechanical structure is carefully inspected, replaced, or repaired.

All guarding is returned to its original configuration and function. If guarding is damaged, requires modification for splash protection from coolant, or affects aesthetics, newly formed panels are designed and manufactured.

9. Chip Extraction

Chip conveyors of various designs and performance configurations are cleaned of swarf, chips and metal particles. Then, all parts, including upper and lower curves, belt rollers, and hinge pins are inspected for wear.

10. Electrical

A new electrical cabinet is installed, with all new motor starters, relays, power supplies, transformers, terminal strips, and more. Since panel building and wiring practices are very critical for integrating controls, MTB is meticulous in its details for control layout and wiring methodology. All new machine wiring is run throughout both the main and auxiliary equipment. New feedback systems, glass scales, and encoders for all axes are installed.

11. Controls and Software

The machine gets new CNC, generally the latest generation CNC FANUC or Siemens control system, along with servo motors and drives. Installation of all new digital drives for the axes, and a new digital spindle drive and spindle motor on its axis. The entire electrical cabinet is replaced, including the air conditioner, and all components and wiring inside will be new. This includes all motor starters, relays, power supplies, transformers, terminal strips, etc. Existing feedback devices will be replaced with absolute scales, thus eliminating the time-consuming homing process. All the motor power and feedback cabling are replaced as well. Most importantly, the CNC is loaded with all the required PLC and conversational program software. MTB's Windows-based conversational software program is designed to speed up and simplify the operator's programming and day-to-day operating tasks. The software is designed to allow operators to run both existing part programs and create new part programs; quickly and seamlessly.

12. Install, Runoff, Train

The final steps are identical to those of a brand-new machine. The machine is delivered to the customer. A team of MTB technicians installs the machine, loads software, and performs the runoff. MTB provides operator and maintenance training following installation. Documentation is provided, including new operating and maintenance manuals as required.

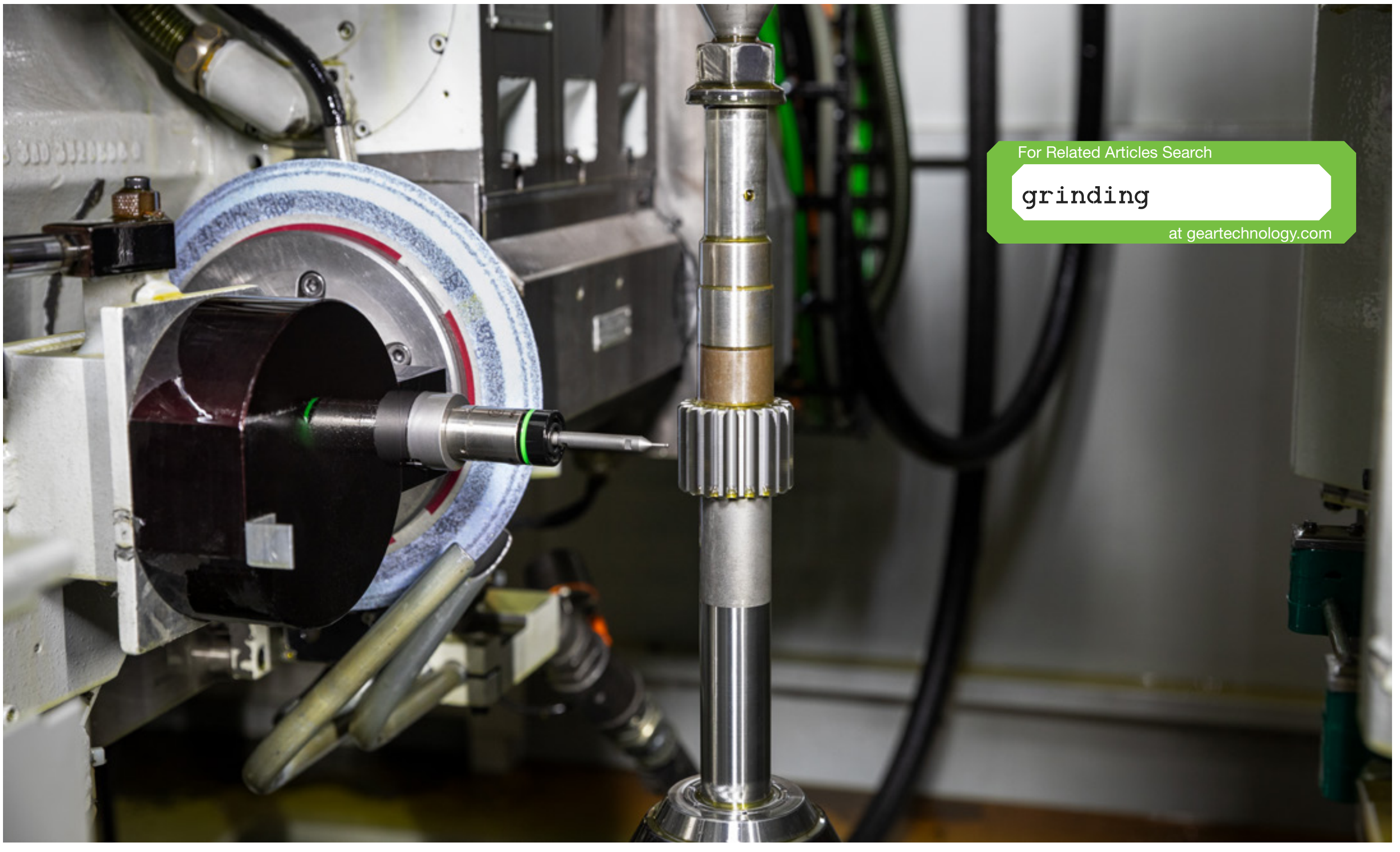
Smart Move

What impresses him most about the machine, according to Gallmar's Zolota, is its versatility—and brainpower. MTB bought the P400G originally as a test bed for the development of its powerful new *Form Grinding Conversational Software*, designed specifically to help bring older CNC form grinding machines to the performance levels of today's machines. This new software package supports all grinding, onboard wheel dressing, and onboard inspection functionality. The package also includes a new onboard, 3D inspection probe to replace the outdated probes typically found on older CNC form grinders. Now, armed with this extremely user-friendly software, the operators of this machine can more easily, and quickly, shift gears from one-off prototype work to production runs of many hundreds of parts. Zolota says he has also used the machine to completely grind prototype gears from solid, thereby eliminating the cost and delivery time required for ordering special hobs to first cut the part conventionally.

Ultimately, as Gallmar Industries has discovered, an MTB rebuild can help address the conundrum that many gear manufacturers today are faced with—either replace their older CNC machines with expensive new equipment or gradually lose the race for more productivity, quality, and reliability. Neither decision is an easy one. New machines bring plenty of added firepower, but with capital expenses that can be hard to justify; relying on legacy machines for too long, however, can lead to cataclysmic downtime and production losses while the user fruitlessly searches for replacement parts and repair expertise. For Gallmar Industries, the rebuilt P400G was the perfect solution: quick delivery of a machine delivering performance on par with modern CNC form grinders, but with a price tag well below that of a new machine.

machinetoolbuilders.com

fvht.com/gallmar/

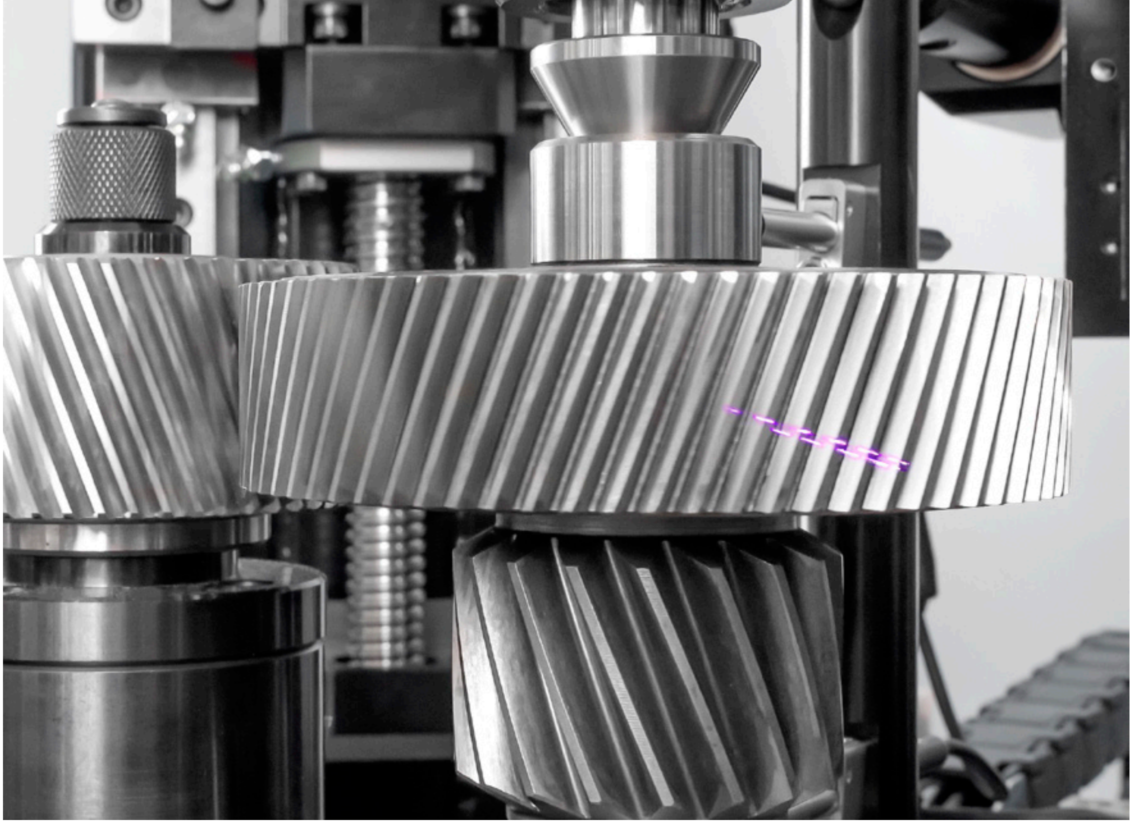


Rebuild includes a modern 3D probe and software for comprehensive on-board inspection.

GRSL Quality Center: Speeding the Way to Quieter Gears

Gleason's GRSL Quality Center brings fast gear inspection to the shop floor for higher quality gears

Klaus Deininger, International Sales Manager, Gleason Metrology Systems Corporation
Parag Wagaj, General Manager Sales and Technology, Gleason Metrology Systems Corporation



GRSL rolls multiple inspection methods into a single platform: optical inspection of profile, lead, and pitch; DOP and tooth thickness; double flank composite testing; and sophisticated in-process gear noise analysis.

The arrival of Gleason's Hard Finishing Cell (HFC) in 2018 represented a paradigm shift in the way automotive transmission gears and gears for e-drives, could be produced in high volumes. Now, for the first time, 100 percent inspection of every gear, and every gear tooth was possible in-process, without impacting the high speeds at which these gears need to be hard finished. Identifying, and correcting for, conditions that create unacceptable noise behavior in these gears, on the fly, was finally a reality too. Compare that to the approach gear manufacturers traditionally take. In a typical hard fine finishing operation like continuous generating grinding, it is not unusual to measure only one or two workpieces per dressing cycle or directly after the machine setup. Depending on the dressing cycle, the number of inspected parts corresponds to only about five percent of workpieces produced in total. However, to guarantee almost 100 percent reliability, statistical evaluation is instead used to validate the gears being produced. Typical measuring characteristics can be represented and statistically evaluated on a Gaussian bell curve. By deliberately narrowing down tolerances on the measured components, it is possible to guarantee compliance with the required drawing tolerances with a sufficiently high probability (typically > 99.99994 percent). This method is commonly used for machine and process capability studies and is globally recognized. The machine or process capability values c_{mk} and c_{pk}, frequently taken as a basis, are usually set above 1.67. Statistically, the reject rate is only 0.57 workpieces per 1 million manufactured workpieces, which means that only about 50 percent of the intended drawing tolerances are available as manufacturing tolerances. This situation is aggravated by the fact of increasing quality demands, especially with e-drive gears, due to NVH and other topics leading to increasingly tight tolerances. This high dependency on statistics poses a significant challenge to a growing number of gear manufacturers.

Another significant challenge is the long wait time between part removal for inspection and the actual availability of measured results. Part movement, waiting, and inspection time can easily amount to between 30 to 45 minutes depending on the inspection room capacity. After inspection, a decision must be made as to whether a correction of machine settings is necessary. The implementation of such corrections must be carried out by the machine operator, taking additional time—all while gears, good or bad, are continuously produced.

Gleason's HFC incorporated a remarkable new inspection solution to address both long-standing issues: the GRSL (Gear Rolling System with Integrated Laser Scanning), featuring a combination of double flank roll testing and laser scanning. GRSL rolled multiple inspection methods into a single platform—optical inspection of profile, lead, and pitch; DOP and tooth thickness; double flank composite testing; and sophisticated in-process gear noise analysis—all performed in just seconds, making it possible to inspect every gear without sacrificing precious cycle time.

GRSL Stands Alone

Fortunately, the many benefits of GRSL aren't simply confined to HFC application. With the arrival today of the stand-alone GRSL Quality Center any manufacturer can meet their 100 percent inspection requirements, while at the same time taking precious time out of the hard fine finishing and inspection of a wide range of high-precision cylindrical gears with low noise requirements. Furthermore, the GRSL Quality Center is 'shop hardened' and designed for installation right on the production floor close to the machines producing parts for inspection. Now, with a single stand-alone GRSL, served by an integrated cobot loader, the manufacturer can eliminate the much more time-consuming, labor-intensive inspection process that typically includes multiple inspection machines (analytical inspection systems, roll testers, DOP gages), skilled operators, and transport between inspection stations. Instead, this single GRSL platform does it all, and in a fraction of the time: optical pitch, lead, and profile inspection for all teeth on a workpiece, as well as dual flank rolling testing including inspection for tooth flank damage, total dual flank working deviation and dual flank working error, functional runout, DOB measurement, average tooth thickness and more. Most significantly, the results of the inspection are available immediately and can be sent back to the production machine in a continuous closed loop so the necessary corrections can be made on the fly, without waiting many minutes, perhaps hours, for inspection results using traditional methods. By inspecting up to 100 percent of parts, manufacturers can monitor trends and apply preventive corrections before parts are even out of tolerance, helping to predict whether a workpiece could cause noise issues within the gearbox after its assembly.

Noise Analysis

With the rise of EVs, reducing or even eliminating gear noise is now uppermost in the minds of gear designers. The work is ongoing, but there's no single, simple solution. Gear noise can have many causes. When gear noise issues occur, producers often focus solely on the manufacturing process. However, this is not always the root cause. For a gearing system to function quietly, it must first be designed properly according to the load characteristics that will appear later in the real gearbox. Gear design that assumes ideal conditions is no longer an adequate predictor of whether that gear will operate quietly in the real world. A much better approach is to employ loaded tooth contact analysis that considers the true gear geometry, realistic loads, and deformations of the gearbox elements. Even perfectly designed gears are subject to manufacturing errors that can also produce the gear noise condition called 'ghost noise'. Hence, it is important to have analysis tools capable of detecting potential noise issues and distinguishing between manufacturing and design root causes. At this, the GRSL Quality Center excels.

In comparison to traditional methods of inspection, and their use in the search for the root causes of noise—whether design or manufacturing-related—GRSL is truly light years ahead. Laser scanning provides comprehensive data volumes that go well beyond standard gear characteristics such as profile, lead, pitch, runout, and size—all in a fraction of the time it would take using traditional methods. Providing a much greater understanding of the profile and lead of all teeth makes it possible to conduct an advanced waviness analysis resulting in an order analysis of the gear topography including the corresponding amplitudes. Now, potential noise issues like "ghost orders" can be detected, which are not related to the mesh harmonics of the gear and are typically caused by small irregularities created during the manufacturing process or involved production machinery. Ghost orders can cause problems once they exceed specific amplitudes. With the advanced waviness analysis and the possibility to inspect up to 100 percent of gears, it is possible to sort out critical parts before they are assembled within the gearbox.

Additionally, the GRSL Quality Center uses *GAMA* (Gleason Automated Measurement and Analysis) software for gear analysis. *GAMA* is a true Windows-based suite of inspection software for all gear geometry types along with gear cutting tools and GD&T measurements. It is easy to use, yet very powerful for gear analyses and flexible reporting and output. Today, *GAMA* has been enhanced to include Advanced Waviness Analysis capabilities, using GRSL's point cloud data of all teeth measurements. Working together, GRSL and *GAMA* can perform comprehensive noise-related detection and analysis in a fraction of the time. Here are a few common, real-world examples:

Large Form Error Detection: The GRSL was tested in an actual scenario where several teeth of a gear were shown to have large form errors. Such form errors are often produced due to manufacturing issues such as a dressing wheel reaching the end of its life and leaving only a few teeth on the gear unfinished. However, finding such conditions using traditional methods can be difficult and very time-consuming. A typical single-flank or double-flank roll tester, for example, won't find such a condition, particularly in this instance where they are of small magnitudes and in negative material. This example (see Figure 1) shows the point cloud collected at the center of the gear in just one rotation. The data extracted from such point cloud on all teeth in a fraction of a second allowed GRSL to easily identify these out-of-tolerance teeth. In addition, the visual information of such conditions, made possible via *GAMA*, is much easier than identifying the same issue based on roll test output.

Tooth Mesh Irregularities: In this real-world application example, the *GAMA* Advanced Waviness software was used to help identify the root cause of noise being emitted from a pinion at first mesh order on the drive flank (left flank). When a good part was compared to the noisy part using standard inspection methods, the standard charts that were generated showed that the index lead and profile for both gears—good and noisy—were within tolerance (see Figure 2).

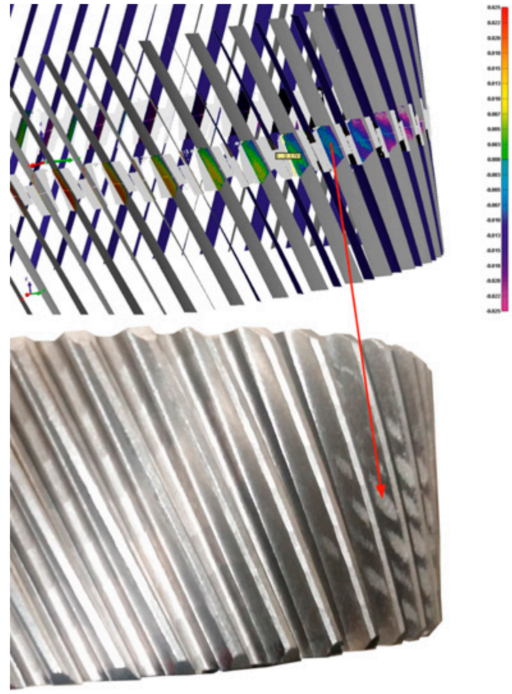


Figure 1—Here, GRSL's point cloud data collection, combined with GAMA *software, performs comprehensive noise-related detection and analysis in a fraction of the time of a traditional single- or double-flank roll tester.*

However, when a good part and a noisy part were compared using the advanced waviness analysis in an analysis done on the GRSL, it was immediately evident that a first mesh order issue was creating the noise that was detected from the gearbox (see Figure 3). Ultimately, this enabled the manufacturer to remedy the issue through manufacturing-process modifications.

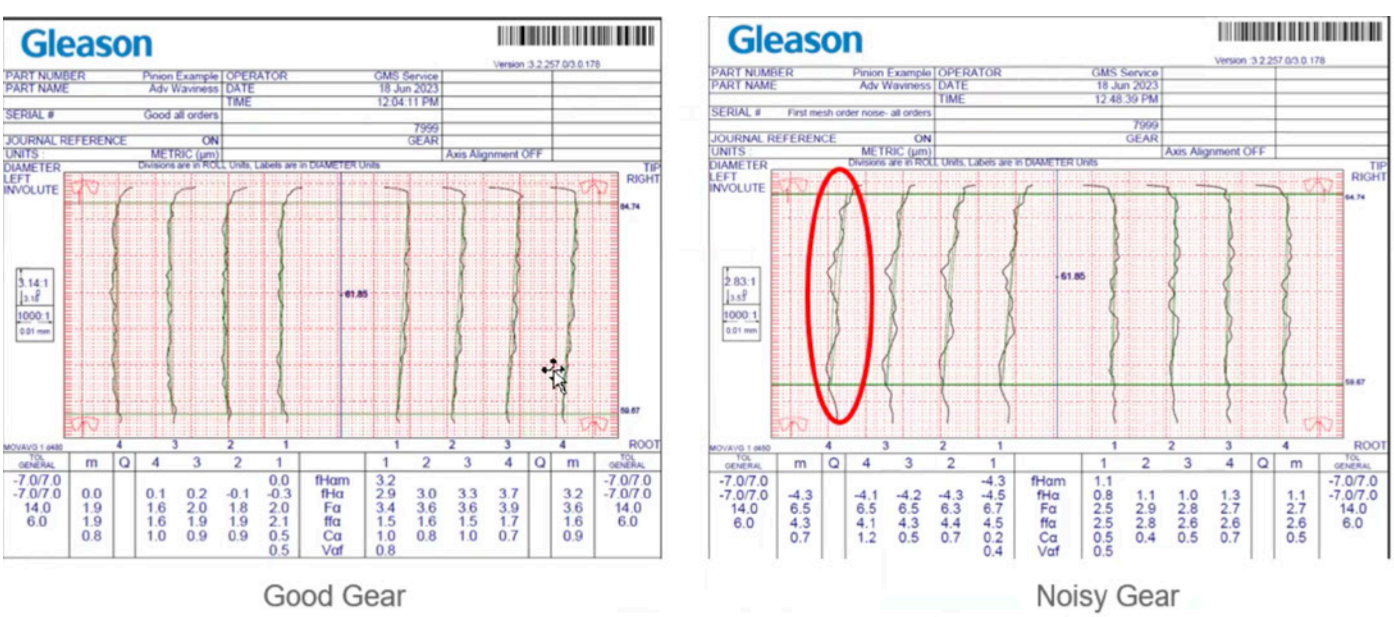


Figure 2—Standard inspection methods show that both a good pinion gear and a noisy pinion gear are within tolerance. The cause of the noise thus goes unidentified.

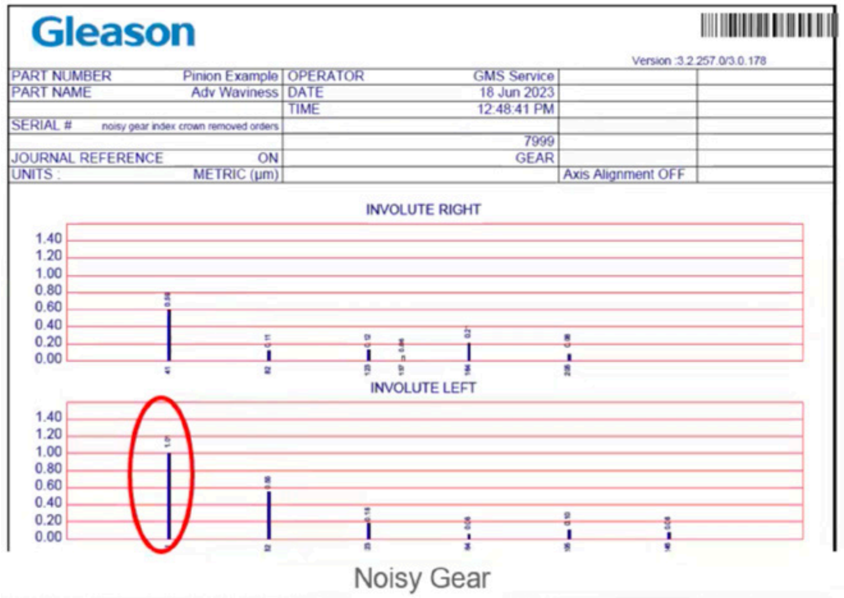


Figure 3—When the good part and noisy part were compared using the advanced waviness analysis in an analysis done on the GRSL, however, it was immediately evident that a first mesh order issue was creating the noise. Manufacturing-process modifications ultimately remedied the problem.

Summary

The quest for noise reduction, whether for e-drive transmission gears or in a fast-increasing number of other applications, is changing the inspection landscape for manufacturers. Slow, labor-intensive inspection involving multiple systems and operators at different locations is neither desirable, nor effective, and can add considerably to cost. With the arrival of the GRSL Quality Center, as a stand-alone system, connected to various automation systems, or as a fully integrated manufacturing cell, gear manufacturers now have the technology they need to produce gears that can be inspected up to 100 percent of the time, and produced quieter than ever before.

gleason.com/grsl

Celebrating 40 Years

Gear Technology's Milestones and Memories

By Randy Stott, Publisher & Editor-in-Chief

Gear Technology began with the May/June 1984 issue. Forty years later, we're still going strong! Please join us in looking back at some of our milestones and celebrating what makes this publication truly unique in the marketplace.

Don't miss some of the related articles throughout this issue, including my own 30-year (and counting!) journey with the

1984

Gear Technology is launched.

"Over the years. we have traveled extensively throughout the industrialized world and become increasingly aware of the availability of enormous amounts of technical writing concerning research, experiments, and techniques In the gear manufacturing field. New manufacturing methods, materials, and machines were continuously being developed, but the technical information about them was not readily available to those that could best use it. There was no central source for disseminating this knowledge. Thus, the idea for *Gear Technology*, The Journal of Gear Manufacturing was born."—Michael Goldstein, founder, from his editorial in the first issue.

1991

Gear Technology gets a makeover. Our first redesign.

1995

Gear Technology The "Addendum" column is first introduced.

1996

The Gear Industry Home Page is launched at *geartechnology.com*.

1997

The *Power Transmission* Home Page is launched at *powertransmission.com*.

2003

E-GT (the digital edition of *Gear Technology*) is launched.

In addition to the print version, we began offering readers the option to get the PDF digital replica edition as well.

2006

First annual "State of the Gear Industry" survey.

publication (p. 8), the history of how *Gear Technology* got its start from our founder, Michael Goldstein (p. 10), and an engineer's perspective from our longtime technical editor and contributor Chuck Schultz (p. 11).

We're extremely grateful for the support we've received from our readers, advertisers and contributors. None of this could have been possible without all of you.

2007

Power Transmission Engineering is launched.

Gear Technology The "Addendum" column is first introduced.

First edition of the *Gear Technology* e-mail newsletter.

2012

Gear Technology launches the "Ask the Expert" column.

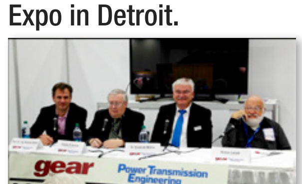
"Ask the Expert was based on previous columns called "Shop Floor" and "Q&A."

2013

Gear Technology redesign #4.

2015

First edition of "Ask the Expert Live!" held at Gear Expo in Detroit.



2019

Founder Michael Goldstein retires as Publisher/ Editor-in-Chief.

At the same time, the American Gear Manufacturers Association acquired both *Gear Technology* and *Power Transmission Engineering* magazines, and our entire staff were hired by AGMA to continue the publications.

2020

Gear Technology begins publishing under the auspices of the AGMA.

2024

40th Anniversary

296 issues and counting!

Why Do You Read *Gear Technology*?

We asked our readers to fill out a one-question anonymous survey: Why Do You Read *Gear Technology*? We received almost 200 responses, including some of the highlights reprinted here:

"I read *Gear Technology* for updates on new gearing applications, new machinery available to the gearing world and promotions within companies. Great source of information."

"I work in maintenance in a steel mill and need to know about many aspects in the production of gears for our needs."

"For technical articles, updates. [Information about] new technologies like skiving."

"I read *Gear Technology* to stay updated on new products and technology related to gear manufacturing…I need to understand how gears are manufactured and how any potential new technology could affect our products and our approach."

"For interesting topics related to *gear technology* (drive systems, gear calculations, failure mechanisms, etc.)"

"When I entered the world of gearing as a gear engineer in 1977, I was drawn to the mathematics behind every design and manufacturing process. My education was in mathematics, but I never would have anticipated using it in this technical field. We had our already established formulas and design criteria based on the years of experience in the heavy-duty truck transmission and axle business. But when the first issue of *Gear Technology* came out, it opened up a whole new world of research and new ideas. I still have some of the early publications, but I wish I had kept them all. Now…working as a consultant in the manufacturing world, I am back to reading most articles and using the advertisements as resources to investigate. I have encouraged all the engineers I work with to subscribe and it is fun to talk with them when they receive their first magazine. Thank you for doing such a great job for the gearing professions. By the way, I still have the set of Michelangelo gear sketches that you offered to subscribers in your first year in circulation. Congratulations on your first 40 years!"

"Because it keeps me informed about the latest technology and gear news. It is a really interesting and amazing magazine."

"For me, [it is] the best publication with respect to the gear industry for all the technical pieces it includes. Plus it keeps you up to date with the latest technologies available from the industry's principal suppliers."

"I read *Gear Technology* magazine to get both a broader view of the gear industry and industries that use gears, as well as to gain a better understanding of engineering concepts that I did not learn from my days in college."

"To open my mind to other types of industries and technologies developed in order to implement them or develop something alike for the off-road industry."

"Tracking the evolution for gear manufacturing and gearbox design. To understand the evolution of new technologies and what this can mean for our applications."

"*Gear Technology* is one of the world's most renowned magazines in the field of transmission and gear technology and therefore a must for every gear specialist. I have been reading *Gear Technology* for more than 15 years.

"To understand better what is going on in the gear industry."

"It gives me a perfect overview of what happens in the gear market."

"*Gear Technology* is the international reference point for gear manufacturers."

"I value the technical content; it is high quality!"

"It is the greatest knowledge available about gears."

"For the love of transmissions! More soberly, to return to basics and to advanced technologies at the same time."

"I am working in a company which is related to gear manufacturing, and Information from the magazine helps to understand new technology and research topics, and to exchange knowledge."

"Because it is very helpful with staying informed about what is new in gear manufacturing."

"*Gear Technology* always delivers interesting articles on gear manufacturing with a lot of technology information. I find it to be a source of knowledge and very informative and will continue to read it due to the rich content."

"To be aware of products, people and events in the gear industry."

"*Gear Technology* provides valuable information on gear design from top to bottom, which enhances our knowledge and also helps us to update our knowledge on new technology."

"To maintain knowledge of latest in gear manufacturing, inspection and analysis methods."

"For my pathway as gear design engineer. *Gear Technology* is a great knowledge source for any engineer involved in the gear field."

"It is a good way to keep updated with the latest technologies and trends in the gear world!"

"I enjoy keeping up with what is going on in the gearing world. This is one of the few publications that is dedicated to this technology field. I wish your publication many more years of success."

"Innovative gear engineering articles and . . . insightful interviews from domain experts gives me the passion to read *GT*...always..."

"I enjoy the technical articles and keeping up to date with the latest in technologies available."

"To learn about gear production technology and industry trends."

I read *Gear Technology* because I work in a factory producing gears, and I am interested in new technology to manufacture gears. Also I need to know about terminology of different kinds of gears and basic principles of manufacture."

"It is a very powerful tool and source of information for all the people involved in gear design, manufacturing, field service, consultants and for all the users of mechanical power transmission equipment."

"*Gear Technology* is very helpful to my job in gear manufacturing technology."

"I read it because it updates me on industry news and also provides technical information of interest to me."

"The technical articles have proven very informative and useful over the years."

"I have been engineering and designing gears and gear units for 50+ years, *Gear Technology* is a wonderful resource for ideas and new technologies."

"To know about the new developments and tendencies of research and industry."

"I began reading *Gear Technology* in the 1990s. I first read Bob Errichello's articles 'The Lubrication of Gears' parts 1, 2 and 3. I had to chase down copies of *Gear Technology* and make photo copies as the online archives did not exist. I have been a subscriber ever since. I have used the information from many of the articles as starting points to improve my knowledge of gear design. I have then taken AGMA courses with both Bob Errichello and Ray Drago among others whose articles appeared in the magazine."

"The best magazine for the gear industry."

Having spent my career as a designer for industrial and marine high speed/high power gearboxes, I like to keep myself updated and abreast with developments within the industry. *Gear Technology* certainly provides this. Thank you so much. I greatly appreciate reading it."

"Great technical content, industry news, editorials and now the ties with AGMA are a great boon. Been reading 30 or more years."

"*Gear Technology* magazine gives lots of information on design, manufacture and inspection of special purpose gearboxes. It also gives references to AGMA and ISO specification for design of special purpose gear drives and manufacturing practices. *Gear Technology* is a top-class magazine for gear drive design and manufacture."

"To keep up with the latest technology relative to gear manufacturing and metrology."

"While I have not been directly involved in gear manufacturing for many years (except that, from time to time, one of our vendor-facing engineers will say, "Hey, I hear you're our gear guy!) I am still an assiduous reader of *Gear Technology*. By any measure, the manufacture and inspection of geared components is the most challenging and, if you want to be ahead of the curve in manufacturing, you must keep abreast of the gear industry.

"Informative with technical information in easy-to-read format featuring timely topics. Enjoy reading the Publisher's Page and Addendum. The ads give a great idea of what's available in the gear marketplace."

"Extremely informative. Great for learning new techniques and gear machines."

"Because it gives me useful information about the state of the art in gear technology. It gives me information about suppliers and specialist gear engineers…I have fun reading the magazine at home."

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Milestones in Motion

Mary Ellen Doran, AGMA Director, Emerging Technology

Congratulations *Gear Technology* on your 40th Anniversary! This magazine has been publishing emerging technology in gearing before we used the term, "emerging." I constantly search past issues to get information on topics we are discussing in committees. From skiving to electric drive development, and lubrication to the beginnings of strain wave gear technology, I have found great information for the work that we are doing today. Thank you!

Emerging Technology committee members at ARM Institute in Pittsburgh.

Speaking of our committees there are many things to share. A group of leaders from our Emerging Tech committees just got back from a Joint Technology Summit with leaders from the Association for Manufacturing Technology (AMT), and the National Tooling and Machining Association (NTMA). This is the second year we have participated in this joint event. Thanks much to AMT and NTMA for extending an invitation to join them. This year, the ARM Institute—Advanced Robotics for Manufacturing in Pittsburgh hosted the event. We spent two days talking about advances in robotics and AI and were afforded presentations from experts in these fields. Pittsburgh, with Carnegie Mellon University, has built one of the leading areas for robotic development in the world with more than 140 robotics companies and a network of support. This institute is a Manufacturing Innovation Institute funded in part by the DoD. They work with industry, government, and academic partners to specifically take on projects to strengthen domestic manufacturing. We were able to see many of these projects in action in their facility. One example, they have an incubator space where local small manufacturers can come and test their robotics application before bringing it in-house. AGMA is in the process of becoming a member of the ARM Institute with the hope of bringing our members crucial information on how you can be supported in your automation projects. I encourage you to learn more about the ARM Institute.

AGMA has already been working with another Manufacturing Institute, LIFT in Detroit. LIFT has similar industry, government, and academic partners with whom they work on advanced materials and processes. AGMA is a member of LIFT and we will be hosting our first live Emerging Technology Forum there on June 10. I invite each of you to join us. We will be touching on the work of each of our four committees (3D, IIoT, Electric Vehicle Technology, and Robotics & Automation) through high-level presentations and hands-on experiences. We will be discussing the future of robotics as we see the changing landscape of robot applications.

Humanoid and non-industrial applications will pose new challenges - with gear drives, and the need for new and different constructions at the forefront. We will look at some of the latest solutions from Siemens, which has invested in advanced technology at LIFT. We are excited to have time with LIFT leaders, including Noel Mack, chief technology officer, who will be talking to us about their advanced materials development work as well as their partnership and work with the DoD. There are many opportunities for AGMA member companies to work on these cutting-edge projects. We hope to provide you with a clear roadmap for participation. And, as we do with all our live events, we hope to provide another collaborative networking opportunity for the gearing industry.

In coordination with this event, the next day on June 11, the AGMA Technical Division, in its work with the AGMA Electric Vehicle Technology Committee, will be gathering engineers and stakeholders for a high-level discussion on standards development at LIFT. This second day is by invite-only because of space. Please reach out to me directly for more information.

If you are looking to be more informed on emerging technology topics, don't forget that all our monthly webinars are taped and available on the AGMA website for free. If you do any government work, you need to make sure you are ready for CMMC compliance. We have a great free primer. Want to hear about the latest in steel developments for electric vehicle applications, we just had a great webinar last week from Gerdau. And the May webinar comes from Hexagon.

Congrats again to *GT*. May you have a great next 40 years!

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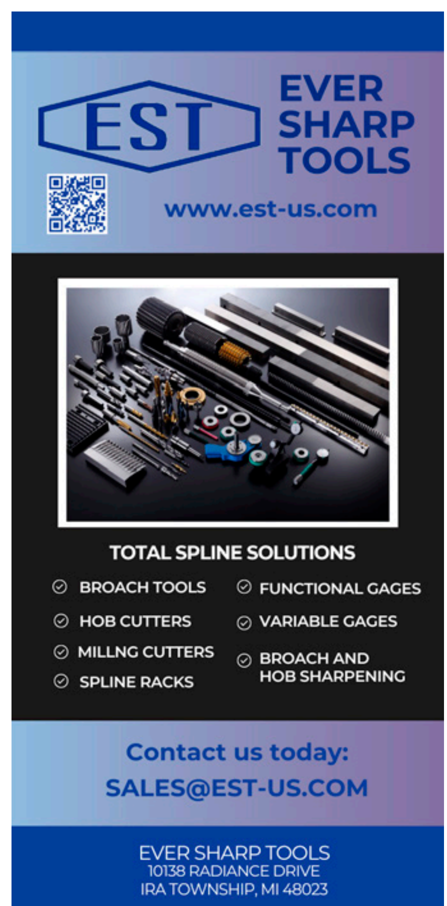
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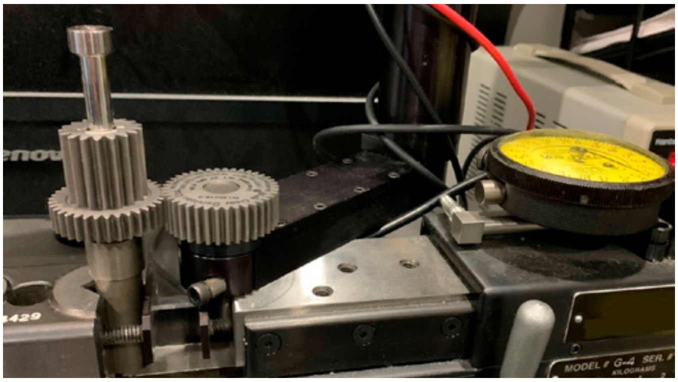
Two Newly Revised AGMA Standards

Phillip Olson, AGMA Director, Technical Services

AGMA is pleased to announce the publication of two new revisions: ANSI/AGMA 2116-B24, Evaluation of Double Flank Testers for Radial Composite Measurement of Gears, written by the AGMA Gear Accuracy Committee, and ANSI/AGMA 6008-B24, Specifications for Powder Metallurgy Gears written by the AGMA Powder Metallurgy Committee.

ANSI/AGMA 2116-B24

ANSI/AGMA 2116-B24 provides the evaluation criteria for double flank testers. It also recommends artifact sizes and geometry along with measurement system conditions. In Annex A of the standard a method for estimating calibration uncertainty is provided.



Double flank tester.

Between 1994 and 1998 the AGMA Calibration Committee published three standards on calibration of gear measuring instruments. The AGMA documents were used as the basis to create ISO 18653:2003 Gears – Evaluation of instruments for measurement of gears, and ISO/TR 10064-5:2005, Cylindrical gears – Code of inspection practice – Part 5: Recommendations relative to evaluation of gear measuring instruments. AGMA adopted the ISO standards, however the ISO standards did not cover evaluation methods of double flank testers. So the first edition of ANSI/AGMA 2116 was created in 2005 to fill in that gap.

This 2024 edition of ANSI/AGMA 2116 has incorporated information from an AGMA information sheet (AGMA 935-A05) into a new Annex A, titled Recommendations relative to the evaluation of radial composite gear double flank testers. Information from the former Annex B, Calibration certificate requirements, has been moved into the body of the document. Other changes are general updates to the latest practices.

ANSI/AGMA 6008-B24

ANSI/AGMA 6008-B24 provides comprehensive details for the design, processing, and specifications of powder metallurgy, PM, steel gears that need to be agreed upon between the PM gear supplier and the purchaser. These include: definition of terms, gear tooth geometry considerations, inspection, PM gear materials, drawing specifications, heat treatment, and mechanical testing.

The AGMA Powder Metallurgy Gear Committee was organized in 1993 to work on this specification standard. The first edition of ANSI/AGMA 6008 was published in 1998. This 2024 edition is a major update from the 1998 edition. There are 70 pages in the new edition compared to 17 pages in the old edition, 29 Figures compared to 8 figures, and 7 tables compared to 5 tables. A new Annex with guidelines for specifying a PM gear has been added. All sections from the 1998 edition have been greatly expanded including more details on how to specify, inspect, certify, and test PM steel gears and an extensive definitions section from ASTM B243-19 has been added.

On behalf of the gearing industry, AGMA would like to extend a sincere appreciation for the participation and the 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.

ANSI/AGMA 2116-B24—AGMA Gear Accuracy Committee

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Flexible Planet Pins for High Torque Epicyclic Gears: Experience with Design, Manufacturing, and Application

Hanspeter Dinner, Deputy General Manager, KISSsoft AG

For wind turbine main gearboxes (MGBs) with about 1 MW or higher power, gearbox designs with multiple power paths are used. They handle several mega-Newton-meter of torque economically. Earlier wind turbines with lower power ratings used parallel shaft gearboxes with only one power path but soon they were superseded by planetary gearboxes having typically three to five planets per stage. This paper describes experiences using planetary gears where "Flexpins" are used to improve the load sharing between the individual planets—representing the multitude of power paths—and along the planet's face width.

Introduction

Wind Turbines MGB, Cantilevered Plant Pin Support

Technologies with respect to materials (high purity steels for bearings and gears), design (use of elastic structures improve load sharing between gears), bearing design (adjusted roller crowning allowing for higher misalignment, integration of raceway into the planet gear, use of hydrodynamic bearings) and gearbox architecture (increased number of planets, optimal selection of ratio per stage, single-walled planet carriers, compound planetary stages) allow for ever increasing torque density. Below, an example design with two planetary stages in series with a high-speed parallel shaft stage is shown. The LSS features five planets, which still yields a good ratio of maximum i_{LSS}~4.1 (see Table 4 [Ref. 7]). By experience, three, four, and five planets result in good load distribution and sufficiently high ratio. Studies in other industries confirm this. For example, in turboprop engines, reduction gearboxes are used where the goal of maximized torque density at high reliability is the same as for wind turbines. Below Figure 1, bottom, from Ref. 8, shows that a planetary stage, considering bearing and gear life, yields the highest system life over a range up to a ratio 1:4 (for five-planet design) to 1:5 (for three- and four-planet designs).

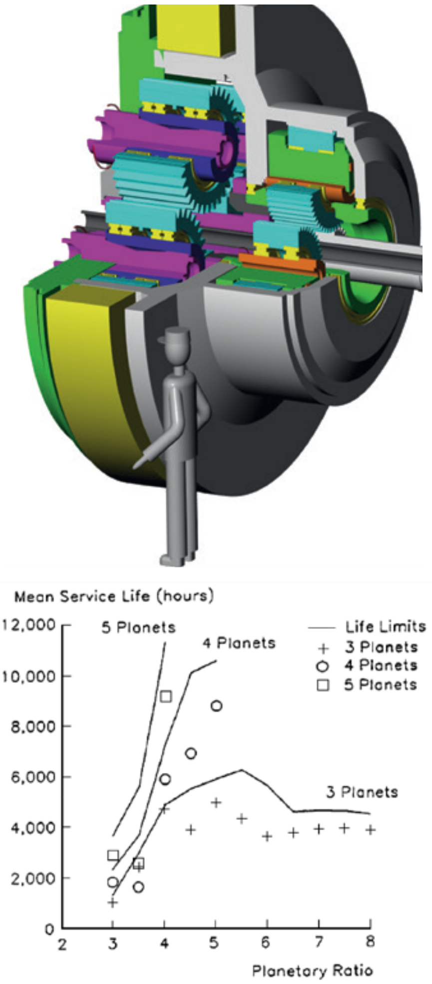

Figure 1—Top: Example 8 MW MGB with five planets, supported on flexible planet pins in LSS and conventional ISS (yellow body represents the turbine main bearing). Bottom: Service life of a planetary stage as a function of ratio and number of planets (Ref. 8).

Designs with a high number of planets face three major design challenges: 1) load sharing among the planets 2) load distribution along the planet's face width 3) space for the carrier. The first two problems are related to the third in that since there is not much space for the carrier, it becomes soft, resulting in a larger misalignment of the planets concerning the sun gear and the ring gear. The solution presented here to tackle all three problems at once is using a single-walled carrier and cantilevered planet pins. The planet pins are of the "Flexpin" type, as invented and patented by Ray Hicks (Ref. 16). Such a design allows for a higher number of planet pins projecting from a flange, while each pin supports a planet gear for orbital rotation about the gearbox axis. No space is required between the planets for the connecting pieces connecting the two flanges of a conventional planet carrier design and planet outer diameters may nearly touch. As a simple rule of thumb use the credit card approach: if you can fit a credit card between the tip diameters, you should be fine. The simple construction of the single-wall carrier accommodates a larger number of planet gears, and hence the planetary stage will handle a proportionately larger torque. The condition is that the tilting of the planets due to the pin bending is managed properly. This paper focuses on "proper management."

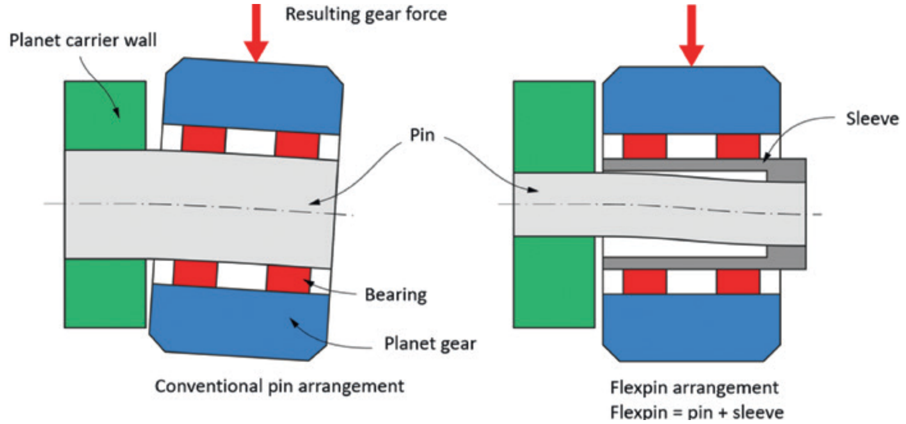

Figure 2—Working principle of the Flexpin arrangement (right). Conventional pin arrangement in single-walled carriers (left). Planet gear (blue) supported in a single-walled carrier (green) does not tilt if Flexpin (grey for the pin and dark grey for the sleeve) is used (right). Planet gear (blue) does tilt if a simple cantilevered pin (grey) is used (left).

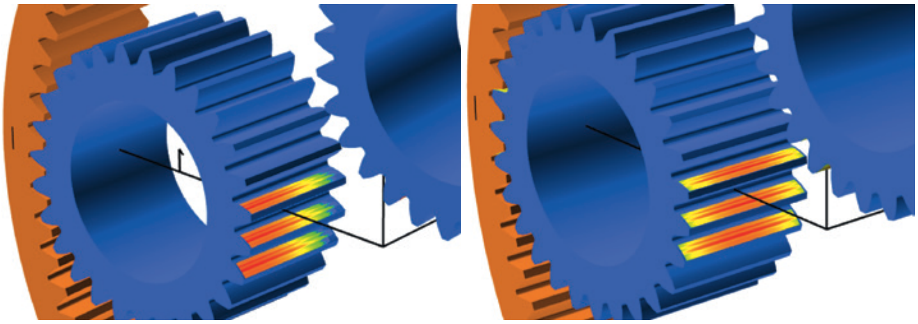

Figure 3—Contact stress distribution on planet tooth in mesh with the sun (not shown). Note gradient (left) and symmetry (right) in contact stress along the face width. Left: Conventional pin arrangement. Right: Flexpin arrangement. Compare to Figure 2 above.

Figure 4–Upscaled carrier design, bearings and planet gears not yet mounted onto the Flexpins. Planets and bearings not yet assembled, for a 6 MW MGB.

Number of Planets and Load Sharing

The basic design problem to solve in planetary gears is to ensure near-equal load sharing among the multitude of planets. A perfect power-split is not achieved and the level of unevenness in the power-split is highly dependent on machining accuracy and system elasticity. The load sharing among the planets gets worse with a higher number of planets, sometimes such that increasing the number of planets does not result in an overall higher power or torque capacity anymore. The load sharing among the planets is expressed by the mesh load factor K_γ in gear design and rating, e.g., along ISO 6336. The mesh load factor or load sharing factor K_γ is defined as $K_\gamma = max(Ti) \,/\, average(Ti)$ where Ti is the torque transmitted through each planet or load path. The minimum value of K_γ is K_{γ_opt} = 1.00, meaning that each planet takes the same load. Typical K_γ values for planetary gear stages are in the range of 1.10 to 1.25. K_γ is used in the gear rating for all failure modes (e.g., scuffing, micropitting, tooth flank fracture, pitting, bending, etc.). Recommended design values are listed in Ref. 7 and shown below. They tend to be conservative when compared to tests.

A study (Ref. 10), on the combined influence of the number of planets, torque levels, and the carrier pinhole position errors on planet load-sharing and gear root stresses confirmed that a floating three-planet gear set has near-equal load sharing, regardless of the manufacturing error values. It also confirmed that the planet loads and gear stresses are sensitive to the carrier pinhole position errors. Other studies, e.g., Refs. 11–15, confirm the trends and to some extent the numerical values shown above.

Second, to the mesh load factor K_γ, the face load factor $K_{H\beta}$ is considered in the

Application level[1), 4), 5)]		Number of planets, N_{CP}								AGMA accuracy grade[2)]	Flexible mounts[3)]
		2	3	4	5	6	7	8	9		
1	K_γ[6)]	1.16	1.23	1.32	1.35	1.38	1.47	1.60	~	A7 or worse	without
2	K_γ[6)]	1.00[7)]	1.00[7)]	1.25	1.35	1.44	1.47	1.60	1.61	A5-A6	without
3	K_γ[6)]	1.00[7)]	1.00[7)]	1.15	1.19	1.23	1.27	1.30	1.33	A4 or better	without
4	K_γ[6)]	1.00[7)]	1.00[7)]	1.08	1.12	1.16	1.20	1.23	1.26	A4 or better	with

Figure 5—K_γ values for different application levels and gear accuracy grades, with and without Flexpin (right side column labeled "Flexible mounts"), Ref. 7.

gear rating, e.g., along ISO 6336. It describes the evenness of the load distribution along the face width in the mesh between the sun and planet and planet and ring gear. If the load along the face width is evenly distributed, then, $K_{H\beta} = 1.00$ applies. $K_{H\beta}$ is defined as the maximum value of the line load width, divided by the mean value, $K_{H\beta} = max(w) / average(w)$. Since the Flexpin results in a movement of the planet parallel to the gearbox axis (see Figure 2, right), the load distribution remains symmetric to the planet's face width and hence optimal (see Figure 3, right). The resulting $K_{H\beta}$ are then typically $K_{H\beta} = 1.15$ and the modifications applied on the planets are only a slight flank line crowning.

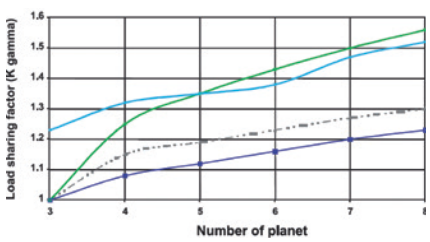

Figure 6—Load sharing factors (blue for measurement with Flexpin) compared to values stipulated in different guidelines. The measurement confirms that the use of a Flexpin allows for a much lower load-sharing factor to be used when compared to general design guidelines (Ref. 10).

Use of Flexpin in Wind Turbine MGBs

The single-wall carrier in combination with the concept of mounting the planet gears on Flexpins gives the design high reliability (because the contact between planet and sun flank and planet and ring gear flank remains near optimal for different torque levels) and high torque capacity (because of the elevated number of planets). Numerous gearbox designs for wind turbine MGBs using Flexpins exist. However, it must be said that the use of the Flexpin concept is not used in high numbers. Most of the leading MGB OEMs companies do not use the Flexpin in their design; this is a strong indicator against the use of the Flexpin for standard gearbox designs. It means that there are probably good reasons not to use Flexpins in a conventional gearbox design and this means that the advantages and disadvantages of the Flexpin design must be carefully considered.

Flexpin Use in SCD Turbine Main Gearboxes

Flexpin as Used in SCD Gearboxes

Figure 8 of Flexpins manufactured by the author shows a similar design. The conical shapes are designed such that an almost constant stress level along the pin axis results, thereby maximizing the utilization of the material or reducing the mass of the pin. The parts shown are hard turned, before machining of the threads for the locknuts and heat treatment. The critical areas of the pin, particularly the fillet radii, are polished to reduce the effect of surface roughness on their strength. Also, pins are nitrided, resulting in a hardened outer layer with very little deformation during the heat treatment process. The hardened layer is thin, less than 1 mm but increases the stress at the surface (where the highest stresses are present) considerably.

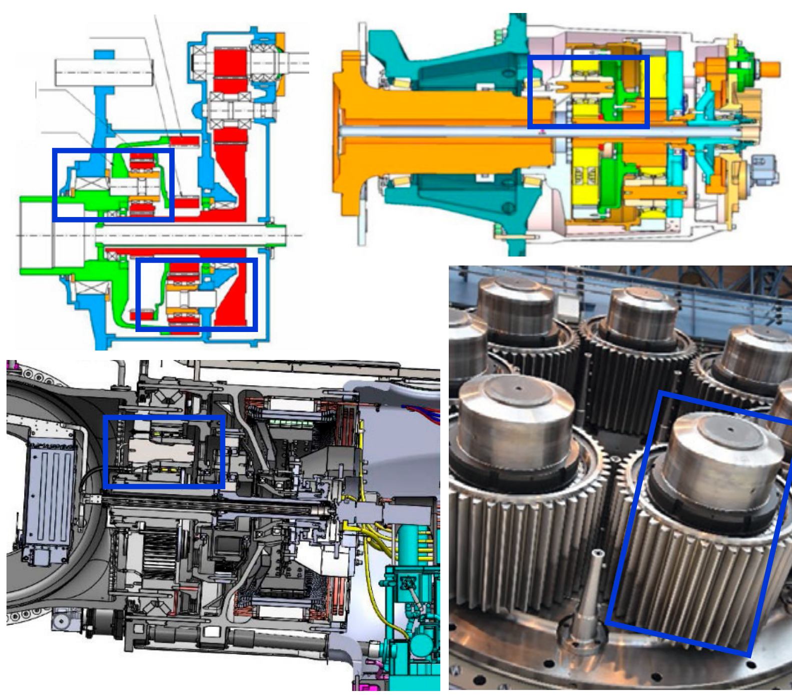

Figure 7—Top left: Gearbox design by MAAG (Ref. 17), believed to be the first wind turbine MGB featuring Flexpins. Top right: Design of a wind turbine MGB using Flexpins, having a compound planetary arrangement (sun gear of second stage connects to the ring gear of first stage (Ref. 19). Bottom left: SCD gearbox designed by the author (Ref. 9). Bottom right: Planetary stage with seven planets, 7 MW wind turbine MGB by WIKOV (Ref. 18). Flexpin highlighted in cross-sectional images.

Figure 8–Flexpin pins, awaiting transport to heat treatment.

The right pin is cooled down and inserted into the sleeve.

Calculation of Load Distribution

The planetary stage having five planets supported on Flexpins is modelled as a combination of springs and gaps. The springs model the stiffness of the parts while gaps are used to model manufacturing errors. Errors considered using gaps included

- Pitch error in the teeth
- Differences in the bearing clearances
- Misalignment between Flexpin pin and sleeve
- Positioning errors of the Flexpin in the carrier

The starting point is the spring model of a planetary stage with five planets as shown below. From the carrier torque and the center distance, a force Ftot is determined that is then distributed—as a function of the spring stiffness values and the gaps (position errors) into the five planets. In the five planets, the five F_1, F_2, F_3, F_4, F_5 are present. They are not exactly the same, K_γ is then K_γ = max(F_1, F_2, F_3, F_4, F_5) / average(F_1, F_2, F_3, F_4, F_5). Each planet is further broken down into a more detailed spring system as shown below.

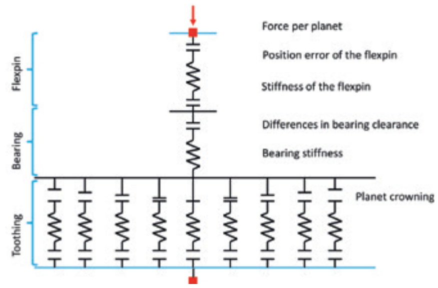

Figure 10—Spring-gap model of one planet. Note the spring representing the Flexpin.

The contacts between ring gear and planet and between sun and planet are represented by one contact. The crowning is considered, it varies over the tooth width. The pitch error is modeled as a gap in the contact between the planet and the sun/ring gear.

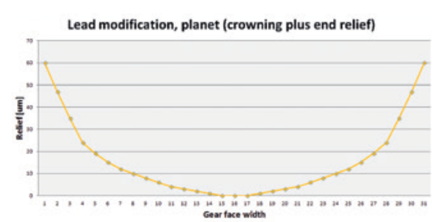

Figure 11—Planet modification combining slight crowning with linear end relief on either side.

For the different errors considered in the model, the following ranges are defined:

- Pitch error of teeth: a gear quality of Q=6 is assumed, resulting in +-20 µm possible pitch error in the mesh. The mesh itself is represented by 31 individual springs to model also a crowning.
- Variation of the bearing clearance: For a bearing with d=320 mm and clearance C3 (305 µm to 225 µm) a variation of ±40 µm is used, this may be conservative.

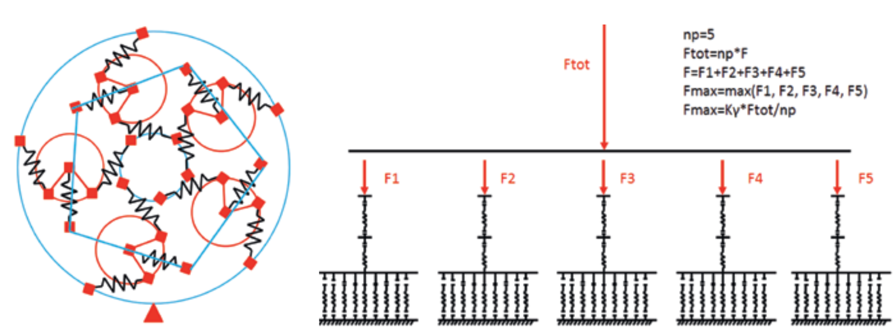

Figure 9—Spring model of a planet stage with five planets. Left: meshes and Flexpins as springs. Right: Corresponding model with gear meshes modeled finely.

- Flexpin: Here, two errors are considered. The positioning error (using quality IT6 on the center distance, giving a tolerance of ±80 µm, again somewhat conservative) and the concentricity error (between pin and sleeve, assuming IT5, giving ±50 µm, again somewhat conservative).

These errors were then determined for all five pins using *Microsoft Excel* number generator. A total of 20 random numbers for each of the errors in the five Flexpins were used and added up giving twenty experiments. Within the above-defined range of the errors, a random number / value for the error was used (using *Microsoft Excel* to determine a random number using a constant probability distribution). So, a random error in the bearing clearance variation (variation from bearing to bearing) of 40 µm to +40 µm, a random error in the flex pin position of -80 µm to +80 µm, a random error in the gear pitch of -20 µm to +20 µm and a random error in the concentricity of the Flexpin pin to sleeve of -50 µm to +50 µm was defined. The random errors were then added up to give five total errors for each planet. The procedure was repeated twenty times to give twenty random error distributions for the planetary stage.

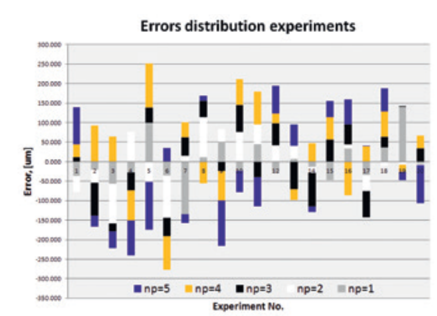

Figure 12—Resulting manufacturing errors for the five planets, shown for 20 random experiments.

Now that the manufacturing errors and gaps in the gear meshes are defined, the force distribution among the five pins may be calculated from the known spring stiffness values. This is done for 20 random manufacturing error groups. From the Flexpin forces F_1, F_2, F_3, F_4, F_5, load distribution factor K_γ may be calculated. The average value is found at K_γ = 1.13 and 95 percent of all values are below K_γ = 1.14.

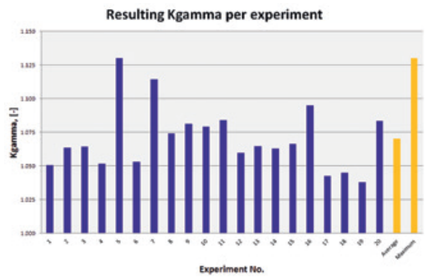

Figure 13—Resulting K_γ *for 20 experiments, average and maximum value.*

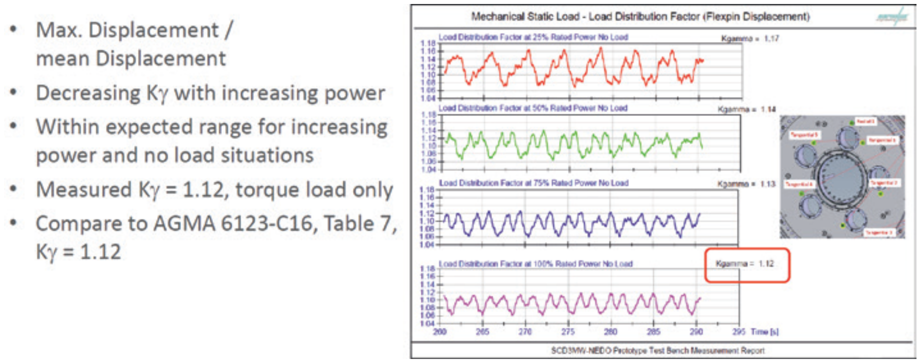

Figure 15—Measurement of load sharing factor (calculated from five measurements of Flexpin deformation), only torque applied, for different torque levels (Ref. 9).

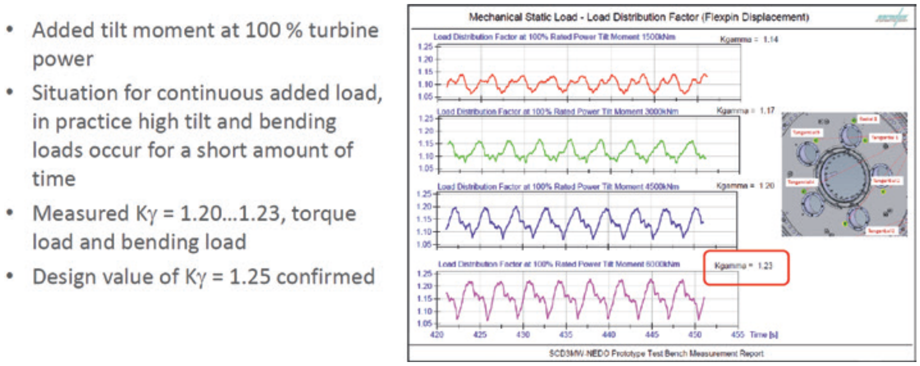

Figure 16—Measurement of load sharing factor (calculated from five measurements of Flexpin deformation) with bending moment applied, for different torque levels (Ref. 9).

Experimental Measurement of Load Distribution

The SCD drive train was subjected to operating loads and the Flexpin deformation was measured. Measurement over time showed a fluctuation of the load-sharing factor, possibly induced by the heavy masses present in the gearbox that are superimposed to the external torque load. Two types of tests were conducted, one where only torque load was applied and a second test where the torque load was superimposed with a bending moment corresponding to the bending moment as experienced in a typical wind situation. Note that the bending moment has a major influence on the load sharing in this design (see exploded view below) as the gearbox is an integral part of the whole load-bearing structure. Also, in the load path there is the main bearing integrated into the gearbox and any clearance or stiffness of the main bearing contributes to a tilting of the planet carrier and therefore affects the load distribution. This is an effect that was not relevant or not considered in all other studies shown here and the additional results generated in this study are worth mentioning. The resulting load sharing factor K_γ = 1.23 was found, well above the load sharing factor under pure torque only. However, the value found in the measurement confirmed the value used for design at K_γ = 1.25.

Figure 14—Test of the drive train under torque and bending load. Blue part in the background: E-motor to generate the torque load. Yellow part: torque coupling. Grey box with angled top: device to apply bending moments (Ref. 9).

Note that the above measured value at K_γ = 1.12 happens to correspond to the value given in AGMA 6123, for five planets, application level 4 with flexible mounts. Application level 4 with flexible mounts is for "high quality, high speed, gas turbine/generator drives, military marine" applications. Wind turbines are classified there as application level 2 in general, there is no specific application level for wind turbines with Flexpins mentioned.

Shape Optimization

Motivation

During the above design, analysis, manufacturing, and testing of the Flexpins, it became apparent that manufacturing costs are largely independent of the pin shape while the load distribution among the planet greatly benefits from a lowered pin stiffness. Optimizing the pin shape to reduce its stiffness while keeping stress levels was attempted to have the best possible design if and when the need for a higher torque main gearbox arises.

Flexpin Pin Shapes Compared

Others have worked on optimized pin shapes earlier. In the study (Ref. 6), five designs are compared.

1. Conventional design / no Flexpin
2. Flexpin with original design by Ray Hicks (see Figure 17, left, for pin shape)
3. Flexpin with circumferential groove (see Figure 17, second from left, for pin shape)
4. Flexpin with spindle shape (see Figure 17, second from right, for pin shape)
5. Flexible conventional planet pin supported on both sides (see right side of Figure 17)

The target in these optimizations is to achieve the lowest stiffness (hence best load sharing among the planets) while not overstressing the pin. While the original Flexpin (Figure 17, left) was strictly cylindrical, the most common design uses a series of several cylinders (second design from left). Montestruc then further improved the design by using two tapered halves. The purpose of the below optimization is to further refine this design to achieve near-constant stress distribution along the pin.

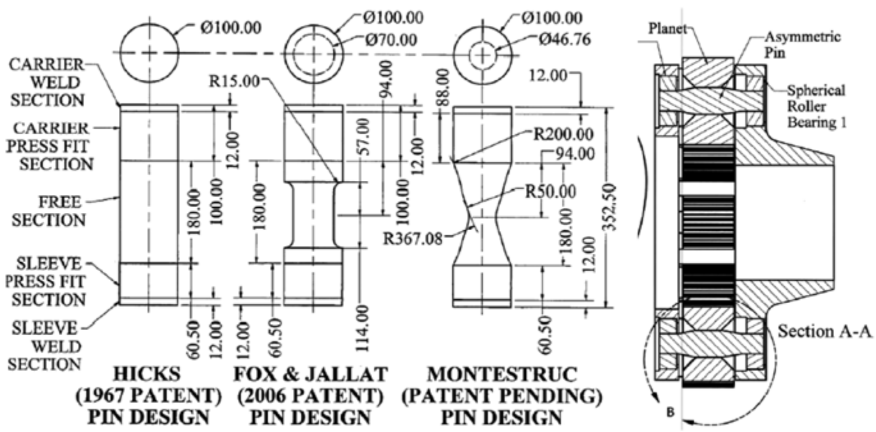

Figure 17—Different pin shapes compared (Ref. 6).

Shape Optimization

Based on the bending moment distribution along the pin, the required diameter at each point along the pin axis may be determined, resulting in an even stress level along the pin length (Ref. 20). Bending moment from left to right along the pin length is shown below.

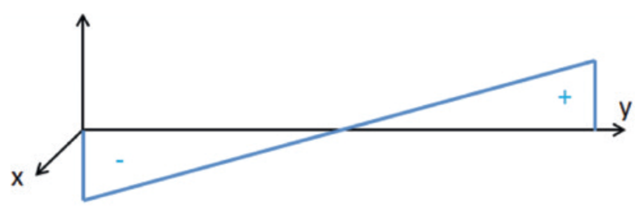

Figure 18—Bending moment over free length of Flexpin (vertical axis) vs. length / y-coordinate.

Bending moment, bending stress and required moment of resistance are then:

$$M_b(y) = F * \left(\frac{1}{2} - y\right), \sigma_{bzul} = \frac{M_b}{W_{erf}}, W_{erf} = \frac{M_b}{\sigma_{bzul}} \quad (1)$$

From this, the required pin diameter along the coordinate y can be calculated:

$$\frac{\pi * d_{erf}^3}{32} = \frac{F * \left(\frac{1}{2} - y\right)}{\sigma_{bzul}}, d_{erf}(y) = \sqrt[3]{\frac{32 * F * \left(\frac{1}{2} - y\right)}{\sigma_{bzul} * \pi}} \quad (2)$$

Note the above only considers bending moment. The resulting function, if plotted, gives a convex shape of the two halves of the pin, see below Figure, left:

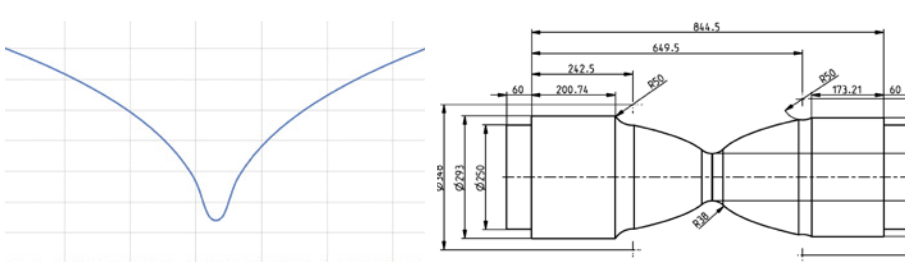

Figure 19—Resulting pin shape, considering bending stresses only, such that the stress level is constant along the pin length (note that in the middle, theoretically, the pin diameter would be zero).

The above shape (Figure 19, left), having a constant nominal bending stress along the longitudinal axis, serves as a basis for to design of the pin shape (Figure 19, right). In the middle of the pin, a cross-section is added such that the shear stress in the thin section is like the bending stress to the left and right. Furthermore, radii and relief grooves are incorporated, minimizing stress raisers. Analytical and FEM-based calculations are then used to confirm the even stress distribution below acceptable levels. Note that since the press fits between the pin of the Flexpin (2), on the lower left side of Figure 20, and the single-walled carrier (1) has a different stiffness than the one to the sleeve (3). Detailed FEM calculations showed that it is necessary to change the shape of the pin to an asymmetrical shape as shown in Figure 20, right.

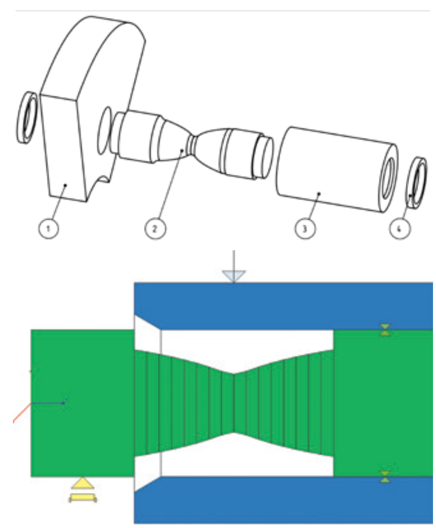

Figure 20—Top: Design with optimized pin (2) shape. Single-walled carrier (1) and sleeve (3). (Ref. 20). Bottom: Calculation model using two Timoshenko beams (green representing pin, blue representing sleeve). Press fit between pin and carrier and between pin and sleeve is by rigid connectors (yellow symbols).

Comparative Strength Assessment on Shape Optimized Flexpin Shapes

For a wind turbine of similar design as discussed above, now targeting 8 MW instead of 3 MW rated power, an initial design of a shape-optimized Flexpin of approximately 600 mm length was assessed. As the FEM analysis and stress assessment using gearbox torque time series is computationally expensive, a preliminary assessment using the nominal stress concept based on FKM guideline (Ref. 1) is used. FKM guideline method is preferred over DIN 743

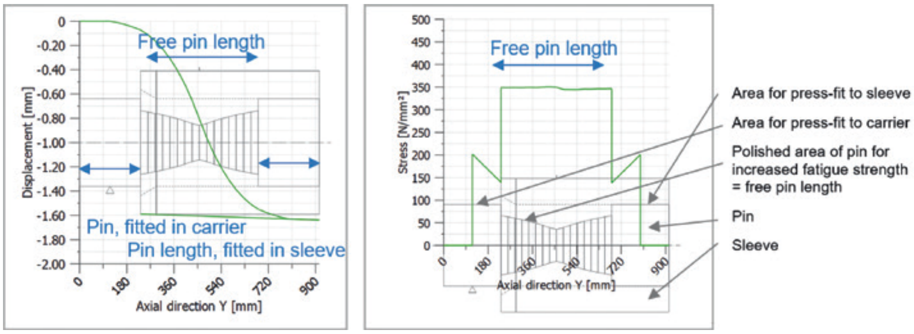

Figure 21—Left: Deformation. Right: Equivalent stress. Note: the nominal stresses (not considering notches/fillet radii) are now nearly constant along the free pin length.

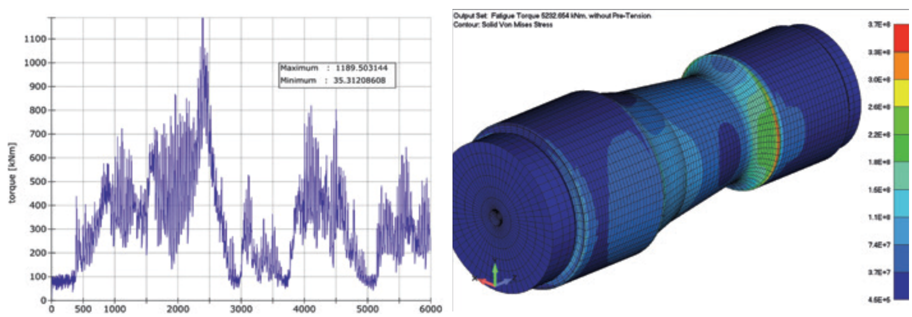

Figure 22—FEM based strength assessment of 3 MW MGB Flexpin. Left: Time series of torque used for fatigue rating of Flexpin. Right: Stress level in the pin at nominal torque.

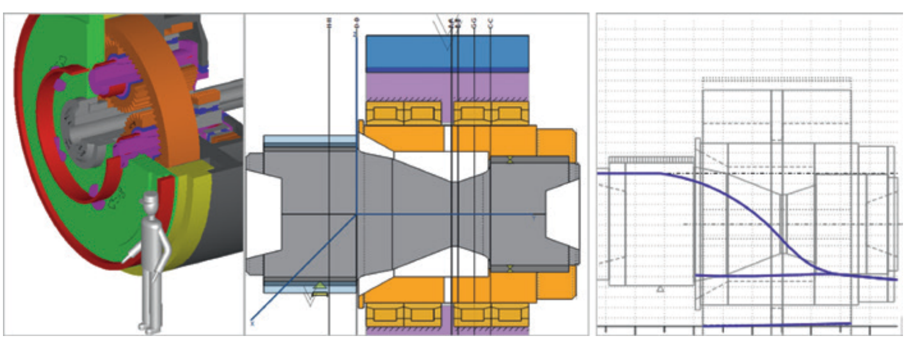

Figure 23—Left: 8 MW MGB model for analytical strength assessment. Middle: Flexpin model with optimized pin shape for comparative strength assessment. Right: Flexpin deformation (blue lines) based on Timoshenko beam model calculation, indicating that shape of Flexpin is suitable for keeping planet gears in parallel to gearbox axis under load.

(Ref. 2) here as the latter neglects shear stresses from shear forces which are relevant for short beams as present in the Flexpin pin. For this, the Flexpin design for which the FEM-based verification had been done and accepted by the certification agency along typical guidelines Refs. 3 and 4 earlier (for the 3 MW gearbox), were analyzed using FKM guidelines. In this, the rated torque, and a conservative assumption for the stress ratio (R=0) were used.

The resulting safety factors were then compared, and it was found that the Flexpin for the 8 MW gearbox displays slightly higher safety factors than the Flexpin for the 3 MW gearbox. In this, the technological and statistical size factors K_{dm} and K_{dp} are considered to account for the influence of larger part size for the 8 MW gearbox. Ultimate tensile strength at 1,250 MPa and yield strength at 1,050 MPa values were defined as target values in the manufacturing drawings and discussed with the forging company producing the forgings with a machining stock. The effect of the surface hardening by nitriding was neglected in the strength assessment as the part size was now such that the hardening depth achievable by nitriding was in the range of the depth of the stress concentration.

Conclusion

Flexpins are used in wind turbine MGB and other planetary gearboxes. It helps threefold:

- It improves the load sharing among the planets, in particular if the number of planets is higher than three. This is expressed in the gear rating with (a low) factor K_γ.
- It improves the load distribution along the gear face width. This is expressed in the gear rating with (a low) factor $K_{H\beta}$.
- It allows for the use of single-walled carriers where the planet pins are supported on one side only.

A low stiffness of the Flexpin is desirable to maximize the effect in the above points 1) and 2). While a thinner Flexpin pin results in lower stiffness, it also results in higher stresses. Optimizing the pin shape allows for a constant stress design, thereby maximizing the flexibility while keeping the stress levels within acceptable limits. As opposed to prior state-of-the-art, where cylindrical and other shapes are used, a parabolic shape, used in a symmetrical arrangement, is proposed here.

Furthermore, using simple spring models, the load-sharing factor K_γ may be predicted reasonably well. A gap–spring model was used to consider manufacturing and positioning errors along with component and gear mesh stiffness values. Numerical experiments using random error distributions were conducted and the 95-percentile value for K_γ was found at K_{γ_95} percent = 1.14. This was close to the value found in torque load test at $K_{\gamma\_torsion}$ = 1.12 yet still somewhat conservative. If in the test also bending loads were introduced, the K_γ value reached up to $K_{\gamma\_bending}$ = 1.23 which was still within the range defined by the value used in the gear design, as stipulated in design guideline (Ref. 3), at K_{γ_design} = 1.25.

As with respect to the design and manufacturing process of the Flexpin, experience has shown that:

- The use of a beam model for initial design of the Flexpin, in particular the pin, is sufficiently accurate for a preliminary design only.
- The beam model, where typically the pin is rigidly supported on

one side to represent its fit in the carrier and where the pin and the sleeve are typically rigidly connected to represent the fit between the two, is not accurate enough for a final design.

- FEM calculations considering the non-linear behavior of the press fits are required for design and verification of the final shape of the Flexpin and its deformation behavior.
- By introducing tilting stiffnesses in the beam model and tuning them such that the beam model yields similar deformation results as the FEM model, greatly improves the accuracy of the beam model. This lowers the number of FEM calculations needed to arrive at a final pin shape.
- Relief grooves in the pin lower stress concentrations induced by the press fits.
- Pin ultimate tensile and yield strength may be defined at 1,100–1,200 MPa to 900–1,000 MPa respectively. These levels may be achieved with commonly used steels such as 34CrNiMo6 and heat treatment applied after near-net shape machining.
- Nitriding, induction hardening, or case carburizing combined with polishing of the pin results in elevated part strength levels. The strength increase was assessed by introducing respective rating factors as per Ref. 1 and Ref. 2.
- The author has no experience with the shot peening of the Flexpin pin. Industry experience with similar parts proves the potential of the process.
- The press fits used were at 0.15 percent overlapping and proved to be working well in the field. No oil creep through the press fits was observed.
- A grinding or hard-turning operation to finalize the bearing seat after fitting the sleeve onto the pin is necessary.

The use of Flexpins in gearboxes allows for maximized torque density. Due to the higher material and manufacturing costs, it has not gained wide use. However, in gearboxes where the planet carrier only has one wall, it indeed solves the resulting issues elegantly.

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Plastic Gear Testing Methods—Characterization of Crucial Material Data Required for Reliable Design of Plastic Gears

Dr. Damijan Zorko, Rok Kalister, and Dr. Borut Černe

High-performance plastic gears are increasingly replacing metal gears in several applications due to the many advantages they exhibit. The main ones are having lower weight, no need for lubrication, cheaper mass production, significantly better NVH (noise, vibration, and harshness) behavior, and chemical/corrosion resistance. Most plastic gears are produced by injection molding, which enables great design flexibility, e.g., joining several machine elements into one molded part, while also gear geometry modifications like enlarged root rounding or altered profile shapes are possible (Ref. 1).

Plastic gears have been used since the 1960s when they were initially used for simple motion transmission applications. Over the years, with the development of new and improved plastic materials, the technology started to make its way into power transmission applications. Until recently, plastic gear drives were employed for applications with power up to 1 kW, however, lately, there have been attempts to use high-performance plastics in gear drives exceeding the 10-kW mark.

An extremely wide selection of different plastic materials is currently available on the market. A major limitation, however, is a huge gap in gear-specific material data on these materials, which is a problem that has been persisting for decades now. Providing a step towards a solution is the German guideline VDI 2736, which proposes design rating methods (Ref. 2) along with testing procedures (Ref. 3) to be followed to generate reliable data required in the gear rating process. This paper delves into the current state of the art in plastic gear testing, providing a comprehensive overview of employed testing methods, supplemented with case studies.

Plastic Gear Design Overview—Which Material Data Is Required?

To ensure a reliable operation of the gearbox each gear needs to be appropriately designed to avoid failure within the required lifespan and operating conditions. Plastic gears can fail due to different failure modes, i.e., fatigue, wear, or viscoplastic deformation, which is usually thermally induced. Examples of the possible failure modes are shown in Figure 1. The fatigue failure mode can result in root fracture (Figure 1a), flank fracture, or in some cases also pitting. Out of the three, the most common fatigue failure mode is root fracture, while the flank fracture is often correlated with unfavorable contact characteristics of the gear pair, and pitting was only observed in some oil-lubricated cases.

There is currently still no international standard available for the mechanical design of plastic gears, which would provide all the required tools and rating procedures to conduct design control against all possible failure modes. The most up-to-date and comprehensive is the German guideline VDI 2736: Part 2 (Ref. 2) where the design rating procedures for each failure mode are proposed. A flowchart representing the entire failure mode control process is shown in Figure 2. While the proposed procedures are feasible, the real problem arises as each control model requires some gear-specific material data, which is very limited. To patch this problem, VDI 2736:Part 4 (Ref. 3) provides testing procedures on how to generate the required material data.

Figure 1—Possible failure modes for plastic gears: a) root fatigue, b) wear, c) viscoplastic deformation at thermal overload.

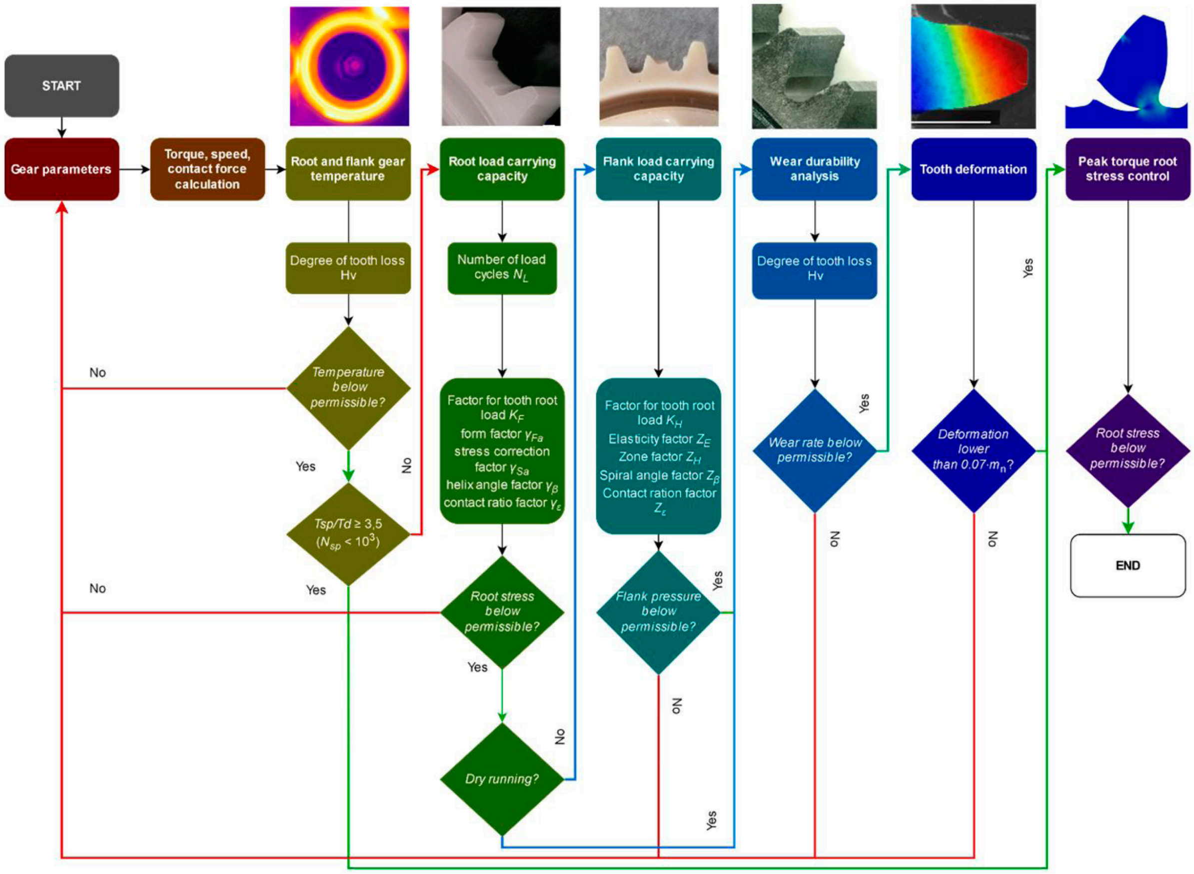


Figure 2—Failure mode control process within the plastic gear's design phase as recommended by the VDI 2736: Part 2 guideline for cylindrical gears.

Gear's Operating Temperature

Gears heat up during operation. An exemplary temperature measurement conducted by a thermographic camera is shown in Figure 3. Friction between the meshing teeth and hysteretic effects are the main reasons for the temperature increase in plastic gears. The rate of heat generation and the resulting temperature rise depend on several factors, e.g. torque, rotational speed, coefficient of friction, lubrication, thermal conductivity, convection, gear geometry, etc. To ensure the reliable operation of a plastic gear, its operating temperature needs to be lower than the material's permissible temperature for a continuous load.

The first rating point is the prediction of the operating temperature to ensure no thermal overload (Figure 1c) occurs under the specified operating conditions. The VDI 2736 guideline employs here a slightly modified Hachmann-Strickle model (Ref. 4), which was presented in the 1960s. The Hachmann-Strickle model was later supplemented by Erhard and Weiss (Ref. 5). The guideline goes further and proposes a model for calculating the temperature in the tooth's root:

$$\vartheta_{Fu\beta} \approx \vartheta_0 + P \bullet \mu \bullet H_v \bullet \left(\frac{k_{\vartheta,Root}}{b \bullet z(v \bullet m)^{0,75}} + \frac{R_{\lambda,G}}{A_G} \right) \bullet ED^{0,64} \tag{1}$$

and on the flank:

$$\vartheta_{Fu\beta} \approx \vartheta_0 + P \bullet \mu \bullet H_v \bullet \left(\frac{k_{\vartheta,Flank}}{b \bullet z(v \bullet m)^{0,75}} + \frac{R_{\lambda,G}}{A_G} \right) \bullet ED^{0,64} \tag{2}$$

The equations are almost the same, as there is a difference only in one factor, the k_ϑ, where the guideline provides different values for the root region and the flank region. In the proposed equation the most important factor is the coefficient of friction, which is dependent on several parameters, e.g. material combination, temperature, load, lubrication, sliding/rolling ratio, siding speed, etc.

The VDI model can be implemented in a rather straightforward manner, while the accuracy of results is limited. Several scientific studies, e.g., Fernandes (Ref. 6), Casanova (Ref. 7), Černe (Ref. 8), were presented recently which dealt with this topic and each one proposed different, advanced, numerically-based temperature calculation procedures.

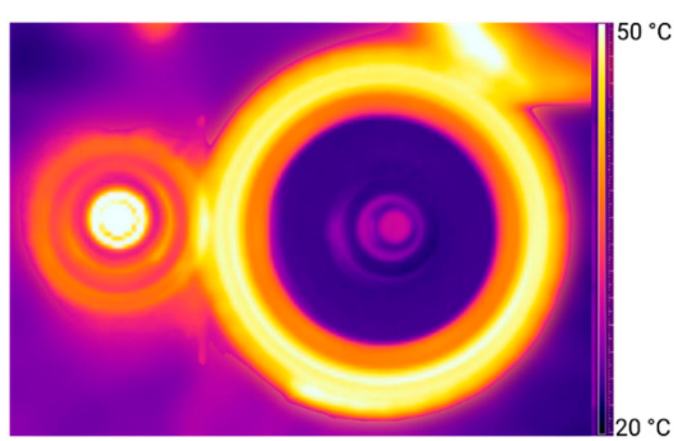


Figure 3—Thermal image of a Steel/Plastic gear pair during operation.

Root Stress Control

To avoid root fatigue fracture, which is a fatal failure, the root stress σ_F in a gear needs to be lower than the material's fatigue strength limit σ_{Flim} for the required operating lifespan (Figure 4). To account for unexpected effects some additional safety S_F is usually also included.

$$\sigma_F \leq \frac{\sigma_{Flim}}{S_F} \tag{3}$$

To calculate the root stress the VDI 2736 guideline proposes the same equation as provided by the DIN 3990 (Method C) (Ref. 9), which is a standard for steel gears:

$$\sigma_F = K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha} \cdot Y_{Fa} \cdot Y_\varepsilon \cdot Y_\beta \cdot \frac{F_t}{b \cdot m} \tag{4}$$

The guideline further simplifies the equation by assuming that for plastic gears, if the condition $b/m \leq 12$ is met, the root load factor can be defined as $K_F = K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha} \approx 1 \ldots. 1.25$.

While Equation 4 is simple to use and familiar to any gear design engineer, the major drawback is that it does not account for the load-induced contact ratio increase, hence overestimating the actual root stress values. A more accurate root stress calculation can be achieved by employing numerical manners, e.g., by a FEM simulation. FEM-based methods are however labor and cost-intensive.

Assuming the root stress for the gear design under evaluation is calculated, it needs to be compared to a fatigue limit σ_{Flim}, which is a material property and needs to be characterized by extensive gear testing on a dedicated test bench. For plastic materials the σ_{Flim} is temperature dependent, therefore several S-N curves generated at different gear temperatures are required (Figure 4).

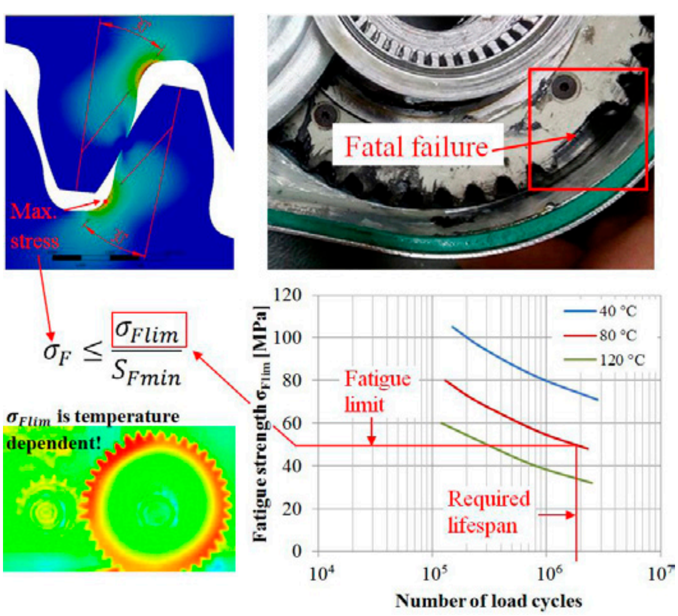


Figure 4—Temperature-dependent S-N curves are needed to conduct root strength control.

Flank Pressure Control

Flank fatigue failures have been observed mostly in oil-lubricated applications with plastic gears. Assuming the operating temperature does not exceed the limit temperature for continuous operation, in dry running conditions plastic gears usually fail due to root fatigue or wear. Thus, for dry running conditions, this step is not included, as it is expected that the wear of flanks will be much more severe than the flank fatigue. To avoid flank fatigue failure in lubricated contacts, the flank pressure σ_H needs to be lower than the material's fatigue strength limit σ_{Hlim} for the required operating lifespan. To account for unexpected effects some additional safety S_H is usually also included.

$$\sigma_H \leq \frac{\sigma_{Hlim}}{S_H} \tag{5}$$

To calculate the flank pressure the VDI 2736 guideline again proposes the same equation as provided by the DIN 3990 standard:

$$\sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_t}{b \cdot d_1} \cdot \frac{u+1}{u} \cdot K_A \cdot K_V \cdot K_{H\beta} \cdot K_{H\alpha}} \tag{6}$$

if the condition b/m≤12 is met, the same simplification as in root stress calculation applies also to the flank load factor $K_F = K_A \cdot K_V \cdot K_{H\beta} \cdot K_{H\alpha} \approx 1 \ldots. 1.25$.

Once the flank pressure for the gear design under evaluation is calculated, it needs to be compared to a fatigue limit σ_{Hlim}, which is a material property and needs to be characterized by extensive gear testing on a dedicated test rig. For plastic materials, again, the σ_{Hlim} is temperature dependent, therefore several S-N curves, with flank fatigue as a failure mode, generated at different gear temperatures are required.

Wear Control

Wear is a common damage mode for dry runs and also some grease-lubricated applications with plastic gears. It can lead to a fatal failure where teeth are worn to the degree that they break instantly under load or that fatigue cracks originate at the worn section (Figure 5). In several applications , even though the gears are still intact, they might not fulfill the application requirements if they are worn to an acceptable degree, e.g., high precision applications. The following equation:

$$W_m = \frac{T_d \cdot 2 \cdot \pi \cdot N_L \cdot H_V \cdot k_w}{b_w \cdot z \cdot l_{Fl}} \leq 0.2 \cdot m_n \tag{7}$$

is proposed by the VDI 2736 guideline for wear control. The only material-dependent parameter is the wear factor k_w, which considers the wear properties of the material pair under evaluation. It is important to note that the wear behavior of plastic gears is dependent on both materials in pairs.

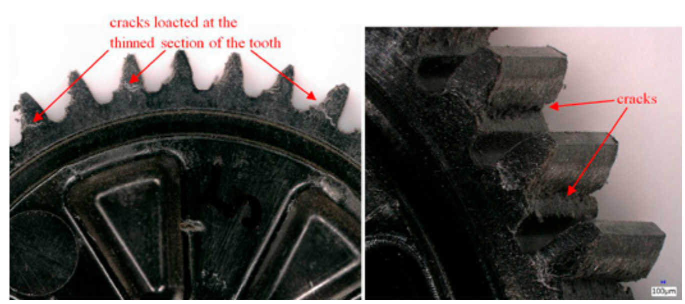


Figure 5—Severe wear, leading to fatigue-induced cracks at the worn section of the tooth profile.

Testing Methodologies

A complete overview of the current state-of-the-art testing methods is provided in the following sections. Where applicable, problems are highlighted, and solutions are proposed. All the presented results were generated on the RD Motion's MTP series test bench by testing the VDI 2736: Part 4 size 1 geometry gear pairs (see Table 1).

Test Samples

To complete each control step for a possible failure mode, as presented in Figure 2, gear-specific material data is required. This data is obtained by dedicated gear testing methods. Currently, there are no standardized test procedures available, which could be employed to generate this data. The most up-to-date is the VDI 2736: Part 4 (Ref. 3) which provides comprehensive recommendations for the testing methodology. As per the guideline, three gear geometries are proposed for experimental characterization. The main geometric parameters of the proposed test gear geometries are summarized in Table 1, more details can be found in Ref. 3. Being closest to the majority of practical plastic gear applications, the Size 1 geometry is most commonly used for testing. The lack of standardization results in several other gear geometries being dealt with in scientific and technical reports. It is however extremely important for the development of future plastic gear rating standards that the test sample geometries are unified similarly as in the vast majority of comparable standards dedicated to the characterization of material's mechanical properties.

The gear's manufacturing quality affects the stress state in the gear when under load (Ref. 10). Controlling the test sample's production quality is equally important for a reliable comparison of test data. The gear manufacturing quality is usually evaluated according to ISO 1328 (Refs. 11 & 12). For material characterization purposes, gears with the majority of rating parameters in quality 10 (or better) are recommended for testing. Besides the gear's geometrical quality, even more important is that the gears are produced without any significant weld lines and without voids. If during gear testing, the failure occurs on the weld line or at a void location the test result is not a function of a material property but rather of the defect in the gear because of a bad-quality sample production. Since the gear tests are used to generate gear-specific data on the material properties the failure should be a single function of the material's performance.

Test Rigs

There are three main test rig layouts used for gear testing. The back-to-back test rig, presented in Figure 6, is a very well-known concept that has been widely used for testing steel gears. For testing plastic gears, the basic concept of this test rig has some limitations. In a back-to-back test rig, the torque on the tested gear pair is applied by a rotational displacement of a loading clutch. Plastic gears deflect under load significantly more than steel ones. Due to the teeth deflection, some of the torque applied with a rotational displacement of the loading clutch is lost. Additional torque loss occurs during the test duration due to the viscous properties of plastic materials and the additional deflection of teeth due to creep. As plastic gears wear quite significantly during operation, another portion of torque loss occurs due

Parameter	Nomenclature	Unit	Size 1	Size 2	Size 3
Type of Gear	/	/	spur gear	spur gear	spur gear
Centre distance	a	mm	28	60	91.5
Normal module	m_n	mm	1	2	4.5
Number of teeth	z_1/z_2	/	17/39	30/30	16/24
Pressure angle	α_n	°	20	20	20
Gear's facewidth	b_1/b_2	mm	8/6	13/12	22/20
Tip diameter	d_{a1max}/d_{a1min}	mm	19.40/19.35	64.916/64.779	82.45/82.36
	d_{a2max}/d_{a2min}	mm	40.40/40.30	63.098/62.902	118.35/118.26
Root diameter	d_{f1max}/d_{f1min}	mm	14.902/14.610	55.916/55.779	61.917/61.215
	d_{f2max}/d_{f2min}	mm	35.866/35.691	54.498/54.301	97.824/97.122

Table 1—Test gear geometries, as proposed by the VDI 2736:Part 4 (Ref. 3).

to tooth wear. This problem can be solved by applying a continuously adjustable electromechanical or hydraulic torque application system, which significantly complicates the test rig's design and control, adding to the overall cost of the test rig. Another disadvantage when it comes to gear testing is that the center distance is fixed and determined by the master gear pair.

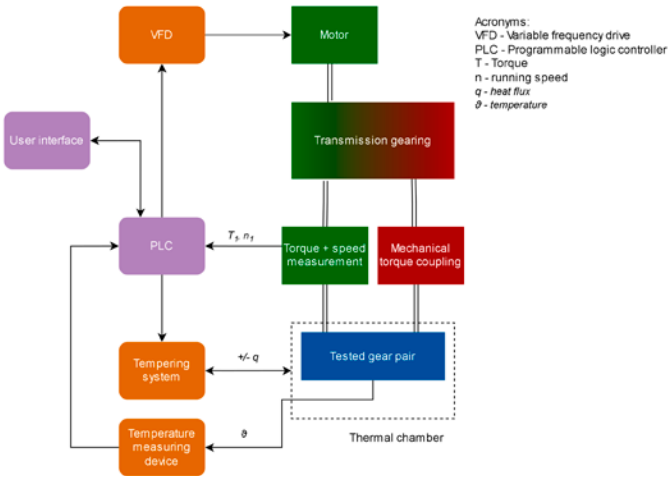


Figure 6—Schematical representation of a closed-loop, back-to-back gear test rig.

Another possible test bench layout is a mechanically open loop system, where on one side, the motion and power are applied by a motor, and on the braking shaft, the braking torque is usually applied by employing a brake or a generator. Such a test rig concept allows for a continuously adjustable center distance, enabling testing of several different gear geometries. By controlling the torque and speed on both sides, the load applied on the tested gear pair can be very accurately controlled.

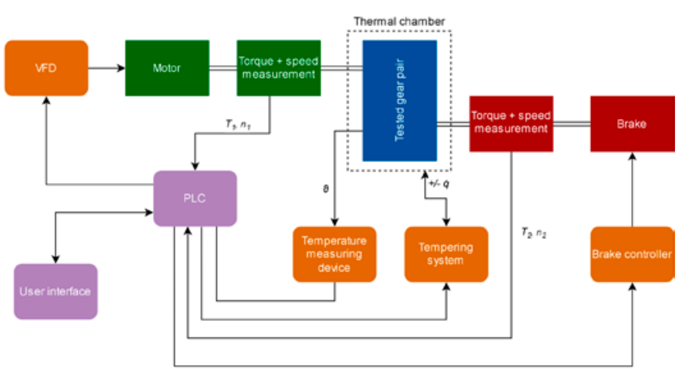


Figure 7—Schematical representation of an open-loop test rig.

Additionally, the open-loop type test rig can be formed of a pair of electric motors where one provides the input driving torque to the pinion, while the other acts as a brake on the driven side. The drive and brake shafts can be positioned in parallel one next to the other in which case the motors have to be connected to both shafts via belts or chain transmissions. A schematic representation od this configuration is shown in Figure 8.

The fourth possible layout is the pulsator test rig, also called a single tooth bending test machine (Figure 9). In this type of test rig, a single tooth is subjected to pulsating cyclic loading in the tangential direction relative to the gear tooth. The limitation of the test rig is that it can only be employed to study root fatigue, while other possible failure modes e.g. wear, pitting or thermal overload cannot be observed. Another limitation is that the load on the tooth is not applied in exactly the same direction as when gears are meshing, requiring a suitable analytical model to correlate the results with gear meshing conditions.

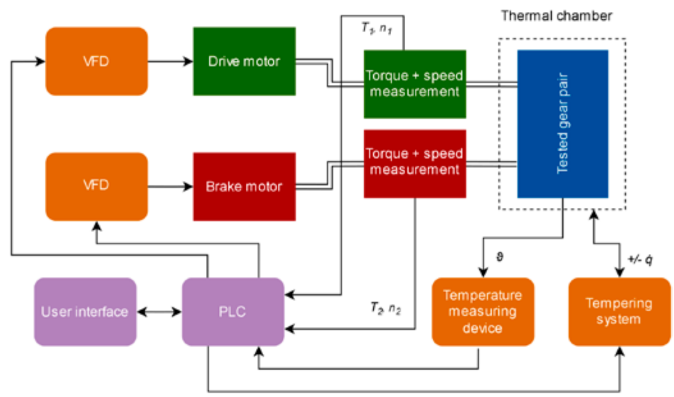


Figure 8—Schematical representation of an open-loop test rig with parallel driving/braking motor configuration.

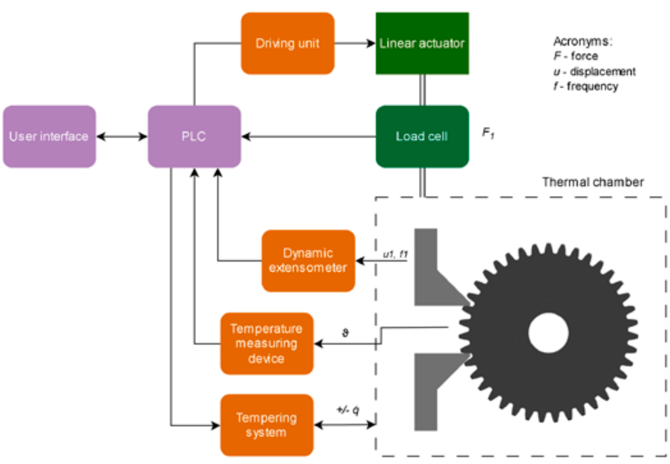


Figure 9—Schematical representation of a pulsator test rig.

Irrespective of the test rig design, the most important testing conditions, i.e., the transferred torque, the plastic gear's temperature, and the rotational speed need to be precisely controlled during the entire test. While torque and speed control can be quite easily achieved, controlling the plastic gear's temperature is a bit more challenging. Tests conducted for S-N curve generation are usually performed at a selected rotational speed and various torque levels. The rate of heat generation and the resulting temperature rise depend strongly on the transmitted torque as can be seen in Figure 10. A sophisticated gear-temperature control system is therefore required to control the plastic gear's temperature at a selected level, irrespective of the tested torque and rotational speed (Figure 11).

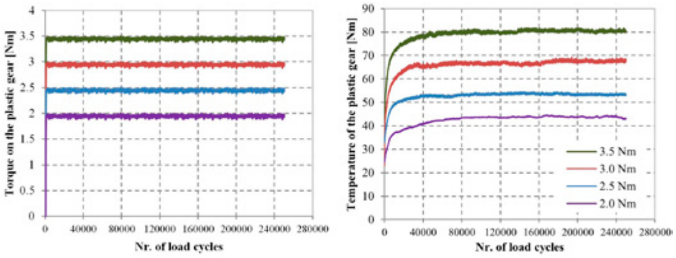


Figure 10—Tested loads and the resulting operating temperature measured on the plastic gear.

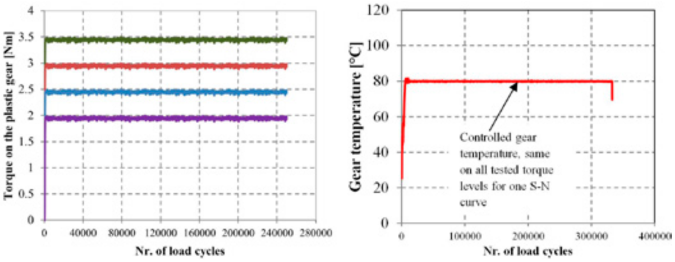


Figure 11—Tested loads and the controlled operating temperature of the plastic gear.

S-N Curve Testing

To avoid root fatigue failure, the root stress in a gear needs to be lower than the material's fatigue strength limit for the required operating lifespan. To account for unexpected effects some additional safety is usually also included. The information on the material's fatigue strength can be summarized in an S-N curve. To generate an S-N curve, several test repetitions need to be conducted at various loads, and all the samples need to be tested until a fatigue-induced failure occurs as shown in Figure 12. For gears, the S-N curves can be generated by extensive testing in a gear-on-gear application or by a single tooth bending test on a pulsator test stand. Both methods have their pros and cons.

In a gear-on-gear test methodology usually a combination of a steel pinion and a plastic gear is employed as presented in Figure 13. The steel/plastic combination is most appropriate for the S-N curve testing since the curve is a property of a single material. Therefore, the failure should occur on the gear of which the material is being evaluated. In the case of a plastic/plastic combination, the failure would be close to impossible to control, and a situation could occur where it would not be possible to induce a failure on a gear made of material under evaluation. Another problem with a plastic/plastic gear combination would be a significantly increased tooth contact, and the actual stress in the material would further deviate from the calculated one. The one calculated by the analytical equation (VDI 2736 or DIN 3990 or ISO 6336), FEA provides an accurate stress calculation if the numerical model is set up accordingly.

While operating, the gears heat up. Friction between the meshing teeth and hysteretic effects are the main reasons for the temperature increase in plastic gears. The rate of heat generation and the resulting temperature rise depend on several factors, e.g., torque, rotational speed, coefficient of friction, lubrication, thermal conductivity, convection, gear geometry, etc. The mechanical properties (strength, hardness, elastic modulus) of polymers and polymer composites are strongly temperature-dependent. Therefore, several S-N curves, generated for different temperatures of the tested sample, are required for the design of plastic gears. Precise temperature control of tested gear samples is therefore crucial for the characterization of S-N curves for plastic gears. Advanced stopping algorithms need to be applied as well since the test needs to be stopped instantly once the first tooth is fractured, see Figure 14.

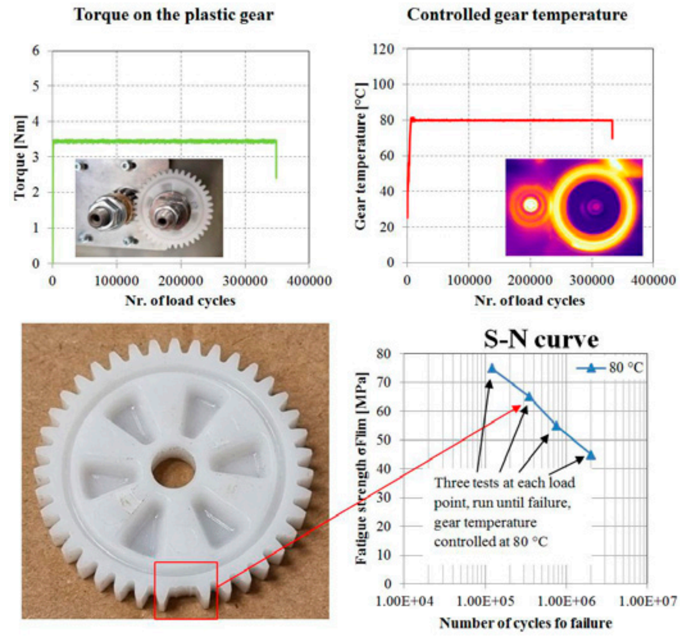


Figure 12—S-N curve generation; Tested gears need to be tested at least at four different load levels, where the torque is accurately controlled during testing. The operating temperature of the plastic gear needs to be controlled at a selected level at all tested torques. At least three test repetitions need to be conducted at each tested torque level to ensure repeatability. All tests need to be conducted until a fatigue-induced failure.

Figure 13—A combination of a steel pinion and a plastic gear is usually employed for the S-N curve generation. As the purpose of testing is to generate fatigue data on the selected plastic material, the failure needs to occur on the plastic gear. In a plastic/plastic configuration, the failure would be impossible to control, usually, both gears get damaged at the end of the test. Furthermore, the load-induced contact ratio increase would be even higher for a plastic/plastic gear configuration.

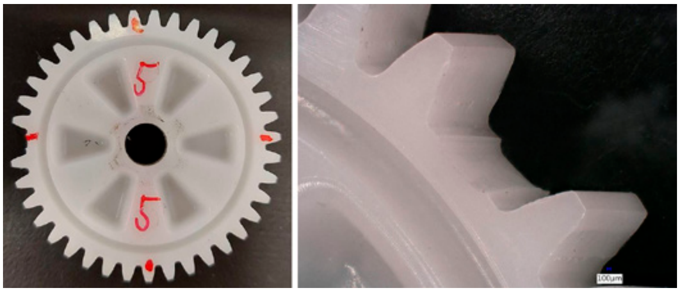


Figure 14—The root fatigue failure. The test should be stopped when the first tooth is fractured.

Wear Characterization

Wear behavior of plastic gears is also best studied by conducting gear tests. Reference gear pair testing is a far more complex testing method than the specimen-based tribological and fatigue tests, but more reliable results for the actual application can be acquired. Simple tribological tests, e.g. disk-on-disk can provide basic information about materials behavior in a rolling-sliding motion under non-conformal contact, but for an in-depth understanding of the wear behavior in the gear contact, gear testing needs to be conducted.

The contact conditions between the two meshing flanks are shown in Figure 15, rolling and sliding motion are present between the surfaces in contact. The direction of sliding and the frictional force are reversed when passing through the pitch point C. On the driven gear, the direction of sliding points is always towards the pitch point C, so the kinematic line is usually clearly visible on the worn gear surface. The main difference, when compared to the disk-on-disk test, is that with the disk-on-disk test, the sliding rate is constant all the time, and also the direction of the frictional force remains the same. The pin-on-disk test is even less suitable since there is only sliding motion present in contact without any rolling.

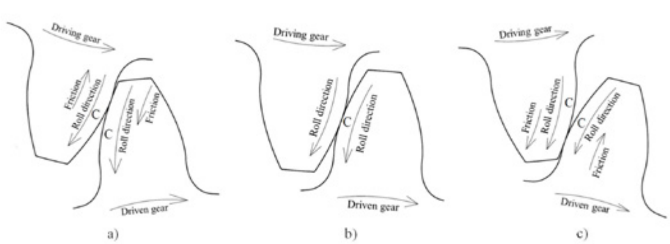


Figure 15—Contact conditions during gear meshing. The direction of friction changes once the contact passes the pitch point. The frictional force is on the driven gear always oriented towards the pitch point and vice-versa on the drive gear.

The gear meshing process is presented in Figure 16. The theoretical path of contact of the involute gears pair has the shape of a straight line. During operation, gears transfer torque, which results in a normal force F_{nY} acting in an arbitrary meshing point Y between the two teeth in contact (Figure 16a). The normal force F_{nY} can be decomposed to radial F_{rY} and tangential force F_{tY}. In involute gear pairs, the normal force acts along the path of contact. The gears start to mesh in point A, this is point A_1 on the flank of the drive gear and point A_2 on the flank of the driven gear. In the meshing area A-B, two pairs of teeth are in contact therefore the transmitted load is divided between them. Point B is the highest point of single-tooth contact for the driven gear. In the area B-D, the total load is transmitted only through one pair of teeth. Point D is the lowest point of single-tooth contact for the driven gear, at this point the next pair of teeth come into contact and the load in the area D-E is again transmitted via two pairs of teeth. Hence, the load on a single tooth is not constant during meshing along the path of contact. Meshing ends in point E, this is point E_1 on the flank of the drive gear and point E_2 on the flank of the driven gear. When gears are meshing from A to C, the flank part A_1C_1 on the drive gear is meshing with the flank part A_2C_2 on the driven gear. Due to the different lengths of the flank parts in contact, specific sliding occurs between the surfaces in contact (Figure 16b). Analogously, the same happens in the meshing part from C to E, except that when passing through the kinematic point C, the direction of sliding is reversed. Most sliding occurs in the root part of the tooth, where the greatest wear is to be expected. In theory, there is no sliding at pitch point C, only pure rolling. Due to tooth deflections, however, sliding is also present at point C. Such specific contact conditions can be best represented by a gear-on-gear test.

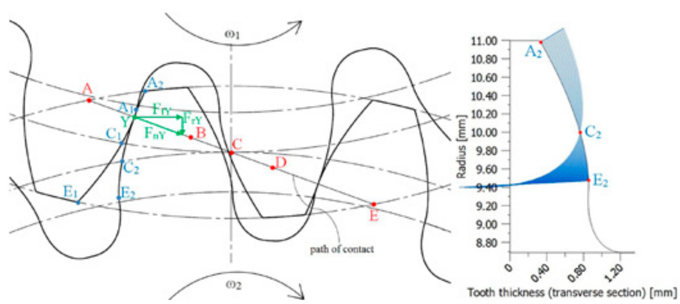


Figure 16—a) The theoretical meshing process of an involute gear pair; b) Representation of relative sliding along the active tooth profile.

Different wear characterization methods can be used as presented in Figure 17. The most common ones are the gravimetric method and the tooth thickness reduction method. When employing the gravimetric method wear is characterized as the loss of mass, while in the tooth thickness reduction method, the wear is determined as the reduced tooth's chordal thickness. Several advanced methods can also be used, e.g., image processing or optical measurements, however, these are more cost- and labor-intensive. The wear can be tracked during testing by conducting regular checkpoints or the wear is measured after a specified number of load cycles. Different stages of wear a presented in Figure 18.

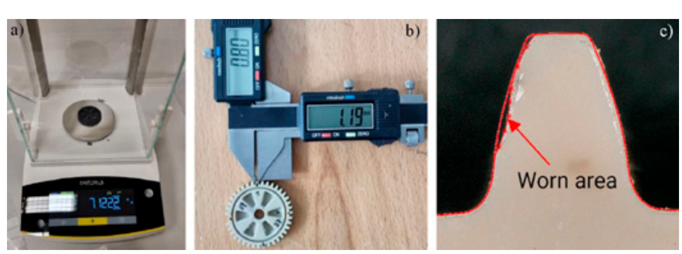


Figure 17—Wear measuring techniques: a) gravimetric method; b) tooth thickness reduction method; c) image processing method

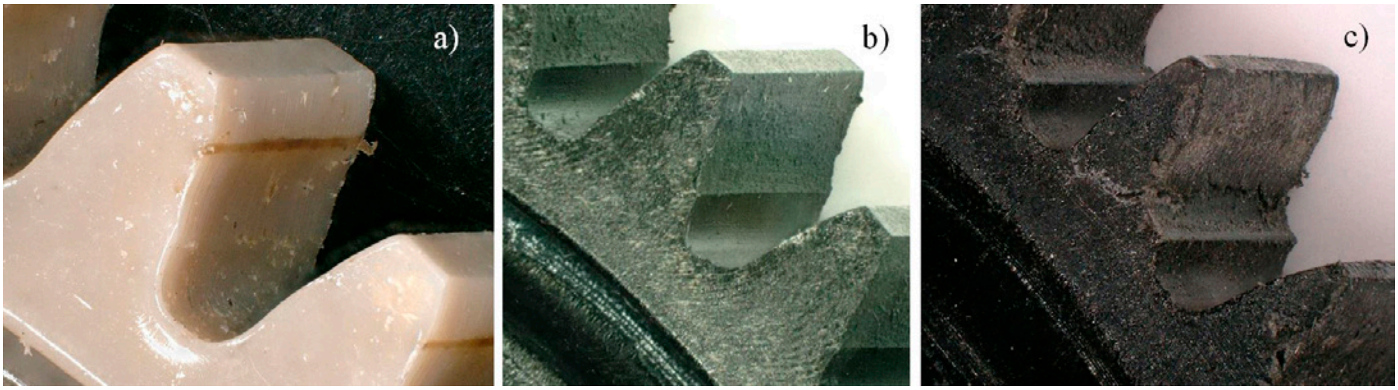


Figure 18—Wear in different stages: a) initial wear, the pitch region is visible; b) Significant wear, in practice usually still acceptable; c) Critical wear which led to failure.

COF Characterization

There are currently no methods that would enable to measure the coefficient of friction directly during gear operation. However, some methods enable the measurement of COF in conditions much closer to gear contact. The coefficient of friction can be assessed fairly well by the use of the disk-on-disk test configuration as shown in Figure 19. In such a test configuration two disks made of selected materials are pressed together with a controlled force and rotate, each with a respective rotational speed, as to generate a rolling and relatively sliding contact between them. All possible material combinations can be tested in such a test configuration, however, when testing plastics, the plastic sample's temperature must be rigorously controlled as the coefficient of friction is also temperature dependent.

Another possibility to get a very good assessment of the COF is by employing an implicit characterization method as proposed by Černe et al. (Ref. 13). The flowchart of the method is presented in Figure 20 and more details can be found in Refs. 8 and 13.

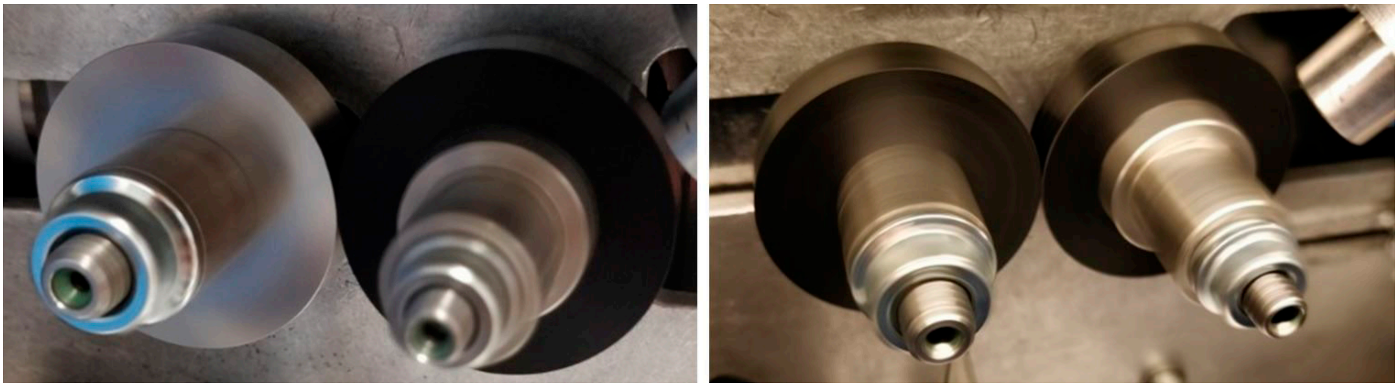


Figure 19—Disk-on-disk test configuration.

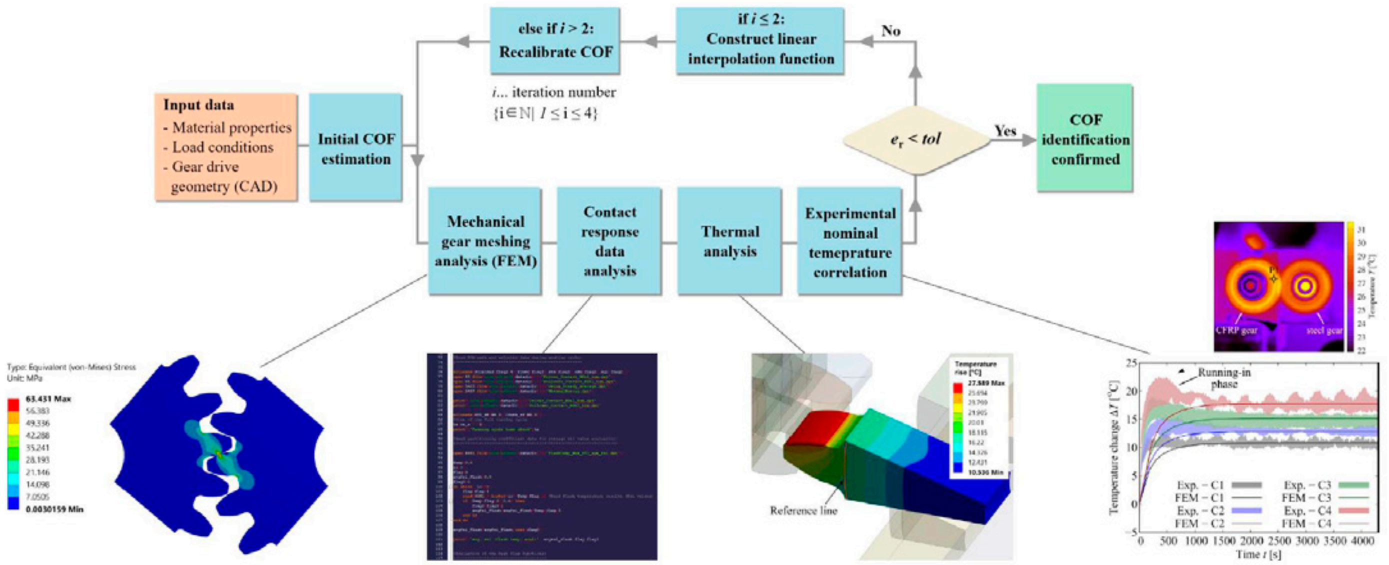


Figure 20—Methodology for the implicit characterization of the coefficient of friction (Ref. 13).

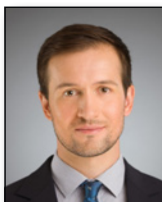
Conclusions

Plastic gears offer several advantages over metal gears. With an increase in e-mobility and the growing demands on the user experience, where the NVH needs to be held at a minimum, plastic gears show great potential. They also provide great benefits in terms of cost optimization and energy savings.

For the reliable design of plastic gears, several different failure modes need to be considered. The VDI 2736 guideline provides methods and models to control individual failure modes in the gear design phase. A major problem preventing the use of these methods is the lack of gear-specific material data, which is required to conduct the required design and control calculations.

Outlook

The lack of reliable gear-specific material data is still a major problem for the design of plastic gears. The data currently available in the guidelines and commercial software packages was in large part generated in a non-consistent way without a traceable and repetitive process. For the generation of reliable material data, a standard is required that would define the test geometries, sample-production process, sample quality requirements, testing methods, and post-processing of the test data. With the emergence of an international standard and high-quality material data generated according to the procedures defined by the standard, the actual growth potential of plastic gears would be reached.



Dr. Damijan Zorko is a Co-CEO at RD Motion. He studied Mechanical Engineering at the University of Ljubljana and received his Ph.D. in 2019. Having 15 years of experience in gear transmissions, he was deeply involved in developing RD Motion's modern test benches and testing methods for experimental research on gears.

Rok Kalister is a VP of technology and product R&D at RD Motion. Holding a master's degree in Mechatronics Engineering at the University of Ljubljana, he has extensive knowledge in control systems design and product development, with a strong focus on polymer gear design and power transmission testing rig design.

Dr. Borut Černe is a cofounder and Co-CEO at RD Motion. With more than 11 years of experience in the fields of solid mechanics, polymer testing, programming, engineering design, and power transmissions, he holds a pivotal role in R&D operations and test rig development at the company.

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Nidec Machine Tool America

BOLSTERS ADDITIVE MANUFACTURING EXPERTISE WITH NEW APPLICATION ENGINEER HIRE

Nidec Machine Tool America has announced the appointment of Tobias Dornai as additive manufacturing application engineer. In this role, Dornai will play a key role in supporting Nidec Machine Tool America's growing additive manufacturing business and customer base.

Dornai brings valuable experience in additive manufacturing, with a proven track record of success in his prior position with Solideon in California. He will be responsible for a variety of tasks, including:

- Collaborating with customers to identify and develop additive manufacturing solutions for their specific needs.
- Providing technical support and expertise on Nidec Machine Tool America's laser powder DED additive manufacturing equipment.
- Assisting with the creation of demonstrations and proof-of-concept projects.
- Optimizing printing processes and developing production recipes.

"We are thrilled to welcome Tobias to the Nidec Machine Tool America team," said Dwight Smith, vice president of additive manufacturing and marketing at Nidec Machine Tool America. "His knowledge and experience in additive manufacturing will be invaluable as we continue to expand our offerings and support our customers in achieving their manufacturing goals."

Dornai said, "As I learn about the advanced technology implemented in the LAMDA DED systems, I am very impressed at how the monitoring/feedback system maintains a specific and controlled melt pool. The local shield system is also very important, as it allows large-scale laser powder DED of reactive materials without an inert gas enclosure. He added, "I am excited to join the team at Nidec Machine Tool America."

nidec.com

Solar Atmospheres

ADDS 3RD CAR BOTTOM AIR FURNACE

Solar Atmospheres of Western PA recently commissioned their third car bottom air furnace manufactured by Heat Treat Equipment Inc. This large Class 2 air furnace with a maximum operating temperature of 1350°F measures 60-in. wide x 38-in. high x 168-in. deep. The newly installed equipment joins two other HTE car bottom furnaces that are 14-ft. long and 20-ft. long respectively.

Bob Hill, president of Solar Atmospheres of Western PA and Michigan states, "The addition of this large air tempering/aging equipment compliments our five (5) state-of-the-art vacuum car bottom furnaces very nicely. Instead of hardening and triple tempering, this 6,000-pound H13 die exclusively in a vacuum environment, Solar can save our customers and our company over 100 hours of valuable and expensive vacuum processing time. After successfully hardening in vacuum at 1850°F +/- 10°F, the fully hardened die was transferred to the air car bottom furnace for the triple temper operation of 1025°F +/- 10°F. These large and uniform car bottom furnaces are a win/win for both the customer and for production - not exclusively for heavy parts but also when treating long components."

solaratm.com

Gear Research Institute

ELECTS EATON'S BEN SHEEN TO BOARD OF TRUSTEES

Eaton recently announced that Ben Sheen, chief engineer, Eaton's Mobility Group, was recently elected to the Board of Trustees for the Gear Research Institute (GRI) at Penn State

University. The GRI is affiliated with the American Society of Mechanical Engineers (ASME) and the American Gear Manufacturers Association (AGMA) to conduct research and development, consulting, and analysis for gear related needs.

"I am honored to be elected as a member of this prestigious board," Sheen said. "This is a great opportunity to continue to grow as an engineer and help develop industry-leading mobility solutions and technologies, including electrified vehicle transmissions, reduction gearing and differentials."

Sheen, who holds a bachelor's degree in mechanical engineering from the University of Wyoming, is currently responsible for supporting new product development and manufacturing capabilities within Eaton's ePowertrain Business Unit. His 20-year career with Eaton began with its Truck Group's heavy-duty transmission site in Shenandoah, Iowa, and for the past 13 years he worked at the Mobility Group headquarters in Galesburg, Michigan. His accomplishments include certifications within Six Sigma (Blackbelt) and Shainin RedX, AGMA Advanced Gear Engineering Certificate and multiple U.S. patents.

The GRI is an independent not-for-profit corporation, registered in the state of Pennsylvania. Over the past three decades, a significant amount of research and test data has been accumulated by GRI and published in many reports for sponsors. Previously published reports are available to members of the Gear Research Institute on a restricted basis.

eaton.com

Seco/Warwick

TO ESTABLISH MEXICO OFFICE

The American branch of Seco/Warwick has decided to expand its presence on the continent. Mexico is an important market for Seco/Warwick USA; hence, the decision was made to open a sales and service office in Monterrey. The new Seco/Warwic, Mexico division will occupy about 2,000 square feet of office space in a high-rise business park, including garage parking and controlled-access reception.

As Mexico's second-largest city, Monterrey is convenient to major road, rail, and air transportation hubs. Major Gulf Coast ports and U.S. points of entry are not far either. As one of Mexico's steel production epicenters, the region is also a major manufacturing center. All of these position the city as a perfect base to connect with regional heat treaters or serve the rest of Mexico, along with Central and South America.

The New Office Is Just the Beginning of a Larger Expansion

"Once the office has established a foothold as a self-sustaining base of operations for sales and field service, the next step will be to build on existing relationships we have with local contract manufacturers and mechanical contractors to fabricate furnaces and supplement field service staffing through outsourcing, respectively," says Marcus Lord, managing director for Seco/Warwick USA.

Leading the expansion is longtime SWC engineer Luis Barragan, who will continue to manage the establishment of the business until it is on solid footing. At this point, he will pivot to managing sales while Marcus Lord will resume operations management. The Mexico office will also have its aftermarket segment, taking on aftermarket support for customers throughout Latin America.

"We've always had furnaces and heat treat Partners to support, from Mexico down to Chile. That demand has grown to the point that it is time to open a base of operations dedicated to that market", concludes Sławomir Woźniak, Seco/Warwick Group's CEO.

secowarwick.com

Nitrex Europe

ADDS MARCIN KRAJDOCHA AS TECHNICAL SALES MANAGER

Nitrex welcomes the newest member of the Nitrex Turnkey Systems Team: Marcin Krajdocha. Marcin steps into the new role of technical sales manager responsible for nitriding systems in the DACH region and the vacuum furnace product line in Europe.

As a key member of our European sales team, Marcin will play a pivotal role in leading the sales efforts for Nitrex in nitriding and vacuum furnaces, all manufactured at our facility in Sosnowiec, Poland—a strategic hub for providing advanced heat treatment solutions to our European clientele. His solid background in vacuum heat treating, nitriding, and general heat treatment is invaluable to his new role.

"Marcin's industry knowledge and customer-focused approach are what we admire. His extensive experience in furnace sales in Europe, coupled with his ability to build lasting customer relationships, makes him a top performer. We look forward to Marcin leading at Nitrex and serving the European and German heat treatment markets," stated Mark Hemsath, president of Nitrex Turnkey Systems.

Krajdocha commented, "What excites me most about joining Nitrex is the opportunity to leverage my many years of experience towards assessing customers' needs and providing the best heat treatment solutions. Important to me is seeing the completion of projects and ensuring our customers' satisfaction. My relational approach to work fosters trust, satisfaction, and strong partnerships with clients. This is also an opportunity for me to contribute to Nitrex's mission of excellence in the heat treat industry and to continue my own professional growth journey."

The objective behind growing the vacuum furnace team is to solidify Nitrex Vacuum's leadership in the European market, mirroring the success in our gas-nitriding furnaces. With Marcin's expertise and dedication, we are well-positioned to achieve this significant milestone.

nitrex.com

Horsburgh & Scott

LAUNCHES INDUSTRIAL GEARBOX FACILITY IN LOUISIANA

Horsburgh & Scott Company announced that it has established a 32,000-squarefoot facility in Slidell, LA, for the repair, service and assembly of industrial gears and gearboxes destined for the defense industry.

The Cleveland-based company expects its $4.9 million capital investment in St. Tammany Parish to create 40 direct new jobs at an annual average salary of more than $100,000. Louisiana Economic Development estimates an additional 57 indirect new jobs, for a total of 97 potential new jobs in the Southeast Region of the state.

"The creation of these well-paying jobs will benefit Louisiana's skilled manufacturing workers, their children and grandchildren, which in turn helps our communities continue to thrive," said LED Secretary Susan B. Bourgeois. "It is especially gratifying when a major capital investment in our state also benefits the men and women who protect our freedoms with their service in America's armed forces."

Horsburgh & Scott's decision to build a new gearbox manufacturing and repair facility in the Gulf Coast region is the result of a recent new defense contract and increased demand for its industrial gearing products/service industrial unit. Following an intensive search, the company selected Slidell to open their new manufacturing, assembly, and repair facility on Town Center Parkway off LA 443/North Old Spanish Trail.

"The H&S Slidell Service Center will assemble U.S. Naval propulsion drives that will be responsible for protecting the sovereignty of our nation and U.S. allies," said Randy Burdick, CEO of the Horsburgh & Scott Company. "The Louisiana marketplace provides ample resources and skill sets to support H&S endeavors in supporting our valued customers and power transmission needs."

H&S will also provide industrial gear and gear drive engineering, repair, and field service capabilities out of the Slidell facility.

"I am thrilled that a company like Horsburgh & Scott, a major defense contractor and international manufacturer for a wide range of industries, sees the value of investing in and bringing quality jobs to our community," said Slidell Mayor Greg Cromer. "The City of Slidell and eastern St. Tammany Parish have all of the right components in place, from strategic geographic location to skilled talent availability, to serve as the Gulf Coast base for H&S's operations."

To win the project, LED offered a competitive incentives package that included the comprehensive workforce development solutions of LED FastStart and a $500,000 Performance-Based Grant from the Cleco Fund. The company is also expected to take advantage of the state's Quality Jobs program.

"Horsburgh & Scott's decision to base their Southeastern U.S. operations in St. Tammany Parish is a move that signals that our area is an ideal place to do business for a company that will be an excellent addition to our economic landscape," said St. Tammany Corporation CEO Chris Masingill. "The outstanding educational and training institutions in our region, the highly skilled talent that chooses to live here, and our central location with easy access to four interstates are just a few of the many assets that our community has to offer to companies like H&S that want to expand their global reach into the heart of the Gulf South. We will continue to support H&S and welcome them to St. Tammany as their Slidell location opens for business and adds jobs to our local economy."

"Horsburgh & Scott's investment is part of an encouraging economic trend in St. Tammany Parish," said Michael Hecht, president and CEO of Greater New Orleans, Inc. "Their decision to establish a new industrial gearbox facility on the Northshore underscores the advantages of our region, including our local workforce. Horsburgh & Scott's new facility will also strengthen our ties to the military, which currently operates five bases in southeast Louisiana."

horsburgh-scott.com

Star Cutter

NAMES ANDREW EPSTEIN VICE PRESIDENT OF HUMAN RESOURCES

Star Cutter Company has appointed Andrew Epstein as vice president of human resources. Epstein oversees all HR functions for the Star Cutter family of companies, guiding HR resources across global locations and analyzing HR strategies. As a member of the Executive Leadership Team, he reports to the Chief Financial Officer, Becky Grech.

"We are pleased to have Andrew take this important role for Star Cutter," said Jeff Lawton, Star Cutter president, and COO. "He brings with him a valuable experience, not only as an HR leader, but one with many years in manufacturing that will complement and advance our culture."

Epstein's previous employers include organizations such as Metaldyne, The Flint Group, and AJM Packaging. Most recently, he was the director of human resources for Real Truck in Ann Arbor, MI, supporting more than 3,000 employees across multiple locations.

"I am genuinely excited to join Star Cutter", said Epstein. "The team spirit is clearly part of this dynamic organization, which has its roots in values and a positive culture. I continue to gain appreciation of our history and am excited to partner in further strengthening our initiatives in employee development, engagement, and teamwork."

Epstein is a graduate of Michigan State University with a bachelor's degree in employee relations and holds an MBA from Kent State. He is located at the Star Cutter corporate office in Farmington Hills, MI.

star-su.com

MAY 15–16

CTI Symposium USA 2024

CO2 reduction is critical for automotive drivetrain. Here the battery electric drive using renewable energy is the focus. What can we do to increase efficiency and reliability, reduce cost and at the same time reduce upstream CO2? At CTI Symposium USA 2024 (Novi, MI) the automotive industry discusses the challenges it faces and promising strategies. Latest solutions in the fields of electric drives, power electronics, battery systems, e-machines as well as the manufacturing of these components and supply chain improvements are presented. For the bigger picture market and consumer research results as well as infrastructure related topics supplement the exchange of expertise.

geartechnology.com/events/5064-cti-symposium-usa-2024

MAY 19–23

2024 STLE Annual Meeting and Exhibition

STLE is celebrating 80 years of technical excellence and innovation during the event. The STLE Annual Meeting & Exhibition (Minneapolis, MN) will feature over 500 technical presentations, a trade show with over 100 exhibitors, a Commercial Marketing Forum, 13 industry-specific education courses, discussion panels on technical and market trends, and more. "This year, we're excited to offer two new panel discussions on topics that are key to the tribology and lubrication engineering community," said Rebecca Lintow, CAE, STLE executive director. "One panel will highlight various sustainability topics from top industry experts, including standards, regulations, technologies, and best practices. The other panel will feature notable women in the lubrication industry and insights about their career paths and experiences."

geartechnology.com/events/5092-2024-stle-annual-meeting-and-exhibition-registration

JUNE 12–13

Zoller 2024 Open House and Technology Days

Explore integrated solutions that make manufacturing more efficient at Zoller Inc.'s 2024 Open House and Technology Days. This two-day event June 12 - 13, 2024, at the company's North American headquarters in Ann Arbor, MI, will highlight real customers who have leveraged Zoller technology to optimize their manufacturing processes and boost profits.

Guest speakers include Tom Bassett II, owner of ProCam Services LLC in Zeeland, Michigan. Bassett will share how incorporating the Zoller »smile 420« tool presetter into the machine shop's workflow generated an additional $1 million in sales over two years. Daniel Skwierczynski, manufacturing engineer at ERA Industries, will speak on why partnering with Zoller improved production efficiency for the contract manufacturer in Elk Grove Village, Illinois.

geartechnology.com/events/5096-zoller-2024-open-house-and-technology-days

JUNE 16–19

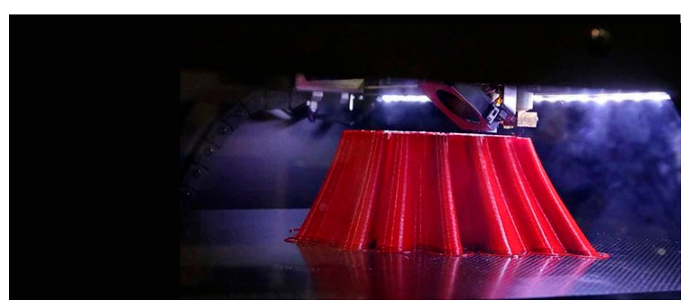
PowderMet 2024

The leading technical conference on powder metallurgy and particulate materials in the Americas, PowderMet 2024 (Pittsburgh, PA) is a hub for technology transfer for professionals from every part of the industry, including buyers and specifiers of metal powders, tooling and compacting presses, sintering furnaces, furnace belts, powder handling and blending equipment, quality-control and automation equipment, particle-size and powder-characterization equipment, consulting and research services, and much, much more. The show is co-located with AMPM 2024 focusing on metal additive manufacturing. AMPM 2024 will feature worldwide industry experts presenting the latest technology developments in this fast-growing field.

geartechnology.com/events/5069-powdermet-2024

JUNE 25–27

Rapid + TCT 2024



For more than 30 years, Rapid + TCT has defined the crucial role of additive manufacturing and industrial 3D printing by empowering the establishment of an industry that continues to conceive, test, improve and manufacture new products at a faster, more cost-efficient pace. SME and Rapid News Publications team up to produce the annual Rapid + TCT event which will take place June 25-27 in Los Angeles. Known worldwide as North America's largest additive manufacturing and industrial 3D printing event, RAPID + TCT provides everything you need to know about the latest 3D-technologies, all under one roof.

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☐ My company **BUYS** gears

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Once More Around the Sun

Aaron Fagan, Senior Editor

A gear is nothing without its counterparts. Gears work in conjunction with other components within a gear system to achieve specific mechanical functions. These counterparts work together synergistically to form functional gear assemblies capable of transmitting motion and torque, converting speed and torque ratios, and performing a wide range of mechanical tasks in various applications across industries.

A sun gear is a central gear component found in certain types of gear systems, most notably in planetary gear systems. In a planetary gear system, the sun gear is located at the center and is usually connected to the input shaft. The other gears, known as planet gears, revolve around the sun gear. The interaction between the sun gear and the planet gears, along with the outer ring gear, allows for various speed and torque combinations, making planetary gear systems versatile and commonly used in transmissions and other mechanical applications.

Gear Technology has been a sun in the gear industry—not a god but a workhorse. Let's explore how *Gear Technology* serves as a central component, much like a sun gear:

Central Information Hub: Just as a sun gear is located at the center of a planetary gear system, *Gear Technology* occupies a central position within the gear industry as a primary source of information, news, and insights. It serves as a hub where professionals, enthusiasts, researchers, and businesses gather to access the latest developments, trends, and advancements in gear technology.

Input of Knowledge and Expertise: Similar to how the sun gear receives input and transmits motion to other gears in a gear system, *Gear Technology* delivers valuable knowledge and expertise to industry stakeholders. Through technical articles, features, interviews, and analysis, the magazine disseminates information on gear design, manufacturing techniques, materials, applications, and best practices, serving as a catalyst for innovation and progress in the field.

Engagement and Interaction: Just as planet gears orbit around the sun gear, industry professionals and enthusiasts orbit around *Gear Technology*, engaging with its content, participating in discussions, and sharing insights and experiences. The magazine facilitates interaction and collaboration among gear designers, engineers, manufacturers, suppliers, and end-users, fostering a vibrant and interconnected gear community.

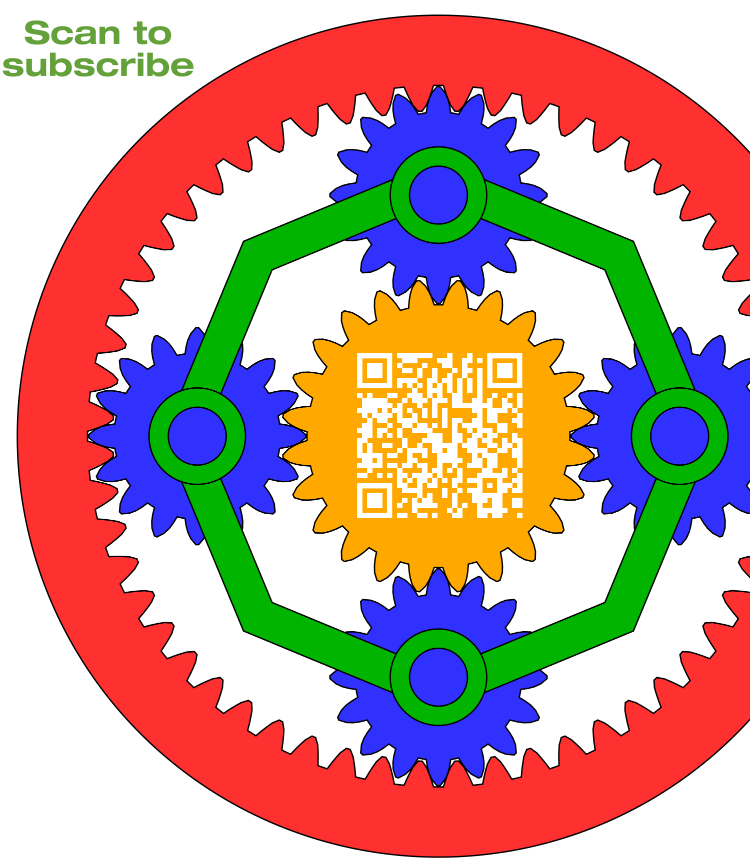
Transmission of Ideas and Trends: Like the transmission of motion and torque from the sun gear to the planet gears, *Gear Technology* transmits ideas, trends, and innovations throughout the gear industry. It showcases emerging technologies, showcases successful applications, and highlights challenges and opportunities, influencing the direction of research, development, and investment in gear-related endeavors.

Adaptability and Evolution: Sun gears in planetary gear systems are adaptable and versatile, accommodating different configurations and requirements. Similarly, *Gear Technology* adapts to the evolving needs and dynamics of the gear industry, covering a wide range of topics, from traditional gear design and manufacturing to cutting-edge technologies such as additive manufacturing, digitalization, and Industry 4.0.

Supporting Ecosystem Growth: By serving as a central information hub and facilitating knowledge sharing and collaboration, *Gear Technology* contributes to the growth and sustainability of the gear-industry ecosystem. It connects tool makers with gear makers, manufacturers with customers, researchers with practitioners, and newcomers with seasoned professionals, strengthening the foundation of the industry and ensuring its vitality for years to come.

In essence, *Gear Technology* acts as a sun gear in the gear industry by centralizing knowledge, fostering engagement, transmitting ideas, and supporting the growth and evolution of the industry as a whole. Just as the choice of sun gear type depends on factors such as the specific requirements of the gear system, including load capacity, efficiency, noise level, and space constraints, so too does the choice of the magazine you subscribe to matter. *Gear Technology* thanks you for 40 years around the sun with more to come.

Scan to subscribe



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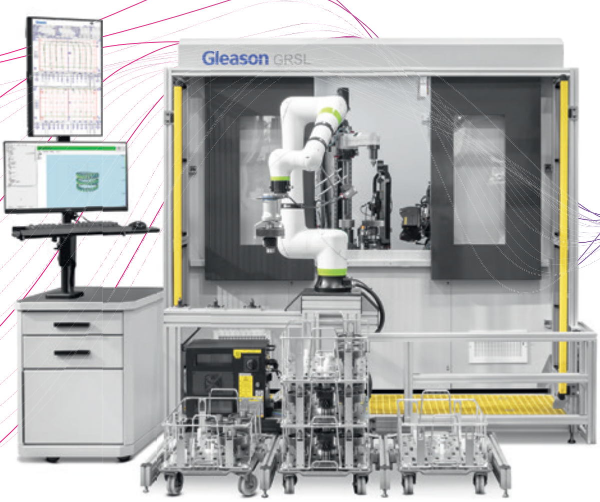

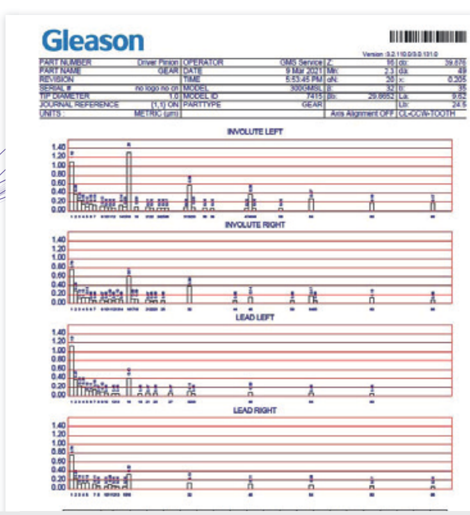

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