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– Highlights from Furnaces North America

Workholding
– Quick change for racing components

Powder Metal Gears
– State of the Industry
– Designing the Gear Body

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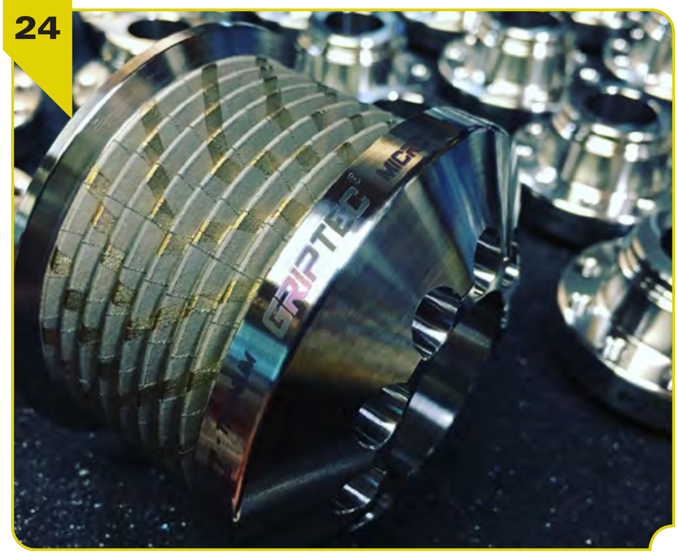

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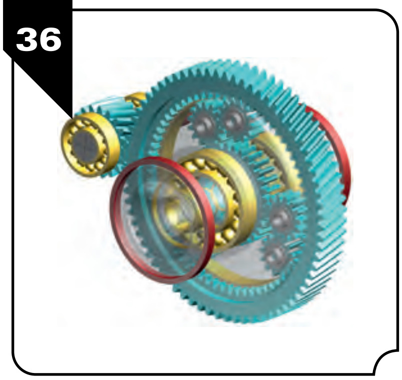

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Vol. 39. No. 7 GEAR TECHNOLOGY. The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by The American Gear Manufacturers Association, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). The American Gear Manufacturers Association makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY. The Journal of Gear Manufacturing. 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

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Vol. 39. No. 7

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GT Videos

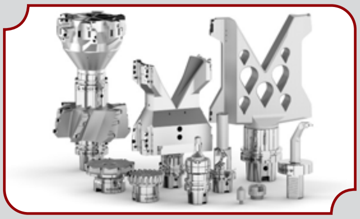
Solar Atmospheres Vacuum Oil Quench Services

Solar Atmospheres details a successful vacuum oil quench commissioning in this video. This robustly designed system delivered hot loads to the internal oil quench tank seamlessly time after time. With a quench system that is entirely self-contained and vacuum tight, the typical positive pressure "flare and smoke-ups" during each quench cycle was nonexistent.

geartechnology.com/media/videos/play/239

Star SU/Neher PCD 3D Printed Tools

Large tools are often required for the machining of powertrain aluminum prismatic parts, including stator housings and additional components for the growing electric motors market. The weight of these tools can prove problematic with traditional machining equipment, which can cause excessive spindle vibration and noise, poor tool life and potentially scrapped components. Full control of the tool coolant channels for optimization in both wet and MQL applications.



geartechnology.com/media/videos/813

GT Revolutions

Beyond Closed Loop but Lean with Klingelnberg

The continuously increase of electric vehicles is well known and manufacturers are adapting their shopfloors. The shift towards e-mobility has consequences throughout the whole supply chain since it has brought a fundamental change in both—the design and quality requirements of a car's drivetrain. The number of gears in the gearbox has been significantly reduced, while the noise behavior of the gearbox has gained even greater importance as a decisive quality characteristic.

geartechnology.com/blogs/4-revolutions/post/30024-beyond-closed-loop-but-lean

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Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein *Gear Technology* Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 38 years' worth of technical articles can be found online at *geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

THE GEAR INDUSTRY'S INFORMATION SOURCE
geartechnology.com

Publisher & Editor-in-Chief
Randy Stott

IMTS Exceeds Moderate Expectations

In September we took part in IMTS along with many of the leading companies in our industry. Most of the exhibitors we talked to before, during and after the show came into the event with moderate expectations. Everyone was hopeful, but after years of shutdowns, travel restrictions and COVID precautions, nobody was quite sure what to expect.

In fact, quite a few of the biggest names in metal cutting simply chose not to exhibit. DMG-MORI, for example, simply wasn't there. Nor was Sandvik Coromant. While most of the gear pavilion regulars took part in the show, there were some notable exceptions, and even those who did exhibit brought fewer machines and less new technology (of course, it didn't help that the dates of IMTS overlapped with AMB in Stuttgart, and many of the major machine tool companies were forced to split their teams and resources). Going into the show, many companies were hedging their bets or taking a wait-and-see approach.

Officially, AMT has reported more than 86,000 registrants for IMTS 2022. Nothing to scoff at, for sure, but only two-thirds of the total from the previous show (more than 129,000 registered in 2018). So IMTS was significantly smaller than previous shows. No one was surprised by this.

From our own observations, the first three days of the show (Monday through Wednesday) were solid, with both aisles and booths full of visitors. And while this is typical for IMTS, with Tuesday and Wednesday generally being the best days, traffic seemed to slow considerably each day after that until Saturday, when attendance slowed to a trickle and most exhibitors were ready to pack things up and go home.

But despite the smaller numbers, exhibitors were almost universally pleased with the results. Here are just some of the things I heard directly from exhibitors in the gear pavilion:

> **"Traffic has been better than expected."**

> **"I've gotten more solid leads in the first two days than I got in the entire show from 2018."**

> **"Customers aren't just coming to walk the aisles. They have specific projects, and they're asking for bids."**

Exhibitors were definitely busy. They were getting quality leads. And you could almost sense a collective sigh of relief at this return to normalcy. Trade shows are still an effective way to do business, and many of those we talked to expressed their enthusiasm at the opportunity to meet customers in person again.

So I'd say it was a successful show. Although expectations were lower than normal, it's clear that for most, those expectations were exceeded. Unfortunately, this doesn't mean that things are back to normal quite yet.

Even though everyone was happy to be back together, manufacturing industries still face a lot of headwinds. There's the war in Ukraine. There's excessive inflation all around the world. There's the continued struggle to find skilled labor. None of this helps with an already stressed supply chain. Machine tool manufacturers are still having difficulty getting anything with computer chips, including the CNC controls that drive their machines. The result of all this is that even if you went to IMTS and ordered a brand new machine tool for your shop, chances are you might not be producing parts on it for a year, 18 months or even two years, because that's what the lead times look like for many of the machine tool manufacturers we talked to.

So we're not out of the woods yet, but if IMTS is any indication, the return to normalcy isn't really a question of "if," it's a question of "when."

Randy Stott

P.S. It's not too early to start thinking about your next in-person event. Motion+Power Technology Expo takes place October 17-19, 2023 in Detroit. For more information, visit motionpowerexpo.com.

Liebherr

EXPANDS PORTFOLIO FOR GEAR SHAPING OF DOUBLE HELICAL GEARS

Patented by André Citroën around 1900, and still indispensable today in many industries, double helical gears are used in all sorts of sizes in a variety of sectors. From tiny dimensions in the aerospace industry to huge dimensions in energy or conveyance technology, they combine the advantages of spur and helical gears: quiet-running, low-noise and low-wear, with a high gear efficiency and suitable for transferring large forces.

Herringbone and double helical gears

A distinction is made between so-called herringbone and double helical gears. The latter have a gap between the two gears. The classic production method, particularly for gears with larger dimensions, is planing. However, the long-serving planing machines are no longer built, so there is an increasing tendency to choose alternative production methods such as shaping or—for very large dimensions—4-axis hobbing.

Double helical gears are easier and cheaper to manufacture than herringbone gears, since the gap between the gears offers space for the tool overrun. The challenge in production here, however, is to align the two gears to each other and position them exactly.

The challenge of precision in production

Depending on the dimensions of the workpieces, double helical gears are produced using two methods. Smaller gears with a low gear width can be produced in one clamping fixture. On the tool holder there are two shaper cutters, which shape the upper gear and up-shape the lower gear or—depending on the width of the gap—shape both gears. In the case of gears with a large gear width, for space reasons it is not only necessary to change the tool but also to turn the workpiece.

In order to align the two gears exactly to each other before the second machining step, their angular position (index) and their axial position have to be determined in an intermediate measurement, in order to manufacture the so-called apex point in the required tolerance. Using conventional measuring technology, this is complex and requires a lot of experience in operation. Inaccuracies can occur due to alignment or handling errors.

Measuring probe improves positional accuracy

A newly developed measuring probe now allows Liebherr-Verzahntechnik GmbH the possibility of precise corrective measurement in the gear shaping machine. The measuring probe sits directly on the tool spindle and is therefore in the same coordinate system as the pinion type cutter itself. This reduces inaccuracies which might arise due to a tool change or turning a workpiece and leads to considerably higher quality and process reliability. In combination with the NC-controlled axes of the shaping machine, a measuring accuracy of a few micrometers is achieved. At the same time, the time and handling work when aligning the two gears to each other are reduced. User-friendly software guides you through all the process steps of the application.

Process reliability and economic efficiency

"The corrective measurement is part of a concept consisting of machine, tool and technology, which expands and optimizes Liebherr's technology portfolio for the production of double helical gears," said Dr. Andreas Mehr, an expert on gear shaping at Liebherr-Verzahntechnik GmbH. "All components, including the tool holder and shaper cutter, are optimally coordinated with one another. By the way, the software and tool holder can also be easily retrofitted on an existing machine."

The gear shaping machines are equipped with powerful shaping heads for stroke lengths between 70 and 240 mm, which are equipped with an electronic helical guide. This allows the helix angle of the workpiece to be easily programmed into the controls system. The reduction of measurement inaccuracies and manual process steps makes the production process more economical, as shown by the following application example of a Liebherr shaping machine with electronic helical guide used by an American job shop.

Machining time reduced, quality increased

A LS 1400 E has been in use at Cincinnati Gearing Systems Inc. (CGS) in Ohio since the beginning of the year. CGS is a recognized market leader in the production and design of precision components for transmission technology and a founding member of the American Gear Manufacturers' Association (AGMA), the United States norming organization for gears. But CGS is much more than just a gearbox manufacturer: The company offers its customers more than 100 years of experience in the manufacturing of high-quality, reliable and inexpensive gear cutting solutions for components and gearboxes for numerous energy transfer applications, such as automobile gearboxes, diesel engines, drives for military and commercial marine applications, turbine-driven generator drives, wind energy, pump drives, and expander and compressor drives.

"Liebherr's CNC shaping machine has significantly reduced our machining time for double helical gears. The machine has doubled our previous cutting speeds," said Alex Rye, head of production at CGS. "The corrective measurement within the machine leads to a considerably higher gear quality. And thanks to the electronic helical guide, we can now shape any helix angle without additional tools."

cincinnatigearingsystems.com

liebherr.com

WFL Millturn

DEVELOPS MOBILE ROBOT AUTOMATION SYSTEMS WITH FRAI ROBOTIC TECHNOLOGIES

Automation tasks are becoming ever more challenging. Using intelligent software in combination with the relevant automation solutions not only enables workpieces to be loaded and unloaded but also means that machine tools can be set up fully automatically through automatic replacement of tools and clamping devices. FRAI strives to be an innovative automation partner and is therefore developing highly flexible robot systems to respond to this trend. Concepts such as the mobileCELL are a complete first and enable a wide range of expansion stages, making them as future-proof and competitive as possible.

Flexible at all levels

Different industries, series production, small batch sizes, a wide variety of machine tools and the uncertainty of many manufacturers as to whether the current product will still be in vogue next year or become a slow seller—all this calls for flexibility in production. For automation, this means keeping pace with the increasing demands: it must produce autonomously around the clock, be flexible to use, and be Industry 4.0 compliant. In addition to the classic changeover of parts, automation also takes on the other tasks such as tool change, parts transport, logistics, host computer functions, part tracking and product history.

The more complex the task, the more elements you need from the "knowhow kit." The "knowhow kit" is what FRAI calls the solutions that have already been successfully implemented in practice and work under real production conditions. FRAI has already developed many kit elements: parts and position recognition, bin picking, reading and inscribing a DMC (Data Matrix Code), parts contour monitoring, automatic gripper exchange, jaw changes, etc. Depending on the task in question, FRAI also has a network of partner companies which cover other aspects such as host computer solutions.

Multitasking in production

There are several mega and macro trends which will shape not only automation, but also virtually all industrial sectors in the coming years. Firstly, there is individualization: there will be smaller series and more frequent product changes/innovations. Secondly, we have connectivity: everything is networked, each component has a QR code and can be tracked through to recycling.

If you think about a smartphone, making a phone call is no longer the key function. The same is true of automation, in the sense that transporting a workpiece from A to B is not necessarily the main task in every application. Instead, the focus has shifted towards recognition, tracking and multitasking. Camera recognition and gripper exchange systems combined with host computer solutions have become the core components of a flexible solution that is compatible with Industry 4.0. Globally, the trend will move towards a small cell solution with high intelligence and a high proportion of IT.

The above-mentioned trends and requirements call for overall networking, in particular information data acquisition and evaluation. This is becoming increasingly important. We need to be able to acquire, process, evaluate and/or pass data on. This allows to optimize production, the sequence and subsequently the capacity utilization, and meet customer requirements, which call for 100 percent traceability and parts history. Improving the capacity utilization lowers unit costs, while higher quality lowers the cost of poor quality. These are well-known requirements; however, they are becoming increasingly important. So, in future, automation will be about using corresponding hardware to ensure a flexible material flow, handle components and implement a variety of set-up processes.

Automation as an overall package

When it comes to modern automation concepts, holistic customer support starts with the technical sales team. Here, experienced technicians must work hand in hand with visionaries, 3D designers and software specialists to create the most useful overall concept for the customer. These resources must be provided at both the quotation stage and later on for order processing.

On the one hand, this requires training young people yourself and on the other hand to ensure a good mix in all departments so you are well prepared for the new tasks. It's essential to develop high-tech expertise in your own company and continually adapt as development in these areas progresses at an incredible pace.

Mobile Robot Solution: the mobileCELL

The mobileCELL of FRAI is a hybrid solution, which impresses with its combination of wide-ranging functions and advantages. There was a time when the classic robot cell could only load and unload workpieces. This basic function was then enhanced with gripper exchange systems.

Due to the significant disadvantages of a location-bound robot cell and the costs for intralogistics tasks, a solution was discussed which would produce

advantages for the customer. This is how the concept of the mobile robot matured and was converted into a prototype.

A generously sized automated guided vehicle (AGV) with a robot cell design with everything that you need. In other words, the robot, workpiece, and tool gripper, along with buffer positions for workpieces and tools, and the necessary control and safety technology. The machine is freely accessible. It is not blocked or obstructed. The AGV collects the required tools and workpieces in the warehouse, it then travels to the front of the machine, locks itself in place on the floor and exchanges parts and/or tools. The vehicle then moves away again and receives the travel instructions for the next machine. The space in front of the machine it has just loaded becomes clear again.

For a mobileCELL to be useful, there must be a long enough cycle time or there must be other advantages such as flexible, internal transport with the use of several mobile robots. The travel paths must be suitably wide (3 m); that is usually the case for normal forklift

operation. The wheels are designed to travel over expansion joints and slots, such as we might have with fire doors or similar, without any problems. A virtual server and a WLAN network must be available, but that is also industry standard these days.

wfl.at

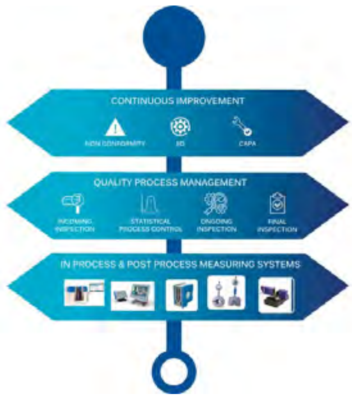
Marposs

ANNOUNCES THE DIGITAL PLATFORM, MAINDO

Marposs has announced MAINDO, its new digital platform that integrates Marposs monitoring, measuring, testing or other manufacturer device/solutions throughout the entire production process, combining quality and process into a holistic production monitoring view. Marposs modular software systems, comprised of brands such as Blulink, MG, Brankamp, Artis, S&K, enable a direct network connection between a production level system, a process monitoring system or a PLC terminal and the production control and quality management systems with higher-level company systems like ERP, PLM, MES, etc. The MAINDO platform offers improved production quality, reduced costs, traceability, and remote data accessibility.

MAINDO embodies Industry 4.0 principles by integrating, sharing, and enhancing data generated by Marposs systems focused on quality control, production processes and environmental conditions. Data that is typically stored in separate domains—such as machine parameters, production process information, inspection results and continuous improvement process information—are brought together to into a single view to provide information for failure detection and prediction. Root cause analysis and domain know-how bring at-a-glance information to all stakeholders with customizable dashboards.

In addition, *QuartaEVO*, Marposs Quality Management Software, provides a structured business process, based on industry sector standards, to assure a secure and efficient quality assurance process for product prototyping, through serial production up to incoming and outgoing goods inspection. Quality and preventive actions to continuously improve product quality, processes, the overall company effectiveness.



marposs.com

Nagel and Gehring

PARTNER FOR HONING, SUPERFINISHING, AND ELECTROMOBILITY INNOVATIONS

Nagel and Gehring recently shared innovative technologies during AMB 2022 including new standards in efficient honing, maximum flexibility in the superfinishing of flat, concave, and spherical surfaces, and efficient internal and external honing of workpieces.

With the EcoHone HRX, Nagel offers efficient honing in the diameter range from 2 to 40 mm. Even multi-stage honing processes can be processed fully automatically on a high-end honing spindle. Measuring, brushing, cleaning, tool change in case of wear, or even a change from pre- to finishing honing tool, all this is handled by the integrated robot unit. An innovative and flexible fixture and clamping jaw concept, that can be adapted to any workpiece geometry, enables working with a wide range of workpieces.

With the EcoHone, components can be cleaned in a controlled and automated manner using compressed air. Brushing of the workpieces as secondary operation during honing process—independent of the station the honing process. This means that secondary burrs can be removed almost without leaving any residue.

The innovative tool management system includes complete inspection of the tools and fully automatic detection of wear limits. As soon as these are reached, the robot automatically replaces the relevant working tools. If it detects a workpiece pallet with new

material, the machine is immediately adjusted to it fully automatically. At the push of a button, the new workpiece can be processed. The equipped workpiece workpiece is checked using permanent diameter control. Switching to different honing operations also takes place without manual intervention. For example, a pallet can be finish-honed immediately and fully automatically after pre-honing.

The NaSphere can machine flat, concave, and spherical surfaces and bores on multiple vertical or horizontal modular workstations. For standard tasks, it offers tool speeds of up to 12,000 rpm. The machine achieves maximum flexibility thanks to optimally coordinated process combinations of external and internal grinding, superfinishing, honing, brushing, and polishing. The workpieces are vertically positioned, transversely indexed under the spindles, clamped, driven, and swivelled. The new NaSphere or NaPlan series machines from Nagel can combine several operations in a single machine, resulting in cost reductions. The machining spindles can be finely adjusted (tilt and cross) to produce hollow and crowned surfaces without tools.

Gehring's deephone series of horizontal honing machines combines optimum performance with a well-balanced, compact design. The deephone 3000 stands for efficient internal and external honing of precision or telescopic cylinders and similar workpieces. Depending on the series, the honing diameter is up to 1,150 mm and the workpiece outside diameter is 65 to 1,200 mm. Honing ensures particularly high accuracy and very good tribological properties. In addition, a wider range of materials can be processed. This means that nothing stands in the way of machining thin-walled aluminium tubes.

Powerful drive systems and a high-precision infeed device result in the perfect configuration for the lowest unit costs in production. A program wizard ensures simple operation. After entering a few relevant items of workpiece, material and tool data, the process and stock removal are determined so that honing can be started directly after positioning the tool.

nagel.com

gehring-group.com

Seco Tools

PROVIDES QUICK-CHANGE MILLING HEAD SYSTEM

To provide manufacturers versatility and high value, Seco has launched its new X-Head quick-change replaceable milling head system. With the system, users can quickly and easily change between various solid carbide milling geometries and types to optimize milling operations while reducing manufacturing costs and tooling inventories.

Fast and easy tool changes with the turn of a wrench

Milling heads mount to a variety of available shank lengths for even greater versatility, with short and long-reach capability for a variety of overhang lengths. Head changes only require a simple turn of a wrench, eliminating the need to remove the holder from the machine to change the cutter. Users also eliminate the need to reset tool lengths thanks to a secure and reliable connection that provides exchange accuracies within 50 microns.

One tool mills it all

According to Gary Meyers, Seco product manager solid milling, shops must often purchase many different endmills and holders to machine different features on a workpiece which adds higher cost to a project. “The Seco X-Head quick-change replaceable milling head system adapts to various machining needs with a range of geometries and types but without additional holders,” he said.

With 194 types of available cutting heads, users can choose between different cutters for multiple operations as well as between specific high-performance, versatile high-performance and universal type geometries. Seco also offers metric and inch products for heads and shanks.

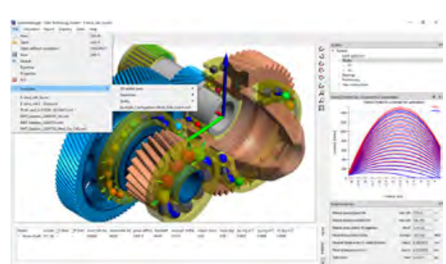
secotools.com

GWJ Technology GmbH

OPTIMIZES *SYSTEMMANAGER*

GWJ Technology GmbH introduces a new version of *SystemManager* as an extension of *eAssistant* as a web solution and *TBK* as a classic desktop application.

SystemManager is an easy-to-use extension of the GWJ solutions *eAssistant* and *TBK* for individual machine elements, such as shafts, bearings, connections, and various gear types, for the design and optimization of gearbox systems, such as multistage gearboxes, power-split and manual gearboxes, etc. In the latest version of the *SystemManager,* template files or examples with subdirectories can be structured and created by the user.



Result graphics are no longer only available for individual load elements of a load spectrum, it is now also possible to display all load spectrum elements in one graphic. This is advantageous, for example, for evaluating flank modifications by means of the line load curve over the facewidth.

An axial offset for the gear force can be defined in case the gears are considered as point loads. This axial offset can also be varied within the load spectrum.

An axial offset can be defined for masses and imbalances; in this case the distance between the center of mass and the force element. This also allows a center of mass outside of the shaft geometry.

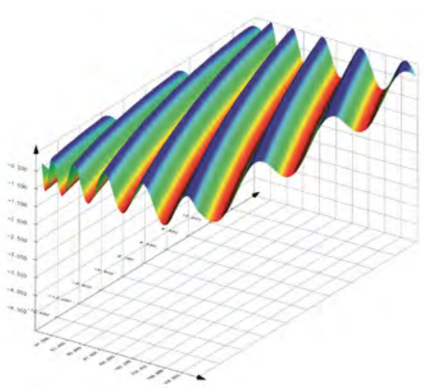
For the transfer to the individual calculations from the *TBK* or *eAssistant,* the gear data for different calculations is now saved for the gear element and thus kept consistent.

When using 3D elastic components, positioning has been made easier and the mesh can be split into several subdomains, e.g., to define different material properties.

gwj.de

KISSsoft

OFFERS MANUFACTURING DEVIATIONS AND FLANK WAVINESS ESTIMATIONS



With the help of *KISSsoft,* the user can now estimate the influence of manufacturing deviation on the resulting transmission error and excitation force.

For the form deviations in the profile or flank line direction, a sinusoidal wave is applied to the theoretically ideal tooth flank. The waviness can be modified by amplitude, length and phase shift. By specifying an additional angular deviation, the total deviation is simulated.

These deviations can be executed in the profile direction, the width direction or combined. The result is a change in the transmission error, excitation force and other significant influences on vibration excitation. The user can thus test how sensitively a theoretically specified tooth flank modification reacts to manufacturing deviations.

kisssoft.com

The Afterglow of Furnaces North America 2022

Takeaways from the heat-treating industry's premier event

Aaron Fagan, Senior Editor

PHOTO CREDIT: NITREX

Furnaces North America 2022 (FNA 2022), presented by the Metal Treating Institute (MTI), in partnership with its media partner, *Heat Treat Today*, is the heat-treating industry's go-to event every other year. FNA 2022 attracted attendees from across North America, including Fortune 500 companies. For three days attendees took part in networking, connections, and learning about the vast changes taking place in emerging technologies, industry trends, and advances in equipment.

Gear Technology spoke with Rick Clift—quality assurance manager for H&S Heat Treat located in Ontario, Canada, and an MTI board member—and he emphasized the value of the FNA show for connecting the gear industry with experts in the heat-treating industry and keeping up with technology: "I meet people who struggle and struggle to meet spec. The gear manufacturer getting some knowledge, exposure, and understanding from the heat-treat industry is critical. FNA is a perfect opportunity. All the commercial heat-treaters in North America will be there, and they have a wealth of experience."

Stabilizing dimensional movement from the carburizing process is especially crucial to the gear industry, and Clift says, "Some of the emerging technologies in heat treat to look out for are in vacuum carburizing and controlled-gas carburizing. They have been used very effectively to control product and process quality to minimize movement." Clift added, "The great thing about FNA for gear manufacturers is they will be able to speak with the people who build and use the furnaces that heat treat the gears they make."

A special thanks to Tom Morrison, CEO of MTI; Rick Clift, quality assurance manager, H&S Heat Treat; and Bob Ferry, vice president of engineering and quality, FPM Heat Treating for their help in assembling this piece.

Nitrex

Nitrex showcased its strength in thermal processing from turnkey heat-treating systems to process control solutions, software/digitalization, and heat-treating services at FNA 2022.

Nitrex revolutionized controlled gas nitriding with NITREG over 40 years ago, and they continue to be at the forefront of this surface hardening technology today. Nitriding and its derivative processes, such as ferritic nitrocarburizing, as well as other special processes for nitriding stainless steels, are the most rapidly expanding processes for the surface hardening of gears.

Nitrex works with gear manufacturers from all over the world, assisting with prototyping to process development, low- to high-volume heat treat orders, and new in-house, high-volume installations as well as retrofit applications. These end-to-end solutions deliver superior quality by improving the durability and performance of gears as well as the efficiency and simplicity of gear manufacturing operations.

When it comes to improved gear performance, Nitrex's controlled NITREG controlled nitriding, NITREG-C controlled nitrocarburizing, and NITREG-S controlled nitriding of stainless steels with its inherent low-temperature processing, are highly beneficial to the automotive, aerospace, defense, mining, and many other industries. Here are some key benefits:

- Optimum and consistent gear properties
- Improvement of gear tribological properties
- Best alternative to eliminate gear distortion (noise reduction)
- Cost-effectiveness by eliminating or reducing several finishing operations, including washing, inspection, hard finish machining, etc.
- Similar bending stress limits and contact fatigue resistance to carburizing
- Environmentally friendly

During the FNA exhibition, Nitrex officially debuted QMULUS, an AI and machine-learning platform designed to digitize the heat treat shop floor for real-time visibility and management of heat-treating operations. Visitors were able to watch a live demonstration of QMULUS and learn how big data and digitalization can help achieve predictive quality and benefit the bottom line.

In addition to its turnkey nitriding systems and technologies, Nitrex showcased its vacuum furnace lines for aerospace and additive manufacturing applications, as well as the UPC-Marathon line of oxygen probes, process control solutions, flow solutions, and endothermic gas production systems, which are enabling customers to extend asset service life while meeting the latest quality and safety standards and supporting sustainability efforts.

"Gear manufacturers recognize that Nitrex's diversified solutions make good business sense for today's gear production," said Mark Hemsath, vice president sales, furnaces and heat-treating services. "Low distortion surface hardening means virtually no hard machining after heat treatment. We improve the quality and longevity of gears, extend the life of furnaces, and are able to process a large volume of gears correctly and on time. With installations across North America, the Nitrex team was excited to demonstrate the capabilities of our systems, equipment, and services at Furnaces North America."

nitrex.com

AFC-Holcroft

AFC-Holcroft was proud to once again exhibit at FNA. This specialized industry event is considered the opportunity for manufacturers—across diverse industries who utilize heat treatment in their production—to learn more about solutions that may be relevant to their unique metallurgical challenges.

Although AFC-Holcroft offers several thermal technologies suitable for the production of gears, one product worthy of a special attention is the UBQA (Universal Batch Quench Austemper) furnace.

While best known for austempering of steel, the UBQA is capable of a number of metallurgical processes including neutral hardening, carburizing, carbo austempering, marquenching, and austempered ductile iron (ADI).

Austempering is unique in its ability to control distortion and the associated costs of machining. AFC-Holcroft's

PHOTO CREDIT: AFC-HOLCROFT UBQA

exclusive water injection system can provide quench severities similar to a water quench and can through harden up to 6-inch (152mm) thick cross sections. The UBQA uses molten salt as a quench medium, which when outfitted with a salt reclamation system allows for over 98 percent recovery of the salt. And the residual waste can typically be disposed of in municipal drains without the need for special permits or methods. The industrial manufacturer seeking a greener alternative would be well served to give this proven design some serious consideration and to inquire about possible cost savings in disposal and salt investment.

In addition, the UBQA design is not limited to gas heating—it is also available as electrically heated, allowing the customer to utilize green-energy options that may be available in their area, such as solar, hydroelectric, and wind.

The UBQA is modular in design, which allows for flexibility in the layout of the furnace itself and its companion equipment. A flexible production cell can be far more accommodating for fluctuations in production volumes, and easier expansion capability for future installations. Several standard size furnaces are offered, and customization is available to meet specific customer requirements.

But the UBQA is not AFC-Holcroft's only product that gear manufacturers may find of interest. Consistently high production volumes may make consideration of a single or multi-row pusher furnace a more cost-effective option in some facilities. Or an AFC-Holcroft rotary hearth furnace for preheating and press quench may be more suitable. There is no one-size fits all option—and that's where their furnace experts can help.

afc-holcroft.com

Rubig

PHOTO CREDIT: ZF Windpower

At the top of heat treatment is nitriding large gearbox components such as those used for wind power generation which can present major challenges including situations where wear resistance is specified alongside the parameter that only certain areas may be nitrided.

Although gas nitriding is also used for certain special applications, PLASNIT plasma nitriding is the preferred process because of the main advantages:

- Mechanical covering is possible and thus eliminates time-consuming masking with pastes, which contaminates the furnace
- No ammonia is used, which makes it environmentally friendly
- The omission of ammonia also means that there are no open flames inside manufacturing sites, there are no poisonous gases in use, and no costly safety measures are required

With component diameters of up to three meters (the size of the treated parts is a big issue for both manufacturers as well as commercial heat treaters), Rubig also offers tailor-made furnaces, which can treat very large components.

rubig.com/en/heat-treatment/rubig-heat-treatment

Gasbarre Thermal Processing Systems

Gasbarre Thermal Processing Systems' continuous vacuum furnaces utilize the latest in controls technology and offer repeatability and modular flexibility to meet the needs of virtually any vacuum heat-treating process. With temperature capabilities up to 2,650°F, they are designed to meet AMS 2750G requirements with uniformity up to Class 2 (±10°F) and instrumentation configuration Types D and E. They can be equipped with oil or gas quenching modules with gas pressure capabilities up to 10 bar, making them ideal for hardening applications. Modular equipment design allows low-pressure carburizing dwell times and index rates to be fine-tuned to meet process and production requirements, optimizing the return on value for your investment.

In addition to their robust design and modular flexibility, Gasbarre's continuous vacuum furnaces offer several unique advantages over other types of vacuum heat treat equipment. Concurrent processing reduces the effective duration of the heat-treating cycle by eliminating work staging and vacuum pumping from floor-to-floor time. The resulting higher throughput allows for smaller load sizes which help overcome challenges with uniformity and repeatability associated with larger workloads required to achieve production rates in batch equipment.

Because heating and cooling are performed in dedicated sections of the furnace, thermal efficiency is dramatically improved over batch-style furnaces where the entire insulation assembly must be heated and cooled every cycle. Similarly, dedicated sections of the furnace reduce process gas requirements for cooling and partial pressure. In addition to reduced utility consumption, the lack of thermal cycling and oxygen exposure dramatically improves the life of refractory consumables within the furnace, reducing maintenance costs and downtime.

Continuous vacuum isn't right for every gear treating process which is why Gasbarre Thermal Processing Systems designs, manufactures and services a full line of thermal processing equipment for virtually any process. Gasbarre's offering includes continuous and batch atmosphere and vacuum equipment; serving customers in the automotive, aerospace, industrial equipment, energy, and commercial heat treating industries.

Gasbarre provides products and services that combine value and design flexibility through knowledge and understanding of your process. For each piece of equipment, Gasbarre takes a 360° approach. From sales and applications engineering to equipment design, manufacturing, commissioning, and aftermarket support, Gasbarre's team of engineers, metallurgists, and technicians aim to understand your process from all angles.

gasbarre.com

PHOTO: Gasbarre Continuous Vacuum Oil Quench

Precision Equals Performance at ZPE GripTec

Automotive racing components need rapid manufacturing capabilities to win the race

Frank Burke, Burke & Towner

In the world of automotive racing, every component is critical, and even the most minute detail can contribute to the difference between winning and losing. No parts supplier is more aware of this than the team at ZPE Inc. of Temecula, Calif., manufacturers of the GripTec pulleys that drive the serpentine belts powering superchargers and compressors in competition cars.

According to Andrew Zimmer, ZPE founder and president, "Although ZPE Inc. started in 2013, our parent company, Z-Industries, was founded in 1984. We are really a second-generation supplier of performance products. My father was involved in aftermarket and OEM calibration in the industry, so I grew up appreciating the importance of precise manufacturing. It was an ideal preparation for the high-tolerance micro machining that's critical to our success. Today, we manufacture pulleys that are available in the aftermarket for nearly every available domestic supercharger. These include OEM and aftermarket superchargers found on GM, Ford, and Dodge/Chrysler family vehicles. Additionally, we restore and upgrade our existing products for customers."

ZPE manufactures pulley and receiver systems for over 20 different supercharger genres in all sizes and rib configurations. Receivers are typically 2 in., and the pulley diameters are between 26 in. Parts are machined from billet round bar stock, and –materials include 7075-T6 aluminum sourced exclusively from Kaiser and Alcoa/Arconic, as well as 17-4 and 304 stainless and Titanium. Original parts typically require 12 to 13 tool paths.

ZPE manufactures pulley and receiver systems for over 20 different supercharger genres in all sizes and rib configurations.

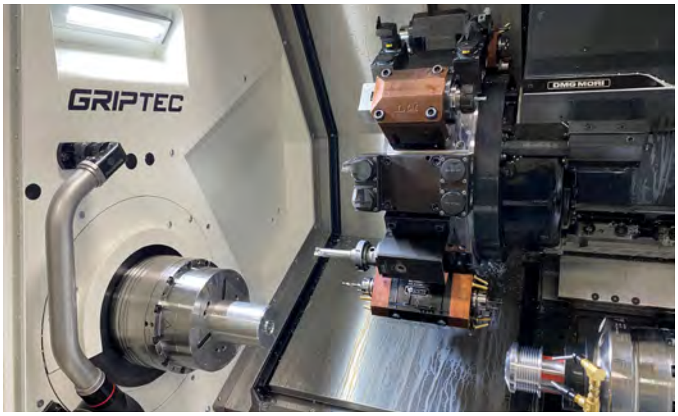
Zimmer noted, "When we launched our line, we offered eight pulleys—we now produce and stock over 4,000 parts. They are available with 4–14 rib configurations in any size that the customer requires. The engineered surface that is machined onto the ribs minimizes slippage to deliver maximum supercharger performance."

"Fast response is essential in our business. Equally important is the ability to meet special customer demands in the timeliest manner. Some of the parts that customers request are only .005 in. different in diameter. We don't charge customers for design services, but the design we produce becomes our own. We have extensive patents covering our micro machining technologies that are available for both standard and special orders. When necessary, we incorporate additive manufacturing and micro welding, but these are typically reserved for unique applications," said Zimmer.

The manufacturing process uses both DMG MORI DS turning centers and a variety of Haas ST-Y standard and twin-spindle lathes. On the DMG units, parts are exclusively processed on Hainbuch collet and mandrel chucks. Starting on the main chuck and finishing on the mandrel, the entire part can be completed in just one cycle. Tolerances extend from ±.0003 to ±.0001 in. on the most critical parts. ZPE's engineered micro machining of surfaces utilizes a patented ablation process that allows for precise control and repeatability in their microstructures.

ZPE prides itself on rapid manufacturing capabilities that can design and complete parts within hours—a critical process when parts are needed the next day. To meet such tight deadlines, Zimmer emphasized the importance of proper tooling and workholding: "We use Sandvik Coromant Capto modular tools. They deliver exceptionally high cutting performance and rigidity. One of their most overlooked features is that the coolant ports are easy to clean.

In selecting the workholding equipment best suited to ZPE's demanding schedules and individual application needs, Zimmer worked closely with Hainbuch regional sales manager Tom Chambers. Chambers explained, "With the Haas lathe, we specified the TOPlus mini chuck equipped with a custom draw tube adaptor. TOPlus uses hexagonal outer profile collets that offer 25 percent more clamping force than round versions. Because of the geometry, these chucks have superior chip contamination control, and, in our mini versions, the reduced contour provides the ability to choose the tool you need without interference.



On the DMG units, parts are exclusively processed on Hainbuch collet and mandrel chucks. Starting on the main chuck and finishing on the mandrel, the entire part can be completed in just one cycle.

"Included with the chuck were several adaptations, including several MANDO Adapt units with segmented bushings for ID clamping, as well as a machinable end stop. The MANDO Adapt can be changed in less than two minutes.

"The DMG MORI dual spindle machines use TOPlus units on the main spindle for extra clamping force and rigidity and a SPANNTOP RD (round) on the sub spindle. The important thing is that ZPE can run production op1-op2 complete parts that are dead nuts accurate and yet the system is fast and flexible on the ID changeover to different IDs," Chambers added.

"When we got our first DMG machine," Zimmer said, "I had heard about Hainbuch but thought it might be expensive. When we investigated, I discovered that the price is competitive, and the product is superior in strength and quality. For instance, the Hainbuch mating surfaces and external sealing surfaces are far superior in design and strength. With other collet chuck systems, the exterior sealing of the collet and chuck was lacking. In the open position, small chips that are resting on the surface can be drawn in between the chuck and collet during the chuck cycle, causing what we call 'denting' in the inside cone of the chuck. When high pressure is present, these small sealing gaps can further be exploited by small chips damaging the interior of the collet chuck. As a result, we needed a solid solution and found that in the Hainbuch collet chucks. Changeover times between sizes, as well as from OD to ID operations, are extremely fast and, even after years of use, we can achieve finishes in the single-digit micron range.

"The TOPlus system, incorporating rigid collets and mandrels, delivers the rigidity and concentricity—especially on short runs—that minimizes post-processing of parts and preserves the finish and high luster that our customers expect. We now produce five times the number of parts that we did when we adopted the Hainbuch system, and the chucks continue to perform like new."

Having worked extensively with high-end competition vehicles and their components, Zimmer has developed a keen eye for the relationship that exists between appearance and quality:

"When a car or product is engineered with attention to every detail, that intrinsic quality shows through in its appearance. The same thing is true in machines, tooling, and components such as the Hainbuch chucks. When you see it, you know it's the best."

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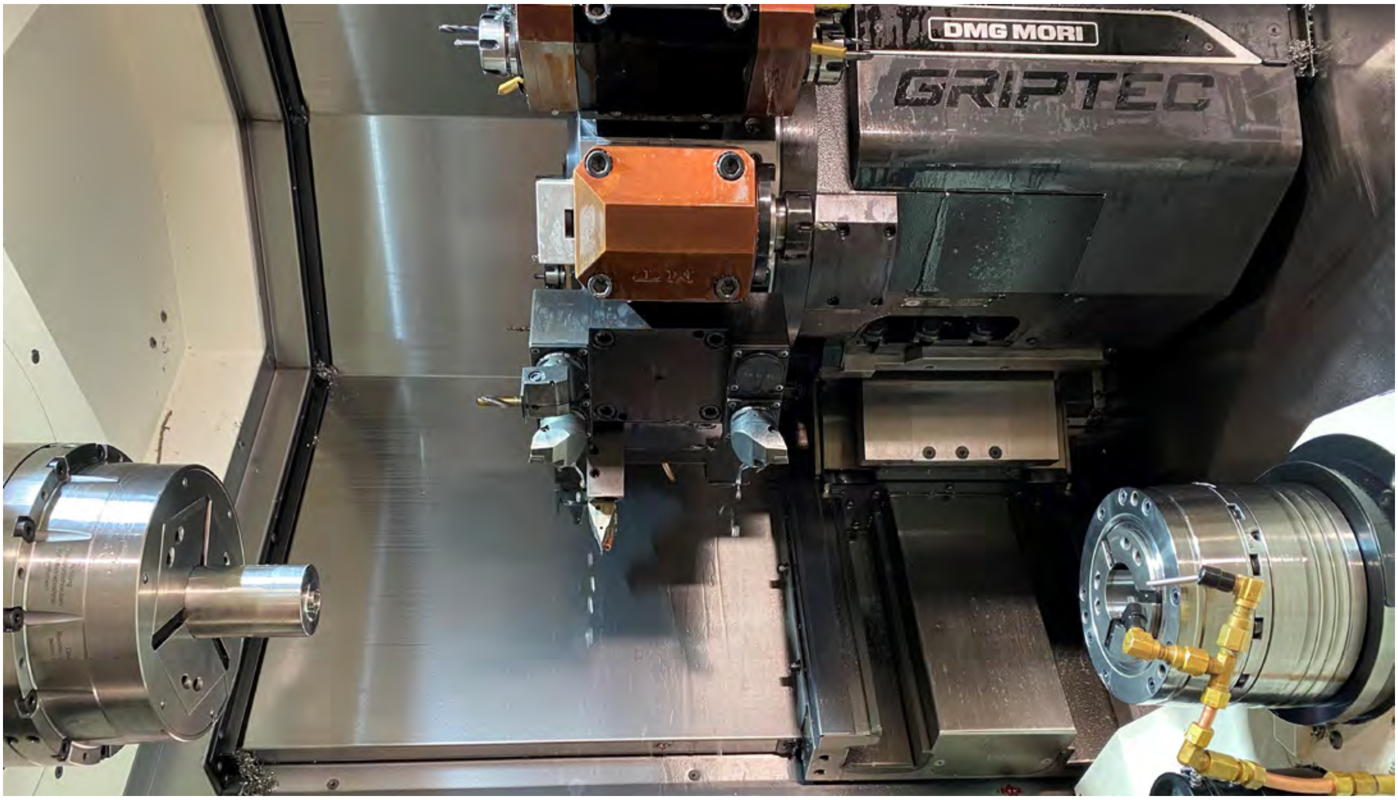

The DMG MORI dual spindle machines use TOPlus units on the main spindle for extra clamping force and rigidity and a SPANNTOP RD (round) on the sub spindle.


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State of the Powder Metal Industry

MPIF Takes a Look at Market Disruptions and Future Forecasts

Rodney Brennen, President, MPIF

The North American powder metallurgy (PM) industry has not been immune from the unprecedented challenges facing the global supply-chain including the negative effects of COVID-19, semiconductor microchip processor shortages, container shortages and the automotive industry's transition to EVs. Most automotive companies, whose vehicles use an estimated 20–100 processors each, depending on the vehicle's features, agree that recovery will begin in the second half of 2022, but a normal supply won't be met until well into 2023. Volkswagen doesn't expect demands to be met until 2024.

The container shortages, that have caused difficulties receiving raw materials and shipping finished product to our customers. The Royal Bank of Canada estimates one-fifth of the global container ship fleet is currently stuck in congestion at ports. In February of this year, total "quits" by employees in the manufacturing sector hit a record 345,000; a short-lived record as March registered 360,000 quits. The invasion of Ukraine by Russia had an immediate effect on the availability of raw materials, sending prices skyrocketing, while also causing other global disruptions.

And let's not forget the ongoing electrification of the automobile, our industry's main consumer of PM parts. All major and minor automotive companies have aggressive plans to discontinue or severely limit the sale of internal combustion engine vehicles by 2030. However, many of these major disruptions should be viewed as opportunities. They have forced companies to work smarter, be more efficient, and innovative. New production output levels are being achieved thanks to changes and innovations made because of the pandemic. Many companies report reductions in energy consumption, furnace atmosphere gasses, scrap, and waste that is sent to landfills as a direct result of operating more efficiently. Some companies have replaced older equipment with the latest computer controlled "Industry 4.0" technology. This "Internet of Things" approach allows equipment to "talk" to each other and learn the best parameters for the process.

Automation within the industry continues to grow as a solution to the overall shortage of workers. From pick-and-place robots at the compacting presses and furnaces, to 100 percent vision system inspections, automation will continue to increase. With nothing on the horizon to reverse the shortage of workers, we can all be grateful that robots usually show up five days a week and don't take extended breaks.

Even with the excessive amount of manufacturing quits during the Great Resignation, the manufacturing sector has proved quite resilient over the past year where new factory orders have soared over 14 percent, year-over-year.

All of this is positive. The PM industry is alive and well, landing back on its feet, and on its way to recovery.

Metal Powder Activities

Powder producers continue to respond to the needs of the industry by developing new and improved materials and additives for conventional press and sinter, MIM, and metal AM.

Over the past two years, dry lubricants have been in limited supply and high demand, forcing companies to seek alternatives. The demand to improve "value-added" machining has resulted in new high green strength materials that are suitable for green machining.

With the electrification of the automobile increasing, soft magnetic and soft-magnetic composites are being researched by all major iron powder producers. Most have ongoing collaborative efforts with their customers and academia to identify higher permeability, lower core loss, and increased part strength materials and processes. The MPIF Standards Committee is keeping a keen eye on this development. These magnetic materials have a vital role in the future of electric vehicles, as well as home appliances and other electric devices, and will require standardization.

MIM and AM powder producers are seeing strong demands for materials. Generally, the materials of choice are stainless steels and low-alloy steels, but there is considerable developmental work being performed on aluminum, titanium, and an array of other metal powders and alloys. Total 2021 North American MIM and AM powder shipments increased by an estimated 5–10 percent to 3,934,767–4,202,178 kg (8,656,487–9,244,792 lb.). Of this amount, an estimated 360,000 kg (793,664 lb.) is dedicated to AM.

Improving powder quality will benefit both MIM and AM. A narrower particle-size-distribution range, greater sphericity, fewer satellites, and less internal porosity will improve throughput, mechanical properties, and overall process consistency. Typically, these powders are manufactured by gas atomization, but capacity has been added recently for plasma atomization and research continues to develop water-atomized low-alloy materials for MIM and AM.

Powder Metallurgy Outlook

I believe the industry will be able to adapt and overcome, but we will need the mindset and resources to adjust to the changing environment. As an industry, we need to showcase our strengths and work together to advance the technology. We have a lot of advantages over other metal-forming technologies. Many companies in our industry have aggressive programs to become carbon-neutral, sooner than later. Last year we learned about iron powder being used as an energy source, combusting it with hot gases to drive an engine, producing sustainable electricity. We also learned about a sustainable energy-focused infrastructure for storing zero-emission metal-hydride energy. This innovative, safe, and renewable energy storage solution utilizes high-density PM pellets. Other non-traditional applications for metal powers include water purification, thermal management, and solar energy. And how about the research to remove oxygen from moon dust? The process byproduct is metal powder that one day could be used to make structures on the moon.

These are just a few examples of creative uses and new opportunities for metal powders. We need to set our sights long-term, not just on meeting our monthly goals. We need to invest in R&D to create new applications and uses for metal powders and PM parts. And we need to work together for a common goal.

PM Design Award Winners

The winners in the 2022 Powder Metallurgy (PM) Design Excellence Awards competition, sponsored by the MPIF, showcase outstanding examples of PM's unique ability to challenge competing technologies. Nine Grand Prize and 18 Awards of Distinction were given during this year's competition.

Grand Prize Awards

Group photo of Grand Prize Winners.

A Grand Prize in the Automotive—Engine Category for Conventional PM components has been awarded to GKN Sinter Metals and their customer Pierburg, for an aluminum metal-matrix composite outer gerotor for an Italian luxury sports car dry sump pump. It is the first aluminum gerotor used in a dual-material aluminum-steel pump gear for a production vehicle application. The inner profile of the gerotor for this high-performance application was critical for it to function in conjunction with a steel inner rotor with a different thermal expansion coefficient. The part provides a 50 percent reduction in rotating mass, which becomes even more significant with six gerotors per gang pump assembly.

A Grand Prize in the Automotive—Chassis Category for metal injection molded (MIM) components has been awarded to Kyerim Metal Co., Ltd, and customer Hyundai Motor Company, for a MIM-316L stainless steel rotary wheel used for selecting various internal functions in Hyundai-Kia Motors automobiles. The MIM part replaced an electroplated plastic rotary wheel and exhibits more than four-times the durability of the plastic part.

A Grand Prize in the Automotive—Chassis Category for Metal Additive Manufactured (AM) components has been awarded to Divergent Technologies, Inc. and their customer Czinger Vehicles, for a brake assembly chassis structure used in the Czinger 21C hypercar. The ultralightweight chassis structure is made by laser-beam powder-bed-fusion using a proprietary high performance aluminum alloy. Full vehicle validation was completed, and the component passed accelerated durability and proving ground abuse, dynamic stiffness, noise-vibration-hardness, as well as various Federal Motor Vehicle Safety Standards.

In the Aerospace/Military/Firearms Category for MIM components, a Grand Prize has been awarded to ARC Group Worldwide and their customer Palmetto State

Armory, for a fire control housing that holds the trigger mechanism in a consumer pistol firearm. The fire control housing mounts into the frame of a pistol and supports various fire control mechanism components. The part facilitates the assembly of the firearm and supports the sear and blocker that are safety components.

In the Lawn & Garden/Off-Highway Category for MIM components, a Grand Prize has been awarded to INDO-MIM Pvt Ltd., for a rotor flow meter used in an agricultural sprayer made from MIM-17-4 PH stainless steel. The rotor is used to measure the flow rate of pesticide or fertilizer that passes through an extended boom on either side of a carrier while spraying a field. The rotors were previously machined. MIM processing was more cost-effective.

A Grand Prize has been awarded to INDO-MIM Pvt Ltd., in the Hand Tools/Recreation Category for MIM components for a quick-change core retaining anti-drill part used in a security door lock assembly. The complex part requires high strength and good wear resistance and is made from M2 tool steel. The cube-like structure has four, square through holes and across its center has three cylindrical projections—one at each edge and one in the center.

In the Medical/Dental Category for MIM components, a Grand Prize has been awarded to INDOMIM Pvt Ltd., for a stainless-steel curved jaw, part of an advanced bipolar device designed for use in open or laparoscopic tissue sealing surgical procedures.

In the Medical/Dental Category for AM components, a Grand Prize has been awarded to 3DEO Inc., for a MIM-17-4 PH stainless steel clevis, the primary component in a wristed end-effector assembly used in robotic minimal invasive surgery. The clevis interfaces with multiple components to enable controlled articulation of remote surgical tools inside the body. A hybrid AM approach is used to make the parts that offers the robustness and accuracy of CNC machining and the scalability of MIM.

In the Electronic/Electrical Components Category for MIM components, a Grand Prize has been awarded to ARC Group Worldwide, for a stator assembly, plate and frame used in small aerospace servo valves. Both parts are produced using two-cavity, three-plate injection molds. The stator assembly is part of a flux-carrying device that delivers magnet and coil flux to an armature. The assembly is used in servo valves for flight control actuation. MIM technology offered an opportunity to produce this assembly at a significantly reduced cost.

Group photo of Awards of Distinction.

Awards of Distinction

In the Automotive—Engine Category for Conventional PM components, an Award of Distinction has been given to Nichols Portland LLC., a division of Nichols Portland Inc., for an eccentric ring used in a variable displacement oil pump. The sinter-hardened parts provide enhanced performance compared with prior generation designs that used steam-treated as-sintered parts.

In the Automotive—Engine Category for Conventional PM components, an Award of Distinction has also been given to DSB Technologies, LLC., formerly SSI Sintered Specialties LLC., and customer Purem by Eberspaecher, for a 309L stainless steel sensor boss that is welded to an automotive exhaust system and holds a sensor for monitoring engine performance.

In the Automotive—Engine Category for MIM components, an Award of Distinction has been given to INDO-MIM Pvt Ltd., for a vane lever that is used as a gas flow controller in the turbocharger of an internal combustion engine. The MIM part is made using HK30 austenitic stainless steel that has good oxidation resistance and strength at operating temperatures of 800–850°C. The part was previously made by machining wrought bar stock.

In the Automotive—Transmission Category for Conventional PM components, an Award of Distinction has been given to Burgess-Norton Mfg. Co., for drive and driven sprockets, a pressure plate, and a sector gear, made for BorgWarner, and used in an automotive transfer case. The sprockets are warm-die compacted from FL-4405 with admixed nickel.

Drive and driven sprocket award winners.

In the Automotive—Chassis Category for Conventional PM components, an Award of Distinction has been given to Metalpó Indústria e Comércio Ltda. and their customer Haldex do Brasil Indústria e Comércio Ltda., for a rack used in a braking system for trucks. The rack is made from diffusion-alloyed FD-0405, warm-die compacted and case hardened to achieve good wear properties.

In the Automotive—Chassis Category for MIM components, an Award of Distinction has been given to INDO-MIM Pvt

Ltd., for an upper cap, lower cap, split center, and split center bleed for a high-end automotive suspension system sub-assembly. The parts are made from MIM-4605 and heat treated.

In the Automotive—Chassis Category for Metal AM components, an Award of Distinction has been given to Azoth, for a shift knob emblem for General Motors Cadillac, Blackwing V-series cars. The part is made by binder jetting using a proprietary 316L stainless steel powder and binder. The part was designed with AM in mind. Other than surface polishing, there are no additional post-sintering operations performed.

In the Aerospace/Military/Firearms Category for MIM components, an Award of Distinction has been given to OptiMIM, a Form Technologies Company, and their customer Savage Arms Inc., for a MIM-4605 bolt end-cap for an SPR Impulse rifle. The bolt end-cap has a large, open structure shape with four side holes. It has comparatively thin walls in relation to its size.

In the Aerospace/Military/Firearms Category for MIM components, an Award of Distinction has also been given to Advanced Powder Products Inc., for a one-piece slide release for a firearm. The part is made from an air quenched and tempered S7 tool steel. The part was originally designed for stamping, but the complex geometry was too much of a challenge.

In the Lawn & Garden/Off-Highway Conventional PM components Category, an Award of Distinction has been given to Alpha Precision Group, a division of Nichols Portland Inc., for a camshaft assembly used in a family of engines ranging from 19–27 hp for consumer lawn & garden machines. The assembly comprises six PM components (a cam gear, four cam lobes, and a thrust washer). All five parts are assembled to the precision ground shaft by means of highly automated, specialized assembly cells.

In the Lawn & Garden/Off-Highway Conventional PM components Category, an Award of Distinction has also been given to FMS Corporation and their customer TEAM Industries, for a spider dampener insert, part of a torque spider sub-assembly for ATV transmissions. The part was originally designed as a metal casting that required secondary machining, but was redesigned for PM, eliminating the need for extensive machining operations.

Ring Gear award winner.

In the Hand Tools/Recreation Category for Conventional PM components, an Award of Distinction has been given to Porite Taiwan Co., Ltd., for a ring gear, used in the gearbox of a cordless drill. It is divided into two parts due to the multisection appearance. The two PM parts are machined, pressed for alignment, followed by a plastic injection overmold operation.

In the Hand Tools/Recreation Category for MIM components, an Award of Distinction has been given to ARC Group Worldwide, for a lock-arm button used in a pocketknife. When depressed, the button fires the blade open or allows the operator to close the cutting tool safely. The part is molded using MIM-420 stainless steel and is hot isostatically pressed after sintering.

In the Hand Tools/Recreation Category for Metal AM components, an Award of Distinction has been given to Amaero and their customer Sankuer Composite Technology, for a "skull" guitar tuner. The parts are made from Inconel 718 using laser-beam powder-bed-fusion processing. The ID of the inner keyway is sized to mate with the tuning machine peg without modification.

In the Industrial Motors/Controls & Hydraulics Category for Conventional PM components, an Award of Distinction has been given to Nichols Portland LLC., a division of Nichols Portland Inc., for a pump head sub-assembly for fluid delivery. The assembly comprises six PM parts, an inlet plate, eccentric ring, inner and outer gerotors, a spline coupling, and an outlet plate.

An Award of Distinction has been given to Indo-MIM Pvt. Ltd. in the Industrial Motors/Controls & Hydraulics Category for MIM components, for a control cone used as a fluid controller in a fuel pump. This is a highly complex part with a cylindrical stepped outer diameter that varies like a dovetail towards one end. The part was previously machined and producing the angular hole through difficult high-volume machining. MIM is far more suitable for high-volume production.

An Award of Distinction in the Industrial Motors/Controls & Hydraulics Category for MIM components has also been given to PTI (Polymer Technologies Inc.) and their customer Elevator Products Corporation (a division of Schindler Elevator Corp.), for an elevator button assembly that is impervious to solvents and disinfectants. These parts solved a problem encountered during the COVID-19 pandemic—elevator button assemblies machined from stainless steel and over-molded with polycarbonate threaded inserts were being degraded by various solvents and disinfectants used excessively to sterilize highly touched areas in elevators.

In the Medical/Dental Category for MIM components, an Award of Distinction has been given to ARC Group Worldwide, for a MIM 14-4PH impaction handle lever, a single-use instrument used in knee-replacement surgery. Tight profiles are maintained in relation to the distal end of the instrument to ensure proper engagement with mating parts. This impaction handle lever represents one of the first single-use instruments converted from plastic to metal injection molding.

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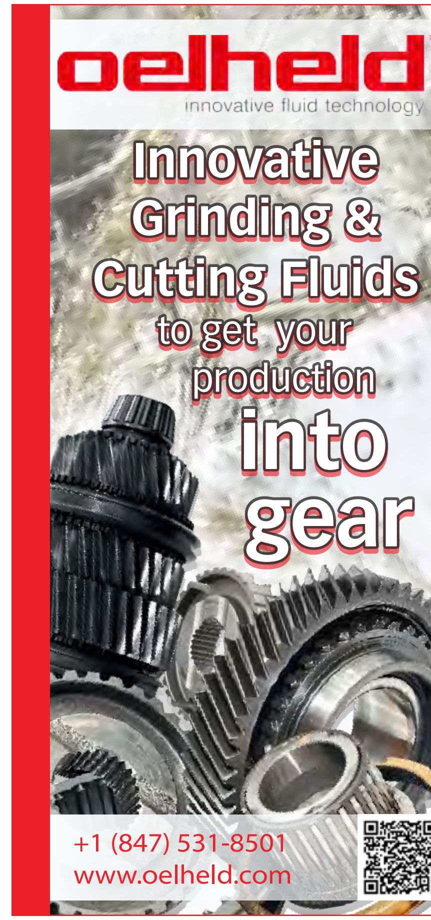
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Seeking Metallurgy and Heat-Treating Experts

Phillip Olson, Director, AGMA Technical Services

The AGMA Aerospace Gearing committee is seeking new committee members to revise *AGMA 926-C99, Recommended Practice for Carburized Aerospace Gearing*. Specifically, metallurgy and heat-treating experts are needed. This information sheet recommends material case properties, microstructure, processing procedures, and other critical parameters for carburized aerospace gears. Due to the unique requirements of aerospace gearing, such as typically smaller lot sizes, demands for higher precision, and stringent quality requirements, this information sheet aims to provide deeper, aerospace-specific information than other already published metallurgical specifications such as *AGMA 923, Metallurgical Specifications for Steel Gearing or AMS2759/7, Carburizing and Heat Treatment of Carburizing Grade Steel Parts*.

The currently published version of *AGMA 926-C99* covers AISI 9310 steel and similar materials, however, examples are limited to atmospheric carburized AISI 9310. The new revision will incorporate newer materials and heat treatment methods that represent the current state of the art in the aerospace industry. The revision will consider adding alloy examples for alloys published in both *AGMA 911-B21, Design Guidelines for Aerospace Gear Systems*, and *AGMA 937-A12, Aerospace Bevel Gears*, as well as possible newer alloy examples. Processes to be added or expanded on include, preoxidation, subcritical anneal, low pressure carburizing, high pressure carburizing, banding, cleanliness, testing acceptance criteria, definitions, and stress relief.

You are invited to take your seat at the table! Committee meetings are a great place to network and collaborate with experts in the field, broaden your knowledge, capture technical expertise in writing, refine the standards you use and see how your influence helps shape best practices throughout America and around the world.

From a company perspective, being involved in standards development saves time and money in a variety of ways, including reduction of redundancy, improved quality, and safety, and better focusing of R&D resources. Also note that if your company's not at the table helping to write the latest standards, the standards that affect your business will be written by your competitors. For the health of our industry, please reach out and make your experience a part of this living record.

For over 100 years, AGMA has been the facilitator for the development of American gear standards. For AGMA to make gear standards the best they can be, everyone in the industry needs to be involved. When AGMA standards-writing technical committees have open projects, they meet approximately six times per year for two-hour virtual meetings, and approximately once per year for a two-day in-person meeting. The next aerospace gearing committee meeting scheduled to discuss this project is December 13, 2022. The meeting will be a two-hour virtual gathering held from 10:00 a.m. to 12:00 p.m. Eastern time.

If you are interested in working on this project, please contact us at *tech@agma.org*.

Taking into Account the Production Methodology and Estimating the Influence of Manufacturing Quality on NVH Performance when Sizing Gears

Dr. Ing. Ulrich Kissling, ETH

Summary

Noise emissions from gear units in electric vehicles are a major problem. It is a well-known fact that if gears with high accuracy are used, their service life is increased and vibrations are reduced, improving the NVH (noise, vibration, and harshness) performance, resulting in less noise. For this reason, many EV (electric vehicle) manufacturers require a high to very high quality according to ISO 1328 (Ref. 8) for gear manufacturing.

In practice, the profile form deviation, in particular, is greatly restricted. In some cases, requirements are specified that are almost impossible to manufacture. This increases cycle times and therefore manufacturing costs. This begs the question whether the requested high quality actually produces any real improvements or whether, for example, a well-sized profile modification isn't more effective than simply reducing the permitted manufacturing allowances.

For this reason, it would be sensible to find a method that can be used to estimate the influence of the manufacturing accuracy. When the gear profile measurement is analyzed, the signal is always statistically scattered and usually overlaid with a certain basic waviness. The size of this waviness directly influences the resulting profile form deviation.

This paper describes the basis for, and results from, a project that investigated the influence of quality on the resulting transmission error and the excitation force in the gear meshing. To achieve this, a sinus-shaped waviness is applied to the theoretical ideal tooth flank. The amplitude, length and initial value of the waviness can be modified. This modification can be applied in both the profile or flank line direction, individually, or both at the same time. The changes in transmission error, excitation force and other fundamental influences on the causes of vibration are then evaluated to obtain a result.

The amplitude or height of the waviness depends on the maximum permitted profile form deviation $f_{f\alpha}$, according to the selected quality. The waviness length or initial value can however vary during production, without any influence on $f_{f\alpha}$, depending on the situation. For this reason, it is necessary to take into account the result scatter for different forms of waviness. This can be achieved in an automatized process by combining different variants of amplitudes, lengths and phase angles, for the purposes of calculation. The changes in transmission error and other values that occur, can then be displayed and used to forecast the effect of the quality on the NVH performance. The application of this method to some current gear units is shown and discussed.

Considering the production methodology in the gear design process

Gear unit design and tooth flank modifications

When a gear unit is sized, a gear unit schematic is created, based on the requirements such as loads, speeds and output reductions. A schematic of this kind can then be modelled very efficiently in a drive systems software design package (Ref. 1)(Figure 1). The dimensions of gears, shafts and bearings can be defined with sizing functions. This very quickly provides the designer with an initial draft that already meets fundamental requirements such as minimum safeties and/or service life.

After adjustment of the gearbox dimensions to given spatial boundaries and other constraints, static and dynamic simulation of the gearbox is performed. This enables the specialist to identify which tooth flank modifications are necessary to avoid tooth damage due to deformation under load. Nowadays, profile and flank line modifications specifically intended to minimize excitations of vibration (noise!) or losses (efficiency!) are extremely important. Tooth modifications of this kind are made for reasons of purely functional nature. Most often such modifications are crownings in the profile and flank line direction.

Tooth flank modifications that have been defined for purely functional reasons can usually only be manufactured approximately. It is then the task of the manufacturing department to achieve this function-oriented tooth modification as accurately as possible.

Gear manufacture methods

A multitude of different processes for manufacturing cylindrical gears are available (Figure 2). For pre-machining, processes such as hobbing, profile milling, shaping, broaching or skiving are available. Fewer processes exist for hard finishing, mainly generation grinding, profile grinding and gear honing. Gears are produced based on the tool geometry and process kinematics. The kinematic is calculated by the control software of the machine, using the theoretical gear data and the required tooth modifications.

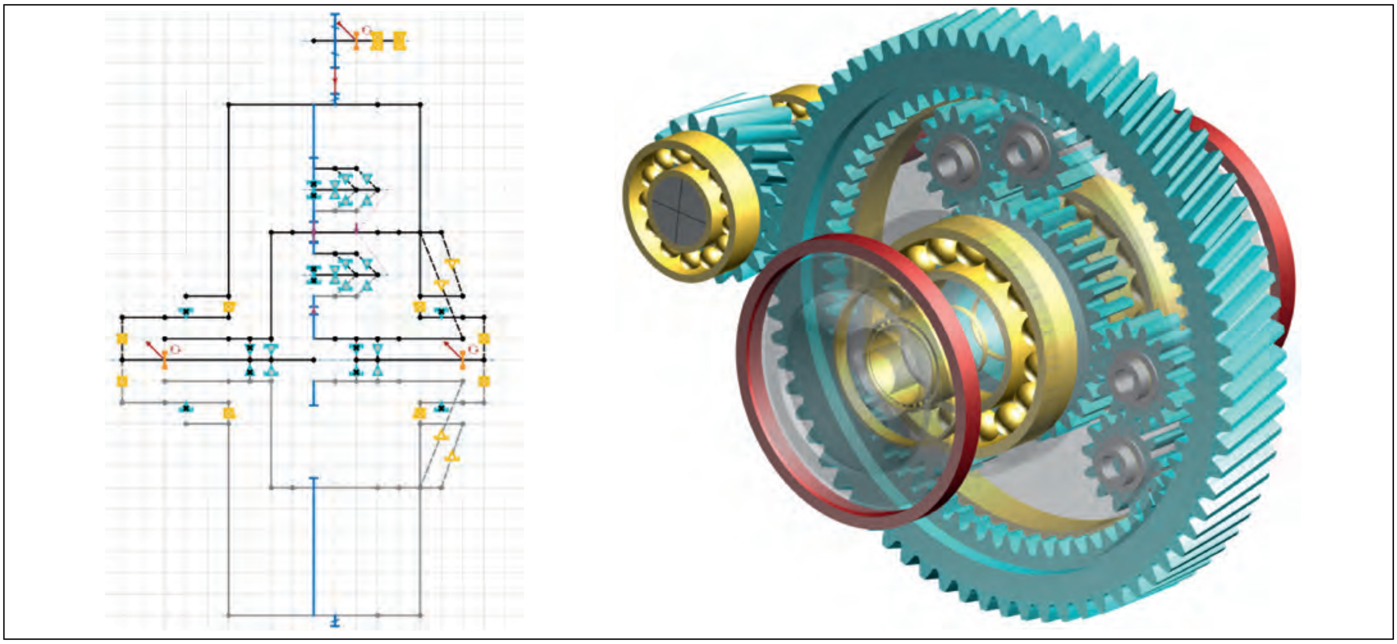


Figure 1—Gearbox design of a lightweight differential, for an EV. Left: Gear unit schematic representation in the KISSdesign Sketcher*. Right: View of the 3D model after pre-sizing in* KISSdesign *(Ref. 1).*

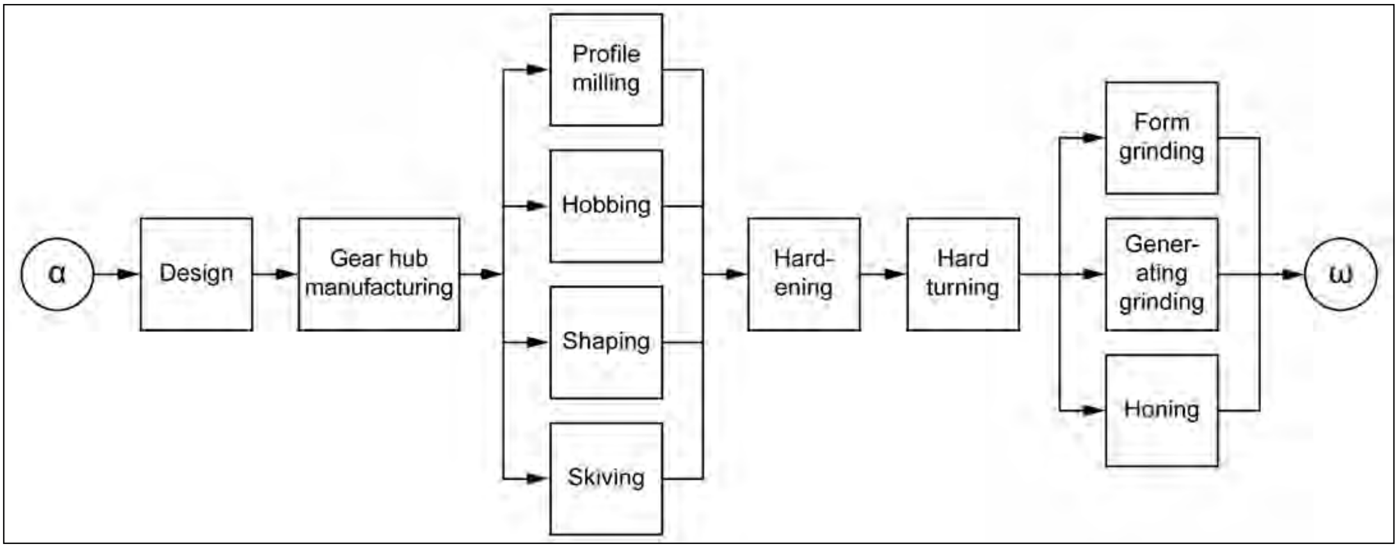


Figure 2—Customary production process for cylindrical gear manufacture.

Usually, the design department designs a gear with little discussion about the production. If the production is outsourced, as is often the case nowadays, during the design phase usually no decision is taken as to who will produce the gears, or which process will be used.

Taking the production methodology into consideration during the design process

Every production method (Figure 2) has its own specific properties that either enable the method to produce a particular tooth modification well, reasonably well or not at all. The machine operator in the production is faced with the problem of producing a modification that cannot be created mathematically exact. Consequently, the required modifications are produced with an approximation which is more or less good. If the operator then succeeds in creating the gear within the specified tolerance, he is happy with that. Deviations from the required modifications are checked during production with profile and flank line measurements. This process is of limited use for checking topological modifications. A reasonable tolerance interval is necessary for gear production, otherwise the production costs may become excessive. The question remains, if a gear produced inside the given tolerances will have the gear properties intended by the designer.

For example, a profile form deviation is defined in such a way that the required profile form, shown as a dashed line in Figure 3, is moved as far to the right and left (shown as pointed lines) as is necessary to touch the measured profile form, shown as a thick blue line. The distance by which the profile form is displaced to the left and right then accounts for the profile form error $f_{f\alpha}$ according to ISO 1328. It is obvious that there are different profile forms that all have the same value for $f_{f\alpha}$. This

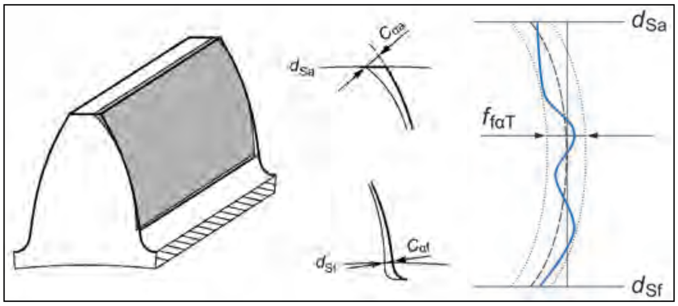


Figure 3—Determination of a profile form deviation $f_{f\alpha}$.

methodology can only partially evaluate the influence that a specific deviation of this kind has on a gear's noise characteristics. The same applies for the flank line form deviation (Ref. 3).

Example: Natural twist resulting from flank line crowning

A classic example, how the manufacturing process can influence the tooth properties, is the production of flank line crowning on a simpler grinding machine. During the generation grinding process of a helical gear tooth, the movement of the tool results in a specific deviation error called "natural twist." This deviation consists of a twist with a small overlaid profile crowning (Figure 4). Modern grinding machines can compensate for this twist caused by manufacturing, but simpler machines cannot. Such a twist can greatly influence the contact pattern and the excitation characteristics in the meshing and is normally not desirable.

However, in the case of a helical gear, a flank twist is sometimes deliberately used as a modification, in certain cases. This shows that a twist caused by manufacturing can sometimes be useful. If the design software enables the twist caused by manufacturing to be calculated and taken into account in the contact analysis, the resulting manufacturing deviation can be included at gear sizing stage. This simplifies the grinding process considerably and it is easier to achieve the target contour.

Integrating Production expertise when sizing gears

As discussed above, it is useful to take a manufacturing method's properties into account when sizing gear tooth geometry and modifications. The manufacturing method also affects the costs and can therefore be extremely important, especially in the case of larger production series. For example, gear honing is a very cost-effective method for large production series but can only be used up to approximately module 6 mm. Alternatively, power skiving can be a very productive way to manufacture a gear, compared to the use of a shaper cutter, but it is necessary to check whether the workpiece and the tool might collide.

However, it is often the case that the gear designer does not have enough expertise in production to overcome the restrictions inherent in the different processes. For this reason, KISSsoft (Ref. 1) strives to integrate production expertise in its sizing software. The challenge is to be able to check the usability of a particular manufacturing method without the designer is asked for details that he does not know. For example, it should be avoided that the designer being asked to enter the diameter of the shaft of a power skiving tool which he may not know. This makes the development of manufacturing verification programs a challenge.

As KISSsoft AG has now been integrated with Gleason (Ref. 2), there are a number of new options for achieving this task.

The influence of manufacturing quality on NVH performance

The nature of the problem

As previously discussed, the production of predefined modifications, especially topological modifications, can be difficult. Naturally, the designer wants that the modifications as defined, e.g., especially for low-vibration gear sizing for EV applications, to be produced as accurately as possible.

In practice, the profile form deviation, in particular, is often greatly restricted. In some cases, requirements are specified

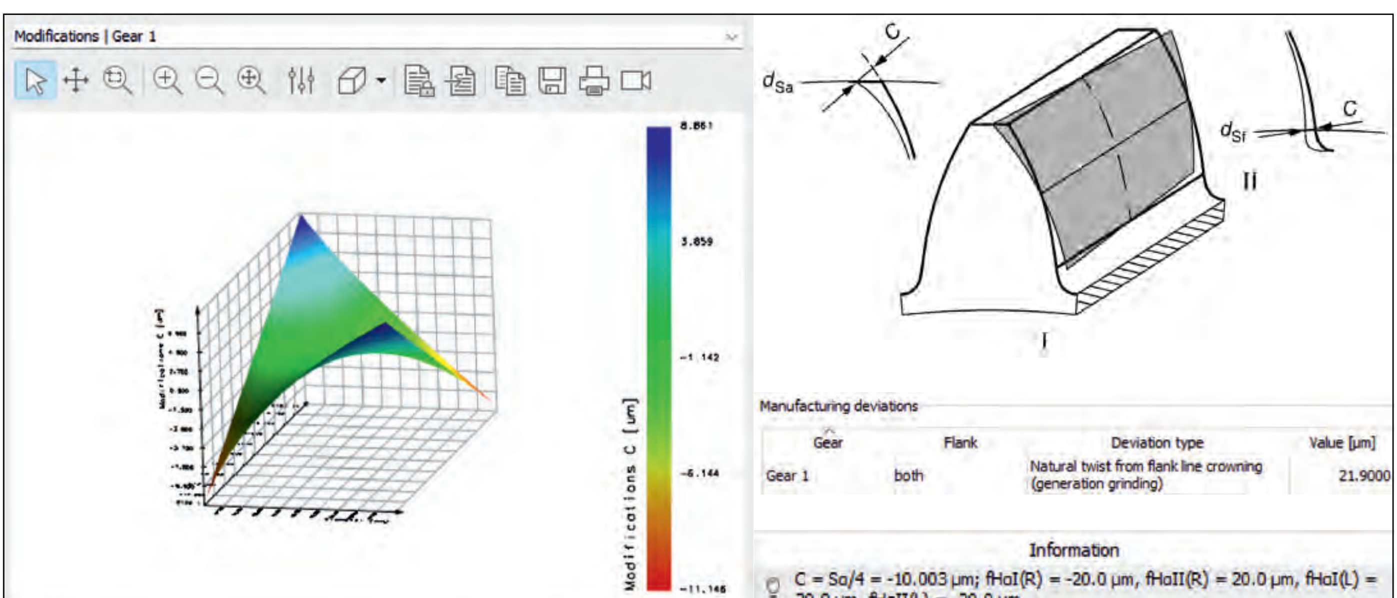
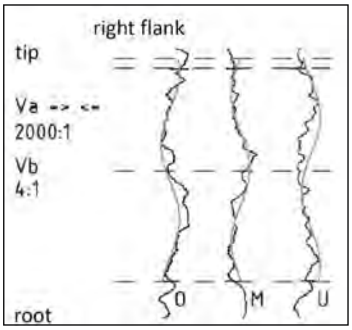


Figure 4—Natural twist caused by manufacturing (S_α 10,004 µm according to ISO 21771) when a flank line crowning (21.9 µm) is produced using generation grinding. Calculation in KISSsoft *(Ref. 1).*

that are almost impossible to manufacture. This increases cycle times and therefore manufacturing costs. This begs the question of whether the required high quality actually produces any real improvements or whether, for example, a well-sized profile modification isn't more effective than simply reducing the permitted manufacturing allowances.



When the profile and flank lines in gear measurements are analyzed, the signal is always scattered and usually overlaid with a certain basic waviness. Consequently, the amount of waviness directly influences the resulting profile and helix form deviation.

It is logical that a waviness on the tooth flank is, or can be, the cause of vibration (Ref. 4). On the other hand, it has also been confirmed that the excitation is not necessarily proportional to the amplitude or length of the waviness (Ref. 5). A certain amount of waviness can even improve the noise characteristics. This has been investigated in tests at TU Munich's FZG (Gear Research Center), which have proven that a significant reduction in noise can be achieved with a precisely predefined waviness (Refs. 6 and 7).

This arose the idea of applying an additional waviness to a theoretically optimally sized tooth (with and without modifications) and then testing the influence of such a deviation on the required properties. First of all, a tooth pair in a theoretically error-free state should be investigated with contact analysis (under load), to determine the usual critical properties such as transmission error, excitation force, Hertzian pressure, loss etc. After that, an additional waviness is applied to the tooth so that the calculation can be repeated and the deviation from the results of the first calculation can be determined. The order of magnitude of the waviness should correspond to the form deviation ($f_{f\alpha}$ for the profile or $f_{f\beta}$ for the flank line) of the intended accuracy grade (e.g., according to ISO 1328).

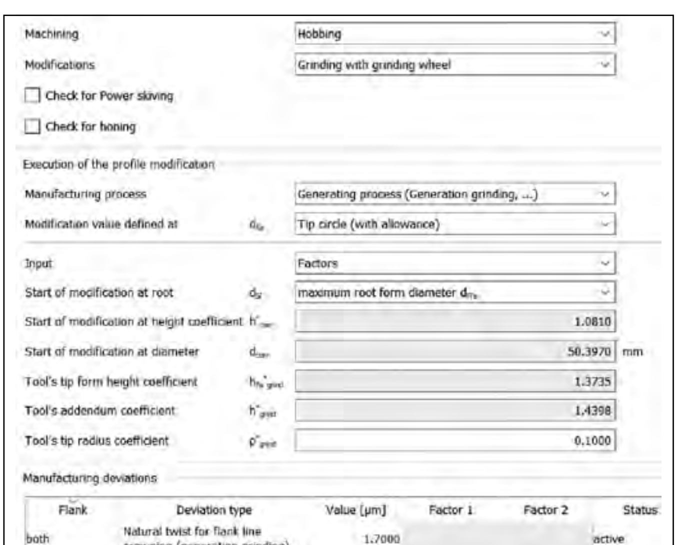


Figure 5—Checking the manufacturability in a special "Manufacturing" tab in **KISSsoft.**

Application in the calculation

To enable this calculation to be performed, a table was added to the "Manufacturing" tab in *KISSsoft* (Ref. 1) (Figure 5), in which the user can enter manufacturing deviations (Figure 6).

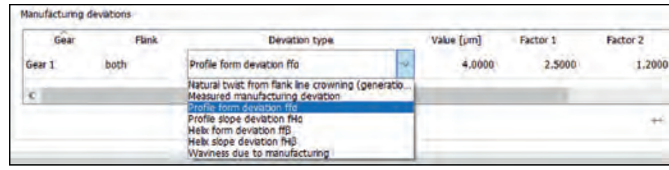


Figure 6—Selecting and inputting waviness types in **KISSsoft.**

The manufacturing form deviation can be simulated as waviness in the profile direction, in the flank line direction, or in the direction normal to the tool which is used to produce the gear, as defined in Table 1. Inputs can also be cumulated by entering deviations multiple times.

Inputs	Form error $f_{f\alpha}$ simulation	Form error $f_{f\beta}$ simulation	Waviness due to manufacturing
"Value", µm	Amplitude *2	Amplitude *2	Amplitude *2
"Factor 1"	Sinus wave length in module (roll length)	Sinus wave length in module	Sinus wave length in module
"Factor 2"	Distance from tip to middle amplitude in module (starting point)	Distance from side I to middle amplitude in module (starting point)	Waviness helix angle β_{well}
Formula used	1)	2)	3)
1)	$\Delta f\alpha$ = value/2* [1 – Sin(2*π (0.25 - Factor2/Factor1 + L(y) / Factor1/mn))]		
2)	$\Delta f\beta$ = value/2* [1 – Sin(2*π (0.25 - Factor2/Factor1 + b(x) / Factor1/mn))]		
3)	$\Delta f\alpha$, $\Delta f\beta$ depending on βwell		

Table 1—Waviness definition

One important problem relating to the determination of the influence of waviness on meshing is that waviness resulting from manufacturing can vary from one tooth to the next, or from one workpiece to the next. The wavelength, wave start (Figure 7), and amplitude will vary randomly. This is obvious in analyses from gear-measuring machines (Ref. 5). So a large number of calculations must be performed to analyze the scatter of these parameters. Different variants of the amplitude, length, and start values are generated. Contact analysis is performed for each variant to calculate the most important results, which are then displayed.

An enormous amount of time would be needed to perform this procedure step by step with manual calculations. The use of the script language integrated into *KISSsoft* (Ref. 1) is a good solution in this case. The engineer performing the calculations can use a script editor to write and run their own functions in the software. This then enables the contact analysis to be calculated automatically many times, with varied waviness (Figure 8). The results are saved and displayed in an overview.

Application for an industrial gear unit

Profile form deviations

As an initial example, the method is applied to an industrial gear unit without modifications. The considered output stage has a module of 6 mm, number of teeth is 26:75, face width is 26 mm and the output torque is 5,000 Nm. The specified quality for the case-hardened gears according to ISO 1328 is Q6. The permitted profile form deviation $f_{f\alpha}$ (Figure 9) equals 12 µm.

The peak-to-peak transmission error (PPTE) is calculated with different waviness types resulting from manufacturing. The double amplitude (peak to valley value) is varied from 0 to 12 µm. A double amplitude of 2*6 µm corresponds to the maximum permitted profile form deviation (12 µm) if the quality is Q6. If the specified quality is 3, 4 or 5, the double amplitude would be 2.1, 3.0, or 4.3 µm. Figure 10 shows the result if the double amplitude is varied from 0 to 12 mm, the wavelength is varied from 3 to 9 mm and the length of the start from the tip is varied with 0, 25, 50, and 75 percent of the wavelength. The graphic contains all the PPTE results with the same amplitude on the same x-coordinates. This shows the bandwidth of the results depending on the length and starting angle. For a given amplitude, the PPTE will consequently lie within the interval shown.

The PPTE for the error-free gear is 16.7 µm. If the tolerance is Q4, the PPTE increases on average by around 11 percent and lies within a range of 15.2 to 22.0 µm. If the tolerance is Q6, the PPTE increases on average by 21 percent, within the range 12.8 to 27.7 µm. When we consider that the PPTE can be reduced by 50 percent or more by using an adjusted profile modification, an increase of 21

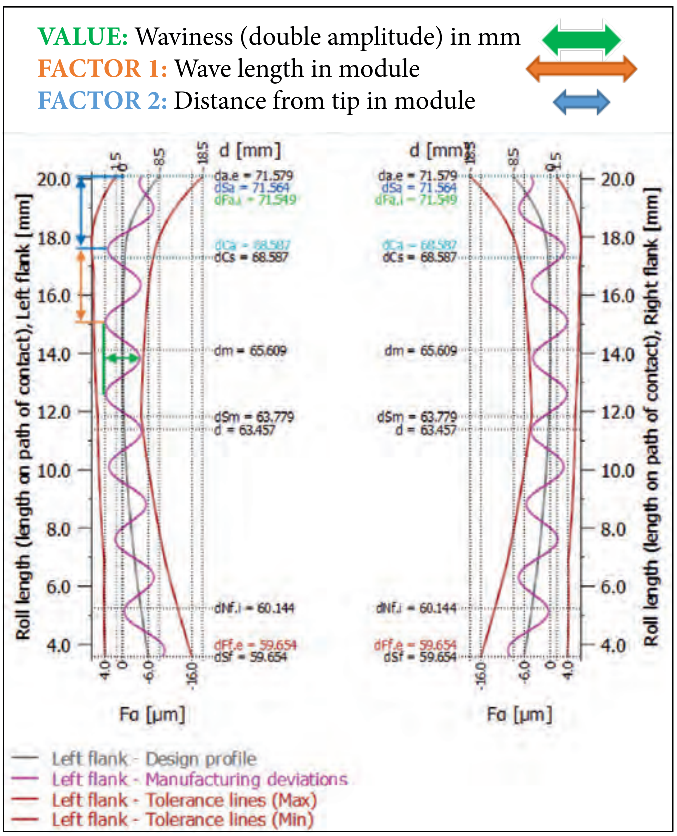


Figure 7—Display of the waviness in the Profile diagram.

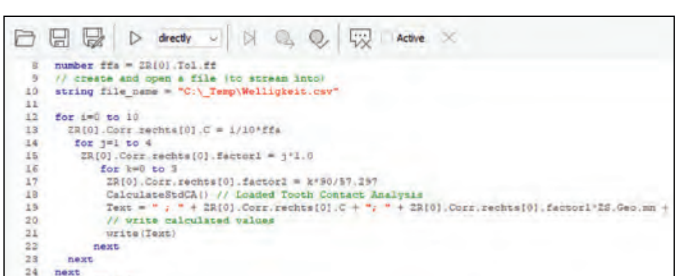


Figure 8—Extract from a script program with which the waviness resulting from manufacturing can be varied (the amplitude is varied in 10 steps, the length in 4 steps, and the start in 4 steps).

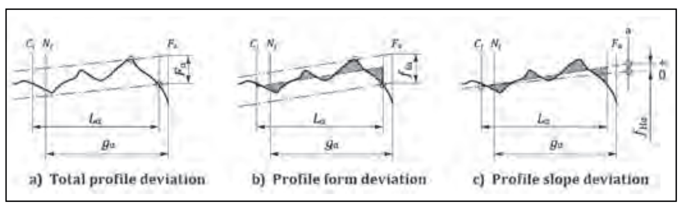


Figure 9—Profile deviations according to ISO 1328-1 (Ref. 8).

Sinus-Ondolation		ffa						
2*Amplitude	Length	Start angle	PPTE	1.Harm.	Loss	sigHmax	LoadVar.	2.Harm.
0	6	0	16.705	5.38	1048.21	949.02	11450.82	5.38
0	6	90	16.705	5.38	1048.21	949.02	11450.82	5.38
0	6	180	16.705	5.38	1048.21	949.02	11450.82	5.38
0	6	270	16.705	5.38	1048.21	949.02	11450.82	5.38
0	12	0	16.705	5.38	1048.21	949.02	11450.82	5.38
0	12	90	16.705	5.38	1048.21	949.02	11450.82	5.38
0	12	180	16.705	5.38	1048.21	949.02	11450.82	5.38
0	12	270	16.705	5.38	1048.21	949.02	11450.82	5.38
0	18	0	16.705	5.38	1048.21	949.02	11450.82	5.38
0	18	90	16.705	5.38	1048.21	949.02	11450.82	5.38
0	18	180	16.705	5.38	1048.21	949.02	11450.82	5.38
0	18	270	16.705	5.38	1048.21	949.02	11450.82	5.38
0	24	0	16.705	5.38	1048.21	949.02	11450.82	5.38
0	24	90	16.705	5.38	1048.21	949.02	11450.82	5.38
0	24	180	16.705	5.38	1048.21	949.02	11450.82	5.38
0	24	270	16.705	5.38	1048.21	949.02	11450.82	5.38
0.6	6	0	16.836	5.36	1049.7	948.41	11618.68	5.36
0.6	6	90	17.062	5.38	1048.57	929.6	11743.61	5.38
0.6	6	180	16.866	5.36	1050.55	957.59	11517.4	5.36
0.6	6	270	16.649	5.32	1050.22	967.84	11427.37	5.32
0.6	12	0	16.428	5.2	1052.55	953.87	11238.15	5.2
0.6	12	90	16.698	5.33	1049.05	947.75	11454.85	5.33
0.6	12	180	16.983	5.44	1049.35	943.75	11620.79	5.44
0.6	12	270	16.692	5.4	1048.26	950	11418.25	5.4
0.6	18	0	17.179	5.55	1051.84	947.05	11794.55	5.55
0.6	18	90	16.643	5.35	1047.03	950.3	11385.27	5.35
0.6	18	180	16.274	5.14	1048.5	948.82	11079.33	5.14
0.6	18	270	17.017	5.42	1051.26	947.35	11689.4	5.42
0.6	24	0	17.003	5.45	1052.62	947.78	11666.03	5.45
0.6	24	90	17.068	5.52	1050.62	948.05	11716.57	5.52
0.6	24	180	16.386	5.2	1047.24	949.87	11189.82	5.2
0.6	24	270	16.373	5.19	1048.05	949.59	11190.82	5.19
1.2	6	0	17.06	5.33	1052	966.24	11854.2	5.33
1.2	6	90	17.497	5.38	1049.33	915.11	12088.74	5.38
1.2	6	180	17.108	5.45	1050.22	967.79	11857.75	5.45
1.2	6	270	16.683	5.33	1049.47	986.66	11527.59	5.33
1.2	12	0	16.15	5.09	1054.14	958.89	11046.6	5.09
1.2	12	90	16.686	5.28	1050.22	946.79	11455.86	5.28
1.2	12	180	17.289	5.55	1047.71	938.65	11832.23	5.55
1.2	12	270	16.716	5.46	1047	951.27	11508.05	5.46
1.2	18	0	17.71	5.81	1053.05	945.28	12214.39	5.81
1.2	18	90	16.525	5.23	1047.27	951.8	11354.38	5.23
1.2	18	180	15.844	4.88	1047.34	951.52	10750.54	4.88
1.2	18	270	17.384	5.53	1051.54	945.91	12004.09	5.53
1.2	24	0	17.39	5.59	1056.46	946.74	11953.6	5.59
1.2	24	90	17.43	5.66	1053.58	947.29	11976.09	5.66
1.2	24	180	16.142	5.09	1043.54	950.92	11006.85	5.09
1.2	24	270	16.081	5.06	1045.13	950.36	10997.96	5.06
1.8	6	0	17.303	5.34	1052.47	982.32	12136.32	5.34

Figure 10—Influence of the waviness (on the profile) resulting from manufacturing on the transmission error (PPTE) in the case of a gear pair with module 6 mm.

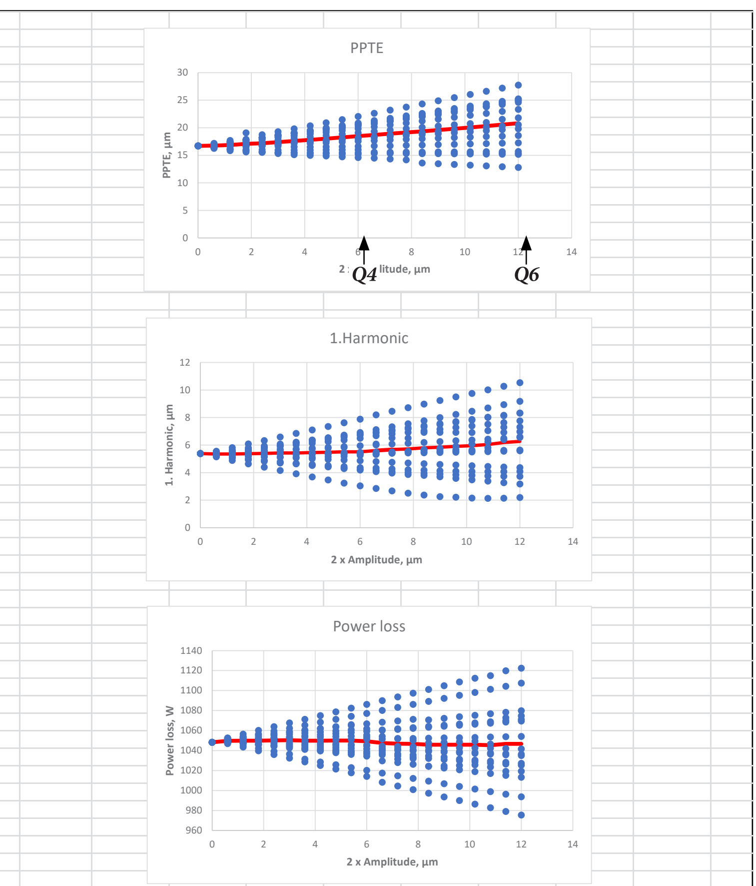
percent is absolutely within the bounds of what is acceptable. Consequently, specifying Q6 for this gear set is appropriate as the manufacturing costs for Q6 are considerably lower than for Q4.

The increase is not relevant for power loss as the average reduction is 1 percent. By contrast, the effect on Hertzian pressure is bigger. In the case of Q6, the maximum Hertzian pressure increases on average by 11 percent (Figure 11).

Flank line form deviations

The specified helix form deviation for the gear under consideration, $f_{f\beta}$, equals 11 µm for Q6, in the case of face width 44 mm. Figure 12 shows the result if a waviness is applied in the flank line direction, the amplitudes are varied from 0 to 11 mm, the lengths are varied from 7.5 to 22 mm and the starting angle is varied with 0, 25, 50 and 75 percent of the wavelength.

The influence of a flank line waviness on the transmission error is extremely low (in the case of Q6, the PPTE increases on average by around 0.2 percent)! The power loss increase is also minimal (< 0.3 percent in the case of Q6). The influence on the Hertzian pressure is greater and in the case of Q6, the maximum pressure increases by approximately 14 percent on average (in the range +11 to +16 percent). So generally, helix form deviations caused by waviness are obviously much less critical than profile form deviations!



(Red line: mean value.)

Waviness normal to the direction of processing

Waviness in the direction normal to the tool which is used to produce the gear can, for example, occur through the milling process. The waviness influence on the transmission error (PPTE) is similar to the waviness influence in the profile direction. In the case of Q6, a maximum increase of 25 percent results. The maximum Hertzian pressure changes in the range +10 percent to +100 percent (Figure 13).

Application in the case of EV gear units

Gear units for industrial applications usually either have no modifications, or only more simple modifications. In contrast, complex modifications are always used in vehicle gear units in general and EV gear units in particular to optimize

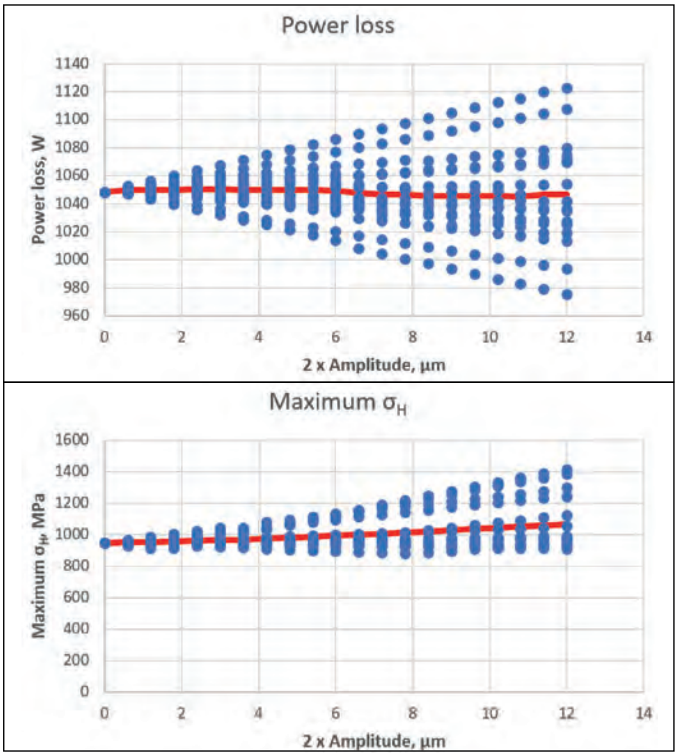


Figure 11—Influence of the waviness (on the profile) resulting from manufacturing on the power loss (top) and the maximum Hertzian pressure (bottom).

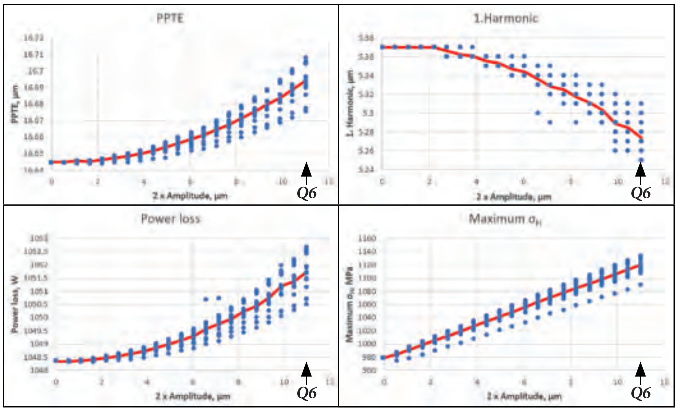


Figure 12—Top: Influence of the waviness resulting from manufacturing (flank) on the transmission error (PPTE) and the amplitude of the first harmonic (FFT analysis) in the case of a gear pair with module 6 mm. Bottom: Influence on the power loss (left) and the maximum Hertzian pressure (right).

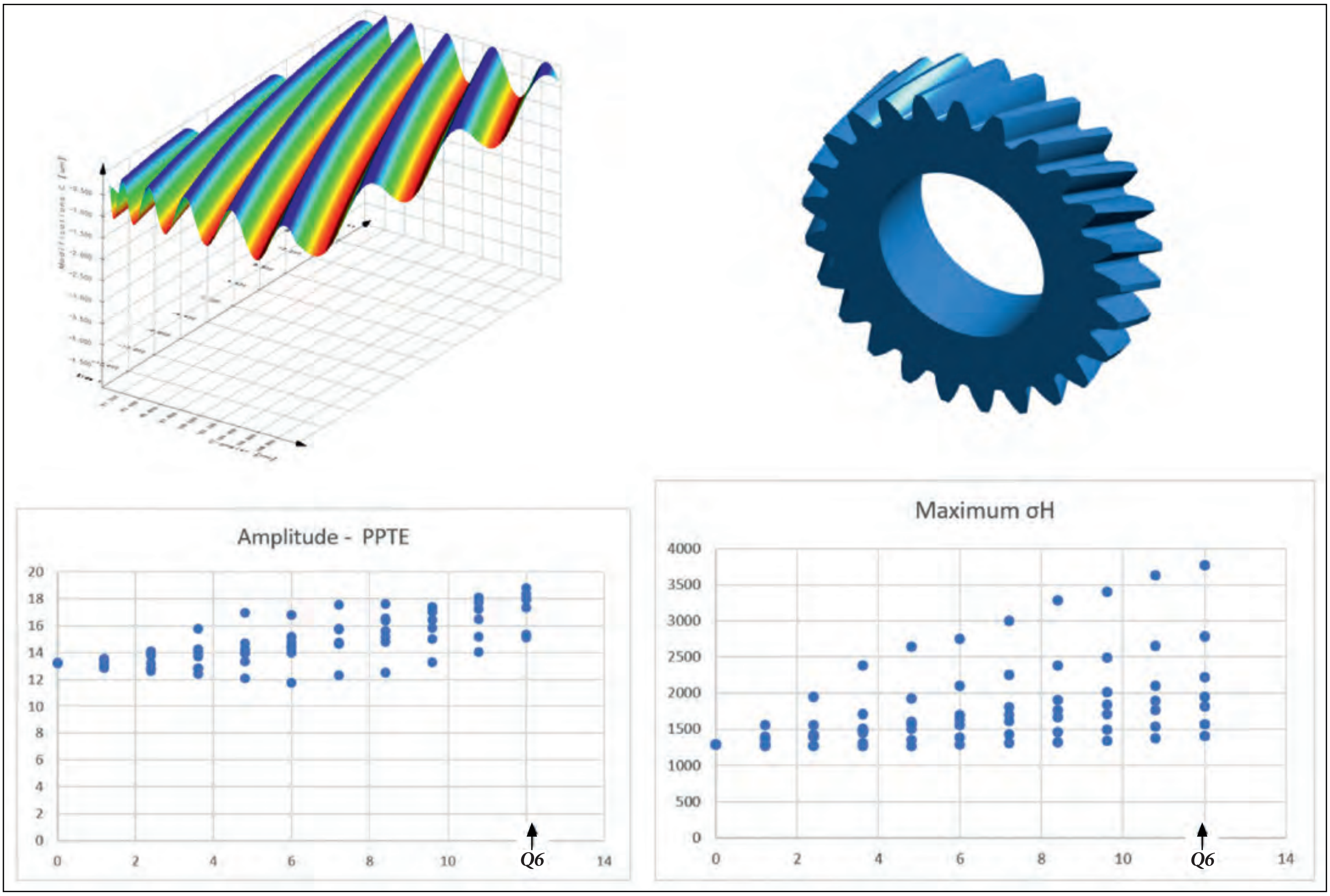


Figure 13—Influence of the waviness resulting from manufacturing in the direction of processing (top left) on the transmission error (PPTE, bottom left) and the maximum Hertzian pressure (bottom right).

load distribution, noise characteristics and loss/efficiency. Gear pairs of this kind usually have much less transmission error than a conventional gear unit. Investigating the effects of manufacturing errors on gears with significant modifications is necessary for that reason, and can produce entirely different results.

The example described is the interim stage in an EV gear unit from a car made by a well-known manufacturer. The gear pair module is 1.57 mm, the number of teeth is 33:87, the face width 35 mm, the helix angle 23.5° and the drive torque 500 Nm. The specified quality for the case-hardened gears according to ISO 1328 is Q5. The permitted profile form deviation $f_{f\alpha}$ equals 6 µm. The flank modifications are shown in Figure 14.

The transmission error (PPTE) of the error-free gear equals 0.71 µm. Without modifications it would be 1.7 µm. This shows the importance of the modifications. In this example, the evaluation (Figure 15) shows that a waviness has very little influence on the mean value of the PPTE (an increase of 10 percent in the case of quality Q5). However, the PPTE scatter—depending on the wavelength or the position of the first amplitude—becomes more significant in the case of greater amplitudes than in the case of the example in "Application for an industrial gear unit." In the case of a tolerance of 6 µm (quality Q5), the PPTE can change by +50 percent (in the worst case) or -28 percent (in the best case). This is not unexpected: Teeth with significant modifications are often less tolerant when it comes to manufacturing

Gear	Flank	Modification type	Value [µm]	Factor 1	Factor 2	Status	Information
Gear 1	both	Profile crowning, roll length-centered	2.0000			active	rcrown=6993mm
Gear 1	both	Flank line crowning	7.0000	1.0000		active	bx=38.000mm, rcrown=25786mm
Gear 1	both	Tip relief, arc-like	4.0000	1.0000		active	dCa=56.453mm, ξ=31.167°, r=312.1mm (Crown_Caα=1.0µm)
Gear 2	both	Tip relief, arc-like	4.0000	1.0000		active	dCa=140.385mm, ξ=23.887°, r=312.1mm (Crown_Caα=1.0µm)
Gear 2	both	Profile crowning, roll length-centered	2.0000			active	rcrown=8505mm
Gear 2	both	Flank line crowning	6.0000	1.0000		active	bx=35.000mm, rcrown=25521mm

Figure 14—Profile and flank line modification of the investigated EV gear unit.

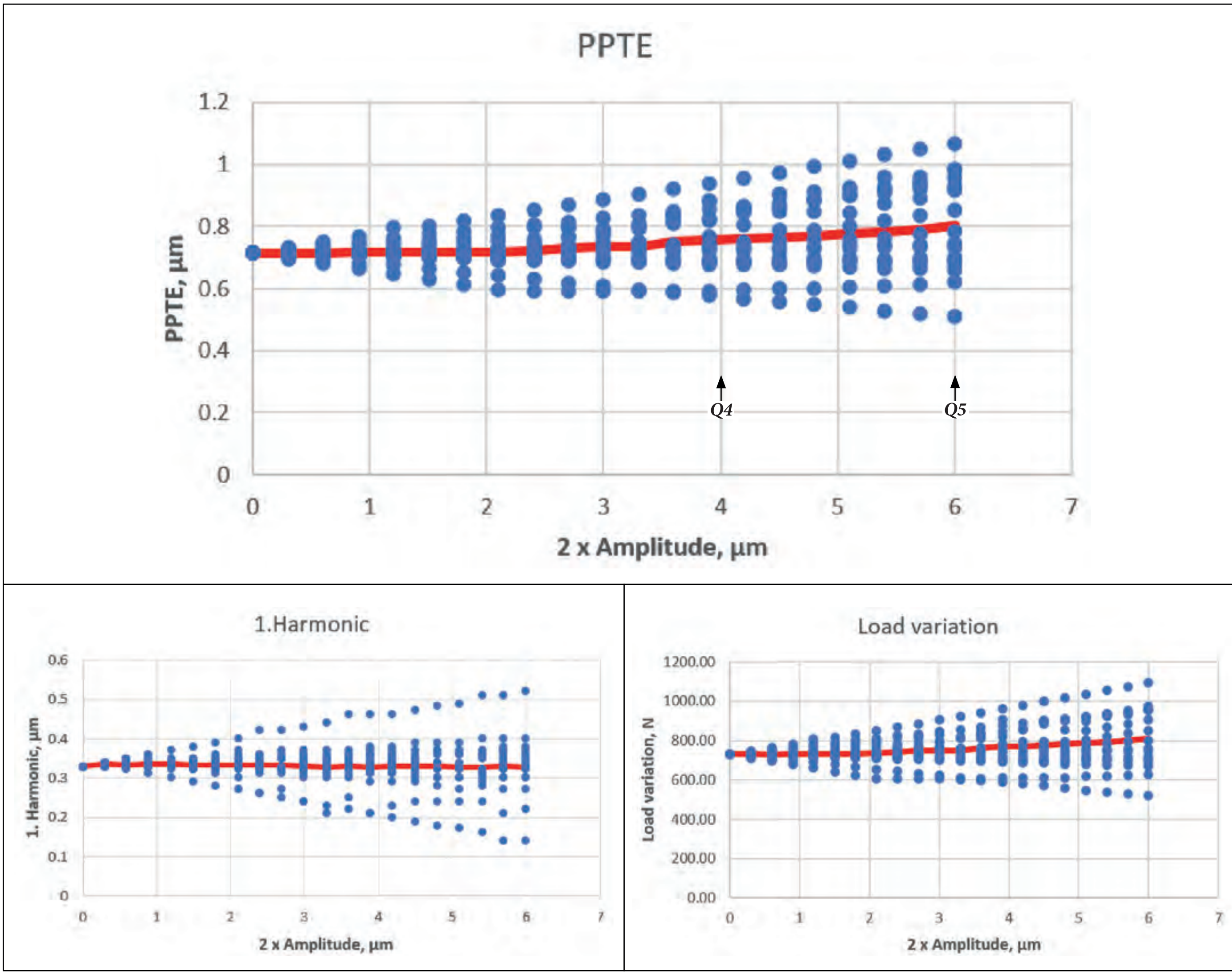


Figure 15—Influence of the waviness (profile) on the transmission error (top), the amplitude of the first harmonic (bottom left) and the excitation force in the case of an EV gear pair (bottom right). (Red line: mean value.)

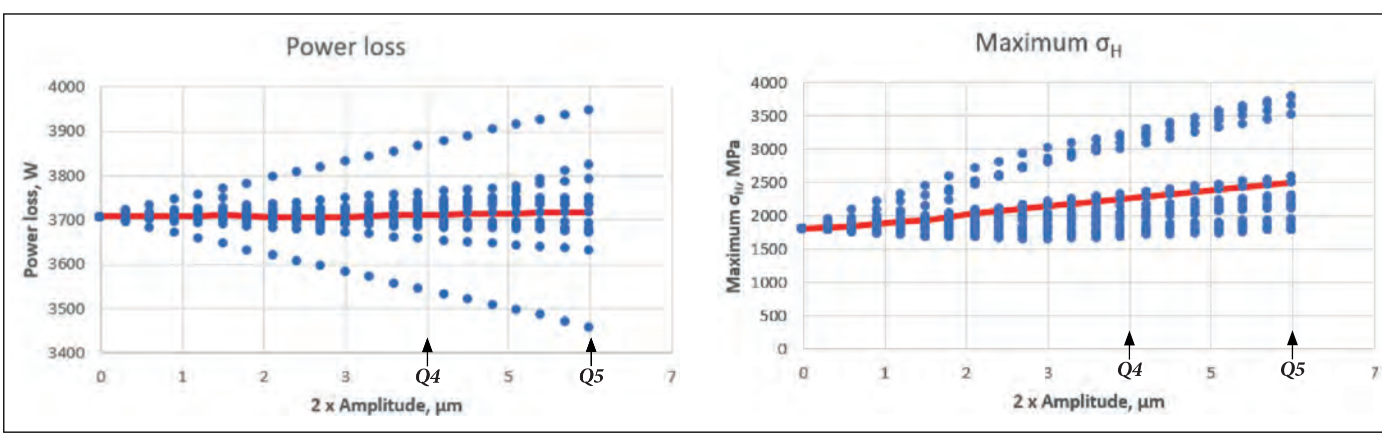


Figure 16—Influence of waviness (profile) on the power loss (left) and the maximum Hertzian pressure (right).

deviations. Naturally, however, the method described here can also be used to define modifications which are as "tolerant" as possible concerning manufacturing deviations!

The influence of the manufacturing deviations on the efficiency (loss) is very low (Figure 16). The loss in the case of Q5 (double amplitude 6.0 µm) only changes in the range ±6 percent, compared with the value for the theoretical tooth. However, in accordance with expectations, the influence of the manufacturing allowances is much greater in the case of the Hertzian pressure. In the case of Q5, the maximum pressure increases on average by 38 percent, ranging from -9 percent to +67 percent (Figure 16).

Inclusion of slope deviations, simulation of total deviations

So far, the influence of form deviations on the profile ($f_{f\alpha}$) and form deviations on the flank line ($f_{f\beta}$) caused by waviness has been discussed. However, tooth flank manufacturing allowances consist of form and slope deviations ($f_{H\alpha}$, $f_{H\beta}$) which are combined to produce the total deviation (F_α, F_β) result (Figure 9). So, different variants of the slope deviation have to be cross correlated with form deviations. This does increase the time needed for calculation, but generalizes the method.

Note: $F_\alpha = \sqrt[2]{{f_{H\alpha}}^2 + {f_{f\alpha}}^2}$ $F_\beta = \sqrt[2]{{f_{H\beta}}^2 + {f_{f\beta}}^2}$

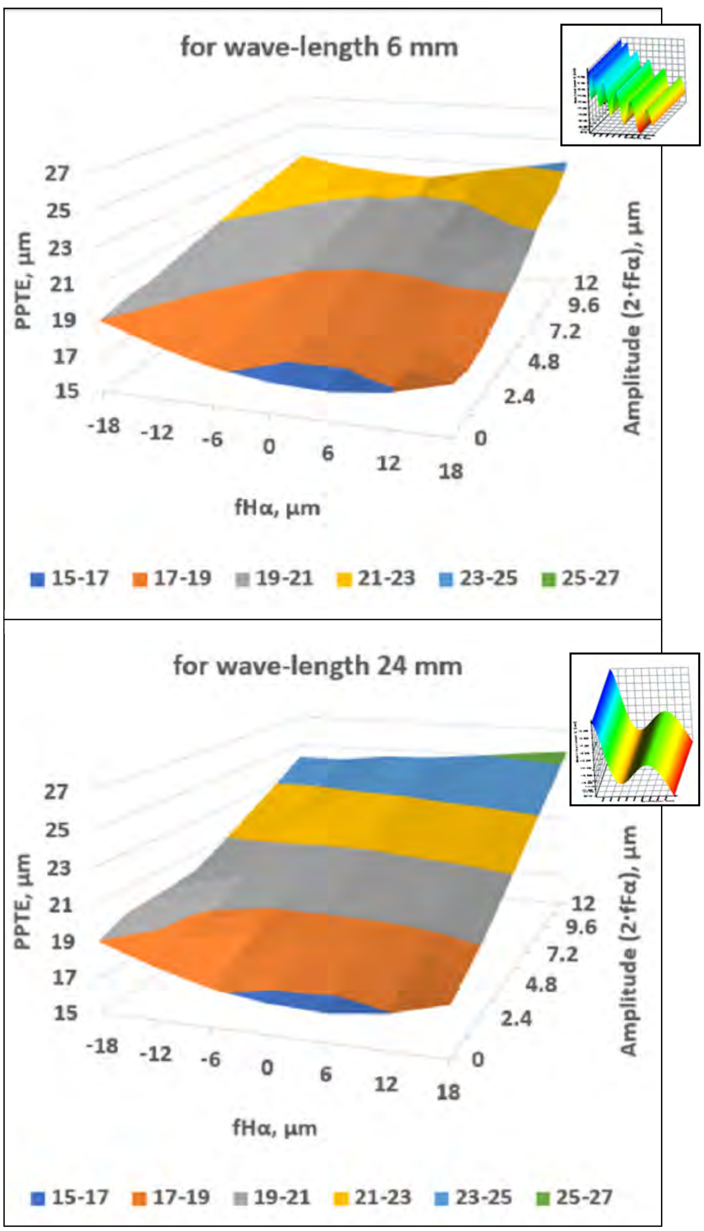


Figure 17—Influence of profile slope deviations $f_{H\alpha}$ combined with profile form deviations $f_{f\alpha}$ on the transmission error (PPTE). Top: short wavelength 6 mm. Bottom: long wave length 24 mm. The manufacturing deviations on the flank with maximum values for $f_{f\alpha}$ and $f_{H\alpha}$ are shown on the left side.

In this example, the profile slope tolerance for Q6 equals ±9.5 µm and the form tolerance is 12.0 µm (amplitude 6.0 µm). The range shown in Figure 17 shows the progression from Q4 to Q6. The analysis shows that the slope deviation has less influence on the transmission error than the form deviation. Figure 18 shows the same results in a different way. The tolerance range permitted up to Q6 is displayed here. The lesser influence of the slope deviation is clearly visible, both in the case of PPTE and the maximum pressure.

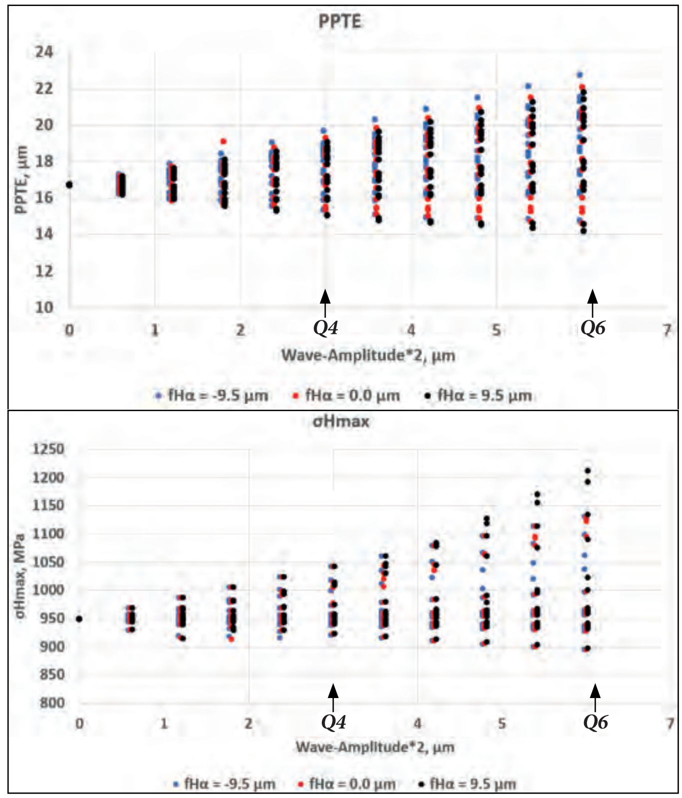


Figure 18—Alternative representation of the results. The profile slope deviations fHα are only varied using 3 variants (-9.5, 0 and +9.5 µm) and are highlighted in color. Top: representation of the transmission error (PPTE) as in Figure 17. Bottom: maximal Hertzian pressure.

Summary

Well-sized modifications on the tooth will enable the service life to increase, will reduce the causes of vibration and reduce noise levels. The modifications must be manufactured as exactly as possible, to achieve the required properties over the speed-torque range of the gearbox. In practice, therefore, the form deviation in particular is greatly restricted. In some cases, requirements are specified that are almost impossible to manufacture. This increases cycle times and therefore manufacturing costs.

To evaluate the influence of the manufacturing deviations, a sinus-shaped waviness is applied to the theoretical ideal tooth flank. The waviness can be modified with amplitude, length and initial value parameters. Such a manufacturing deviation can be applied in both the profile or flank line direction, or in the direction of manufacturing tool, or a combination of the above. By systematically varying these parameters, it is possible to investigate the extent to which the required gear properties, such as transmission error, excitation force, efficiency or maximum Hertzian pressure, change.

For example, if the double amplitude of the waviness on the profile approximately matches the profile form deviation tolerance ($f_{f\alpha}$) according ISO 1328 for a specified quality X, it is possible to determine how "stable" the gear is with regard to manufacturing errors. The quality requirement can then be increased appropriately, to X-1, or reduced appropriately, to X+1, which will in turn also change the manufacturing cost.

Besides form deviations, also slope deviations and total deviations can be investigated. Slope deviations in the range of the specified quality tend to have a lesser influence on the gear properties.

Two examples from practice are discussed: An application involving an industrial gear unit and one from an EV gearbox (electric vehicle). The analysis shows that gears with well-sized modifications that already have a low PPTE value are more sensitive to manufacturing deviations. The discussed examples show clearly that, in this particular case, there is no point in specifying an accuracy that is higher than Q4. The changes to the meshing's properties are then so minimal that the extra effort involved cannot be justified.

Manufacturing deviations in the profile direction only have a minimal effect on the power loss. However, the transmission error (PPTE) and maximum Hertzian pressure are clearly dependent on deviations. As investigations at the FZG in Munich have proven, the transmission error can even improve in the case of certain waviness. Flank line form deviations caused by waviness are much less critical than profile form deviations. When the investigation was extended to include form deviations in combination with slope deviations—i.e., to simulate total deviations—it showed that slope deviations have less influence on the gear performance.

The methodology can also be used to test different modification variants, and to evaluate how tolerant a certain gear design is regarding manufacturing deviations.

Dr. Ulrich Kissling was born in Zurich. He studied Machine Engineering at the Swiss Technical University (ETH). He continued his academic career with a doctorate. In 1981, he started his professional career as calculation engineer in a Gearbox Manufacturing Company in Zurich, continued then as Technical Manager and Managing Director.

As calculation engineer for gearbox design, he started to develop software for gear, bearing and shaft layout. In 1985, he named this software *KISSsoft* and started to market it. In 1986 the first license was sold. In 1998, he founded his own company, KISSsoft AG, to take care of the software activities. Since then, the staff of KISSsoft AG is growing constantly from three people in 1998 to over 40 in 2022. Today the software is the leading drive train design software, used by more than 3500 companies on all continents.

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

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This paper first appeared: Dresdner Maschinenelemente Kolloquium DMK 2022, April 26–27, 2022.

Sustainable Gears—Design of Gear Body Modified Powder Metal (PM) Gears

Philipp Scholzen, Jens Brimmers, and Christian Brecher

Introduction

The increasing requirements for noise emission and resource efficiency of drive systems are determined based on the awareness of the surrounding noise and climate change as well as the legally increasing emission limits (Ref. 11). The progressive electrification of the powertrain is, as a result of the reduction to the elimination of the masking noise of the conventional internal combustion engine, a major influencing determinant (Ref. 21). In order to reduce the costs and increase the power density of the electric motor, there is a trend towards high-speed electric motors in combination with a transmission (Ref. 10). The demand for high ratios of the individual cylindrical gear stages leads to an increase of the outer diameter of the gear.

The increase in power density can be achieved by reducing the gear body mass. Regarding a limited load-carrying capacity, a reduction in mass can be achieved by gear body modifications in the generally oversized gear body of a cylindrical gear. Due to their locally adjustable material density, powder metallurgical (PM) gears offer additional lightweight design potential as well as increased damping properties. As a result of the near-net-shape production of the gears, gear body modifications can be manufactured without additional process steps.

The manufacturing process for PM gears is characterized by special tools, which are required for the pressing and densification process. Due to the high cost of specialized tools, the PM production chain is particularly suitable for series production of gears (Ref. 9). The pressing tools have a service life of several thousand components (Ref. 14). The higher investment costs of the tools can be compensated due to the higher resource efficiency in terms of material and energy use (Ref. 15). Frech et al. and Klocke et al. determine the potential savings in raw material used as well as the savings in energy costs for a typical PM gear in the range m_n = 2 mm compared to machining (Refs. 8, 12).

The resource efficiency of the PM process chain leads to a savings potential of 5.4 percent with respect to energy and 52.2 percent with respect to the material used. In summary, these two potential savings result in a cost advantage of 21.7 percent for the PM process chain compared with the conventional process chain. Furthermore, the lower material input due to gear body modifications leads to a reduction in transport costs, which have not yet been taken into account in the savings potential. Other cost advantages include lower machine costs due to shorter process times and lower space and maintenance costs (Ref. 22).

Objective and Approach

PM gears have a higher resource efficiency than conventionally manufactured gears. On the other hand, the determination of the load capacity is not standardized and the investment costs for production machines and tools are high. Therefore, additional incentives are needed to switch to powder metallurgical production. In terms of electromobility, the optimization of noise behavior is coming into focus. The basis for a noise-optimized design of PM cylindrical gears is the knowledge of the effects of local material properties and the modification of gear body geometry and density on noise behavior. In order to investigate and optimize the mechanisms of excitation and structure-borne noise transfer, it is necessary to consider the excitation of the gears and the transfer of structure-borne noise. The work is motivated by the research hypothesis that a specific design of the gear body geometry is reachable on the basis of a systematic investigation and determination of the influencing variables on the noise behavior. The overall objective is: Noise-optimized design of the gear body of PM cylindrical gears.

To achieve this objective, the mechanisms for damping and insulation on structure-borne noise transfer are first qualified for use in PM cylindrical gears. On this basis, test gears are designed, manufactured, and characterized. To investigate the vibration behavior, a test rig is developed to measure the structure-borne noise transfer through the gear body under forced excitation. In addition to the vibration behavior, the excitation behavior is investigated on the basis of the transmission error and the noise behavior during dynamic speed run-ups by means of structure-borne noise emission. The experimental results of the excitation behavior are used to validate the method for calculating the operational behavior, taking into account the material density and gear body modifications. The results of the investigation are discussed and the influence of the gear body mechanisms for influencing the noise behavior is determined. With the knowledge gained from the investigation, a noise-optimized design of the gear body is designed and investigated.

Methods for Calculating and Evaluating the Influence of the Gear Body

Calculation of the Operational Behavior

The consideration of gear body modifications in the calculation of the operational behavior of gears forms the basis for a successful design. For this purpose, the method for calculating the influence of the gear body was developed. The objective of the method is to calculate the influence of free gear body modifications on the operating behavior of cylindrical gears using the FE-based tooth contact analysis *FE-Stirnradkette (Stirak)*.

Figure 1 shows the calculation method. In contrast to the gear simulation with partial segments of the gears, in the calculation of the gear body influence, the gear rim and gear body are comprehensively considered, so that the changed stiffness

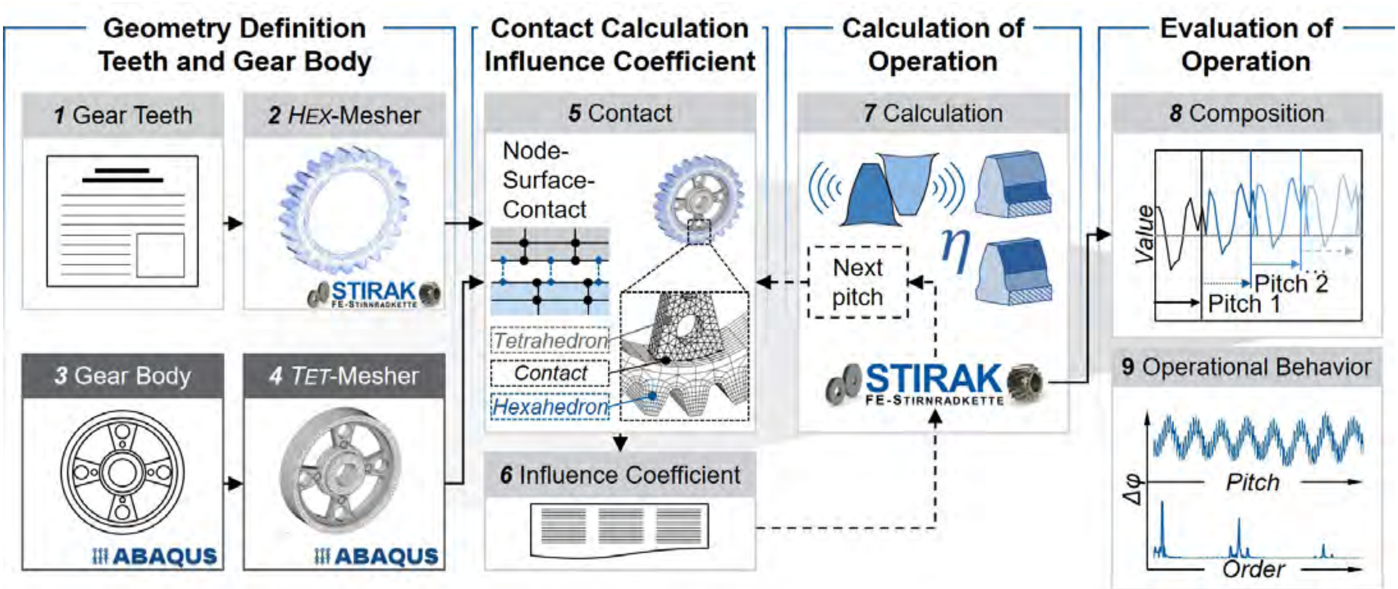

Figure 1—Method for calculating of the operational behavior.

is mapped over the entire circumference. The number of teeth mapped in the simulation is reduced to the teeth that are in mesh to reduce the FE elements to be calculated. The material properties are defined linearly elastically by the modulus of elasticity, the poisons ratio and the density.

The step-by-step procedure of the calculation of the operational behavior includes six steps. In the first step (step 1), the geometry of the gear rim and teeth is calculated with the FE-based tooth contact analysis and meshed with a parameterized FE hexahedral mesh, which is used to calculate the tooth flank pressure, tooth root stress and stiffness. The parameterized FE hexahedral mesh leads to an increase in the quality of results in the tooth contact (step 2). The gear body geometry is automatically parameterized in *Abaqus CAE* (step 3) and freely meshed with an FE tetrahedral mesh (step 4). The mesher available in *Abaqus CAE* allows the meshing of a variable gear body geometry.

The contact between the gear body and the gear rim is made via the extended node-surface contact with the *SolverZ88* (step 5). In this process, the surface is additionally discretized with the Gaussian support points so that the location of the smallest distance can be determined as precisely as possible during the contact search (Ref. 16). If the distance is smaller than a numerical tolerance, a contact constraint is defined for the current contact pair and incorporated into the equation system of the finite element analysis using the perturbed Lagrangian method (Ref. 17). In this application, a bonded contact (i.e., a transmission of both normal and tangential forces) is required. With the bonded FE model of the gear, the influence coefficient are calculated in the sixth step (step 6), analogous to the general procedure of FE-based tooth contact analyses (Ref. 13). The load definition is taken from the FE-based tooth contact analysis and the gear body is bound in the bore. Then, the system of equations is solved with the *SolverZ88* and the FE-based tooth contact analysis is used to calculate the operational behavior (step 7). The operational behavior includes the characteristic values such as the transmission error, tooth flank pressure, tooth root stress and efficiency. The gear body modifications lead to a circumferential stiffness variation in the tooth contact. Therefore, it is necessary to calculate and evaluate the gear body influence over one revolution of the modified gear. For evaluation, the calculation results are combined (step 8). In this way, the long-wave effects on the operational behavior can be evaluated. The result of the method is the characteristic values of the operational behavior over the revolution of the gear body–modified gear (step 9).

Calculation of the Vibration Behavior

The vibration behavior is calculated in *Abaqus CAE,* see Figure 2. A modal analysis is performed in the loaded tooth contact. The objective is to evaluate the influence of the gear body density and geometry on the transfer function of the gear. The vibration behavior is analyzed under operating conditions, taking into account the support effects in the tooth contact. Analogous to the calculation of the operational behavior, the geometry of the gear rim and teeth (step 1) is meshed with a parameterized FE hexahedral mesh from the tooth contact analysis (step 2). The gear body geometry is automatically created and parameterized in *Abaqus CAE* and freely meshed with a FE tetrahedral mesh (step 3). The contact between the gear body and the gear rim is made via the node-to-surface tie constraint, where the main surface is assigned to the gear rim and the secondary surface to the gear body (step 4). The tooth contact is defined by the surface-to-surface contact with finite sliding (step 5). The surface-to-surface contact definition offers more precise stress and pressure results if the contact surface geometry is sufficiently accurate (Ref. 4). To reduce the contact search effort, only the tooth flank surfaces are defined as contact pairs.

For the general component definition, the geometry, the material density and the resulting material stiffness and material damping are specified. This is followed by the alignment of the two gears according to the center distance in the same coordinate system. Rotationally, the gear teeth are aligned with each other in such a way that there is an initial penetration of the tooth flank surfaces of one percent of the pitch of the gear. For connection to the environment, the bore of each gear is connected in the center of the axis to an axis reference node by a structural coupling (step 6). Along the two axes, two further

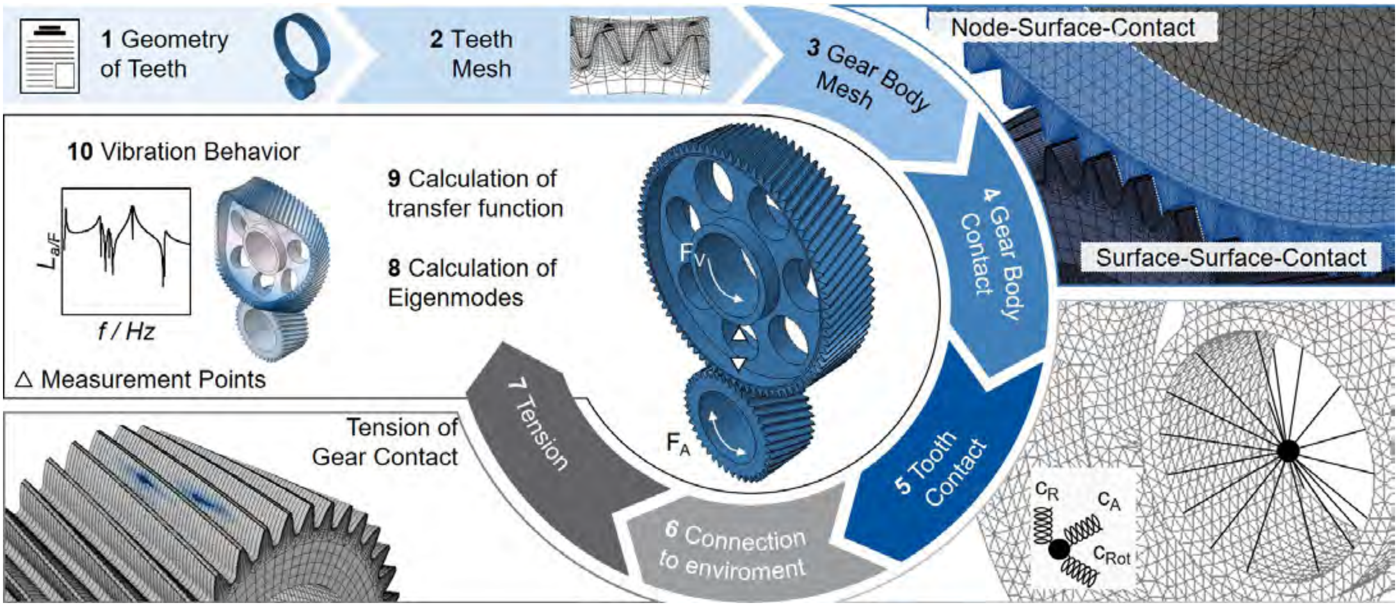

Figure 2—Method for calculating of the vibration behavior.

environment reference nodes are defined, which are connected to the axis reference nodes by spring elements. The environment reference nodes are bounded in all spatial directions. With the specification of the spring stiffnesses in axial, radial and rotational direction, the connection of the gear teeth to the surrounding system is defined.

The first calculation step is the preload of the gears (step 7). Torque is applied at the axis reference node of the pinion. In the Static calculation step, the torque is increased successively in 10 steps until the final torque is reached. The successive increase of the torque is chosen to ensure a stable solution of the calculation. In accordance with the defined spring stiffnesses, the gears turn until the force equilibrium between the spring force and the applied torque is achieved in each time step. At the end of the calculation step, the tooth contact is statically tensioned. The second calculation step Frequency is the determination and visualization of the natural frequencies of the system (step 8). The natural frequencies of the gear set are determined for a defined frequency range, taking the tooth contact into account. The result contains the frequencies and shapes of the eigenmodes. The determination of the frequency-based vibration behavior is performed in the third calculation step Steady-State-Modal under forced force excitation (step 9). For excitation, a periodic torque excitation is defined at the axis reference point of the pinion. The load is applied with a force amplitude of F_A = 1 N along the path of contact. To evaluate the transfer function, the frequency is successively increased. The vibration behavior is evaluated by analyzing the eigenmodes and the resulting structure-borne noise emission at the inner diameter and outer diameter of the gear body on the line connecting the two axis reference points (step 10).

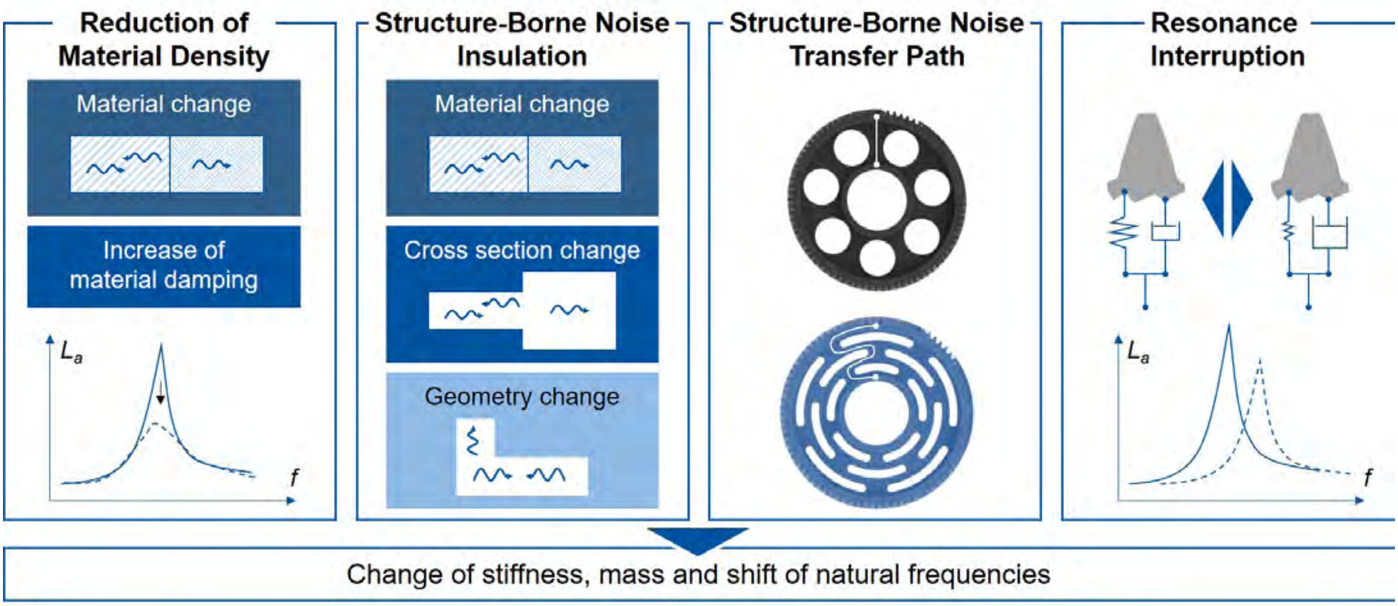

Figure 3—Mechanisms of the gear body to optimize the noise behavior.

Mechanisms of the Gear Body to Optimize the Noise Behavior

The noise behavior of technical systems is influenced by several mechanisms. The two basic mechanisms are structure-borne noise damping and structure-borne noise insulation. The challenge is to transfer the mechanisms to gears and to systematically design and investigate them separately. In the case of PM gears, both the density and the gear body geometry can be used to optimize the noise behavior. Figure 3 shows mechanisms of the gear body to optimize the noise behavior.

Reducing material density leads to an increase in material damping (Ref. 2). As a result, more vibration energy is dissipated to the environment. The reduction in material density is limited by material load carrying capacity. While the highly loaded teeth are densified as much as possible, the material density of the gear body can be reduced. In addition to material damping, a density reduction in the gear body also causes a material change due to the density-dependent stiffness. According to the Snellius refraction law, the structure-borne noise transfer is influenced with respect to the energy content of the wave types due to different elasticity moduli (Ref. 3). Accordingly, the reduction of the gear body density can be attributed to the mechanism of both material damping and insulation.

In addition to material changes, structure-borne noise insulation can be achieved by geometric modifications. Gear body modifications increase the number of impedance elements. Impedance elements, such as material changes or cross-section changes, lead to reflection and transmission of the individual wave types, which changes the energy distribution between the wave types (Ref. 3). The change in geometry affects the stiffness and mass, causing the number and location of natural frequencies to differ from the unmodified gear (Ref. 2). Due to this, a different frequency-dependent vibration behavior is expected.

The structure-borne noise transfer path is another mechanism resulting from gear body modifications. Due to cut-outs, the direct path between the gear body outer diameter and inner diameter is interrupted. So the structure-borne noise transfer taking place via the remaining material sections. In the case of excitation above a cut-out, the structure-borne sound transfer path is extended, resulting in an optimization of the noise emission according to Dietz et al. (Ref. 5).

With gear body modifications, the stiffness of the wheel body and the mesh stiffness in the tooth mesh change, resulting in a stiffness modulation over the circumference (Ref. 18). The resonant frequencies of the system are directly related to the stiffness. Accordingly, a varying stiffness in the tooth contact leads to a varying resonant frequency over the revolution of the gear. The excitation frequency of the tooth contact can therefore no longer be equal to the resonance frequency, which dampens the resonance of the system. This mechanism is described below as resonance interruption.

The mechanisms make it possible to optimize the noise behavior. For a systematic investigation of the mechanisms, test gear variants are designed and characterized below. The challenge is the separation of the individual mechanisms, whereby the greatest potential for optimization is assumed to lie in a combination of the two basic mechanisms of structure-borne noise insulation and damping.

Test Gears

The design of the test gears is based on the first gear stage of an electrical car transmission. While the gear macrogeometry is based on an industrial application, the microgeometry is designed for high robustness against manufacturing and assembly deviations. The cylindrical gear has a normal module of m_n = 1.42 mm, a number of teeth z_{gear} = 81, a normal pressure angle α_n = 19° and a helix angle β = 19°, see Figure 4. The gear body is designed as a web with a web width of b_{web} = 12 mm. The gear body modifications are designed and manufactured within this web. The gear width is b_{Gear} = 29 mm.

The pinion is designed with regard to achieve a center distance of a = 91.5 mm. With a number of teeth of the pinion

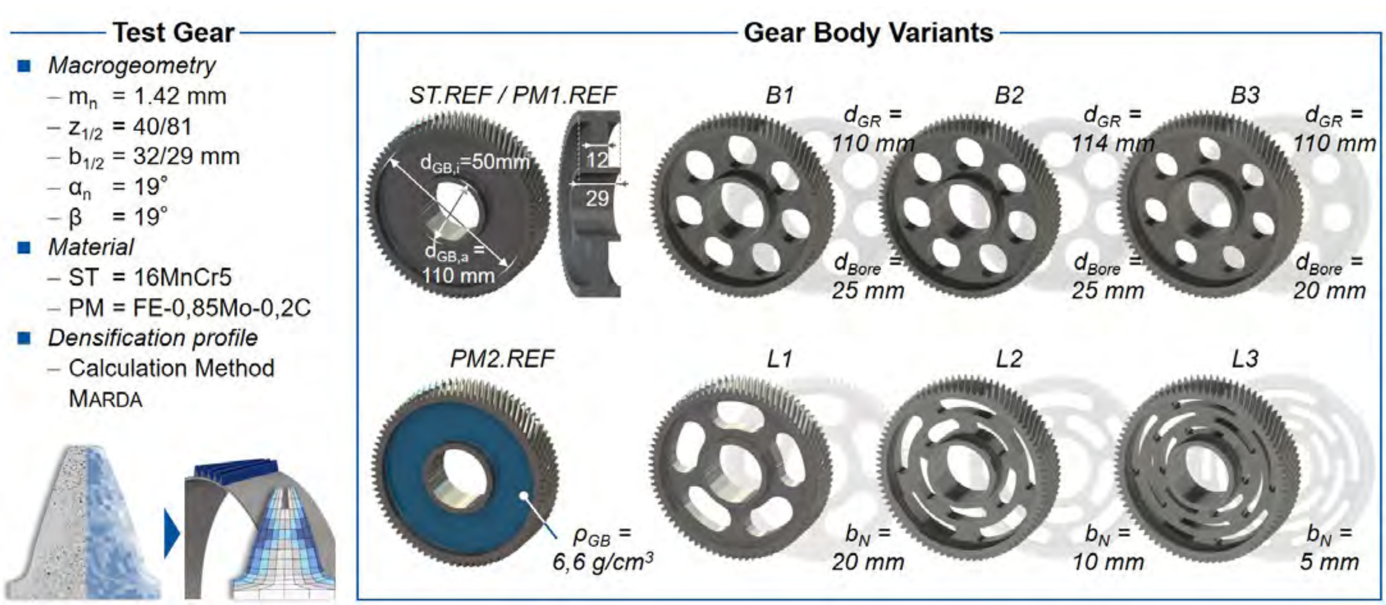

Figure 4—Test gears.

of z_{pinion} = 40, a gear ratio of i = 2.025 results. In contrast to the gear, the pinion has a higher width b_{pinion} = 32 mm to compensate assembly or manufacturing deviations in the axial direction. The microgeometry is also designed regarding assembly and manufacturing deviations. Any potential misalignments during the experimental test rig investigations need to be compensated by the microgeometry so that the resulting influences do not affect the validation of the calculation results.

In addition to an unmodified, rotationally symmetrical reference variant, six different gear body geometries are designed. Notches are designed for three variants. One variant is designed with notches as a labyrinth variant. In two other labyrinth variants, further notches lead to labyrinth structures. With the increasing number of notches in the labyrinth structure, the structure-borne noise transfer path increases as well as the number of impedance elements. In addition to the labyrinth variants, three bore variants are investigated. Gear body bores are often used in the industry because of their low manufacturing cost. The results of the investigation of the three bore variants address the mechanism of resonance interruption. While the comparison of variants B1 and B3 highlights the influence of the bore diameter, the comparison of variants B1 and B2 evaluates the influence of the gear rim thickness on the excitation and vibration behavior.

The test gears are manufactured conventionally from the material 16MnCr5 (ST) and powder metallurgically from the material FE-0.85%Mo-0.2%C (PM1/PM2). The PM1 variants, except for the local densification profile of the teeth, has an overall density of ρ_{PM1} = 7.15 g/cm^3. For the PM2 variant, the gear body density is reduced by $\Delta\rho$ = 7.7% to ρ_{PM2} = 6.60 g/cm^3. The density of the teeth and the hub are equal to the PM1 variants. The densification profile of the teeth is also the same. As a result of the reduced density of the gear body, the PM2 variants have a lower material stiffness and a higher material damping of the gear body (Refs. 2, 7).

Validation of Calculation Methods

The focus of the investigation of the gear body influence is the analysis of the resulting acoustics of the gearing. The acoustics include the excitation and vibration behavior as well as the dynamic noise behavior. The aspects are investigated experimentally with the WZL cylindrical gear measuring cell and the WZL structure-borne noise transfer test rig and compared with the calculation.

Conception of the Experimental Investigation

The experimental investigation of the excitation behavior is carried out with the WZL cylindrical gear measuring cell on the electrical power circle test rig (EVP) in the running test. The design of the measuring cell is described in Klocke et al. (Ref. 13). For the validation of the calculation results, contact pattern, transmission error profiles, order cuts over the torque and order spectra are evaluated and compared. The Marda calculation method is used to adjust the FE-Model regarding the densification profile (Ref. 1). The measured quasistatic transmission error of the experiment and the simulation are compared. The deviation between the measured results and the simulation results provides the measure of validation of the calculation.

In order to measure the misalignments due to assembly, the test procedure was started with a contact pattern test at three torque levels (T_2 = 20 Nm, T_2 = 100 Nm, T_2 = 200 Nm). In the next step, the test rig was warmed up for t = 45 min. The measurements were performed at a constant oil temperature of T = 60°C. After this, the transmission error test was carried out in accordance with VDI 2608 (Ref. 23). At a drive speed of n_1 = 60 rpm, the torque was successively increased in 14 steps from T_2 = 20 Nm in ΔT_2 = 20 Nm steps up to a maximum torque of T_2 = 280 Nm and the transmission error profile of the gear sets was measured. In addition to the order spectrum, order cuts are evaluated for the gear body orders and the first gear mesh order.

The influence of the material density and the gear body geometry on the vibration behavior is investigated with the developed

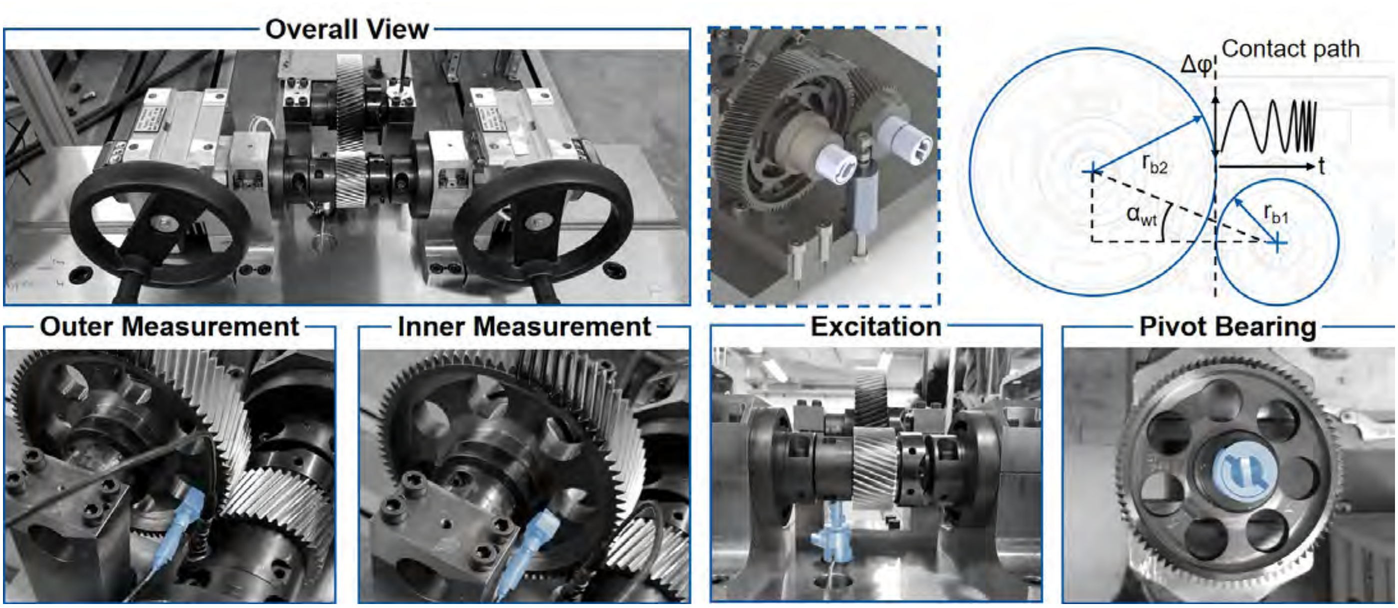

Figure 5—Structure-borne noise transfer test rig.

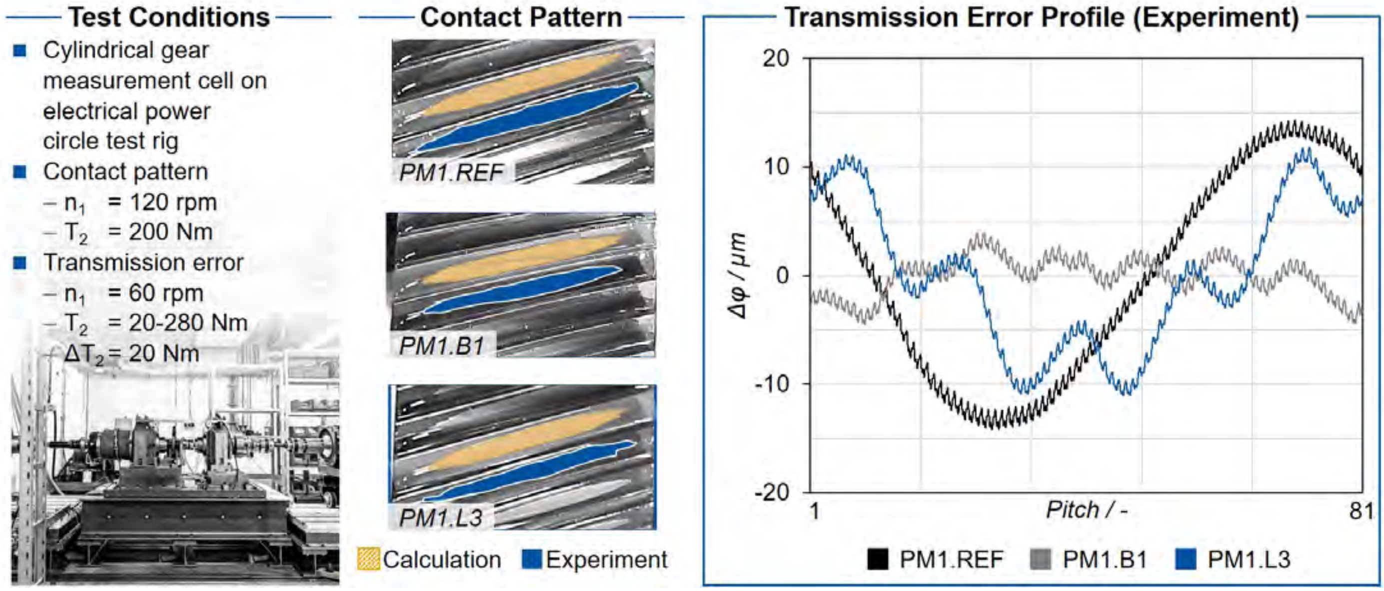

Figure 6—Test conditions, contact pattern and transmission error profile.

WZL structure-borne noise transfer test rig, see Figure 5. Since the gears do not rotate, the gear body positioning is varied. The transfer functions on the inner and outer diameters of the gear body are used to analyze the vibration behavior.

The construction of the structure-borne noise transfer test rig is based on a statically tensioned system in which the meshing conditions of the test gear set under load are reproduced. The base plate for position and assembly forms the basis of the design. To achieve the working height, the base plate is mounted on two pyramids. Both pyramids are filled with quartz sand, which dissipates external and internal vibration energy. The two test gears are mounted on the pinion shaft and gear shaft with an interference fit and are axially secured with a precision shaft nut. The shafts are designed with respect to a low moment of inertia and the natural frequencies outside the frequency range under investigation. The shafts are mounted via pivot bearings. Pivot bearings are solid-state rotational bearings, allowing torsion and torsional vibration of the shafts. The forced excitation of the system is achieved by the force excitation of the pinion shaft with a piezo actuator. According to the radial force support of the pivot bearings, the translational force excitation via the lever results in a rotational excitation of the pinion shaft. The excitation point is positioned in the contact path of the gear mesh, whereby the excitation is tangential to the base diameter of the pinion.

The structure-borne noise transfer test rig enables an evaluation of the gear material and the gear body geometry with regard to the vibration behavior. As a result of the forced excitation via a piezo actuator, the interaction with the excitation in the tooth contact is not present. Despite this, the excitation takes place via the tooth contact, whereby the force direction components are formed according to the gear geometry.

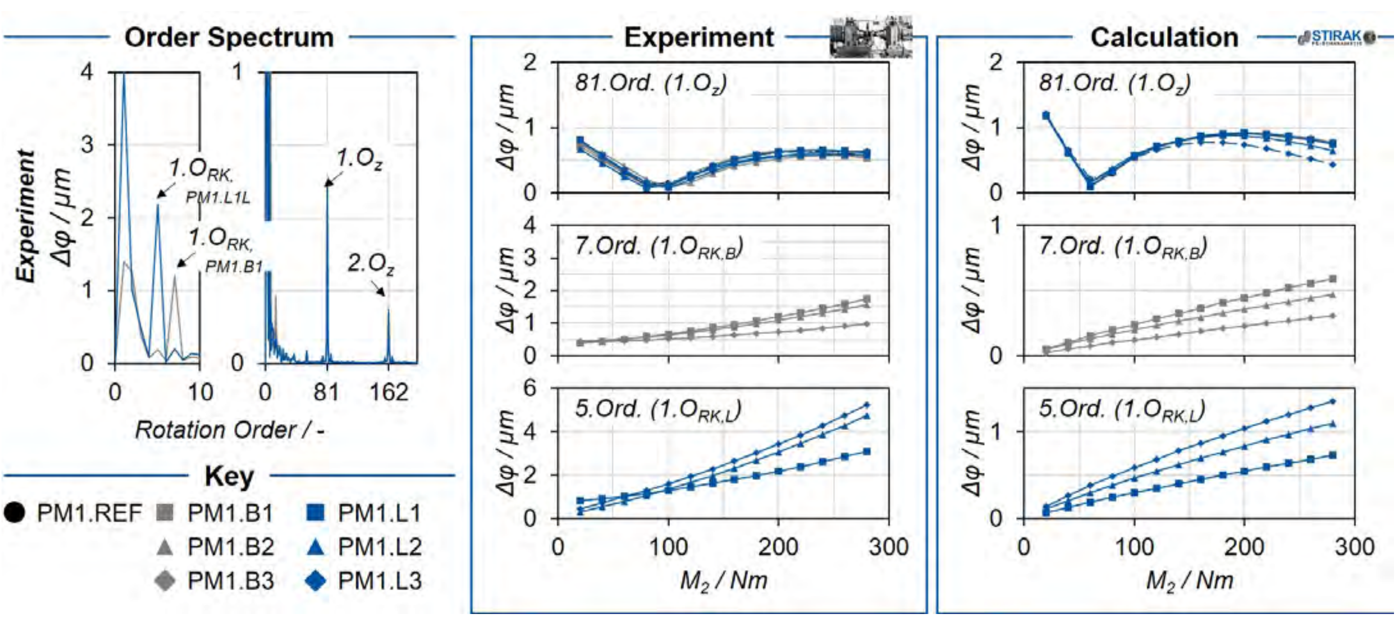

Figure 7—Order cuts of the first gear mesh order and gear body order.

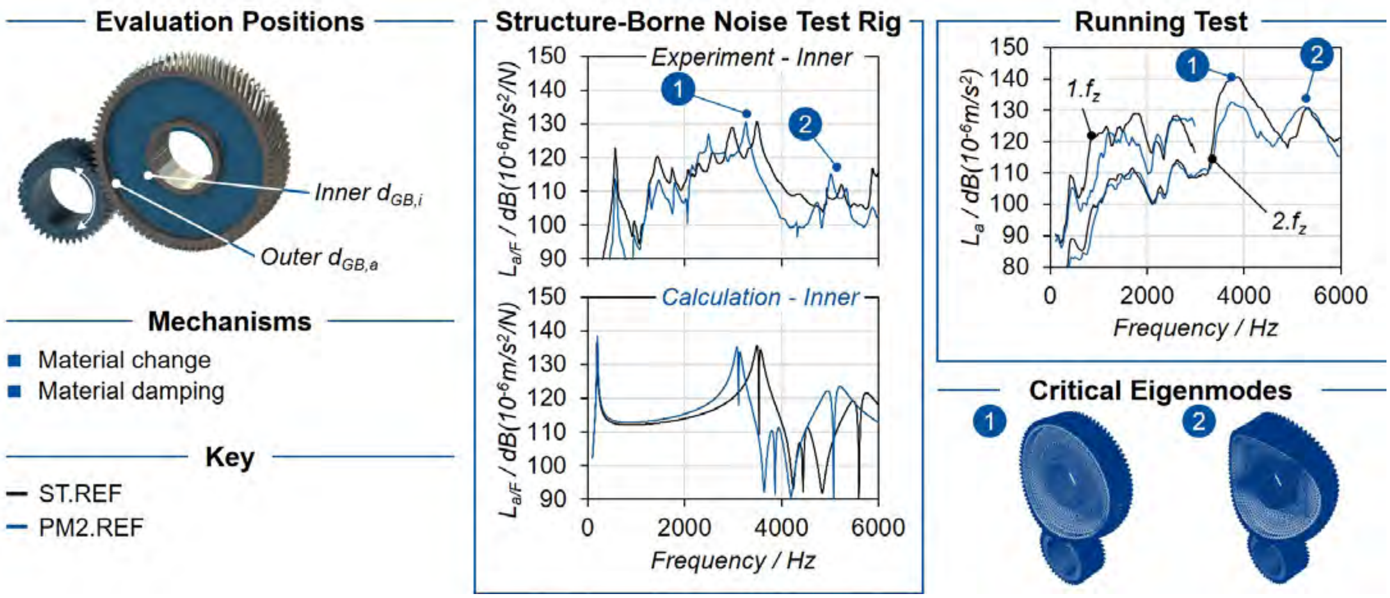

Figure 8—Influence of material density on vibration and noise behavior.

The final step of the investigation is the transfer of the quasi-static excitation characteristics due to the material density and gear body geometry as well as the vibration behavior to the dynamic noise behavior. For this purpose, the WZL cylindrical gear measuring cell is used for dynamic speed run-ups at constant load levels on the electrical power circle test rig. The structure-borne noise emission is measured at the bearing positions of the measurement cell. In addition to the evaluation of the structure-borne noise emission, psycho-acoustic parameters are analyzed, which describe the human hearing characteristics. Loudness and sharpness are evaluated in accordance with the DIN 45631/A1 standard (Ref. 6). The parameters tonality and roughness are based on the hearing model of Sottek, which is integrated in the used evaluation program *Artemis-Suite 12.7* (Refs. 19, 20).

Excitation Behavior

The alignment of the gears was qualified with a contact pattern test. As a result of the profile and width crowning as well as the tip relief, there is no flank contact in the tip or root area and no edge contact. Accordingly, no assembly or manufacturing deviations were found which are not compensated by the tooth flank modifications, see Figure 6. As the torque increases, the contact pattern of the tooth flank increases uniformly. An influence of the gear body modifications on the contact pattern is not detected in the investigations. The calculation result also reflects the observations described and shows no significant deviations from the experiment, which validates the calculation method with regard to the contact pattern. The excitation behavior of the test gears is influenced by two mechanisms: The lower stiffness due to the material density and due to the gear body modifications.

With lower density or lower material stiffness, the transmission error profiles over the torque of the PM variants are shifted towards lower loads compared to the ST.REF variant. This shift of the transmission error profile is defined as load shift. The load shift is load-dependent and increases exponentially with higher load. The effect can be observed for the first as well as for the higher harmonic gear meshing orders and is described by Brecher et al. (Ref. 1).

The influence of the gear body on the transmission error is shown in the diagram on the right. The reference variant shows a long-wave transmission error component of the first rotational order as well as the short-wave transmission error component resulting from the tooth contact. The long-wave component arises as a result of long-wave deviations of the drive train components as well as the gearing, which lead to an eccentricity or runout deviation. Without these deviations, only the short-wave component would be present. The variation in stiffness due to the gear body modifications superimposes the first rotational order transmission error component with the gear body order. In the case of the bore variants, as a result of the seven bores in the gear body, seven additional local maxima and minima are recorded in the longwave transmission error per revolution. In the labyrinth variants, the five notches are reflected in five maxima and minima in the long-wave transmission error. The modulation of the transmission error profiles results from the stiffness variation in the tooth contact and confirms the result of the calculation method.

Figure 7 shows the order spectrum on the left side. The order spectrum shows the significant amplitude of the gear body and gear mesh orders. On the right side, the order cuts of the first gear mesh order and the gear body order over torque are shown. The amplitude of the first gear mesh order over the torque first drops to a minimum and then rises again. The minimum results from the change in the load-induced overlap. With increasing load, the transmission error amplitude increases again and, after reaching the local maximum, decreases towards the end of the investigated torque range. The calculated profiles as well as the amplitude of the transmission error of the first tooth meshing order match with the experimental measurement results, which validates the calculation method for the first tooth mesh orders.

In contrast to the gear mesh orders, the transmission error amplitude of the gear body orders increases linearly with

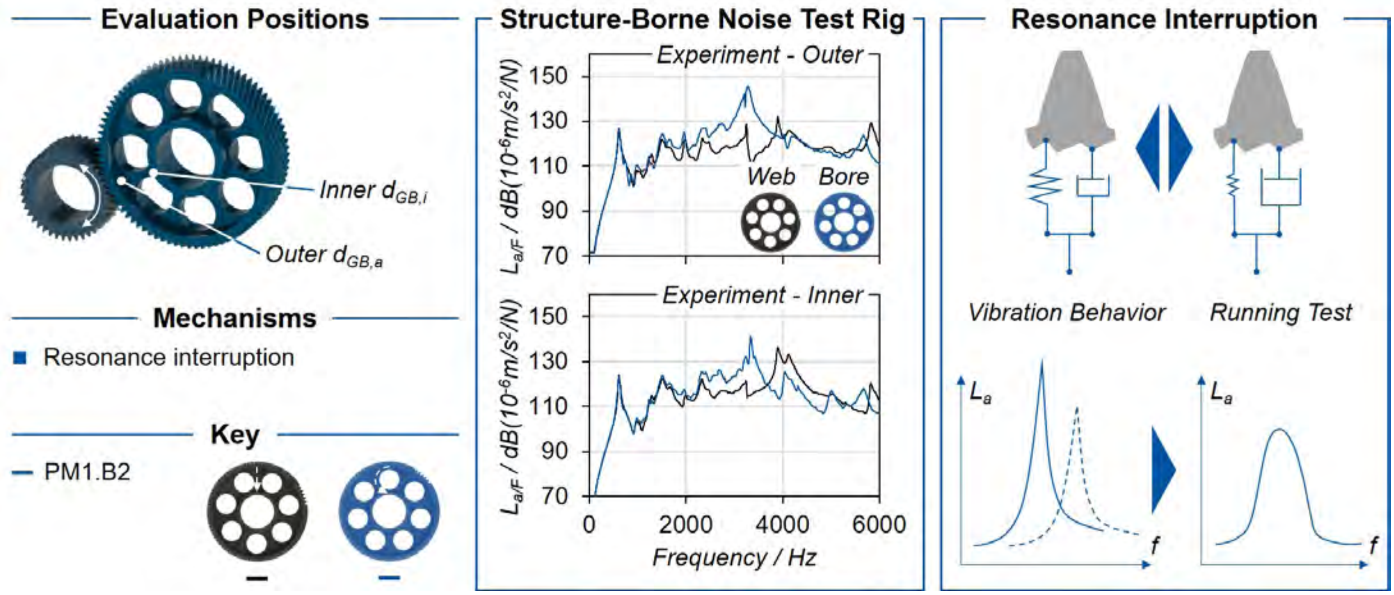

Figure 9—Resonance interruption.

increasing torque. The profiles match between the experiment and the simulation results. The excitation of the gear body order can be assigned to the stiffness modulation over one revolution of the gear. Since the stiffness is proportional dependent to the force, the profiles can be classified as physically plausible. While the amplitudes of the first and second gear mesh order in the experiment and in the calculation show a comparable amplitude, the amplitude of the gear body order is underestimated in the calculation. This deviation is attributed to the influence of the natural frequencies during the transmission error measurement. As a result of the excitation of the natural frequency of the test rig by the gear body frequency, the amplitude of the gear body order increases in the experiment. The calculated amplitudes of the gear body order are lower than the experimental results by a constant factor of about four. However, the gradations between the variants are clearly reproduced and agree with the experiment. The comparison between variants, which is crucial for the design of gearing, can thus be validated.

NVH Behavior

The influence of material density and gear body modifications on vibration behavior and structure-borne noise transfer is investigated using the WZL structure-borne noise transfer test rig. The transfer function between measured acceleration and excitation force is analyzed for evaluation.

Influence of material density on vibration and noise behavior

Figure 8 shows the influence of material density on the vibration and noise behavior in the structure-borne noise transfer test rig and in the running test. To determine the influence of material density, the reference geometry of the two material variants ST.REF and PM2.REF is compared.

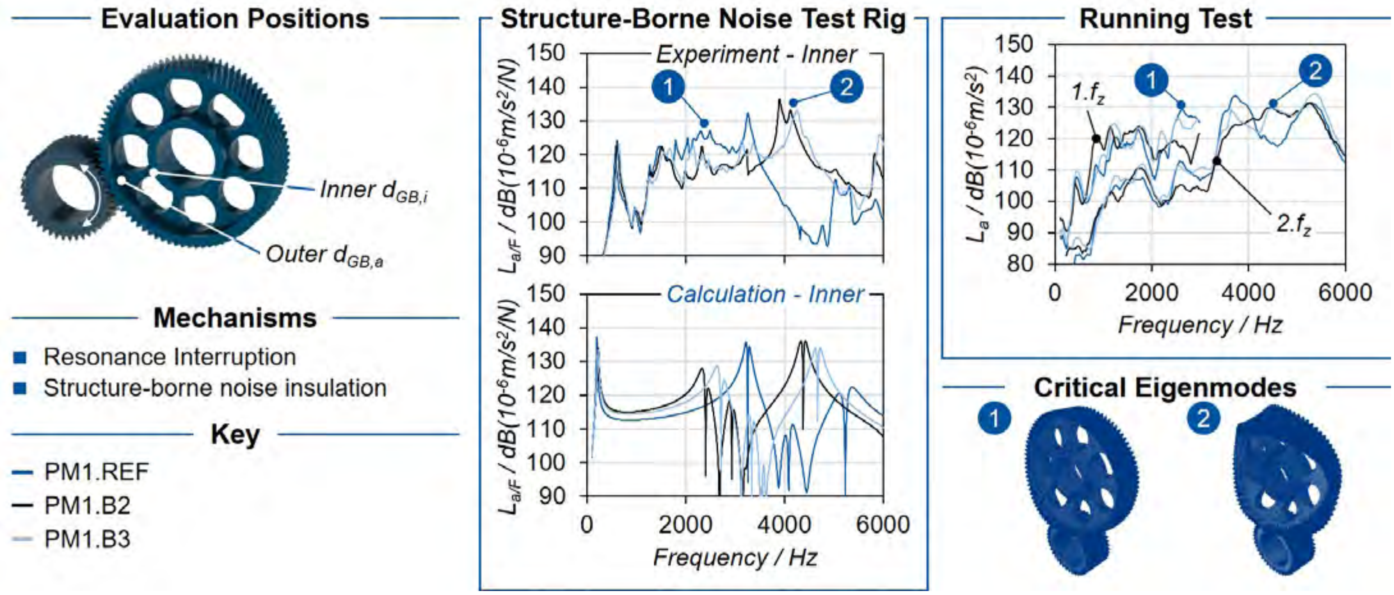

Figure 10—Influence of gear body bores on vibration and noise behavior.

The comparison addresses the influence of a lower gear mesh stiffness, higher material damping and impedance due to the low gear body density of PM2.REF. The two middle diagrams show the experimental results on the structure-borne noise transfer test rig (top) and the calculation results (bottom). The vector sum of the three spatial directions of the acceleration is analyzed force-normalized at the inner diameter of the gear body.

The results show a reduction of the acceleration due to the reduced gear body density. Only in the range around f = 2000 Hz is a higher acceleration measured for the PM variants compared to ST.REF. The PM variant show a lower acceleration at the inner diameter of the gear body, especially in the higher frequency range from f = 3500 Hz. Accordingly, a reduction in structure-borne noise transfer is attributed to the reduced material density. There are a total of six resonance frequencies in the frequency range investigated. Of these, two eigenmodes critical for operation can be identified ($f_{crit,1} \approx 3600$ Hz, $f_{crit,2} \approx 5300$ Hz). As a result of the reduction in material density, the resonant frequencies of the gear set decrease.

On the right side of Figure 8, the structure-borne noise emission of the first and second gear mesh orders is shown versus frequency in the running test. While the profile of the structure-borne noise level of the second gear mesh order in the first half of the speed range is comparable to the profile of the first gear mesh order, the maximum amplitude is reduced by about $\Delta L_a = 10$ dB. At higher frequencies f > 3000 Hz, the structure-borne noise level of the second tooth meshing order - in particular of the reference variant ST.REF—increases to a maximum of $L_{a,ST.Ref} = 140$ dB.

The two critical resonance frequencies identified in the calculation as well as in the experiment can be transferred to the running test. The reduction in structure-borne noise transfer can also be transferred to the running test. Despite comparable excitation in the gear mesh, the lower material density of the PM variants—especially in the higher frequency range—leads to a reduction in structure-borne noise emission. Due to the low material density, the frequency of the maximum structure-borne noise emission is shifted and a reduced amplitude is measured.

Influence of gear body bores on vibration and noise behavior

The stiffness modulation in the tooth contact of the gear body modified variants leads to a different vibration behavior depending on the gear body position investigated, see Figure 9. The comparison between the measurement result over a bore and over a web addresses the mechanism of resonance interruption. Due to the piezo actuator there is no change of excitation over a PM1.B2 bore and a PM1.B2 web in the WZL structure-borne noise transfer test rig.

As a result of the lower gear mesh stiffness over the bore, the resistance to vibration insertion is lower. The result is a higher acceleration at the outer diameter of the gear body. There is a significant change in vibration behavior between the two gear body positions. This confirms the mechanism of resonance interruption. At the inner diameter of the gear body, the change in gear body position causes a significant change in the frequency of the maximum acceleration. The higher acceleration at the outer diameter of the gear body is compensated due to the low structure-borne noise transfer over the bore.

With regard to the resonance interruption as a result of the gear body modifications, it should be noted that both the vibration insertion into the system and the structure-borne noise transfer differ depending on the observed position. A shift of the maximum amplitude over the frequency can be observed. Due to the continuous change between the two gear body positions during rotating operation, there is no continuous excitation of the two states. Accordingly, a lowering of the maximum amplitude is expected, which leads to an improved noise behavior due to the gear body modifications. Since the reference variants are measured over a web due to

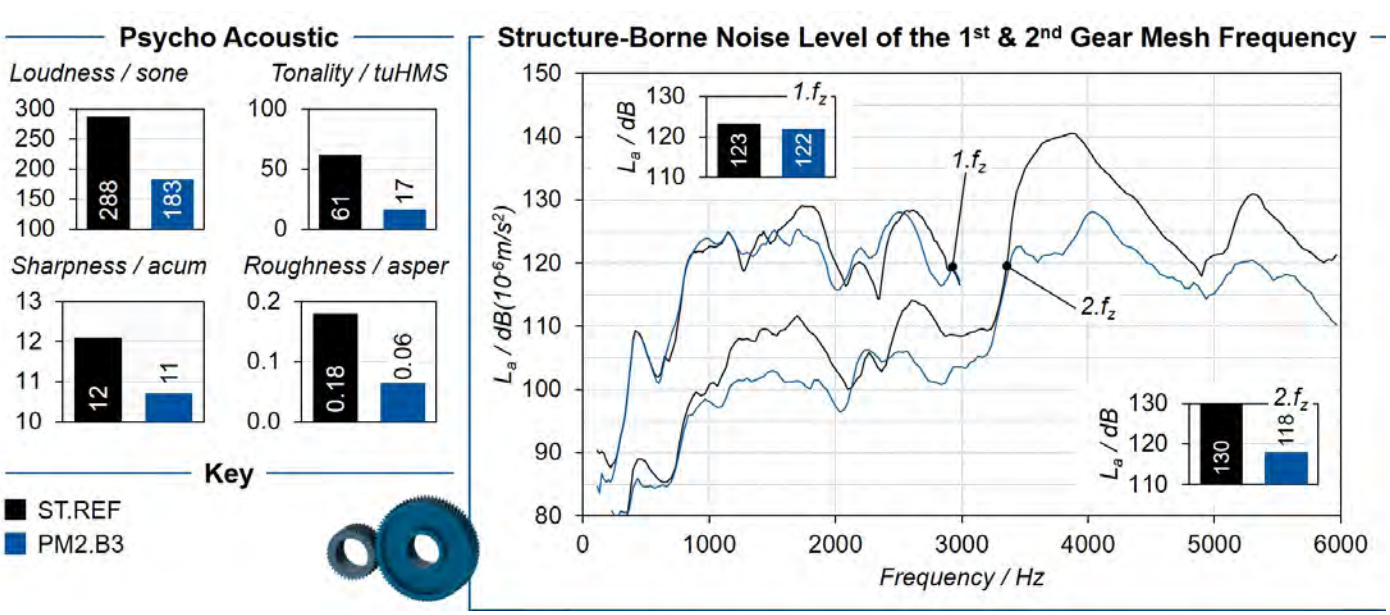

Figure 11—Reduction of NVH behavior through a combination of gear body geometry and density.

their geometry, the comparison with the gear body modified variants is carried out on the basis of the gear body position over the web.

Figure 10 shows the test results of the variants with bores PM1.B2 and PM1.B3 on the vibration and noise behavior compared with the reference variant PM1.REF out of the same material. As a result of the change in the mass and stiffness of the gear body, the resonance frequencies and the structural damping of the critical eigenmodes are shifted. With respect to the first critical eigenmode around $f_{1,krit} \approx$ 2300 Hz, the structure-borne noise emission of the bore variants is below the reference variant. At the second critical eigenmode $f_{1,krit} \approx$ 4100 Hz, a significantly higher structure-borne noise amplitude (over the web) is recorded. The different vibration behavior is also represented in the calculation and can be transferred to the running test.

Despite the significant resonances in the structure-borne noise transfer test rig, a reduction of the maximum structure-borne noise emission is recorded in the running test. Here, the mechanism of resonance interruption leads to a reduction of the maximum amplitude, so that this mechanism is confirmed.

A systematic influence of the different labyrinth structures on the structure-borne noise transfer cannot be identified. The thin-walled gear body structure lead to a higher number of natural frequencies in the investigated frequency range. Corresponding to the increased number of natural frequencies compared to the reference, an increased number of local maxima of the structure-borne sound emission occur in the frequency range. Despite the higher structure-borne noise transfer path and the increase in the number of impedance elements in the gear body from the PM1.L1 to the PM1.L3 variant, there is no significant decrease in the body-borne noise emission. Nevertheless, individual frequencies are reduced or damped. Labyrinth structures thus offer the possibility of reducing the vibration behavior only in certain frequency ranges. The advantage of labyrinth structures in the gear body can therefore be used primarily in drive systems with a small number of operating points, whereby the labyrinth structure is designed for this operating point or specific frequency. In drive systems where a wide frequency range is run through, the higher number of natural frequencies is not recommended.

Conclusion

As a result of the mass, the stiffness and the damping mechanisms of the gear body, a different excitation and vibration behavior results. The WZL structure-borne noise transfer test rig is developed to investigate the vibration behavior. In non-rotating operation, a forced excitation with a piezo actuator takes place via the tensioned gear mesh. The reduction of the material density causes a lowering of the maximum structure-borne noise level as well as a reduction of the structure-borne sound transfer at higher frequencies. The mechanism of resonance interruption is confirmed. As a result of the varying stiffness due to gear body modifications over the revolution of the gear, the vibration behavior changes, reducing the maximum structure-borne noise amplitude.

The lengthening of the structure-borne noise transfer path and successively increasing number of impedance elements in the gear body are investigated with labyrinth structures. A systematic influence of the different labyrinth structures on the structure-borne noise transfer cannot be identified. The thin-walled gear body structures lead to an increased number of natural frequencies in the investigated frequency range, which are not compensated as a result of the impedance elements and the structure-borne noise transfer path.

The results of the investigation of the vibration behavior on the WZL structure-borne noise transfer test rig can be transferred to the noise emission in the dynamic running test. While the labyrinth structures show no systematic influence on the noise behavior, an optimization of the noise behavior is achieved as a result of the reduced gear body density and gear body bores. As a result of the resonance interruption, the maximum structure-borne noise level of the gear mesh frequencies is reduced. The low overall material density and additionally lower wheel body density also result in a reduction in structure-borne noise emission of the first and second gear mesh frequencies.

NVH Optimized Gear Body

The PM2.B3 variant combines the two mechanisms of structure-borne noise damping and insulation. The lower gear body density leads to an increase in material damping, while the gear body bores result in impedances and resonance interruption. Figure 11 shows the results of the PM2.B3 variant compared with the conventional ST.REF reference variant. The combination of reduced gear body density and bores leads to a significant reduction in structure-borne noise emission, especially with regard to the second gear mesh order. Both the mean value of the second tooth meshing frequency decreases by ΔL_a = -12 dB and the maximum structure-borne noise amplitude decreases by ΔL_a = -12.4 dB. As a result of the material damping and the material change, the reduced gear body density causes a reduction in structure-borne noise emission in the higher frequency range from f = 3400 Hz. The gear body bores result in a reduction of the maximum level due to the resonance interruption and an optimization of the low frequency range. The reduced structure-borne noise emission of the PM2.B3 variant compared with the ST.REF variant is attributed to the sum of the mechanisms, whereby an optimization of the noise emission is achieved in the entire frequency range.

The comparison of the psychoacoustic parameters of the two variants also shows a significant optimization of the noise behavior of the PM2.B3 variant compared to the reference. Loudness is reduced by -36.5 percent, tonality by -72.1 percent, sharpness by -7.3 percent and roughness by -66.7 percent. The reduction of the characteristic values is mainly due to the reduction of the structure-borne sound level of the second tooth meshing frequency in the higher frequency range.

Summary and Outlook

The reduction of noise emission is a general objective of transmission design. In addition to the macro- and microgeometry, the design of the gear body geometry and density can optimize the NVH behavior as a result of the mechanisms influencing the vibration behavior. The partly counteracting mechanisms of influence require a multidimensional evaluation of the operational behavior. Therefore, calculation methods of the gear body influence on the operational behavior and on the vibration behavior are developed and validated by the experimental test results. For the systematic investigation of the mechanisms influencing the vibration behavior, nine test gear variants are designed, which differ in terms of material, density as well as gear body geometry. To evaluate the influence of the gear body variation, excitation, vibration and dynamic structure-borne noise behavior are investigated experimentally. Due to the gear body modifications, the gear mesh stiffness varies over the circumference, which results in a discontinuous stiffness characteristic. This leads to an excitation of the gear body order and sidebands besides the gear mesh frequencies. The lower material stiffness of the PM variants causes a load shift of the transmission error profile of the gear mesh orders. As a result, there is a shift in the minimum and maximum excitation regarding load, which is relevant for the design. For the optimization of the NVH behavior, the mechanisms of material damping, material change and resonance interruption show the greatest influence. With regard to an extension of the structure-borne noise transfer path and the number of impedance elements, no systematic influence can be measured. The combination of a reduced gear body density and bores in the gear body of the PM2.B3 variant combines the three most potential mechanisms. The test results show that the influence of the mechanisms superposes, resulting in a significant optimization of the NVH behavior. Both the structure-borne noise level of the first two tooth meshing frequencies and the psychoacoustic parameters are significantly reduced.

Overall, the influence of gear body modifications and material density is multidimensional. The excitation in the gear mesh, the stress, the vibration behavior and the NVH behavior are influenced. The results of the systematic investigation are the basis for a resource-efficient, noise-optimized design of the gear body of powder-metallurgical gears. The future goal is to integrate the gear body design into the gear design, which has so far focused on the gear macro- and microgeometry.

Acknowledgement

The authors gratefully acknowledge financial support by the German Research Foundation (DFG) [BR2905/98-1] and the WZL Gear Research Circle for the achievement of the project results.

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1. Publication Title	2. Publication Number	3. Filing Date
GEAR TECHNOLOGY , the Journal of Gear Manufacturing	0 7 4 3 _ 6 8 5 8	October 1, 2022
4. Issue Frequency	5. Number of Issues Published Annually	6. Annual Subscription Price (if any)
Monthly except Feb., Apr., Oct., Dec.	8	$70.00

7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®)
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GEAR TECHNOLOGY, the Journal of Gear Manufacturing	AUGUST 2022

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UNITED STATES POSTAL SERVICE

Statement of Ownership, Management, and Circulation (Requester Publications Only)

16. Electronic Copy Circulation	Average No. Copies Each Issue During Previous 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Requested and Paid Electronic Copies ▶	3,598	3,312
b. Total Requested and Paid Print Copies (Line 15c) + Requested/Paid Electronic Copies (Line 16a) ▶	7,272	6,624
c. Total Requested Copy Distribution (Line 15f) + Requested/Paid Electronic Copies (Line 16a) ▶	9,793	9,050
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17. Publication of Statement of Ownership for a Requester Publication is required and will be printed in the September/October 2022 issue of this publication.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner	Date
Randy Stott, Publisher & Editor-in-Chief (signed) Randy Stott	10-1-2022

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Forest City Gear

ANNOUNCES LATEST PROMOTIONS

Forest City Gear recently announced the promotion of Amy Sovina to quality assurance manager. Sovina has worked at Forest City Gear since 1994, starting as a CNC machine operator, then moving on to gear hobbing technician, gear inspector, and most recently customer quality engineer. As quality assurance manager, Sovina will be responsible for developing, implementing, and maintaining Forest City Gear's Quality Systems to prevent or eliminate defects in new and existing products and ensuring compliance with industry quality standards.

Amy Sovina

According to Kika Young, president of Forest City Gear, "We are overjoyed to continue Amy's forward trajectory in her career at Forest City Gear. Her commitment to the company and our motto, Excellence without Exception, is top tier. We are proud to have her represent Forest City Gear."

Additionally, Forest City Gear recently announced the promotion of Kent Blatchford to gear hobbing supervisor. Blatchford began his career with Forest City Gear in 2001 in gear hobbing. Over the years, Blatchford has held many roles, including gear hobbing set-up technician, mechanical engineer for gear hobbing, gear inspector, quality technician, and gear cutting customer service.

Kent Blatchford

"We are delighted to make this move with Kent in his career and are thankful for his dedication and commitment," added Young.

forestcitygear.com

Atlanta Gear Works

SIGNS AGREEMENT WITH MCCLAIN INDUSTRIAL TECHNOLOGIES, INC.

Atlanta Gear Works has announced a new working agreement with Jim McClain, general manager of McClain Industrial Technologies, Inc., DBA MiTek, a manufacturers' rep that will help the gearbox repair and manufacturing firm spread its 34-year reputation in pulp and paper to the steel and aluminum industries.

"Atlanta Gear Works is a leader in the pulp and paper industry," said Cory McClain, MiTek president. "We're looking forward to offering their same exceptional service and support to our contacts in steel and aluminum."

Jim McClain

In business since 1987 and headquartered in Alabaster, Alabama, MiTek has extensive contacts with mechanical maintenance decision makers in steel and aluminum rolling mills throughout the Southeast U.S. MiTek's exclusive territory will include Alabama, Arkansas, Louisiana, Kentucky, Mississippi, Kentucky, Tennessee, Texas, and southern Indiana.

"We were pleased when MiTek became available to help us grow our relations with the steel industry," said Craig Massa, Atlanta Gear Works vice president-sales. "Their 30-year experience with steel will help us better serve our steel customers."

Cory McClain

Even though the U.S. economy has experienced two consecutive quarters of negative growth, this agreement comes at a time U.S. steel capacity is expected to increase even as prices drop, thus increasing mills' need for gearbox repair services.

According to *ArgusMedia.com*, despite growing signs of a recession, the big four steelmakers signaled in their latest earnings reports that they are betting that demand will remain steady or increase, as they pointed to persistent backlogs. The companies say they will be ramping up at flat-rolled mills that had been running at sub-optimal levels and restarting other mills that had been down for maintenance.

"Given this forecast, the timing for bringing MiTek on board is optimal and should enable us to maintain and even grow our market share of the industry, no matter what happens in the wider economy," said Massa.

atlantagear.com

Ayla Busch

HONORED WITH THE GERMAN LEADERSHIP AWARD 2022

Expertise, vision, information management, success, ethical conduct, human competence, and diversity: Ayla Busch had convinced the jury in all these categories and therefore received the German Leadership Award 2022.

"Ayla Busch is a leader with a special, with a unique style, based on appreciation, a sense of family, communication and, above all, diversity—in the fullest sense", said laudator Lars Wagner, chairman of the German Leadership Award jury and chief operating officer (COO) at MTU Aero Engines AG.

The award was presented at the annual alumni convention of the "Collège des Ingénieurs" in Munich. In her acceptance speech, Busch explained how far back equality and diversity go in the history of Busch Vacuum Solutions: "My parents founded our company as an equal partnership back in 1963. That is unique. And even at the very beginning, we had an employee who was deaf and whom my parents supported in becoming a master craftsman."

Prof. Hans-Peter Mengele (left) Ayla Busch (right)

After a reception at the beginning of the event and before he handed it over to Wagner, Prof. Hans-Peter Mengele, chairman of the sponsoring association of the German Leadership Award, explained its significance to the approximately 200 guests: "The German Leadership Award is a particularly authentic award for innovative corporate leadership in the German economy. It is sponsored by the network of German alumni of the 'Collège des Ingénieurs'. The engineers and scientists from the 'Collège des Ingénieurs' are among the excellent leaders of the next generation." Since 2014, these young leaders nominate personalities for the German Leadership Award who are role models for them every year.

After the ceremony, Busch exchanged views with former award winners in a round table discussion. Afterward, the participants of the event had the opportunity to network and taste Bavarian delicacies.

buschvacuum.com

Seco Tools

OPENS NEW PRODUCTION UNIT IN MEXICO

Seco Tools Production Unit (PU) in Mexico opened on September 29th. The new plant houses special tool manufacturing. This strategic move will allow Seco Tools to consolidate its presence in the Mexican market which extends and strengthens the configuration of its manufacturing chains worldwide.

Located in the modern 360 Industrial Park, the new PU will have privileged access to the Saltillo-Monterrey highway, with direct road communication to industrial cities in the North (Monterrey, Nuevo Laredo, Matamoros, and Reynosa) and the South (San Luis Potosí, Guanajuato, and Querétaro).

The new 2,500 square meter manufacturing facility features Seco Tools unique architecture, design, and production cell layout standards. Additionally, all Ramos Arizpe's PU employees will have exclusive training and education spaces with multifunctional rooms for strategic, commercial, and administrative activities.

It's been two years since the acquisition of the cutting tools division of QCT (Quimmco Technological Center), and the machinery and equipment from the previous facility will now be transferred, occupying approximately two-thirds of the PU floor. New equipment for standard tool production is expected to come soon and fill the remainder of the space.

Seco Tools has a focus on sustainability and this new location is no exception. Solar cells will be installed on the plant roof and on the top of car ports to generate up to 50 percent of the power needs of the PU.

"Seco is strongly committed to the environment and green technologies. It is not surprising that we are investing in solar panels in our new facility in México", said Oksana Wade, CFO at Seco Tools. Seco Green Fund, created in 2012, supports many environmental initiatives, "which is not only about green power but also other efforts. In México, Seco Tools is not only selling new tools but also regrinding and remanufacturing carbide and PCD tools, as well as recycling carbide at the end of the tool life. Taking care of the whole tool lifecycle, the customer wins and the environment wins too," Wade added.

In addition to the focus on sustainability, Seco Tools philosophy is rooted in being a good corporate citizen and developing social responsibility activities to support local schools, public squares, and activities-oriented programs in the perimeter community.

This new PU is an example of Seco Tools' commitment to the Mexican market and will be strategically positioned to better serve the growing demand for carbide and diamond tools both in México, throughout North America, and some countries in South America and Europe.

secotools.com

Rego-Fix

CELEBRATES 50TH ANNIVERSARY OF THE ORIGINAL ER COLLET

This year marks the 50th anniversary of a revolutionary invention that changed the way today's manufacturers hold metalworking cutting tools. What has been an industry standard for decades now, the Rego-Fix ER collet is the most widely used clamping system in the world and still produced at the company's Tenniken, Switzerland, plant.

Prior to the Rego-Fix ER collet, the "E collet" was the technical standard. Unfortunately, though, after machining, the collets were anchored so firmly in their holders that they could scarcely be removed. Shops would use wooden bars and rods to knock collets out through the lower part of the holder with a hammer. This required a lot of force, damaged the rear sides of the collets and shortened their service lives considerably.

In 1972, Fritz Weber and Rego-Fix solved these problems with the creation of the ER collet. Weber added a groove to the outer side of the collet, which was then inserted into the eccentric ring of a newly created clamping nut. With his design, users could quickly and easily pull the collet directly out of the holder after unscrewing the nut. Additionally, Weber's ER collet design incorporates more slits, facilitating a wider clamping range of 0.5 to 1 mm for increased versatility.

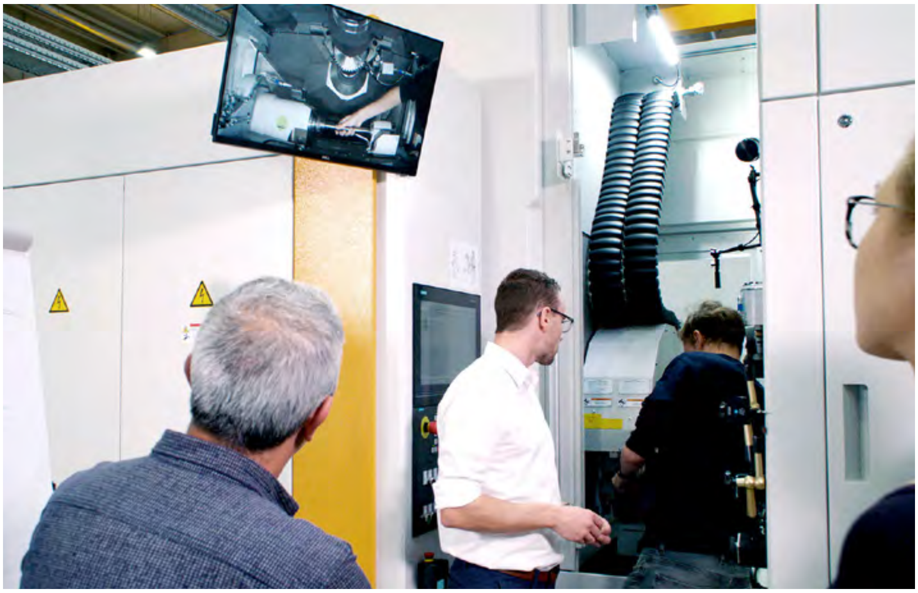
"Our father's vision that the industry would use millions of ER collets was met with skepticism and disbelief by many," said Stefan Weber, vice president of Rego-Fix and son of founder Fritz Weber. "But today, they are in use in thousands of machining centers worldwide."

After receiving considerable recognition, the Rego-Fix ER collet was declared the DIN standard 6499 in 1992. And according to Richard Weber, CEO of Rego-Fix and son of Fritz Weber, the ER collet is the foundation upon which the company has built and continues to advance its ER concept as well as other tooling innovations over the past decades.

regousa.com

Liebherr

OFFERS MACHINE TRAINING CENTER IN KEMPTEN



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

Here, the participants find out in detail what the machines can do, so that later they can fully and efficiently exploit that potential—and they do this by manufacturing real workpieces. After completing the training, they receive a certificate. If any questions arise when they return to their day-to-day work, they can ask the service team for advice.

Up to eight cameras transmit images from different perspectives inside the machine to large monitors. Even the smallest components of the machine electronics can be easily seen by all participants using the visualizer. Various scenarios can be tested on simulators without the risk of damaging an expensive machine. "The simulators take away the fear of breaking something. Everyone is then much more relaxed when they actually come to use the machine," said Markus Bahsler, head of the Liebherr Academy. "The training teaches them to use the ideal parameters."

Liebherr also offers individual, modular and topical training on the maintenance of the mechanical and electrical systems. The mechanical training courses focus on troubleshooting and geometric testing of the machine axes, and on carrying out the necessary adjustments so that the machine can produce with the highest quality. They also include analysis of the fluid diagram and cooling systems as well as replacement of specific drive components and wear parts. The electrical training courses focus on data backup, the PLC program structure and cycle diagnostics, adjustment of measuring systems as well as advanced troubleshooting and fault elimination. The company's own personnel are trained this way to correctly analyze and repair the machine.

The practical handling of the machines is best learned on site. However, thanks to the Academy's modern media technology, subjects such as programming can also be easily taught in online training courses.

"Our camera technology for live online training conveys images and situations that you can otherwise only experience live—and in some cases it's even better," said Bahsler. In the online format, for example, flexible, user-defined dressing of grinding worms with single or multiple starts can be practiced using a form disc with point or line contact. Didactic elements maintain the attention of the participants and ensure that what they have learned remains firmly anchored. The live online training is ideal for anyone who is experienced and familiar with operating the machine. Participation is possible practically anywhere in the world, thus saving travel time and costs.

Small groups of no more than six people and the latest media technology ensure that the training is as effective as possible. "At the MTC, the participants are not distracted by day-to-day business and can concentrate fully on the subject at hand," said Bahsler. "And they don't just look over the trainer's shoulder, they practice on real workpieces themselves. As you can see, real chips are flying here!"

Businesses benefit from increased process reliability and efficiency. If the operating personnel can get the best out of the Liebherr machines, productivity can be increased and there are fewer downtimes and disruptions.

liebherr.com

October 26–27—AGMA Involute Spline Design & Rating

This online virtual course will address both geometry and rating of involute splines of various types. The types of spline joints and their applications will be discussed. Spline configuration variations, including half depth, full depth, and special function designs, will be addressed. Both fixed and flexible spline configurations will be examined in terms of usage and design. Lubrication methods, including grease, oil bath, and flowing oil, as well as coatings appropriate for various spline applications, are examined. Shear and compressive stress rating methods are discussed with analyses methodology presented in both equation and graphical methodology via various rating charts.

geartechnology.com/events/5044-agma-involute-spline-design-rating

November 2–3—AGMA Operator Precision Gear Grinding

Explore gear grinding processes, machine kinematics and set-up, pitfalls, failures, and expectations related to finish ground gearing. Learn definitions of gearing component features, process steps from blanking, through heat treatment to finished part ready to ship. Study aspects of quality assurance, inspection documentation and corrective actions for measured non-conformances. Understand pre-heat treat, heat treatment and post-heat treatment operations including the "hows" and "whys" to produce finished gears that conform and perform to end user expectations. The event takes place at the AGMA National Training Center in Chicago.

geartechnology.com/events/5045-agma-operator-precision-gear-grinding

November 9–10—Aachen Conference on Gear Production

At this year's Aachen Conference on Gear Production (ACGP), which is organized hand in hand by the Machine Tool Laboratory WZL of RWTH Aachen University and the FVA Forschungsvereinigung Antriebstechnik e.V., topics ranging from work preparation to soft and hard finishing, quality control, assembly and operation of gears will therefore be addressed. The spectrum of topics ranges from process design and tool design in line with requirements to the production of individual gear geometries and measures for continuous quality assurance. In addition, aspects of digitalization and improving sustainability in the production and application of gears will be presented.

geartechnology.com/events/5036-aachen-conference-on-gear-production

November 15–18—Formnext 2022

Formnext (Frankfurt, Germany) is more than an exhibition and conference. It's an entire platform for companies from the world of additive manufacturing. Here, a veritable who's who from the realms of design and product development, industrial tooling, production solutions, quality management, and measurement technology comes together with leading providers in basic materials and component construction. It will also explore clever ways in which AM can be integrated into process chains in industrial production. In addition, top international speakers and other experts will be on hand to engage conference attendees in in-depth discussions at the highest technical level.

geartechnology.com/events/5042-formnext-2022

January 23–27—SciTech 2023

Spanning over 70 technical discipline areas, AIAA's conferences provide scientists, engineers, and technologists the opportunity to present and disseminate their work in structured technical paper and poster sessions, learn about new technologies and advances from other presenters, further their professional development, and expand their professional networks that furthers their work. Focus areas include science and technology, aviation, space, propulsion and energy/defense. The 2023 SciTech forum will be a hybrid event which will include both in-person and virtual components, offering attendees the flexibility and choice of how to participate. Experts will present more than 3,200 technical presentations on fluid dynamics, applied aerodynamics, propellants and combustion, intelligent systems, structures, and guidance, navigation and control.

geartechnology.com/events/5040-scitech-2023

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Ladies First

Kate Gleason's life was one full of firsts

Aaron Fagan, Senior Editor

With our zeitgeist of presentism—the judging of the past through the lens of current standards—it's refreshing if not essential to know the past was not entirely without figures who not only exceeded the standards of their time but even those of today. At a time when women's suffrage was in its nascency, Catherine "Kate" Anselm Gleason (1865–1933) helped stage what would become the Gleason Corporation in the global cutting tools industry as a sales engineer for her family's gear-cutting machinery business.

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William Gleason—who emigrated from Ireland and opened a machine shop where he produced metalworking tools and machines, such as engine lathes and planers—began The Gleason Works in Rochester, N.Y., in 1865, and then by 1874, he had invented and patented the bevel gear planer, often misattributed to his daughter Kate whose deep technical understanding of the gear cutting equipment she sold may very well have led to the assumption she invented this machine that revolutionized the potential for the transmission of motive power.

In a letter to *The New York Times* dated May 18, 1910, she submits a witty and charming erratum to an article that had credited her with designing the bevel gear planer when "the nearest I have come to designing it is in having a father and a brother smart enough to do it. My place in the business is Secretary and Treasurer. You see, I have captured two jobs, but neither of them has anything at all to do with designing. About the most important training for the treasurer is not to take what does not belong to one, and it looks to me as though I would be falling down on my own job if I get credit for other people's work."

Kate's life was one full of firsts. In addition to being the first female student admitted to Cornell University's engineering program, she was the first to become a member of the Rochester Chamber of Commerce, the Rochester Engineering Society, the American Gear Manufacturers Association (AGMA), the German Engineering Association, and the American Society of Mechanical Engineers (ASME). And last, but not least, among her firsts is that The Kate Gleason College of Engineering at the Rochester Institute of Technology was the first engineering school named for a woman. In 2011, the ASME Foundation established the Kate Gleason Award, which recognizes the contributions of distinguished female leaders in the field of engineering.

James Gleason, the former Gleason CEO who passed in June, credited his great aunt with laying the groundwork for Gleason's presence overseas. Today, the lion's share of Gleason's sales is made outside the U.S. In 1893, when automobiles were still out of reach for the average citizen and the American Industrial Revolution had not reached full steam, Kate Gleason's European trip marked one of the earliest attempts by an American manufacturer to establish overseas markets.

In a 1997 *Gear Technology* feature by Nancy Bartels titled "The First Lady of Gearing," Dr. Hermann J. Stadtfeld, vice president, bevel gear technology and R&D at Gleason (who should be familiar to *Gear Technology* readers) said most of the straight bevel gear machines installed in Europe can be traced to Kate's sales activities at the turn of the 20th century. Stadtfeld said, "When we sell a straight bevel gear machine to one of those countries to replace an old straight bevel planer, I always think of Kate's legacy."

Inspection at Nano Level

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