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Vol. 36, No. 2 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by Randall Publications LLC, 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). Randall Publications 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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departments

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Gear Talk: Origin Stories

Our weekly blog has been featuring great stories about how many in the industry first became involved with gears. Read recent entries from Ray Drago, Octave LaBathe, Chuck Schultz, Chris Trochelman, Matt Rossiter and more here: *www.geartechnology.com/blog/*. And be sure to send YOUR gear story to *publisher@geartechnology.com* to be included in future blog entries.

Klingelnberg Bevel Gear Grinding with 3M Cubitron II

The bevel gear grinding machine Oerlikon G 30 allows the use of the entire potential of 3M Cubitron II for bevel gear grinding. Learn more at *www.geartechnology.com/videos/Klingelnberg-Bevel-Gear-Grinding-with-3M-Cubitron-II/*

Oelheld Fluid Technology

This video gives viewers an inside look at the research and development behind Oelheld's fluid technology. Learn more here: *www.geartechnology.com/videos/Oelheld-Fluid-Technology-/*

A Look at Helios Gear

Helios Gear builds upon the legacy of Koepfer America and the 150-year reputation of Koepfer machine tools. Learn more about the company here: *www.geartechnology.com/videos/A-Look-at-Helios-Gear/*

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What's in a Name?

[Overheard]

"You going to Gear Expo this year?"

"Um, well, I'm going, but it's not Gear Expo anymore. It's called Motion + Power Technology Expo now."

"What? There's no more Gear Expo?"

"Don't Panic. It's the same show, but now with an expanded focus."

As most of you know by now, the trade show formerly known as Gear Expo is now the Motion + Power Technology Expo. If you're a gear-industry veteran, you might be confused by this change. If you've been coming to the show for years — or exhibiting at it — you might even feel a little betrayed.

But I'm here to tell you it's going to be alright. In fact, if AGMA is able to see its vision through, it's probably going to be a whole lot better for the show's visitors and exhibitors alike.

The show has always included a wide variety of exhibitors. On one end of the supply chain, you have suppliers of machine tools, cutting tools, forgings and services — everything you need to make gears yourself. On the other end, you have a wide variety of gear job shops, capable of manufacturing gears in any size, type or volume. Lately we've also seen a number of manufacturers of gear drives – complete systems engineered for a particular end use.

All of these suppliers are interrelated. In many cases, the exhibitors buy from each other. In many other cases, they compete against each other. Even the machine tool manufacturers and the gear manufacturers are competitors, in a way. One wants to sell you gears, and the other wants to sell you the ability to make them yourself. The engineer walking down the aisles of the show might consider one or the other — or both, depending on what makes most sense. Likewise, he might consider buying loose gears and assembling them himself, or he might be looking for a more complete system.

The point is, the gear industry supply chain has always been complex. What benefits exhibitors the most is getting more potential customers in the building. And what gets more potential customers in the building is options.

"The technical reality is that our joint end user customers are looking for power transmission solutions, including gears/mechanical solutions, fluid power and electric drives," says AGMA President Matthew Croson.

That's why the AGMA has partnered with the National Fluid Power Association, and the NFPA is hosting a fluid power pavilion at the new Motion + Power Technology Expo. It's also why the AGMA continues to look for other ways to expand the show.

"The overlying concept the AGMA board approved is to evolve…and position AGMA's trade show at the center of all aspects of power transmission, as the industry has evolved."

In addition, the show continues to be co-located with the ASM Heat Treating Show, providing even more reason for buyers to come.

Finally, Gear Expo has always included a wide variety of educational opportunities. This, too, is expanding now that the show has become the Motion + Power Technology Expo. In addition to the AGMA's Fall Technical Meeting, whose dates overlap with MPT Expo, there are a wide variety of seminars on gear-related subjects, as well as educational opportunities focusing on bearings, lubrication, fluid power and electric drives. This year, AGMA has added the MPT Conference, with one track focusing on emerging technologies like 3-D Printing, IoT and robotics, and another track focusing on business intelligence, with topics like cybersecurity, blockchain and skilled workforce issues.

MPT Expo takes place October 15–17 at the Cobo Center in Detroit, and there are more reasons than ever for you to attend. Solve all your gear and mechanical power transmission needs, in one place, at the same time.

Michael Goldstein

P.S. As we've done at previous shows, we'll once again be recording sessions of our "Ask the Expert Live!" show for Gear Technology TV. Do you have a gear and/or power transmission design or manufacturing problem that's been difficult to solve? Send it to *publisher@geartechnology.com* with the subject line "Ask the Expert Live!" to have it considered for answering by our panel of experts.

Gleason

Modular Standard Workholding puts the performance benefits of tool-less quick-change workholding into a system of standard, interchangeable, and readily available modules.

Tim Zenoski, director, global product management, workholding, The Gleason Works

Gear manufacturers are meeting fast-changing customer demand with just-in-time production of smaller batch sizes requiring frequent part changeover. Traditional workholding taking 20 or 30 minutes for changeover and considerable operator experience are, out of necessity, giving way to quick-change alternatives. These new solutions can be installed and removed in just seconds, with only a single tool, and by even a novice.

Benefits such as increased spindle time, more productivity and lower cost per workpiece are readily apparent for users of this latest generation of workholding. Gleason's Quik-Flex and Quik-Flex Plus systems, for example, have enhanced workholding changeover for small and medium size cylindrical gears with a system of modules that can be installed on a base arbor permanently mounted in the work spindle with just the twist of an activation handle. (Quik-Flex is so simple and effective that even non-operator contestants in our tradeshow demonstration challenges have routinely removed and installed Quik-Flex in under 10 seconds.)

The new modular, off-the-shelf standard. Today, we're raising the quick-change bar even higher, with introduction of a system of Modular Standard Workholding that puts Quik-Flex performance into a system of small, medium and large standard interchangeable modules that span the most common range of cylindrical gear diameters. If Quik-Flex results in shorter cycle times chip-to-chip, then Modular Standard Workholding does it one better: shorter *ship-to-chip* time. Now, there's an in-stock, off-the-shelf solution available to users almost overnight to meet the latest workholding requirements of many of the most common cylindrical gear bore sizes and diameters. End result: elimination of many weeks of waiting, and the inherent cost, for special tooling whenever a new application arises. Instead, manufacturers can meet most, if not all, of their needs with any of a family of just eight standard modules covering bore diameters ranging from 18 mm to 100 mm.

Each of these small, medium and large modules consists of an interchangeable clamping head connected to an interchangeable arbor body, both of which come in a variety of sizes to form a multitude of standard combinations to fit the user's part-specific application requirements. These modules interface with just three sizes of Quik-Flex base adapter, permanently mounted in the work spindle. The base unit is designed to be fine-tuned during its installation for minimal axial and radial runout. The modules can be installed, and removed, in just seconds with just a quick twist of the system's simple, removable, activation handle. No other tools are required, nor any of the usual mounting bolts, set screws or ejector screws to deal with. Note that an internal cam locking mechanism built into the base ensures that modular colleting tooling is centered and drawn firmly against the seating face of the base.

Most importantly, modular standard workholding makes no compromises on quality. Accuracies and repeatability of 5 microns (0.0002") TIR — identical to the other Gleason workholding — is guaranteed. It's also equipped with Gleason's 'New Blue' segmented collet, which delivers exceptional reliability over an extremely long life as well as a particularly wide expansion range of up to .50 mm (.019") for increased flexibility.

Finally, since customers are increasingly in need of the ability to track critical data, Gleason is incorporating 'Gleason 4.0' and gTools technology into its workholding. gTools gives users of modular standard workholding the option to use RFID chips to, for example, to determine how many times the workholding has cycled. Knowing this can help the customer to determine when preventive maintenance is required. It can also be used to trigger reorder points for wear parts such as collets.

For additional information on the new modular standard workholding, and the complete array of Gleason workholding solutions., visit the website below.

Editor's note: Learn additional information in the workholding feature on page 26.

For more information:
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Klingelnberg

PRESENTS MACHINE TOOL TECHNOLOGIES AT CIMT 2019

Since its inception in 1989, the China International Machine Tool Show (CIMT) has evolved according to show organizers to become a leading platform for the international machine tool industry in China, and in the entire East Asian region. Organized by the China Machine Tool & Tool Builders' Association (CMTBA), the show is one of the four largest international machine tool trade shows in the world.

Machine manufacturer Klingelnberg will be presenting its innovative Closed Loop concept for cylindrical gears — a pioneering Industry 4.0 solution — at booth A105, located in Hall W1 from April 15–20. With its entry into the robotics industry, Klingelnberg is also launching an initiative to expand its business outside the gear industry. Klingelnberg's cycloid measurement option for precision measuring centers provides a reliable solution for monitoring high production standards.

Focused on highly effective generating grinding in large-series manufacturing, the Höfler Speed Viper Cyclical Gear Grinding Machine draws on the successful concept of the well-established Viper 500 series of Höfler Cylindrical Gear Grinding Machines. Four different machine models are available to suit individual requirements: Speed Viper 300 and 180 in a single-spindle configuration, and Speed Viper² 180 and 80 in a dual-spindle configuration. Speed Viper is designed for maximum workpiece diameters of 80, 180, and 300 mm, depending on the model. The Speed Viper² dual-spindle concept achieves the shortest auxiliary times and therefore fulfills the productivity requirements of the automotive industry. With an outside diameter of 320 mm and a width of 200 mm, the grinding worms ensure a long tool life while minimizing auxiliary times for tool changes. An automatic tool clamping system with an integrated balancing unit also contributes to shorter tooling times. With a partial or full automation system, the Speed Viper can also be equipped with an automation interface that meets the VDMA 34180 standard.

The Speed Viper platform is optimally designed for the Industry 4.0 manufacturing environment. Thanks to a broad array of applications and software, Klingelnberg's cyber-physical production system centralizes production control, leading to a standardization of results achieved on different machines and even in different plants.

Designed for use in Closed Loop processes, the P 26 Precision Measuring Center stands for quality management of gearing with scope for future development, and is designed as a compact unit suited to a workpiece diameter range of up to 260 mm. The machine and software concept is optimized for the measurement of complex drive components using a technology that replaces up to six conventional measuring methods: gear measurement, general coordinate measurement, form and position measurement, roughness measurement, contour measurement and optical measuring technology. This guarantees maximum measuring accuracy and reproducibility.

With the cycloid measurement option, Klingelnberg now offers a reliable solution for monitoring the high production standards of the robotics industry. Cycloid transmissions enable high reduction ratios and are used to transmit forces in robot arms. As the need for high-precision robots increases along with increasing levels of automation, the combination of precision measuring centers and gear grinding machines for cycloids ensures continuous improvement in production quality.

For more information:
Klingelnberg America, Inc.
Phone: (734) 470-6278
www.klingelnberg.com

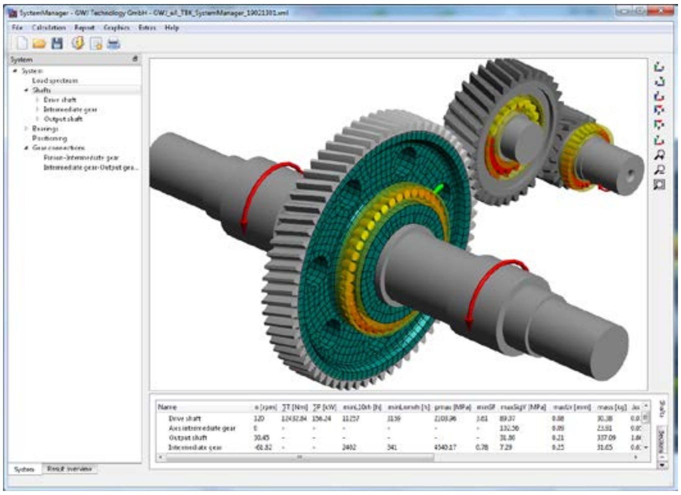
GWJ Technology

EXPANDS SYSTEM CALCULATION SOFTWARE

GWJ Technology, Germany, a manufacturer and provider of calculation software for mechanical engineering and gear manufacturing, recently introduced a new version of its system calculation.

A major extension is the possibility to consider gear bodies of cylindrical gears as 3D elastic and meshed parts. This functionality of 3D elastic parts (meshed FE parts) for housings and planet carrier, which has been around for years, was further extended. By means of 3D elastic gear bodies, the gear body stiffness can be considered in a better way, especially when it comes to the dimensioning of flank modifications. 3D geometries of gear bodies can be defined using either a polygon or the direct import via 3D STEP/IGES. It is thereby possible to define forces and bearings directly on 3D elastic parts.

The extended rolling bearing calculation allows the use of elastic bearing rings for even more detailed analyses. There are several more improvements in the software like the addition of the REXS format, which is developed by FVA (German Research Institute for Drive Technology) for gearbox systems or additional result tables in XLS and XLSX format. Needle bearings type HK and BK are now available. The bearing database from SKF was updated to the latest data and a bearing database from Schaeffler with FAG and INA bearings was added. For documentation points on the shafts, a stiffness matrix can be determined. A new option for supporting positions was integrated too. GWJ provides an outlook on its ongoing activities in software development at this years´ Hannover Messe at Hall 25, Stand A23.



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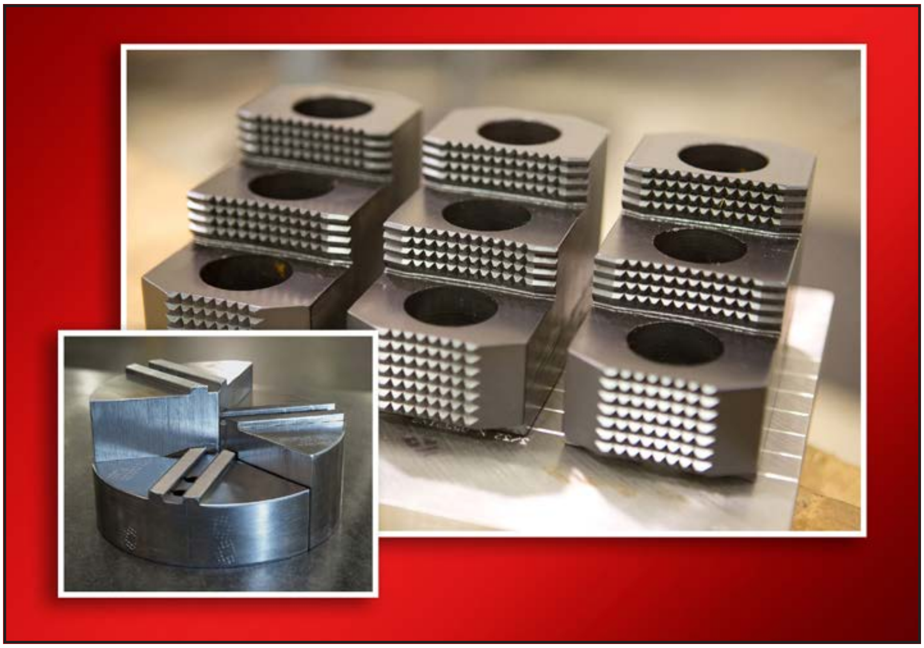
Dillon Manufacturing

OFFERS CUSTOM, SPECIAL OR MODIFIED TOP JAWS

Special Top Jaws from Dillon Manufacturing can be manufactured to grip a components ID, OD or a combination of both, to suit any workholding application. Available in soft or hard jaws, or full grip jaws, for virtually any chuck manufacturer, Dillon manufactures special top jaws from 1018, 1045, 4140, 8620, A-2, 6061 aluminum, and stainless steel. A comprehensive website provides complete details and includes an "easy quote" format with "fill-in-the-blanks" convenience at the website below. Dillon standard and custom chuck jaws and collet pads and jaws are ideal for high speed machining, as well as precision boring, tapping, drilling and finishing across virtually all industrial markets. Dillon custom, special, or modified hard, soft or full grip top jaws are manufactured with industry-best turnaround time, which saves time and money by reducing downtime.



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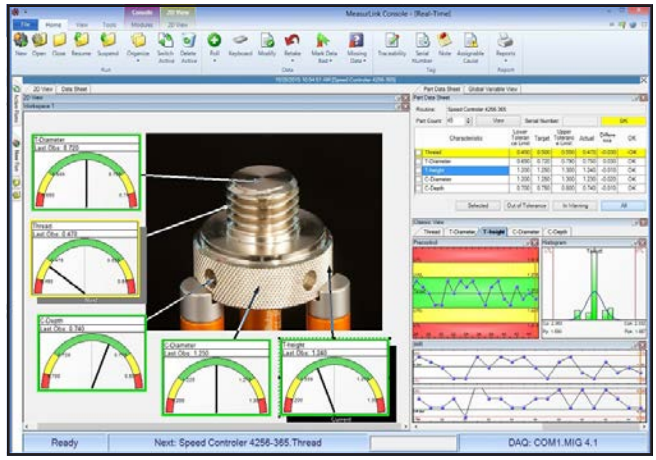
Mitutoyo America Corporation

RELEASES MEASURLINK 9



Mitutoyo America Corporation is pleased to announce the release of *MeasurLink 9*, the latest version of Mitutoyo's real-time statistical process control and data collection software.

Updates on the *MeasurLink 9* release include:

- Supports Windows users and allows single sign-on ideal for teams, groups and companies
- Run hypothetical "what-if" scenarios in Process Analyzer
- Displays dynamic data from a data source in high sampling rates
- Uncertainty Chart provides a visual representation of how the gage performance affects measurement
- Copy/paste Gage R&R Data
- Improved Gage Management by importing information from an external source
- Automatically identify characteristics during data collection based on tolerancing
- Better traceability to ensure proper data recording for serial numbers
- Ability to import calibration data in Gage Management

MeasurLink is a modular data management software system that enables collecting data from a wide range of Mitutoyo measuring tools and systems including calipers, indicators, sensors, vison and coordinate measuring machines.

For more information:
Mitutoyo America Corporation
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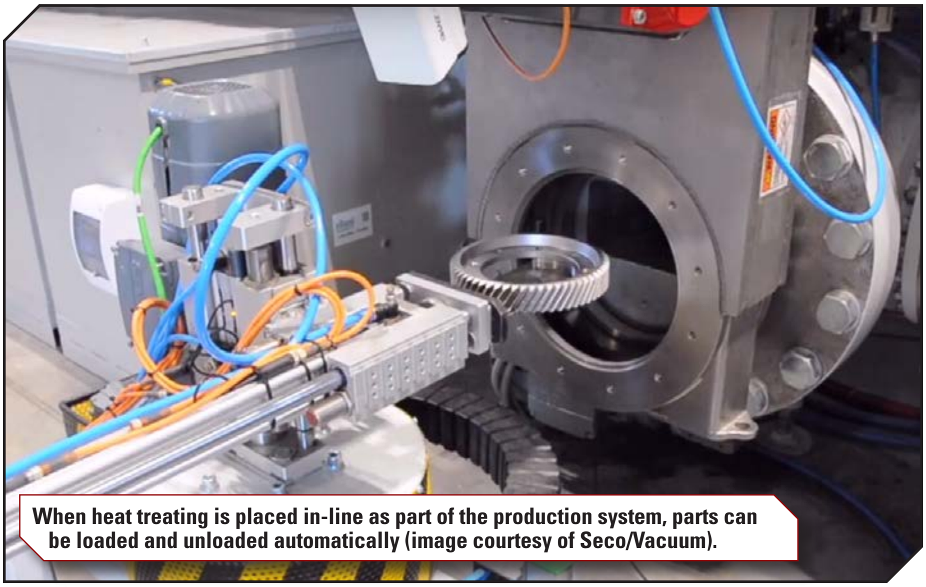
www.measurlink.com

Moving Heat Treating In-Line

Single Piece Flow Streamlines Production for High-Volume Gear Manufacturers

Randy Stott, Managing Editor



When heat treating is placed in-line as part of the production system, parts can be loaded and unloaded automatically (image courtesy of Seco/Vacuum).

Over the past decade, low pressure carburizing (LPC) combined with high pressure gas quenching has come to dominate the heat treating of high-volume automotive transmission gears. The reasons are simple: minimized distortion and highly controllable case depth. But today, those processes are becoming even more efficient, automated and controllable, and they're beginning to move out of the heat treat department and directly into the production line via a concept known as single piece flow.

"While case hardening with LPC has been around for several years, the ability to process parts one at a time in extremely consistent environments is relatively new," says Maciej Korecki, vice president for global vacuum technology at Seco/Warwick (represented by Seco/Vacuum in the USA). "Single piece flow is proving to be of significant interest to leading companies in aerospace, automotive, transmission, robotics and electrical drives."

Seco/Warwick has been working on the concept for about five years, and the company is scheduled to install its first production-scale equipment at a major automotive manufacturer in 2020. The company's UniCase Master system is designed for case hardening gears in a one-piece flow system. Each part is processed individually to minimize distortion and ensure repeatability.

Dennis Beauchesne, general manager of ECM USA, agrees that single-piece flow is the direction high-volume gear heat treating is moving: "We feel that single piece flow with heat treat furnaces that operate more like machine tools… will be the future of heat treating. We see large heat treat departments being replaced with heat treat systems in-line with manufacturing operations."

The concept of single piece flow is not new. The idea goes back to Henry Ford, and it's one of the central concepts in modern lean manufacturing. By eliminating the waste of moving parts back and forth, quality and efficiency improve.

While that has traditionally been a challenge with heat treating, times are changing, and today's furnace manufacturers are building systems that can be placed in-line with the machine tools.

"This has been the trend for the last 20 years from all the captive gear manufacturers, and we are starting to see it even more from tier 2 suppliers," Beauchesne says.

ECM's Nano furnace line is designed for small batch sizes, allowing for better control over case depth, core hardness and distortion. Instead of large batches, where the results vary depending upon the part's location within the batch, these systems provide much tighter control. More importantly, they're designed to be placed right in line with the CNC machine tools.

One of the most important advantages of these small-batch, inline systems is their ability to control the quality of the parts.

"Due to the ability to process gears one at a time in a static environment, distortion is being minimized, eliminating or reducing the need for post-heat treat machining," Korecki says. "Additinally, advances in technologies

The ECM ICBP Nano furnace is designed to be placed in-line like a machine tool (image courtesy of ECM-USA).

The ECM ICBP Nano furnace is capable of extremely small batch sizes and can be single-piece loaded and unloaded (image courtesy of ECM-USA).

have allowed us to precisely control the case depth. In many cases, this results in a shorter heat treating cycle and substantial time and dollar savings."

Getting heat treating in-line with gear manufacturing creates a number of advantages. One is the ability to automate the process. Instead of unloading parts from machine tools onto pallets, stacks or baskets, the parts are kept in-line and can be loaded and unloaded via conveyors, robots and automatic grippers. The parts never have to leave the production line, nor do they have to be manually loaded or unloaded.

"Automation is important," Korecki says. "Gear manufacturers are requiring heat treating equipment to be automated so there is less chance for human error."

In addition, automation helps combat the skilled labor shortage so many manufacturers face.

"ECM has now developed a robotics team to work along with our heat treat furnaces to bring the systems into a new level of ease for loading and unloading," Beauchesne says.

Another advantage is the level of information available on each individual part, from design all the way through testing. In today's Industry 4.0 world, that level of information is extremely important.

"Gear manufacturers are producing more requirements that link the furnace manufacturers with not only heat treat specifications, but also distortion results as part of the heat treat specifications.

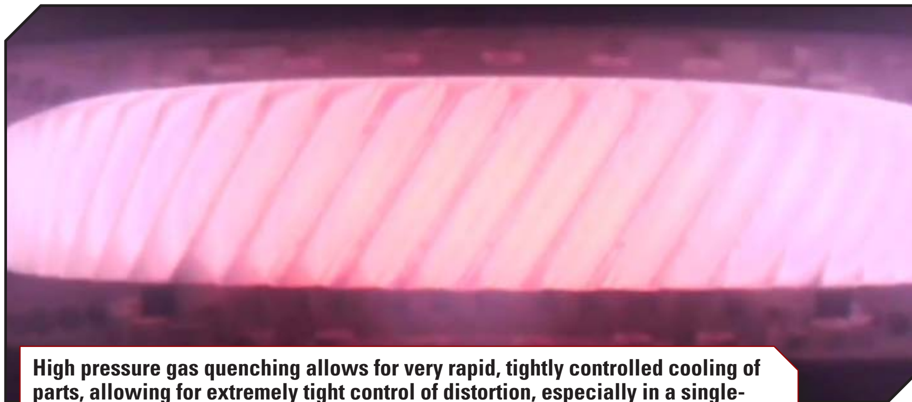
Beauchesne says. "Industry 4.0 has played a role in how furnace companies are looking into the future by using interfaces with the system that can predict maintenance and potential downtime to the system before it happens.

Beyond that, Beauchesne says, the in-line heat treating also introduces

the possibility of in-line testing and validation.

Korecki also sees testing as an important element of in-line heat treating. "Companies would rather validate the heat treating process in-line than have parts taken off-line for testing. More importantly, more and more manufacturers are requesting single-part monitoring and reporting. Every gear needs to be 100% accurate."

Flexibility is another benefit to in-line, single-piece heat treating. Manufacturers want to be able to process a variety of parts – with varying sizes and varying case depth requirements – without having to make major changes to the equipment.



High pressure gas quenching allows for very rapid, tightly controlled cooling of parts, allowing for extremely tight control of distortion, especially in a single-piece flow environment (image courtesy of Seco/Vacuum).

Finally, protecting the environment is a major concern. Today's low-pressure carburizing, high-pressure gas quenching systems are much cleaner than older systems that relied on quenching in oil. Also, because they can easily be turned off and on, and because they use much smaller batches, there is much less energy wasted.

All things considered, the trend toward heat treating with single-piece flow seems likely to continue and improve, says Korecki. "The days of batch processing are numbered in the gear industry because every gear counts."

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Trends in Induction Hardening

An Interview with Dr. Valery Rudnev, FASM, IFHTSE Fellow, Director of Science & Technology at Inductoheat, Inc.

Randy Stott, Managing Editor

We sat down recently with "Professor Induction," otherwise known as Dr. Valery Rudnev of Inductoheat, to discuss trends in heat treating 2019.

Q: What heat treating technologies are helping gear manufacturers address the need for quieter gears?

A: There are numerous factors impacting noise characteristics of gears. Besides gear design, tooth profile, materials specification, etc., manufacturing of quieter gears is directly related to a minimization of a gear distortion after heat treating. However, in my opinion, what is EQUALLY important is the repeatability/consistency of the heat treatment results. Due to obvious reasons and based on the physics of the heat treatment process, there will always be a distortion (to different degree though) after heat treatment (phase transformations associated with heat treatment is one of the reasons for that). A repeatable distortion can be compensated at previous operation steps of the manufacturing chain. There is a technical terms used in heat treat community - Distortion Engineering or Distortion Management. The term of Distortion Engineering was originally proposed by Professor Peter Mayr from University of Bremen, Germany. Distortion Engineering requires the consideration of all process stages of the manufacturing chain in order to ensure a geometrical accuracy of the final product. If for whatever reason, it is inevitable to have size and shape distortion of gears after heat treatment, then an entire manufacturing chain should be analyzed and the most appropriate manufacturing step(s) should be selected to compensate for size and shape distortion of gears, racks with teeth, sprockets and other gear-like components after heat treatment.

Q: What are the newest advances in induction heat treating?

A: New technologies appear quite regularly. In the induction heat treatment area, technologies that probably made the most noticeable impact over the last decade were associated with the appearance of new semiconductors and developing novel medium- and high-frequency power supplies, as well as sophisticated high-speed monitoring and control systems. Advances in the design of tooling and fixtures have also made pronounced impact.

Q: How have changes in gear manufacturing technologies altered the heat treating requirements in recent years?

A: Induction heat treatment "does not like" sharp corners and sharp edges and other geometrical discontinuities and irregularities. It is beneficial to have appropriate radiuses to avoid an excessive local heat generation within edge areas of the teeth. Therefore, gear manufacturing must take those features of electromagnetic induction into consideration. It is also important to have a sufficiently "friendly" prior microstructure (structure of parent material) when induction hardening gears and gear-like components. It is highly desirable to use sufficiently homogeneous (both chemically and structurally without excessive segregation and severe banding) prior structures in applications where rapid induction heating is used. This will help to improve a consistency of induction heat treatment.

One of the goals of induction heat treating for gears is developing highly repeatable, consistent results, so that distortion can be predicted and managed throughout the manufacturing process (image courtesy of Inductoheat).

Q: How can gear manufacturers learn more?

A: A good place to start is the upcoming book, "Advances in Gear Design and Manufacture", by Dr. Stephen Radzevich. I contributed Chapter 10 of this book, and it's called "Induction Heat Treatment of Gears and Gear-like Components."

Editor's note: The book will be available in June, but you can pre-order it now from CRC press: www.crcpress.com/Advances-in-Gear-Design-and-Manufacture/Radzevich/p/book/9781138484733

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Gear Nitriding 2019

A Conversation with Sabine Kreuzmayr of Rübig

Randy Stott, Managing Editor

Both gas nitriding and ion/plasma nitriding are important heat treating technologies for gear manufacturing, so we sat down with Sabine Kreuzmayr, Sales Manager for industrial furnaces at Rübig GmbH & Co.

Q: What types of gear parts are best suited for ion/plasma nitriding?

A: Here are just a few examples from all kinds of gears and industries which are currently nitrided in our furnaces in series (either in our heat treat shops or at our customers in-house):

- Disc carriers of dual-clutch transmissions
- Ring gears for wind industry (up to 2 m/6.5 feet in diameter!)
- Crankshafts for automotive, racing as well as aerospace, as well as their forging dies
- Main shafts for automotive
- and many more...

Q: What are the main reasons for nitriding (either conventional or ion/plasma)?

A: For either conventional nitriding or ion/plasma nitriding, manufacturers can expect to require fewer production steps after hardening. Case hardening/carburizing processes generally take place at a much higher temperature than nitriding, which requires only 850–1,200°F. Consequently, nitriding causes less distortion, which means fewer machining steps after hardening.

With ion/plasma nitriding, you have the additional benefits of easier masking and environmental friendliness. During other heat treating processes (such as carburizing or even gas nitriding), masking requires time consuming applying of pastes (mostly copper pastes),

Rübig's Mircopuls Everest system is designed for plasma nitriding gears, shafts, bearings and similar parts (image courtesy of Rübig) which need to be removed afterwards again, mostly mechanically and again time consuming. Masking in ion/plasma can be done by a mechanically made sleeve/cover. In addition, ion/plasma nitriding does not require the use of ammonia, nor does it involve the use of open flames in the production environment, which increases work safety. In addition it provides for a better ecological footprint, as well as easier compliance with local regulations concerning toxic gases.

Q: How widespread is nitriding?

A: Conventional gas nitriding or ferritic nitrocarburizing is already very popular and used in many industries. Ion/plasma nitriding is the latest nitriding technology and not nearly as prominent.

What we experience is that the trend further moves into the direction of ion/plasma nitriding. The combination of lower tolerances, new materials and more severe regulations in terms of environmental friendliness will force manufacturers to find alternatives to carburizing and gas nitriding.

Q: What are the latest trends?

A: Talking about 4.0, everybody is talking about something different. For us as a machine builder we see a network of smart dat**a:** Learning out of data, simulations, joined-up machines, usage of augmented reality in daily business (one answer for skills shortage).

Robotic loading, remote maintenance, or conformity to all kinds of aerospace or automotive norms are standard for us.

Q: What should gear DESIGNERS be thinking about with regard to heat treatment?

A: People as creatures of habit tend to stick to long-standing technologies—also designers. What we experience is that the latest heat treat technologies are most of the times not known to designers. To avoid mistakes, they stay with processes they know.

Heat treaters (not only commercial, but also captive) are under highest pressure, as all unplanned changes, mistakes and stresses, which could not be determined before heat treatment, will be visible AFTER heat treatment! Knowledge about less-distorting processes would help!

By the way, this is one reason why we also offer heat treatment training for designers. It's an urgent need.

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The Quick-Change Advantage

Workholding Systems Continue to Focus on Speed and Efficiency to Improve Machining Operations

Matthew Jaster, Senior Editor

Sensors, robotics, mechatronics, and digitalization are helping machine tools excel at repeatability, precision, efficiency and speed in 2019. While there are several factors for this, quick-change workholding is one area that continues to advance and make manufacturing gears easier for operators on the shop floor.

The very definition of "quick-change" in gear manufacturing has evolved through the years.

"Initially what Gleason and others in the industry referred to as quick-change workholding still required some manual interaction to install and remove the workholding. An Allen wrench, for example, was used to remove mounting bolts, set screws and ejector screws. The latest quick-change systems offered by Gleason are more modular and can be installed and removed quickly with the limited use of tools," said Tim Zenoski, director global product management-workholding at Gleason Corporation.

Sandvik Coromant introduced Coromant Capto back in 1990 and the coupling has never changed, according to Brent Godfrey, product specialist, machine integration at Sandvik Coromant. "However, more and more tools with the Coromant Capto coupling have been introduced over the years and other quick-change systems have come and gone over that period of time."

For Emuge, the company generally offers a custom design for a specific run of workpieces, and/or workpiece families where interchangeability is one of the keys to a successful and profitable operation.

"The real evolution is the fact end users are recognizing the bigger advantages of a custom quick-change system which is generally more expensive than an off-the-shelf quick-change workholding system," said David E. Jones, precision workholding manager at Emuge Corp. "Initially quick-change devices were being used by customers who have part families where parts have similar geometries, and similar machining operations. Now, however, we are seeing some of these part family quick-change connections staying on the spindle after the initial program has finalized. In this scenario, quick-change is used on the next program, regardless if there is a part family or not. The end user can quickly change out a workholding device for any reason at any time."

Smart Developments

It's a strange, new world on the shop floor—one that involves automation cells, robotics and a push for the factory of the future. This makes the equipment as dynamic as ever and a steep learning curve for machine operators as the technology changes. We asked our experts to discuss, for example, how Industry 4.0/IIoT and automation are making workholding products smarter.

"Automation is growing in the metal cutting industry," said Godfrey. "Quick-change tooling has to be adaptable to work with robots and unmanned cells."

Zenoski said that many of today's workholding customers want the ability to track critical data. Incorporating Industry 4.0/IIoT into quick-change systems is the next step.

"The use of RFID chips, for example, can allow the customer the ability to determine how many times the workholding has cycled. Knowing this can help the customer to determine when preventive maintenance is required. It also can trigger reorder points for wear parts such as collets," said Zenoski.

Sandvik Coromant is starting to introduce some sensor-based tools that can send helpful information to the user.

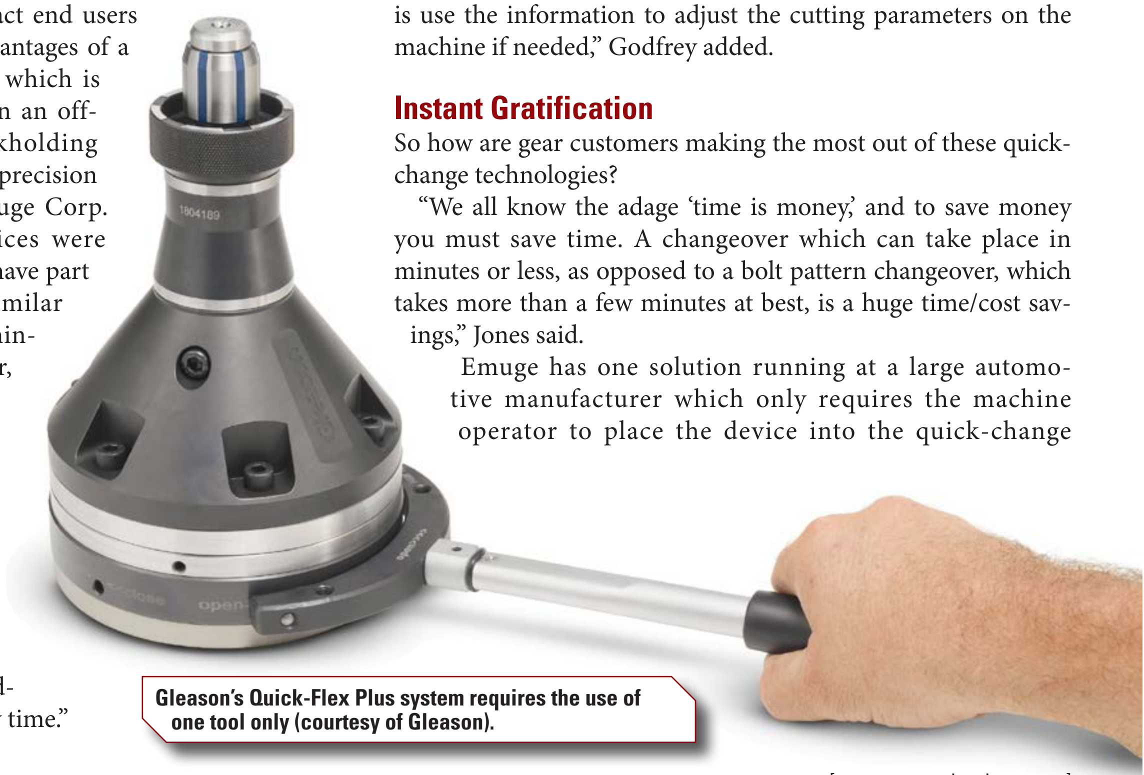
"We recently introduced a product called Silent Tools Plus which includes a program of long dampened boring bars that have sensors that measure things like temperature and vibrations and they have a Bluetooth connection to an application on a tablet outside of the machine. One thing the user can do is use the information to adjust the cutting parameters on the machine if needed," Godfrey added.

Instant Gratification

So how are gear customers making the most out of these quick-change technologies?

"We all know the adage 'time is money,' and to save money you must save time. A changeover which can take place in minutes or less, as opposed to a bolt pattern changeover, which takes more than a few minutes at best, is a huge time/cost savings," Jones said.

Emuge has one solution running at a large automotive manufacturer which only requires the machine operator to place the device into the quick-change



Gleason's Quick-Flex Plus system requires the use of one tool only (courtesy of Gleason).

Machine side of an Emuge Quick Change shaving arbor with a male bayonet feed through feature.

machine adaptor, give the device a quarter turn, and then hit a button on the machine controller, at which time the device is pulled back into the tapered spindle.

"This type of change is done in a mere fraction of the time it would take for a typical bolt-on device or say a conventional bayonet style of connection. The design is a quick-change without any additional tooling or support tooling required. Not a wrench in sight!" Jones added.

Godfrey at Sandvik suggests two good ways to maximize the performance of the quick-change tooling.

"One is using *redundant tools* meaning for each tool on the turret you have a *new* version of it sitting next to the machine preset and ready to go. When the insert wears out and needs to be indexed, unclamp the tool and take the redundant tool and clamp it and start the machine again. Index the insert outside of the machine," Godfrey said. "The second way is to *kit* the tooling for the different jobs that run on the machine. Each time a new program is called up the tooling for it can be on cart somewhere near the machine."

For gear applications, Godfrey said that since most gears have internal and external turning operations done prior to tooth cutting, all the turning operations can utilize quick-change-tooling.

The speed and ease of changeover when utilizing these systems can eliminate the need for skilled machine operators and toolmakers, which in this industry are becoming harder to find.

Mating tailstock side of an Emuge Quick Change shaving arbor with female bayonet feed through feature.

Zenoski said that the single biggest advantage of quick-change setup for machine tools is increased spindle run time. Traditional workholding set up and changeover can take 30 minutes or more, depending on the application. Toolless quick-change setup and changes over from one workpiece to the next can be done in a matter of seconds. The benefits to a company that runs small batch lots can be an hour or more of increased spindle run time per day.

Sandvik Coromant introduced a product called Silent Tools Plus which includes a program of long dampened boring bars that have sensors that measure things like temperature and vibrations (courtesy of Sandvik Coromant).

"Several years ago Gleason developed a quick-change system called Quik-Flex Plus which requires the use of one tool only. The base for this system is made in several different sizes to allow Quik-Flex Plus to be used on all of the cylindrical machines produced by Gleason. It's also sufficiently universal to be used on other gear manufacturers' machines. Once the base is mounted to the machine spindle the part clamping module is mounted to the base with just the turn of a handle. The changeover process from one workholding module to another can be done in 30 seconds or less with radial/axial repeatability of .0002" (5 microns) or less," Zenoksi added.

For Gleason's bevel workholding product line, the company has also incorporated a stir-ability feature into its modular workholding to allow a customer to be able to reduce fixture runout to as close to zero as possible.

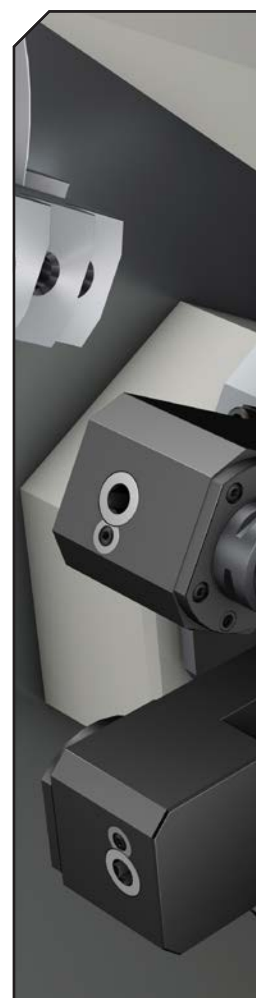
Keeping the Customer Informed and Educated

Repeat business is the end game in gear manufacturing. The effort needed to meet quality demands and lead times tend to keep operation managers up at night. Therefore, sales and service departments work to ensure training and customer support is emphasized regularly.

"Gleason has a global network of sales and service in most regions of the world. Workholding is designed and manufactured in four strategic locations worldwide. Aside from quality, lead time is the main driver in gaining and maintaining repeat business. Gleason offers wear part stocking programs for many customers throughout the industry. This reduces customers' lead time to get critical replacement parts such as collets and springs, from weeks to days in many cases," Zenoski said.

Preventive maintenance is the key to the life and quality of these systems.

"Periodic disassembly, cleaning and re-lubrication of workholding can add years to the life of the fixture," he added. "Gleason has work instructions and offers training classes for the troubleshooting and maintaining workholding. Incorporating smart technology (RFID chips) into workholding to register chuck cycle counts can help the customer to understand when preventive maintenance is required."



Sandvik's customers are more successful running the tools in the machine when they really know how to use them.

"We place a large emphasis on services that help our customers. For example, for our Coromant Capto driven tooling we have a repair program. And troubleshooting is done on a daily basis by our sales engineers and specialists," Godfrey said.

According to Jones, communication is extremely crucial to long-term success.

"Whether application feedback is a best or worst scenario, it is absolutely necessary to provide customers all details in a timely manner because they have a job to do, and schedules to keep. With every order of a new workholding device, we supply a handbook which has specific directions on how to exchange any wear or part touching details, and maintenance instructions.

Additionally, Emuge prefers having personnel available on-site for any first time use of a new design, or when they have a new customer. It's important to be immediately available in the event a problem occurs, and also to be present for any guidance or initial questions regarding the tooling, its mounting, or operation etc.

"As for preventative maintenance, every workpiece and environment is different, and sometimes the environmental issues dictate preventative maintenance timetables," Jones said. "One example when more maintenance is required would be a hostile environment resulting in workpieces that have inconsistent clamping tolerances as compared with a very clean environment, where the workpieces always get presented to the workholding device within consistent tolerances."

What Comes Next?

Workholding will continue to evolve with the changing systems inside machine tools. The future promises more automation, more information and emerging technologies incorporated into the equipment.

"One increasing trend is automatic clamping and unclamping. We offer hydraulic Capto clamping units and spindles that are integrated in the machines and the cutting tools use the machines' ATC function. Also, as machines evolve and can do more operations quick-change tooling needs to be adapted where it can be beneficial," Godfrey said.

In the future it will become more common for modular workholding to be installed and removed utilizing the function of the machine spindle.

"Basically the operator would put the workholding in the spindle and push an install button on the controller. This is currently a feature that Gleason offers on Phoenix 280G Bevel Grinding Machines. The next evolution of modular

Sandvik Coromant quick-change turret.

workholding is for the fixtures to be loaded and unloaded utilizing an automatic tool changer," Zenoski said.

Zenoksi added that numerous factors will play into making workholding more efficient in the future, including: Industry 4.0, new materials, advancement in heat treatment processes, 3D printing technologies, and life cycle testing for workholding components and assemblies.

But before focusing on the future, Jones at Emuge believes it's important to understand the significance of quick-change systems today.

"Quick-change systems have already made workholding more efficient, and it doesn't matter if they are being used with short run workpieces and part families, or being used in a dedicated run for years," Jones said. "Anytime you can make job changeovers quickly, on the same machine with minimal impact on time and production, it's a win."

The single biggest advantage of quick-change setup for machine tools is increased spindle run time (courtesy of Gleason).

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Loading Upgrades

The latest advances in gear manufacturing automation all seem to revolve around a common theme: automated loading.

Alex Cannella, Associate Editor

Automation plays an ever-increasingly important role in gear manufacturing, and right now, the area of manufacturing that has people's attention is the loading process. A big part of automation's appeal is reducing manufacturing downtime, and one of the biggest parts of reducing downtime is minimizing setup time as much as possible, so perhaps it doesn't come as much of a surprise that this is still a primary focus for the field.

But even so, the incentives and challenges can differ from company to company. Klingelnberg, for example, has been following trends in the automotive industry, and they've seen that component demands are getting more varied. Gear manufacturers in the automotive industry are expected to be able to work with an ever-wider array of workpieces. That translates to more small lot production and a lot more setup time as Klingelnberg's customers constantly change up what they're making.

EMAG, for their part, has been continuing to expand their existing Trackmotion system, focusing on integrating more and more of their machines into the automated system. Instead of expanding the types of workpieces or the workholding, EMAG is expanding the list of gear manufacturing processes their equipment can automatically load a part for.

Gleason, meanwhile, has been working on the support side of the equation. They've been spending their time error-proofing the automated loading process with a number of smaller new technologies, improving part identification and integrating secondary operations into the automation process. Smaller backend advances like these may not be glamorous or eyecatching, but their usefulness in preventing potential production halts and eliminating user error can't be understated.

Automated loading is but one of many ways automation can reduce setup time and improve productivity, but it's being actively focused on by numerous manufacturers (Photo courtesy of Gleason).

All three of these companies are tackling different issues in the field of automation in completely different ways, so let's take a look at each one in a little more detail.

Widening Scope

The automotive industry is a-changin'. Electronic transmissions are growing in popularity, which means fewer gears per transmission, but also more demanding specifications and an increased emphasis on craft. Components are becoming more specialized, and as the people at Klingelnberg are starting to notice, more varied. And when manufacturers have to constantly stop and start their production lines to set up new runs of multiple different parts instead of churning out the same workpiece all day, we need to have solutions as flexible as the industry's demands.

Klingelnberg's most recent answer to the issue? Two flavors of conveyor-based automated part loading: a shuttle system for bevel gear machining, and a swivel loader for cylindrical gear grinding.

The first of these two solutions, the shuttle loading system, is designed for working with bevel gear cutters and grinding machines. This one was developed for use with the G 30 and C 30, machines built by Oerlikon, one of several companies that make up the Klingelnberg Group.

"The shuttle principle follows the idea of a pick-up solution but without compromising travel ways or speeds of the machine axis," Dr. Hartmuth Müller, head of technology and innovation at Klingelnberg, said.

The other solution, the swivel loader, is designed for cylindrical gear grinding and specifically installed in Klingelnberg's Speed Viper machines. It first uses a robotic arm to take a workpiece off the conveyor, then transfers the component to the machine's internal swivel loader, which then installs the piece on the work spindle. One machine, the Speed Viper^2 80, even has two independent work spindles, allowing the machine to grind one workpiece while loading the next.

Both of Klingelnberg's solutions are squarely targeted at small batch production. According to Müller, using their autoloading processes gives a technician

30–60 extra minutes to walk away and work on something else. And, as Müller noted, both solutions do so without any oil getting out of the machine and into the auto-loading system.

Joining the Family

On the opposite side of the spectrum, we've got EMAG continuing to expand their Trackmotion system. Trackmotion itself has been around for a few years now, so we can't really say the technology itself is breaking new ground, but bringing tried and true technology into new fields is just as useful.

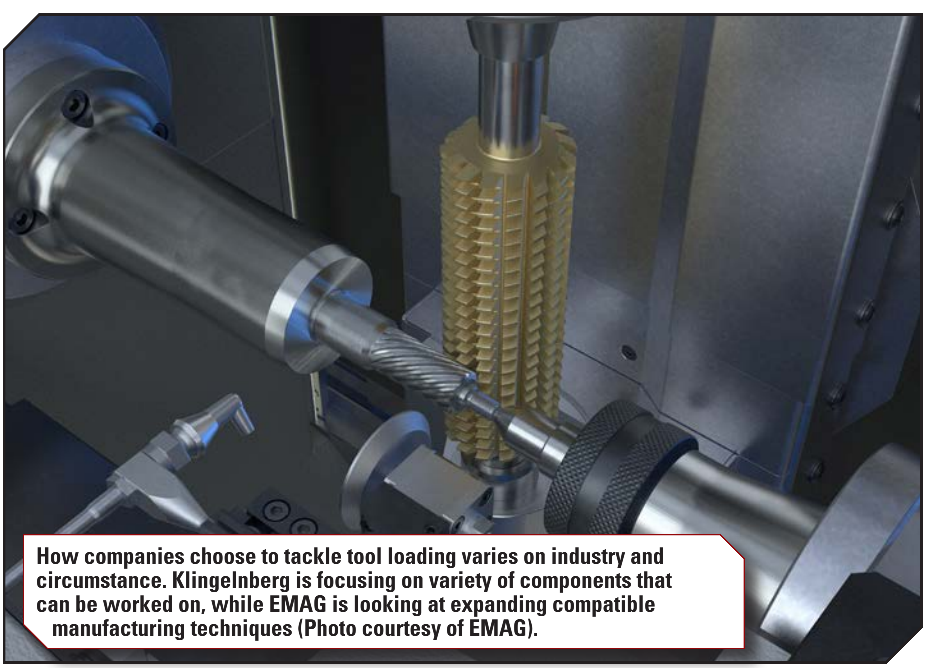
"EMAG has historically always provided our machines with the concept of being self-loading… This has always been part of EMAG's dna," Kirk Stewart, vice president of sales at EMAG, said.

Latest on EMAG's docket to add Trackmotion to is the HLC 150 H, a self-loading horizontal gear cutter that Stewart refers to as EMAG's "all-rounder." Much like with Klingelnberg's latest technology advances, the HLC 150 H is capable of tackling a wide range of components, handling dimensions up to 20" in length and 1–6" in diameter. It works with straight, angled, and worm gear profiles and performs hobbing, worm milling, skiving, chamfer cutting and deburring.

Beyond its wide-ranging applicability, there are two things notable about HLC 150 H. One is the Trackmotion system integration its gained. Trackmotion is EMAG's primary automation system, a low profile gantry set behind the cell that takes components from machine to machine, then auto-loads them. The idea is that if you have a full suite of EMAG machinery, you can set a Trackmotion system up to turn them all into one compact assembly line that automatically handles a part from start to finish.. And with the HLC 150 H's wide array of gear tooth cutting processes, that start-to-finish process chain can almost be done with just one supplier. This piece of the puzzle helps fulfill EMAG's mission of "providing the best manufacturing systems for precision metal components."

The HLC 150 H's other notable trait is its adoption of Fanuc controls. EMAG's usual in-house controller is more adapted specifically for gear hobbing, but in keeping with the machine's focus as an all-rounder, EMAG opted to utilize Fanuc controls that are used by a wider market. That's not to be mistaken as a shift towards making the HLC 150 H more of a multitasking machine, however — it's still firmly focused on gear manufacturing — but the broader market this machine targets is already more familiar and comfortable with Fanuc's controls.

"The conventional control…is rather specific to gear hobbing, which serves many customers very, very well," Stewart said. "But for larger users, there is some hesitation to use that niche solution. So ultimately, it's going after the much broader customer base which is already using, very comfortabl with, and very familiar with the Fanuc control."



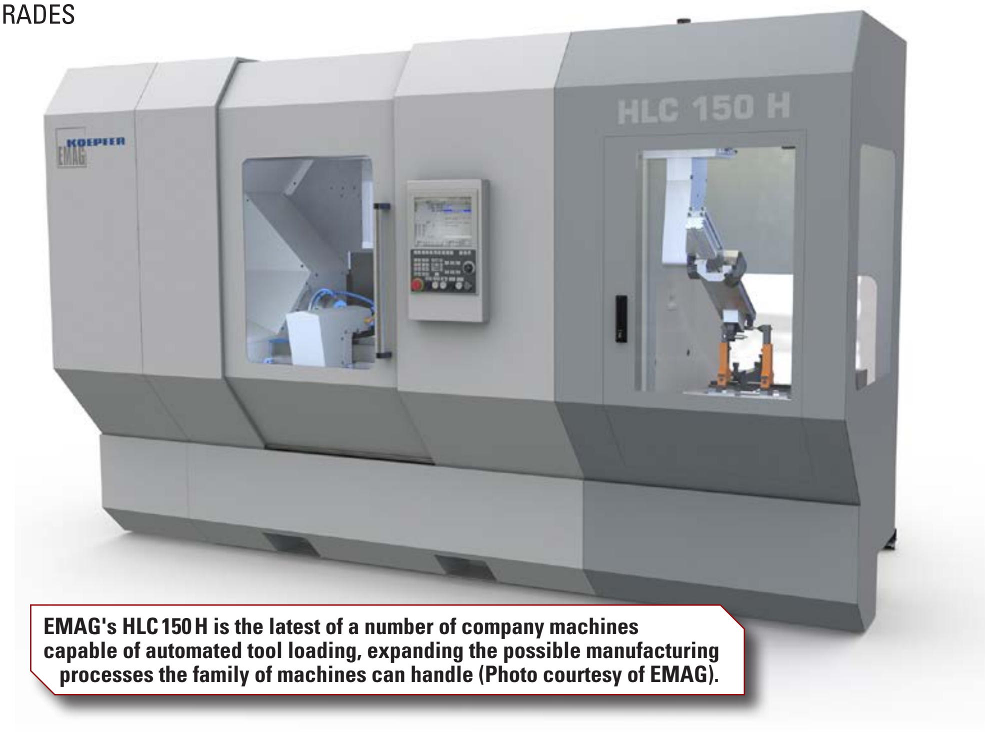
How companies choose to tackle tool loading varies on industry and circumstance. Klingelnberg is focusing on variety of components that can be worked on, while EMAG is looking at expanding compatible manufacturing techniques (Photo courtesy of EMAG).

Error-Proof End of Arm Tooling

Eliminating errors is one way that companies can control costs and compete in the global market. Incorporating error elimination into products is one way that Gleason is meeting this challenge. Gleason has found that reliability is one of the strong selling points for automation and is incorporating error proofing into their machine tool tending automation.

When part identification is critical, Gleason uses a system that combines a camera and an illumination LED to verify that the correct part is being processed and that the part is oriented correctly. If the part is not oriented correctly an automated part flip process is employed to orient the part correctly. "This allows our customers to operate with complete confidence," said Christian Sterner, chief engineer at Gleason Automation Systems.

Sterner relates that, "Using smart grippers is another way we eliminate human error by verifying that the correct gripper fingers are installed before production begins."



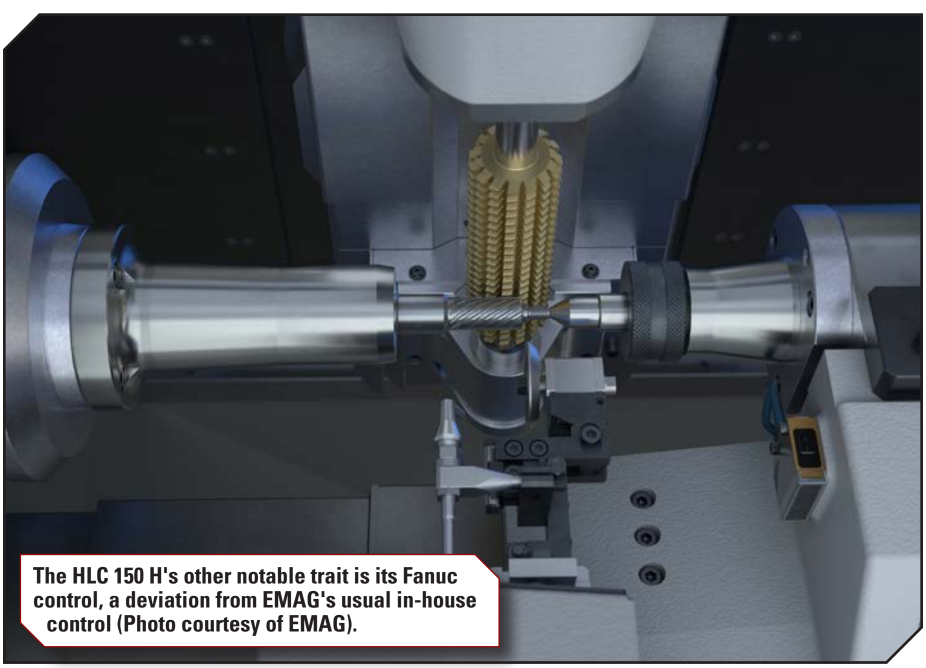
EMAG's HLC 150 H is the latest of a number of company machines capable of automated tool loading, expanding the possible manufacturing processes the family of machines can handle (Photo courtesy of EMAG).

This technology reduces costly halts in production due to mismatches between the part being processed and the gripper fingers that are being used. To reduce the time it takes to change the EOAT for a new part run and eliminate the potential for damage to tooling as well as ensure the certainty of repeated setups, Sterner recommends using Gleason's quick-change EOAT that automatically changes one complete EOAT for another. All mechanical, electrical and pneumatic connections are disconnected from one EOAT and then connected to another EOAT, in an automated process with the disconnected EOAT held in storage for future use.

"We have many proven solutions for our customers," Sterner said, "but when they present us with a unique set of requirements, we step up to the plate to create an innovative, cost-effective, solution."

One area that Gleason has focused on is the integration of secondary operations into the machine tool tending automation. Sterner emphasized, "We integrate test and verification solutions into the automation to ensure that all of the customer's parts are good and when necessary, we halt production before the process goes on uncontrolled."

Other secondary operations that Gleason has incorporated into the automation include rust prevention that is added to protect parts from corrosion and part marking which is used by some customers to identify critical information such as which cell manufactured a part for traceability when machining errors occur. "This value-added focus is what sets Gleason apart from our competition", said Sterner, "It's one of our strengths."



The HLC 150 H's other notable trait is its Fanuc control, a deviation from EMAG's usual in-house control (Photo courtesy of EMAG).

What Is It Good For?

The benefits of automated loading are the same as for other automated processes: improved setup time, reduced risk of user error, and the ability to walk away and just let the machine work for an extended period of time. Automated machines work faster and, for better or worse, don't ever deviate from their programming, making them also more consistent. It's just one of a hundred different ways that a manufacturer can reduce setup time and improve efficiency.

But people are always on the lookout for ways to do exactly that, and automation companies will always continue to expand what can be automated, be it an expansion of the components you can automatically produce, the methods you can use automation with, or the number of machine products you can apply automation to. And that trend shows no signs of ever slowing down.

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Automation to Lighten Your Load

New turnkey, 'off-the-shelf' Gleason 2700AR system automates larger-gear load/unload to speed throughput, optimize process flow — and take the weight off the operator.

Christian Sterner, Chief Engineer, Gleason Automation Systems

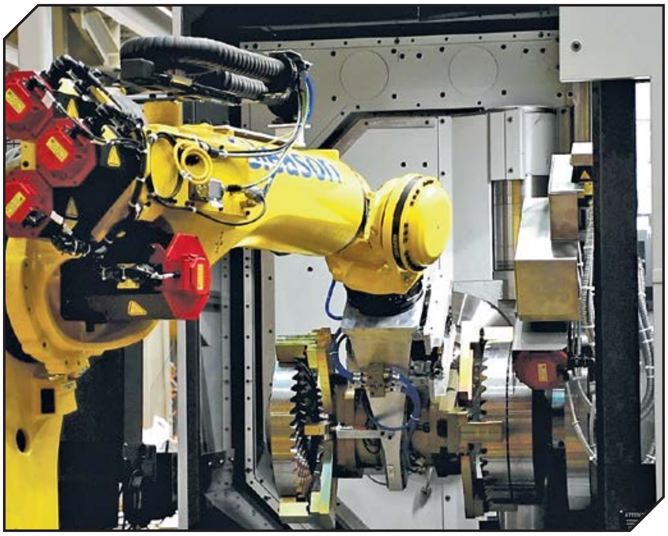
For many gear manufacturers today, small batch sizes and frequent part changeovers are the rule rather than the exception. For large part producers, manually handling workpieces is particularly burdensome. Finding a fast, economical and reliable solution to automate this operation has never been more critical.

A New 'Standard' for Large-Parts Automation. With a product portfolio that spans the complete range of gear solutions, Gleason has been keenly aware of the challenges that exist for manufacturers of all types of gears. At Gleason Automation Systems, we've worked hard to develop a turnkey load/unload automation solution that can be seamlessly, and economically, integrated with both Gleason, and non-Gleason, bevel and cylindrical gear machines producing parts weighing upwards of 150 kg . In the new 2700AR loader, we've achieved that objective. Now, for the first time, an automation system exists that uses standard, off-the-shelf components to automate the handling of larger workpieces.

Benefits of the 2700AR to the customer are truly significant. A labor-intensive process that would typically take the operator three or four minutes to perform, even with the assistance of an overhead crane, can now be completed in just 30 to 40 seconds using the 2700AR. The potential for human error resulting in product damage or misidentification of parts is eliminated, along with the possibility of operator injury that always exists when manually handling large parts. Now, the operator can be available for other tasks, while the 2700AR does all the heavy lifting.

Exceptional 'Plug and Play' Performance. In the past, achieving this automated capability would have required a customized solution only available to the customer at prohibitive cost. Now, through a combination of readily available robot and vision system components and Gleason Automation Systems 'know-how', the 2700AR is available as a 'plug-and-play' solution with truly remarkable capabilities. Here's how it works, in a typical large bevel gear cutting machine cell application:

Large-part blanks arrive at the machine on wooden pallets or plastic dunnage trays. Prior to picking up a gear blank a FANUC 6-axis robot uses FANUC 3DL Vision Guidance, consisting of camera and laser, to identify the part and establish its position and orientation. In this application, there are 14 possible parts, making accurate part identification critical. There is always the risk with customer dunnage that parts will arrive in a less than ideal arrangement, or even upside down. This system ensures that the robot can identify what part is being picked up, as well as being able to accurately grip the part to ensure proper orientation before loading it into the machine tool. If the system determines that the part is upside down, the part will be transported to a fixture where it can be placed and then re-gripped before transport to the machine tool in the correct orientation.



The end-of–arm tooling consists of multiple grippers. Each gripper has three Gleason-designed gripper fingers which apply frictional forces to grip the part firmly and accurately. The gripper fingers accommodate a wide range of parts, saving changeover time. When necessary, the gripper fingers can easily be replaced.

If plastic trays are used for the dunnage, when they become empty the robot gripper fingers pick and move them to the dunnage storage area. If plywood dividers are used instead, a special end of arm tooling is used that employs a vacuum head to pick the plywood divider sheets from the dunnage and store them in the dunnage storage area.

When the uncut blank is ready for transport to the machine tool, a network connecting the robot PLC and the machine CNC ensures that the robot/machine dialogue is intelligent. For example, the robot can tell the machine that it's ready to load a particular part number, rather than just a part. The machine tool can then determine if this particular part matches the summary that it has prepared to run for that part. This greatly reduces the risk of time-wasting, scrap-producing errors.

The robot is equipped with multiple grippers for unloading and loading the machine tool. This allows the robot to unload a finished part with one gripper, swivel around and load a raw part with a second gripper, thus improving productivity. In addition, the robot can be used to transport parts to and from other secondary, post-machining operations, including part marking, part gauging, the application of rust preventative solutions and more.

For additional information on the new Gleason 2700AR, and the complete array of Gleason Automation Solutions, visit:
www.gleason.com/automation

Contact Christian Sterner at: *csterner@gleason.com*.

Fluid Fundamentals

PSP Peugeot Improves Production Process with Blaser Swisslube

Matthew Jaster, Senior Editor

In a recent move to boost manufacturing production, PSP Peugeot changed a few things in their production facility. They purchased two new cutting machines and upgraded the material needed to manufacture the "poire" or "pear" (pepper mills you'd find in restaurants, for example) with S250 stainless steel.

Production managers also reached out to Blaser Swisslube to discuss how the company's Liquid Tool could add additional benefits to the manufacturing process. The poire is ground via gear hobbing, a demanding machining process where cycle time and tool life are vital to productivity and machining efficiency. The Liquid Tool by Blaser Swisslube helped PSP Peugeot improve their production process considerably by saving tool costs, omitting deburring and improving surface quality.

A History of Fine Craftsmanship

Those pepper and coffee mills — regarded by many as the most famous in the world — were first produced by PSP Peugeot back in the 19th century. In 1810, the Peugeot family transformed their father's grain mill into a steel foundry. By 1840, the first coffee grinder was created, followed by the first pepper mill as a table model in 1874 (The Z-Model).

In 1889, the rapid development of the organization would include the production of scissors, saws, clock springs, planing knives and automobiles. For decades, the company would be renowned for the quality, longevity and craftsmanship of its products and technologies.

Currently, the plant located in Quingey, France (with 130 employees), produces roughly 2 million pepper and salt mills annually in over 80 countries worldwide.

High Quality Cutting and Grinding Fluids

Blaser Swisslube is a globally active company in the metalworking fluid sector. The independent and family-owned Swiss company was founded in 1936 and has since grown from a small business into a global player, employing around 600 people worldwide. Blaser Swisslube is represented in about 60 countries, close to its customers.

The company develops and produces high-quality cutting and grinding fluids so that its customers can produce a wide range of products, from the tiniest of components to large, critical and structural components in all manufacturing industries.

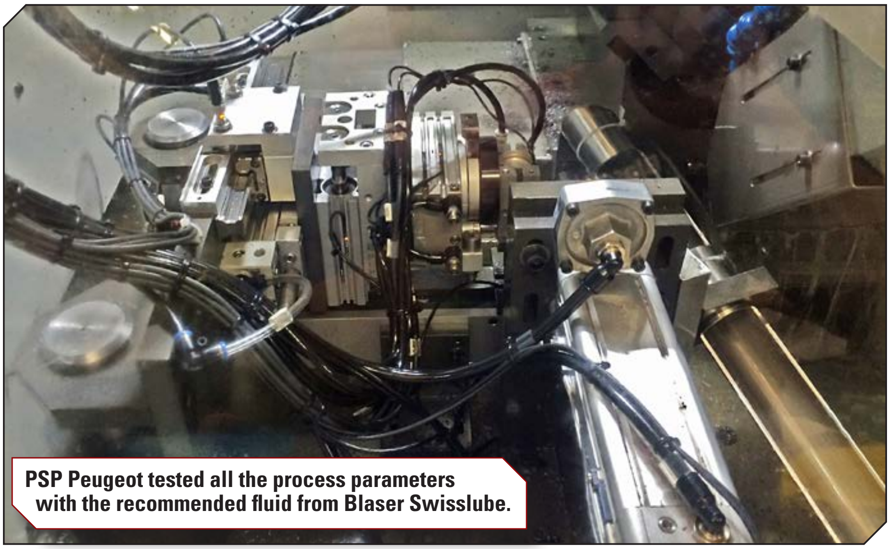
Machining Tests

Ghislain Jouffroy, methods engineer at PSP Peugeot contacted Blaser Swisslube in France. He was willing to perform machining tests with the recommended metalworking fluid Blasomill GT 22 on a Tech-Tech machine for three months. Blaser specialist Christophe Simon intensively oversaw this test phase, systematically recording all processing parameters.

The workpieces were aligned, guided, machined and then ejected by a spiral vibrator — everything was automated.

"In addition to the metalworking fluid, we also switched the milling tool from HSS to carbide," said Simon. Per machine and year, 1.2 million poires are produced during shift operation, with a cycle time of 13 seconds per pear.

The improvements thoroughly impressed PSP Peugeot. Thanks to the Blaser metalworking fluid, 90,000 instead of the previous 30,000 workpieces could be produced — reducing the tool costs by 21 percent. Additionally — because the workpieces no longer heat up during the hobbing process — no more brows are formed, making the deburring process superfluous.



PSP Peugeot tested all the process parameters with the recommended fluid from Blaser Swisslube.

"The Blasomill GT 22 releases the air very quickly, does not foam and is the perfect choice for this machining process at PSP Peugeot," said Simon. The litre price of Blasomill GT 22 is higher than that of the previous oil, but the various savings result in net savings of 25,173 euros per year.

Jouffroy was pleased with the results. "Everything is running like clockwork and we are very satisfied," he added.

The recording of these processing parameters were completed by using Blaser's online tool, Liquid Tool Analyzer.

According to Philippe Lacroix, general manager of Blaser Swisslube France, they were able to document the gained values in many different areas.

"Besides the mentioned tool cost savings, the machining time was reduced by 1 second per piece with an annual production of 1,200,000 units. This is equivalent to one month of production of one machine. In addition, coolant consumption was lowered by nine percent. All in all, the customer expectations were exceeded," Lacroix said.

A Look at Blasomill Cutting Oils

Blasomill cutting oils suit various segments and requirements. The high-pressure and wear protection performance of these products varies according to each individual application.

Blasomill GT 22 is a high performance cutting oil. It was developed specifically for machining stainless, acid- and heat-resisting steel, titanium and non-ferrous metals. It is suitable for milling, hobbing, drilling, turning, automatic turning, threading, tapping, broaching, reaming and sawing. It is also suitable for high-speed machines like Escomatic.

PSP Peugeot produces more than 2 million salt and pepper mills annually.

> **"Besides the mentioned tool cost savings, the machining time was reduced by 1 second per piece with an annual production of 1,200,000 units. This is equivalent to one month of production of one machine."**
>
> Philippe Lacroix, general manager, Blaser Swisslube France

An Evolving Collaboration

PSP Peugeot has found the right coolant partner in Blaser Swisslube. They do not want to rest on their laurels, but want to continuously optimize their processes together. Thus, for the next project, they want to jointly analyse and improve the operation of the turning lathes.

Based on the great results with Blasomill GT 22, PSP Peugeot also tested Blasers Vascomill CSF 35 for minimal quantity lubrication (MQL) — cutting punched DN40 steel. This resulted in additional tool cost savings and post processing gains.

"The engineers from the customer side have a profound understanding of their manufacturing process and can estimate what an improvement will bring to the entire production process," Lacroix said. "Our Blaser Swisslube engineers have a long-term experience in the field of manufacturing and know precisely the strengths and skills of the coolant solutions. Therefore, with the collaboration, we get the most out of the machines and tools and optimize the process verifiably."

Metalworking fluids play a significant role in many manufacturing processes. In the future, Blaser Swisslube will grow and develop products simultaneously with new machining technologies and materials.

"Blaser Swisslube will develop further to support and to achieve measurable added value to our customers and partners in the industry," Lacroix said.

For more information:

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Phone: (845) 294-3200
www.blaser.com

PSP Peugeot
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The two companies will continue to collaborate in the future to optimize cutting and tooling procedures.


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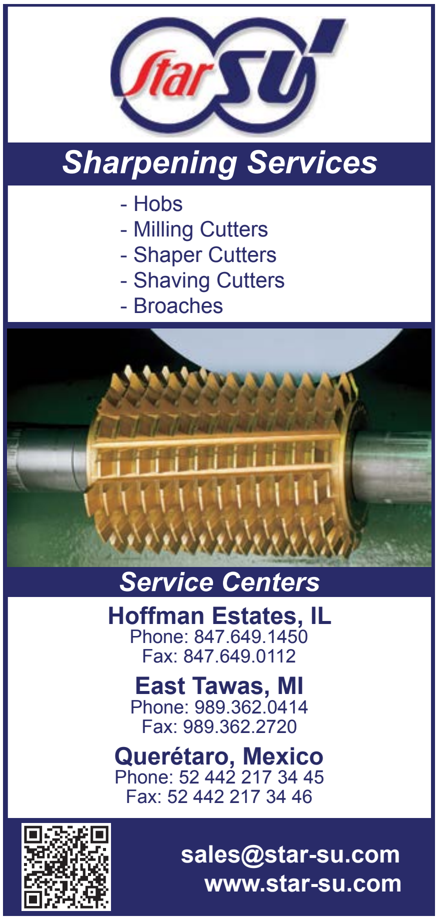
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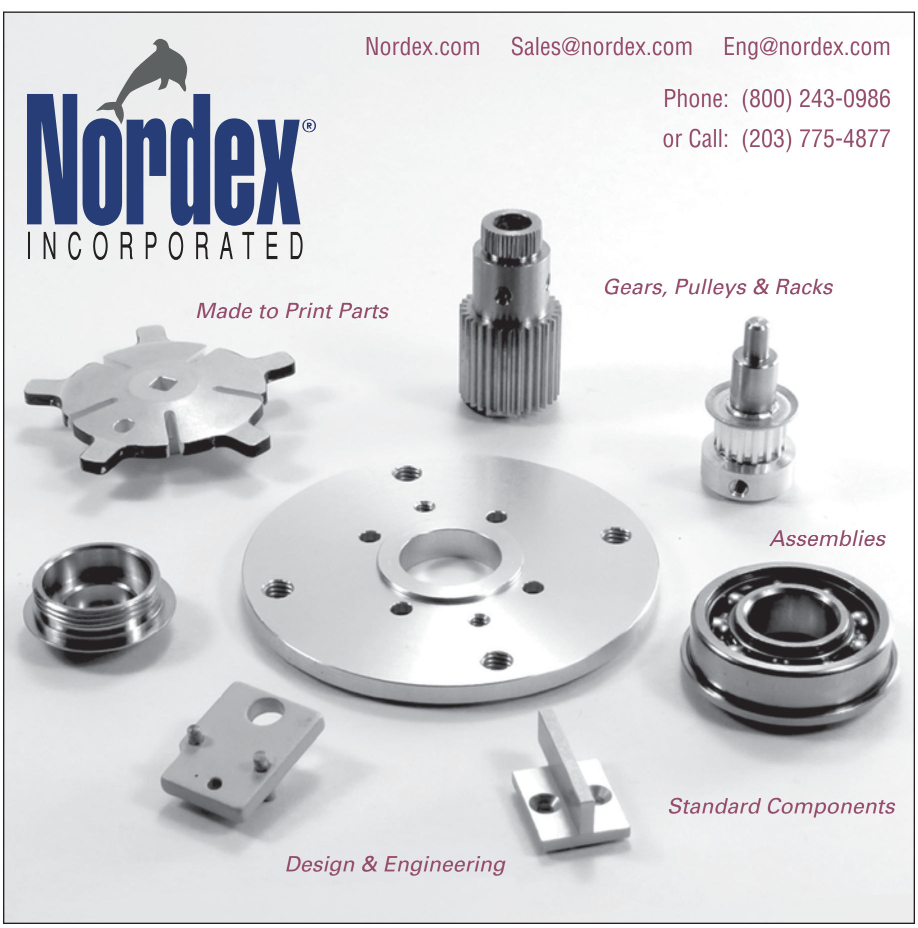
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Relationship between Misalignment and Transmission Error in Cross-Axes Helical Gear Assemblies

Email your question — along with your name, job title and company name (if you wish to remain anonymous, no problem) to: *jmcguinn@geartechnology.com*; or submit your question by visiting *geartechnology.com*.

QUESTION

I am a gear engineer for a motor manufacturer in China. I am writing about noise generated from cross-helical gear assembly error. I want to learn the relationship between the misalignment (center distance change and cross-angle shift) and transmission error. It is better under the loading and theory conditions. What is the trend of cross-helical gear development (use ZI worm and involute helical gear, point contact)?

Expert Response Provided by Dr. Hermann J. Stadtfeld. Cross-helical gears are manufactured by a generating process using a trapezoidal generating profile. In the question, the pinion is referred to as a "Z1 worm." A Z1 worm is paired with a worm gear. Although the worm has an involute profile, the worm gear pair has line contact and is not considered cross axes helical gearing. A Z1 worm gear pair is conjugate due to the fact that the worm gear is manufactured with a tool which resembles the mating worm. The following answer concentrates on cross axes helicals, where the contact and meshing conditions are quite different compared to those in worm gear drives. Figure 1 (left) shows a spur gear pair and (right) a 90° cross-axis helical gear pair.

Due to the cross-axes angle, the transverse involute profiles are in different planes and rotate about axes with different directions. In their theoretical position, the generating trapezoid can be placed between both members. As the generating element shifts, both members rotate without transmission error. This is a result of the kinematic coupling condition and not a result of the involute-based gearing law. Changes of the center distance eliminate the basis of the kinematic coupling condition, which then leads to transmission error. The larger the cross-axes angle, the larger is the transmission error caused by a center distance change. The cross-axes angle helical pair is meshing in its theoretical position like a spur gear with extremely large length crowning.

The shaft angle error will cause edge contact and transmission error in spur gears. In the case of 90° shaft angled cross-axis helical gears, the effect of the shaft angle error is minimized because of the located point contact. Cross-axis helical gears have a virtual length crowning, which causes the point contact and reduces the sensitivity to shaft angle errors.

The following factors are unique to crossed-axes helical gears:

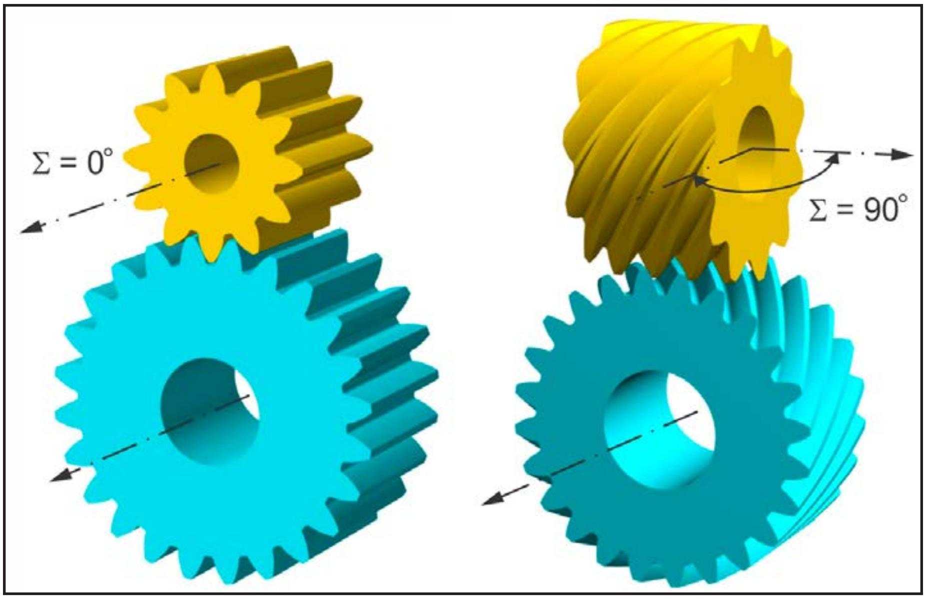

Figure 1 Spur gear pair (left) and 90° cross angle helical gear pair (right).

Spur Gears

- Are special cases of cross-axes helical gears
- If the axes cross angle is zero, then the gears are spur gears
- The flank surfaces have line contact
- In this case the path of contact is oriented in profile direction (Fig. 2, bottom)
- The gearset is center distance-insensitive, but highly shaft angle-sensitive

Introduction of Cross-Axes Angle

- If the axes cross angle is not equal to zero, then in the standard case both members have the same kind of helix, and a helix angle that is 50% of the shaft angle
- The axes cross angle is the sum of the two members' helix angle value

Cross-Axes Angle 90°

- If the cross-axis angle is 90°, then the path of contact has the shape of a quarter circle (Fig. 2, bottom)
- The flank surfaces have point contact
- The gearset is sensitive to center distance changes, but has little sensitivity to shaft angle misalignment

Small Cross-Axes Angle

- If the cross-axis angle is small (close to 0°), then the path of contact has the shape of a slim quarter ellipse (Fig. 2, center)
- The flank surfaces have point contact that will already spread under light load to contact lines
- The gearset is almost insensitive to center distance changes, but the sensitivity to shaft angle misalignment is medium to high

The bottom graphic in Figure 2 shows one contact line between generating rack and gear 1, and a second contact line between generating rack and gear 2. The contact lines are crossing under an angle and have only one common point. This is why crossed-axel helical gears have point contact rather than line contact. The sum of the intersecting points of gear 1 and gear 2 define the path of contact. Only the gear pair with zero-degree shaft angle in the top graphic has matching contact lines between gear 1, generating rack, and gear 2. Only contacting points along the theoretical path of contact (in red) transmit the correct ratio.

The relationship between generating rack and the two mating helical gears that mesh under a cross-axis angle is shown (Fig. 3). The two gear rotations, as well as the generating rack movement, are in three different planes. The graphic in Figure 3 makes it evident that the common contact location between pinion and gear in each shift position of the rack can only be a single point.

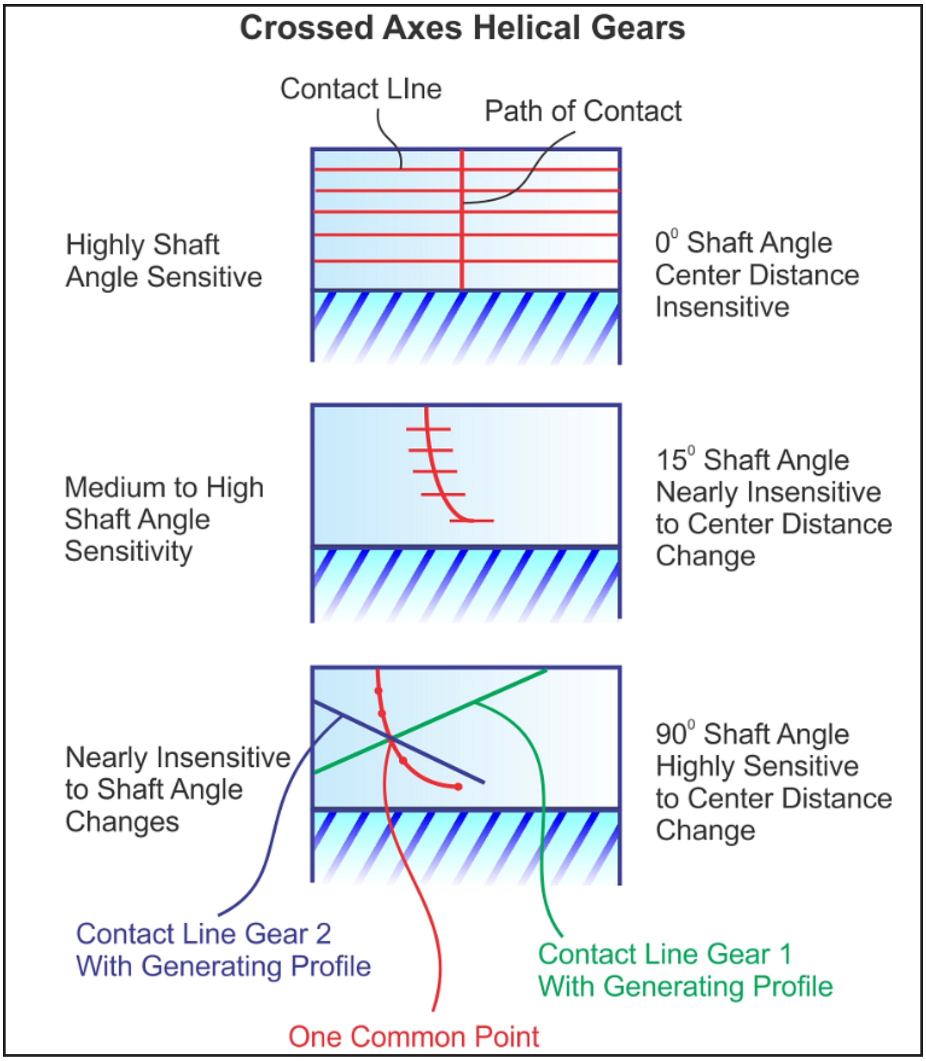

Figure 2 Crossed-axes helical gear relationships.

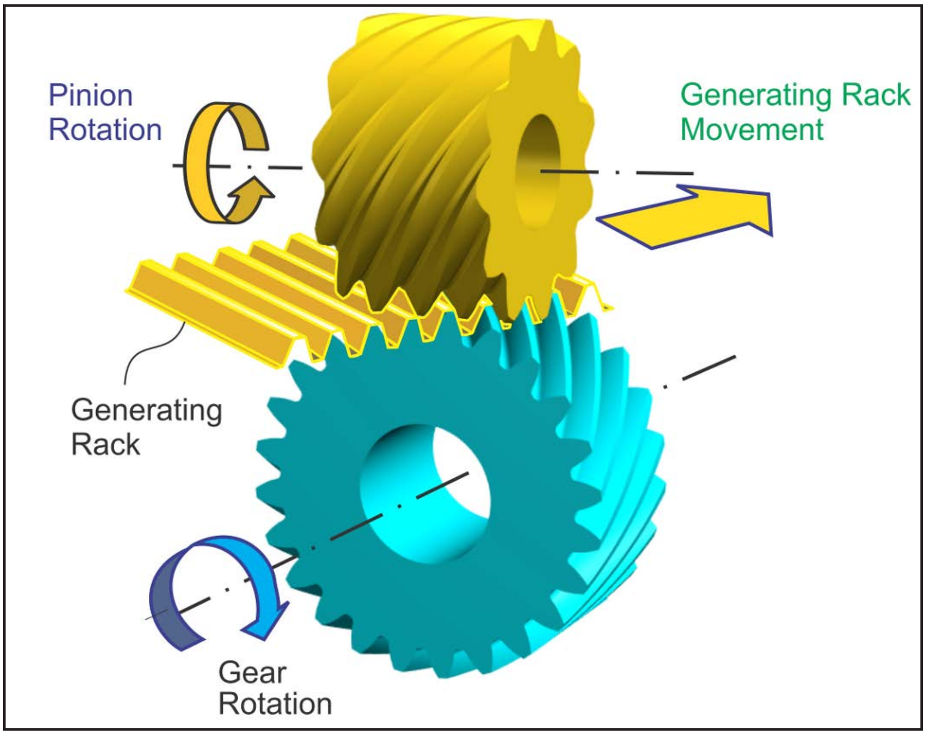

Figure 3 Generating rack between pinion and gear.

Figure 4 shows in 4 steps the changes to the contact location and contact normal vectors in order to explain the physics behind the center distance sensitivity of cross-axes helical gears. The initial pair of normal vectors is drawn as an example in the pitch point. The center distance change moves the normal vector of the upper gear to location 2. The rotation 3 is required to eliminate the backlash that was caused by the center distance change. The new contacting point of both gears will neither be in position 1 or position 3. A new contacting point with a normal vector pair will result from the interaction of the two gear flank profiles (location 4). As a result, the initial path of contact (Fig. 4, left) is distorted to the green path of contact.

The different location of the path of contact in face width direction causes no direct transmission error. However, the different location in profile direction will create a transmission error. The reason is that the contact points on the two mating involutes that rotate in different planes lost their kinematic relationship. This relationship only exists if the two helical gears are located at their correct center distance, and the trapezoidal generating profile has contact with one helical gear at the top and with the mating helical gear at the bottom (Fig. 5).

The attempt to quantify the influence of a center distance change to the transmission error is shown (Fig. 5, left). A center distance change shows no influence if the cross-axes angle is zero. The transmission error increases with a parabolic characteristic as the shaft angle departs from zero. The transmission error reaches its maximum in case of 90° cross axes angle. The qualitative influence of an axes misalignment to the transmission error is shown (Fig. 5, right). The influence is the highest for the case of zero-degree shaft angle (spur gear) and diminishes as the shaft angle increases. The lowest point is reached at 90° shaft angle. Small, medium and large misalignments show equidistant graphs. Although the diagrams are only qualitative, the relative relationship reflects the correct trends.

Summary

Crossed-axes helical gears have point contact and their surfaces are subject to high surface stress. The point contact can be explained with the orientation between generating rack, pinion and gear. A low transmission error can only be achieved in the low-load condition. Also the center distance insensitivity of spur and helical gears does not apply for crossed-axes helical gears (Fig. 5, left). However, the opposite characteristic can be seen regarding shaft misalignments. Spur and helical gears without length crowning react with high transmission error if the shafts are misaligned. Crossed-axes helical gears offer a "natural" length crowning, which reduces the sensitivity to small shaft angle changes (Fig. 5, right).

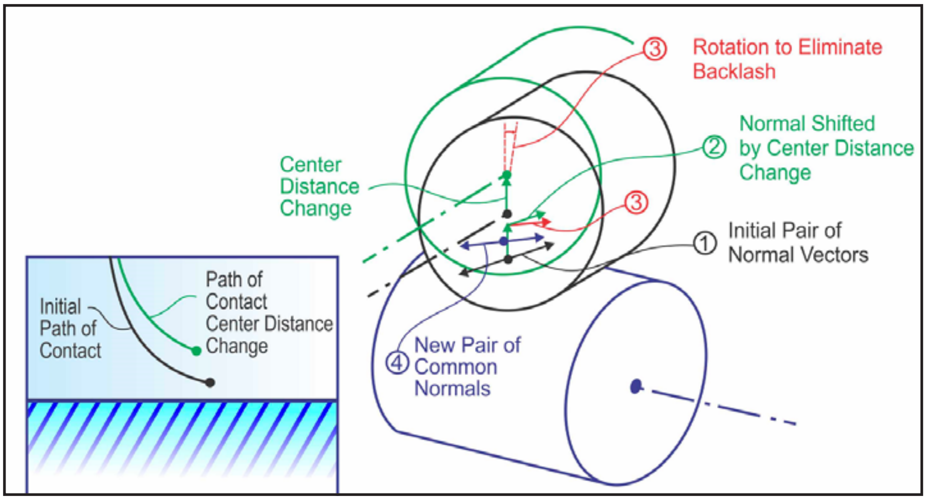

Figure 4 Influence of center distance change.

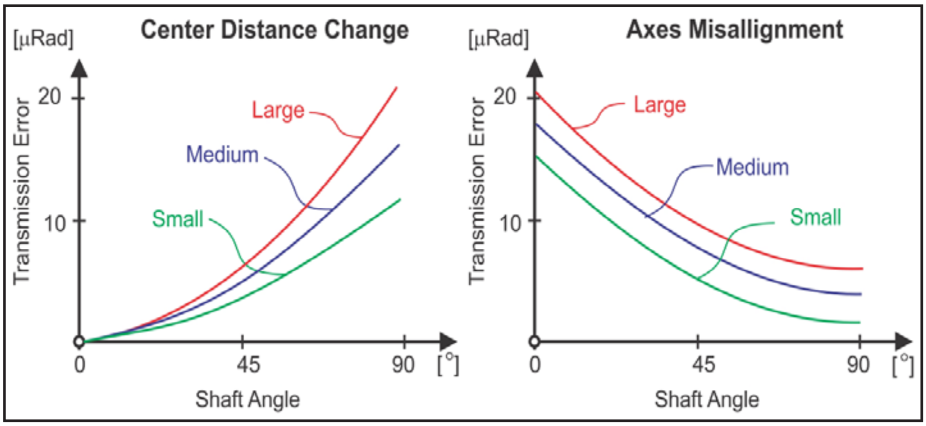

Figure 5 Qualitative influence of center distance and shaft angle changes.

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Experimental Study on the Pitting Detection Capabilities for Spur Gears Using Acoustic Emission and Vibration Analysis Methods

M. Grzeszkowski, C. Gühmann, P. Scholzen, C. Löpenhaus, S. Nowoisky and G. Kappmeyer

Introduction

To run all components of an aero engine at optimal speeds a planetary gearbox between fan and turbine is required. This new aero engine design allows slow fan rotation together with high turbine speed. As a result, the efficiency and bypass ratio increase significantly. However, using a gearbox introduces additional failure modes such as gear wear, pitting and gear teeth cracks.

Usually, high attention is paid to pitting initiation since this failure mode leads to subsequent destructive failures. Therefore, the early detection of pitting using a feature-based condition monitoring system is recommended to avoid unplanned engine shutdown and expensive gear replacements.

This paper describes an experimental investigation on spur gears to characterize the pitting degradation process using monitoring features.

Specific question or relationship. Previous investigations have revealed that pitting has an impact on the gear vibration behavior (Ref. 27). But is it possible to detect pitting at an early stage using acceleration sensors and acoustic emission (AE) sensors to avoid consequential damages and subsequent correction activities?

It is assumed that the pitting initiation process begins with the excitation of high frequency AE impulses above 50 kHz. Moreover, pitting progression causes increased sidebands in the gear mesh order spectrum. Therefore, the AE sensor technique with a higher bandwidth seems to be more suitable for early pitting detection.

The main goal of this experimental investigation is to understand, if an early pitting detection can be achieved using AE sensors combined with appropriate signal processing methods.

Method. The authors investigated several gears manufactured with different pitch deviations and surface properties. The gears were pre-loaded in a back-to-back test rig and driven until distinctive pitting occurred. Multiple acceleration sensors and AE sensors are mounted on the stationary housing adjacent to the gear bearing shell.

The sensors measure the vibration characteristics of the intermeshing gears. The signals were then filtered, resampled and pattern recognition methods were applied to extract monitoring features (Ref. 4). These features allowed a conclusion to be made regarding the correlations between those features and the pitting degradation process of the gears.

Results. For pitting detection, the AE sensors seem to be more suitable due to their higher bandwidth in comparison to the industrial acceleration sensors, for which the bandwidth ends around 50 kHz. The results show that a detection of pitting is possible several hours before complete gear failure. The test run results also depict the advantages and disadvantages of both the acceleration and the AE sensors.

Conclusion. The results indicate that early detection of pitting damage is possible. Based on the results, the requirements for potential production sensors and the corresponding signal processing algorithms can be defined for the integration in the control monitoring system for future aero engines. Furthermore, the influence of manufacturing processes and manufacturing deviations on the pitting progression can be investigated. A correlation between different finish qualities and the last machining step must be assessed to identify the associated impact on surface integrity.

The following introduces the requirements to monitor a planetary gearbox integrated in future aero engines followed by the fundamentals regarding the pitting. Afterwards the generation of acoustic emission due to pitting development will be presented and how the pitting affects the gear vibration behavior.

Power Gearbox Monitoring

Engine manufacturers are developing a power gearbox capable to transfer up to 100,000 horsepower. The technology will be demonstrated to achieve those levels. The trend of increasing flight capacities for the next decades indicates a strong demand of efficient propulsion systems. Further aspect is the demand to reduce the noise of power plants. To reduce the noise and make the power plant more efficient a power gearbox must be introduced between fan-shaft and turbomachinery. The planetary gearbox allows the Fan to rotate slower than the fast-rotating core engine. The associated improvement in efficiency and reduction in weight will allow the UltraFan to offer a 25% fuel efficiency improvement over the first generation of engines (Ref. 1). It is common state-of-the-art to monitor high-value machines during operation. The power gearbox is a new technology. The capability to monitor such a power gearbox will be increased in parallel to the hardware development. The requirements to monitor the power gearbox are made evident by the use of various system design tools, e.g. — *Functional Failure Mode* and *Effect Analysis* (FFMEA).

The assessments depict a clear demand to monitor the geartrain to depict typical gear failures such as gear wear, pitting and gear teeth cracks (Ref. 2). Depending on the failure progression, different effects, e.g. — acoustic emission (AE), vibration, particles or heat — could be measured to indicate an impending failure (Ref. 3). An important requirement is the early failure indication and the subsequent correction activity without disrupting the operation of the customers.

Former research (Ref. 4) worked to identify viable methods to detect geartrain failures based on subscale test environments. The next step is to use subscale component test rigs with comparable gear material, geometry and gear quality. This paper answers the question: what kind of sensor fits for the purpose of early geartrain failure indication? To prove theoretical ideas, subscale component rigs are more efficient than full-scale application. To improve the geartrain monitoring capability ahead of the used back-to-back (B2B) configuration presented in this paper, further experiments are planned. The next test vehicles are based on subscale and full-scale power gearbox applications.

Pitting Damage and Phenomenological Models

The main fatigue damage that occurs in the tooth flank area is not only micropitting and flank fracture, but also macropitting damage. If the local rolling strength of the edge zone is exceeded, pitting damage occurs, which is characterized by a shell-shaped triangular breakout (Ref. 5). The breakout surface propagates parallel to the tooth flank surface. With respect to the tooth flank, pitting damage preferably occurs below the pitch diameter in the area of negative slippage. The tip of the triangle shape points in the direction of the tooth root, and thus in the same direction as the tangential or frictional force related to the damaged surface (Ref. 6). Different phenomenological models exist for the development of pitting damage, which differentiate between surface and sub-surface-induced pitting damage (Fig. 1; Ref. 7).

Surface-induced pitting damage is caused by surface material cracks due to periodically rolling stress (Refs. 5 and 8). The breakout of particles can be explained by the fusion of individual cracks or the hydraulic blasting effect of the lubricant (Refs. 6 and 9). The characteristic fluid incompressibility of the oil leads to an increase in stress in the notch of the crack gap during over rolling, since the rolling movement closes the crack in the area of the negative slip and the oil cannot escape. In contrast, sub-surface-induced tooth flank damage occurs due to crack initiation below the surface. According to Ding, the crack initiation takes place at material defects in the surface zone (Ref. 10). Further crack propagation is supported by the cyclic alternating stress in the surrounding area of the initial crack. The connection to the fatigued zone, which starts at the crack end of the initial crack, leads to an enlargement of the total crack. The high pressure and shear stresses in the intermediate areas lead to the failure of the undercut particles, and thus to deep pitting damages (Refs. 10–11). On one hand, global analytical phenomenological approaches provide the calculation of the standard load-bearing capacity, according to ISO 6336 or AGMA 2001 (Refs. 12–13). On the other hand, local numerical material physical calculation methods based on the concept of local fatigue strength were developed (Refs. 14–15). In all methods, the present stress state is compared by forming a reference stress with a permissible stress of the material (Ref. 16).

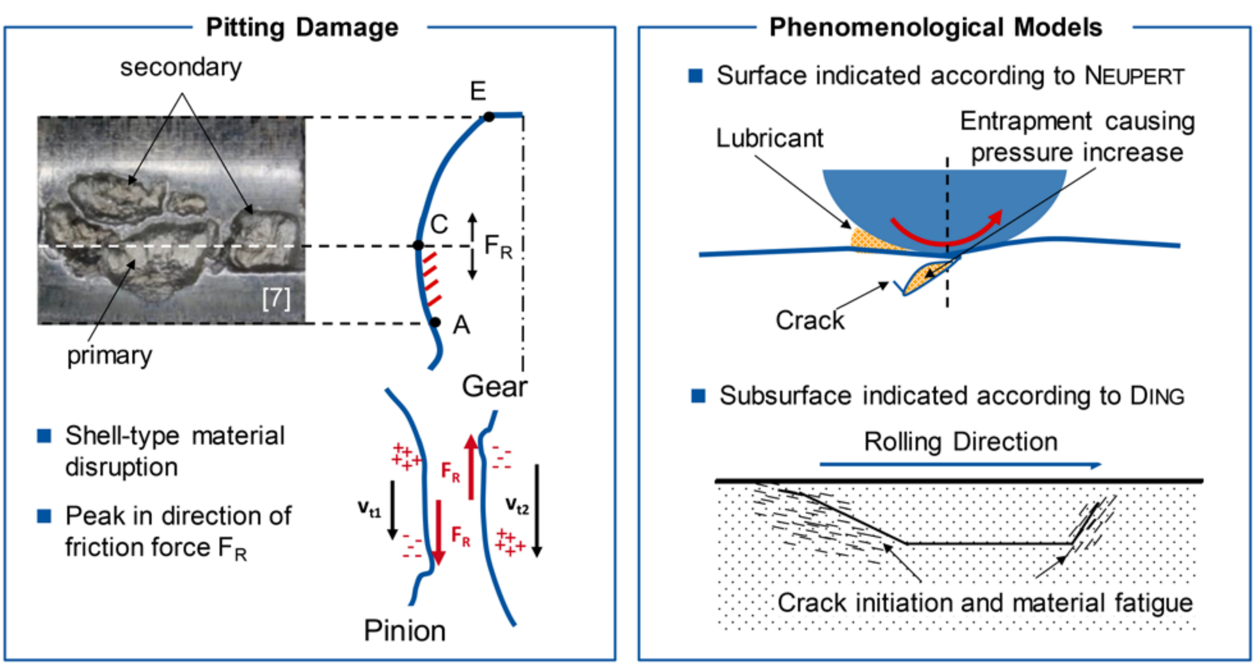


Figure 1 Pitting damage and phenomenological models (Refs. 7, 11 and 27).

Experimental Investigations on Pitting Detection

Due to the fact that pitting is caused primarily through crack initiation below the tooth surface and in the surface area, these material defects lead to a disturbed vibration characteristic during periodic load of the spur gears. Cracks at the tooth surface zone result in an excitation of elastic waves within the material, which lead to AE signals (Ref. 17; Fig. 2). This distinctive crack damage leads to particle breakout that directly influences the mesh stiffness of the teeth. Depending on the distribution of those particle breakouts, an additional vibration excitation of the gears can be observed in the vibration spectrum (Ref. 17). With the foregoing considerations there are two principle sensor methods, which potentially allow a pitting detection, i.e. — acceleration sensors and AE sensors.

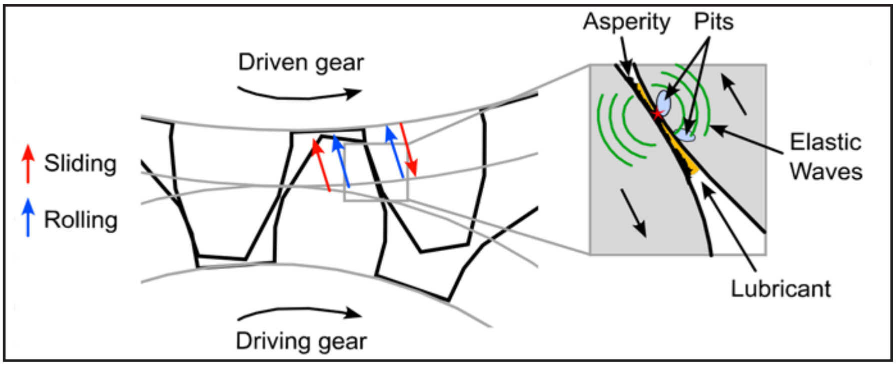


Figure 2 Initiation of elastic waves during negative sliding contact (Ref. 18).

The following authors already studied the possibility of detecting the pitting progression during operation conditions using vibration and other type sensors. Cheng (Ref. 18) used dynamic models for healthy and pitted gears to carry out sensitive and robust features, and to calibrate and normalize them. Pitting was artificially induced and the accelerometer signals were acquired to estimate the pitting severity of the gearset. Tan (Ref. 20) compared accelerometer measurements, AE measurements and spectrometric oil analysis to their capability of detecting naturally caused pitting. Their results showed a high sensitivity of AE RMS value to sliding speed on the tooth flank and tooth stresses. Additionally, an increased AE amplitude with increasing pitting breakout zone could be observed. Tan also concluded that the AE measurement method is suitable for early pitting detection. There are also publications where the authors investigated the causes of macro- and micropitting initiation using other equipment, such as microscopes, CNC gear measuring instrument or other optical measuring instruments. Al-Tubi (Ref. 21) investigated the impact of tooth flank roughness and lubricant film thickness on the micropitting initiation process for different load stages. To evaluate the micropitting progress, the tooth flank surface quality was captured after each load stage using a microscope; the tooth profile deviations were captured after the last load stage using a CNC gear measuring instrument. Further, Al-Tubi calculated the specific lubricant film thickness for different points on the tooth flank, based on analytical models. Comparing the experimental results and analytical calculations, Al-Tubi discovered that the initiation of the micropitting starts to occur in the tooth root area, where the maximum contact stress leads to a minimum of lubricant film thickness. Moorthy (Ref. 22) studied gears with varying coatings and their influence on the initiation of micropitting damage. Contact fatigue tests have been carried out and the tested gear tooth flank surfaces were analyzed using a scanning electron microscope and compared to untested gears. Moorthy determined that micropitting is primarily initiated by sharp valleys on the tooth surface, when the valleys are preferentially orientated against the tooth sliding direction.

Most of the published research work uses offline-capable, optical measurands to quantify the natural provoked pitting

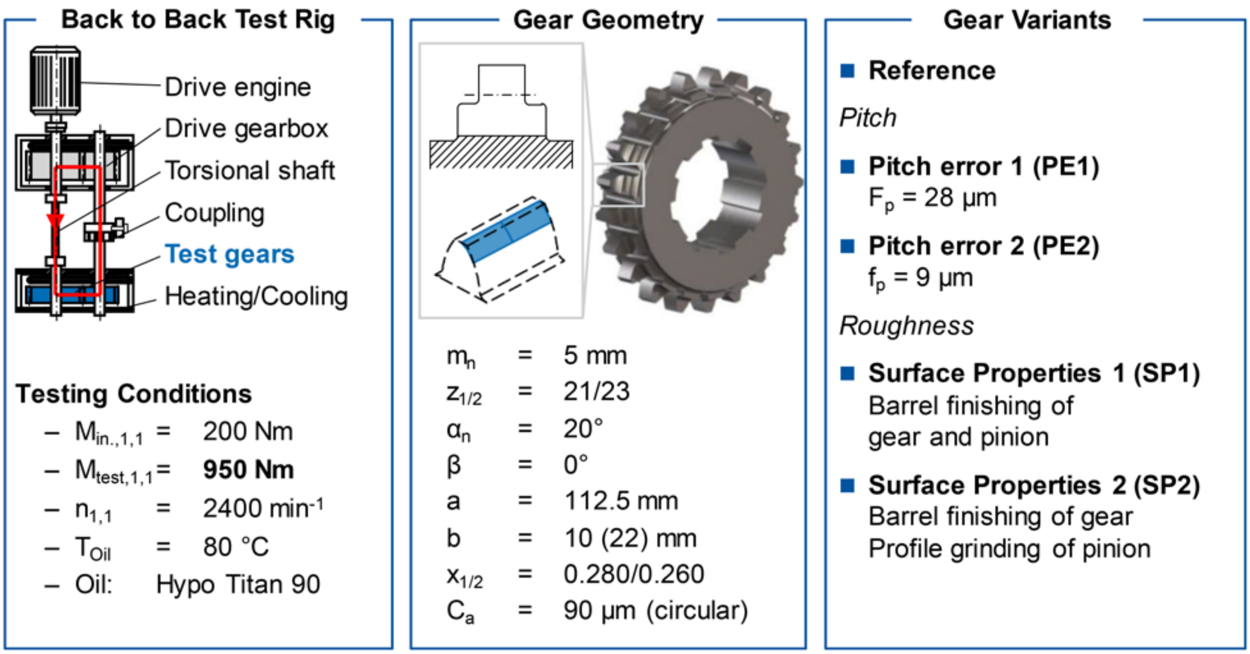


Figure 3 Conception of the study.

degradation of gears — or the pitting degradation is induced artificially. So far, there are rarely publications that use acceleration or AE sensors to monitor the pitting damage progression during load capacity tests. Whereas, the investigation in this paper presents online-capable geartrain monitoring methods using acceleration and AE sensors that allow detection of pitting damages during gear operation.

Experimental Design

In this section the experimental setup will be described. The back-to-back (B2B) test rig and the applied gears are explained, as well as the sensor setup used to acquire the data. Furthermore, the theory of the applied feature extraction methods is also discussed.

Conception of the Study

The pitting load-carrying capacity tests in this report are carried out on a B2B gear test rig with a center distance of $a = 112.5$ mm. The principle of the B2B gear test rig is standardized according to DIN ISO 14635 (Ref. 23). The test rig consists of a power circle, which consists in particular of the test gears, a drive gearbox, a torsional shaft and a coupling (Fig. 3).

After running-in at a torque of $M_{in.,1.1} = 200$ Nm, all tests were run at a test load of $M_{test,1.1} = 950$ Nm in order to enable a classification of the test variants on a constant load level. The gear speed is $n = 2{,}400\ min^{-1}$ for the entire test run. The test temperature is regulated to $T_{Oil} = 80°C$ with sump lubrication; Hypo Titan 90 oil is used as lubricant. The gear geometry is an established test geometry of type 21/23 with an involute tooth form, using a stepped tooth root according to Tobie with a common tooth width of $b = 10$ mm for a secure separation of pitting and tooth root safety regarding the investigation (Ref. 24). In addition to a crowning on the pinion of $C_{\beta,pinion} = 2$ µm and $C_{\beta,gear} = 1$ µm on the gear to avoid edge loading, a circular tip relief of $C_a = 90$ µm is used for the two gears to avoid premature tooth engagement.

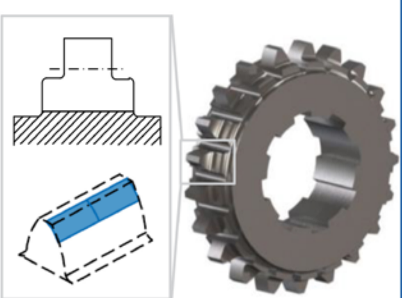
Five different variants were investigated depending on their geometry and final manufacturing step. To classify the test results, a reference variant was first tested, which was manufactured without any deviations. The other four variants differ in geometric pitch errors and tooth flank roughness. The "Pitch Error 1" (PE1) variant is characterized by a cumulative pitch error of $F_p = 29$ µm compared to the reference, whereby the "Pitch Error 2" (PE2) variant has a single pitch error of $f_p = 9$ µm. The two variants — "Surface Properties 1 and 2" — differ in terms of surface characteristics and their final manufacturing step. For the "Surface Properties 1" (SP1) variant, both gear and pinion were barrel-finished to minimize tooth flank roughness. In the "Surface Properties 2" (SP2) gearset, only the gear is barrel-finished. In the B2B test rig the gear is paired with a profile ground pinion. The different gear qualities allow testing significant differences of selected gear properties to demonstrate the robust pitting detection method. For the load capacity tests, all test variants were made from case hardened steel (DIN EN 10084).

Measured Gears

Figure 4 shows the measurement results of the gear geometry deviations and the roughness. According to the measurement results, there is a clear difference between the individual variants. With a total pitch deviation of $F_P = 29.3$ µm for the PE1 variant, and a single pitch deviation of $f_p = 9.5$ µm for the PE2 variant, the given specifications were reached. The variants SP1 and SP2 also show a lower roughness compared to the reference. This allows differences or similarities in pitting detection to be traced back to the deviations.

Sensor Instrumentation

The instrumentation in Figure 5 was applied on the B2B gear test rig. Two identical piezoelectric accelerometers (Kistler, Type 8702) were placed on the bearing shell, mounted orthogonally and oriented to measure radial acceleration components. This sensor application aims for measuring radial accelerations resulting from locally distributed pitting. The accelerometer signals were acquired with a sampling frequency of 200 kHz. (*For the acceleration sensor signals the data acquisition board PXIe-4464 from National Instruments with an ADC resolution of 24 bits was used.*) Additionally, one AE sensor, provided as piezo-ceramic sensor, was applied on the bearing shell of the



m_n = 5 mm
$z_{1/2}$ = 21/23
α_n = 20°
β = 0°
a = 112.5 mm
b = 10 (22) mm
$x_{1/2}$ = 0.280/0.260
C_a = 90 µm (circular)

	V#	Variant	$f_{p,max}$ / µm	Q	F_p / µm	Q	$R_{a,av.,3\ teeth}$ / µm
Gear - z=23	V1	Reference	3.0	Q3	3.0	Q1	0.26
	V2	Pitch error 1	1.5	Q1	7.9	Q2	0.26
	V3	Pitch error 2	1.7	Q2	7.7	Q2	0.24
	V4	Surface Properties 1	4.4	Q5	16.1	Q4	**0.05**
	V5	Surface Properties 2	2.4	Q3	15.9	Q4	**0.13**

Key

- F_p Cumulative pitch error
- $f_{p,max}$ Maximal single pitch error
- $R_{a,av.,3\ teeth}$ Average roughness over three tooth flanks
- Q Toothing quality (DIN 3962-1)

Figure 4 Measured pitch error and roughness.

test gears ±45° to the acceleration sensors. Because it is assumed that the pitting initiation process begins with high frequency AE impulses above 50 kHz, an AE sensor with a bandwidth of 150 kHz was selected and sampled with 500 kHz. (*For the AE sensor signals the data acquisition board PXIe-6341 from National Instruments with an ADC resolution of 16 bits was used.*) The oil temperature within the test gearbox housing was measured using a Pt1000 thermocouple and acquired with a sampling frequency of 1 kHz. The angular information of the driven shaft is also used in this paper for resampling methods to describe the vibration signals in angular-domain. Therefore, the instantaneous shaft rotation angle of the torsional shaft was acquired using an incremental magnetic encoder with a rotation angle resolution of 15 bits.

The data of all sensors were recorded synchronously every 10 minutes with duration of 10 seconds using a multi-channel measurement system. The start of a measurement procedure was triggered by the incremental encoder at a defined rotation angle of the pinion. (*To ensure a synchronous sampling of all measurement channels a custom-build measurement application was developed in LabVIEW to trigger the data acquisition of digital encoder signals and analog vibration and temperature signals for a defined torsional shaft rotation angle point.*)

Pitting Diagnosis System

The data were processed to extract quantifiable indicators for the pitting damage. The angular signal resampling, the feature extraction, feature evaluation and feature selection constitute the proposed pitting diagnosis system (Fig. 6).

Pre-processing. Before the feature extraction step, the measurement signals data have to be pre-processed. First the instantaneous shaft angle is extracted from the incremental encoder signal. This is then used for resampling (Ref. 25) the acceleration sensor and AE sensor data into angle-dependent signals. This data format allows a speed-independent vibration signal processing using the order spectrum, and smearing of the vibration signals in the spectral representation, due to speed variations, is reduced. This enables the extraction of more robust features for the failure detection. Additionally, the logged run times and load cycles of the load capacity tests are pre-processed and merged to make them available for subsequent signal processing stages.

Feature extraction. Afterwards sensor-customized features will be extracted from the acquired sensor data. The following feature extraction methods were realized in this paper. To evaluate the impact of tooth flank pitting on the oil temperature the four central moments mean value, variance, skewness and kurtosis of the distributions from the sampled temperature data were calculated, whereas kurtosis w is defined as:

$$w=\frac{1}{N}\sum_{k=1}^{N}\left(\frac{x_k-\mu}{\sigma}\right)^4 \tag{1}$$

And the standard deviation σ and mean value μ are defined as:

$$\sigma=\sqrt{\frac{1}{N}\sum_{k=1}^{N}(x_k-\mu)^2}, \qquad \mu=\frac{1}{N}\sum_{k=1}^{N}x_k. \tag{2}$$

Additionally, the root mean square (RMS) value was used as a feature. From the accelerometer and AE sensor signals the same features are generated as for the oil temperature sensor. Locally distributed tooth pitting failures stimulate additional vibrations with the order of one shaft revolution and their harmonics. This causes amplitude modulation effects and sidebands in the order spectrum. The goal is to map these effects into additional features, which are generated by calculating the spectral power density for 9 defined frequency intervals. The frequency intervals range from the i^{th} harmonic of the gear mesh order to the $i+1$ harmonic, respectively, excluding the harmonics itself. Other significant features are extracted using the continuous

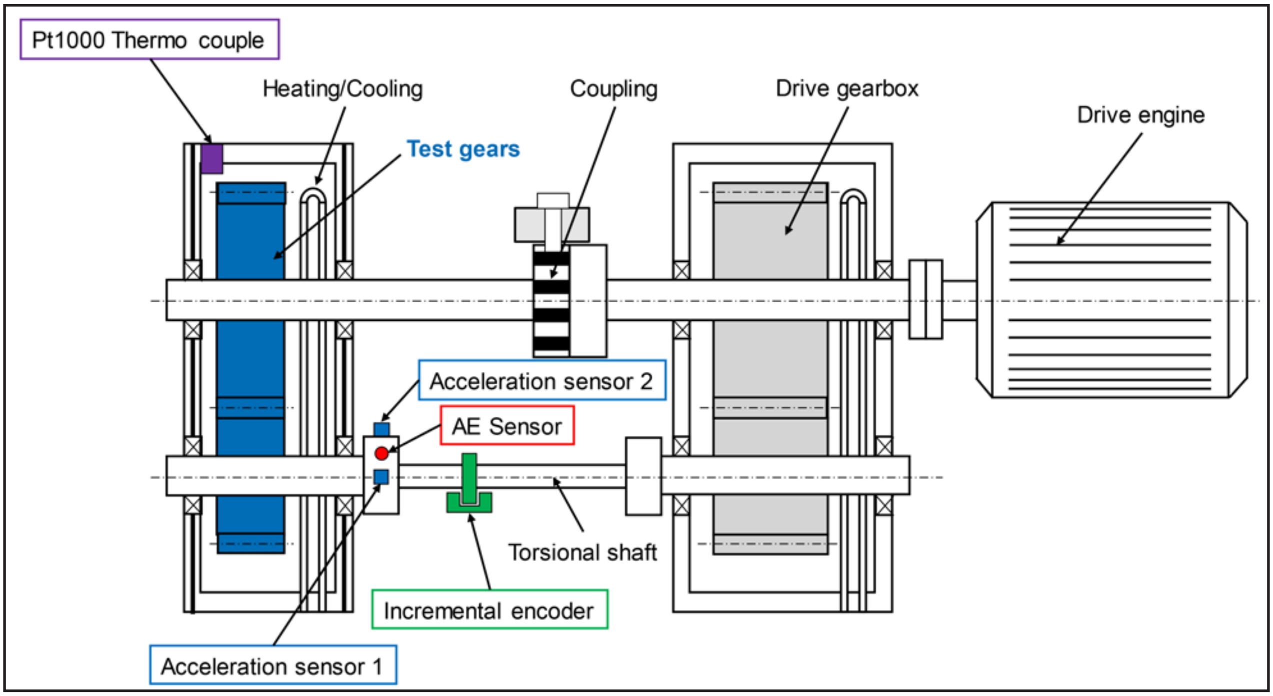


Figure 5 Sensor instrumentation for the B2B gear test rig.

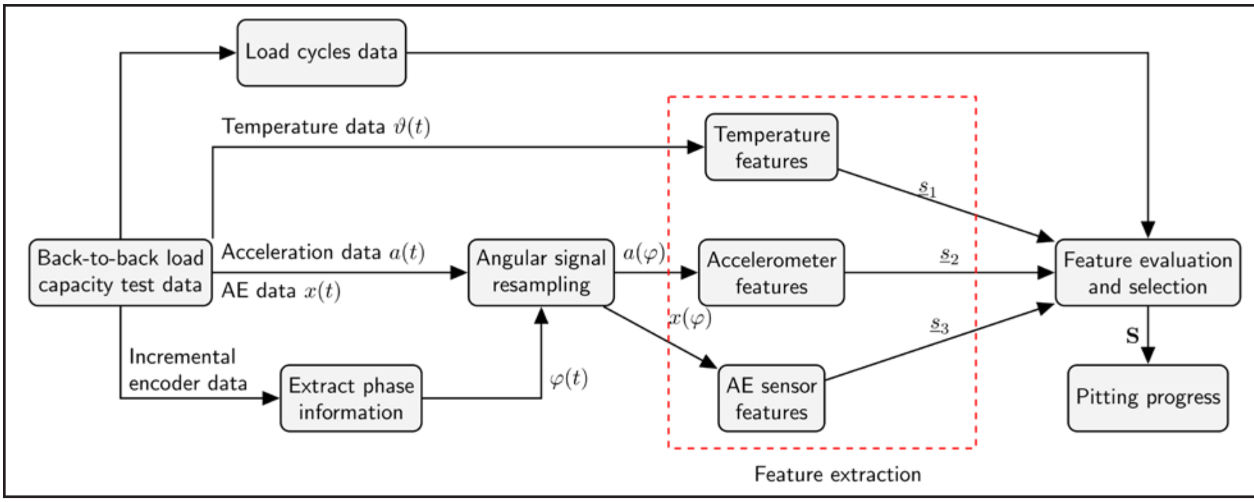


Figure 6 Schematic diagram of the proposed pitting diagnosis system.

wavelet transform (CWT):

$$X\omega(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} x(t) \cdot \overline{\Psi}\left(\frac{t-b}{a}\right) dt \tag{3}$$

In the CWT the analyzing function is not a single variable. Analogous to ω in the Fourier transform, in the CWT wavelets are compressed or stretched using variable *a*. Therefore, executing the CWT on a signal using high-scaled wavelets leads to a low time resolution and high-frequency resolution, and vice versa for low scale factors (Ref. 29). In this paper the CWT coefficients were calculated using a Morlet wavelet. Afterwards the statistical values such as mean, variance and kurtosis from the CWT coefficients are generated to obtain CWT-based features. Because wavelets provide good localization at high frequencies and are sensitive to impulsive signals, they can be used for detecting local gear faults — like pitting. In addition to the already mentioned features, in this paper further features are generated from a bandpass filtered version of the AE sensor signals with a filter center frequency of 130 kHz. Here again statistical values are extracted to obtain features out from the bandpass filtered AE sensor signal. For one acquired measurement sample every 10 minutes, a set of one-dimensional features is generated. In case of M consecutive measurement samples, the feature extraction methods will generate M-dimensional feature vectors.

Feature evaluation. In the next signal processing step the generated features are being normalized to a uniform value range to allow a consistent feature evaluation. Although the measured sample data points were labeled using two classes (healthy gears and pitted gears), the problem is that the extracted feature values show an overlapping of the class distributions. Therefore, the Fisher discriminant criterion (Ref. 26) was used to find a class separation measure for every labeled feature vector. The Fisher criterion:

$$J_i = \frac{(\mu_2 - \mu_1)^2}{\sigma_1^2 + \sigma_2^2} \tag{4}$$

is defined as the ratio of the between-class variance to the within-class variance for a given feature *i*, whereby μ_j and σ_j^2 are the mean and variance, respectively, of the feature values of class *j*. In the last processing step those features with the highest separation value J_i are selected to depict the correlation between the pitting progress and the feature values. The assumption is that the selected features have the highest sensitivity with respect to pitting damage.

Results

This section presents the results generated by the applied feature extraction on the acceleration and AE sensors.

Testing results. Figure 7 shows the results of the load capacity tests. The upper part of the figure shows the damage patterns and the lower part shows the run times of the variants up to the point of damage. Except for the SP2 variant — which failed with a broken tooth over the stepped tooth root — all other variants failed from pitting. The results of the investigation show different running times for the gearset variants. However, since only one gearset-per-variant was tested, it is not possible to make a statistically reliable statement about the effects of roughness and pitch deviations on the tooth flank loading capacity.

Acquired sensor signals. The above-mentioned load capacity tests lead to the acquired signals in Figure 8 and Figure 9. As already in context with the signal processing chain in Figure 6 referenced, locally distributed tooth pitting induces additional vibrations. This is clear in the order spectra of acceleration sensor 1(Fig. 8). The left plot shows the order spectrum of gears without damage from the PE2 load capacity test. Here, acceleration amplitudes with the gear meshing order (GMO) and its harmonics are dominating the signal spectrum. The inset in the right order spectrum shows the pitting damage. Here, an extensive stimulation of sidebands at one order around the GMO's harmonics can be observed. This supports the idea of extracting features out of the sideband amplitudes between the GMO's harmonics.

In Figure 9 the Wigner-Ville distribution of the AE sensor signal from the PE2 test is shown. And again, the left plot represents the angle-order distribution of the AE signals without any gear damage, whereas the right plot shows the AE signal distribution of a pitted tooth flank in meshing contact. The figure shows that pitting leads to excitation of frequency components around 130 kHz. Therefore, the abovementioned statistical features, generated from the bandpass-filtered AE sensor signal, allow gathering additional robust pitting features.

Discussion of suitable features. After the sensor signals were processed using the signal processing chain in Figure 6, only the features with the highest Fisher criterion value will be presented in this discussion. For a clearer presentation, only a few features are shown in the following figures. The below discussed features are normalized through all tests to zero-mean feature values with a standard deviation of $\sigma = 1$ using translation and scaling.

Pitch error (PE) tests. In the gearset variants PE1 and PE2 (Fig. 10), the feature values generated from the oil temperature sensor did not identify any abnormalities. However, the kurtosis feature of the CWT coefficients generated from the AE sensor and the calculated spectral power densities between the 7th and 8th harmonic of the GMO, generated from the acceleration sensors, provided usable feature values. In the PE1 test it can be observed that the features show a significant value slope near the end of test run time.

In the PE2 test, the pitting could be detected 70 minutes (corresponds to 94% of test run time) before the complete pitting damage occurred. The indication is visible using both acceleration sensors and the AE sensor at a motor speed of 2,400 rpm. As shown in the right plot of Figure 10, first abnormalities in the feature values could be detected about 8 hours (corresponds to 68% of test run time) before complete pitting damage. Visual inspections were made, but quantifiable evidence of the pitting initiation requires non-intrusive measurements such as ultrasonic scans or X-ray measurements.

Surface properties (SP) tests. The evaluation of the features generated from the SP tests showed that in comparison to the PE tests the oil temperature within the tested gears increased with tooth pitting. The authors cannot explain how the gear geometry deviations influence the oil temperature. To answer this question further investigation is required. In Figure 11 the left plot shows the resulting features for the SP1 test, where pitting could be detected 230 minutes (corresponds to 91% of test

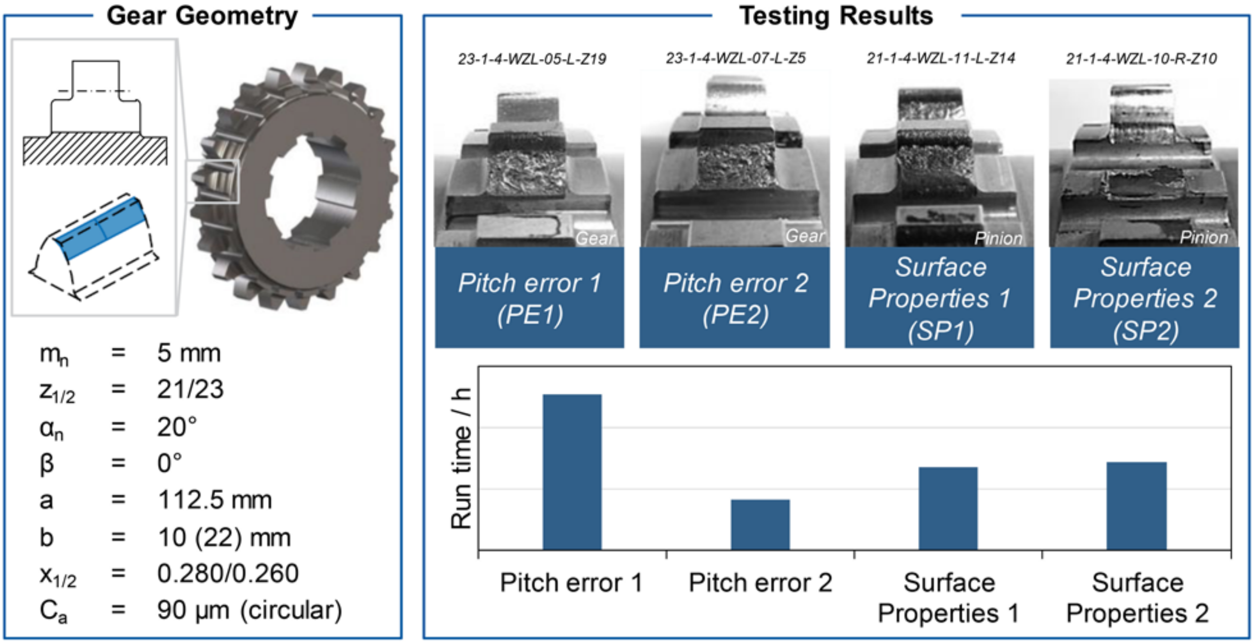


Figure 7 Testing results.

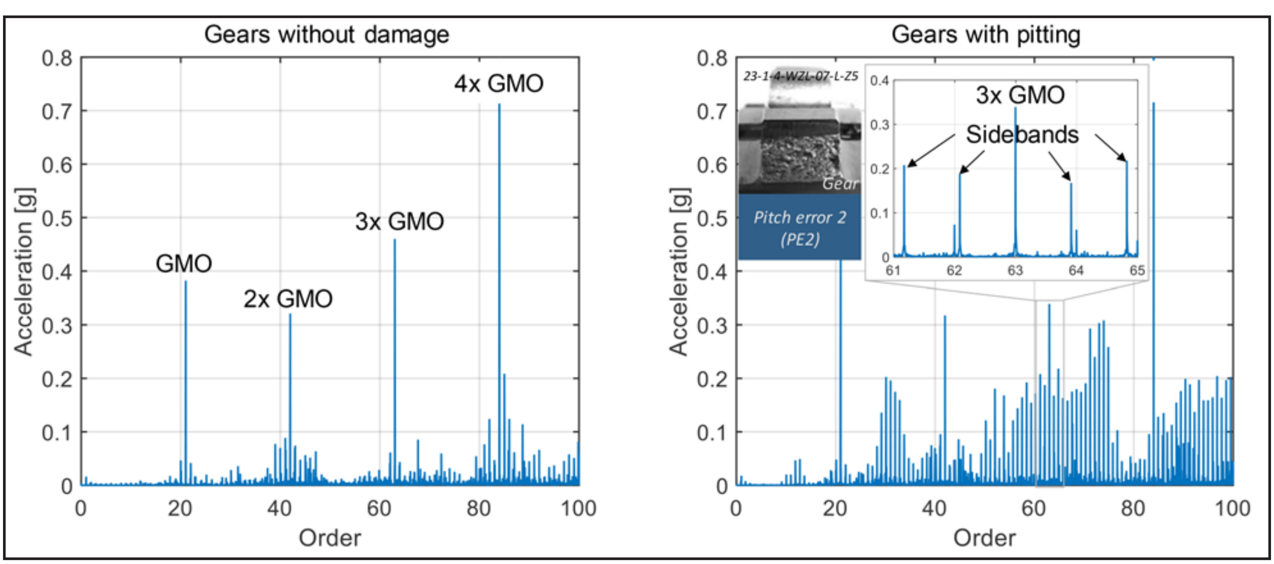


Figure 8 Order spectra of acceleration sensor 1 signal (PE2 test).

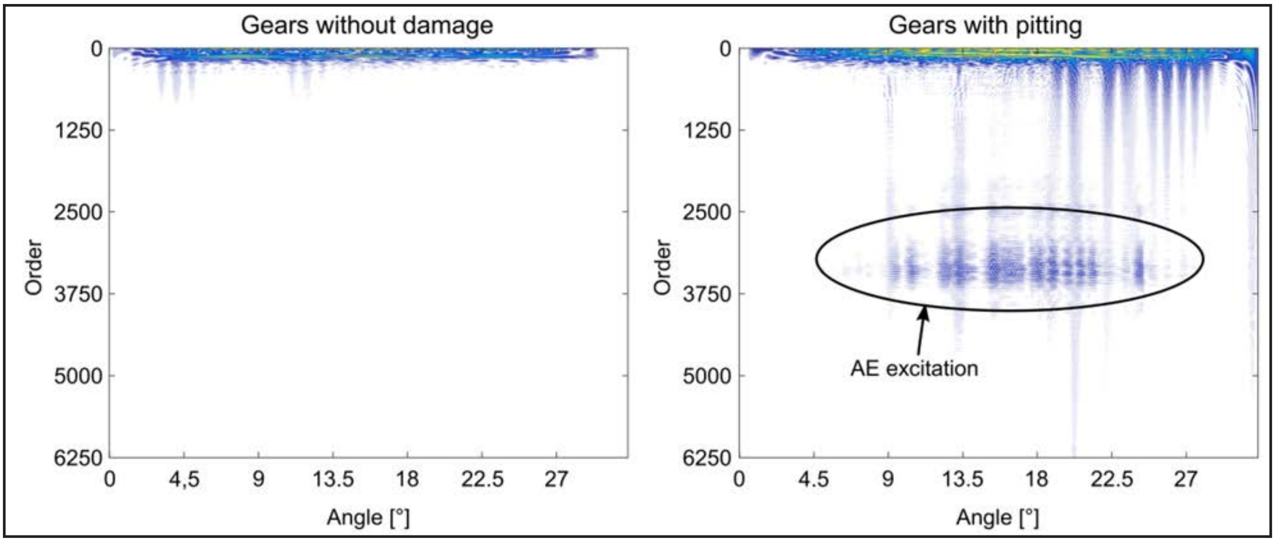


Figure 9 Wigner-Ville distribution of AE sensor signal (PE2 test).

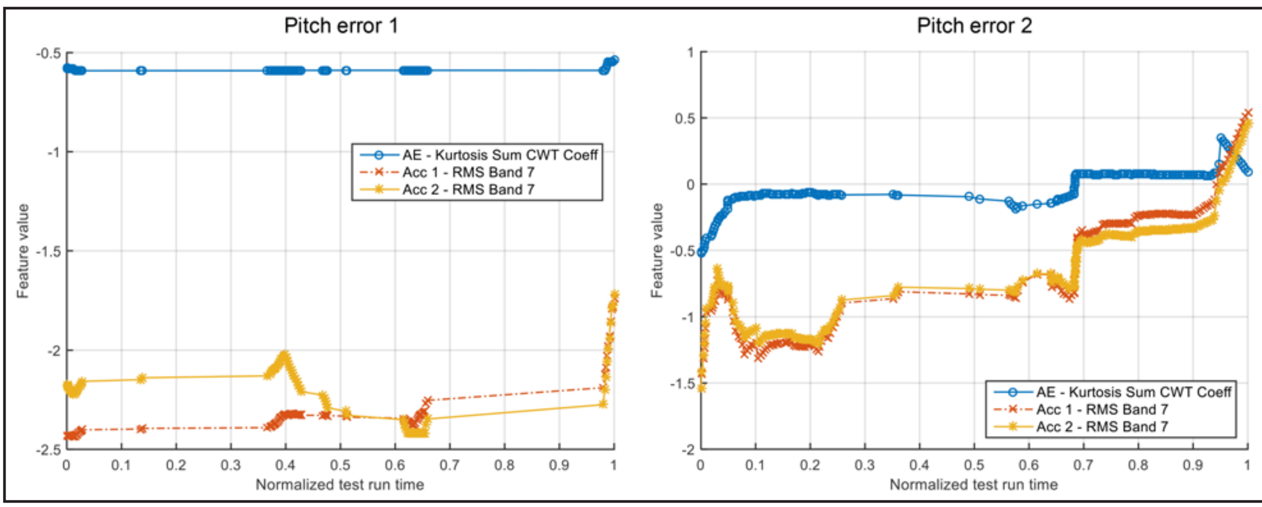


Figure 10 Pitting detection features generated from PE1 and PE2 tests.

run time) before complete pitting damage occurred at a motor speed of 2,400 rpm. In addition to already discussed features, in tests PE1 and PE2 additional features show pitting development.

Because the SP2 variant failed with a broken tooth over the stepped tooth root before any pitting occurred, no significant feature value variations are generated in this test, as shown in the right plot in Figure 11.

Comparison between acceleration and AE sensor. Both sensor techniques — acceleration and AE sensors — are suitable for the detection of pitting effects. This statement is valid with the premise that the used feature extraction methods are adjusted for the used sensor type, because of the different physical measurement variables and different sensor bandwidth.

Acceleration sensors showed a more sensitive behavior to pitting damage using features that concentrate on the evaluation of the sideband spectrum. AE sensors seem to be more sensitive to high-frequency elastic waves and, therefore, to impulse signals, which can be revealed using CWT coefficients. The use of AE sensors does not automatically ensure earlier pitting detection compared to accelerometers; it is possible that an AE sensor with greater bandwidth could provide earlier detection.

Nevertheless, the AE sensor has one important advantage compared to the accelerometer, i.e. — generating features from AE signals at a high-frequency range improves the distinction between different gear and test rig vibrations. The AE measures above the gear mesh frequency and its harmonics. Specific gear failure types can be identified, which can occur in different spectral ranges.

Conclusion

The experimental study showed that early detection of pitting damage is possible a few hours before severe pitting occurred on the tooth flanks. The results demonstrated the capability of accelerometers as well as acoustic emission (AE) sensors for indicating pitting damage on spur gears. Here, the automated evaluation of generated features using the Fisher criterion showed that, because of different measuring principles, the acceleration sensor and the AE sensor need sensor-specific feature extraction methods. Analyzing the sidebands of the acceleration sensor's order spectrum and calculating the statistical measurands of the AE sensor's wavelet coefficients provided the best results. This experimental study does not show that pitting is detectable with AE sensors earlier than with the use of acceleration sensors. Furthermore, recognize the influence of pitch

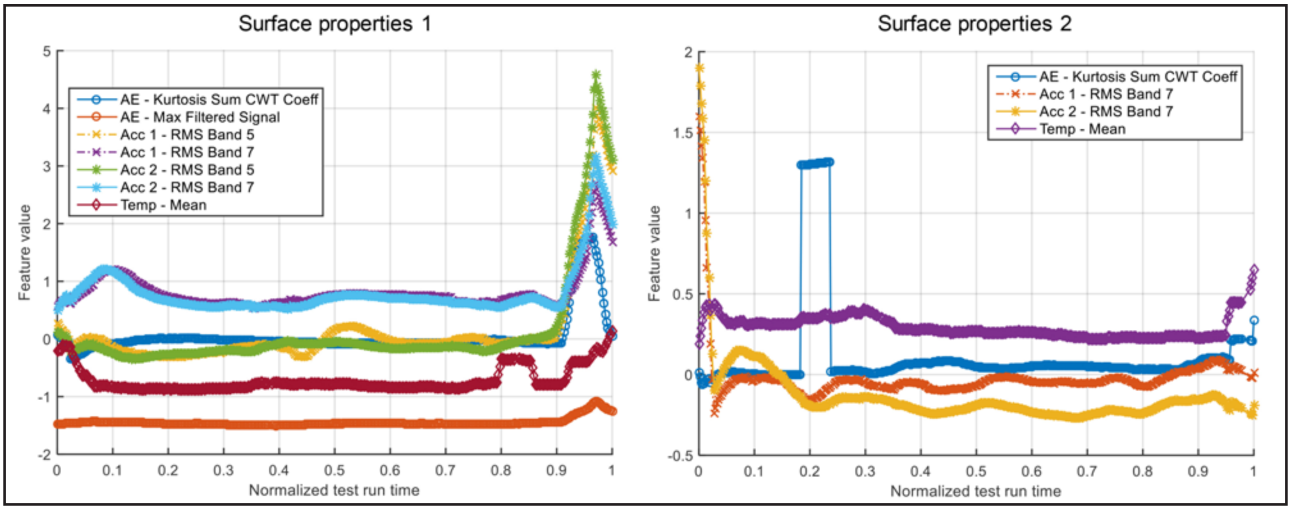


Figure 11 Pitting detection features generated from SP1 and SP2 tests.

deviations and different flank roughness. More load capacity tests with a larger sample size of gear variants must be carried out to allow statistically reliable propositions about the influence the manufacturing deviations have on gear life.

High-pitch deviations lead to a greater variation of the feature values than low, average flank roughness. Furthermore, more sensitive features to pitting damage are available if the flanks of the gear variant have a low- average roughness. Therefore, the assumption can be made that gears manufactured with a low-average flank roughness provide more robust pitting detection features; this also must be demonstrated with more testing. Sensitive features to pitting damage could be identified also for different pitch deviations. Overall, the investigations showed that the applied signal processing algorithms and features are tolerant of gear geometry deviations such as pitch deviations and tooth flank roughness.

Outlook

Based on the presented results, further measurements with a larger number of test gears must be performed to learn whether average tooth flank roughness has a greater impact than pitch error deviations on the pitting detection capability. Answering these questions could improve the future manufacturing process to guarantee, on the one hand, robust pitting detection methods and, on the other hand, a long service life without pitting damage. Additionally, the presented pitting detection methods also have to be verified with a greater sample size of tested gears. However, these gears should have comparable geometry deviations to control the main factors affecting pitting damage like geometry parameters and surface roughness. Furthermore, these signal processing methods may possibly be useful in evaluating gear quality such as at end-of-line testing of gearboxes.

Acknowledgment. *This work was supported by the Federal Ministry for Economic Affairs under the German National Aeronautical Program DeFiHog (20T1505). Thanks to Rolls-Royce Germany for permission to publish the results.*

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New Consideration of Non-Metallic Inclusions Calculating Local Tooth Root Load Carrying Capacity of High-Strength, High-Quality Steel Gears

Daniel Fuchs, Stefan Schurer, Thomas Tobie and Karsten Stahl

Demands for higher performance have caused a need for improved component characteristics, e.g.—through surface strengthening of gears and increased cleanliness of gear steels. Unfortunately, a resultant drawback is that cracks in such high-strength gears are more often initiated in the material matrix at non-metallic inclusions and not at the surface. In standardized calculation methods, the degree of cleanliness of steels is not yet directly correlated to the tooth root load carrying capacity. This paper considers the effects of non-metallic inclusions in the steel matrix on the tooth root strength based on the theoretical approach of Murakami.

Nomenclature

Symbol	Unit	Parameter
HV	HV	Vickers hardness of the steel matrix
K	$MPa \sqrt{m}$	stress intensity factor
K_A	–	application factor
K_v	–	dynamic factor
$K_{F\beta}$	–	face load factor for tooth root stress
$K_{F\alpha}$	–	transverse load factor for tooth root stress
M	–	mean stress sensitivity
M_E	–	residual stress sensitivity
m_n	mm	normal module
$\sqrt{area}$	m	square root of a defect area projected onto a plane perpendicular to the applied stress
σ_A	N/mm^2	local fatigue strength
σ_F	N/mm^2	maximum tooth root stress at the surface
σ_{F0}	N/mm^2	nominal tooth root stress at the surface
$\sigma_{inclusion}$	N/mm^2	local load induced stress at the depth of the non–metallic inclusion
σ_m	N/mm^2	local mean stress
σ_{RS}	N/mm^2	residual stress
σ_W	N/mm^2	local bending fatigue strength
$\frac{\sigma_{inclusion}}{\sigma_A}$	–	local material strength ratio

The trend towards higher performance requirements is becoming ever more important for gear manufacturers. According to the current state of knowledge, there are two common approaches for increasing the power density: either to build smaller gearboxes with equal transmittable power or to increase the transmittable power without changing the dimensions. Consequently, approaches such as the surface strengthening of gears have become more important in the last decade. In addition, a lot of effort has been invested by steel manufacturers in improving material properties, such as an increased cleanliness of the steel or use of new alloy combinations.

Unfortunately, the approaches are not without drawbacks, such as cracks in high-strength gears that are now more often initiated in the material matrix and not at the surface—even after years of operation. If such damage mechanisms occur during operating, they result in high costs and are a major problem for both gear manufacturers and operators.

Most of these sub-surface-initiated cracks occur at non-metallic inclusions; therefore the degree of cleanliness of the steel used is highly important. In standardized calculation methods, e.g.—ISO 6336-3 (Ref. 15) or DIN 3990-3 (Ref. 17)—the degree of cleanliness of steels has not yet been directly correlated to the tooth root (bending) load carrying capacity. Therefore, it is not yet possible to determine the actual bending strength of high-quality gears.

The theoretical approach of Murakami (Ref. 2) provides a first basis for determining the load carrying capacity for component parts with non-metallic inclusions. The research conducted for this paper is based on this approach and on extensive experimental results obtained on FZG back-to-back gear test rigs and pulsator test rigs.

It can be shown that the model of Murakami can be adapted for gears. The developed model is in good correlation with the experimental results. This paper shows how these results allow a consideration of the effects of non-metallic inclusions in the matrix of gear steels on the tooth root bending strength.

Basics

The cracking mechanism of shotpeened gears is different from that of un-peened gears. Due to high beneficial, compressive residual stresses in the area near to the surface, the critical stress for crack initiation lies below the surface. In the event of a non-metallic inclusion in this area, the stress is increased even more due to local stress step-up.

A typical crack area caused by a crack initiation at a non-metallic inclusion is illustrated (Fig. 1). This kind of crack mechanism is known as "fish-eye-failure" because of the typical appearance. Typically, a non-metallic inclusion is surrounded by an optically dark area (ODA)—also known as granular bright face (GBF) or fine granular area (FGA). As soon as the fish-eye reaches the surface, the crack propagates rapidly through the

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rest of the material and the part fails.

Non-metallic inclusions in gear steels. In gear steels such as 16MnCr5 and 18CrNiMo7-6, the common non-metallic inclusions are manganese sulphides in the case of MnCr-alloyed steels and aluminum oxides in the case of CrNiMo-alloyed steels. The shape of manganese sulphide inclusions is primarily oblong, while the shape of aluminum oxide inclusions is primarily spherical (Refs. 7–8).

The cracks are primarily initiated at non-metallic inclusions, so the fewer the number and the smaller the inclusions, the lower is the probability of crack initiation at such inclusions. In the case of MnCr-alloyed steels, the cracks are primarily initiated at manganese sulphide inclusions (Fig. 2a); in the case of CrNiMo-alloyed steels the initiators primarily occur at aluminum oxide inclusions (Figs. 2b and 2c) (Refs. 7–8).

Test rigs. To substantiate the model approach, extensive experimental tests were performed on FZG back-to-back test rigs with a center distance of a = 91.5 mm (Ref. 14) and on pulsator test rigs (Ref. 8). The FZG back-to-back gear test rig utilizes a recirculating power loop principle (Fig. 3a) to supply a fixed torque to a pair of test gears in the test gearbox. A three-phase asynchronous electric motor drives the test rig at a constant speed. Test pinion and test gear are mounted on two parallel shafts that are connected to a drive gear stage with the same gear ratio. The shaft of the test pinion consists of two separate parts connected by a load clutch. A defined static torque is applied by twisting the load clutch. The torque can be controlled indirectly at the torque-measuring clutch by twisting the torsion shaft. (Ref. 10)

On the pulsator test rig the test gear is fixed over, for example, four teeth between two clamps (Fig. 3b); a defined mid-load is applied by the mid-load actuator. The variable exciting mass, pole spring, and upper clamp are excited by the exciting magnet to test the test gear. To obtain a uniform load distribution for all tests, the clamping was always symmetrical and fine flank angle deviations were adjusted. (Ref. 19)

Test gears. The test gears were made of the steel grades 16MnCr5, 20MnCr5 and 18CrNiMo7-6, supplied by various steel manufacturers with a higher degree of cleanliness than common grades. The cast processes, ingot, and continuous casting were used in combination with metallurgic processes such as open-melted or electro-slag re-melt (ESR). A few special grades, such as aluminum-free, complete the test matrix. A total of 17 different steel variants were tested in three gear sizes.

The test gear sizes used were $m_n = 1.5$ mm, $m_n = 5$ mm and $m_n = 10$ mm; an excerpt of the gear data is listed in Table 1. All three test gear sizes were tested on the pulsator test rig. Tests on the FZG back-to-back test rig were performed with module $m_n = 1.5$ mm gears only.

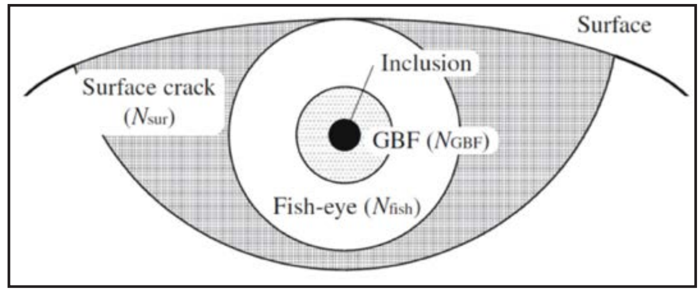
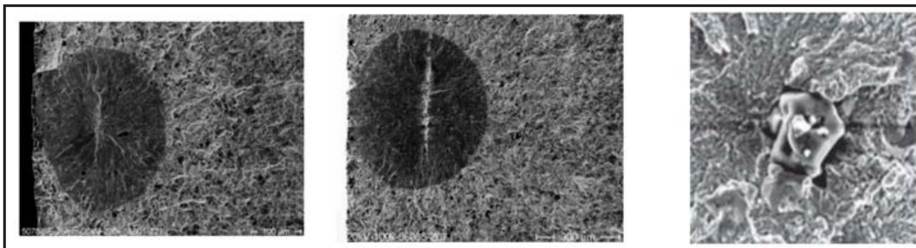


Figure 1 Schematic illustration of sub-surface crack growth around a non-metallic inclusion (Ref. 9).

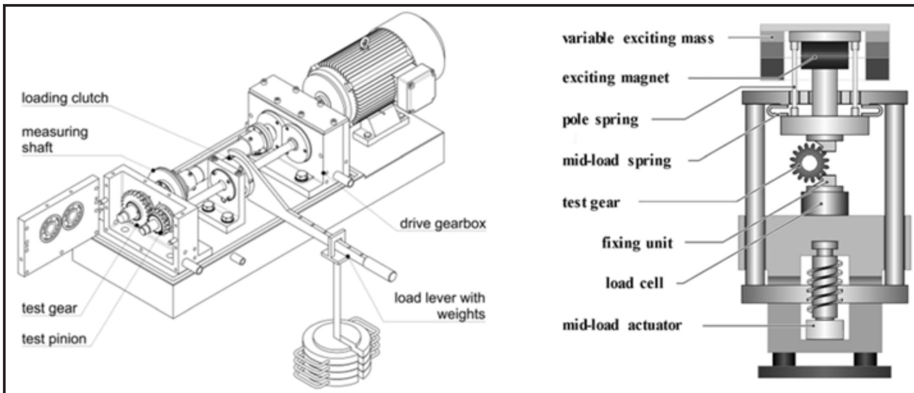


a) Oblong manganese sulphide inclusion in a MnCr-alloyed steel

b) Oblong aluminium oxide inclusion in a CrNiMo-alloyed steel

c) Spherical aluminium oxide inclusion in a SAE52100 (4)

Figure 2 Typical non-metallic inclusions in gear steels.



a) FZG back-to-back test rig with a centre distance of a = 91.5 mm (14)

b) Pulsator test rig (8)

Figure 3 Test rigs at the Gear Research Centre (FZG) at the Technical University of Munich (TUM).

Table 1 Excerpt of the test gear data (Refs. 7–8)

normal module in mm	$m_n = 1.5$		$m_n = 5$	$m_n = 10$
test rig	FZG back-to-back test rig	Pulsator test rig		
center distance	91.5 mm	–		
tooth number z_1/z_2	59 / 61		24	
gear width	8		30	
standard pressure angle	20°			
helix angle	0°			

A scanning electron microscope (SEM) and an energy-dispersive X-ray spectrometer (EDX) were used to analyze the non-metallic inclusions in the fractured surfaces. Amongst other things, the area and distance from the surface of the non-metallic inclusions were analyzed (Fig. 4).

Measured distances from the surface were between 77 µm and 1,377 µm across all the gear sizes tested. The average for the gears with module $m_n = 1.5$ mm was 138 µm; for module $m_n = 5$ mm 227 µm; and for module $m_n = 10$ mm 1,067 µm. In the current research all of the non-metallic inclusions that were responsible for causing a failure were located within the case hardened layer (Fig. 5).

The parameter $\sqrt{area}$ used in the theoretical approach of Murakami (Ref. 2) is the square root of a defect area projected onto a plane perpendicular to the applied stress (Fig. 6). It shows an internal crack in the x–y plane of an infinite solid that is subject to a uniform remote tensile stress σ_0 in the z-direction.

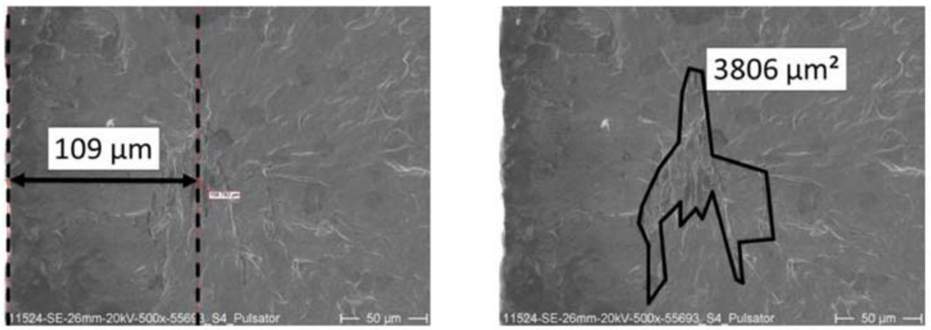


Figure 4 Typical analysis of the characteristics of a manganese-sulphide non-metallic inclusion.

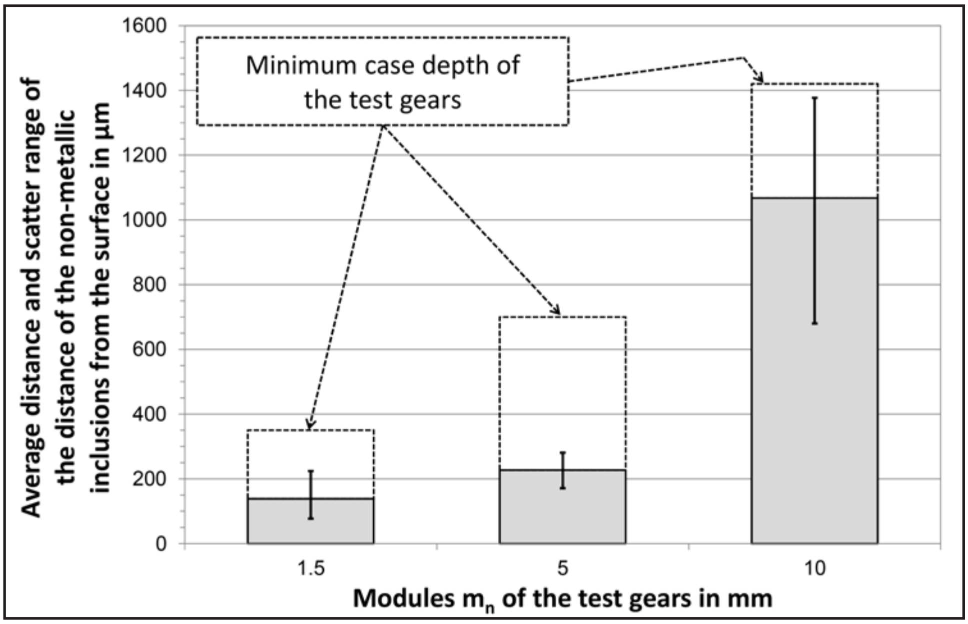


Figure 5 Average distance and scatter range of the distance of the non-metallic inclusions from the surface and comparison with the minimum case depth of the three test gear sizes.

Model Approach

The local material strength ratio $\sigma_{inclusion}/\sigma_A$ — which defines theoretically whether crack initiation occurs or not — is the ratio of the local stress at the non-metallic inclusion $\sigma_{inclusion}$ to the local bending fatigue strength σ_A (Fig. 7). However, certain input factors are necessary for calculation and these are presented below.

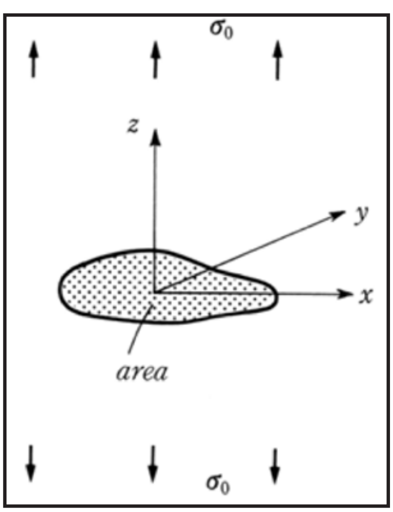


Figure 6 Arbitrarily shaped 3D internal crack ("area" = area of crack) (Ref. 2).

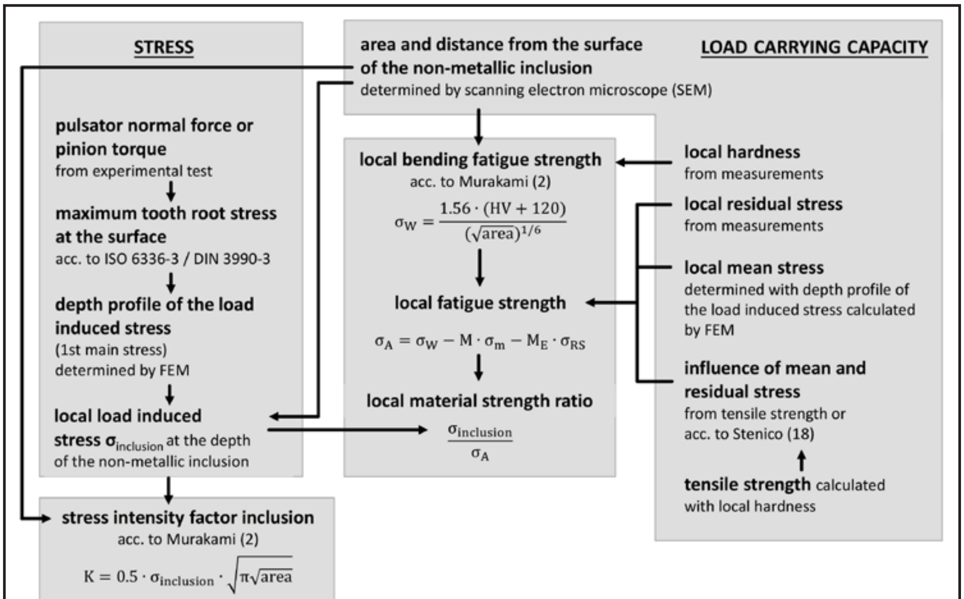


Figure 7 Schematic diagram of the procedure of the calculation study (Ref. 7).

Determination of local stress at the non-metallic inclusion: $\sigma_{inclusion}$. A number of steps are required to determine local stress at the non-metallic inclusion $\sigma_{inclusion}$. First, in accordance with ISO 6336-3 (Ref. 15) or DIN 3990-3 (Ref. 17), the maximum tooth root stress at the surface σ_F must be calculated according to Equation 1, based on the pulsator normal force or pinion torque.

$$\sigma_F = \sigma_{F0} \cdot K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha} \tag{1}$$

Next, the depth profile of the load stress (1st main normal stress), determined using the finite element method (FEM) (Fig. 8), is required to convert the value at the surface to a value at the specific local distance from the surface of the non-metallic inclusion. The local distance is determined by examination of the fractured surface of the broken tooth using the scanning electron microscope (SEM). These input factors form the local stress at the non-metallic inclusion.

Determination of the local fatigue strength: σ_A. The local bending fatigue strength σ_W according to Murakami must be determined based on Equation 2, using the measured area of the non-metallic inclusion $\sqrt{\text{area}}$ and the local Vickers hardness *HV*—which are both determined by measurement.

$$\sigma_W = \frac{1.56 \cdot (HV + 120)}{(\sqrt{\text{area}})^{1/6}} \tag{2}$$

By considering the local mean stress σ_m and residual stress σ_{RS} the local bending fatigue strength σ_W can be reassessed using the Goodman approach to form an equivalent local fatigue strength σ_A (Eq. 3). To do so, the local hardness and the local residual stress must be measured. Based on a depth profile of the load-induced specific local stress determined using FEM, the local mean stress σ_m is calculated. The influence of the mean and residual stress is evaluated by the tensile strength respectively, according to Stenico (Ref. 18); the tensile strength is calculated using the local hardness.

$$\sigma_A = \sigma_W - M \cdot \sigma_m - M_E \cdot \sigma_{RS} \tag{3}$$

On the basis of comparable case hardness and core hardness of the steel used and previous investigations (Refs. 12, 18) the parameters $M = 0.3$ and $M_E = 0.2$ were used.

Results

As described in the previous section, the non-metallic inclusions were investigated and measured using a SEM and the stress intensity factor *K* calculated according to Equation 4. The stress intensity factor *K* is plotted against the number of load cycles *N* until failure (Fig. 9).

$$K = 0.5 \cdot \sigma_{inclusion} \cdot \sqrt{\pi \cdot \sqrt{\text{area}}} \tag{4}$$

The results show that with decreasing local stress step-up, i.e. a smaller inclusion size and/or local stress, the number of load cycles *N* until tooth root failure increases. Crack propagation is slower at greater distances from the surface of the non-metallic inclusion, or if the local stress is lower and therefore the high cycle fatigue lifetime increases.

Based on the extensive experimental data, an asymptotic trend and consequently a limiting threshold of the stress intensity factor *K* are to be expected. The results are also in agreement with other research (Refs. 2, 3, 6 and 18). The aluminum-free variant *S3* differs from the other variants. This can be explained by the specific production route, as well as the

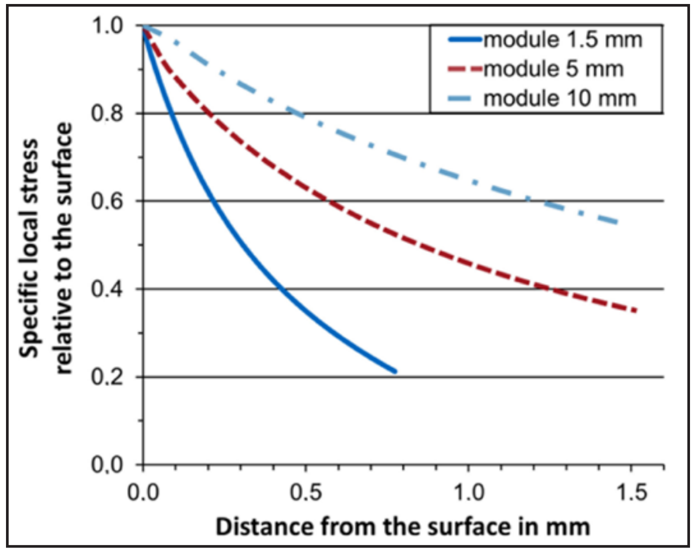


Figure 8 Depth profile of the load-induced specific local tooth root stress relative to the surface determined using the finite element method (1st main stress) (Ref. 7).

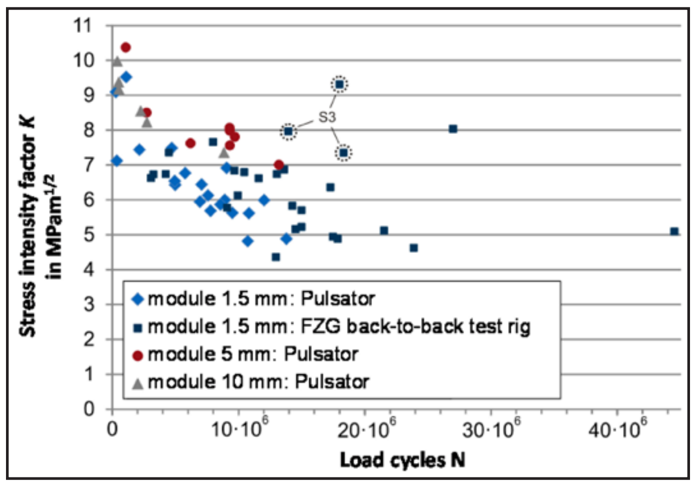


Figure 9 Estimation of the local stress intensity factor K according to Murakami (Ref. 2) plotted against the experimentally determined number of load cycles N until tooth root failure (Ref. 7).

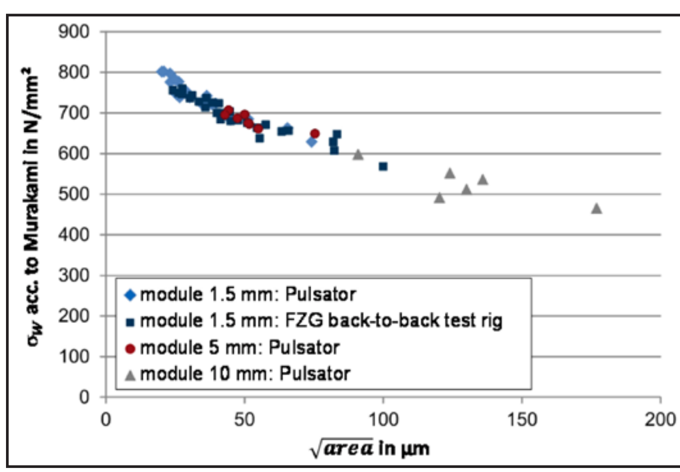


Figure 10 Estimated local bending fatigue strength σ_W taking into consideration of non-metallic inclusions according to Murakami (Ref. 2) for the experimentally performed tooth root load carrying capacity tests (Ref. 7).

special heat treatment.

According to Equation 2, a local bending fatigue strength σ_w for each determined failure can be estimated by taking into consideration the hardness depth profile and the local hardness near the non-metallic inclusion (Fig 10). The results indicate that with increasing inclusion size ($\sqrt{area}$), the local bending fatigue strength σ_W decreases in agreement with Murakami (Ref. 2).

An estimation of the local fatigue strength σ_A according to Equation 3 is possible based on the approach of Macherauch and Wohlfahrt ((Refs. 1, 11) according to (Ref. 6)), taking into consideration the existing mean stress and residual stress. The local material strength ratio $\sigma_{inclusion}/\sigma_A$ is plotted against the number of load cycles N until failure in Figure 11.

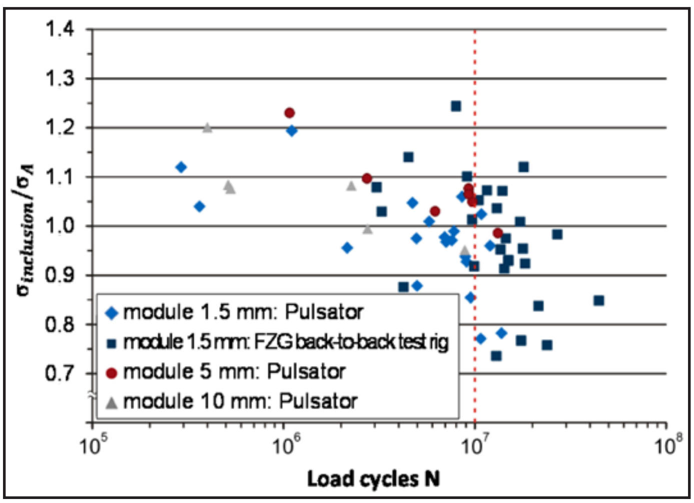


Figure 11 Local material strength ratio $\sigma_{inclusion}/\sigma_A$ plotted against the number of load cycles N until failure; load cycle limit of 10^7 according to Murakami (Refs. 2 and 7).

Most of the tests with load cycles below 10^7 comply with the common knowledge of the strength of materials and the model approach according to Murakami (Ref. 2). A crack initiation can occur when the local material strength ratio $\sigma_{inclusion}/\sigma_A$ is greater than 1. Almost all data points for $N < 10^7$ are in the range 1.0 ± 0.1. Only when the number of load cycles is greater than 10^7 does an increased number of test points fall outside this range that is below 0.9. However, it should be noted that the model used according to Murakami firstly only has a test accuracy of ±10% and is only valid up to 10^7 load cycles. According to Murakami, the optically dark area (ODA) must also be considered for higher numbers of load cycles (Ref. 5).

The results show that, in general, the model approach developed by Murakami (Ref. 2) can be applied to high-strength gears and that a direct correlation between the tooth root load carrying capacity and the degree of cleanliness of high-strength gears exists.

Conclusion

In modern engineering, surface strengthening of gears and increased cleanliness of gear steels have become more important. However, a resulting drawback is that cracks initiate more frequently at non-metallic inclusions, and not at the surface. In standardized calculation methods such as ISO 6336-3 (Ref. 15) or DIN 3990-3 (Ref. 17), the degree of cleanliness of gear steels is not currently directly correlated to the tooth root load carrying capacity.

It can be shown that, subject to a few restrictions, an approach for correlating between the cleanliness of gear steels and the resulting tooth root load carrying capacity based on the theoretical approach of Murakami (Ref. 2) is now possible. The results of the current research work show good agreement with the research work of Murakami. However, validation of the scatter range would be beneficial. The model approach for Murakami for $N > 10^7$ is basically applicable to gears; however, further research work is necessary.

Acknowledgment. *The present research work (Ref. 7) was equally funded by the "Arbeitsgemeinschaft industrieller Forschungsvereinigungen e.V. (AiF)," the German Federal Ministry of Economics and Technology (BMWi, IGF no. 16662 N) and the "Forschungsvereinigung Antriebstechnik e.V. (FVA)." The results shown in this work were taken from the research project FVA 293 III "Späte Zahnfußbrüche/Reinheitsgrad" (Ref. 8). More detailed information on the influence of non-metallic inclusions is given in the final report.*

The research work of (Ref. 18) was equally funded by the "Forschungsgemeinschaft der Eisen und Metall verarbeitenden Industrie e.V. (AVIF)" and the "Forschungsvereinigung Antriebstechnik e.V. (FVA)". The results shown in this work were taken from the research project FVA 293 II "Späte Zahnfußbrüche" (Ref. 13). More detailed information on the influence of non-metallic inclusions is given in the final report.

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Prof. Dr. Karsten Stahl is Chair, Machine Elements, Mechanical Engineering, at TUM. He leads and conducts research in the area of mechanical drive systems, with particular interest in investigating the load capacity, efficiency and dynamics of all gears types. His other areas of interest include applications in automotive engineering such as synchronization systems and multi-disc clutches. Stahl has developed methods for analysis that have been incorporated into international standards, together with the component strength values derived by means of these methods. He studied mechanical engineering at TUM and performed his doctoral studies from 1994 to 2000 in the Machine Elements Department. In 2001, he joined BMW, first as a gear development engineer, then as the manager of gear development in Dingolfing. In 2006 he transferred to the MINI plant in Oxford where he was initially quality manager for transmissions, then quality manager for powertrains and suspensions. In 2009 he took over responsibility for the initial development and innovation management of powertrain and vehicle dynamics systems at BMW in Munich. Stahl has been a full professor in the Machine Elements Department since 2011.

Electric Vehicle Whine Noise — Gear Blank Tuning as an Optimization Option

Owen Harris, Paul Langlois and Andy Gale

Introduction

Noise issues from gear and motor excitation whine are commonly faced by many within the EV and HEV industry. In this paper we present an advanced CAE methodology for troubleshooting and optimizing such NVH phenomenon. Experience has shown that to achieve good NVH behavior in such a challenging environment requires a combination of optimization options. A traditional focus on gear micro geometry to minimize TE alone is often seen as not sufficient for achieving the desired targets. Rather all aspects of the noise phenomenon including, amongst others, gear macro geometry, micro geometry, system dynamics, transfer paths, damping and acoustic isolation should be considered. Given the multiple optimization options, multiple objectives and often stringent timescales, a high-fidelity analysis model can be critical in assessing the effects of design changes in the allowable timeframe while minimizing hardware and testing loops. Here we focus on an example using gear blank dynamic tuning as an optimisation option for gear whine dynamic performance.

As a transmission engineering services provider, we are seeing increased and sustained interest in the analysis and optimization of transmissions for whine noise issues. This is particularly the case with the EV and HEV market where there is no, or less, IC engine noise to mask any other noise sources. Further, ever-increasing standards and expectations are pushing noise targets to even more stringent levels. In this dynamic and still-developing market, jumps to new configurations with less incremental development and an abundance of new market entrants with less long term automotive experience are further contributing to these issues. This highly competitive market atmosphere further drives development to tighter and tighter timescale targets. As a result, there is an ever-increasing need for advanced CAE tools that can help design and optimize for noise performance throughout the development cycle, and significantly reduce hardware and testing loops.

In this paper we present an advanced CAE process — available in SMT's *MASTA* software — for the design and analysis of transmission systems, with a specific focus on the EV automotive market. We introduce a specialist full transmission system analysis model that considers all the multiple performance targets of interest within the design process. Static deflections of the system, durability, efficiency and frequency and time domain dynamics can all be considered. The focus of this paper is gear whine simulation in the frequency domain.

Following an introduction to the analysis model a design optimization option for NVH is discussed. Gear blank dynamic tuning involves changing the dynamics of a gear blank via geometry changes to rim and web to reduce the dynamic mesh force at the gear mesh and subsequently reduce the vibration/noise response of the system. The fundamentals of gear blank tuning are introduced; a novel, automated process implemented within the CAE tool is then discussed. An example is demonstrated of the dynamic tuning of the gear blank of one stage within a typical two-stage helical automotive EV transmission.

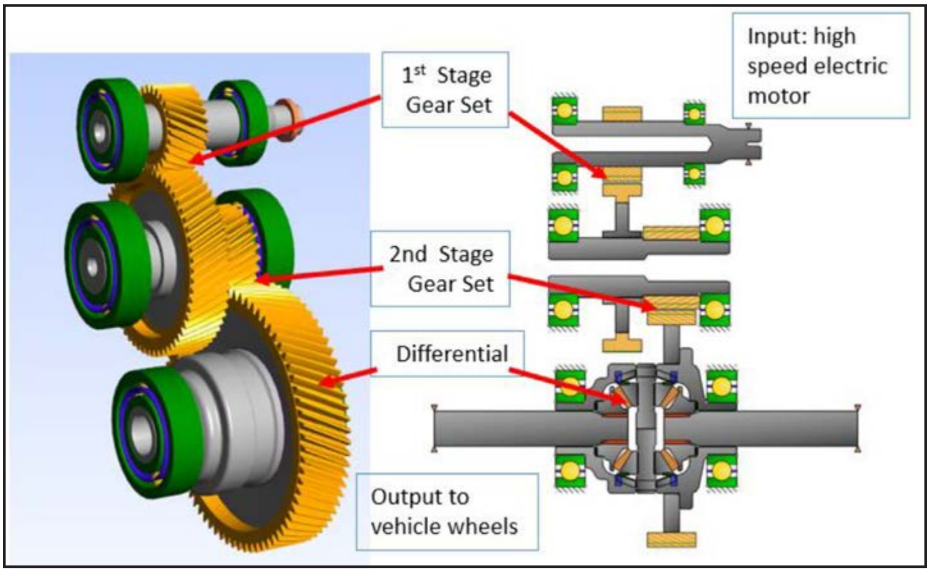


Figure 1 Typical two-stage helical E-Drive transmission.

Whine Noise in Electric Vehicles

EVs have a range of different noise sources. Excitation from transmission error at the gear meshes, torque ripple, and radial out of balance at the rotor, dynamic tangential and radial forces at the stator teeth of the motor, and switching frequencies of the controller can all lead to irritating tonal noises within the vehicle as the frequency of excitation crosses certain resonances of the mechanical system.

One classic E-Drive architecture with some mature and competing products within the market consists of a permanent magnet motor connected to a two-stage helical speed-reducing transmission to provide the required torque to the wheels (Fig. 1). Some mature products with this architecture and their maximum quoted operating speeds include the Nissan LEAF (10 K rpm), Borg Warner eGear (14 K rpm), and the GKN eTransmission (15 K rpm). Although many other architectures are available in the marketplace — and are currently being developed — the simplicity and low cost of this single-speed solution is still very attractive.

Motor speeds within this group range up to 15,000 rpm. Speeds are being pushed higher and higher in current and planned future developments driven by the benefits for the motor. High-speed motors can be designed smaller for the same power output with higher power-to-weight ratios. For permanent magnet (PM) machines, smaller, higher-speed motors require less magnets — thus leading to significant cost reductions.

The evolution towards higher-speed motors has led to higher and more challenging demands on the transmissions required to reduce the speed and increase the torque to the wheels. The design challenges, including those for NVH performance, require significant engineering tools and ingenuity to be overcome.

Figure 2 shows typical noise and vibration responses for a mature EV.

The vibration results show clear gear orders and their harmonics, motor orders, and higher-frequency "fans" due to controller PWM switching frequencies. A potential resonance is seen at around 4,500 Hz. Within the driver's ear noise measurements only the gear orders are visible, but are also mostly masked by other noise sources, such as road noise.

Figure 3 shows order cuts through the gear and motor orders of the noise results in Figure 2.

A small region of high 1st stage gear order can be seen. An interesting question that arises is how to quantify gear noise objective targets; here the difference between total noise and gear order noise is greater than 20 dBA. The maximum absolute gear order noise is approximately 37 dBA. By studying the tone-to- noise ratio of the peaks on the order lines, one can see if they show up as prominent tones that will be heard above external noise. In this case all the peaks — including the one circled in red in Figure 3 — pass the criteria set out in ECMA-74 and so won't be heard as distinct tones during a speed sweep of the motor. This result may be expected for a mature product such as this.

Advanced CAE Methodology for Whine Simulation

To design for good NVH performance, or to solve NVH problems, a combination of experience and the right tools are required to find solutions with minimal cost and timescale. CAE tools have been typically used within this process for system model static analysis and prediction of gear misalignments, gear macro and micro geometry design for low transmission error (TE), and transmission mount tuning to limit structure-borne noise.

With the increasing complexity and higher demands of the modern EV market, more attention also needs to be paid to system dynamics. A high-fidelity model can be used to investigate in detail

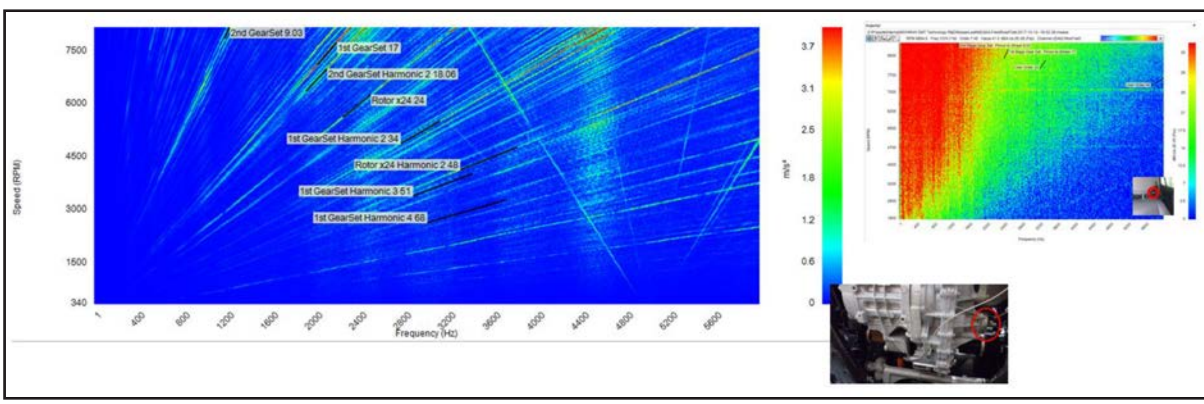


Figure 2 Typical vibration responses and noise at driver's ear for a mature EV.

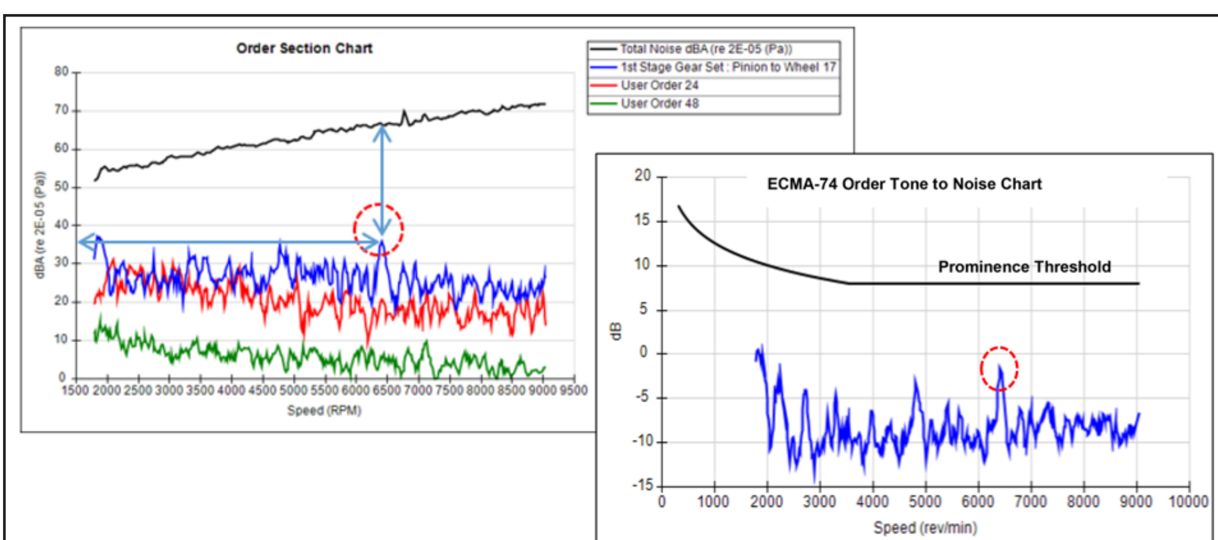


Figure 3 Order cuts of noise response at driver's ear for a mature EV, and associated tone to noise chart for the 1st stage gear order.

the full dynamic system and to tune for low dynamic transmission of vibration and noise sources.

The model used in this study consists of a fully integrated, mechanical FE-based model of the motor and transmission system (Ref. 1) (Fig. 4). Within the analysis model, shafts are included as Timoshenko beams or full solid FE representations. Gear blanks, gearbox casing and motor casing — including the motor stator — are included as full-solid FE models. Bearings and gear mesh contacts are included as bespoke nonlinear stiffness models. The model can be used to run static, frequency domain dynamic, and time domain dynamic analyses.

Here we focus on the frequency domain harmonic response of the EV gearbox model to excitation by gear TE, motor torque ripple, and stator tooth harmonic forces.

For excitation of the model by TE in the frequency domain a standard assumption is made that the excitation is the static transmission error. The static transmission error is calculated via a hybrid Hertzian- and FE-based tooth contact analysis model (Ref. 2), and introduced to the dynamic system level model as an enforced relative displacement in the line of action at the gear mesh. Taking care to recall that transmission error is defined in the transverse line of action, whereas the relative displacement is to be applied normal to the flank, i.e. — normal to the helix. The static TE is enforced into the model using a method well documented by Steyer et al (Refs. 3–4). First the dynamic compliances are calculated on either side of the gear mesh. The compliance at one side is calculated by applying a unit harmonic force in the line of action at that side and calculating the resulting harmonic displacement at the mesh in the line of action. The total compliance is then calculated as the sum of pinion and wheel side compliances. The dynamic mesh stiffness is calculated as the inverse of the mesh compliance. The dynamic mesh force for a given harmonic of TE is then calculated as the product of the TE and the dynamic stiffness.

$$C_{mesh}(\omega) = C_p(\omega) + C(\omega)$$
$$D(\omega) = (C_{mesh}(\omega))^{-1}$$
$$Fi(\omega) = D(\omega)\,\delta_i$$

Where:

$C_{p,w}(\omega)$ — Dynamic compliance in the line of action at the mesh, at the pinion (p) and wheel (w) sides, at frequency ω

$C_{mesh}(\omega)$ — Total compliance at the mesh in the line of action

$D(\omega)$ — Dynamic mesh stiffness in the line of action

$F_i(\omega)$ — Dynamic mesh force for the ith harmonic of the TE

δ_i — The ith harmonic of the TE — transformed normal to the flank, normal to the helix

At a specified frequency the dynamic mesh force can be considered to be the harmonic force required to be applied both equally and opposite at the gear mesh in the line of action, such that the resulting relative displacement in the line of action at the mesh is given by the static transmission error. The dynamic mesh force is calculated and applied to the FE model for a sweep of input speeds to give the dynamic response of the whole system.

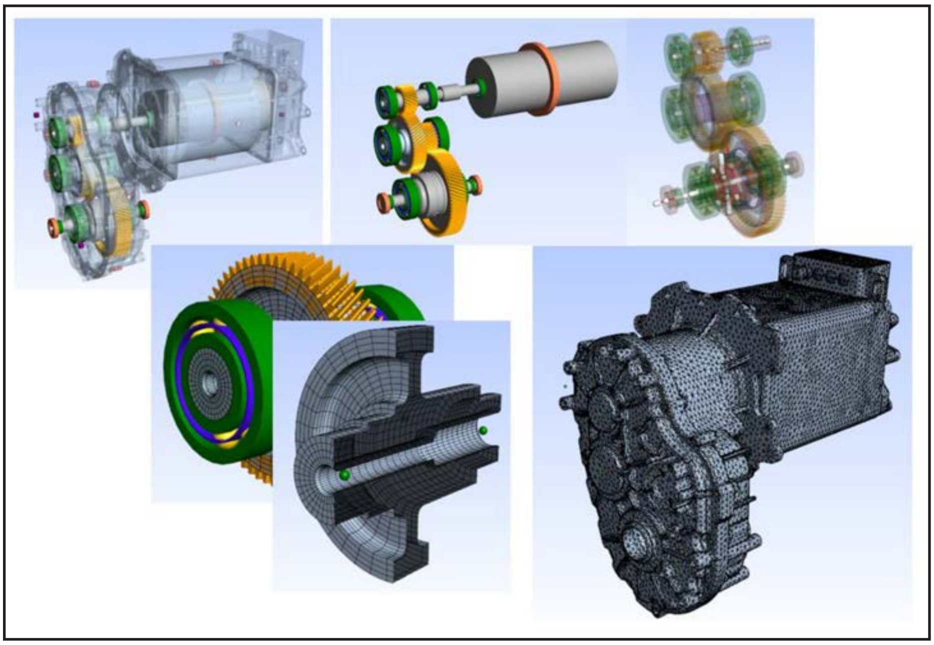


Figure 4 FE-based bespoke EV system analysis model.

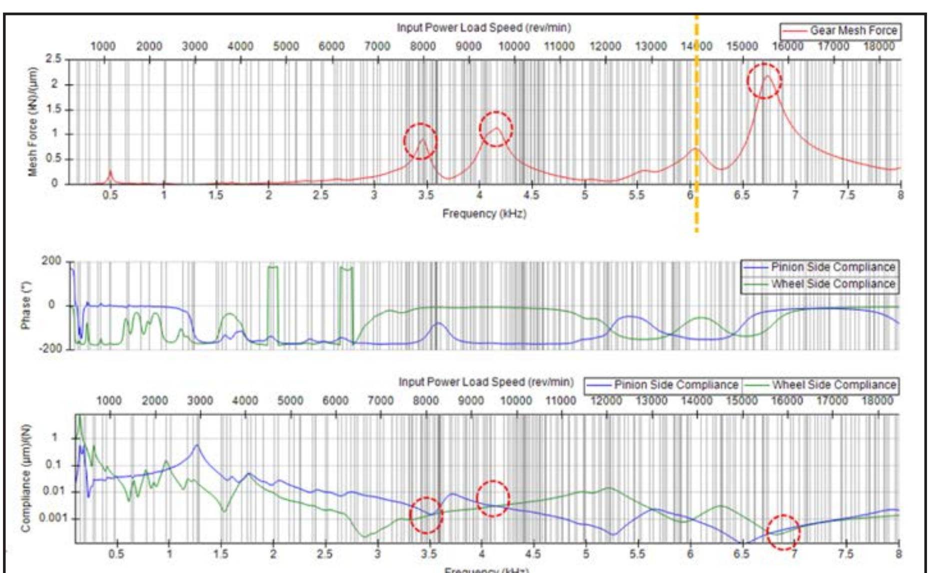


Figure 5 Dynamic mesh force peaks where compliances are equal in magnitude and opposite in phase. The dotted line is the maximum operating speed of this transmission of 14,000 rpm.

As this is a frequency domain analysis it is fast and lends itself well to design optimization. The understanding of the dynamic compliances at the gear mesh and their relation to the dynamic mesh force enables a mechanism for tuning the dynamics to decrease the dynamic mesh force. Gear mesh force peaks occur when the compliances on either side of the mesh are equal in magnitude but opposite in phase (Fig. 5).

Understanding how the compliances are made up helps in optimizing the dynamics. The high-fidelity model had many degrees of freedom and therefore many modes. Only a small number of key modes with respect to the pinion and wheel sides control the compliances. The gear blank modes in particular in this transmission architecture are seen to be very involved in the wheel side compliance (Fig. 6).

The gear blank modes can be tuned to try to avoid high gear mesh forces within the operating range. It is important, however, to also check transfer paths as well, using predicted bearing and housing responses. A change in gear blank dynamics influences both the dynamic mesh force and the transmission of that force through the system.

The excitation from the electric motor is applied to the model in a simpler way than the transmission error. A third-party electric motor analysis tool is used to calculate the dynamic forces at the rotor and stator teeth at several speed operating points. These forces are imported into the mechanical motor and transmission model. For a given speed the imported forces are interpolated and applied as harmonic forces directly to the model. The response to the forces from the motor and the TE are calculated within the same analysis (Fig. 7).

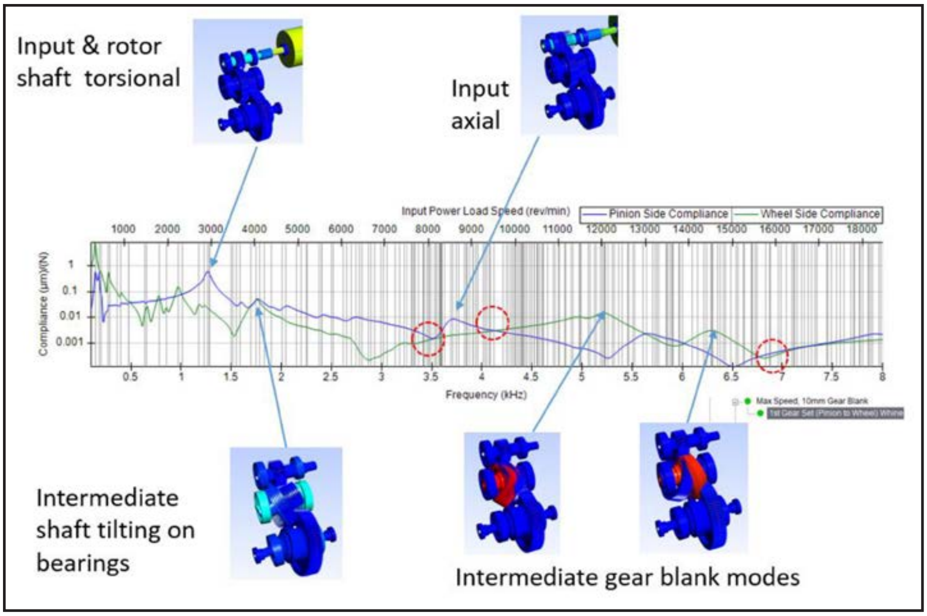


Figure 6 **Gear blank mode influence on wheel-side compliance.**

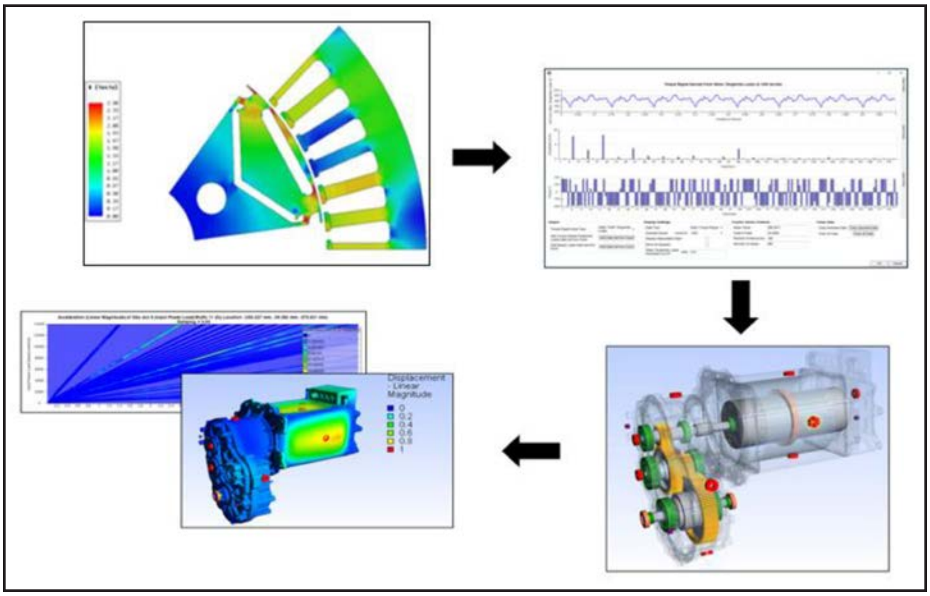


Figure 7 **Electric motor forces calculated from a motor analysis tool and imported to the mechanical motor and transmission model.**

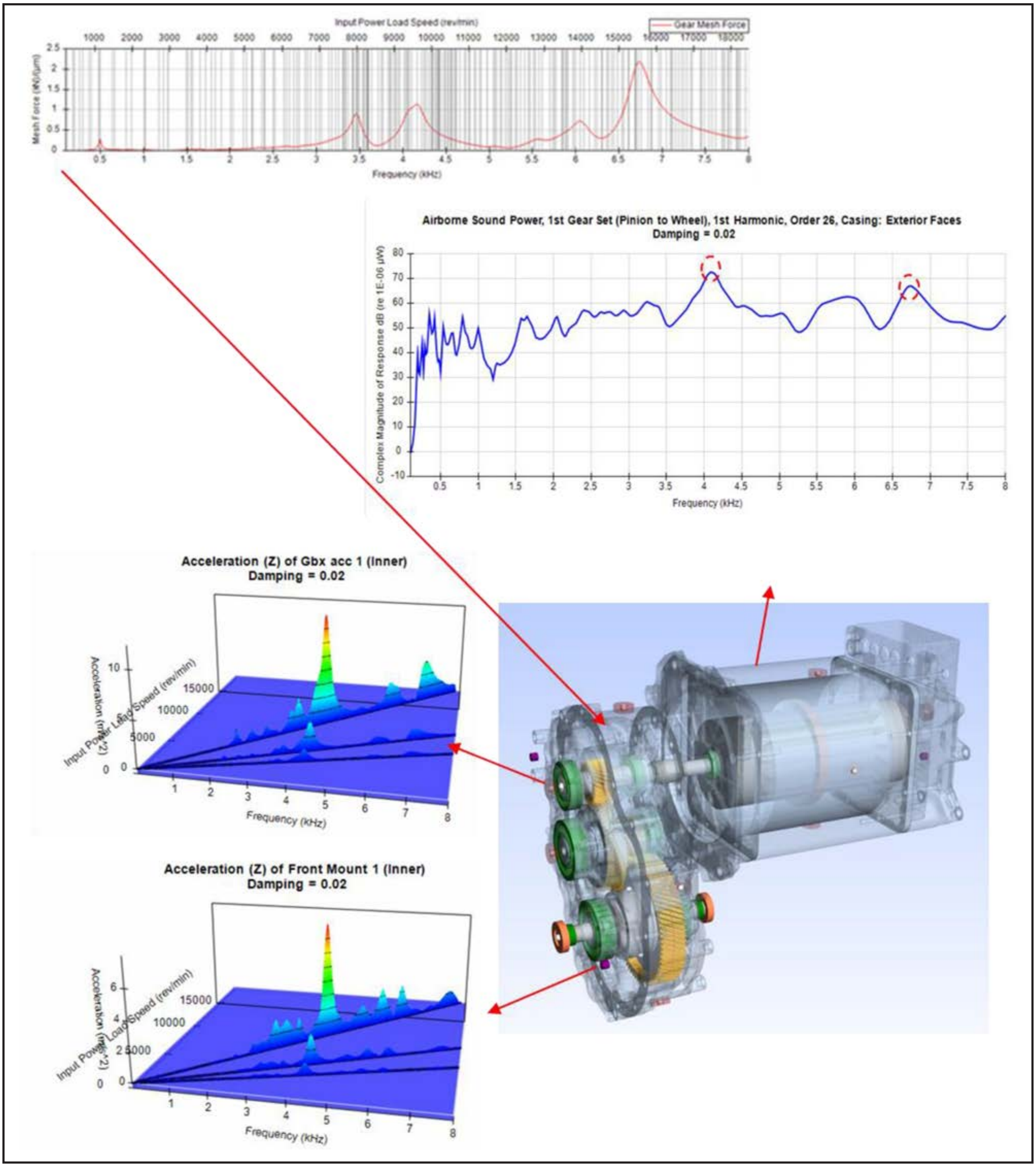


Figure 8 System response to TE and electric motor excitation.

The system response to the transmission error at the gears and harmonic excitations from the motor can be checked at different locations in the model (Fig. 8). Typical metrics for assessing system response include the bearing dynamic response, casing accelerations (which are often compared against accelerometer tests), mount dynamic responses (which give an indication of structure borne vibration), and housing response as sound power via ISO 7849.

Velocity response of the housing can be further exported to acoustic simulation packages for full radiated noise predictions (Fig. 9).

Radiated noise prediction is a slow process and does not fit into typical optimization loops; however, it can provide a high-fidelity check of final design changes.

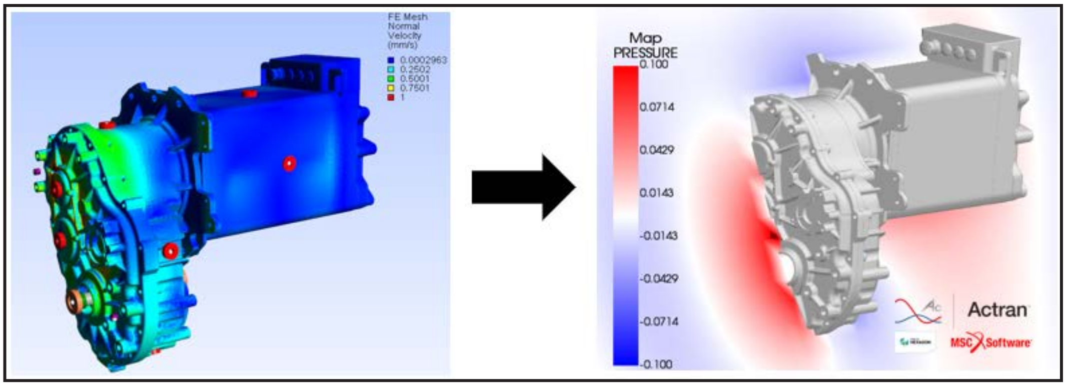


Figure 9 Export of housing velocities and subsequent radiated noise predictions in Actran.

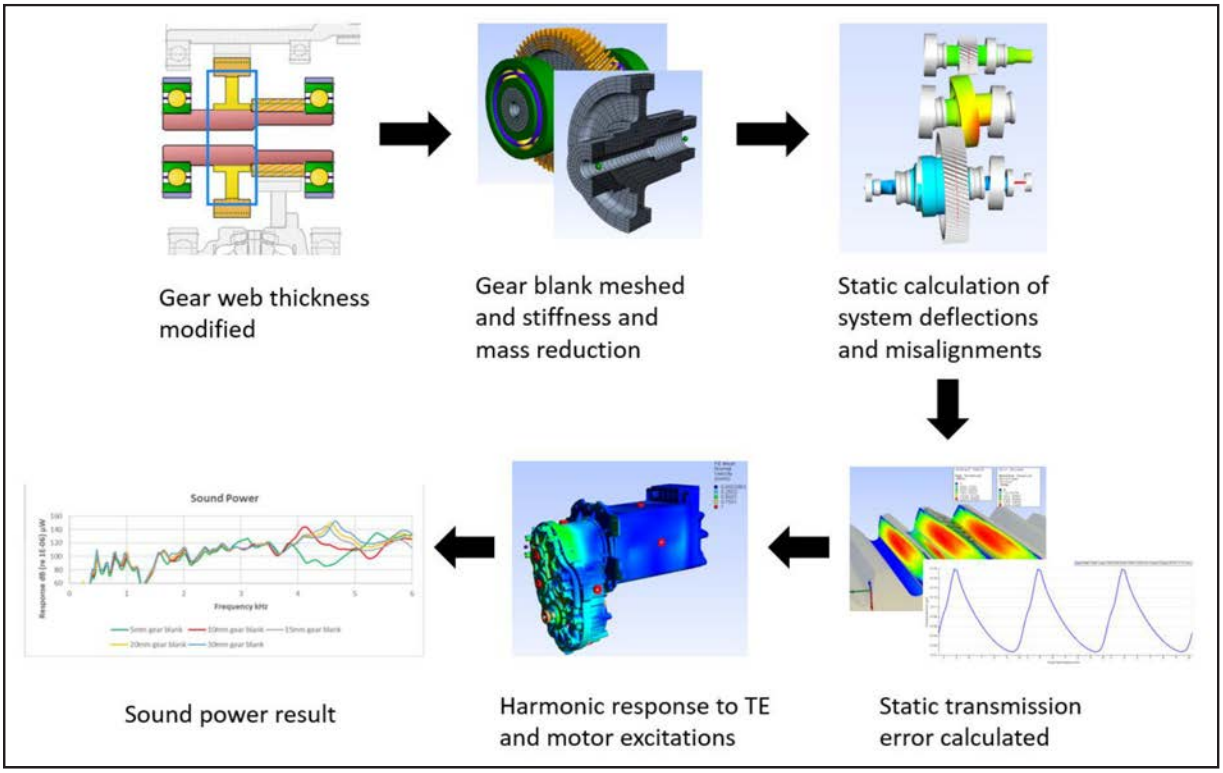


Figure 10 Automated optimization methodology used to investigate the effect of gear blank web stiffness on system dynamics.

Optimization via Automated Gear Blank Dynamic Tuning

The implemented simulation tool and analysis model includes general integrated design of experiments and external batch running capabilities. A huge number of model and analysis parameters are available to these functions, providing a broad range of possibilities for automated design optimization.

In this study such capabilities were utilized for automated optimization of gear blank geometry to minimize dynamic mesh force and system response. Thinner gear blanks are lighter, but may give higher gear mesh misalignments — especially at high loads. Thinner blanks may be beneficial dynamically as they add compliance to the system and can therefore reduce the dynamic mesh force. However, changing the blank dynamics can also change the transmissibility of that dynamic mesh force from gear mesh to housing.

In order to find an optimum gear blank design, a parametric study was set up to modify the web thickness of the blank between 5mm and 30mm, and the rim thickness between 3mm and 15mm. In this process the gear web is modified automatically by the software. The gear blank is then automatically meshed and a stiffness and mass matrix dynamic reduction automatically run in order to capture the dynamics of the gear blank in a reduced model. Static deflection analysis of the system is run to calculate the system stiffness under the specified operating load. The transmission error is then calculated. Frequency response analysis to excitation by transmission error and the electric motor excitations is automatically run and the dynamics results are recorded; Figure 10 shows a workflow of this automated process.

The outcome of this methodology was an optimized gear blank with a web thickness of 11mm and a rim thickness of 3.5mm, chosen for giving the lowest combination of peak results in gear dynamic mesh forces and system dynamic response over the frequency range of interest, while complying with the minimum rim thickness required for the gears' tooth height according to ISO 6336-3.

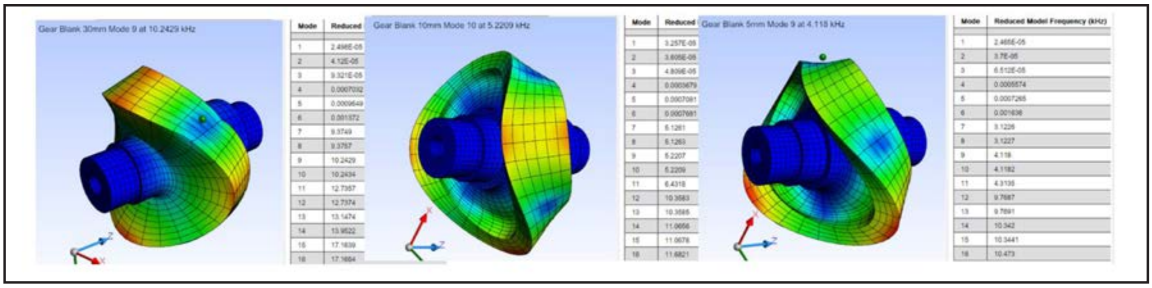


Figure 11 Free-free natural frequencies and first gear blank "potato chip" mode shape. For models with a rim thickness of 12.25 mm and web thickness of 30, 10 and 5 mm.

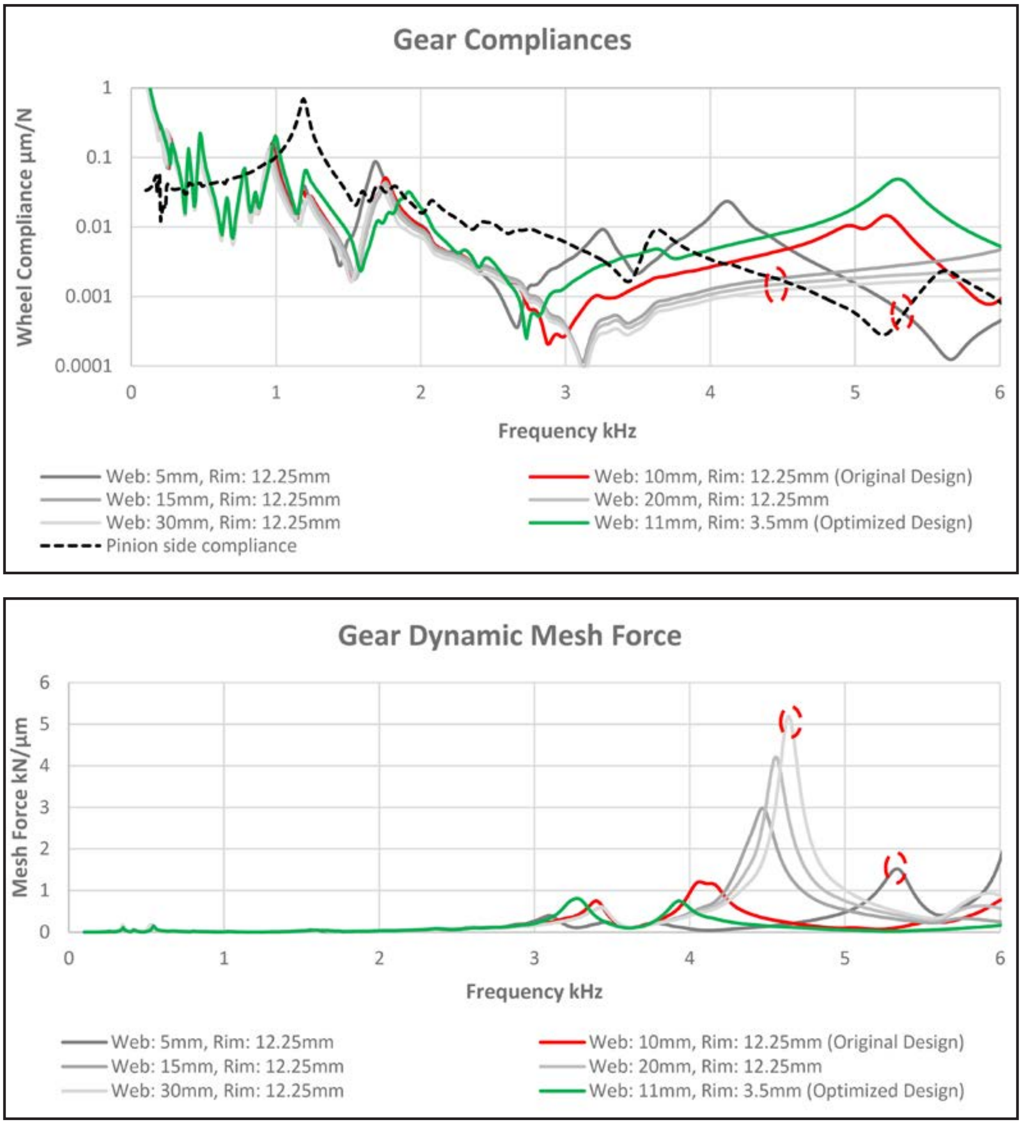


Figure 12 Dynamic compliances and mesh force for different gear blank dimensions.

Figure 13 Gear mesh misalignments for different gear blank dimensions at maximum torque.

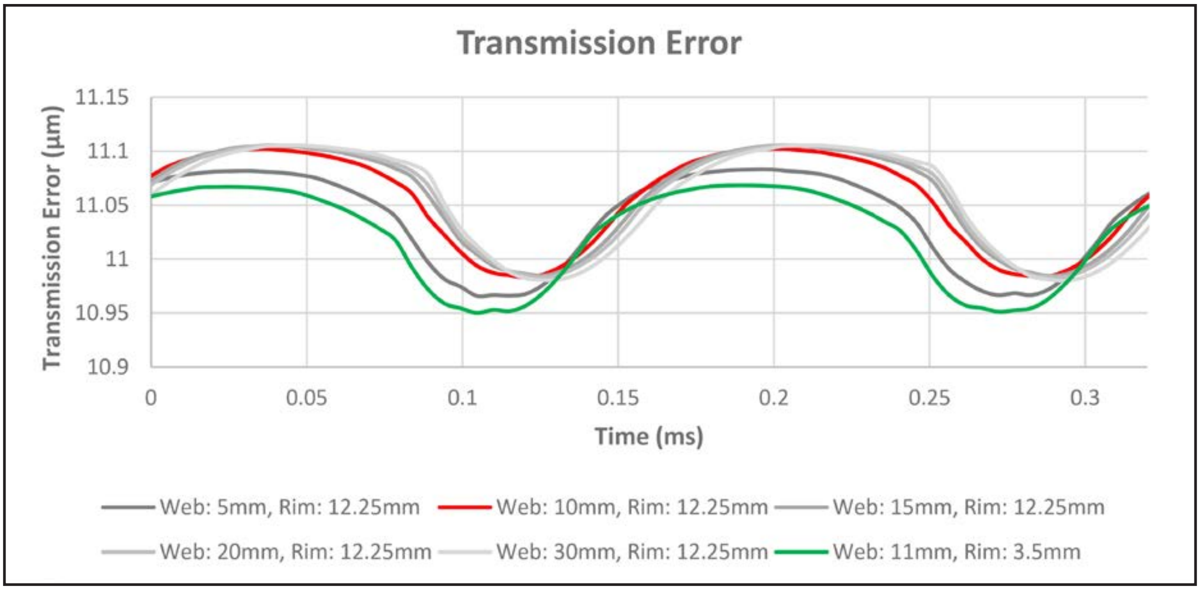


Figure 14 Transmission error for different gear blank dimensions.

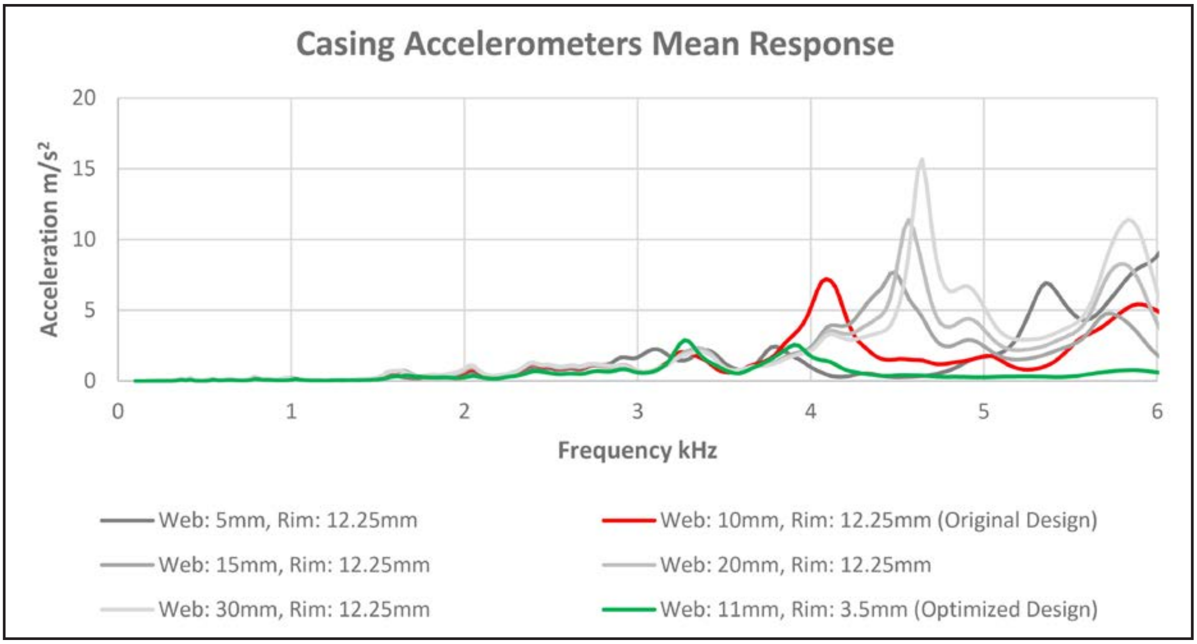


Figure 15 Casing accelerometer mean response for different gear blank dimensions.

In order to give some indication of the blank dynamics it is instructive to look at the free-free modes of the gear blanks first in isolation. Figure 11 shows the natural frequencies and the mode shapes of the first gear blank "potato chip" mode.

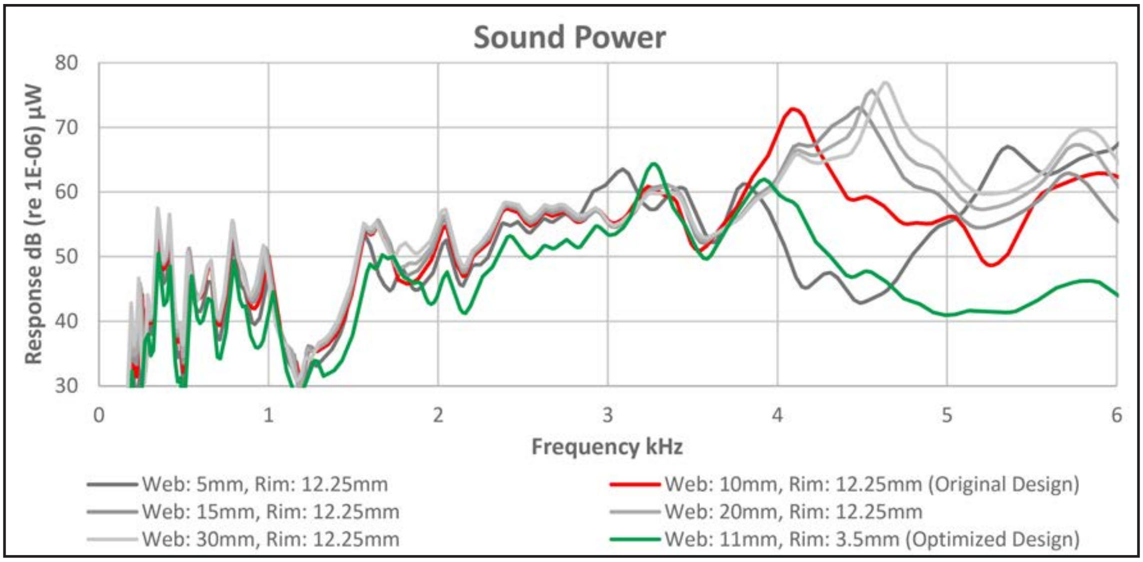
This first mode is important for the dynamics and transmissibility of the TE excitation. For a 30 mm blank the first mode is at 10.24 kHz; for 15 mm it is 7.5 kHz, and for 10 mm it is 5.6 kHz. For the 5mm gear blank there are 5 modes from 3 to 5 kHz.

Figure 12 shows that the change in gear blank dynamics has a very significant effect on the dynamic compliances of the system and the derived dynamic mesh forces.

The thicker and stiffer blanks have potential resonances at higher frequencies, outside the operating range for web thicknesses greater than 15 mm. However, thicker blanks have less compliance, and this gives higher gear dynamic mesh forces within the operating range. The optimum solution provides a good balance of these effects, with an associated decrease in mesh force due to a high compliance from a low rim thickness.

In Figure 13, very thin- or thick-webbed blanks can be seen to have higher misalignments, while in Figure 14 thinner blanks can be seen to have slightly lower transmission errors — but the same peak-to-peak TE values. The optimum solution had the lowest transmission error, but also had a higher misalignment than the wider-rimmed 5 to 30 mm web thickness blanks — one minor drawback to the optimization process. It should be noted here that a single micro geometry design was used for all gear geometries so that the effect of blank changes on the TE could be seen, although in practice the micro geometry would be optimized for every gear geometry.

Figure 15 shows the dynamic response in terms of casing acceleration based on



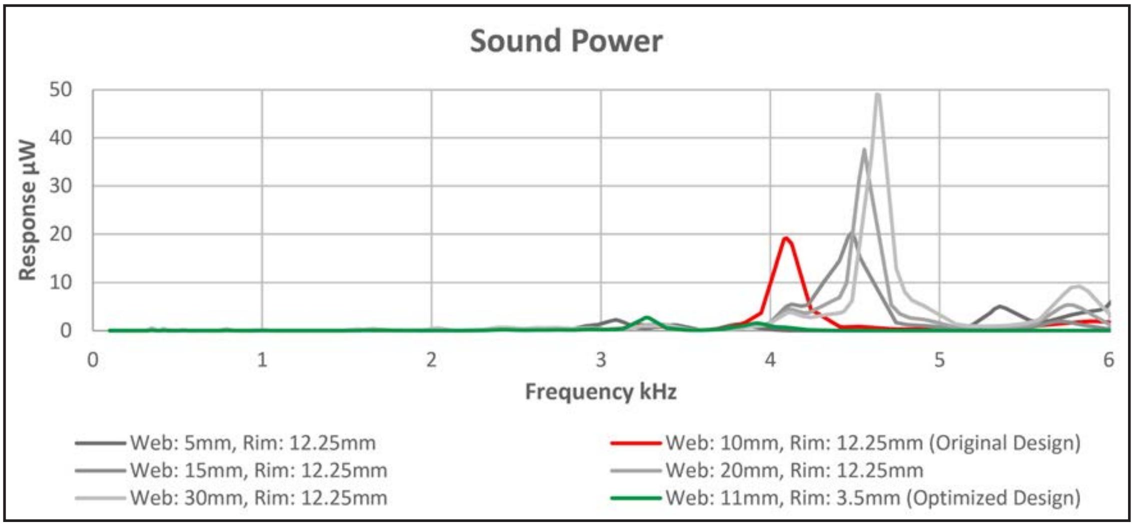


Figure 16 **Casing sound power in logarithmic and absolute scale. Original design (red), optimized design (green). The other lines demonstrate the sensitivity to the web thickness alone**

the mean value of 12 accelerometers at a range of points on the casing for the different gear blank dimensions, while Figure 16 shows the calculated sound power of the casing for the different gear blank dimensions.

Significant reductions are seen in casing acceleration response and sound power for the optimized solution. Comparing Figures 12 and 16, it is seen that in this case the reduction in dynamic mesh force is reflected in the reduction in sound power results at the same frequencies for each gear blank design.

It should be noted however that, in general, modifying the blank thickness modifies the TE excitation, the dynamic mesh force, and the transfer path of the dynamic mesh force from mesh to housing. The optimization is a careful balance of these effects.

Conclusion

This paper discussed the issues facing EV and HEV gearbox design to achieve demanding NVH requirements. An advanced CAE methodology was presented to analyze and optimize such designs for motor and gear whine. The method presented is available in SMT's *MASTA* software. A good understanding of the system dynamics is required. The paper used an example of gear blank tuning as an optimization option. The study shows how significant predicted noise reductions can be achieved using careful dynamic tuning. The example used in this paper was a generic non confidential example. In a real application an additional step is required to design accurate gear blank geometry which reflects the improvements seen in the study in terms of gear blank dynamics. The presented methodology has been used successfully in several engineering services projects by the authors and their clients, optimizing gear blank web and rim thicknesses for the multiple targets of:

- Weight: cost
- Gear mesh misalignment: durability and TE/noise
- Gear mesh dynamic force: NVH and gear durability application factors
- System dynamic response as bearing loads, casing accelerations, mount loads and casing radiated sound power.

The high-fidelity CAE and system dynamic optimization methodology presented provides a route to achieve quieter gearbox designs or to troubleshoot existing problem designs. Such designs can lead to significant cost savings by, for example, reducing the need for very high gear manufacturing quality and the use of

Dr. Owen Harris, a graduate of Trinity College Cambridge., has worked in the analysis of transmissions and geared systems for over fifteen years. He was instrumental in writing some of the first commercial software codes for housing influence, system modal analysis and gear whine and planetary load sharing. Harris has filled many roles in over ten years working at Smart Manufacturing Technology Ltd. (SMT). He has worked on SMT's state-of-the-art MASTA software, while at the same time being heavily involved in many engineering projects. Harris's current focus is to lead SMT's research department.

Dr. Paul Langlois is the Software Engineering Director at SMT. Having worked for SMT for 13 years, he has extensive knowledge of transmission analysis methods and their software implementation. He manages the development of SMT's software products and is a main contributor to many aspects of the technical software development. As a member of the BSI MCE/005 committee, Langlois contributes to ISO standards development for cylindrical and bevel gears.

Andy Gale is a research engineer at SMT. He has a background in mechanical engineering, and research experience in a variety of fields including additive manufacture and control systems. He has recently been a main contributor to acoustics research and development at SMT.

additional sound proofing materials within an EV or HEV vehicle.

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Questions or comments regarding this paper? Contact Paul Langlois — *Paul.Langlois@smartmt.com*

Klingelnberg

HONORS EMPLOYEES FOR YEARS OF SERVICE

At the start of each year, Klingelnberg's executive management recognizes colleagues who have worked at the company for 25, 40 or 50 years in a ceremony dictated by tradition. On February 1, 2019, this year's anniversary celebration was once again held at Kleineichen Haus in the German town of Hückeswagen.

Eleven award recipients in total commemorated their many years of service and commitment to the company during a pleasant evening meal shared with Klingelnberg's executive management. Awards were given to eight employees for completing 40 years of service and two employees for 25 years of service — as well as one employee now in his 50th year of service to the company.

"Whether employed in production, technology, or in our commercial operations — each one of these employees has contributed significantly, through their commitment and performance, to positioning our company as an international brand in the mechanical engineering industry," said Group CEO Jan Klingelnberg. "We are extremely grateful for this and are delighted to have another opportunity each year to celebrate the accomplishments of our long-serving employees."

The CEO added: "I am particularly pleased today to honor our employee Hans-Jürg Spiess, because Mr. Spiess already has a full half-century of Klingelnberg history behind him." In 1968, Spiess began his training as a technical draftsman (machinery designer today) in the area of gear cutting at the Oerlikon Bührle AG machine tool factory. In the early 1970s, Spiess studied mechanical engineering at the Technikum Winterthur (now the School of Engineering at ZWAH University of Applied Sciences) in Switzerland. In 1975, he graduated with distinction as a mechanical engineer with a major in process engineering. Spiess subsequently worked as a mechanical engineer and project manager in various technical departments and was promoted in 1989 to the position of technical expert and development engineer. To this day, he has remained faithful to the division whose line of business was ultimately acquired by Klingelnberg in 1993 and continues to work as a development engineer in the mechanical design department at the company's headquarters in Zurich (Switzerland)."

Klingelnberg expressed thanks in his speech: "It's always the employees who make a company. So we are all the more proud of the fact that we still manage to foster such long career trajectories in our company — something that has become quite rare in these fast-paced times." (*www.klingelnberg.com*)

DVS Tooling

INAUGURATES MODERN COMPANY BUILDING IN GERMANY

In May 2015 Sandro Schäfer stood on a stage in his new function as managing director and ceremoniously opened the 300 m^2 production area of his newly founded start-up DVS Tooling in Hemer, Sauerland. Four years later, the start-up and member of the DVS Technology Group has become a medium-sized company with a turnover of over 10 million euros. The high-precision tools for Präwema gear honing are used not only on the domestic market, but also in Brazil, China, the USA and India. In principle, the Hemer Hightec honing tools are in demand wherever gear components are manufactured, because in combination with the technology of the sister company Präwema they contribute to a better noise behavior in vehicle transmissions.

The success soon made the old location too small and so four years later Schäfer stands again on a stage to inaugurate the modern new building of DVS Tooling. 1,500 m^2 of production area and 500 m^2 of office space were built on Amerikastraße in Hemer, taking into account further expansion reserves. Enough space for further developments and an impressive opening ceremony with 140 invited guests. Among the guests was Josef Preis, CEO of the DVS Technology Group, who praised the DVS Tooling team and the development of the company in his opening speech. He also attributed the success to the "Sauerland inventor mentality and the down-to-earth attitude of the people in the region." Steen Rothenberger, chairman of the group's supervisory board, added: "Extraordinary people can achieve extraordinary things" and referred to all employees of the DVS Technology Group.

The highlight of the celebration was an impressive laser show, which took the guests on a journey through time on the development of laser technology. The bundled electromagnetic waves are used by DVS Tooling for the fine machining of diamond-coated surfaces on dressing tools. The diamond coating, which is chaotically structured under microscopic view, thus becomes a homogeneous surface and produces high-precision dressing results on the honing tool. (*www.dvs-technology.com*)

GMTA

NAMES SCOTT KNOY PRESIDENT

After 27 years as president of GMTA (German Machine Tools of America), formerly American Wera, Walter Friedrich appoints **Scott Knoy** as his successor to the presidency of GMTA.

Friedrich was one of the first three employees when GMTA (American Wera at the time) started in January of 1991. Previously, he worked as a project manager for Liebherr Machine Tool for 4 years and completed vocational training in toolmaking and NC programming while working for 12 years at Pittler (now DVS Group) in Germany with whom he moved to the USA in 1983. On January 30 of this year, he spoke with the company's board of directors and decided to step down. The change was effective on February 8, 2019.

Since joining GMTA on July 1, 2005 Scott Knoy has contributed greatly to the growth of the organization. GMTA is a leading supplier of machine tools, laser welding systems and parts washers to the automotive power transmission, gear and other markets in North America. Friedrich is confident that Knoy is fully prepared to handle all his new responsibilities. "From day one, Scott has proven his commitment, determination, and knowledge of the automotive and gear industries. I'm sure he will continue the company's expansion."

Scott Knoy is grateful for this opportunity saying, "I am honored and excited to begin this new chapter as GMTA's president. My objective is to make sure that GMTA continues to serve our customers' needs, while looking for new opportunities." Knoy is a graduate of the University of Michigan and has a master's degree from Lawrence Technological University.

Walter Friedrich will maintain an active role in the company as senior advisor and board member. (*www.gmtamerica.com*)

Solar Manufacturing

PREPS FOR OPENING OF NEW BUILDING IN 2019

Anticipation is growing, as Solar Manufacturing's new facility is beginning to take shape. With the exterior of the building now fully enclosed, including the nearly 20,000 square foot two story office building situated in the front of the manufacturing area, the next phase of building can begin, bringing the project

closer to completion. Bill and Myrtle Jones, owners of the Solar Atmospheres family of companies, stand in the center of the 40,000 square foot manufacturing area during the most recent site inspection.

"This plant will be one of the most advanced facilities in the United States for the assembly of vacuum furnaces," Jones stated. The new facility is built on the 44 acre Brownfield redevelopment site on the Sellersville Business Campus in Sellersville, PA.

The $8 million project is approximately 85% complete and they expect to be operational by late summer or early fall 2019. (*www.solarmfg.com*)

Ipsen USA

STRENGTHENS CUSTOMER SERVICE GROUP WITH NEW MANAGER

Ipsen USA is pleased to announce the promotion of **Matt Clinite** from Midwest regional sales owner to Ipsen customer service sales manager, effective immediately.

The position is new to Ipsen, and in it, Clinite will be responsible for building the Ipsen Customer Service sales team to provide the best in the industry aftermarket support for parts, engineered solutions and service.

Clinite joined the company in June 2014 as a sales engineer and for the past four years has served as the regional sales owner for the Midwest region. Clinite earned his bachelor's degree in business administration from Illinois State University in 2011.

"Since day one, Matt has influenced Ipsen in a positive direction," said Pete Kerbel, vice president of sales, Ipsen USA. "Matt has exceled because of his work ethic and determination to solve problems for customers."

Ipsen's customer service team is responsible for providing customers with comprehensive aftermarket support and services. Clinite's experience and proven approach to customer service, combined with his technical ability, makes him the ideal fit for this role. (*www.ipsenusa.com*)

May 6–9—AISTech 2019 Pittsburgh, PA. This event will feature technologies from all over the world that help steel producers to compete more effectively in today's global market. AISTech is a can't-miss event for anyone involved at any level of today's steel marketplace, providing perspective on the technology and engineering expertise necessary to power a sustainable steel industry. More than 8,000 people are expected to attend AISTech 2019. Along with over 500 exhibiting companies, AISTech 2019 allows attendees to meet face-to-face with key individuals involved in the production and processing of iron and steel. The AIST Conference programs are developed by technology committee members representing iron and steel producers, their allied suppliers and related academia. Committees focus on ironmaking, steelmaking, finishing processes, and various engineering and equipment technologies. For more information, visit *www.aist.org*.

May 6–9—OTC 2019 Houston, Texas. The Offshore Technology Conference (OTC) is where energy professionals meet to exchange ideas and opinions to advance scientific and technical knowledge for offshore resources and environmental matters. Celebrating 50 years since 1969, OTC's flagship conference is held annually at NRG Park (formerly Reliant Park) in Houston. OTC has expanded technically and globally with the Arctic Technology Conference, OTC Brasil, and OTC Asia. OTC gives you access to leading-edge technical information, the industry's largest equipment exhibition, and valuable new professional contacts from around the world. Its large international participation provides excellent opportunities for global sharing of technology, expertise, products, and best practices. OTC brings together industry leaders, investors, buyers, and entrepreneurs to develop markets and business partnerships. For more information, visit *2019.otcnet.org*.

May 13–15—SAE Fundamentals of Modern Vehicle Transmissions Seminar Jacksonville, Florida. Starting with a look at the transmission's primary function -- to couple the engine to the driveline and provide torque ratios between the two -- this updated and expanded seminar covers the latest transmission systems designed to achieve the most efficient engine operation. Current designs, the components and sub-systems used, their functional modes, how they operate, and the interrelationships will be discussed. This seminar is intended for anyone not familiar with the operational theories or functional principles of modern vehicle transmission systems. As the material covered is targeted at a number of design and engineering disciplines, attendees should have a minimum of two years design experience in the automotive powertrain field, or preferably a B.S. in engineering or related field. For more information, visit *www.sae.org*.

May 13–16—CTI Symposium USA Novi, Michigan. The CTI Symposium USA is the International Congress and Expo for Automotive Transmissions, HEV and EV Drives. The event features a two-day introductory seminar, a transmission expo, evening networking party and test drives for the latest development cars. Participants include automotive suppliers, transmission manufacturers, OEMs, metal processing, mechanical engineering and others from North America, Europe and Asia. Topics include powertrain technologies, hybrid transmissions, future considerations, commercial vehicles, starting devices, manufacturing and more. Autonomous driving, NVH, tools and performance forecasting will also be discussed. Speakers this year include Dave Filipe, vice president, global powertrain engineering, Ford, Mayank Agochiya, managing director at FEV Consulting, Inc., Mamatha Chamarthi, CDO at ZF, Stephan Tarnutzer, president, AVL Powertrain Engineering, Inc. and many more. ***Gear Technology*** and ***Power Transmission Engineering*** are co-sponsoring this event. For more information, visit *www.transmission-symposium.com/usa*.

May 14–16—Eastec 2019 West Springfield, Massachusetts. With more than 500 exhibitors, complimentary conference sessions, industry keynotes and much more, Eastec is an event dedicated to keeping northeast manufacturers competitive. It's where manufacturing ideas, processes and products that make an impact in the northeast region, are highlighted through exhibits, education and networking events. The event offers a unique chance to connect with resources that can solve your company's most pressing problems, improve productivity and increase profits. This year's show includes in-depth workshops that explore several management topics as well as information on additive manufacturing. The Smart Manufacturing Hub examines IIoT, 3D printing, and the latest automation technologies. Keynote speakers include Alan Beaulieu (ITR Economics), Denise Ball (Tooling-U-SME), Mary Ann Pacelli (MEP) and Michael Munday (Arwood Machine Corporation). For more information, visit *www.easteconline.com*.

May 20–22—AGMA Steels for Gear Applications Alexandria, Virginia. This AGMA class allows attendees to make use of steel properties in a system solution and understand the potential that different steel options can offer for their various applications. Those in attendance will explore performance of the material and how the steel produced effects the component and system. Objectives include material properties, selecting materials, verifying and specifying steel properties, and applying methods. Gear engineers, gear designers, material specialists or metallurgists at OEMs, Tier 1s, Tier 2s etc., production engineers, technicians and managers should consider attendance. Instructors include Lily Kamjou and Patrik Olund. For more information, visit *www.agma.org*.

May 20–23—AWEA Windpower 2019 Houston, Texas. Windpower 2019 is the wind industry's premier North American event with wind energy professionals from all over the world gathering in one place. It's the most effective way for attendees to expand their knowledge base and business network. With competitive pricing and stable policy in place, the wind industry is booming. Now the industry can focus on the future and the other drivers that will propel the industry forward through the 2020s. The program will feature speakers with "disruptive" and innovative ideas that will continue to strengthen wind energy's value proposition and challenge the current way we do business. For more information, visit *www.awea.org*.

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