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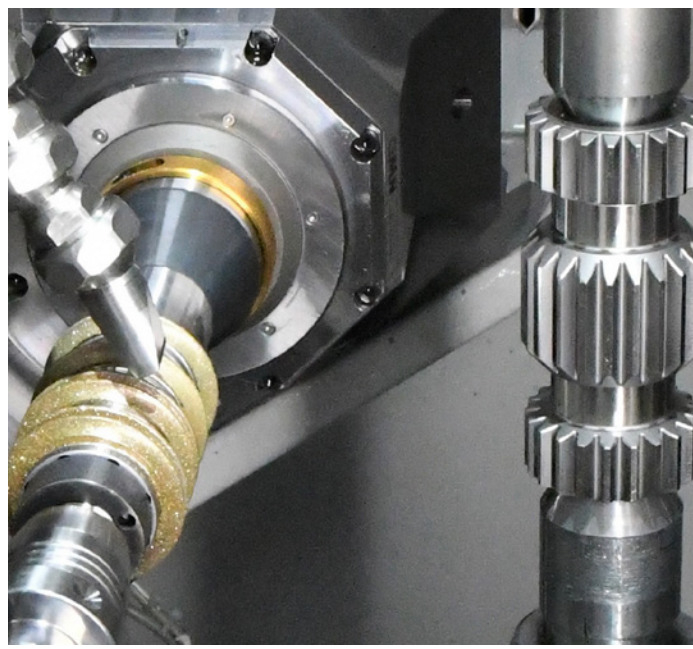
Cover Photo by David Ropinski



THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

Maintaining Synchronization

Basic gear tooth milling is possible on any standard full simultaneous 5-axis multi-tasking machine. However, gear power skiving and hobbing on those machines requires two additional key elements—spindle speed synchronization and advanced software specifically for programming those particular gear machining operations. Learn more here:

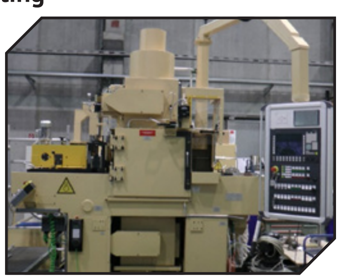
www.geartechnology.com/blog/maintaining-synchronization/

esco Offers Power Skiving Software Solutions for E-Mobility

The impending mobility revolution and the electric vehicles associated with it are currently the talk of the town. When it comes to their production, a number of changes are on the horizon, particularly with regard to gear manufacturing. The new recipe for success for flexible gear cutting is power skiving. This innovative machining method offers enormous potential for all those working in the field of gear manufacturing. Learn more here:

www.geartechnology.com/blog/gear-manufacturing-for-e-mobility-applications/

DVS Technology Examines Retrofitting



Retrofitting is a sensible alternative in many cases—but not in all. The option can be decided only in the individual case and will depend on many, complex factors. The choice requires a well-founded recommendation with experience and an analytical view. Learn more here:

www.geartechnology.com/blog/retrofit-how-to-bring-technology-tradition-into-the-modern-age/

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Michael Goldstein founded Gear Technology in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein Gear Technology Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 36 years' worth of technical articles can be found online at *www.geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

Where Are We Going?

Publisher & Editor-in-Chief
Randy Stott

The past year has been quite a wild ride for the world, and that includes the manufacturing economy. When COVID hit, every industry took its share of lumps. But for some time now, manufacturing industries have been charging forward.

According to the Institute for Supply Management, the manufacturing economy has now been in expansion mode for 13 straight months, with the June Manufacturing PMI registering at a respectable 60.6% (anything above 50% is generally considered to indicate expansion).

Likewise, the AMT's reports on manufacturing technology show that machine tool orders and cutting tool orders continue to be far above where they were in 2020.

All that growth is promising, but the fact remains that most manufacturing industries are not quite yet to the levels they were at before COVID. And there are significant challenges facing manufacturers today.

If you're experiencing difficulty finding skilled (or even unskilled) labor, you're not alone.

If you're struggling with delays in obtaining raw materials, or sharply rising prices, you're not alone.

Most manufacturers we talk to are extremely busy. They could sell more if they had the capacity. But they're limited by those bottlenecks of staffing and supply chain.

So what does this all mean? Where are we going?

Of course, it's hard to say. But one place you should at least be thinking about going is to MPT Expo in St. Louis, September 14–16. It's the gear industry's main event, and it's the only place where you can meet with experts from the entire power transmission supply chain and network with peers to learn what others are doing to address the challenges we all face.

I'll be there, as will much of the AGMA and AGMA Media team. We're excited about the return of in-person events, and we're looking forward to seeing as many of you as possible at the show. This issue we've begun our extensive pre-show coverage. See Jenny Blackford's commentary, "Building Connections at MPT Expo," beginning on page 10. The rest of our coverage begins on page 26, including details about the many educational opportunities to be found at the show, as well as the co-located ASM Heat Treat show.

I, for one, am optimistic that the manufacturing rebound will continue for some time, which makes it a great time to invest in your business. I've already seen several announcements about new technology that will be presented at MPT Expo. So there are plenty of reasons to attend.

Many we've talked to in the gear industry have expressed renewed trepidation about traveling, as news spreads about the now-dominant delta strain of the coronavirus, which is causing havoc in many parts of the world.

So it's probably not going to be as big of a show as it has been in past years. Like I said above, we're not quite to the level we were at in 2019. But MPT Expo has never been about the size of the crowds or the number of exhibitors. It's been about the quality of the exhibitors and attendees, and it's been about finding everything under one roof that you need to be successful in the gear industry. And that hasn't changed.

I hope to see you there.

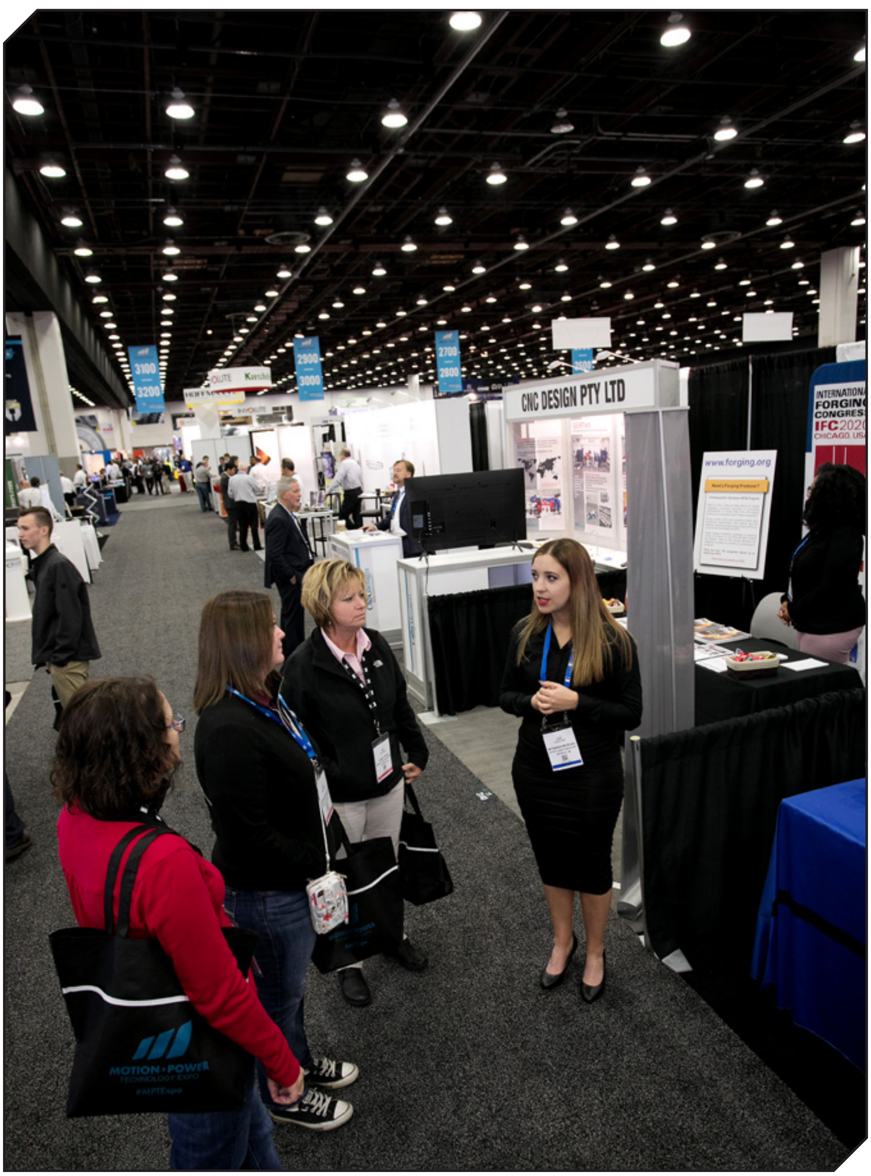
Randy Stott

Building Connections at MPT Expo

Jenny Blackford, V.P. Business Management Division, AGMA

What did you learn during the pandemic? We all learned a lot about how adaptable we are, what matters most both in our jobs and our personal lives, and how much we all crave human interaction. I don't know about you, but I hit "Zoom fatigue" about a month into lockdown when I realized I had six video meetings on four different meeting platforms that day and that the rest of the week looked about the same. We all tired quickly of trying to figure out what a virtual trade show booth was, how to staff it, and most importantly how to set expectations for return on investment in a virtual show.

Thankfully, those days appear to be behind us and we can gather face-to-face. I can't wait to see everyone at MPT Expo this September in St. Louis — to catch up with old friends that I haven't seen in two years, to meet new AGMA members and to see the latest technologies that the power transmission industry has to offer.



While usually the number one reason to attend a trade show, especially MPT Expo, is to see the latest products, technologies, and services that exhibitors have to offer, I would argue that for MPT Expo 2021 the number one reason to attend — by far — is to see people face-to-face. It is time to take a step back and reconnect with your friends in the industry, to welcome those who are new, see the customers you have not been allowed to visit, and just to see how everyone is doing post-pandemic. By all measures, the power transmission industry is roaring back, and economists predict that double digit growth will continue for at least the next year to 18 months. This will require capital investments. Business will happen on the show floor, new leads gathered, RFPs discussed, etc., but I believe it is the human connection that will be top of mind for everyone gathered in St. Louis.

In June AGMA held its first post-pandemic in-person meeting, the Strategic Resources Network event in Charleston, SC, and what struck me was how happy and energetic people were to be out with their peers, talking shop and generally catching up with one another. There was a buzz in the room. I also found out that people have not been sitting stagnantly but that innovations have taken place, to some degree because of the pandemic. MPT Expo will have the same energy — for most attendees and exhibitors it will be their first trade show in two years — with people exchanging tales of how they weathered the pandemic, checking in on one another's businesses, and seeing what the sentiment is for the future.

Will the show be exactly the same as MPT Expo 2019? No, little is the same post-COVID. We expect the show to be

> ***"It occurs to me that our survival may depend upon our talking to one another."***
>
> Dan Simmons, Hyperion

smaller; industry statistics are reflecting a 30% drop in attendees and exhibits year-to-date for trade shows in the United States. We also see that these numbers are slowly improving as more opens up. We expect that the show will continue to excel in providing the quality leads, connections and technical expertise that it has always had. I would encourage you to rethink your normal trade show strategy. Maybe in the past you focused on the number of business cards collected, LinkedIn connections gained or number of hands shaken. Perhaps now you can take time to look for value in quality of the leads, the authenticity of the connections and the information you learn from your peers.

Even before the pandemic, workforce issues were the number one challenge facing all power transmission companies. Post-pandemic, this trend and the worker shortage is even worse. Managers, I challenge those of you who are looking to grow their workers to bring at least one of your promising employees to MPT Expo and introduce them around. We all know that recruiting and retaining talent is one of the hardest things to do today but by investing in your up-and-coming talent and bringing them to MPT Expo it shows them that you value their professional development and want them to learn more about the industry. A trade show is a great opportunity for your newer talent to get a feel for the rest of the industry, meet your vendors and customers, see the newest technologies first hand, and begin to build their own professional network that can serve your company well into the future.

AGMA is ALL IN for MPT Expo. We have great support in St. Louis — even the Missouri Governor is helping us promote the show! We have expert keynote speakers on the pressing issues of cybersecurity and changes in the electric vehicle market. So come for the peer and customer engagement. See what people have been up to behind-the-scenes these past 18-months. Meet new contacts and make sales. The show will not disappoint in providing a forum for you to be successful.

Vice President, Business Management Division
Jenny Blackford

Norton Quantum Prime Grain

OPTIMIZES GRINDING WHEEL PERFORMANCE

Saint-Gobain Abrasives has announced the introduction of Norton Quantum Prime Grinding Wheels featuring new, proprietary nano-crystalline ceramic grain which offers unprecedented productivity gains across a wide range of applications. The new Quantum Prime grain delivers exceptionally high grinding efficiency and part quality, as well as significantly longer wheel life than traditional ceramic grains.

"We are excited to offer our customers with a superior grinding solution which is producing substantial productivity increases," said Rama Vedantham, director of product management, bonded and superabrasives, Norton | Saint-Gobain Abrasives "In an Outer Diameter (OD) Bearing Grinding application, the Quantum Prime Wheel resulted in 150% more parts per dress than a previous generation ceramic wheel, and also resulted in 300% faster rough/ finish infeed for a plunge face grinding application compared with a competitive ceramic OD wheel."

Norton Quantum Prime Wheels have several important advantages including a new micro-fracturing grain that has unparalleled sharpness and cutting efficiency which reduces power draw and cycle times, while increasing material removal rates. The unique grain is free cutting, which combined with advanced bond technologies such as Norton Vitrium3, allows Quantum Prime to wear more consistently, improving part quality, geometry and finish even at high material removal rates. Also, Quantum Prime has a more friable self-sharpening grain technology so grinding wheels stay sharper longer, reducing dress requirements and drastically improving wheel life.

Applications for new Norton Quantum Prime are diverse including OD, Centerless, Internal Diameter (ID), Gear, Toolroom, Disc, Surface, Flute and Creepfeed Grinding and Mounted Wheels. Also, newly introduced Norton IDeal-Prime ID Wheels for precision applications feature Quantum Prime grain embedded in an optimized matrix of Norton Vitrium3 bond. The combination of the micro-fracture properties of the new ceramic grain and the retention capability of the bond, ensures long wheel life, excellent grinding efficiency and consistent part quality which results in substantial cost savings.

Key industries for Norton Quantum Prime include automotive, aerospace, energy, primary steel, gear, bearing, cutting tools, and metalworking/engineering. Quantum Prime Grinding Wheels are made-to-order to meet customer requirements. The grain blends are available in all standard grain combinations, and bonds are organic or Vitrium3 vitrified.

nortonsga.us/QuantumPrime

Danobat

INTRODUCES NEW CYLINDRICAL GRINDING MACHINE

The new CG generation is the perfect combination of productivity, versatility and compact design. With its new core technology and the process know-how of experts, users will get finished parts in less time, thanks in part to Danobat's ability to use conventional grinding wheels at 80 m/s (16,000 sfpm) without affecting the quality of the workpiece. With a long life cycle, customers will enjoy decades of optimum performance from this machine. In addition, it incorporates heavy duty precision assemblies that deliver extraordinary stiffness, making it the ideal choice for the most demanding 24/7 production environments. Discover the smart machine and benefit from connectivity in a virtual presentation that took place May 18. If you missed the recent live event, you can watch it by registering using the following link:

danobatgroup.microsoftcrmportals.com/newCG-eventregistration-EN/

Big Kaiser

INTRODUCES NEW ROUGH BORING TOOL

Big Kaiser Precision Tooling has introduced the Series 319 SW rough boring head with the BIG CAPTO connection. The new SW BIG CAPTO Rough Boring Head makes it possible to perform rough and finish boring processes seamlessly with the finishing heads it has offered for years. Big Kaiser currently offers the widest range of rotating BIG CAPTO tooling of any provider.

In accordance with ISO 26623-1, the polygon shape of the taper and one-piece body construction provides for highly repeatable accuracy and torque transmission, an ideal fit for rough boring work. The SW BIG CAPTO achieves high repeatability, in part, thanks to the flush fit of the polygon taper with the spindle. The combination of a self-centering 1:20 taper and the long taper edge ensures stable runout accuracy.

The SW BIG CAPTO is available in sizes C3, C4, C5, C6 and C8. The diameter range is 0.984"–8.000".

www.us.bigkaiser.com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Heidenhain Touch Probe

OFFERS BENEFITS TO GRINDERS AND LATHES

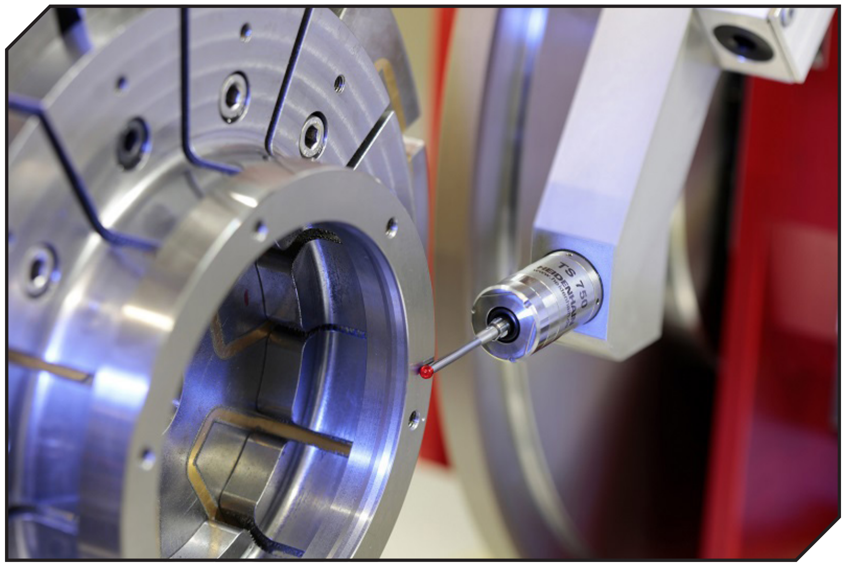
Heidenhain's new TS 750 high-precision touch probe is now available for in-process workpiece measurement in grinding machines and lathes. This extremely durable new probe offers the ability to state the reproducibility of its jobs at increased probing speeds better than its competitors. And the low probing force inherent in the new TS 750 is an important benefit when working with soft or delicate workpieces.

The TS 750 operates with high-precision pressure sensors, with force analysis for generating the trigger pulse. The forces that arise during probing are processed electronically. This method delivers extremely homogeneous, 360° probing accuracy. It offers high probing speed of up to 1 m/min and does not require a minimum speed.

Also, due to its very low probing forces of approximately 1.5 N (axial) and 0.2 N (radial), the TS 750 can attain high probing accuracy (±1 µm) and repeatability with almost no effect on the measured object. Only on further deflection do the forces of the springs take effect until the machine stops.

Delivering reliable measurements after prolonged use — even after five million probing cycles — this TS 750 touch probe is still highly accurate: with a probing repeatability of down to 2 $\sigma \leq 0.25$ µm at its high probing speed. This is highly unusual in the industry.

www.heidenhain.com/products/touch-probes/workpiece-measurement/ts-150-750



Schunk ADHESO Gripper

OFFERS BIONICALLY INSPIRED ADHESION TECHNOLOGY

The bionically inspired gripper technology ADHESO, based on the principle of adhesion, uses the intermolecularly acting Van der Waals forces for handling components. Made of special polymers, the patented surface architecture is optimized by numerical simulation, creating a structure of extremely finely structured legs that adhere to different materials and objects.

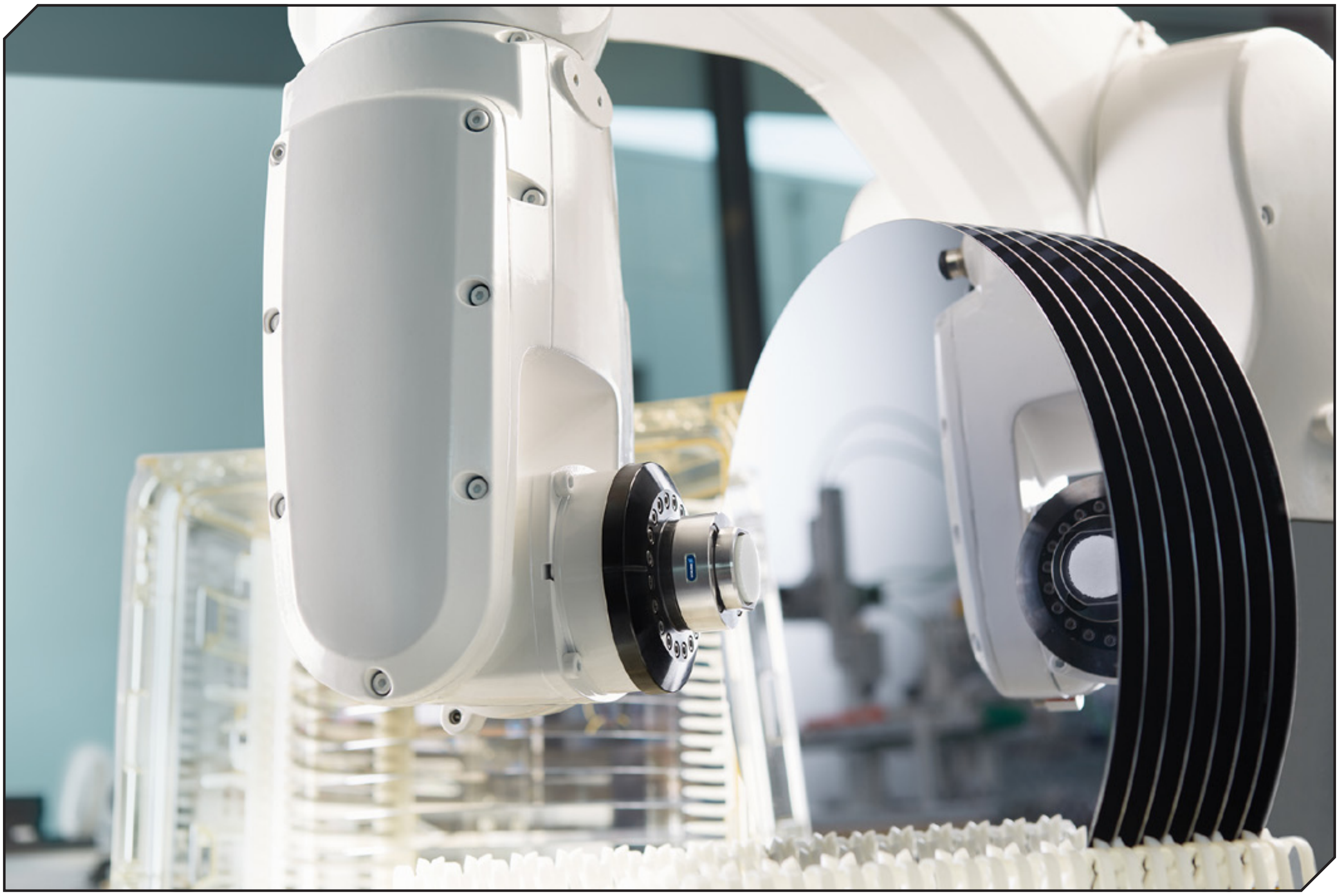
Glass fibers as light as feathers; the smallest SMD components or micro-mechanical parts; sensitive battery components; plastic films; paper and glass - all can be handled by the ADHESO gripper. Gripping of automotive or mechanical engineering components of a weight of 33 pounds and more is also possible. Automated separation of breathable components is also feasible. With the ADHESO gripper, solutions can be tailored to each customer's individual needs, creating opportunities that are as diverse as the applications themselves.

Using Van der Waals forces, the face of the gripper is gently pressed onto the workpiece during the gripping process, increasing the contact surface and locking the grip into place. This effect can be reversed by applying a slight pressure/rotary movement so that the gripper can be loosened from the object without leaving a residue or any marking. The alternative use of a wiper ensures that the object is gently put down.

The respective adhesive forces and removal of ADHESO depend on the type of material, surface roughness or flatness, and miniaturization, and can be customized to the different requirements of the relevant environment. Therefore, the adhesive structures can be adapted to the required size and the loading condition (horizontal/vertical) of the application, and can be designed transparent, translucent, or opaque. This high degree of individualization ensures that components with dimensions of a few hundred micrometers can be handled as reliably as those measuring several meters.

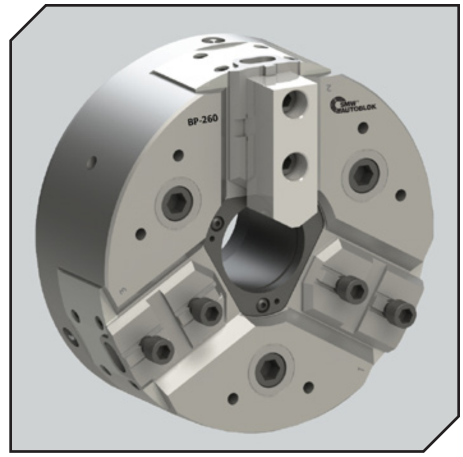
Installation costs and commissioning efforts are minimal. The adhesive technology is gentle on components, low-noise, and doesn't require compressed air, vacuum, or current. An external energy supply is not necessary for gripping or for maintaining the gripping force. In case of a power failure in the handling system, the holding forces of the gripper are reliably maintained. Schunk ADHESO allows gripping times of < 100 ms: It can be used in conventional industrial environments, but also in cleanrooms and vacuum environments. In the field of micro handling, repetitive positioning accuracies of < 0.01 mm can be achieved with this technology and it can be also used in collaborative applications. The ADHESO gripper has a bayonet lock and therefore the grippers can be exchanged in just a few simple steps.

Schunk.com



SMW Autoblok BP Chuck

PROVIDES FLEXIBILITY AND EFFICIENCY IN WORKHOLDING



SMW Autoblok presents the BP chuck, the only standard fully sealed power chuck on the market with large through hole for maximum lifespan, throughput and durability.

Ideal for lathe applications, BP's large through hole provides tremendous flexibility for virtually any application where a standard chuck is used including: O.D. and I.D. clamping, bar stock clamping and shaft clamping. Easily convert BP to a collet chuck using collet pads for small diameter parts.

A true workhorse, BP maintains high efficiency even in harsh environments of dry machining, abrasive powders, high pressure or corrosive coolants, and more. Constant grease lubrication provides clamping force consistency and reduced wear, greatly reducing downtime and loss of productivity. With BP, daily maintenance intervals become a thing of the past and only requires maintenance checks every 2,000 hours.

Being fully proofline sealed from outside contaminants allows BP to maintain a consistent grip force for excellent repeatability at high speed, versus non-sealed chucks which can lose more than 50 percent grip force if not maintained properly. Other advantages include a case-hardened body and internal parts for high resistance and longer life.

Available in 210, 260, and 320 mm, BP series chucks accepts all industry top jaws. The BP-D utilizes master jaws with inch serration while the BP-M operates with metric serration (suitable for Japanese jaws). The American standard, tongue and groove master jaws, are available on the BP-C.

www.smwautoblok.com

WFL Millturn Technologies

INTRODUCES WFL ICONTROL PROCESS MONITORING SYSTEM

Thanks to the fundamental redevelopment of its in-house process monitoring system, WFL has significantly expanded its range of functions. With the new WFL iControl system, process signals can be registered, evaluated and recorded in the CNC-kernel of the control with the maximum sampling rate. The introduction of new monitoring strategies, such as so-called "yellow limits," results in considerable advantages in tool breakage and tool wear monitoring. Another new feature is the option of integrating external sensors into process monitoring. The latter allows, for example, continuous monitoring and recording of performance data from coolant pumps or conclusions about the condition of spindle bearings.

With the new iControl process monitoring system, WFL gives the future machine operator a whole bundle of functions to ensure reliable and economical production, particularly in series production. On the one hand, the machine and tools should be used with maximum productivity; on the other hand, the process should run as stably and reliably as possible. The software package that WFL provides for this is extremely diverse and offers a suitable monitoring tool for practically every processing situation. The up to 16 process signals to be monitored are configured by WFL at the factory according to the machine equipment and displayed live on the control screen. Important process signals include the forces or torques of the NC axes and spindles, but also the signals from integrated sensors (vibration, pressure, flow, temperature, etc.). These are built into machine components or tools and can be used for a wide variety of applications such as process control, optimization or monitoring.

Process monitoring is typically divided into functions for protecting machines, workpieces and tools, and functions for recording tool wear and ensuring constant productivity. Key new features for detecting tool wear and total breakage include the "wear limit" and the "tool missing limit." The goal was to develop a solution that would respond sensitively and reliably to all conceivable abnormalities in the machining process. This is complemented by a long-time data recording function for process data that WFL offers as an additional option under the name "iControl Data Recording", which is an important topic in the production of safety-relevant components in particular.

WFL is launching two design variants of the new iControl process monitoring system. The "iControl Basic" version monitors the designated maximum machine loads only and triggers a quick stop within ten milliseconds in the event that these are exceeded. The "iControl Advanced" variant also makes it possible to select an individually customisable monitoring strategy for each machining operation and systematically develop a machining process that provides maximum productivity. The software was designed by WFL to ensure that the optimal monitoring strategy could be selected easily and intuitively, and freely combined with other limits.

For example, the energy consumption per operation can serve as a comparative value when this operation is repeated, making it possible to detect excessive tool wear or a total breakage at an early stage during drilling and avoid serious damage. However, brief and isolated load peaks in the process sequence probably would not have any bearing on this operation and even small partial breakages on the cutting edge would be acceptable. As a result, the process would not be interrupted provided that the event was not identified as a total failure of the tool. By contrast, when it comes to finish turning, even the tiniest partial breakage on the cutting edge could lead to an unacceptable surface quality, even though in principle the tool would still be functional. These types of events happen in a matter of a few milliseconds and are difficult or impossible for the operator to see during machining. With dynamic monitoring enabled, iControl would detect the inconsistency, interrupt the process immediately and inform the responsible staff member.

The maximum loads on the individual axes and spindles — known as "red limits" — can be freely selected anywhere up to the collision limit. This means that, for each operation, there is a pre-set percentage of the maximum permissible load for each axis or spindle. If no limit is selected, the collision limit set at the factory will apply automatically.

The process signal from a complete machining sequence can be recorded using a teach-in cut. The allocation of upper and lower process limits defines the tolerance band within which the process signal must remain during machining. If these limits are violated, the machine will stop. It is also possible to select a pre-warning limit, otherwise known as a "yellow limit." If this limit is reached, the machine will not stop immediately. Instead, a message will be generated to enable the operator to respond in good time, i.e. before another limit is reached. This primarily serves to ensure uninterrupted operation and makes it possible to replace worn tools even if they have yet to reach the end of their (theoretical) tool life. Typically, the collision limits set at the factory will always automatically limit any process-related forces to a level that is safe for the machine.

Nevertheless, there are often applications where the stability of the workpieces, the clamping devices or the required tools simply does not permit large machining forces. The "red limit" can help in these cases in particular because the machine will stop immediately — even if the limit is exceeded for only the briefest of moments. However, the "red limit" also serves to detect tool breakage, chip jams or blanks that are too large and can always be activated in the background so to speak.

The "iControl" process monitoring system is typically characterized by its extremely high sensitivity and reliability. The signal value for process monitoring is derived directly from the drive torques of the NC axes and spindles. A special algorithm eliminates friction and acceleration forces, making it possible to analyze the process signals with particular precision. "iControl" provides essential services for automation and series production in particular. However, making the machining process fully transparent is also beneficial for complex internal machining tasks.

www.wfl.at

FANUC
EXPANDS SCARA ROBOT SERIES

FANUC America has expanded its line of high-performance SCARA ROBOTS, offering more reach and payload options to companies with assembly, packaging, pick and place, and inspection processes.

FANUC's family of 4-axis SCARA robots has grown to include the SR-3iA, SR-6iA, SR-12iA, and new SR-20iA models with 3kg, 6kg, 12 kg and 20 kg payload capacities, and a 400–1,100 mm reach, respectively.

The small SR-3iA and SR-6iA SCARAs have a compact footprint and space-saving design for maximum efficiency. In addition, the SR-3iA/H and SR-6iA/H are 3-axis variants that provide strong performance and an affordable alternative to small linear slide products. The higher-payload SR-12iA and SR-20iA provide flexibility with a large vertical stroke, and an environmental option for harsh conditions. All of FANUC's SCARA robots include superior robot motion, high-speed operation and ultimate precision.

"FANUC's SCARA robots provide great solutions when speed and repeatability are essential," said Eric Potter, director of FANUC's general industry and automotive engineering segments. "Our SCARA robots are designed to help customers increase productivity in a number of industries including consumer electronics, auto components, plastics, food & beverage, lab automation, appliances and medical device manufacturing."

Powered by the R-30iB Compact Plus controller, FANUC's SCARA robots have the same intelligence and reliability that's available on all FANUC robots, including integrated iRVision, conveyor tracking (iRPickTool), and most other software options. FANUC's latest SCARA iRProgrammer user interface makes it easy to setup and program the robot on a Tablet or PC (Teach Pendant is optional).

"With over 715,000 robots installed globally, FANUC is a household name in manufacturing. Now, with our expansive line of SCARAs we're able to help more companies solve their manufacturing issues," added Potter.

www.fanucamerica.com/products/robots/series/scara

MHI

LAUNCHES TWO NEW HOBBING MACHINES

Mitsubishi Heavy Industries Machine Tool Co., Ltd., a part of Mitsubishi Heavy Industries (MHI) Group, announces the June 2021 launch of the new GE15HS and GE25HS models of hobbing machines. Emphasizing high speed, precision and efficiency, the new machines produce gears for electric and hybrid cars amid the global trend toward reducing the carbon footprint.

The GE15HS model is for gears with a maximum diameter of 150 mm, widely used in automobiles and motorcycles. The high-speed, high-torque direct-drive motor for the main cutting spindle provides a maximum spindle speed of 6,000 rpm — three times faster than previous models. The high efficiency spindle holding the workpiece uses a special table that provides high rigidity and high-speed rotation to handle the necessary thrust load for high efficiency machining. Cutting gears with Mitsubishi's super-hard cutting tools yields a surface roughness, *Ra*, of less than 0.4; on par with gear grinding. The GE15HS provides process efficiency, eliminating the finishing process of shaving prior to heat treatment, improving productivity and reducing processing cost.

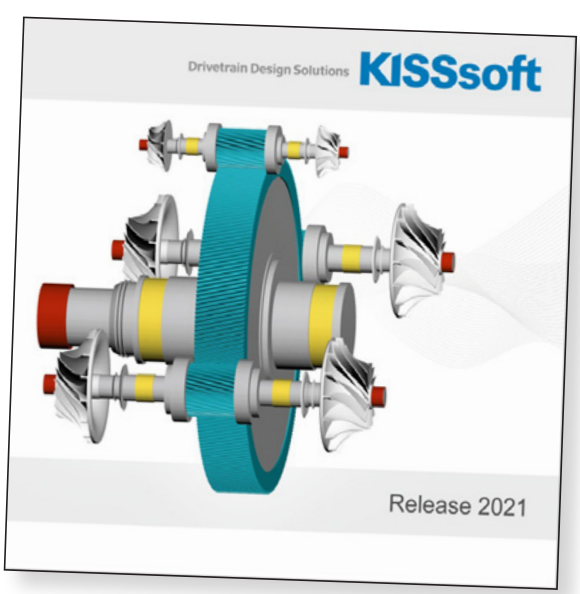
The GE25HS is for larger gears up to 250 mm in diameter, such as automobile differential gears. With its high-efficiency processing, this model utilizes a high-speed, high-power spindle eliminating the effects of temperatures variation during production. The high rigidity table has the backlash eliminator incorporated as standard equipment. In addition, the motor torque and maximum spindle rotation speed of the main spindle have been increased 1.5 times from previous models, providing a 42% reduction in processing time.

Used in combination with MHI Machine Tool's new materials and coatings for cutting tools, the GE25HS model provides stable mass production with a cutting speed of more than 400 m/min.

MHI has delivered and installed more than 2,800 GE Series hobbing machines since the product launch in 2004.

Demand for mass production of high-precision gears is continuing to rise with the shift to electrification of vehicles. With the need for improvements in NVH and fuel efficiency, and the move toward low-cost manufacturing, MHI Machine Tool, with expertise in both gear machine tools and cutting tools, offers a full lineup of gear production machines, including these two new models. By delivering precision cutting tools and processing solutions to achieve high-precision, high-efficiency processing, MHI provides comprehensive support for manufacturing in a wide variety of industries.

www.mhi.com



KISSsoft

RELEASE 2021 NOW AVAILABLE

The new *KISSsoft Release 2021* contains numerous innovations; for example, the 7th edition of the FKM Guideline has been implemented.

The revised 7th edition of the FKM Guideline (2020) contains a number of innovations in the nominal stress concept for shaft calculations. The revision includes a protective layer factor for galvanized steels, a new material group "Austempered Ductile Iron (ADI)" and equations for a cross-section of the shaft with hub seat (aligned with DIN 743). All material properties have also been adapted. The FKM guideline is thus state of the art.

www.kisssoft.com

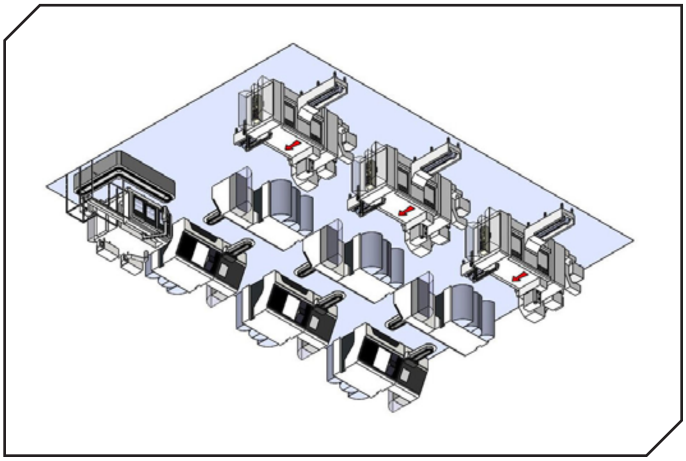
DVS

REPORTS RISE IN DRIVE SHAFT PRODUCTION

In order to meet the emissions targets, drive shaft production is being further expanded by automotive manufacturers. They will ultimately be used in modern hybrid or electric engines.

Two products are currently in series production in Krauthausen; for a Scandinavian and an American manufacturer.

The process begins with the procurement and delivery of the raw material. Subsequent turning operations, including gear manufacturing, are carried out on the WMZ H200 machine, while the hardening process is performed externally. Finally, grinding and hard machining are carried out on the DVS Universal Grinding machine UGrind. The subsequent gear honing is performed on the Präwema Synchrofine. With the final inspection, the products are finally checked and finally packed and shipped. The traceability concept is ensured by a DMC code applied to the shaft.



The challenge in the production of drive shafts lies in compliance with the specified tolerances and noise, vibration, hardness values. Due to the now high-quality requirements, the demands on production processes and machines have also increased. DVS Production maps these characteristics with its portfolio.

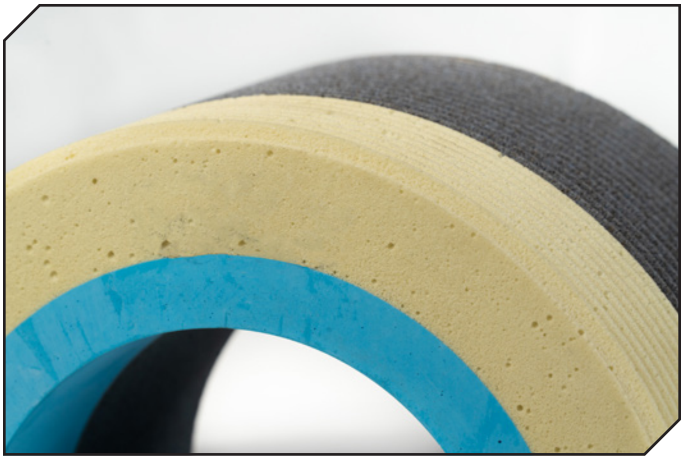
Previously, the customer manufactured the components in-house. However, DVS makes it possible to manufacture the drive shafts with up to a 50 percent time savings, which means that the advantage of cost-effectiveness clearly lies with the manufacturing company. The customer has no investment commitment when placing an order. This is for him, with fluctuating call-offs of the OEMs and Tier 1s, of great benefit.

technology.dvs-gruppe.com

Helios Gear

OFFERS ABRASIVES FOR GEAR MANUFACTURERS

Demand for ground gears continues to grow, especially in the automotive and truck power transmission industries. Consequently, manufacturers need improved solutions for abrasive tools. Helios Gear Products has supported manufacturers and this need for decades with world-leading tools for the hard finishing of gears. Today, Helios announces the latest line of abrasives backed with dedicated application engineers specifically for gear manufacturers. These tools cover all applications for gearing, including form grinding wheels, continuous generating grinding wheels, diamond dressing tools, honing rings, bevel grinding cups, and traditional solutions for OD and ID grinding. Moreover, gear manufacturers rely on the Helios team of dedicated application engineers to improve their gear grinding success.



Gear grinding means quality, so manufacturers require state-of-the-art abrasive tools. The Helios abrasives line includes such tools that use the latest technology for ceramic and aluminum oxide grains and bonds. For example, the Tyrolit Burka-Kosmos Mira Ice series of form (single-profile) grinding wheels use the latest grains combined with an innovative, high-strength bond system and increased porosity to achieve industry-leading "cool" grinding. Put simply, Mira Ice enables gear manufacturers to push the envelope on speeds and feeds. Said Tim Lee, technical sales manager — hard finishing from Helios, "It is not uncommon for gear manufacturers to decrease cycle times 20–30% by switching to an optimized grinding wheel technology, such as Helios's Mira line. Additionally, manufacturers can extend tool life dramatically by optimizing their processes (engineering their applications) with the Helios team."

Several solutions comprise the rest of the Helios abrasives line for gear manufacturers. These tools for generating grinding, tool dressing, honing (with the industry's shortest lead times), and bevel gear grinding meet the Helios standard of globally competitive manufacturing solutions. Many of these tools are manufactured in technically cutting-edge European and U.S. factories, and they equip manufacturers to serve global markets.

Choosing a tool specification ("spec") can be a daunting task. Some manufacturers make a conservative choice and use a traditional spec employed at relatively slow speeds and feeds. By leaning on the Helios team of application engineers, gear manufacturers can reap the benefits offered by contemporary wheel specs. After manufacturers establish an open communication channel, Helios engineers become a powerful tool for the gear manufacturer's team. Consequently, Helios advises on optimal wheel specs to push the limits of an application's cycle times, tool life, and part quality. "Successful manufacturers know that what comes in the box is not just a grinding tool but also the team of engineers to support it. By literally using the Helios team, manufacturers can stay at the top of their game," said David Harroun, vice president from Helios.

Gear manufacturers rely on Helios abrasives for profitably productive grinding. By using Helios engineers for application support, manufacturers optimally use their resources: tool life, machining time, and tool costs. For future grinding jobs, gear manufacturers should contact Helios Gear Products and speak with an engineer.

Heliosgearproducts.com

Open Mind

INTRODUCES LATEST HYPERMILL SOFTWARE SUITE

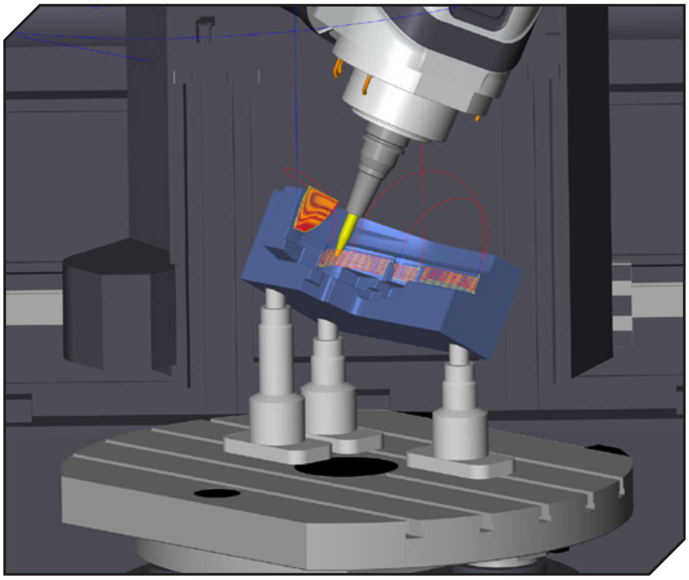
Open Mind Technologies AG has introduced its latest *hyperMILL 2021.2* CAD/CAM software suite which offers users innovative and enhanced features for efficient, user friendly machining in applications ranging from 2.5D to 5-axis. "With our continued focus on providing a rich, simplified user experience, the latest version of *hyperMILL* offers enhanced machining strategies, increased options for data feedback, as well as more convenience," said Alan Levine, managing director of Open Mind Technologies USA, Inc.

Resulting in simplified programming and increased process reliability, *hyperMILL* VIRTUAL Machining NC code-based machine simulation has also been enhanced. Within the VIRTUAL Machining Optimizer module which links individual part programs with smooth and safe connections, the cutter is able to remain close to the workpiece, violations of the axis limitations are now detected and movement sequences are optimized accordingly. There is also a new option in VIRTUAL Machining to apply a special approach and retract strategy to machines where the cutting tool can be retracted into a tunnel.

A forerunner in CAM Additive Manufacturing, Open Mind has introduced more capabilities in *hyperMILL 2021.2* ADDITIVE Manufacturing including a Weave Mode. This new mode generates a toolpath in a wave-shaped or zigzag movement, to apply material to contours or to fill areas, allowing the application area to be widened and the thickness to be increased for the individual movement. This continuous application also improves the metallurgical properties of the applied material.

In the integrated hyperCAD-S CAD module, additional file formats for import and export have been added including SAT as standard ACIS text, and OBJ and 3MF for importing mesh data. Also, electrode creation has been improved via the optimized selection of the raw material. To support EDM machining, the hyperCAD-S Electrode Converter can now be used to create import files for several EDM machines such as Exeron, Zimmer & Kreim and OPS-INGERSOLL.

For increased quality and ease of use, enhancements to some CAM cycles are offered in *hyperMILL 2021.2* such as 3D and 5-axis Equidistant Finishing capabilities that define the milling area by selecting bounding curves so that individual areas on a surface model can be targeted. With 3D ISO Machining, multiple bounding curves can now be used to allow different areas to be machined in one job. In addition, 3D Z-level Shape



Finishing includes several innovative features to improve machining quality, including optimized sorting of toolpath, smooth overlap at boundary, free tool geometry and trim toolpath to stock.

For improved clarity, *hyperMILL 2021.2* also has new functions that provide better feedback during CAM programming. Automatic Stock Display displays stock automatically for any machining job. Also, there is a new Preview of Selected Entities feature that highlights entities such as curves, faces or points when a job is selected. And for component alignment at a touch of a button, a new BEST FIT feature aligns the NC program automatically to the component position, eliminating manual alignment and optimizing the options offered by VIRTUAL Machining.

www.openmind-tech.com

LK Metrology
HELPS CUT INSPECTION TIME IN HALF

At the U.S. transmission plant of a global automotive manufacturing group, component inspection times have been reduced by half or more following the decision to partner with LK Metrology Inc, which has upgraded all of the CNC coordinate measuring machines (CMMs) on site to use 5-axis scanning technology in addition to touch probing. The Brighton, Michigan-based metrology company is the U.S. subsidiary of British CMM manufacturer, LK Metrology, Ltd. which built 19 of the 26 CMMs in use at the US factory. Two are on the shop floor, while the others are installed in five different quality control (QC) rooms.

A spokesperson at the world class manufacturing center explained, "We have been using LK machines for controlling the quality of our machined components for more than two decades. They have proved to be a reliable supplier and their ceramic-bridge machines are very accurate."

"There are a couple of other makes of CMMs here as well and we also asked those suppliers if they would convert all our machines to the REVO 5-axis scanning system from Renishaw, which is another UK company. They did not offer us a solution, however."

The impetus for investing in the metrology upgrade, where four- and six-speed transmissions have historically been manufactured, was the addition of eight and nine-speed versions. Since then, electric hybrid transmissions have also entered production. It put the inspection team under pressure to cope with the increased throughput, so the company ordered extra LK machines and decided to award the site-wide, turnkey REVO upgrade and servicing contract to them.

The spokesperson added, "LK had been pro-actively offering the conversion, but we needed to satisfy ourselves that our other CMMs could be similarly modified. Our engineers proved it could be done on a small, non-LK machine at another one of our plants. The results showed how fast the REVO process is, while being just as precise as the touch probing method we have traditionally employed."

"Some machined features on our transmission components need to be held within ± 30 microns true position. To achieve this level of accuracy, it is essential for us to be able to hold single-figure micron tolerances on other dimensions, as tolerance build-up is inevitable. Obviously we need to measure those features and REVO on our CMMs allows us to do that quickly and accurately."

Jobs swapped between CMMs in minutes

About 1,500 steel and aluminum parts per day are inspected, some being the same item but at different stages of manufacture. Overall, 200,000 features are checked daily. The benefit of the present metrology set-up is that each of the five QC rooms houses identical technology and capability, with fixtures and probes freely interchangeable. As a result, any operator can flexibly transfer jobs between CMMs around the site within minutes and it feels like he or she is using the same machine, a level of commonality that delivers highly consistent results. Previously this would not have happened, as the disparate measuring platforms within the facility meant that it would have taken hours or even days to move parts around for checking.

The benefits of scanning

The scanning system is Renishaw's REVO, a two-axis CNC head that moves in unison with the three CNC axes of the CMM under program control to provide full 5-axis inspection, collecting dimensional data accurately using a tactile stylus. It can measure discrete points on a component in a conventional manner but is also able to scan over some areas, where it is expedient, to collect data at much higher speeds without leaving the surface. It is this latter feature that has on average halved cycle times at the US transmissions manufacturer.

Controlled by Renishaw's MODUS software, the nimble head with its two rotary CNC axes minimizes the linear acceleration and deceleration of the CMM's large moving elements during a measuring routine, whether touch probing or scanning. It means that the three orthogonal axes move for the most part with constant velocity, allowing changes in component geometry to be followed without introducing dynamic errors. Programs are created either in teach mode using the same software or from a CAD model.

The spokesperson concluded, "The system works extremely well, so we get results faster. We are currently looking at the possibility of having LK retrofit the latest REVO-2 head to our CMMs, which would allow us to acquire information on the surface finish of components in the same CNC cycles. The need for dedicated test equipment to check surface roughness could then be reduced or even eliminated."

"The system would also enable a multi-sensor approach to our measurement, as it can incorporate non-contact inspection using a vision probe as well as tactile methodology, should we ever decide to go down that route."

www.lk.metrology.com

Meet Me in St. Louis

The Gear Industry — and companies from the entire power transmission supply chain — will gather in-person at Motion + Power Technology Expo 2021

Randy Stott, Publisher & Editor-in-Chief

MOTION + POWER TECHNOLOGY EXPO
SEPTEMBER 14–16, 2021
ST. LOUIS, MO
MOTIONPOWEREXPO.COM

The Motion + Power Technology Expo (formerly Gear Expo), produced by the American Gear Manufacturers Association, will feature top manufacturers, suppliers, buyers and experts in the gear and mechanical power, electric power and fluid power industries when it comes to the America's Center Convention Complex in St. Louis, September 14–16, 2021.

Over three days, visitors will be able to shop the latest technologies in gear products and services on the show floor, network with customers, colleagues and peers in the many scheduled events, and take advantage of in-person education and training that are custom-designed for the gear and power transmission industry.

MOTION + POWER
TECHNOLOGY EXPO

The Show Floor

Exhibitors will conduct demos, host information-rich seminars and offer up their technical expertise. As of July 1, more than 130 exhibitors had registered for booth space at the show, but show organizers are expecting more to finalize their plans as the country continues to open up and companies become more comfortable with travel in a post-lockdown world.

The exhibitors will include a wide selection of the leading suppliers to the gear industry, including all the major machine tool, cutting tool, workholding, inspection equipment and related technology providers. In addition, visitors will be able to speak with dozens of gear and gearbox manufacturers. On top of all that, the show is once again co-located with the ASM Heat Treat Show (see our additional coverage beginning on p. 30).

Networking Events

MPT Expo and ASM Heat Treat combine to offer a number of scheduled opportunities for professional networking.

Opening Night Reception

Tuesday, September 14, 5:00 p.m. – 6:00 p.m.

Free to registered attendees

Make new connections and say hello to old friends during an hour of networking, food, and drinks. The event is free for MPT Expo attendees and includes two drink tickets per attendee.

Young Professionals Reception

Tuesday, September 14, 6:00 p.m. – 7:30 p.m.

$15/person

The Young Professionals Reception is open to all Motion + Power Technology Expo, the Heat Treat Conference & Exposition, IMAT, or Cold Spray attendees ages 40 and under.

AGMA and ASM are excited to announce the Young Professionals Networking Reception for all those business professionals 40 and under to attend. The evening will be a great opportunity for networking and industry discussion while enjoying food drinks and entertainment.

The Heat is On

Wednesday, September 15, 7:00 p.m. – 10:00 p.m.

$85 for members; $95 for nonmembers

The Heat is On at the Anheuser-Busch Biergarten! Join conference attendees from MPT Expo and ASM Heat Treat for a celebration of beer and food at this iconic and historic brewery. Attendees will also have the opportunity to tour the famous Clydesdale stables, historic brewhouse, and Beechwood aging cellars. Transportation provided from the convention center.

Education and Training

Why Bearings are Damaged

Tuesday, September 14, 8:00 a.m. – noon

ABMA

The American Bearing Manufacturers Association is offering this course on rolling element bearings for those involved in industrial equipment design, reliability, and maintenance. It will include a basic overview of rolling bearings, their selection, precision and mounting considerations, service life estimation, and lubrication-related influences. A hands-on damage analysis session will be the featured portion of this program.

Modern Automated Gear Quality Assessment Technology

Tuesday, September 14, 8:00 a.m. – 5:00 p.m.
William Mark McVea, KBE+, Inc.

This course is intended to provide you with a thorough understanding of the information contained within a typical gear inspection report. Specifically, we will look at the contents and meaning of the information contained within the gear charts, as well as the techniques used by the gear measurement system to assess gear quality. An explanation of basic gear measurement techniques, how measurement equipment and test machines implement these techniques, and how to interpret the results from these basic measurements will be covered. We will also discuss how to interpret the results and what corrective actions may be considered if the quality of a particular gear is unsatisfactory.

Design Basics for Spur and Helical Gears

Wednesday, September 15, 8:00 a.m. – noon
Terry Klaves

Learn how to develop and understand gear drive application specifications and target performance expectations. Review, select and calculate basic gear terminology variables and design parameters which define tooth bending and contact rating safety factors. Learn how to fit new gear design and ratio into existing center distance. Use commercially available software to calculate and optimize gear set power density through application of profile shift, accuracy, material, and heat treatment. Review other gear design related factors of operating noise level, efficiency, lubrication and micro-pitting.

Basics of Gearing

Wednesday, September 15, 8:00 a.m. – 5:00 p.m.
William Mark McVea, KBE+, Inc.

Dramatically improve your knowledge and productivity through Basics of Gearing. This course will be presented in a two-day format and will give you a comprehensive overview of standard gearing nomenclature, gear involute geometry, inspection procedures, and much more.

External Spur and Helical Gear Mesh Contact Analysis

Wednesday, September 15, 1:00 p.m – 5:00 p.m.
Terry Klaves

Evaluation of loaded tooth contact and development of tooth modifications using commercially available software to improve Khb and optimize power density. Two real-life gearing examples will be presented in the course, one will have a cantilever mounted pinion, the other a shaft pinion straddled non-symmetrically by bearings. Both examples demonstrate component deflections under load which significantly reduce tooth mesh contact which is then corrected with developed helix and profile modifications.

Basics of Gearing
Thursday, September 16,
8:00 a.m. – 5:00 p.m.
William Mark McVea, KBE+, Inc.

Dramatically improve your knowledge and productivity through Basics of Gearing. This course will be presented in a two-day format and will give you a comprehensive overview of standard gearing nomenclature, gear involute geometry, inspection procedures, and much more.

Education & Training Pricing	Early Bird Member	Early Bird Nonmember	Regular Member	Regular Nonmember
Basics of Gearing	$795	$850	$895	$995
External Spur and Helical Gear Mesh Contact Analysis	$295	$350	$395	$450
Materials Selection and Heat Treatment of Gears	$495	$550	$595	$650
Modern Automated Gear Quality Assessment Technology	$495	$550	$595	$650
Why Bearings are Damaged	$295	$350	$395	$450

Materials Selection and Heat Treatment of Gears
Thursday, September 16, 8:00 a.m. – 5:00 p.m.
AGMA and ASM

Because of their unique contribution to the operation of so many machines and mechanical devices, gears have received special attention from the technical community for more than two millennia. New developments in gear technology, particularly from the materials and heat treatment perspectives, have improved gear performance. This course, development jointly by AGMA and ASM International, will provide an overview of materials selection and heat treatment of gears. Topics covered include: Gear material selection, heat treatment, material hardenability, allow steel selection, gear failure concerns, manufacturing considerations, material form, cast iron, powdered metal, bronze and brass, and plastics.

Solutions Center

Don't miss these special FREE presentations right on the show floor. The Solutions Center is located in booth #3837, and additional presentations will be added as we get closer to the show. Two of the sessions include a focus on the global vehicle outlook with featured customer preference vs. market direction, and discussions of EV innovation, supply chain, disruptive forces, key partnerships, standardization, trade and more. Solutions center speakers will include:

- Joseph McCabe, CEO of AutoForecast Solutions LLC. With decades of industry experience and knowledge, McCabe provides production forecasting and advisory services to the global automotive community.
- Casey Selecmen, a 20+ year expert in powertrain forecasting. Selecman focuses on helping companies navigate industry risk and opportunities by using critical market intelligence to give them an edge in their strategy and business planning efforts.

Gear Technology and *Power Transmission Engineering* – Booth # 2813

Our magazines will be featured as part of the AGMA booth, #2813. We look forward to seeing you there. Our editors will be on hand to discuss article ideas and trends in our industry. We'll also help you renew or begin a free subscription, or answer any questions you might have about advertising — in print, online or via one of our e-mail newsletters.

Watch Out for Roaming Editors!

This year our editorial team will be taking its show on the road. At MPT Expo, we'll have a roaming video crew shooting interview segments for *Gear Technology TV* and *Power Transmission Engineering TV*. If you'll be at the show and you have any new technology you'd like to have featured, or if you have other news or opinions you'd like to share, please contact us to set up a time for our crew to meet with you (e-mail Randy Stott, Editor-in-Chief, at *stott@agma.org*).

More Information

Look for additional extended coverage in the August 2021 issue of *Gear Technology*; the August and September 2021 issues of *Power Transmission Engineering*; and the *2021 MPT Expo Show Guide*, which will include complete booth listings, as well as articles about exhibiting companies. In addition to being distributed in person at MPT Expo, the *Show Guide* will also be distributed by e-mail on Sept. 1 to anyone who is a subscriber to the *Gear Technology* e-mail newsletter (sign up or renew today at *geartechnology.com*).

To register for the show or any of the related networking or educational events, visit:

motionpowerexpo.com

Heat Treat 2021

The Bridge Between Research and Industry in Heat Treatment

Matthew Jaster, Senior Editor

Heat Treat 2021 is a conference and expo for heat treating professionals featuring 2½ days of face-to-face networking opportunities with approximately 200 heat treat exhibitors/companies. All of the top heat treating companies will offer the latest research and industry insights during more than 100 technical presentations. This year's show includes a VIP-guided industry tour, as well as student/emerging professionals initiatives, including free college student registration, Fluxtrol Student Research Competition and the new ASM Heat Treating Society Strong Bar Student Competition. Heat Treat 2021 is co-located with Motion + Power Technology Expo 2021 with access to additional exhibitors. The event takes place September 14–16, 2021 at the America's Center, St. Louis, Missouri.

Bodycote — Booth #621

Bodycote offers an international network of plants, providing thermal processing services including heat treatments, metal joining, hot isostatic pressing and surface technology. The global network operates from over 180 locations, with customers benefiting from Bodycote's comprehensive range of services from multiple locations. Customers know that if their business expands, Bodycote has the capability to meet their needs. The same process at the same quality standards can be obtained from multiple locations.

Bodycote recently announced the opening of a new facility in Syracuse, New York.

The new Syracuse facility is the second new facility to be opened in North America in as many months, following on from the announcement of the opening of the new Elgin, Illinois facility in December 2020.

The Syracuse facility, encompassing 60,000 square feet of operating space, is now operational and offers a wide range of heat treatment processes. These include vacuum heat treating, atmospheric carburizing, low-pressure carburizing, carbonitriding, ferritic nitro carburizing, nitriding and aluminum heat treating. It is envisaged that the site will secure all major OEM approvals as well as Nadcap accreditation which it is already well on the way to achieving.

Bodycote also announced the opening of a new facility in Elgin, Illinois in December 2020.

The Elgin facility upgrades the company's capabilities and positions Bodycote as part of an ongoing strategy to provide the best possible capabilities and geographical network to better serve customers from the agricultural, mining, construction, automotive and various other manufacturing supply chains in the Upper Midwest region.

The facility is now fully operational and supporting customer requirements. Bodycote continues to provide all of the processes and capabilities which were previously offered at the Melrose Park location. Additionally, the new state of the art facility in Elgin offers nitriding, Corr-I-Dur, nitrocarburizing and low pressure carburizing (LPC) solutions.

www.bodycote.com

ECM USA Inc. — Booth #1413

ECM Technologies is an innovative low pressure vacuum furnace manufacturer with headquarters in Grenoble, France. With subsidiaries and ventures around the world, ECM's global presence is well known in the automotive, aerospace, nuclear, energy, electronic, induction and 3D additive industries. With such versatile product lines and service capabilities, ECM is the ideal furnace system supplier for heat treatment processes ranging from rapid thermal processing (RTP) to low pressure vacuum carburizing (LPC). Our service capabilities include advanced automation, robotics, after sales, spare parts, on-site training and more.

ECM was recently recognized as one of the companies who is leading the way towards a better, brighter, greener future. ECM's ECO Furnace was presented the Green Business Award for accomplishing a cleaner, safer, and more efficient operation in the heat treat industry; more specifically the environment benefits from a low carbon footprint (energy consumption is minimal and CO_2 emissions are near 80% less).

www.ecm-usa.com

Ipsen — Booth #1906

Ipsen provides atmosphere and vacuum heat-treating systems and supervisory controls systems, which are used in many mission-critical applications. This advanced equipment is developed for aerospace, automotive, energy, medical, tool and die and various industries across the globe. Ipsen offers global modular platforms, as well as custom designs for specialized processes and requirements. Available in a wide range of sizes, our atmosphere and vacuum systems deliver versatility of processes, including annealing, brazing, hardening, low-pressure carburizing, solution nitriding, stress relieving and tempering.

Education: In addition to classroom-style trainings at their manufacturing facility, Ipsen offers on-site Ipsen U courses to accommodate large groups at customer facilities. Ipsen U is a course designed to teach heat treatment fundamentals, best practices and new methods. Attendees receive an extensive overview of vacuum furnace equipment, processes and maintenance.

For on-site trainings, customers can choose which topics to focus on, allowing for a customized, hands-on experience that follows safety protocols. Ipsen sends highly qualified technical resources, sometimes those who were directly involved with the build of the furnace they are training on.

Condition Monitoring: A feature on the PdMetrics dashboard monitors incoming three-phase utilities, voltage and frequency on Ipsen's Titan 2.0 vacuum furnaces. This addition offers further diagnostics for the diffusion pump heater assembly.

By adding these parameters, PdMetrics adjusts the expected kilowatt usage based on incoming line voltage, reporting precise diagnostic data, avoiding the potential for false alarms. Ipsen has nearly 100 Titan 2.0 furnace installations with the software.

Ipsen's predictive maintenance software for vacuum furnaces was developed in 2016 and helps customers minimize high-cost events and maximize up time. The software is available on any model of Ipsen furnace new or old.

www.ipsenusa.com

Seco/Vacuum Technologies — Booth #1607

Seco/Vacuum Technologies (SVT) is the North American arm of Seco/Warwick Group focusing on vacuum furnaces, gas nitriding furnaces, and related professional services. SVT is the North American sales, applications engineering and service support team for Seco vacuum furnaces.

CaseMaster Evolution

Seco/Warwick CaseMaster Evolution vacuum furnace and BREW atmosphere furnace will make up a new production line in the specialized commercial hardening plant of Aalberts Surface Technologies Heat in Kalisz (Poland).

Last year, the Dutch branch of Aalberts Surface Technologies Heat (formerly Hauck) in Eindhoven received a furnace, operating under high vacuum, with the working chamber of 1200 × 1200 × 2000 mm, which is not only the largest furnace with an all-metal heating chamber but also the largest device of this kind to be operated in the Benelux Region of Europe (Belgium, the Netherlands and Luxembourg). Now the Polish, Kalisz-based branch of the heat treatment systems and services provider will expand its production line getting a solution that can only be described with "the most" prefix.

The new furnaces will create a production line that will be used for successive vacuum carburizing (LPC) and gas quenching (CMe-T furnace), followed by annealing (BREW furnace) to reduce the internal stress of the treated metals. Performing so many processes is possible thanks to the combination of vacuum technology with atmosphere technology.

Gas Nitriding

A process that has been known for more than a century, gas nitriding, has seen a technology breakthrough that is a real game changer in the field of metal heat treatment. The ZeroFlow method introduced to global industry by Seco/Warwick in cooperation with scientists from one of the best technical universities in Poland, Poznan University of Technology, reduces process costs with performance that is far more ecologically friendly.

LPC Technology

LPC technology is applied wherever carburizing is used as a process improving the mechanical properties of elements and parts of machines as well as power and movement transmission systems. In short, wherever the drivers include cost reduction, efficiency, quality and reliability, exploitation flexibility and environmentalism. The LPC technology made in SECO/WARWICK is especially popular amongst the manufacturers carburizing massive or longitudinal elements like gears, bearings, drilling tools and other elements requiring thick carburizing layers.

For example, atmosphere retort furnaces have long avoided LPC due to their unique feature which is the ability to expose work to air at the process temperature, a design that classic vacuum furnaces could not replicate. The Pit-LPC solution has overcome this barrier and currently presents an advanced and comprehensive alternative to pit furnaces and their functions, bringing all of the LPC technology-related advantages into this application area. The LPC equipment can be tailored in such a fashion that allows Seco/Warwick to assemble the new equipment in the existing atmosphere furnace bay. Such a non-standard approach impacts the continuous expansion of the sectors interested in the furnaces equipped with LPC technology and the Pit-LPC furnace.

www.secovacusa.com

Solar Manufacturing — Booth #1313

Solar Manufacturing is a privately held, U.S.-based company providing technologically advanced vacuum heat treating furnaces. The company offers designs for heat treating processes such as hardening, brazing, stress relieving, normalizing, annealing, tempering, carburizing, nitriding, and sintering as well as durable and energy-efficient graphite and molybdenum hot zones. Highlights include the SolarVac Polaris advanced and interactive control system with remote access offers preventive maintenance diagnostics and the ConserVac energy management system.

Solar Manufacturing recently shipped and installed a vacuum heat treating furnace for NexGen Advanced Fuel Systems, an Allied Power Group Company, based in Houston, Texas.

NexGen, a premier gas turbine component overhaul facility, ordered Solar Manufacturing's new HFL-7472-2IQ furnace to help increase their capacity and reduce turnaround time for their heat treating and brazing operations. Built specifically to heat treat land-based turbine equipment, with attention to specific cooling requirements required by NexGen's customers, the furnace features a Solarvac Polaris Control System and a graphite hot zone accommodating loads up to 48" wide × 48" high × 72" deep. The furnace has a maximum load weight capacity of 6,000 pounds.

Additionally, Solar recently shipped a Mentor vacuum furnace to a medical device and implant manufacturer in the Southeast United States. The Model HFL-2018-2IQ features an all-metal insulated hot zone, a load weight capacity of up to 250 lbs., and a maximum operating temperature of 2400°F. The Mentor vacuum furnace will be used to age harden and anneal medical devices and implants.

Solar Manufacturing recently shipped an external quench vacuum furnace to a West Coast aerospace manufacturer. The Model HFL-7472-2EQ features an all-metal hot zone, a load weight capacity up to 10,000 lbs., a maximum operating temperature of 2400°F, and a 2-bar quench system optimized for argon with a 150 HP quench motor and a variable frequency drive. The furnace working zone measures 48"W × 48"H × 72"D, includes the SolarVac Polaris control system, and is AMS2750F compliant.

solarmfg.com

Educational Opportunities

The show features 100+ technical presentations including the following: (Please note that sessions and times are subject to change).

Tuesday September 14, 2021

8:30 – 9:50 a.m.

Applied Technology I
Session Chair: Rozalia Papp and Dr. Jerzy Barglik
Microstructural Development and Characterization
Session Chair: Prof. Robert L. Cryderman and Eva Troell
Residual Stress I
Session Chair: Prof. Lesley D. Frame and Collin Russell

10:30 – 11:50 a.m.

Applied Technology II: Energy Consumption and Efficiency
Session Chair: Dennis Beauchesne and Dr. Bernardo Hernández-Morales
Residual Stress II
Session Chair: Prof. Lesley D. Frame and Collin Russell
Vacuum Processes and Technology
Session Chair: Roger Jones and Dr. Emilia Wolowiec-Korecka

1:00–2:20 p.m.
Additive Manufacturing I
Session Chair: Michael Pershing
Induction Heat Treating I
Session Chair: Robert C. Goldstein and Prof. Bernard Nacke
Quenching Technologies I: Simulation
Session Chair: David A Guisbert and Dr. Imre Felde

4:00–5:30 p.m.
Fluxtrol Student Research Competition - Phase I - Posters
Session Chair: Mr. Robert C. Goldstein
Poster Session

Wednesday September 15, 2021

9:00–10:20 a.m.
Industry Internet of Things/Automation and Control
Session Chair: Jim Oakes
Quenching Technologies II
Session Chair: Andrew L. Banka, P.E. and Dr. Kyozo Arimoto

1:30–3:10 p.m.
Induction Heat Treating II
Session Chair: Dr. B. Lynn Ferguson and Dr. Egbert Baake
Process Simulation / CALPHAD
Session Chair: Dr. Zhichao (Charlie) Li
Quality Control
Session Chair: Dr. Olga Rowan

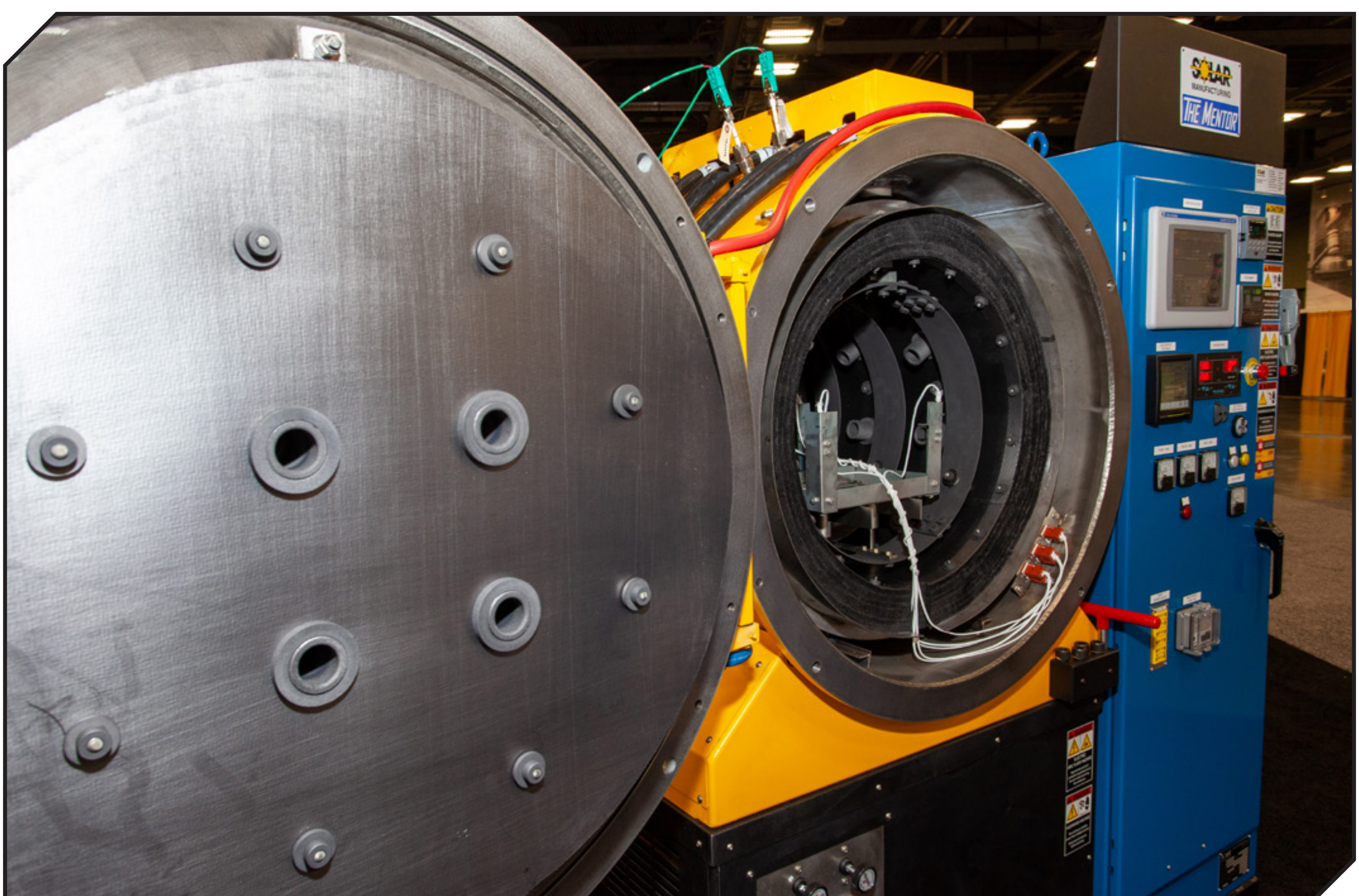
4:00–5:40 p.m.
Additive Manufacturing II
Session Chair: Mr. Thomas Wingens and Prof. Reinhold S. E. Schneider

4:00–6:00 p.m.
Atmosphere Technology and Surface Engineering
Session Chair: Ms. Larissa Vilela and Dr. Satyam S. Sahay

Thursday, September 16, 2021

8:30–9:50 a.m.
Materials Durability/Mechanical Testing I
Session Chair: Dr. Mohammed Maniruzzaman
Quenching Technologies III
Session Chair: Dr. Thomas Lübben

10:10–12:30 p.m.
Applied Technology III
Session Chair: Prof. Mei Yang
Materials Durability / Mechanical Testing II
Session Chair: Dr. Lee M. Rothleutner
For additional information, visit
www.asminternational.org/web/heat-treat.



Current and Future Gearmaking Challenges in Workholding

Quick-change capability and high clamping forces deliver both flexibility and strength

Frank Burke and Michael Larson

The combination of worldwide pandemic and current and anticipated changes in technology have severely impacted both high-production gear manufacturers and shops producing limited runs of gears. Concerns include the availability of qualified personnel, proper allocation of capital investment, productivity requirements, and market demand. While these are not unheard of under normal conditions, the present situation has caused a major disruption on virtually all fronts and, as a recent survey of the industry by *Gear Technology* magazine has shown, (*www.geartechnology.com/issues/0121x/Gear-Indusatry.pdf*) many in the industry are deeply concerned about the future.

The Future: Different but Better

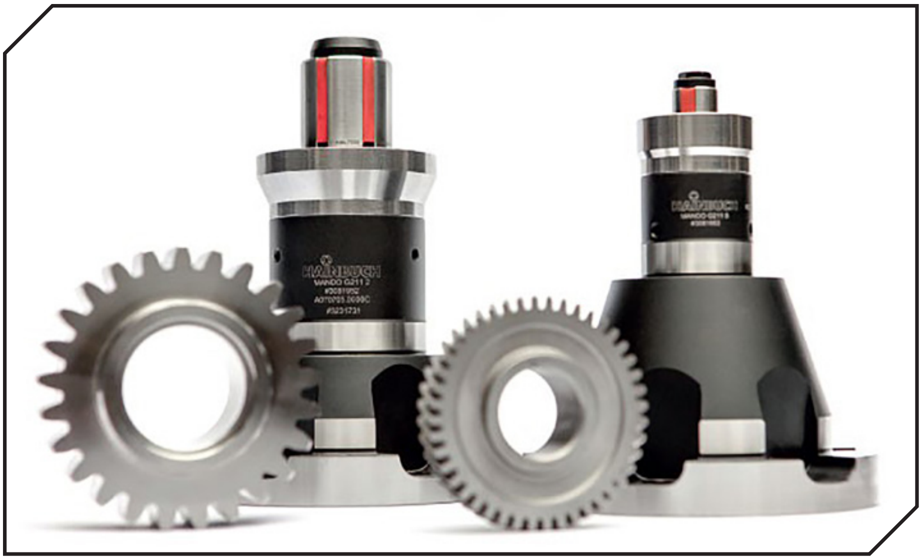
Timothy Wachs, president of Hainbuch America Corp., sees a future that will be different but will offer multiple opportunities. "Hainbuch's long history of involvement with gear manufacturing has given us a perspective that is realistic yet optimistic. Some of the changes that have taken place have been accelerated by the pandemic and will remain. For instance, the use of social media and remote conferencing has become much more commonplace, and many individuals not previously familiar with it now use it on a daily basis. As an international corporation, we can see that this familiarity will translate into a new type of marketing and an increased presence in the worldwide marketplace.

"Individuals involved in design and engineering, as well as management and staff functions, will be able to work remotely, and the ability to involve an overseas pool of talent will increasingly become a reality," he added.

With regard to the factory floor, Wachs sees the need for other equipment manufacturers to follow Hainbuch's lead in the development of equipment that is extremely user-friendly. "One of the greatest challenges faced by industry today is the availability of machinists, operators, and other workers. There are any number of reasons for this, including competition from other industries and businesses and the shortage of technical training that has long been a problem in the American educational system. Although many schools have come around and are now emphasizing STEM (Science, Technology, Engineering, and Math) courses, the full impact of this will not be felt for a number of years. To solve this deficit, some amount of automation may be practical, but that is typically expensive, not just in terms of equipment but in the need for programming skills. The labor shortage is notably difficult because it comes at a time when American manufacturing has moved from high-volume production to a low-volume, high-mix model."

Hainbuch has developed a product line that can effectively use robots in changeover operations for different parts, according to Wachs. "More to the point, our equipment is designed to permit fast and accurate change that is easy to complete. The machine operator can be taught how to use our equipment in a matter of hours, and the repeatability can accommodate tolerances at the micron level. I like to say that we are helping to redefine the meaning of 'skilled labor' and that we are providing a means for less experienced individuals to start building a successful career in manufacturing," he said.

MAXXOS Mandrel with hexagonal taper.



'Multi-purpose' mandrel for gear production.

Technology Drives Product Changes

Wachs sees opportunities in gearmaking's changing product mix as well. "Any number of technological innovations are going to offer new opportunities. From an automotive standpoint, hybrid and electric vehicles (including both cars and trucks) will alter or eliminate the traditional drivetrain but will result in opportunities with the manufacture of smaller high-precision parts. A very big factor will be the advances taking place in drone technology that range from defense applications to package delivery and vehicles capable of vertical takeoff and landing. All of these will require a new generation of gears. At the same time, there will be no shortage of more traditional gear designs," Wachs said.

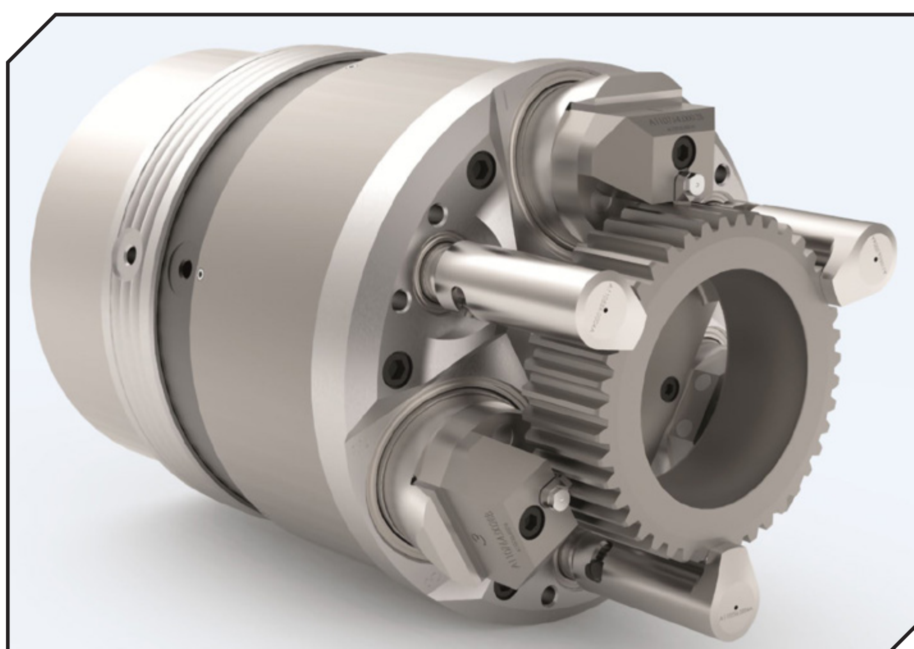
As the need for new technology increases, a primary concern of manufacturers in every industry is the allocation of capital expenditures. Following the general slowdown caused by the pandemic, as well as gaps in the supply chain, many are planning new investment strategies.

"We have found that a significant number of Hainbuch customers, including those involved with gear manufacturing, have employed two different but effective means of conserving capital. On the one hand, by equipping older legacy machines with Hainbuch precision workholding systems, they have been able to achieve results comparable to what a new machine could deliver at a fraction of the cost. In fact, I recently visited a plant that had equipped a number of 70-year-old lathes with Hainbuch systems and were cutting gears to desired tolerances. Admittedly, this is the exception, but it's a vivid demonstration of what precision workholding can do.Other customers have purchased less expensive machines and equipped them with our systems so that they perform to the standards of much more costly units," Wachs said.

"It is pleasantly ironic that the primary factors in gear cutting are rigidity and clearance, typically difficult to achieve. We have been able to deliver those results in a system that is easy to use, reduces setup time, and offers unlimited flexibility," he added.

LEGO-Based Innovation

Dean Winkel, Hainbuch manufacturing representative serving eastern Canada, cites specific Hainbuch product advantages. "Although we regularly work with customers in developing special products for unique applications, one of our main objectives is the development of standard products that can be used in most situations. A primary example of this is our G211 mandrel, which we refer to as the 'multi-purpose mandrel.' The original design is very short and rounded out with a wide base, but it is also available in a longer and thinner version. On a hobbing machine, it is extremely versatile and can be used for multiple sized gears by simply changing the clamping bushings or substituting regular bushings with a set specially



One of a kind, specially designed and manufactured for a customer in the aerospace industry. this gear chuck positions the part in microns. Changeover from one diameter to the other is accomplished with less than 3 microns variance.

ground to specific diameters."

The mandrel itself alternates sturdy metal construction with specially formulated vulcanized material and provides high clamping torque without marring the part. The vulcanized bushings also give a great amount of stroke and feature more room for easy loading. It is far superior to traditional mandrels that are, in effect, slotted cylinders placed on a shaft and subject to breakage. G211 vulcanized strips are not brittle and, therefore, avoid breakage.

Winkel said that Hainbuch offers special sizes for smaller bore gears including the T213, which extends from ⅝ to ¾ inch, and the Micro Mandrel for bores as small as 8 mm.

"Hainbuch's large diameter collet chucks deliver accuracy and stability in the production of ring gears. They're available in a wide range of sizes and are easily and quickly changed with minimal setup time," Winkel said.

"We term our approach 'LEGO based innovation' in that our family of products is designed to be truly modular and capable of multiple applications. Our customers frequently contact us to tell us how they've adaptable our standard products to special situations to derive greater flexibility at less cost," Winkel added.

Peter Mueller, director of strategic sales for Hainbuch, works out of the corporate headquarters in Marbach, Germany, where he has access to the engineering and R&D departments. He notes the evolution of demand in the gear manufacturing industry. "In the past, the majority of our sales were to customers in the automotive sector. Today, the largest growth comes from aerospace and defense."

Thanks to Hainbuch's innovative design, customers have the ability to machine a larger range of gear sizes on the same mandrel. "The vulcanization process is really the 'heart of Hainbuch,'" said Mueller. "In developing material, we've tested it for resistance to oils, heat, and virtually any other hostile condition that could possibly affect the mandrel."

One of Hainbuch's latest innovations is the MAXXOS mandrel, which was introduced in 2019.

"The MAXXOS uses a unique hexagonal design for strong clamping power in the 18 mm to 100 mm range. The run-out accuracy extends from 0.01 mm/0.007 mm possible to an accuracy of $\leq$0.002 mm by special order. The hexagonal pyramid shape allows maximum machining capacity with less vibration and thereby less tool wear. And, like all Hainbuch products, setup time is fast and easy," Mueller said.

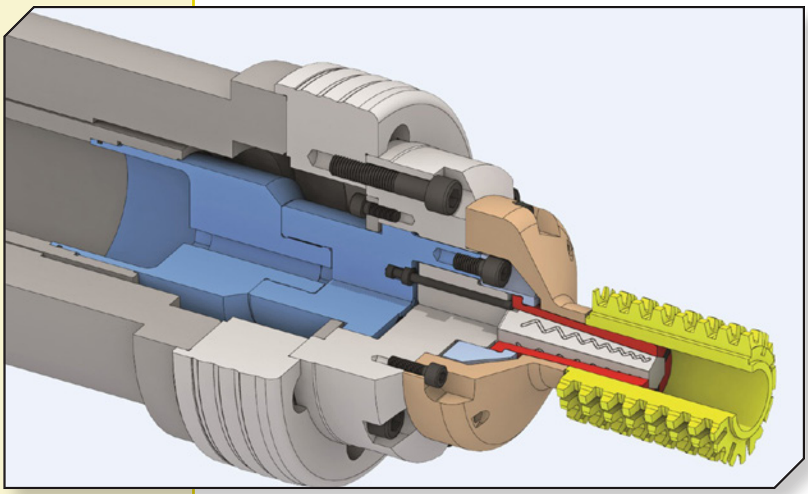
The Evolution Continues

"As customer demands change, it's our goal to provide them with high precision and maximum flexibility in an efficient and affordable package. As the gearmaking industry emerges from a very difficult time, Hainbuch continues to provide technology and the support necessary to move toward a brighter future," Wachs said.

www.hainbuchamerica.com

MAXXOS Line Resists Extreme Cutting Forces

For ID workholding, Hainbuch's Mando product line is well-known for its rigidity, parallel expansion clamping, and its unrivaled clamping forces. However, in exceptional cases when a clamping length is minimal, or extreme torque is generated by cutting forces, special design features are required.



In this case, a customer needed an internal clamping chuck that would maintain its functional integrity under severe cutting forces.

By integrating a hexagonal cross-section to the Mando's clamping cone, the bushing is unable to begin slipping on the Mando column—where slippage first appears. To generate more radial clamping force, a shallower clamping angle was also incorporated. Although this slightly lessens the radial stroke, it greatly enhances the force generated to the workpiece.

The MAXXOS line, of which this is an example, was added to Hainbuch's Mando family for more demanding machining forces. Where necessary, the Hainbuch design team can add additional features to accomplish virtually any ID workholding challenge. Learn more here:

www.hainbuch.com/en/products/mandrels/mandrel-maxxos/

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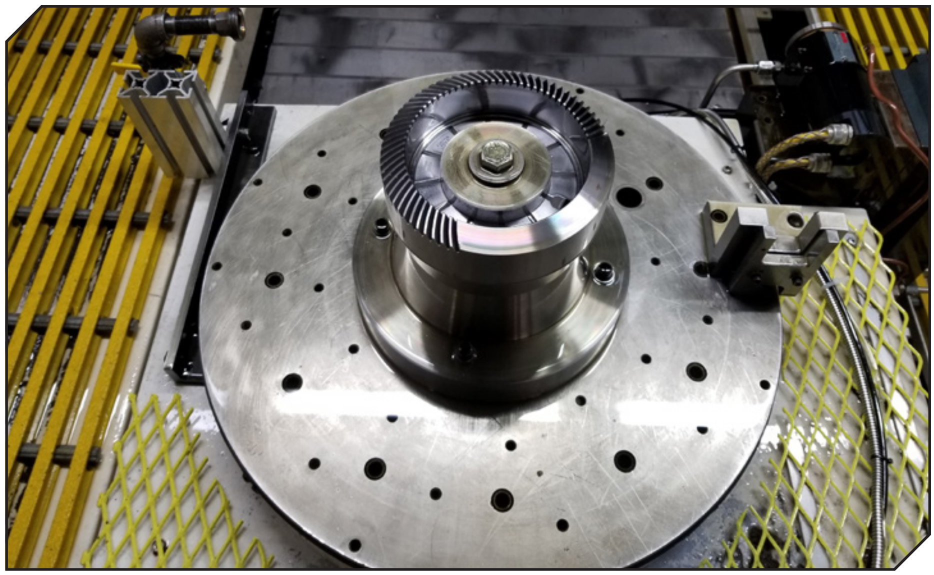
Teaming Up to Solve Bevel Gear Grinding Application Challenges

Norton|Saint-Gobain Abrasives and Gleason Works Collaborate to Achieve a High Performance Gear Grinding Solution

Mark Martin, Phil Plainte and Eric Mundt



Fine pitch grinding from solid can be particularly problematic, as the typically narrow wheel tip width required to grind these gears makes it very difficult to achieve good balance between tip wear and productivity. To achieve the most efficient fine pitch bevel grinding solution, Norton|Saint-Gobain Abrasives (Worcester, MA) and Gleason Works (Rochester NY,) teamed up to evaluate, test and implement the latest, best abrasives application. Norton|Saint-Gobain Abrasives is a one of the world's largest abrasives manufacturers. Gleason Works is a global leader in state-of-the-art manufacturing equipment for all types of bevel gears and produces bevel and cylindrical gear machines as well as tooling products.

Norton and Gleason have a longstanding working relationship and wanted to accelerate the development of new grinding wheel technology in the bevel gear market. The goal was to expedite grinding wheel product development, so that Gleason could apply the latest technology. Norton wanted to provide Gleason with a well-defined grinding product that would enhance the operation of its machines for specific bevel grinding applications.

In order to do this, Norton needed a viable screening method for testing new grinding wheels on bevel gears. This would allow Gleason to select the best products for use on their machines and their customers' specific needs, reducing Gleason process development times.

System Approach

To advance grinding technology, innovative materials research and development teams at Saint-Gobain Research North America's Higgins Grinding Technology Center (Northborough, MA) work with business and customer partners to solve problems in challenging industrial markets.

For the fine pitch bevel grinding challenge, Norton used a "system approach" methodology aimed at evaluating the variables that influence the output of the process. The diagram below (Fig 1.) shows the process as well as the importance of understanding the microscopic interactions in a grinding process.

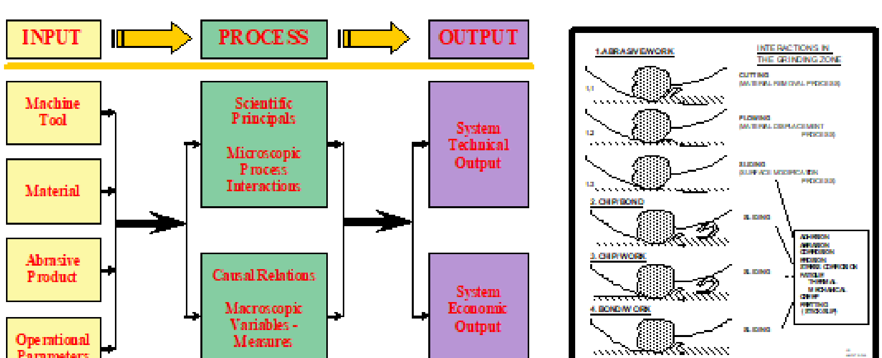


Figure 1 **The "Systems Approach" methodology evaluates the variables that influence the output of the process.**

Key Technical Background Details for the Systems Approach:

Grinding zone interactions

The area of contact between the wheel and workpiece is referred to as the grinding zone. The energy used during grinding is consumed by various interactions within the grinding zone. The diagram (Fig.1, box on the right) illustrates these interactions. An understanding of these interactions is needed to interpret the observations and measurements taken during testing.

Technical Approach

A bevel gear set is comprised of a pinion and ring gear. The pinion is ground using the generating method to satisfy the required tooth contact tolerances, and to ensure proper contact characteristics when the gears mesh. In the automotive world, the ring gear is generally ground using the formate process (non–generating). The formate process offers higher productivity than the generating method because the generating roll is eliminated in the former method.

A Waguri spindle used in grinding bevel gears is essentially a spindle within a spindle. The inner spindle drives the grinding wheel. The inner spindle axis is radially offset from the outer (Waguri) spindle axis so that it moves in an orbital fashion about the outer spindle axis. The orbital motion prevents the grinding wheel from being in full contact across the entire tooth length at any instant, but the frequency is high enough that the ground tooth surface is smooth and continuous. For this test, Gleason engineers used their CAM system to generate a tool path to plunge a wheel directly into the tooth space, as well as a tool path for dressing a required shape onto the wheel. The modified wheel shape is designed so that both tooth surfaces are finished at the same time and to the proper geometry without the eccentric action of a Waguri spindle.

Gleason's CAM system was used to develop software & programing that allowed Norton's 5 axis grinder to model form grinding of bevel gears to a point where data could be collected and used to screen the Norton product for Gleason's bevel gear applications.

A Multi-Phase Project

- Gleason developed software and assisted with part fixtures designed to enable the Norton 5-axis machine to simulate bevel gear grinding.
- Gleason provided parts to be ground.
- Norton provided new grinding wheel technology for testing on the parts.
- Norton conducted testing, compiled the resulting data, mapped the new grinding wheel in a format that was useful for Gleason to apply on their specific application projects.

Test Objectives

The purpose of the screening test was to reduce the number of tests needed at Gleason's location to qualify wheels for grinding bevel gears. This test ranked wheel performance for fine pitch bevel gears with a major focus on root radius wear.

1. Tested multiple Norton bevel gear wheels for grinding fine pitch bevel gears from solid in order to identify new technology that could outperform popular older technology.
2. Ranked products for their ability to hold a 0.127 – 0.178 mm root radius.
3. Identified the highest metal removal rate that each product can reasonably achieve while maintaining the 0.13 – 0.18 mm root radius.
4. Screened the influence of wheel speed on root holding capability for each product.

Test Setup

The 184 mm gear blanks, supplied by Gleason, were made of 4140 carbon steel at 90 HRB hardness. The gear blanks were mounted in the machine using a fixture supplied by Gleason.

Test method

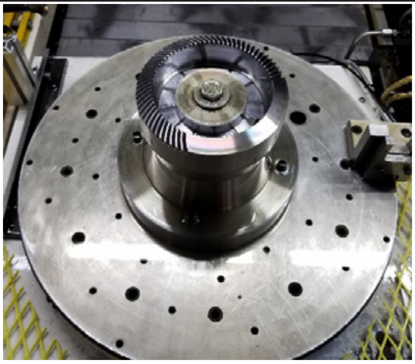
Dressing

Using a diamond roll dresser, a ~0.127 mm tip radius was dressed into each wheel specification (Table 2) using the dress parameters in Table 1. A graphite coupon was ground and the radius was measured using an optical comparator at 50X.

Phase 1

Seven teeth were ground at the parameters in Table 3 using a wheel speed of 23 ms^{-1} and a graphite coupon was cut after tooth number 1, 4 and 7. If a 0.25 mm radius was reached, grinding was stopped before seven teeth were completed. Power was also recorded for each grind.

Table 1 Dress Parameters



Dress Conditions	
Wheel Speed (rpm)	2480
Dress Roll Speed (rpm)	2458
Dress Speed Ratio	0.65
Lead (mm/rev)	0.051
Compensation (mm)	0.013

Table 2 Wheel Specifications

120 Grit Ceramic New Product
150 Grit Ceramic New Product
180 Grit Ceramic Standard Product
220 Grit Ceramic Standard Product

Table 3 Grind Parameters

Material	4140 @ 90 HRB
Full Wheel Dimensions (in)	178 × 127 × 89
Wheel Speed (m/sec)	~ 23 & ~ 28
MRR' ((mm³/sec)/mm)	2.7, 5.4, 8.1
Main Coolant Pressure (bar)	8.6
Main Coolant Flow (lpm)	182
Scrubber Pressure (bar)	34.5

Results Phase 1

The coupon radius measurements indicated what radius each specification could sustain after grinding. When tested at 23 ms^{-1}, only the 180 Grit Standard Product wheel could hold ~0.013 mm radius at 2.7 ((mm³/sec)/mm). None of the wheels run at 23 ms^{-1} could hold ~0.013 mm radius at an MRR' of 5.4 ((mm³/sec)/mm). However, some held much better at 28 ms^{-1}. Figure 2 shows the radius size for each tooth ground.

Results Phase 2

After testing at 23 ms^{-1}, the wheels were tested at 28 ms^{-1} using the same parameters in Table 3 at 5.4 and 8.1 ((mm³/sec)/mm).

Radius

The 180 Grit Standard Product wheel and the 150 Grit New Technology wheel both held ~0.013 mm radius at 5.4 ((mm³/sec)/mm) when run at 28 ms^{-1}. The 150 Grit New Product

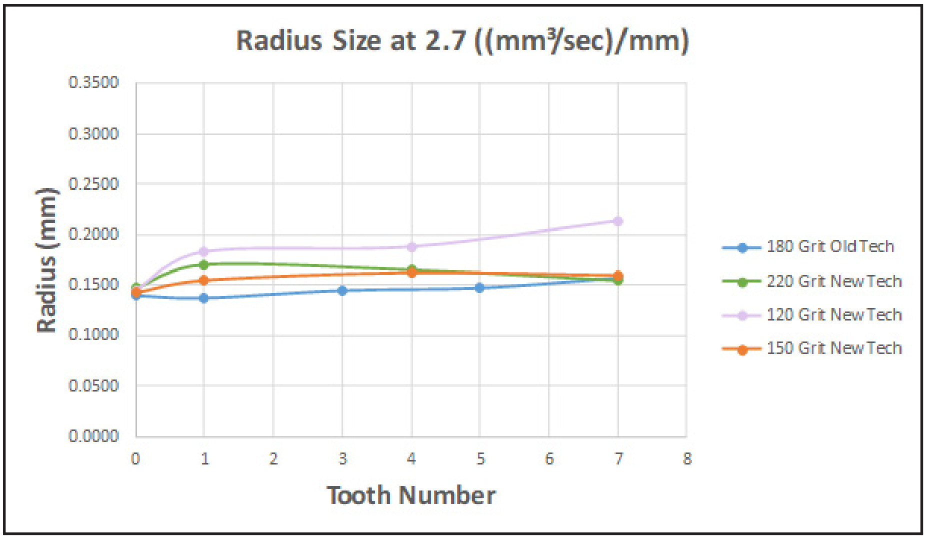


Figure 2 Radius Size at 23 ms^{-1}.

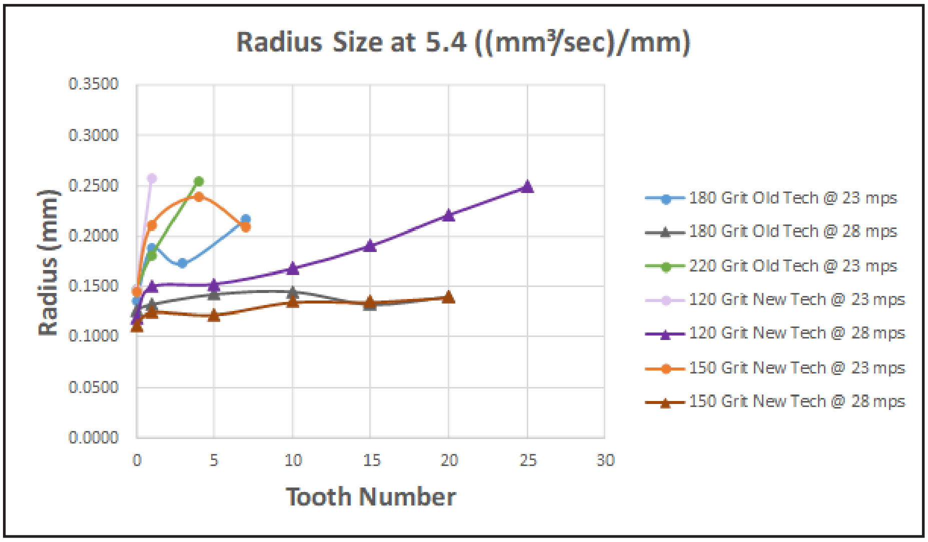


Figure 3 Radius Size 23 ms^{-1} vs 28 ms^{-1}.

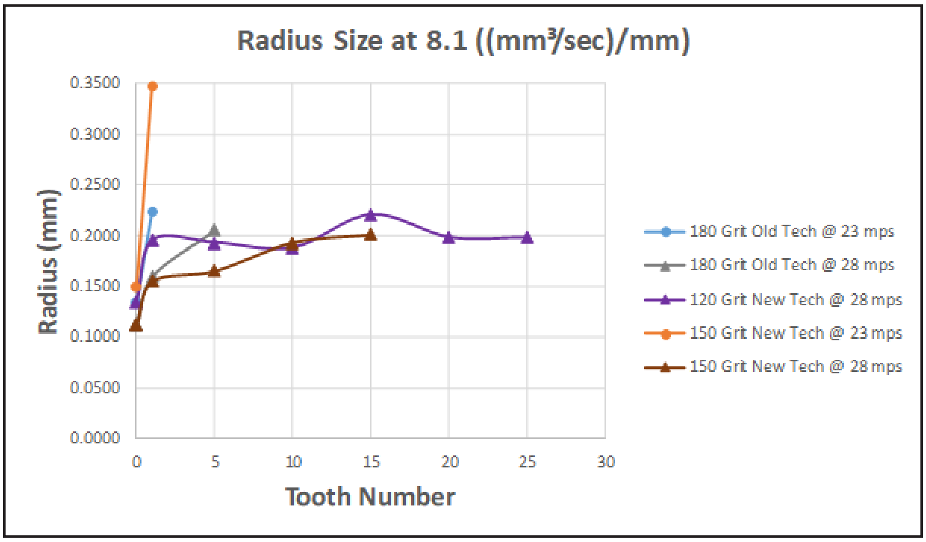


Figure 4 Radius Size 23 ms^{-1} vs 28 ms^{-1}.

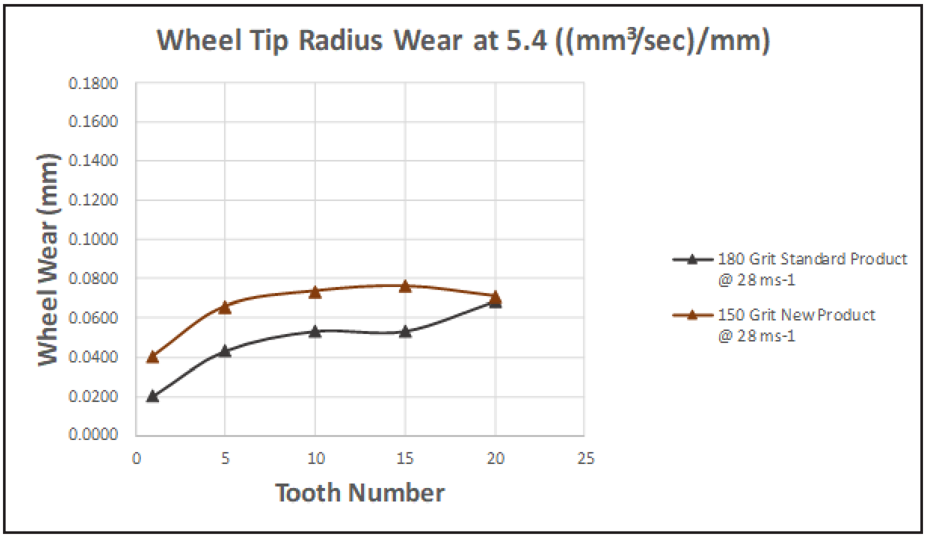


Figure 5 **Wheel Tip Radius Wear for 5.4 MMR' at 28 ms^{-1}.**

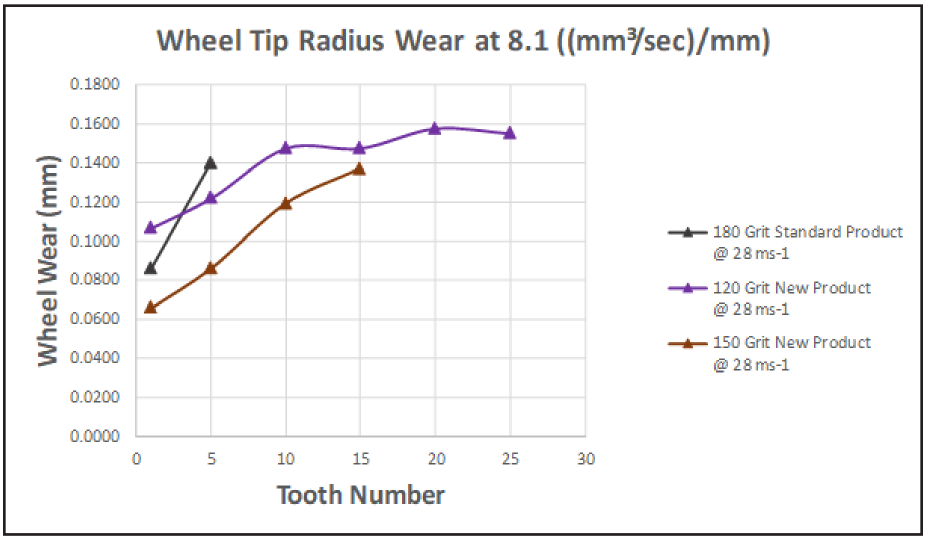


Figure 6 **Wheel Tip Radius Wear for 8.1 MMR' at 28 ms^{-1}.**

wheel held the radius better than the 180 Grit Standard Product wheel at both 5.4 ((mm^3/sec)/mm) and 8.1 ((mm^3/sec)/mm). Figures 3 and 4 show the radius size for each tooth at 5.4 and 8.1 MRR' respectively.

Wheel Wear

Wheel tip radius wear was measured for wheels tested at 28 ms^{-1} using the graphite coupons measured on an optical comparator at 50×.

Figures 5 and 6 show wheel tip radius wear for each tooth at 5.4 and 8.1 MRR' respectively. Though the 180 Grit Standard Product had less wheel wear at 5.4 MRR' than the 150 Grit, New Product Figure 6 shows that as the products are pushed into higher MRRs the new technology outperformed the old technology.

Summary

The new product showed improvements in radius holding when using higher metal removal rates, indicating a reduction in cycle time for the end user.

The collaboration of Norton | Saint-Gobain Abrasives and Gleason Works has benefited both companies and their customers. The ability of both companies to work together has also improved the knowledge of the individuals involved in the projects, mutually providing new solutions to further the development of grinding wheels and machining technology for gear grinding.

Mark Martin is an application engineer at Norton | Saint-Gobain Abrasives.

Phil Plainte is an application engineer at Norton | Saint-Gobain Abrasives.

Eric Mundt is chief research and development engineer at The Gleason Works.

For more information:

Gleason Corporation
www.gleason.com

Norton | Saint-Gobain
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Increasing Energy Efficiency through Improved Gear Surfaces in e-Mobility

Patrick Duhre and José López

The electric motors used in e-mobility have a significantly higher efficiency compared to conventional combustion engines: Up to 80 percent of the energy stored in the battery is transferred to the wheels as kinetic energy by the highly efficient electric motors by means of a transmission. When burning fossil fuels. the yield of 30 to 40 percent is only about half.

Nevertheless. efforts are underway to further increase the energy efficiency of electric cars. especially regarding the achievable ranges. A key element is also the surface texture of the gear flanks in the transmissions used.

The process which determines the quality is the hard finishing of gears through grinding and subsequent superfinishing at the end of the gear processing chain. There are constantly increasing demands on service life. smooth running. power transmission and efficient use of the introduced energy.

Since there is no official definition for the terms of fine grinding and polishing. Kapp Niles has created a definition that refers to the achievable surface quality during generating grinding (Table 1).

Table 1 Achievable surface qualities.

Method of Generating grindin	Achievable surface quality	
Conventional Generating grinding	Rz > 3 µm	Ra > 0.6 µm
Fine grinding	Rz 1 – 3 µm	Ra 0.2 – 0.6 µm
Polish grinding	Rz < 1 µm	Ra < 0.2 µm

The average roughness depth R_z and the average roughness height R_a were used as comparative values. However. it is understood that from certain surface qualities onwards. other values such as material ratios are better for characterizing the surface than R_z and R_a.

In order to meet the increasing surface requirements. various tools are also used in the different processes. as described below.

Conventional generating grinding

In standard generating grinding. a vitrified bonded corundum grinding worm is used. which consists entirely of one specification.

Fine grinding

In the multi-stage. combined machining process of superfinishing. a different grinding worm specification is used for rough grinding (conventional generating grinding) than in the actual fine grinding. Both specifications include a vitrified bonding but may have different types of corundum and/or grain sizes.

Polish grinding

In the multi-stage. combined machining process of polishing. a grinding worm with vitrified bonding is used for rough grinding (conventional generating grinding) and a grinding worm with a polyurethane or synthetic resin bonding for polishing.

In a one-step machining process of polishing (not in combination with direct rough grinding). a one-piece tool with polyurethane or synthetic resin bonding is used.

Fine grinding

The tool consists of two different tool specifications. In the area used for fine grinding. the feed speed is reduced during dressing (Fig. 1). This makes it possible to influence the achievable surface quality of the workpiece. This procedure for dressing influences the surface quality of the gear wheel. even if the grinding worm consists of only a single specification.

In the following images. profile and flank line measurements are each shown before and after fine grinding. It is already apparent in the profile measurement log of the gearing measurement (Fig. 3) that the profile shape deviation ($f_{f\alpha}$) could be significantly improved with this grinding/dressing technique.

As expected. there was no change in the lead measurement (Fig. 5). as the grinding grooves are in the direction of the tooth width in accordance with the largest velocity vector.

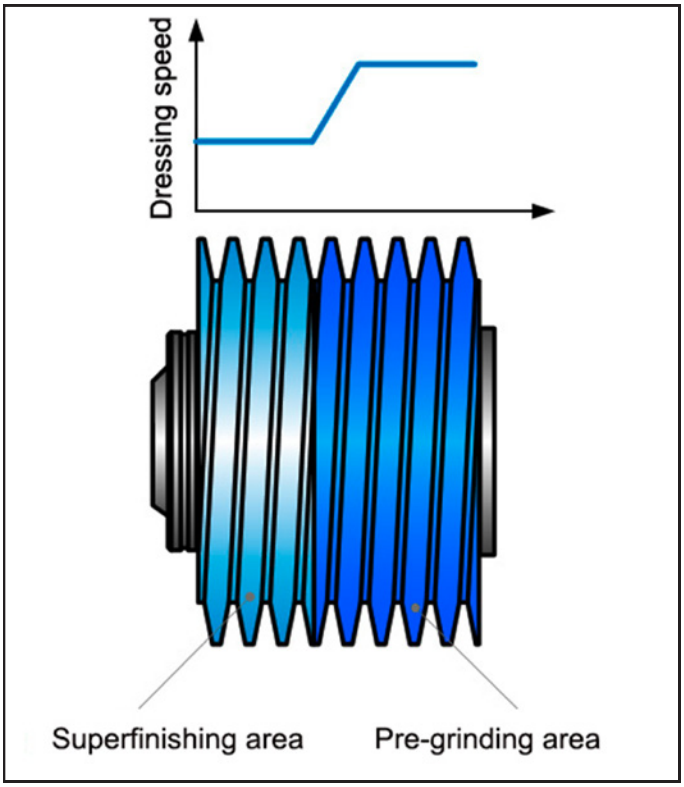

Figure 1 Reduction of dressing speed.

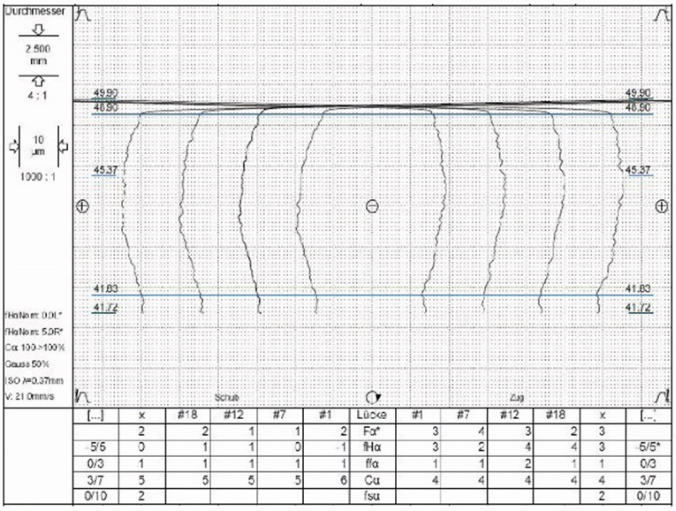

Figure 2 Profile measurement after pre-grinding.

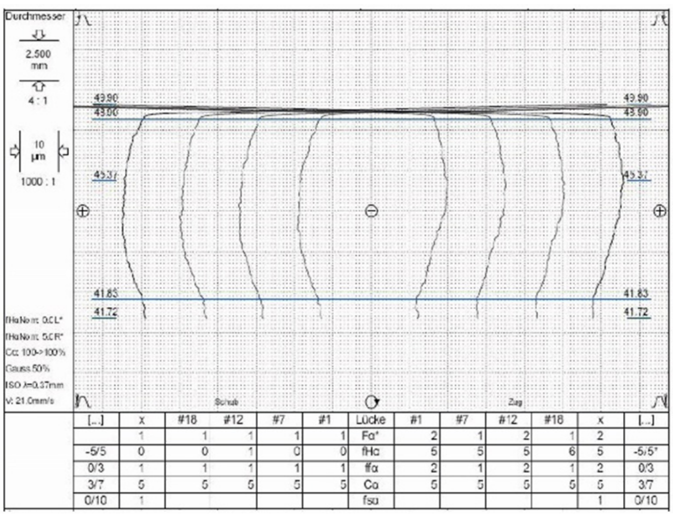

Figure 3 Profile measurement after fine grinding.

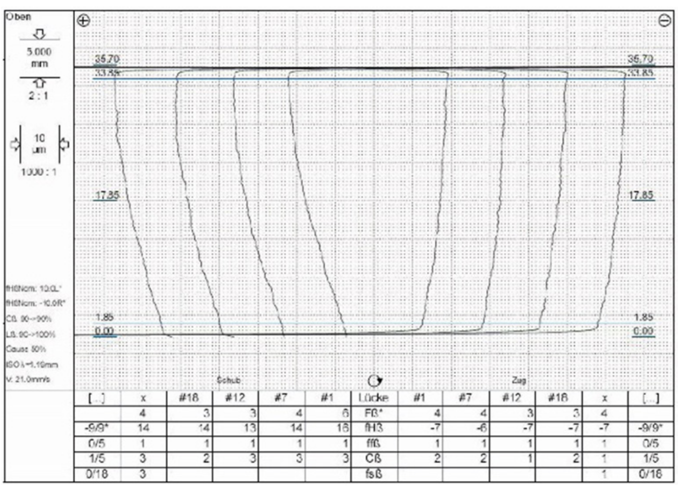

Figure 4 Lead measurement after pre-grinding.

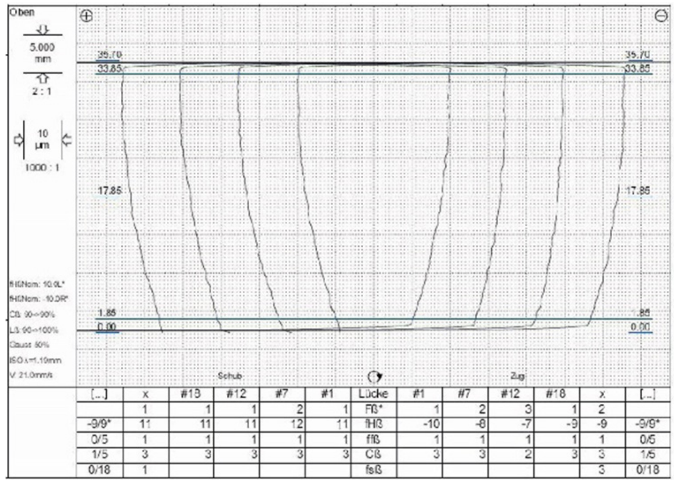

Figure 5 Lead measurement after fine grinding.

From the graphical comparison of the roughness measurement (Figs. 6–7). it can be seen that the surface has been smoothed. However. a roughness structure can still be seen. That is to say. the average roughness depth R_z and the average roughness height R_a could be reduced by a factor of 2 to 3. The core roughness depth R_k and the reduced centre height R_{pk} could be reduced by a factor of 2 (see Table 2).

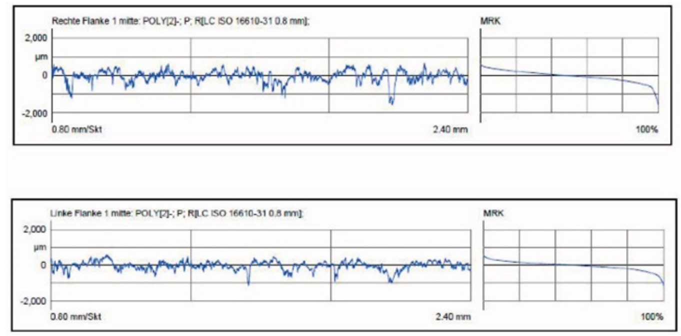

Figure 6 Roughness measurement after conventional generating grinding.

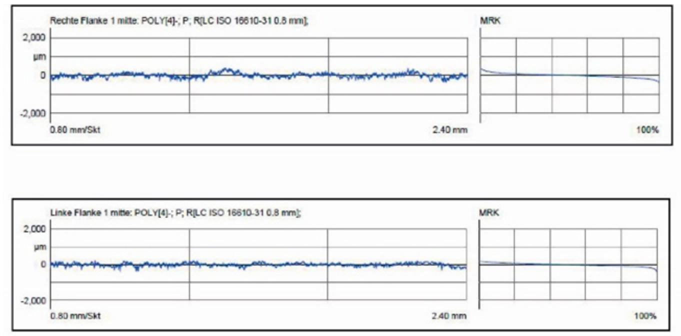

Figure 7 Roughness measurement after fine grinding.

Table 2 Comparison of surface characteristics.

	Conventional generating grinding		Fine grinding	
[μm]	left flank	right flank	left flank	right flank
R_{pk}	0.183	0.212	0.074	0.093
R_k	0.524	0.703	0.288	0.287
R_z	1.467	1.938	0.536	0.639
R_a	0.261	0.283	0.069	0.085

Polishing of shot-peened gears

Another area of application for high-precision machined gear flank surfaces are truck transmissions for both electric drives and conventional drivetrains. Nowadays. electric trucks are used in areas such as waste management or for the delivery of consumer goods in cities. Some food discounters even advertise that the transport of their goods between their stores in big cities is carried out with electrically powered trucks.

The polish grinding of shot-peened gear flanks is presented below.

The work sequence is as follows: After hardening. gears are machined as usual with the generating grinding process. using a one-piece grinding worm. As a result. the existing grinding stock including heat distortions is eliminated and the final workpiece geometry is produced. Afterwards. the gear flanks of the workpieces are shot-peened. The reason for shot peening is the hardening of the gear flank surface. which serves to extend the service life of the gears and therefore the transmission. In the last step. the gear flanks are polished on a generating grinding machine with a one-piece polyurethane bonded tool.

By polishing. microscopic raised areas caused by shot-peening can be eliminated. It is not necessary to eliminate all indentations.

Two gears were compared in Figure 8. On the left. the workpiece is shown after shot peening and on the right. the workpiece is shown after polish grinding of the gear flanks.

Figure 8 Comparison of two workpieces.

Figures 9 and 10 show the basic comparison of the profile geometry. In Figure 10. the reduction of the corrugation by polishing is clearly visible. The basic geometry of the profile is not affected. The profile angle deviation $f_{H\alpha}$. the profile convexity C_α and the tip relief $C_{\alpha a}$ are generated during conventional generating grinding processing prior to shot-peening.

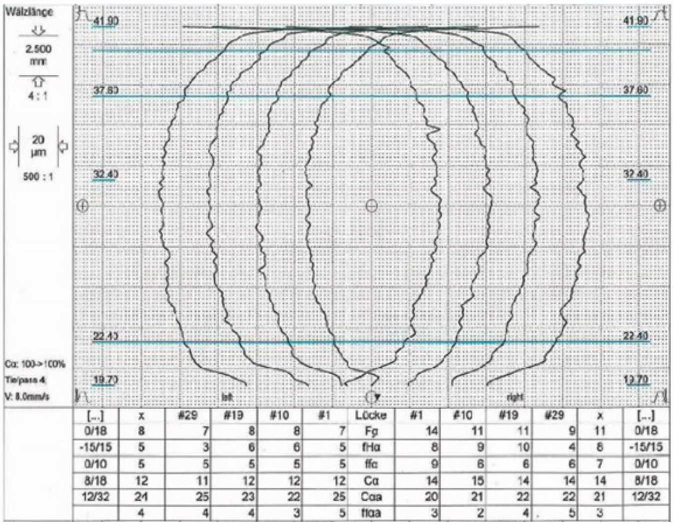

Figure 9 Profile measurement after shot peening.

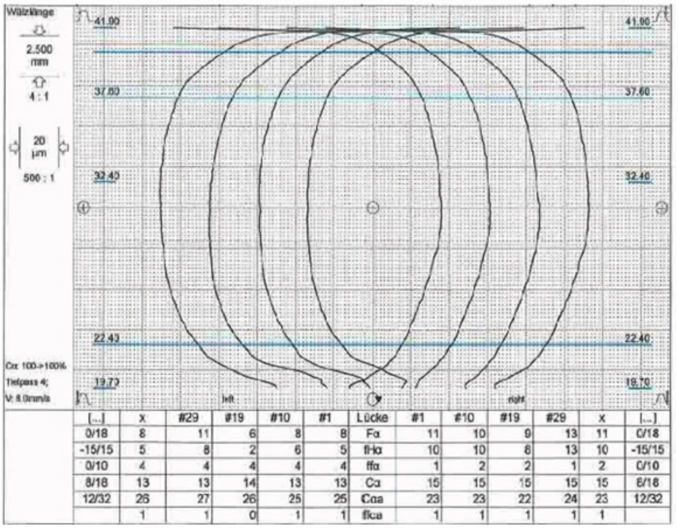

Figure 10 Profile measurement after polish grinding.

Figures 11 and 12 show the comparison of the flank line geometry. The measurement log of the lead measurement after shot peening is shown in Figure 11. Here. the lead shape deviations $f_{f\beta}$ at approx. 7 µm are clearly visible. Figure 12 shows another workpiece of the series being machined. here the lead measurement after polishing.

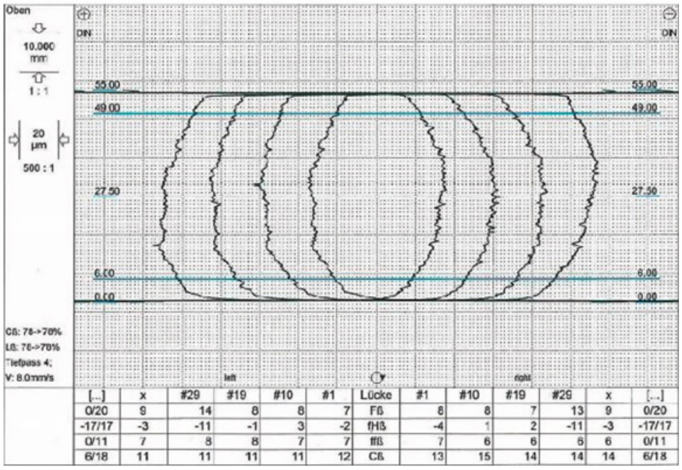

Figure 11 **Lead measurement after shot peening.**

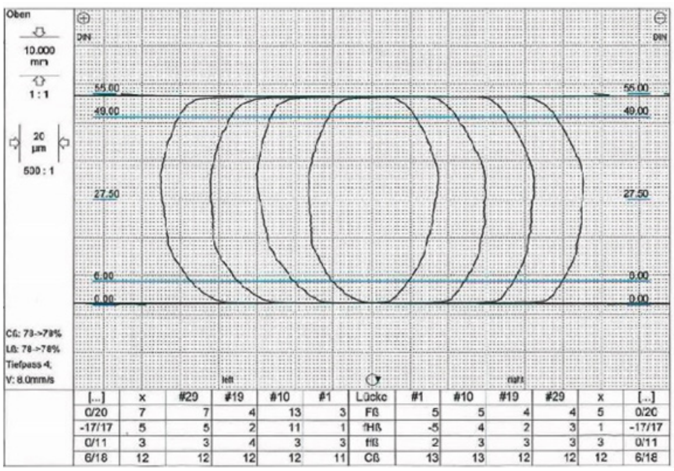

Figure 12 **Lead measurement after polish grinding.**

The basic geometry of the flank line is not affected. The lead angle deviation $f_{H\beta}$ and the lead convexity C_β are generated during conventional generating grinding processing prior to shot-peening. As documented in Figure 12. the lead shape deviation $f_{f\beta}$ is reduced by half.

As a final evaluation criterion. a comparison of the surface quality (Figs. 13–14) is now carried out. After shot peening. the average roughness height value R_a is significantly above the usually required qualities at ~0.85 µm. Likewise. at ~5.8 µm. the R_z is too large for the required application.

After polishing. the characteristic values R_a and R_z show very small values. These are no longer meaningful enough in the description of the surface quality.

Rather. material yield fraction R_{mr} or the "reduced peak value" R_{pk} together with the core roughness value R_k come into play here. In this context. there are a wide range of evaluations to describe the achieved surface quality.

In summary. the following advantages are combined with the production sequence shown here:

- Geometric accuracy through conventional generating grinding
- Surface compaction through shot-peening
- High-precision surfaces through polishing

This work chain contributes to increasing the efficiency and service life of the transmissions of today and tomorrow.

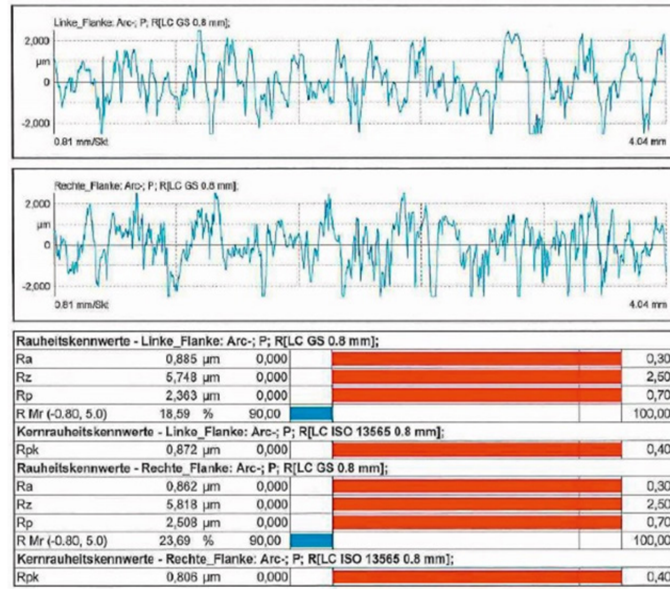

Figure 13 **Surface quality after shot peening.**

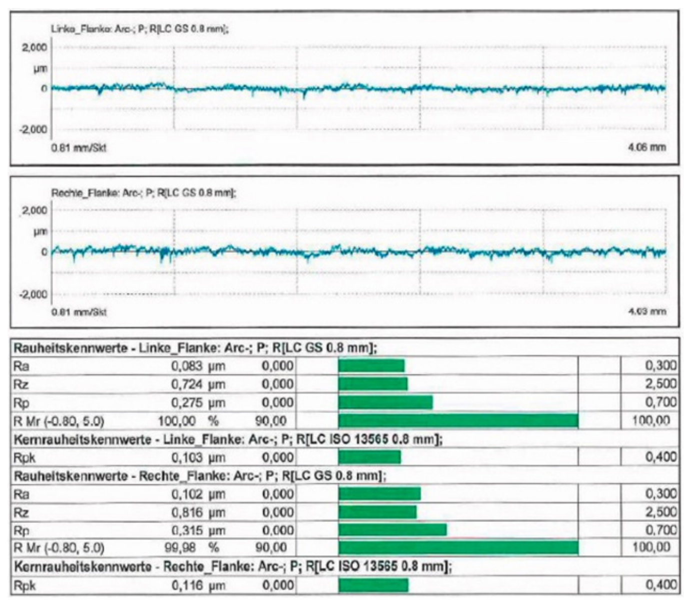

Figure 14 **Surface quality after polish grinding.**

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José López. Dipl.-Ing., has been employed at Kapp Niles since 1983. Currently the Head of Technology and Tool Development, he was the recipient of the Henry Ford Award in 1996. He is a member of various working groups of the Research Association for Drive Technology (FVA) and the Association of German Engineers (VDI).


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Single Tooth Bending Fatigue Testing at any R Ratio

Matthew Wagner, Aaron Isaacson, Kevin Knox and Thomas Hylton

Introduction

A bending fatigue failure in the root region where bending stresses are highest is often considered the most catastrophic failure a gear can experience. Consequently, evaluation of the bending fatigue performance (stress to life relationship) of different gear materials subject to various manufacturing processes and subsequent post processing treatments is of significance to gear and transmission designers.

One method for establishing bending fatigue performance is the single tooth bending fatigue (STBF) test. An example of a fixture used to implement this type of test is shown in Figure 1. Although this test has the advantage of being relatively simple, one limitation is that it is not directly representative of typical gear applications. The test load is unidirectional and the root areas of the tooth under test are subject to tensile stresses only, with no ability to load the test tooth root fillet in compression. This paper outlines the need for an STBF test that can accommodate reversed loading, followed by the development of a new test fixture design to execute this type of test.

Related Work

Using STBF testing to evaluate the bending fatigue strength of gear teeth has been documented in literature dating back over 60 years (Ref. 1). A few inherent advantages in this type of test are that it eliminates unwanted failure modes, uses relatively simple fixturing, and uses readily available fatigue testing equipment to apply the necessary loads.

Some variations in STBF fixture design exist, however the tooth loading method shown in Figure 2 generally applies regardless of the particular implementation. The test gear is mounted on a spindle in a test fixture and the gear teeth

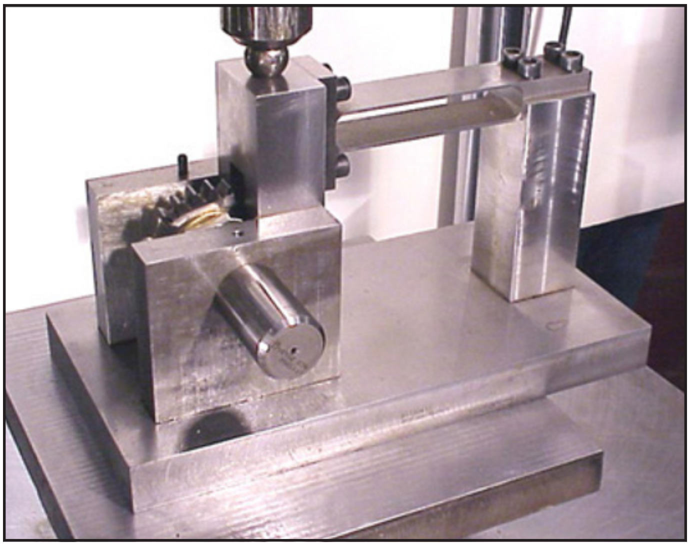
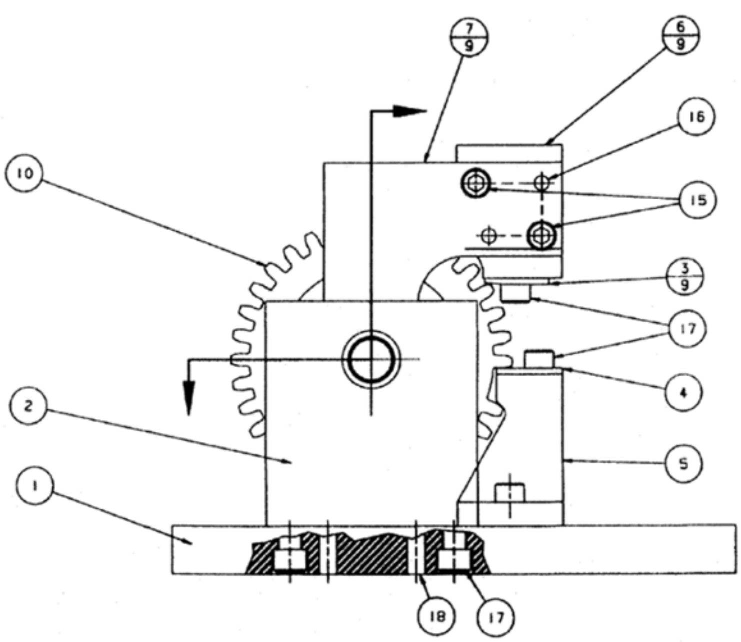


Figure 1 Single Tooth Bending Fatigue Test Fixture.



ASSEMBLY			
NO.	PART NO.	PART NAME	QTY
1	S4661	BASE PLATE	1
2	S4662	BEARING SUPPORT	2
3	S4628	INSERT, UPPER ANVIL	1
4	S4630	INSERT, LOWER ANVIL	1
5	S4627	LOWER ANVIL	1
6	S4629	UPPER ANVIL	1
7	S4659	LOADING ARM	2
8	S4631	MANDREL	1
9	S4660	ARM & ANVIL SUB ASSEMBLY	1
10	S4658	SPUR GEAR TEST SPECIMEN	1
11	NO DETAIL	SPACER (BRASS)	2
12	NO DETAIL	BEARINGS - ARM	2
13	NO DETAIL	BEARINGS - SHAFT	2
14	NO DETAIL	BEARINGS - GEAR	2
15	NO DETAIL	HEX CAP SCREW, M10X1.5X25	6
16	NO DETAIL	Ø7.9X25 DOWEL PIN	4
17	NO DETAIL	HEX CAP SCREW, M10X1.5X19	2
18	NO DETAIL	Ø6.3X19 DOWEL PIN	2
19	NO DETAIL	HEX CAP SCREW, M12X1.75X28.5	4
20	NO DETAIL	Ø9.5X31.75 DOWEL PIN	4
21	NO DETAIL	EXT RETAINING RING	2

Figure 2 Loading Schematic for STBF Test [6].

under test are held between two independent anvils (Figure 2, items 3 and 4). The entire fixture is placed in a universal fatigue test frame and the anvils are subjected to cyclical loading until a bending failure occurs or a run out limit is reached. Several teeth on each gear can be tested to provide multiple data points from each test gear. This type of fixture is well documented in literature (Refs. 1–5) and established test standards (Ref. 6). Some variants of this method can also be found in literature, such as application of three-point loading (Ref. 7) or testing of asymmetric gears (Ref. 8), however all of the methods discussed thus far load the test tooth in one direction only.

The stresses in fatigue testing are characterized by an R value as defined in Equation 1. In the authors' experience an R value of 0.1 is typically used in STBF testing, in other words the stresses are cycled from 10% of the maximum to 100% of the maximum tensile stress. Although the exact R ratio may vary, the methods previously described are inherently limited to testing with positive R values. For reasons which will be discussed in more detail, this is not always fully representative of the stresses the gear tooth experiences in practice.

$$R = \frac{Stress, min}{Stress, max} \tag{1}$$

Where the following sign conventions are used for stress:
Root tensile stress (+)
Root compressive stress (-)

Given this limitation, the alternative to unidirectional STBF testing has been to use running gear bending fatigue testing, which is also well documented in literature (Refs. 1, 3, 9, 10). This type of test uses rotating meshing gear pairs operating under a load, often in a four-square / back-to-back arrangement. The running gear bending fatigue test has the advantage of subjecting the gear teeth to actual operating conditions, however it also has some significant disadvantages compared to the STBF test. The first is cost, since running gear test equipment is more complex, and also requires more test gears for a given number of desired data points. More significantly, the gear design must be carefully evaluated so unwanted failure modes such as pitting, wear or scuffing do not occur before the desired bending failure is generated (Refs. 1, 3).

The Need for STBF Testing at Negative R Ratios

The STBF test method's inability to realistically simulate loading of a tooth in mesh has relegated it to a comparative assessment role. As such it has typically been used for evaluating the relative performance of various gear materials and manufacturing processes. The difference between STBF data and running gear bending fatigue data is for two primary reasons discussed in (Ref. 11). First, STBF testing forces a failure on specific teeth on the gear, while running gear tests effectively use all of the gear teeth and develop a failure on the weakest member of the population. This is a statistical issue which can be addressed with the methodology shown in (Ref. 11).

Second, in STBF testing the limitation of using a positive R ratio means that the stress is cycled from a maximum to some percentage of that maximum. For this reason, the tensile stress is never fully released in an STBF test in the same way as when a gear tooth exits the mesh in a running application. In some cases in running gear applications, depending on geometry and speed, the root fillet may also be subject to a small amount of compression as the adjacent tooth is loaded, resulting in a slightly negative R ratio in practice. An example of measured root fillet strain alternating between tension and compression through a rotating mesh cycle is shown in Figure 3. For this reason, a positive R value STBF test may yield "optimistic" results when compared to running gear data at the same maximum stress level. This was one motivation to develop an STBF test that can be used to test under negative R ratios. Furthermore, in some applications such as idlers (Ref. 10) or planet gears (Ref. 13), teeth mesh with more than one mating gear during a rotation and thereby experience fully reversed stresses (R = –1.0). In these cases, very generic derating factors have typically been used (Ref. 14) to relate non-reversed stress allowables to design parameters for fully reversed stresses. The desire to establish more specific derating factors further emphasizes the motivation to develop an STBF test method that can use negative R ratios.

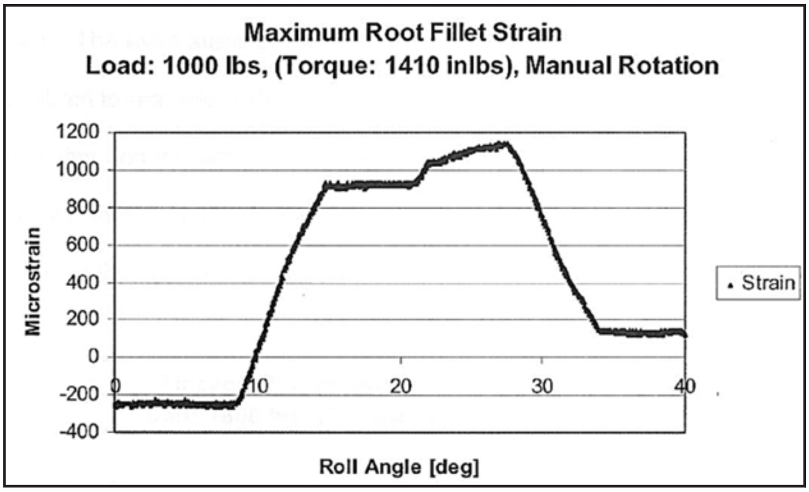


Figure 3 Root Fillet Strain vs. Roll Angle (Ref. 12).

Documentation of STBF methodology that can accommodate negative R ratios is scarce in open literature. One method is shown in (Ref. 15), where the load is reversed via torsional oscillation. Few details are provided, however this type of test does not appear to be compatible with commonly available tension and compression type fatigue test frames. Specifically designed test gears that utilize a splined bore are also required. A second method outlined in (Ref. 16) uses a servo motor to oscillate a mating gear against a fixed test gear. This test method was developed for polymer composite gears with a maximum test torque of 14 N-m, which was well below the loads required in the authors' testing. A running gear test method which allows negative R ratios is shown in (Ref. 10) and was shown to be successful, however this methodology was not practical for the authors' work for reasons which are described below.

Testing of Production Gears

A final comment on motivation for this work involves the ability to use production gearing in bending fatigue testing. When gear testing is undertaken to understand fundamentals such as material properties, specifically designed test gears are frequently used. In the literature cited, this was most often the case. If running gear tests are to be used, this has the advantage of allowing the test gear designer to make their best attempt to "force" bending failures by controlling various gear design parameters. Design of STBF test gears is more straightforward due to the limitation of possible failure modes.

Often however, it may be necessary to test production gears to gain insight into the performance of an existing gear design or manufacturing process. In these cases a representative test gear design may also be employed, however the best practice if possible is to use existing production gears in order to fully capture any inherent variables that may not be well understood. Using production gears in running gear tests can be a challenge, especially due to the fact that under running conditions bending fatigue may not be the dominant failure mode of the gear under consideration. Also, modifying existing rotating gear test equipment to accommodate a preexisting gear design can be costly due to geometry or power limitations. In the past, the only other option has been to use unidirectional STBF testing with production gears, while accepting the limitation of using R values that are not fully representative of the final application.

The work described here was motivated by the desire to test several production gears with widely varying geometries under unidirectional and fully reversed conditions. Implementing running gear bending fatigue tests with the range of sizes under consideration would have been impractical, and would have likely resulted in unwanted failure modes.

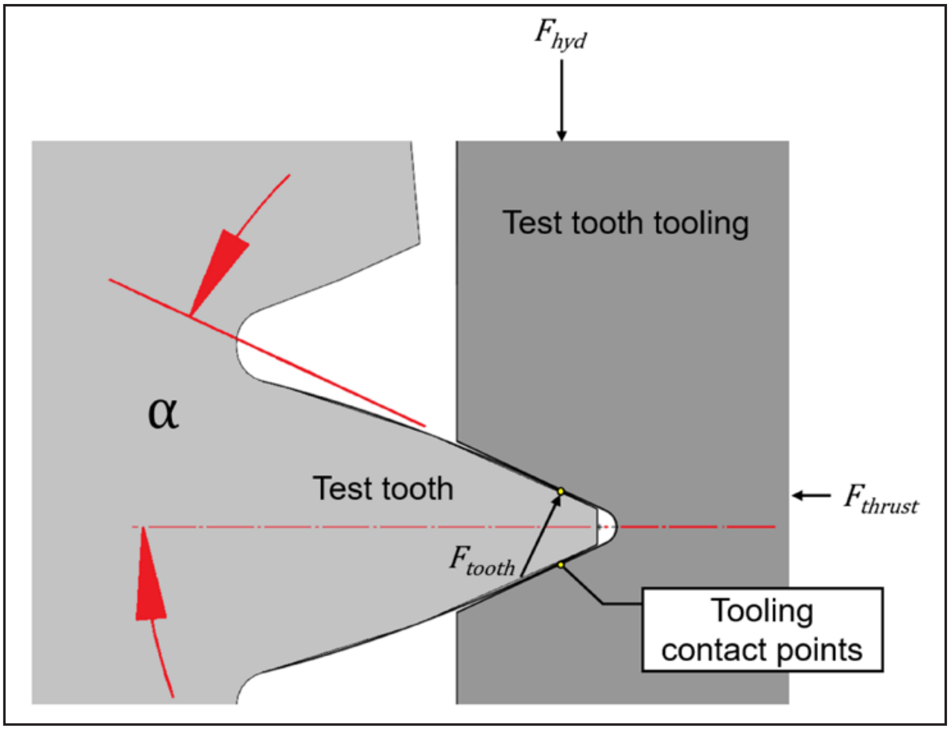


Figure 4 Test Tooling Angle and Contact Points.

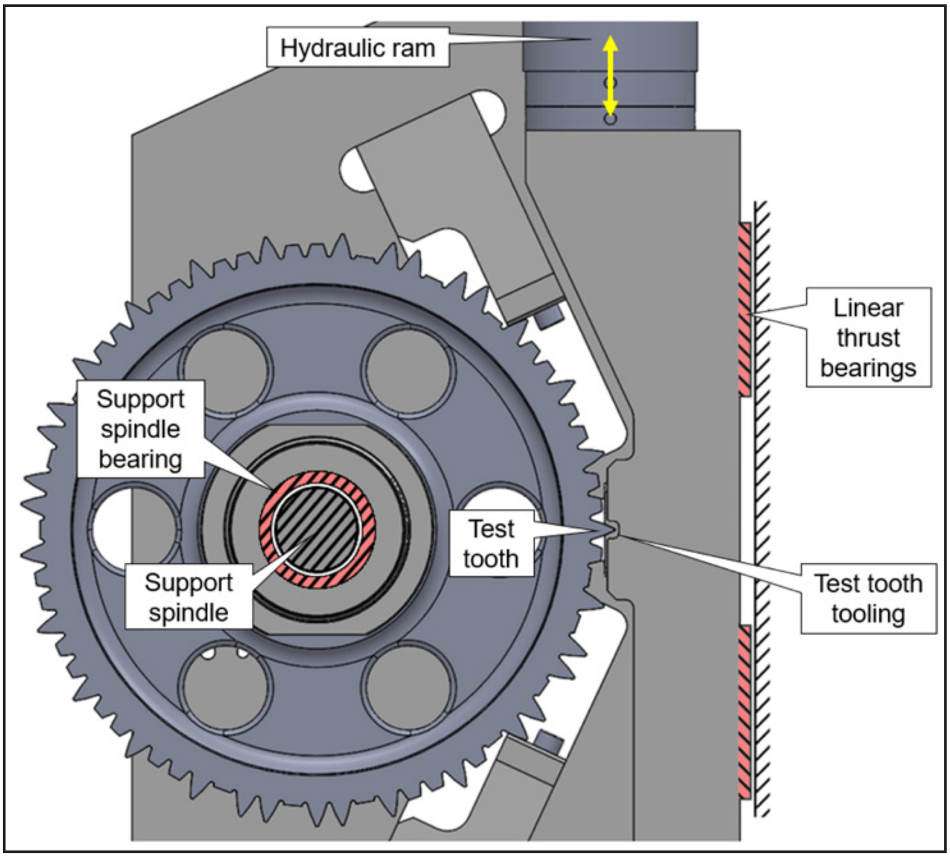


Figure 5 STRBF Fixture Layout.

Single Tooth Reversible Bending Fatigue Fixture Overview

An overview of the tooling used to interface with the test tooth on the newly developed Single Tooth Reversible Bending Fatigue (STRBF) test is shown in Figure 4. A v-shaped feature in the tooling contacts the test tooth on both flanks. The tooling v-notch half angle (α) is chosen such that the contact point is at an appropriate roll angle to induce a bending failure, but not too close to the tooth tip as to cause chipping. The tooling is loaded hydraulically (F_{hyd}) in the vertical direction in both compression and tension to apply a load to both the upper and lower flanks of the tooth respectively.

One caveat of this of layout is that the force vector normal to the test tooth involute surface (F_{tooth}) is not parallel with the force vector for the applied hydraulic load. For this reason, there is a horizontal component of the test tooth load that needs to be accommodated on the tooling (F_{thrust}) to avoid side loading on the hydraulic actuator. Also, the effective test load on the tooth needs to be computed from applied load to take the off-axis loading into account. The relationships between applied load, thrust load and effective tooth load are given in Equations 2 and 3.

$$F_{thrust} = F_{hyd} \tan\alpha \tag{2}$$

$$F_{tooth} = \frac{F_{hyd}}{\cos\alpha} \tag{3}$$

Where:

α is tooling v-notch half angle
F_{hyd} is applied hydraulic load from test frame
F_{thrust} is resultant thrust load
F_{tooth} is load normal to tooth involute surface at tooling contact point

An overview of the remainder of the fixture is shown in Figure 5. A spindle is used to locate the bore of the gear, and the gear is allowed to rotate freely about its axis. Linear bearings allow the test tooth tooling to move vertically, but support the resultant thrust loads. The bearings on the gear spindle as well as the linear thrust bearings are Teflon based plain bearings specifically designed for use in high cycle, short stroke applications.

Similar to a typical unidirectional STBF fixture, a support tooth is used to react to the test load, however in this design two support teeth are used instead of one. When the hydraulic ram is in compression, the upper flank of the test tooth is loaded, and the lower support tooth reacts to the test load (Figure 6a).

Likewise when the hydraulic ram is in tension, the lower flank of the test tooth is loaded, and the upper support tooth reacts to the test load (Figure 6b). The support tooth contact point

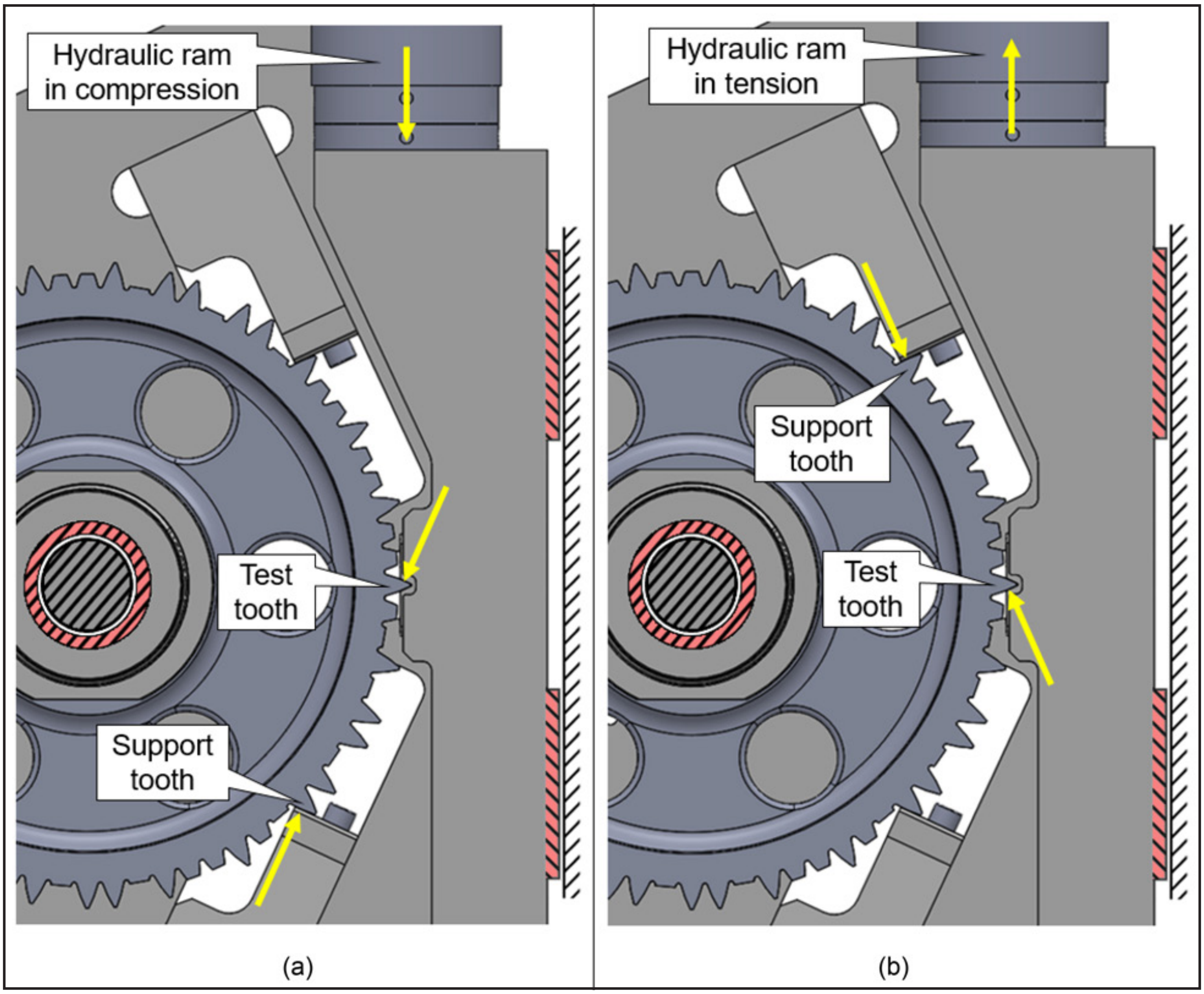


Figure 6 Fixture Load Path in (a) Compression and (b) Tension.

(Figure 7) is chosen to be at a lesser roll angle than the test tooth contact point in order to avoid support tooth failures. The support tooth contact point is also chosen so the line of action from the test tooth and line of action from the support teeth are collinear, which minimizes a component of the test load from being transmitted into the gear support spindle and bearings.

As previously shown in Figure 4, portions of the teeth adjacent to the test teeth need to be removed to allow for tooling clearance. A minimum amount is removed from teeth adjacent to the test teeth in order to minimize any possible effect on the stress distribution in the test tooth root fillets. As shown in Figure 7, teeth adjacent to the support teeth need more clearance due to the lower contact location of the support tooth tooling.

The test tooth and support tooth tooling sets were designed to be modular so the same base fixture would accommodate a range of sizes. The test program for which this method was developed, which is still ongoing, uses six different gear geometries ranging from 120 mm to 300 mm in pitch diameter. Figure 8 shows the STRBF fixture with the largest and smallest gear geometries.

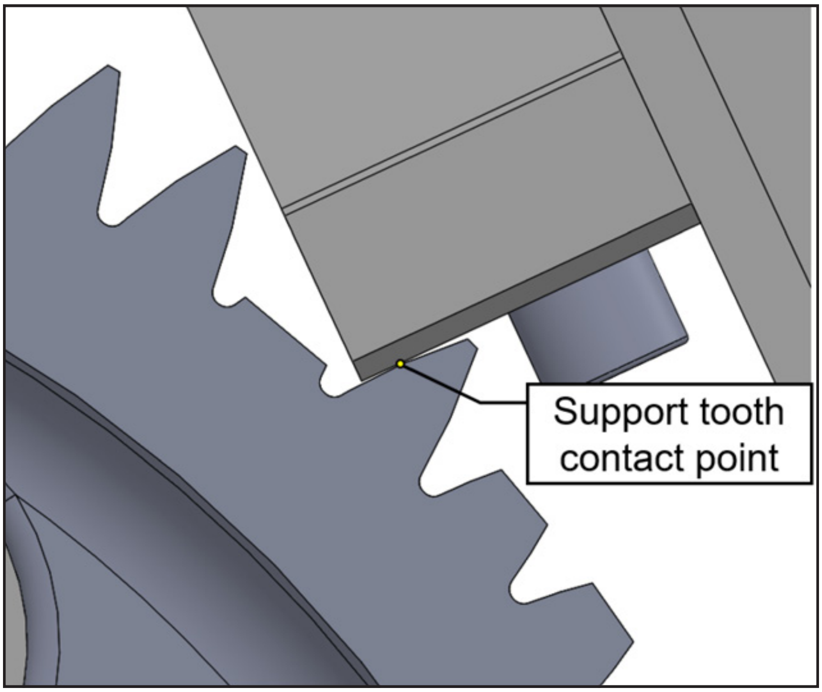


Figure 7 Support Tooth Detail.

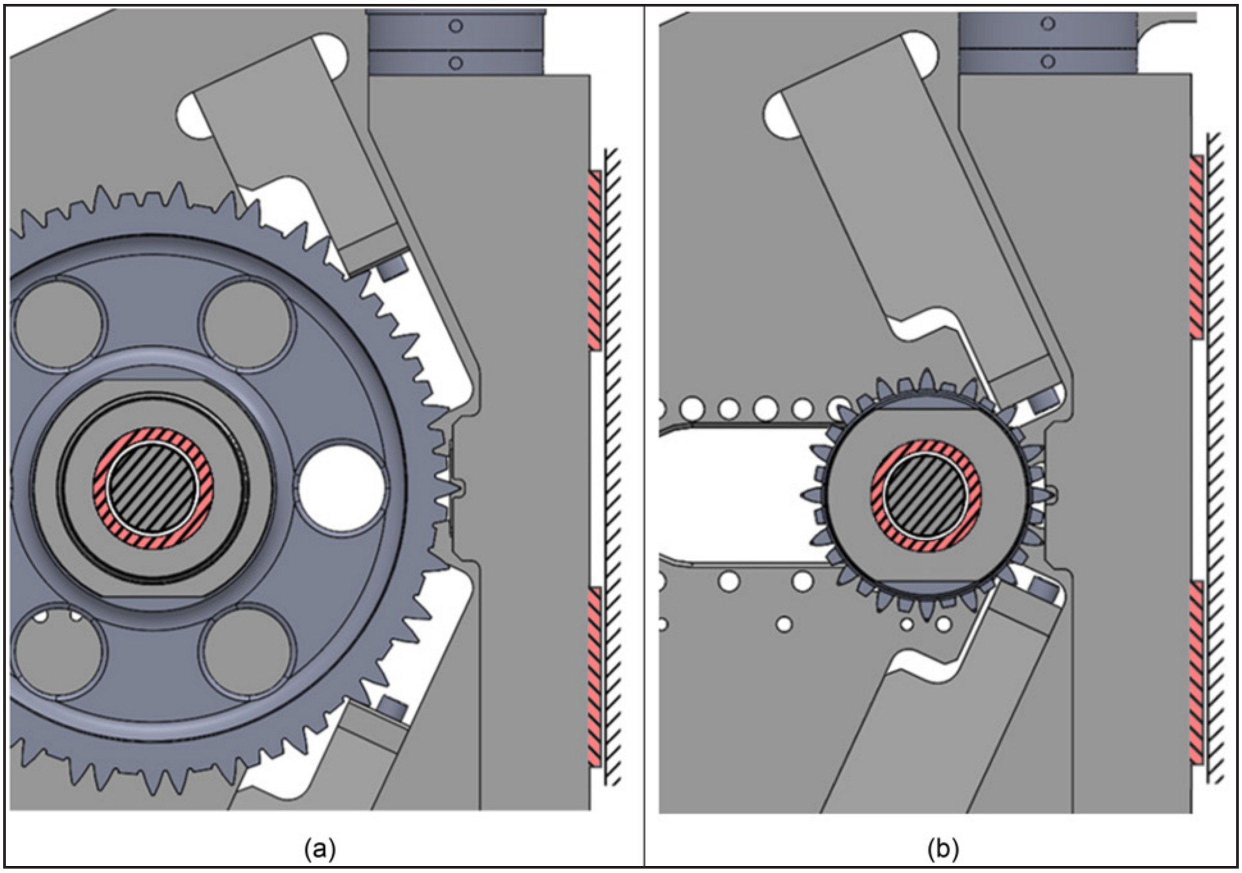


Figure 8 STRBF Fixture with (a) Largest and (b) Smallest Gear Geometries.

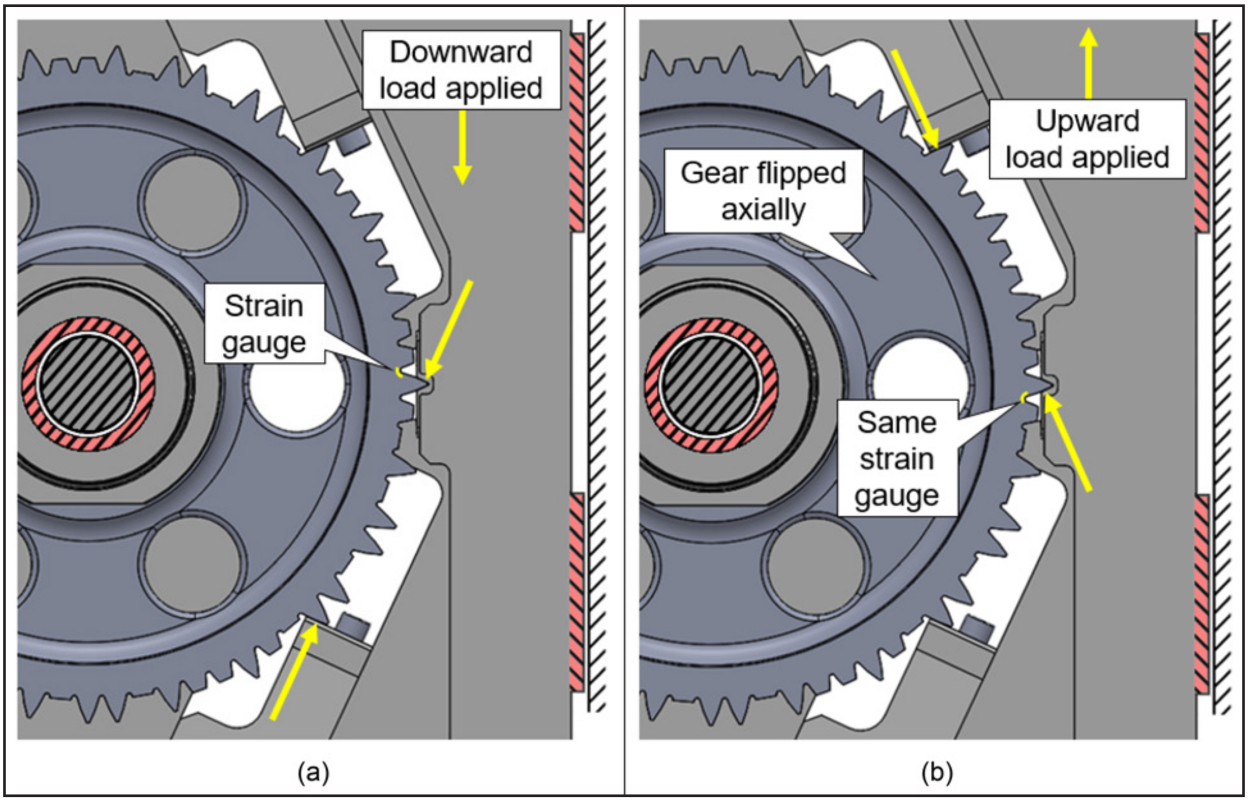


Figure 9 Fixture Calibration with Strain Gauge.

Calibration and Testing

Before testing, calibration of the fixture was carried out using a strain gauge applied to one root fillet of a test tooth. The gear was first installed to the fixture such that the strain gauge was oriented on the upper side of the tooth as shown in Figure 9a, after which a downward hydraulic load was applied to induce a tensile stress on the instrumented area. A relationship of applied load to strain was developed for this orientation. The gear was then flipped on its axis, so the same strain gauge from the first step was oriented on the lower side of the test tooth as shown in Figure 9b. Upward loads of identical magnitude to the first step were applied and a load to strain relationship developed for this orientation. Tooling adjustments were then made until both load vs. strain relationships were symmetric about zero.

An image of the assembled STRBF fixture is shown in Figure 10. Testing was executed at frequencies up to 30Hz using R ratios of 0.1 and −1.0, with maximum applied loads ranging from 5kN to 80kN depending on the gear being tested. All unidirectional tests were completed using a downward (compressive) load on the hydraulic ram, however unidirectional tests could be conducted in either direction. Failures were detected by monitoring the minimum and maximum position of the hydraulic ram, which can be used to compute tooth deflection. An example of tooth detection data taken during a bending failure is shown in Figure 11. Root fillet cracks present after the deflection limit was exceeded were significant and visible without magnification.

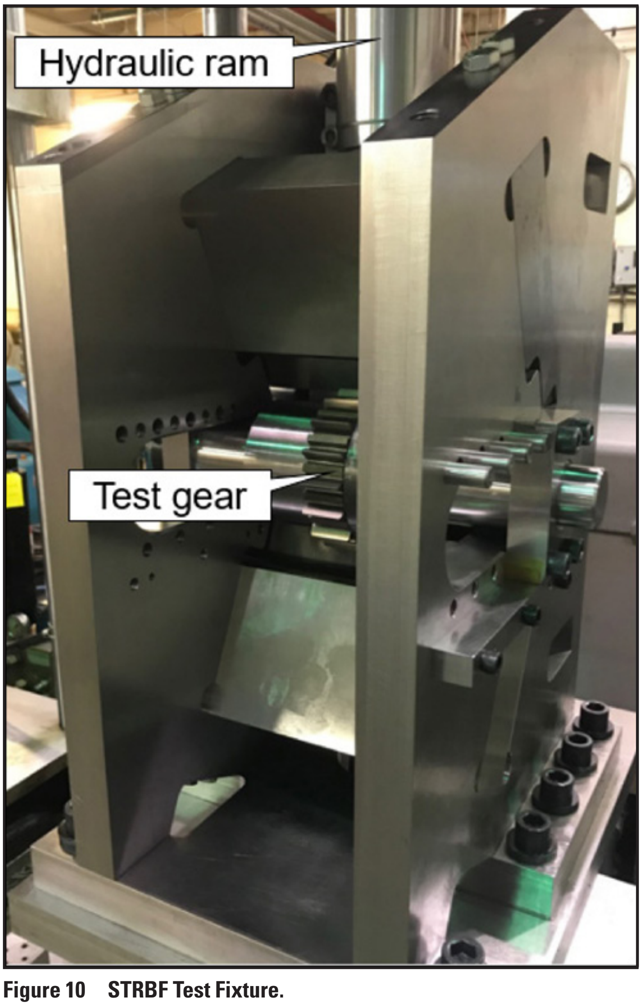


Figure 10 STRBF Test Fixture.

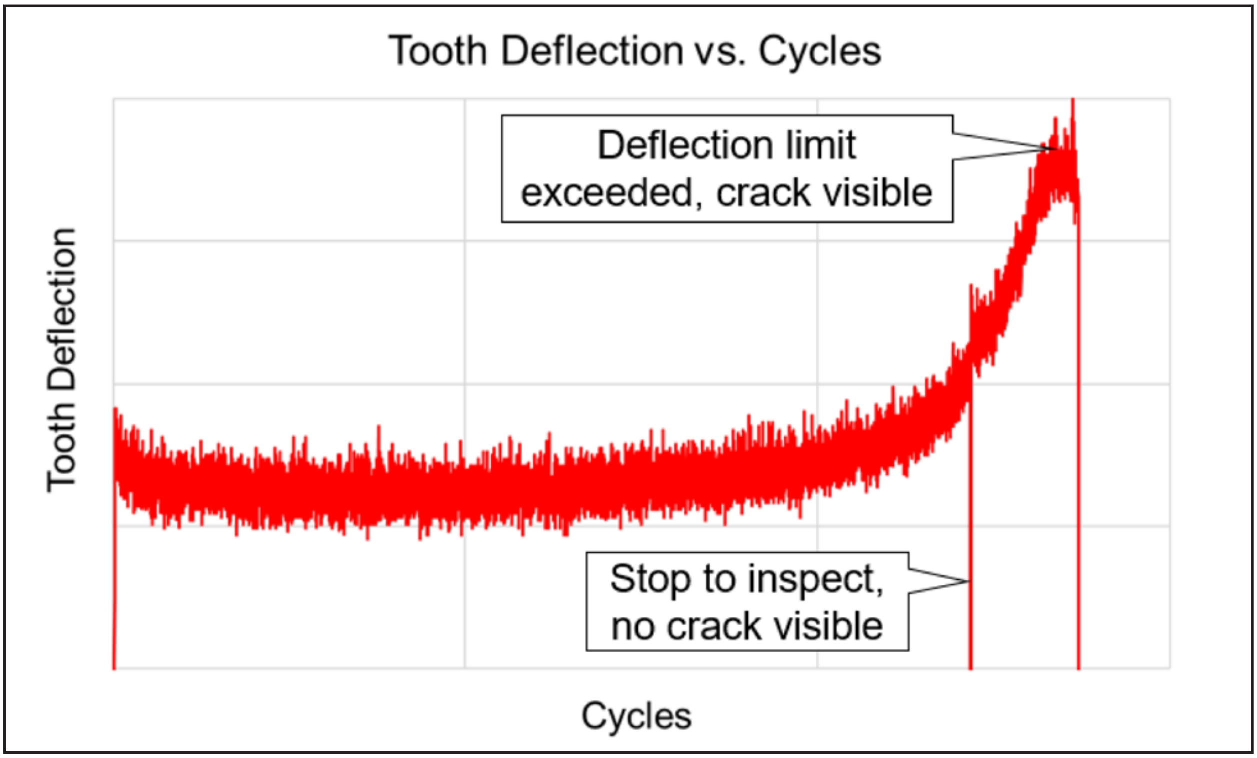


Figure 11 Example of Tooth Deflection Monitoring.

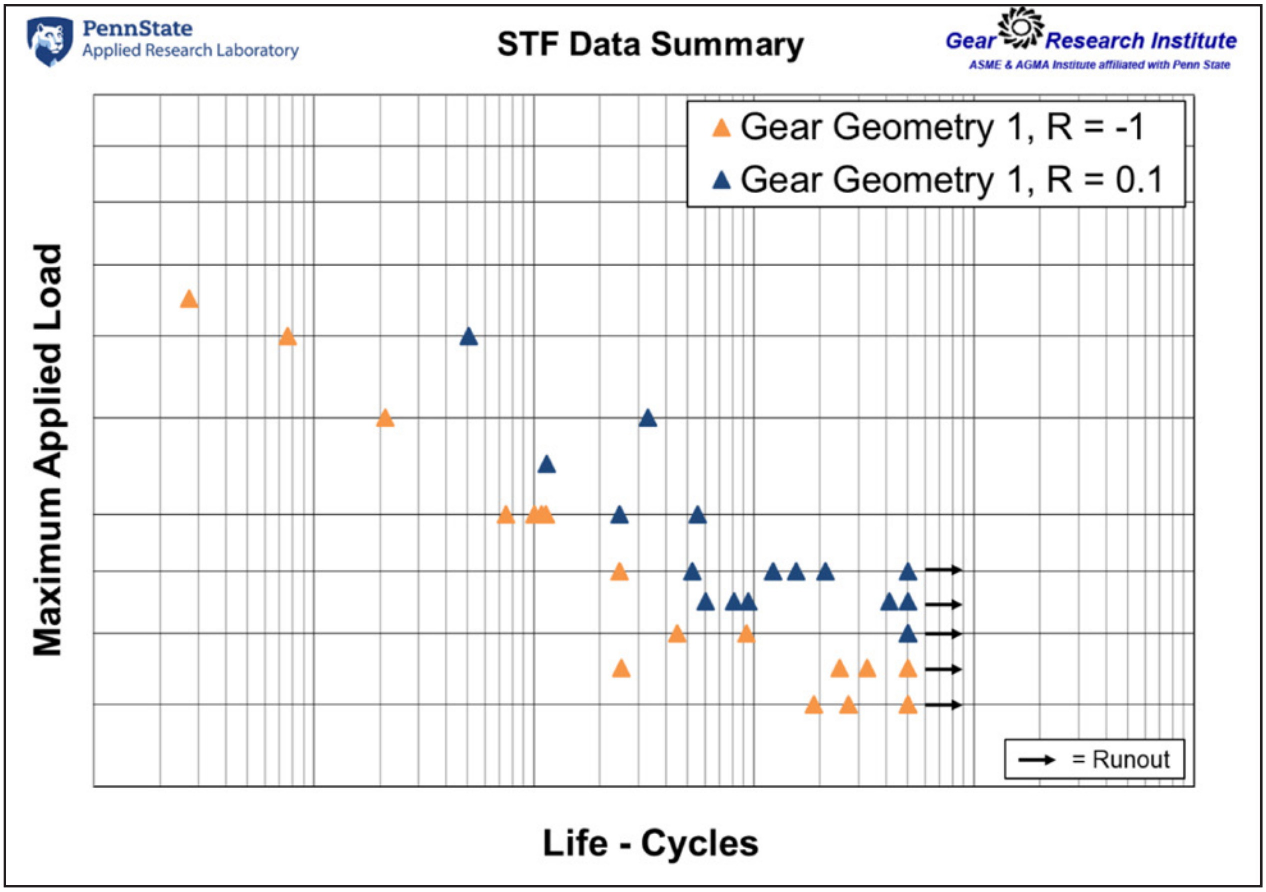


Figure 12 Example Data Set using two R Ratios - Gear Geometry #1.

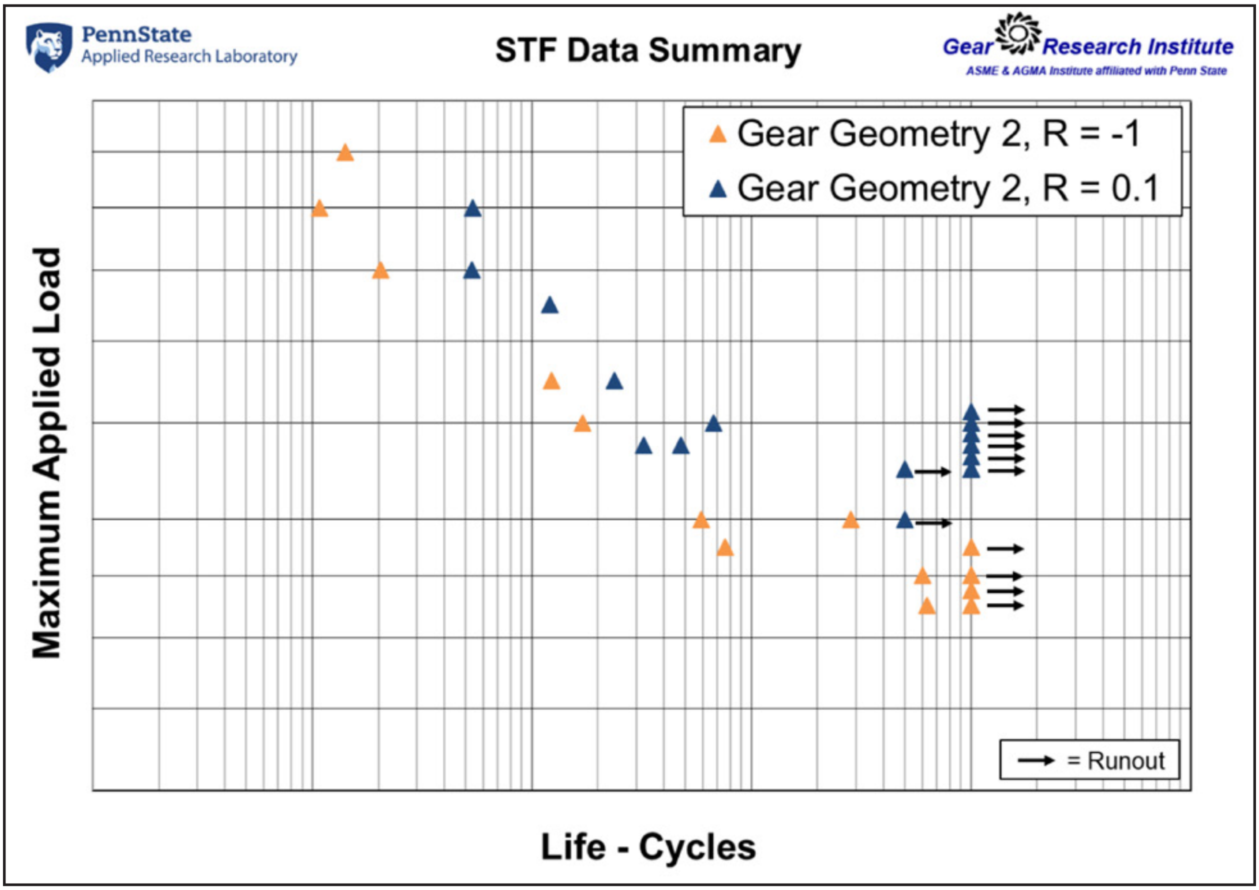


Figure 13 Example Data Set using two R Ratios - Gear Geometry #2.

Figure 12 and Figure 13 show non-dimensional examples of data comparing the unidirectional (R = 0.1) and fully reversed (R = –1.0) results from two different gear designs. Both plots utilize the same scaling on the Maximum Applied Load axes. In the data sets shown, the slopes of the finite life portions of the data sets from both R ratios are similar, however as expected the unidirectional finite life data sets are offset toward increased cycles to failure. The knees (intersections of finite life and infinite life slopes) in both unidirectional data sets also occur at fewer cycles and at higher loads than the knees in the fully reversed data sets, which leads to the fully reversed data sets having more long cycle failures. It should be noted that these trends are comments on the specific data sets presented here, however many factors such as residual stress, geometry, material cleanliness, etc. can influence bending fatigue performance. It was expected that the knees in the fully reversed data would occur at lower loads, since this is what is captured in the generic derating factors typically used for fully reversed loading on gear teeth [14].

Testing has shown that the actual derating factor can vary with various gear design parameters and may not be fully represented by the generic factors found in literature.

The test method outlined here has successfully generated unidirectional and fully reversed bending failures on a variety of gear geometries. All failures have been on test teeth only, with no support tooth damage observed. Also, no unwanted failure modes on the test tooth such as flank fracture have occurred. The program referenced is ongoing, and to date over 180 tests have been completed representing over 500 million fatigue cycles. Although this program uses R ratios of 0.1 and –1.0, any R ratio ($1 > R \geq -1$) can be implemented by altering the programming of the fatigue test load frame. No further changes to the fixture tooling or setup are required to accommodate other R ratios.

Summary and Future Work

In conclusion, this paper outlined the development of a new type of single tooth bending fatigue test method in which both tensile and compressive bending stresses can be applied to the test tooth root fillets, which allows fatigue testing at any R ratio applicable to gear bending fatigue testing ($1 > R \geq -1$). Using this method, negative R ratios up to and including fully reversed loading can be tested. The need for this type of test exists because traditionally used single tooth bending fatigue fixture designs are limited to applying tensile bending stresses only, which is not fully representative of running gears. The only alternative in the past has been to use running gear bending fatigue tests, which create several other challenges and are not always practical. This method was developed to allow testing of a range of sizes of actual production gears rather than representative test specimens. Loading the test tooth root fillet in tension and compression dictated the design of a novel fixture concept which is described in detail. The STRBF test method has been shown to effectively generate bending fatigue failures under unidirectional and fully reversed conditions on a variety of gear geometries. The development of this test method is a significant step forward in single tooth bending fatigue testing and has generated substantial interest from gear engineers from a variety of industries.

Future work for this test method includes testing of additional R ratios, specifically slightly negative R ratios representative of non-reversed gear applications. Additional gear geometries and materials are also planned for testing. Results will be compared to running gear bending fatigue test data in order to compare the results of both test methods.

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References

1. Halgren, J.A. and D. J. Wulpi. "Laboratory Fatigue Testing of Gears," in *SAE Transactions, SAE National Tractor Meeting*, Milwaukee, 1956.
2. Buenneke, R.W., M. B. Slane, C. R. Dunham, M. P. Semenek, M. M. Shea and J. E. Tripp, "Gear Single Tooth Bending Fatigue Test," in *SAE Technical Paper Series, International Off-Highway Meeting & Exposition*, Milwaukee, 1982.
3. McPherson, D.R. and S. B. Rao, "Mechanical Testing of Gears," in *ASM Handbook, Volume 8*, ASM International, 2000, pp. 861–872.
4. Vučković, K., I. Galić, Ž. Božić and S. Glodež, "Effect of friction in a single-tooth fatigue test," *International Journal of Fatigue*, vol. 114, pp. 148–158, 2018.
5. Winkelmann, L., M. Michaud, G. Sroka and A. A. Swiglo, "Impact of Isotropic Superfinishing on Contact and Bending Fatigue of Carburized Steel," in *SAE International Off-Highway Congress*, Las Vegas, 2002.
6. SAE International, *Surface Vehicle Recommended Practice, J1619 - Single Tooth Gear Bending Fatigue Test,* 2017.
7. Akata, E., M. T. Altinbalik and Y. Can, "Three point load application in single tooth bending fatigue test for evaluation of gear blank manufacturing methods," *International Journal of Fatigue,* vol. 26, pp. 785–789, 2004.
8. Ravainagy S. and M. Lobontiu, "Gear teeth bending test upon the gear with asymmetric teeth," *Academic Journal of Manufacturing Engineering,* vol. 13, no. 1/2015, pp. 63–68, 2015.
9. Winkler, K.J., S. Schurer, T. Tobie and K. Stahl, "Investigations on the tooth root bending strength and the fatigue fracture characteristics of case-carburized and shot-peened gears of different sizes," *Journal of Mechanical Engineering Science,* vol. 233, p. 7338–7349, 2019.
10. Hong, I.J., A. Kahraman and N. Anderson, "A rotating gear test methodology for evaluation of high- cycle tooth bending fatigue lives under fully reversed and fully released loading conditions," *International Journal of Fatigue,* vol. 133, 2020.
11. McPherson, D.R. and S. B. Rao, "Methodology for Translating Single-Tooth Bending Fatigue Data to be Comparable to Running Gear Data," *Gear Technology,* pp. 42–51, March / April 2008.
12. Schwanger, V.C. "Experimental Measurement of Dynamic Bending Stresses at the Root Fillet of Spur Gear Teeth," A Thesis in Industrial Engineering, Penn State, 2003.
13. Singh, A., A. Kahraman and H. Ligata, "Internal Gear Strains and Load Sharing in Planetary Transmissions - Model and Experiments," in *Proceedings of the ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Las Vegas, 2007.
14. ANSI/AGMA 2001-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth,* 2016.
15. Chen, J. "Single Versus Bi-Directional (Reversal) Gear Tooth Bending Stress and Life Evaluation,"*Applied Mechanics and Materials,* vol. 86, pp. 287–292, 2011.
16. Modeeswaran, M., A. Verma, R. Suresh and S. Senthilvelan, "Bi-Directional and Uni-Directional Bending Fatigue Performance of Unreinforced and Carbon Fiber Reinforced Polyamide 66 Spur Gears," *International Journal of Precision Engineering and Manufacturing,* vol. 17, no. 8, pp. 1025–1033, 2016.

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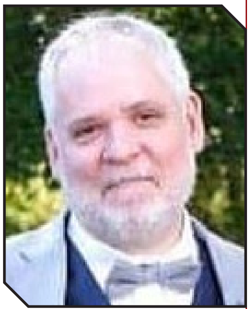

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Potentials for Process Monitoring in Bevel Gear Grinding

Thomas Bergs, Christoph Löpenhaus and Mareike Solf

Manufacturing of Bevel Gears

Manufacturing of bevel gears commonly takes place in one of two possible process chains, as can be seen in Figure 1. In both process chains, the machining of the gear body follows the production of the blank. The soft machining of bevel gears can be carried out either in a discontinuous face milling or a continuous face hobbing process. After soft machining, the bevel gear is subjected to a heat treatment which is usually followed by hard finishing.

Since the macro geometry of bevel gears is directly dependent on the manufacturing process, there are limitations in the combination of pre-machining and hard finishing processes which are related to the geometry of the gaps (Ref. 9). For this reason, grinding is most commonly used for hard finishing of face milled bevel gears. For face hobbed bevel gears, lapping is the dominant hard finishing process.

In bevel gear grinding, machining is usually carried out using vitrified grinding wheels. The defined and correctable machining with the grinding wheel allows good gear quality and reproducibility to be achieved, enabling free pairing of the bevel gears (Ref. 13). In addition, the process provides more possibilities for tooth flank modifications and is less sensitive to deviations from pre-machining and heat treatment.

During a bevel gear lapping process, the pinion and ring gear are engaged under low load, so that the grains contained in the lapping compound remove material from the tooth flanks in the contact zone (Ref. 7). In one process setting, a complete gear set is machined simultaneously, but subsequently the gear and pinion cannot be separated from each other. Regarding the gear properties, the surface structure resulting from lapping and the less uniform pitch are often classified beneficial for the noise excitation behavior (Ref. 13).

Bevel gear grinding. Bevel gears are theoretically always produced by a generating motion between the workpiece and the virtual generating gear (Ref. 14). In the manufacturing process, the tool profile represents the geometry of the virtual generating gear. The most important parameters for generating bevel gear grinding are the cutting velocity v_c and the rolling velocity v_w as shown in Figure 2 (Refs. 7 and 17). The cutting velocity v_c results from the grinding wheel rotation around its center axis. The rolling velocity v_w indicates the speed at which the tool is guided around the cradle axis (Ref. 7). The rotation around this axis, which corresponds to the center axis of the virtual generating gear, results in the relative rolling motion between the tool and the tooth gap.

For transmission ratios larger than 2.5, the rolling motion is often left out when machining the ring gear in order to achieve

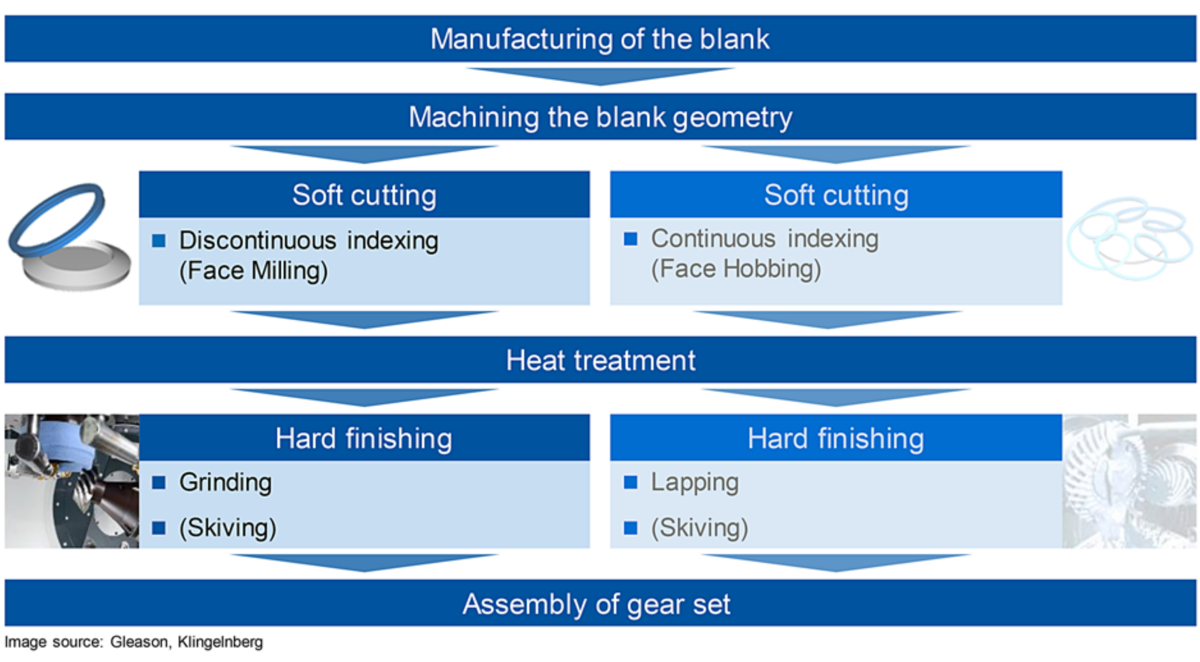

Figure 1 Process chain of bevel gear manufacturing.

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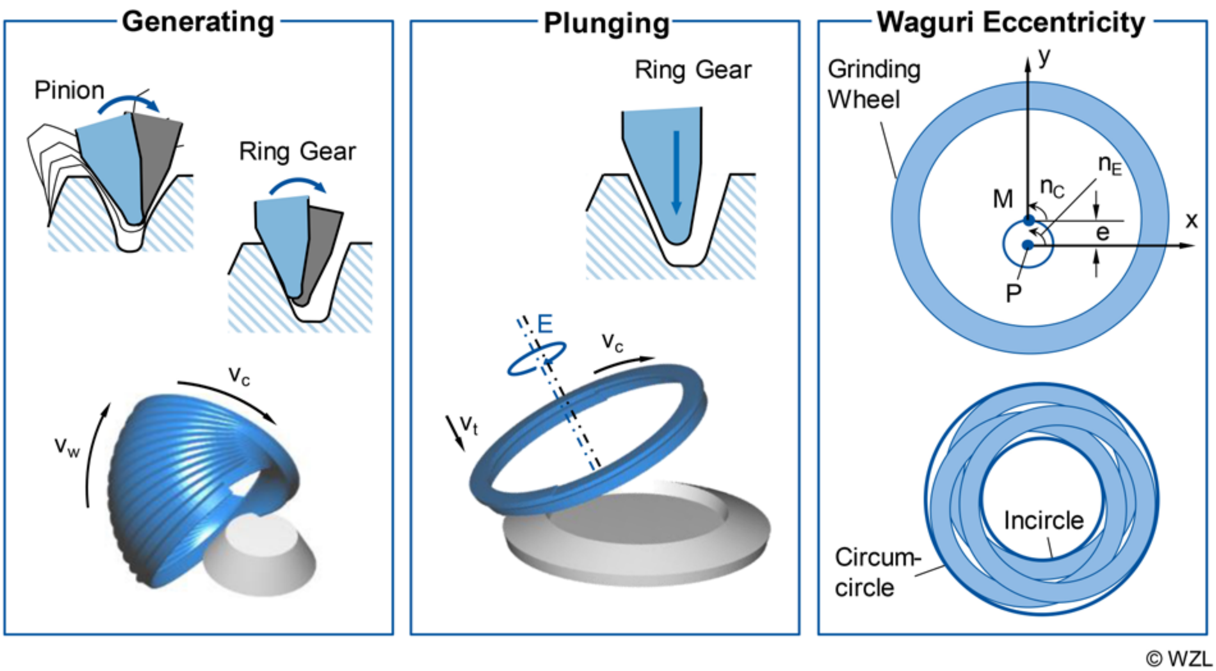

Figure 2 **Bevel gear grinding.**

shorter machining times (Ref. 7). In this simplified process, also referred to as plunging, the tool infeed takes place along a straight line vector. The target geometry of the resulting ring gear is therefore determined directly by the profile of the tool (Fig. 2). Except for tooth flank modifications such as crownings, plunged ring gears have straight flanks in tooth height direction. The most important process parameters for plunging bevel gear grinding are the cutting velocity v_c and the plunging feed rate v_t (Refs. 7 and 17.)The cutting velocity v_c results from the rotation of the grinding wheel. The plunging feed rate v_t indicates the speed at which the grinding wheel is plunged into the gap.

In non-optimized plunging bevel gear grinding, there is permanent, full-surface contact between the grinding wheel and the tooth flanks. Due to the continuous contact between the grinding wheel and the workpiece, thermal energy is continuously introduced into the entire surface zone. In addition, the supply of cooling lubricant is almost completely eliminated (Ref. 9). This results in a high risk of grinding burn.

As shown in the right of Figure 2, an eccentric motion is superimposed on the grinding wheel rotation to reduce the risk of thermal damage (Ref. 7). This eccentric motion, also known as WAGURI motion after its inventor, leads to a displacement of the grinding wheel perpendicular to its central axis. Depending on the machine tool manufacturer and grinding machine type, the eccentricity e varies from several hundredths of a millimeter to a few tenths of a millimeter and is usually not adjustable by the user (Ref. 17).

The grinding wheel geometry must be adapted so that the same tooth gap geometry is produced despite the superimposed eccentric motion. Compared to the theoretical grinding wheel geometry, whose profile corresponds exactly to the gap geometry, the inner diameter of the eccentric grinding wheel is increased by twice the eccentricity e whereas the outer diameter of the eccentric grinding wheel is reduced by twice the eccentricity e. In this way, the eccentrically moved grinding wheel forms the contour of the theoretical grinding wheel and thus the curvature of the tooth flanks.

Motivation and Objective

Due to increasing requirements concerning efficiency and noise excitation of gear drives, the hard fine machining of gears has become a necessary process step for many applications. The hard fine machining by grinding is an established manufacturing process for wide variety of applications, as good geometric and surface quality can be achieved (Ref. 1). Grinding of bevel gears is used especially for the machining of gears with high requirements concerning the gear quality, such as for automotive transmissions (Ref. 13). In industrial environments, bevel gear grinding processes are usually designed based on experience (Ref. 17). Suitable process parameters are determined for each workpiece geometry and grinding wheel specification in time and cost-intensive empirical investigations. In addition, it is not known whether the derived process parameters are within the range of the productivity maximum.

Knowledge of the cutting force is necessary for predicting both the thermal influence on the near surface zone and the load and thus the wear of the grinding tools (Ref. 15). In addition, the cutting force is of high relevance for the misalignment behavior of the tool in the process and is thus required for determining the process-machine interaction, as shown in Figure 3. Knowing the cutting force therefore plays a decisive role in knowledge-based process design and process optimization.

The process force can be determined by means of force modelling or measurements in the grinding process. Monitoring of the cutting force in the process can help to identify and eliminate critical process conditions. Therefore, this work shall introduce and analyze potentials for the application of process monitoring in plunging and generating bevel gear grinding.

Testing Procedure and Conditions

Due to the complex component geometry, process kinematics and clamping devices, measurement of the cutting force in the bevel gear grinding process is not yet easily possible. In order to still be able to determine the cutting force, an adapted test setup was designed for plunging bevel gear grinding, see Figure 4 on the left. A 9129AA force measuring platform from Kistler

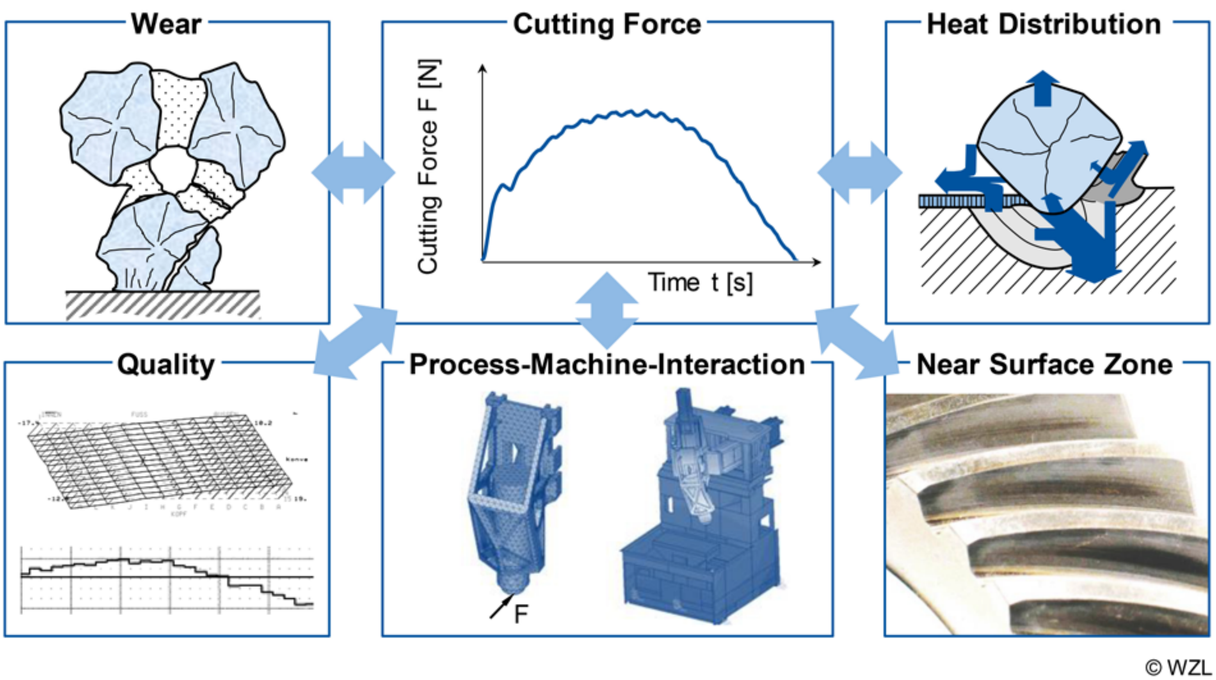

Figure 3 Influence of the cutting force in grinding processes.

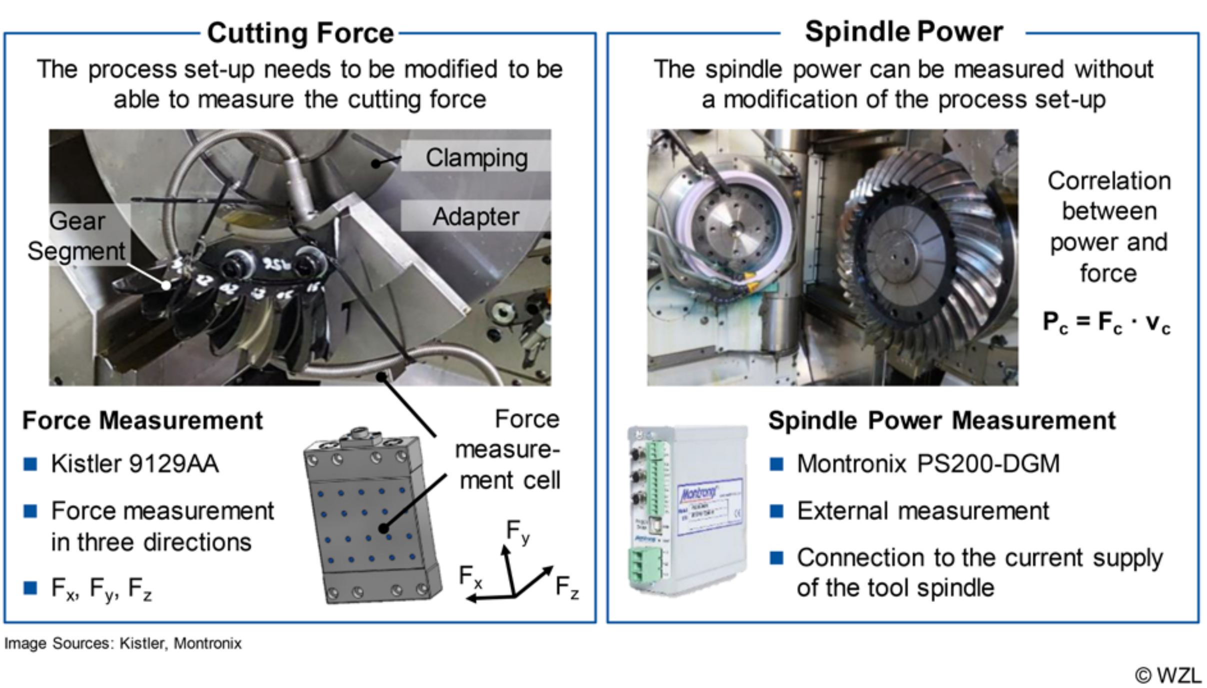

Figure 4 Measurement of the cutting force and the tool spindle power.

was used for the measurement. To ensure that the cutting force can be correctly measured by the force measuring platform, the entire cutting force must pass through the force measuring platform and a force shunt must be prevented. For this reason, grinding was performed on a segment of a ring gear. Using an adapter, the ring gear segment was attached to the force measurement platform. This assembly was bolted to another annular adapter, which had the same internal diameter as the ring gear. The measuring setup was clamped in the machine using the standard clamping device via the inner diameter of the annular adapter, see Figure 4, left. With this setup, it was possible to measure the cutting force in a process comparable to the conventional plunging bevel gear grinding process.

The measurement setup presented here cannot be used with a complete ring gear, as otherwise a force shunt would occur. For this reason, it is currently not possible to measure the cutting force in series production without implementing sensors in the clamping device. Alternatively, process monitoring can also be performed by a measurement of the tool spindle power (Ref. 3). Monitoring of the tool spindle power is possible without a complicated adaption of the process. The total tool spindle power P is the sum of the cutting power P_c and the idle power Pi. The idle power is assumed to be constant at constant process parameters and corresponds to the power before the grinding wheel comes into contact. Therefore, the increase in power from the initial point of contact is interpreted as an increase in cutting power. According to the equation on the right side of Figure 4, the cutting power P_c is commonly assumed to be proportional to the cutting force component Fc (Ref. 8). Due to the alignment of the cutting velocity vector tangential to the flank surface, the cutting force component Fc corresponds to the tangential force F_t in plunging bevel gear grinding.

The load on the main spindle of machine tools can be determined via the machine control or via external measuring devices. Depending on the type of machine control, the spindle load is sometimes only output in relation to the currently possible maximum load and is therefore dependent on the characteristic curve of the machine drive. Because the determination of the physical spindle power from the machine control can therefore be difficult, an external measuring device of type PS200-DGM from Montronix was connected to the main power supply of the tool spindle as part of the investigations presented. The measuring setup shown in Figure 4 and the Montronix power meter were used to measure the cutting force and spindle power in plunging bevel gear grinding. The test results presented in the following chapter were used to validate the relationship between cutting force and spindle power for bevel gear grinding. In this way, it will be verified whether process monitoring can be performed by means of a measurement of the spindle power.

The investigations presented in this report were carried out at Scania CV AB in Södertälje, Sweden. All tests were performed in the series production on a Gleason PHOENIXII 600G bevel gear grinding machine. The workpieces were the ring gear and the pinion of a bevel gear set with a module of $mnm = 9$ mm from a Scania axle gearbox as can be seen in Figure 5. Existing clamping devices, coolant nozzles and dressing tools from series production were used for machining. Analogous to series production, grinding of the ring gear was carried out with a vector feed and a superimposed eccentric movement according to WAGURI. The pinions were ground in a generating process. For the tests, Saint-Gobain grinding wheels were used that consisted partly or completely of rod-shaped sintered corundum (Altos grain) in a vitrified bond.

In this work, the tests and measurements performed for plunging and generating grinding are shown. The correlation between the monitored signals and potentials for process monitoring for bevel gear grinding will be introduced.

Figure 5 Testing conditions.

Plunging Bevel Gear Grinding

In the field of bevel gear production, the research environment has mainly focused on the milling process in recent years. For plunging bevel gear grinding, an empirical model was developed for predicting the risk of grinding burn as a function of the process parameters (Ref. 17). However, no modelling was carried out and the results are only valid for a very limited range of components and grinding wheels. Investigations on the measurement or prediction of the cutting force in bevel gear grinding do not exist so far.

Cutting Force and Spindle Power in Plunging Bevel Gear Grinding. A model that is frequently used in grinding processes is the force model according to (Ref. 16). Originally, this model was developed for surface grinding processes. For gear grinding, the calculation approach has already been adapted (Ref. 5). In the calculation according to (Ref. 16), the specific normal grinding force F'_n is calculated according to equation 1 (Ref. 16).

$$F'_n = \int_0^{lg} k \cdot A_{cu}(l)^n N_{kim}(l) dl \qquad (1)$$

F'_n	[N/mm]	Specific normal grinding force
l_g	[mm]	Contact length
k	[N/mm²]	Specific cutting energy
A_{cu}	[mm²]	Chip cross section
N_{kin}	[l/mm²]	Kinematic number of cutting edges
n	[-]	Exponential coefficient

In the investigations carried out, it was examined whether the Werner model could be used for bevel gear grinding processes (Ref. 11). In order to transfer the force model from Werner to bevel gear grinding, the contact conditions of plunging bevel gear grinding were analyzed. The cutting rate and the chip cross section over time were calculated using the example of a heavy automotive ring gear. For the finishing process, an almost constant average material removal rate over time was determined. On the basis of the contact conditions, the cutting force model according to Werner was applied for plunging bevel gear grinding (Refs. 16 and 11). With the aid of the transferred model and the contact conditions determined, the expected force curve for plunging bevel gear grinding was derived, as shown on the left side of Figure 6. The expected force curve according to Werner was qualitatively compared to the measured tool spindle power. The investigation of the measured spindle power signal revealed a strong increase in power during the process despite theoretically approximately constant geometric and kinematic contact conditions, see Figure 6 (Ref. 11). This increase is most likely caused by an increase in cutting force, as the cutting force is commonly assumed to be directly proportional to the tool spindle power.

This increase of the cutting force cannot be predicted directly by the Werner model, which mainly takes into account geometrical and kinematic conditions and no material changes and elastic effects in the contact zone (Ref. 16). The increase of the cutting force despite theoretically almost constant geometric and kinematic contact conditions could also be determined for gear honing (Ref. 6). The main difference between the grinding processes in which the Werner model could be applied for the entire process duration and plunging bevel grinding as well as gear honing is the main direction of feed. In profile grinding and generating grinding, the main feed component points in the direction of the tooth width and the infeed into the material takes place in discrete passes outside the tooth gap. In plunging bevel gear grinding and gear honing, the feed is continuous in the direction of the tooth height into the material, resulting in an infeed of only a few micrometers per tool pass.

Due to the continuous feed into the material, the same areas of the tooth flank are repeatedly machined with increasing plunging depth. If the workpiece-tool-machine system deforms elastically during grinding, not the entire infed stock is machined (Ref. 2). If the theoretical stock is insufficiently machined, an increase in the volume to be machined at the next

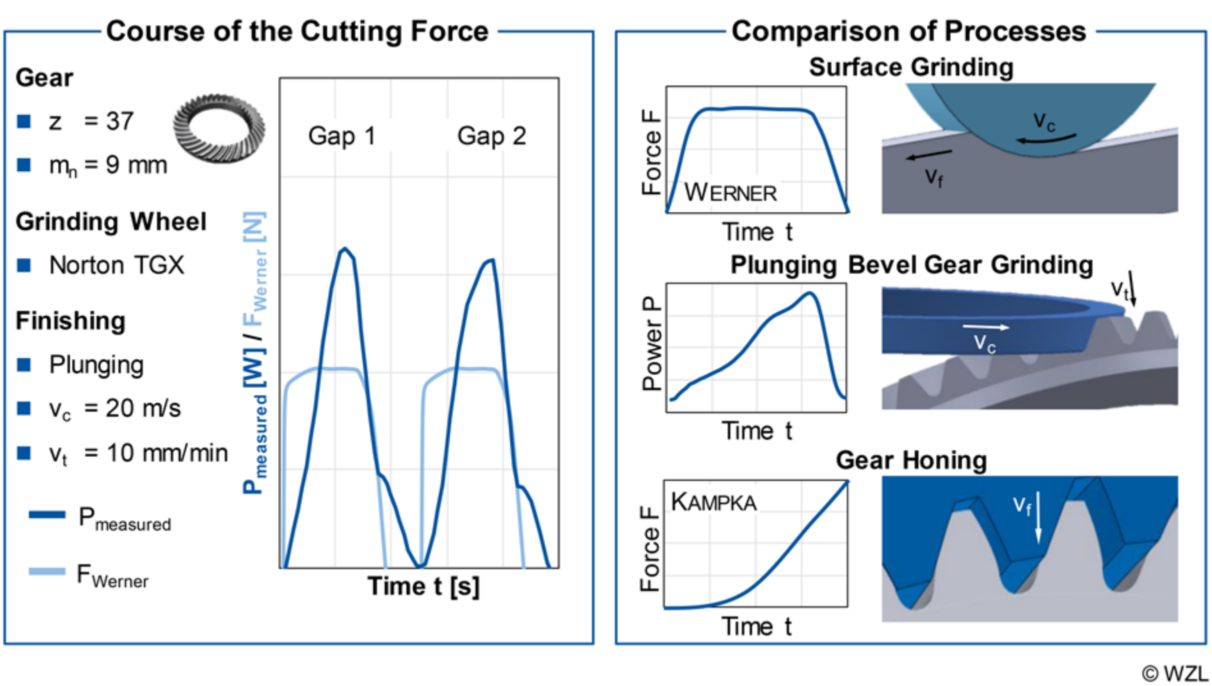

Figure 6 Investigations on the cutting force in plunging bevel gear grinding (Ref. 11).

grinding wheel pass can occur, leading to an increase of the cutting force required for machining.

In order to validate the correlation between the tool spindle power and the cutting force and to further examine the division of the force components, the cutting force in plunging bevel gear grinding was measured in a single flank grinding process with the setup shown in Figure 4.

With the aid of a coordinate transformation, the measured force signals were transferred to the tooth flanks. The components were divided into a tangential force F_t component parallel to the flank and the tool rotation and a normal force F_n component perpendicular to the flank. For the grinding of the convex flank, the cutting force components tangential force Ft, normal force F_n and the simultaneously measured power are shown in Figure 7.

It can be seen from the diagrams that the normal force F_n accounts for the largest share of the cutting force. This is in accordance with the state of the art for surface grinding (Ref. 8) and profile gear grinding (Ref. 4). The course of the force components initially shows an increase that reaches its maximum value at the same time. The measured spindle power increases in a comparable manner. The start of the rise and the maximum value of the power are reached with a slight delay compared to the force. The almost identical increase in cutting force components and spindle power confirms the previously determined increase in spindle power for plunging bevel gear grinding, see Fig. 1. This confirms the assumption that the cutting force for plunging bevel gear grinding increases over the process duration, although the penetrated material removal rate remains almost constant (Ref. 11).

All force curves show an oscillation with the frequency $f = 1{,}500\ min^{-1}$ corresponding to the frequency of the eccentric movement. For single-flank grinding, it can be seen that the cutting force components vary between a maximum value and zero at the beginning of machining with every rotation of the eccentric axis. Therefore, it is assumed that the eccentric movement leads to the grinding wheel losing the contact completely in every rotation during single-flank grinding. The measured signals also show that the force level does not return to zero after a process time of $t = 1.7$ seconds. Since the kinematics remain unchanged, this is an indicator for elastic deformation, which was already assumed in earlier investigations (Ref. 11).

Elastic deformation in the contact zone due to the flexibility of the workpiece-tool-machine system means that the infed stock is not entirely machined. This can result in the grinding wheel no longer leaving the engagement completely, despite the superimposed eccentric movement. Another indication of elastic deformation is that the cutting force does not drop to zero immediately after reaching the final depth. Due to the elastic deformation of the system, not all of the theoretically penetrated material is cut immediately and the grinding wheel must remain in the tooth gap at the end of the plunging bevel gear grinding process. During this dwell time, the remaining stock is machined at a constant infeed depth, with the force decreasing approximately linearly.

Concluding, the presented measurement of the forces confirms the existence of significant elastic deformation in bevel gear grinding. Furthermore, the proportionality between the tool spindle power and the tangential force could be validated for a bevel gear grinding process. Therefore, the tool spindle power can be used for a simplified process monitoring in further investigations. In the following, an investigation on the influence of elasticity in plunging bevel gear grinding and whether a stationary process can be achieved will be carried out.

Influence of elasticity on the course of the cutting force. In plunging bevel gear grinding, no stationary condition was determined in the previous tests. For this reason, the following section will examine whether a stationary state can be achieved

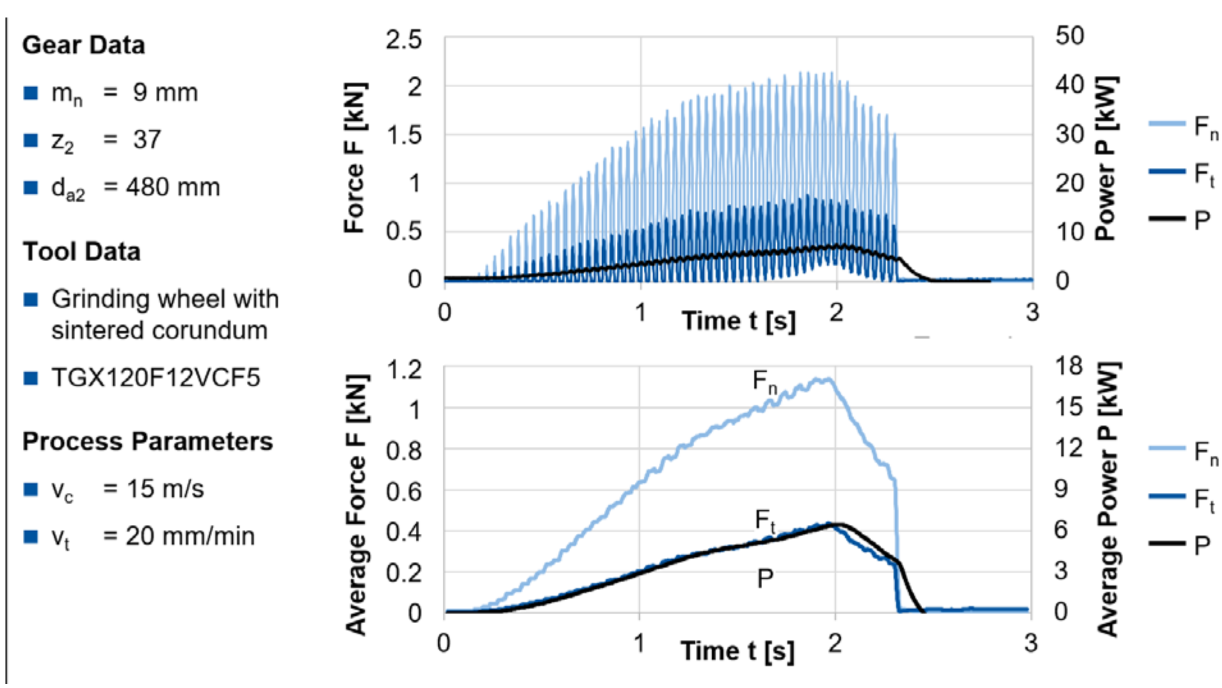

Figure 7 Investigations on the cutting force in plunging bevel gear grinding.

with increased cutting force. With increased force, there is the possibility that elastic effects can be overcome and thus a complete machining of the infed material can be achieved. The increase of the cutting force should be achieved by successively increasing the maximum plunging depth. The aim was to determine the relationship between the machined stock and the cutting force as well as the characteristic course of the cutting force over the infeed in plunging bevel gear grinding.

For each plunging depth tested, one gear was pre-ground and subsequently finished to the desired plunging depth while measuring the tool spindle power. The infeed per flank Δs can be calculated out of the plunging depth d according to eq. 2:

$$\Delta s = d \sin(\alpha) \qquad (2)$$

Δs	[µm]	Infeed per flank
α	[°]	Angle between flanks and feed vector
d	[µm]	Plunging Depth

For the investigation, the maximum tool position was increased in steps of d = 50 µm plunging depth. According to equation 2, steps of $\Delta s = 17$ µm infeed were obtained. The total infeed per tooth flank was successively increased by $\Delta s_{tot} = 17–137$ µm. In comparison, the maximum total infeed in the reference process is $\Delta s_{tot} = 50$ µm. By increasing the total infeed, it should be determined whether a stationary process and thus a stationary cutting force level can be achieved in this way. The grinding wheel tip was shortened to avoid machining the tooth root despite the increased plunging depth. Finishing was carried out at a cutting velocity of $v_c = 15$ m/s and a plunging feed rate of $v_t = 30$ mm/min. The course of the spindle power during the machining of one tooth gap each over the process time for the various total infeeds Δs_{tot} is shown in Figure 8.

The Figure shows that an increase in the maximum total infeed is accompanied by an increase in the maximum spindle power. In addition, three phases are visible in the power curve. In the first phase, there is a roughly linear increase in spindle power for all variants regardless of the maximum total feed Δs_{tot}. As this phase takes place before the initial contact between grinding wheel and flank it is attributed to oil friction in the gap (Ref. 12).

The first phase of increase is followed by a faster linear increase in the second phase for all variants which is caused by the material removal. For the spindle power curves, both the points in time and the gradients are comparable.

The first phase of increase is followed by a faster linear increase in the second phase for all variants which is caused by the material removal. For the spindle power curves, both the points in time and the gradients are comparable. For the variants with maximum total infeed $\Delta s_{tot} \leq 67$ µm, the rapid increase in spindle power after reaching the maximum value is followed by a rapid decrease in spindle power to the initial level. For the variants with maximum total infeed $\Delta s_{tot} \geq 85$ µm, the second phase of the rapid increase in spindle power is followed by a third phase with approximately constant spindle power before the spindle power drops. From this it can be seen that with an increase in infeed and thus of the machined material, a stationary tool spindle power level can be achieved in plunging bevel gear grinding. Based on the previously determined proportional relationship between tangential force and spindle power, this means that the tangential force also reaches a stationary level in

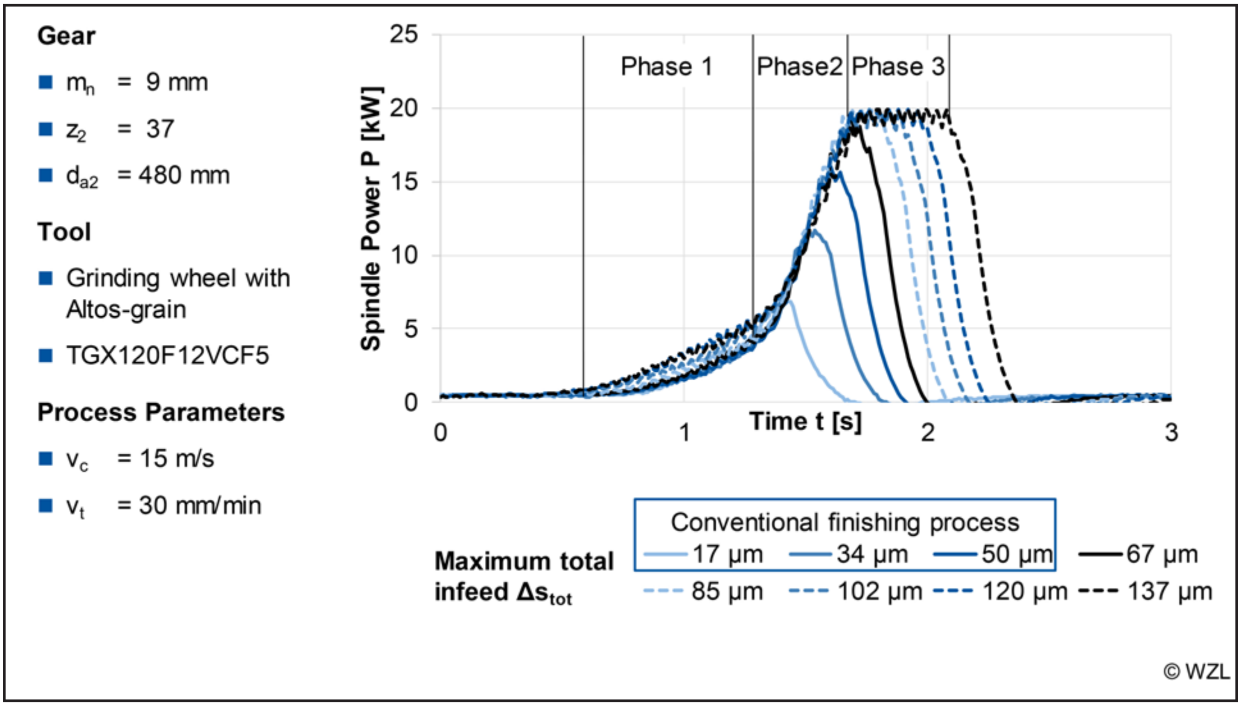

Figure 8 Influence of the infeed on the tool spindle power.

this state. This is due to the fact that machining conditions have been achieved under which the entire stock can be machined.

In the following, the elastic deformation in plunging bevel gear grinding is determined with the help of the gears from the previously performed tests with variable infeed Δs_{tot}. In order to be able to determine the actually machined volume as a function of the maximum total infeed, no dwell time after reaching the maximum plunging depth was set for finishing. After machining, the tooth thickness for all gears was determined and compared with the theoretical tooth thickness as a function of the maximum total infeed. In this way, the remaining stock Δs_R per tooth flank could be determined, see Figure 9.

The light colored points and the regression line represent the course of the remaining stock Δs_R per flank depending on the maximum total infeed Δs_{tot}. It can be seen that the remaining stock initially increases with the infeed and then reaches a near stationary level. If the maximum total infeed is set to $\Delta s_{tot} = 137\,\mu m$, the remaining stock of $\Delta s_R = 16\,\mu m$ per tooth flank occurs. It can be assumed that the remaining stock is composed of a deformation of the tool, workpiece and machine tool. In the future, this should be further investigated by individual displacement measurements. The dark points in the diagram represent the maximum spindle power P over the maximum total infeed Δs_{tot} for all test points. The comparison shows that the remaining stock Δs_R and the maximum spindle power P increase proportionally. The last three test points with the highest total infeed have an approximately constant remaining stock and an approximately constant maximum spindle power.

If the maximum spindle power P is plotted over the remaining stock Δs_R, an approximately linear relationship becomes apparent, see bottom of Figure 9.

The spindle power P is proportional to the tangential force F_t and approximately proportional to the normal force F_n. This correlation corresponds to the theory according to (Ref. 10) that the overall system behaves like a spring with the stiffness k_e (Ref. 10). Accordingly, the relationship between the normal force F_n and the deflection and thus the resulting remaining stock Δs_R can be described using the usual approximation for springs, see equation 3

$$F_n = k_e \cdot \Delta s_R \tag{3}$$

F_n	[N]	Normal force
Δs_R	[µm]	Remaining stock
k_e	[N/µm]	Total spring stiffness

Based on the stiffness, the system deformation and thus the remaining stock Δs_R can be predicted for the considered test setup with the aid of the monitored spindle power. In this way, for example, the required dwell time can be set. In order to be able to transfer the relationships determined to other process configurations, the composition of the spring stiffness must be determined more precisely in the future. In addition, the validity of the relationship between the spindle power and the normal force for must be checked for different gear geometries.

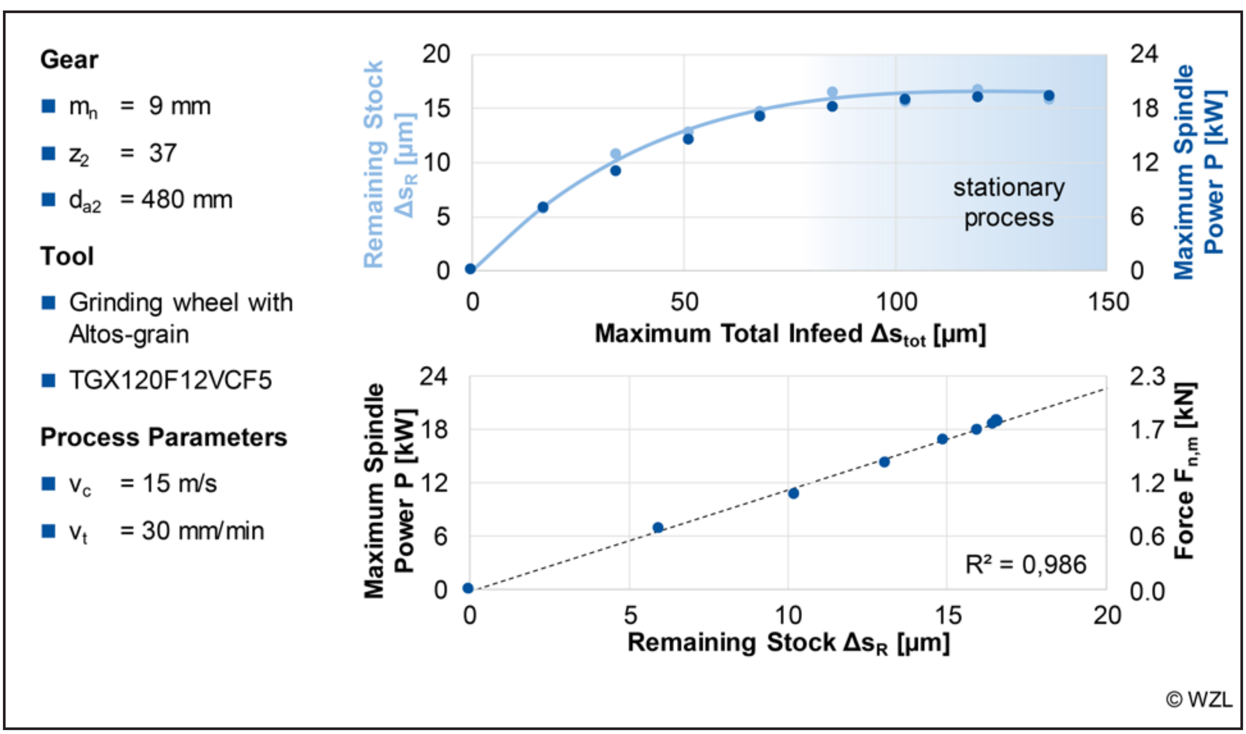

Figure 9 Correlation between the remaining stock and the tool spindle power.

Generating Bevel Gear Grinding

In addition to the tests performed for plunging bevel gear grinding, tests for process monitoring were also performed for generating grinding of bevel pinions. In these tests it was evaluated, how the tool spindle power signal can be used to detect critical process conditions. By this means, process monitoring should be made applicable to find a suitable process design. It was tested if the rolling velocity v_w in the series production could be increased in order to optimize the process productivity. The monitored tool spindle power for three levels of rolling velocity are shown in the top of Figure 10.

The test results showed, that the tool spindle power is directly influenced by the rolling velocity of the process. An increase of the rolling velocity led to an increase of the tool spindle power. In the examinations, an increase of the rolling velocity by 25% compared to the reference process was tested. After the grinding process, the geometry of all ground pinions was measured. The pinions ground with a significantly increased rolling velocity showed remaining stock on the tip area of the heel. The amount of remaining stock increased with the number of flanks ground before. An analysis of the grinding wheel showed, that whole areas of grains and bonding had broken off the tool.

This failure of the tool is directly correlated to a continuous overload. Most likely, the combination of stock, rolling velocity

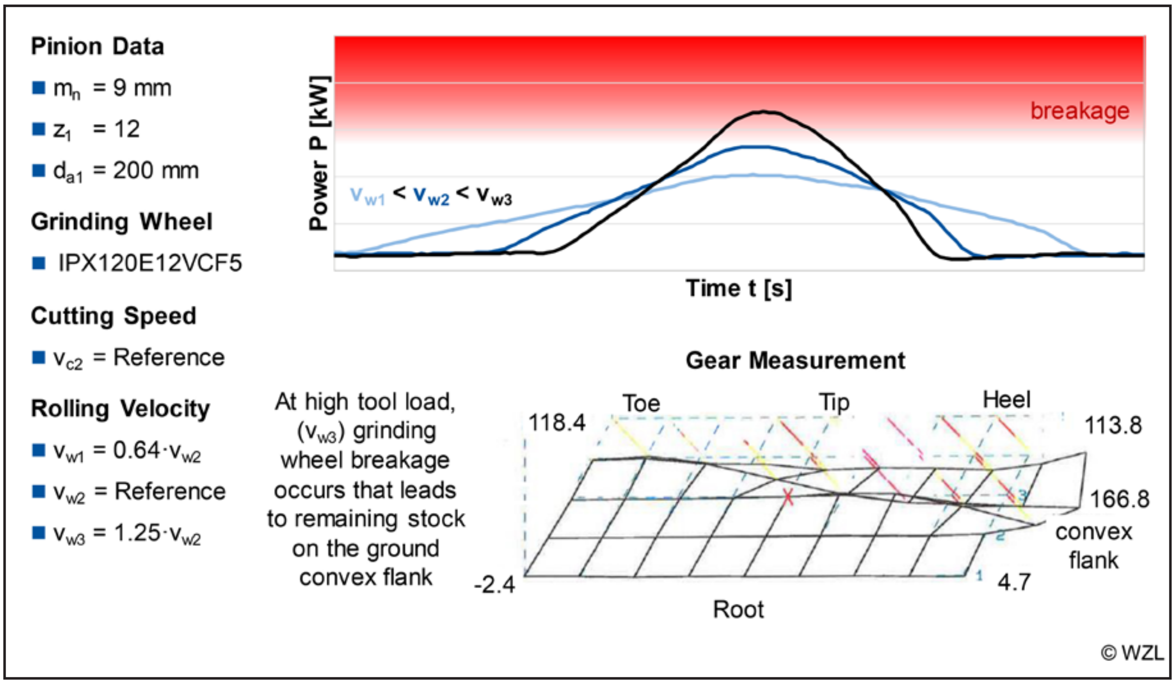

Figure 10 Influence of an increased rolling velocity in generating bevel gear grinding.

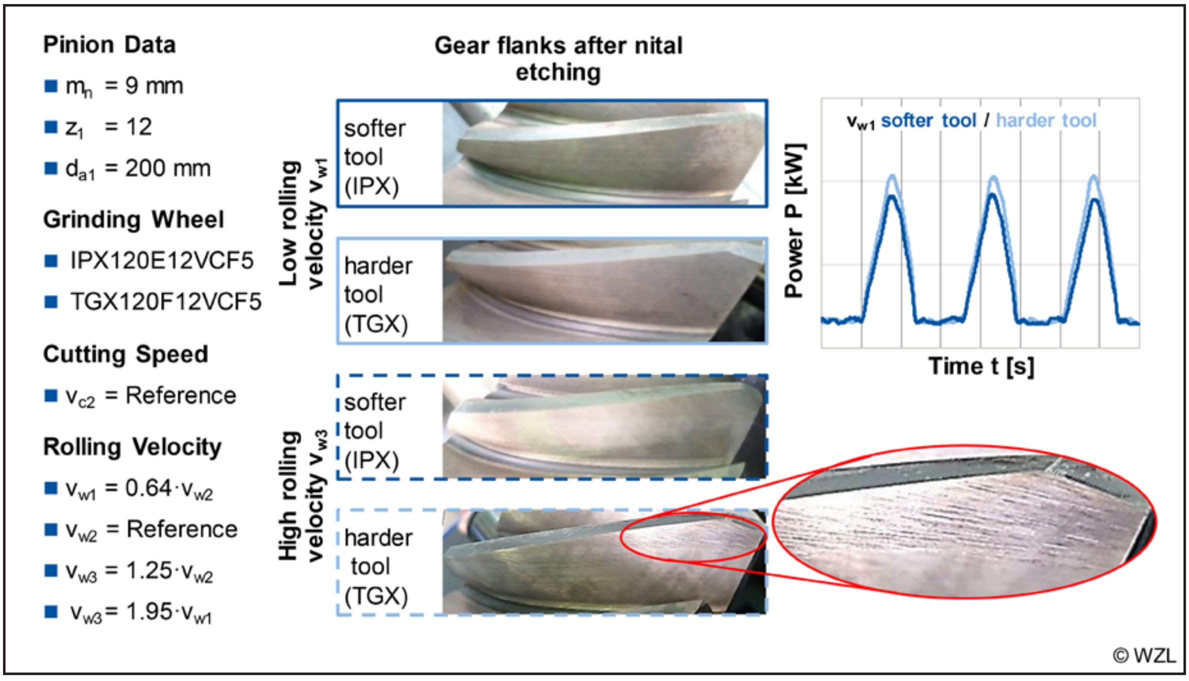

Figure 11 Influence of the grinding wheel specification in generating bevel gear grinding.

and cutting velocity have caused a critical load on the grains. By means of a monitoring of the tool spindle power, this type of overload can be avoided. From the tool spindle power, the tangential force in the contact zone can be calculated. From the tangential force, the load per grain can be estimated. Depending on the type of grinding wheel used, a maximum tolerable load level can be determined. By this means, a tool breakage can be prevented in advance and suitable process parameters can be determined.

In addition to the variation of the rolling velocity, the grinding wheel specification was varied in the tests performed. In the previously described tests, an IPX grinding wheel with a mix of Saint-Gobain Altos grain and conventional corundum was used. For grinding of the ring gears, a TGX grinding wheel with 100% Altos grain was applied. In further tests, the applicability of the TGX tool specification also for pinion grinding was investigated. The test results can be seen in Figure 11.

In case of a successful test, the number of different tool specifications for bevel gear grinding could have been halved. This would have been beneficial for purchase and storage capacities. Furthermore, the harder TGX grinding specification showed the tendency to be more stable in previous tests. The results from the generating pinion grinding confirmed these test results.

While the softer IPX grinding wheel broke at the increased rolling velocity v_w, the gears machined with the harder TGX wheel did not show any geometric deviations caused by tool failure. During the tests, it could already be seen that the tool spindle power consumption is increased for the harder TGX grinding wheel compared to the softer IPX grinding wheel, see top right of Figure 11. A higher tool spindle power can be an indicator of a higher energy input into the contact zone. Nital etching after the grinding process showed a slight change of color for the gears that were machined with the harder grinding wheel and increased rolling velocity v_w. Especially the area of the heel close to the tip turned out darker after nital etching. This was also the area, where the geometric deviations occurred due to a breakage of the softer grinding wheel. These results suggest that the load on the grinding wheel and the flank is maximum in this area. A measurement of the Barkhausen signal could also confirm the increased thermal influence on the pinion flanks for the combination of higher rolling feed and harder grinding wheel. It can be seen that the more stable harder grinding wheel can induce a higher risk of thermal damage.

The presented results for generating bevel pinion grinding showed possibilities to indicate critical process conditions by means of process monitoring. Both an overload of the tool as well as a higher energy input due to an increased tool hardness could be detected by means of the tool spindle power. When a process is well known, these signals can be applied for process monitoring and to successfully adapt or design a bevel gear grinding process.

Potentials for Process Monitoring in Bevel Gear Grinding

In the previously presented work, different potentials for process monitoring in bevel gear grinding were shown. An increased energy input into the workpiece caused by a critical feed rate can be detected by means of the tool spindle power. The tool spindle power is directly influenced by the process parameters, the grinding wheel and the lubrication. In order to be able to interpret the signal, the process has to be well known.

In addition to the influence on the workpiece, the influence on the tool can be determined by means of process monitoring. In order to determine the load on the tool, the cutting velocity needs to be taken into account. The ratio between the tool spindle power and the cutting velocity is proportional to the cutting force components. When the force and therefore the local load on the grinding wheel is too high, a high risk of breakage occurs. Too small loads on the grinding wheel can also cause difficulties, when the load is not sufficient for the tool to self-sharpen, as can be seen in Figure 12.

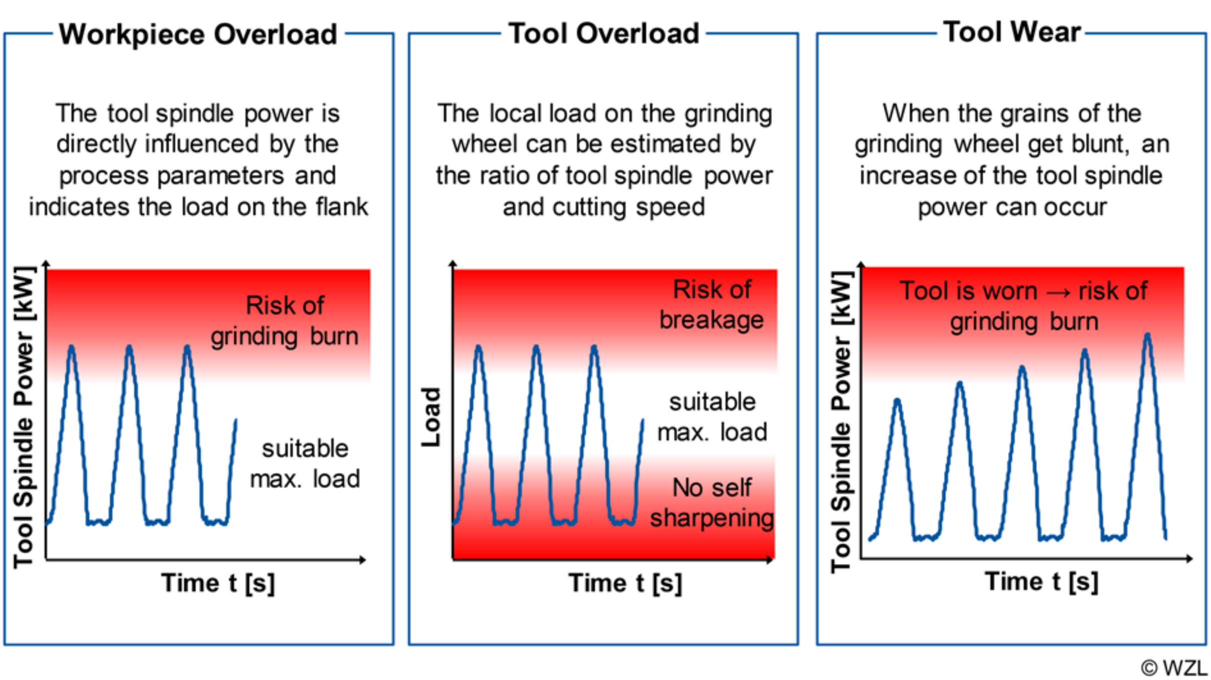

Figure 12 **Potentials for process monitoring in bevel gear grinding.**

When the grinding wheel gets blunt due to wear or a lack of self-sharpening, an increased amount of rubbing and therefore increased friction in the contact zone can occur. This increased friction can lead to a rising spindle power and a higher energy input into the workpiece. Therefore, in case of a significantly increasing tool spindle power over time, a dressing process or a replacement of the grinding wheel should be taken into consideration. If the tool wear leads to a breakage of a large amount of grains, tool wear can also cause a drop in the spindle power. Each change of the signal should therefore carefully be examined and the process needs to be well known to interpret the signals.

For tool condition monitoring, a measurement of the dressing spindle power can also be useful. The course of the measurement can show if the dressing wheel is in contact from the first pass on. This can be an indication of the occurring amount of tool wear in a grinding process. By monitoring the dressing process, a sufficient dressing of the grinding tool can be assured and the number of dressing passes can be optimized. In addition, wear of the dressing tool can lead to a change of the dressing spindle power. The work presented shows that the tool and dressing spindle power of the machine tool is a relatively simple accessible signal which can give essential process information. To be able to use the spindle power signals for reliable process monitoring, the process needs to be well known and a reference process measurement is required for comparison purposes.

Summary and Outlook

In previous scientific research in grinding processes, the relevance of the knowledge of the cutting force for the prediction of the thermomechanical influence on the workpiece and the load on the grinding wheel have been shown. Therefore, for plunging bevel gear grinding an approach to model the cutting force was analyzed. As the cutting force measurement in bevel gear grinding processes is very complicated, the correlation between the cutting force and the tool spindle power was examined. It could be validated that the tool spindle power is directly proportional to the tangential force in plunging bevel gear grinding. In the tests performed, a strong increase of the cutting force was determined. This increase was most likely correlated with elastic effects in the process. These elastic effects could be described and directly correlated to the measured tool spindle power. Therefore, for plunging bevel gear grinding it could be shown that the measurement of the tool spindle power can be used to determine the cutting force and to estimate the elastic deformation in the process.

For generating grinding of bevel pinions, measurements of the tool spindle power have been applied to detect critical process conditions. A direct correlation between the tool spindle power and the load on the grinding wheel as well as the workpiece could be determined. It was shown that process monitoring can be used to design the bevel gear grinding process, to avoid tool failure, to detect grinding burn and to determine dressing cycles.

The test results showed that a lot of essential information can be obtained from the measurement of the machine spindle power signals. Furthermore, it could be seen that a detailed knowledge of the process is required in order to interpret the signals correctly. Therefore, in the future, further analysis on the interpretation of the process signals should be performed. This analysis could support the successful application of process monitoring for bevel gear grinding processes.

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References

1. Bausch, T.: Innovative Zahnradfertigung. Verfahren, Maschinen und Werkzeuge zur kostengünstigen Herstellung von Stirnrädern mit hoher Qualität. Bd. Nr. 175, 3. Aufl. Renningen: Expert, 2006.
2. Bock, R.: Schleifkraftmodell für das Außenrundund Innenrundschleifen. In: Tagungsband zum Jahrbuch Schleifen, Honen, Läppen und Polieren. Essen: Vulkan, 1987.
3. Brinksmeier, E.; Tönshoff, H.; Czenkusch, C.; Heinzel, C.: Modelling and optimization of grinding processes. In: J. Int. Manuf., 1998, Nr. 9, S. 303–314.
4. Grinko, S.: Thermo-mechanisches Schädigungsmodell für das (Zahnflanken-) Profilschleifen. Diss. TU Magdeburg, 2006.
5. Hübner, F.; Klocke, F.; Brecher, C.; Löpenhaus, C.: Development of a Cutting Force Model for Generating Gear Grinding International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Boston, Massachusetts, 02.-05. August, 2015.
6. Kampka, M.: Lokal aufgelöste Zerspankraft beim Verzahnungshonen. Diss. RWTH Aachen University, 2017.
7. Klingelnberg, J.: Kegelräder. Grundlagen, Anwendungen. Berlin: Springer, 2008.
8. Klocke, F.; König, W.: Fertigungsverfahren 2. Schleifen, Honen, Läppen. 4. Aufl. Berlin: Springer, 2005.
9. Klocke, F.; Brecher, C.: Zahnradund Getriebetechnik. Auslegung - Herstellung - Untersuchung - Simulation. Aufl. München: Hanser, 2017.
10. Malkin, S.; Guo, C.: Grinding technology. Theory and application of machining with abrasives. Aufl. New York: Industrial Press, 2008.
11. Solf, M.; Löpenhaus, C.; Klocke, F.: Contact Conditions in Bevel Gear Grinding. In: Tagungsband zum WGP-Jahreskongress. Aachen, 05.-06.10.2017. Aachen: Apprimus, 2017.
12. Solf, M.; Löpenhaus, C.; Bergs, T.: Einfluss der elastischen Nachgiebigkeit auf die Kraft beim tauchenden Kegelradschleifen. In: Forsch. Ingenieurwes., 83. Jg., 2019, Nr. 3, S.-741-750.
13. Solf, M.; Löpenhaus, C.; Bergs, T.; Klocke, F.: Analysis of the Grinding Force in Plunging Bevel Gear Grinding 8th Congress of the German Academic Association for Production Technology (WGP). Aachen, November 19–20, 2018. Cham: Springer International, 2018.
14. Stadtfeld, H.: A Split Happened on the Way to Reliable, Higher-Volume Gear Grinding. In: Gear Technol., 2005, Nr. 5, September/October.
15. Stadtfeld, H.: Gleason Kegelradtechnologie. Ingenieurwissenschaftliche Grundlagen und modernste Herstellungsverfahren für Winkelgetriebe. Renningen: Expert, 2013.
16. Tönshoff, H.; Peters, J.; Inasaki, I.: Modelling and Simulation of Grinding Processes. In: CIRP Ann. - Manuf. Technol., 41. Jg., 1992, Nr. 2, S. 677–688.
17. Werner, G.: Kinematik und Mechanik des Schleifprozesses. Diss. RWTH Aachen University, 1971.
18. Weßels, N.: Flexibles Kegelradschleifen mit Korund in variantenreicher Fertigung. Diss. RWTH Aachen University, 2009.

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Psychoacoustics Applied to eDrive Noise Reduction

Dr. Hermann J. Stadtfeld

Physical Effects Causing Transmission Noise

Transmissions in electric vehicles appear to require new and different mechanisms for the reduction of the high pitch noise they are emitting. If the question is asked why the frequency of the eDrives noise is significantly higher than the frequencies in conventional automotive transmissions, then the answer is that the transmission input RPM is higher by a factor 3 to 10. Basically this means the physical phenomena which generate the noise are the same phenomena that generate noise in a conventional transmission. This means the tooth mesh frequency and its higher harmonics are also responsible for the high pitch noise emitted from eDrives.

High pitch noise is recognized as more annoying than low pitch noise. Although the same effects are responsible for the noise in both conventional and electric vehicle transmissions, the same disturbance which was tolerable in a conventional vehicle with an internal combustion engine becomes now a deciding factor of why to buy one vehicle versus another. The importance of small tooth mesh impacts which were rated as acceptable in the past becomes critical in connection with an eDrive.

Cylindrical gears as well as bevel and hypoid gears have the same identical noise generation principles and both can be reduced with the same noise reduction mechanisms.

This Chapter 9 book excerpt introduces the phenomena between noise generation, analysis and recognition by the human ear. The acknowledgements and conclusion are then applied to two different levels of noise reduction, Micro Topology (flank form modifications), discussed in chapter 10.

Main Topics of Chapter 9 are:

- Designed flank surface crowning and theoretical motion transmission
- Fourier analysis and its limits in gear noise analysis
- Gear noise and psychoacoustics
- Practical example of Fourier analysis and the residual phenomenon

Psychoacoustics

Sound is created by the vibration of mechanical elements and magnified by structures with certain surface areas and certain resonance frequency. The original or the magnified sound is transmitted through structures (structure borne noise) and then transmitted through the air (sound pressure waves) and finally received by the human ear. The physics of sound transmission is based on the compression and expansion of solid materials as well as fluids. The mathematical function of the compression and expansion of elastic materials is most likely always a sinusoidal function. The assumption that all sounds which are transmitted and emitted consist solely of sinusoidal elements seems reasonable.

The answers which engineers would be interested to receive from the Psychoacoustic Science regard the receiving of sound transmission by the human ear. If sound was created as a non-sinusoidal signal and also transmitted to the ear in a media which supports non-harmonic functions, how is this sound recognized by the human brain? An inverse

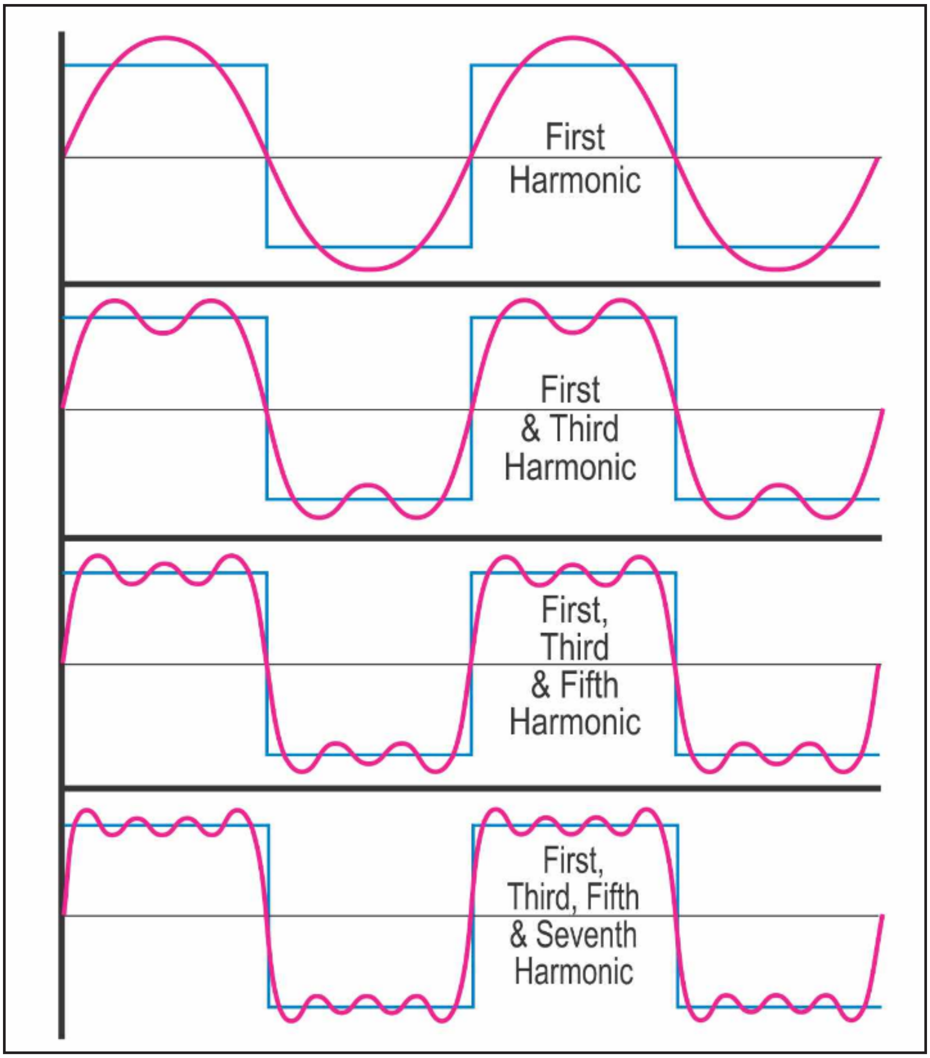

Figure 1 Fourier series development for a square wave.

question is whether our entire environment, including the laws of physics, is strictly supporting harmonic sounds. This would govern that sound sources, sound transmission as well as the receiving and recognizing of sound by a listener, are all based on the harmonic movement of elements by certain amplitudes and with a certain frequency.

Studying the vertical sequence of the graphics in Figure 1 makes it evident that according to the common acoustic interpretation a square wave would cause a listener to hear several high frequencies. This raises a number of questions:

- Is the transmission of waves through the air or other media only possible in sine waves?
- If a true square wave was received by the human ear, would the brain first recognize the received wave form and replace it with a sine wave of the same frequency and similar intensity and then substitute the higher frequencies, similar to Figure 1?
- If the human ear could hear the original square wave as a plain periodic plus-minus signal, would it sound the same as an artificial square wave which is a superimposition of four or more different frequency sine functions?

The questions above require some basic relationships between sound transmission and the psychoacoustics between the sound received by the human ear and its processing by the brain. A complete Fast Fourier Transformation (FFT) also analyzes the frequencies between the harmonics in certain Hertz increments in order to more accurately capture the working variation. If the result of a FFT is used as the absolute measure of the noise characteristic of a gear set, then the conclusion is made that the human ear only recognizes acoustic signals or sound pressure waves in the form of true sine waves.

The concert pitch A of 440 Hz from a tuning fork sounds different to the human ear than from a violin or from a piano. The reasons are overtones which consist of higher harmonics, side bands and/or other elements in the sound waves which might not be captured by the FFT. However, the fact that the 440 Hz can be recognized precisely by a listener is explained with the higher harmonics accompanying the fundamental frequency (Ref. 1).

The assumption that the ear tends to recognize only harmonic signals is partially correct. The outer ear acts as equalizer and compressor which boost the sound pressure by 15 to 20 dB. The airwaves actuate the eardrum which in turn actuates the ossicles which acts as equalizer, compressor and impedance matcher such that the processed pressure waves are transferred into the cochlear fluid. The pressure waves are transmitted by the cochlea fluid to the tectorial membrane. The snail house shaped cochlea is lined with the tectorial membrane which moves hair cells. Along the windings of the cochlea, the hair cells are sensitive to different frequencies, performing a spectral analysis of the sound signal. The hair cell neurons convert the mechanical vibration into digital electronic signals which are transmitted to the brain. The diagrams in Figure 2 show the Fourier analysis of the noise emission from a gear set and how the vibrations are converted to airborne sound which is received by the order tracking neurons in the ear. The recognized frequencies and amplitudes are similar but different than the ones found in the Fourier transformation. One reason for this is the residual error which is not captured by the Fourier analysis.

An interesting phenomenon is that the pitch identification of ear and brain not only uses the fundamental frequency, but also employs the available (audible) higher harmonic orders. The ear still identifies for example concert pitch A if only the second to sixth harmonics are received, and the fundamental frequency is absent in the received sound signal (ghost fundamental). The "A-signal" without the fundamental sounds "smoother" than if the fundamental frequency was present.

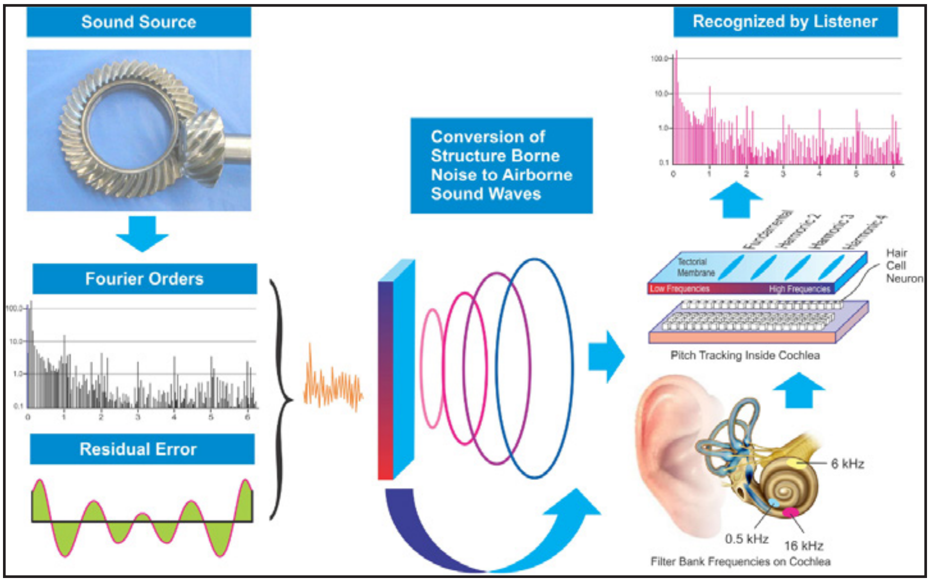

Figure 2 From sound source human recognized sound.

The conclusion is that the ear as a pneumatic-mechanical-hydraulic-electronic system has masses, springs and dampening and is created to recognize frequencies. It will mostly recognize harmonic air pressure changes which are received in a periodic signal. However, an impulse will also be recognized, while ear and brain try to supplement the missing periodicity. The Fourier transformation of an impulse is shown in Figure 3. The impulse generates bars in the entire frequency range which die down in amplitude as the frequency increases. This means that all those frequencies have been found by the Fourier transformation, although the impulse was an isolated occurrence with virtually no frequency. The human ear will respond similarly because its design will cause an excitation of all hair cells along the windings of the cochlea and send signals of all audible frequencies to the brain.

Another interesting question is how a square wave sounds to the human ear compared to the results of a Fourier analysis. A perfect square wave which is approximated with a Fourier series shows an overshoot at the corners of the square (Gibbs phenomenon) (Refs. 2–3). Figure 1 shows a square wave which is approximated by a first, third, fifth and seventh order sine wave. The overshoot never dies out; it approaches a finite limit of 18% of the square wave amplitude as the number of orders increases. The question is if the human ear, because of its function, will basically send a similar exaggerated signal to the brain when it receives a perfect square sound wave. This question might be academic because no sound generating source is capable of creating a perfectly square signal without the overshoot. Besides this, the airwaves would not be able to transmit such a signal without distortion. The square wave has a ringing sound to the ear which is attributed to the overshoot. An additional peculiarity of the Fourier series of a square wave is that only the odd orders 1, 3, 5… are represented. The verification of the fundamental frequency of a square wave which the ear conducts with the higher harmonics in numerous distinct areas of the tectorial membrane is not given and a strange hearing experience is the result. The square wave not only rings, it also sounds "cold and synthetic."

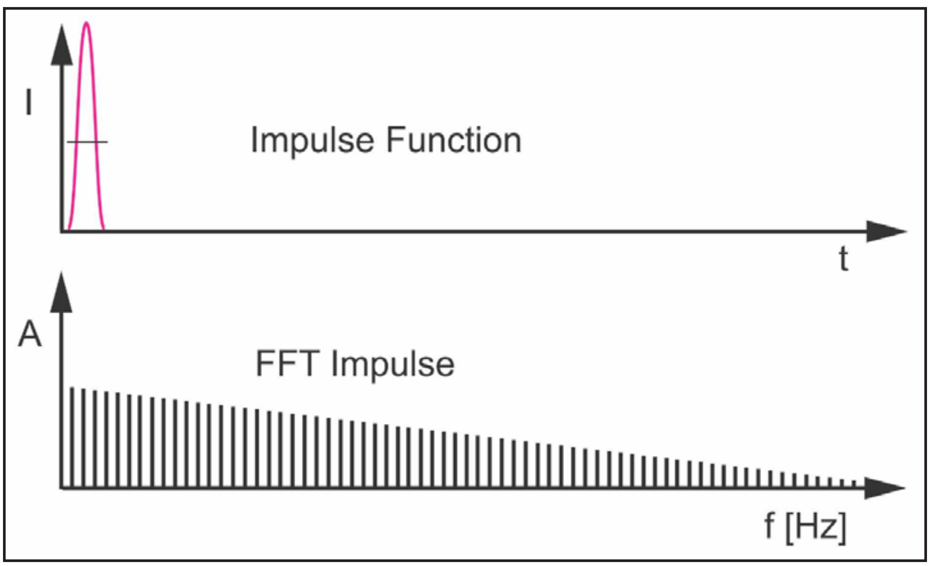

Figure 3 Impulse recognition in Fourier analysis.

Acoustical experiments with pure single frequency sine waves seem to confirm the theory that ear and brain will not complement the non-transmitted higher harmonic multiples of that sinusoidal sound. The pure single frequency sine wave sounds smooth and rather quiet compared to a same intensity square wave. This raises the question, if in case of a parabolic motion error, will the ear notice the same higher harmonic frequency levels which result in a Fourier analysis of such a motion error? The Fourier analysis mirrors in many cases the psychoacoustics of the human ear very well (e.g., music), but also fails in many cases to deliver representative evaluation results (e.g., disturbing mechanical noise).

Depending on the motion error characteristic, there are higher harmonics amplitudes in the FFT result and residual approximation errors which are ignored. It is assumed that certain residual non-sinusoidal waves are audible as distorted sine waves and certain harmonic amplitudes do not really exist in the sound waves received and processed by the ear. The non-existing harmonic amplitudes are merely a result of the Fourier summation scheme. It has been proposed to apply the smoother Fejér summation or Riesz summation or using the continuous wavelet transformation in order to gain more relevant dynamic analysis results.

Dynamic analysis results have commonly two applications. One is the mentioned audible experience by humans and the second is the conclusion to gear geometry related manufacturing errors. The latter asks for a sufficient qualitative and a concrete quantitative interpretation in order to allow for corrections in the machining process. The fundamental harmonics and the side bands can give certain hints to machining errors. The harmonics above the fourth order point in some cases at surface structural and roughness problems. Especially the second to fourth harmonic amplitudes can lead to the belief that there is, for example, a disturbance which occurs 2, 3 or 4 times at each tooth mesh. As a matter of fact, this is possible, but it only might be the result of the Fourier summation process required to capture a particular motion graph, which only repeats its disturbing rotational transmission once per tooth mesh.

Example of Fourier Analysis and the Residual Phenomenon

In order to approximate a realistic motion transmission graph, a parabola of the form $\Delta\varphi = \alpha \cdot (\varphi - \varphi_0)^2$ as it is typical for bevel gear sets, is used in Figure 4 as the subject of a Fourier analysis.

As starting point, a sine-function with suitable amplitude and a period of the meshing time of one pitch is drawn into the parabola shaped motion graph. If the first harmonic is subtracted from the motion transmission graph, the result is the first harmonic residual which has twice the frequency of the motion transmission graph itself. This does not mean that the original motion transmission graph contained any elements of double frequency, it merely means that in the attempt to approximate a parabola with a sine-function the residual will show a dominating second order. If the dynamic transmission media is capable of transmitting the original parabola shaped sound wave, and if the receiver e.g., a human ear was rather capable in receiving and processing sinusoidal waves, only then would this second harmonic be noticed.

A sinusoidal function with half the period of the original function and an amplitude of about half of the residual magnitude is now used to approximate the residual function from the first harmonic. The residual from this approximation step result is shown in Figure 4 underneath the second harmonic. This graph appears to have some third and some fourth order elements. As a matter of fact, it requires the elimination of the third and fourth order harmonic elements in order to notice a visible reduction of the residual function. The unequal spacing of the waves makes it particularly difficult for a Fourier analysis to closely approximate a parabolic function. The residual error after the elimination of the third harmonic element still contains some first order residual, which can be determined at this point and then be added to the amplitude A_1. The frequency-amplitude spectrums of the four sine waves in Figure 4 have been plotted into the graphic in Figure 5. Although this graphic shows the amplitudes for the dynamic gear set evaluation, only the first order peak-to-peak values are relevant because only they represent the stroke of the excitation ripple and can be correlated to the transmission error. A true mechanical disturbance (e.g., second order) would show as an amplitude above the enveloping curve (red dashed bar). There are several conclusions that came out of the experiment demonstrated with Figure 4:

- A true parabola shaped graph was approximated. The result of a Fourier analysis of a perfect parabola shaped motion transmission graph results in more than four harmonics of significant amplitudes. If the analysis is stopped after the four harmonic separation steps, a residual amplitude of about 50% of the original function is found.
- The value 2A1 is larger than the original value of the motion error DjGear
- Many gear analyses are performed with only a four harmonics analysis. The residual function is so significant for the effective noise emission of the gear set that no absolute noise rating is possible.
- FFT's have their value if they are used in the comparison of similar gear sets which have been found acceptable in their noise emission.

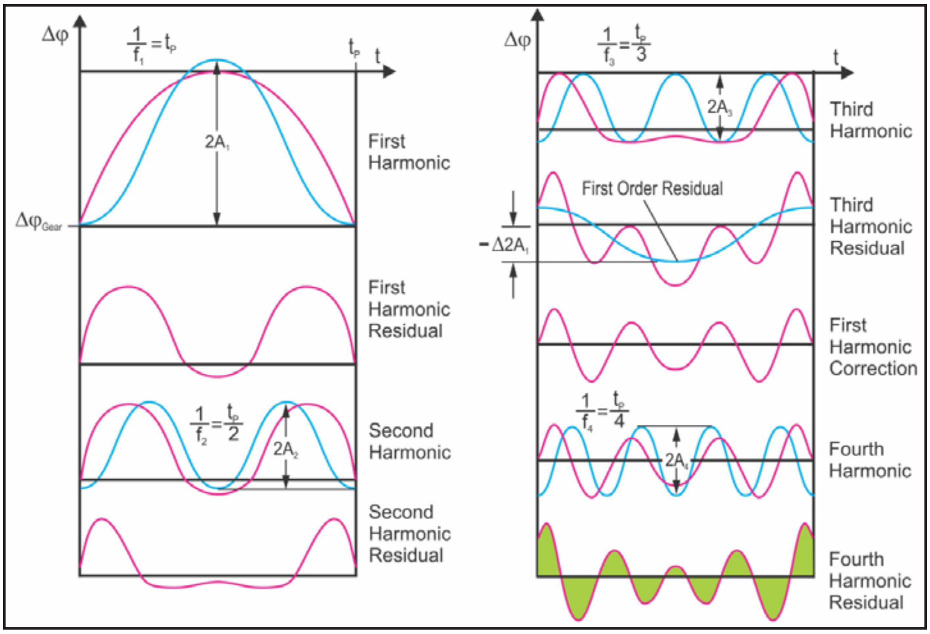

Figure 4 Fourier analysis of parabolic function.

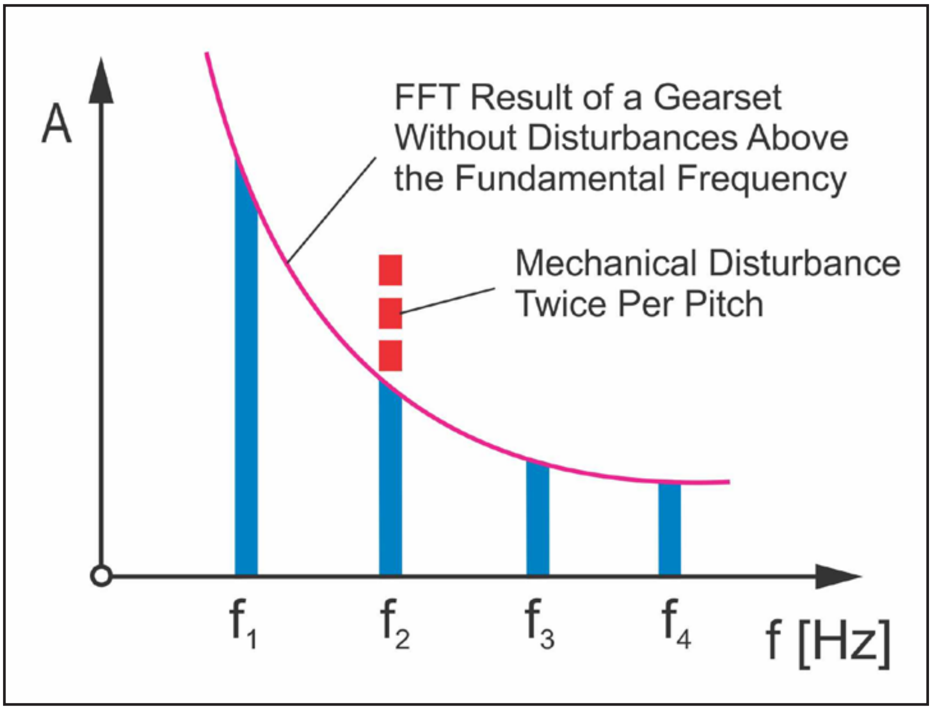

Figure 5 Frequency-amplitude spectrum of harmonic contents of a periodic parabola.

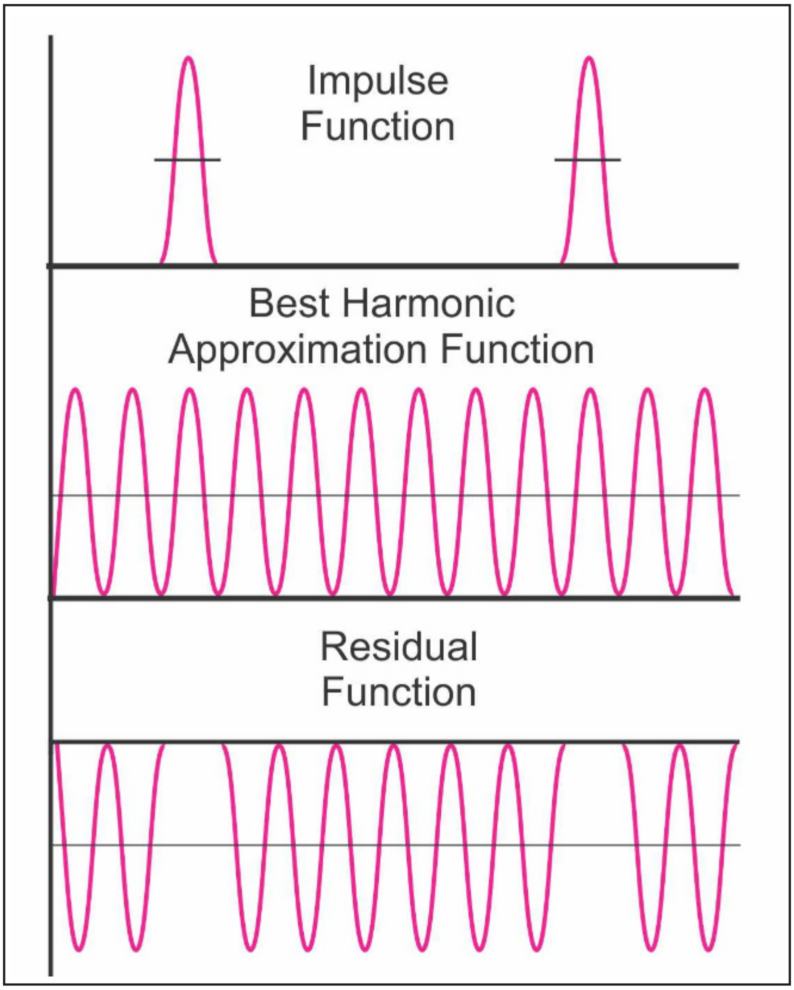

Figure 6 Residual error in case of a periodic impulse.

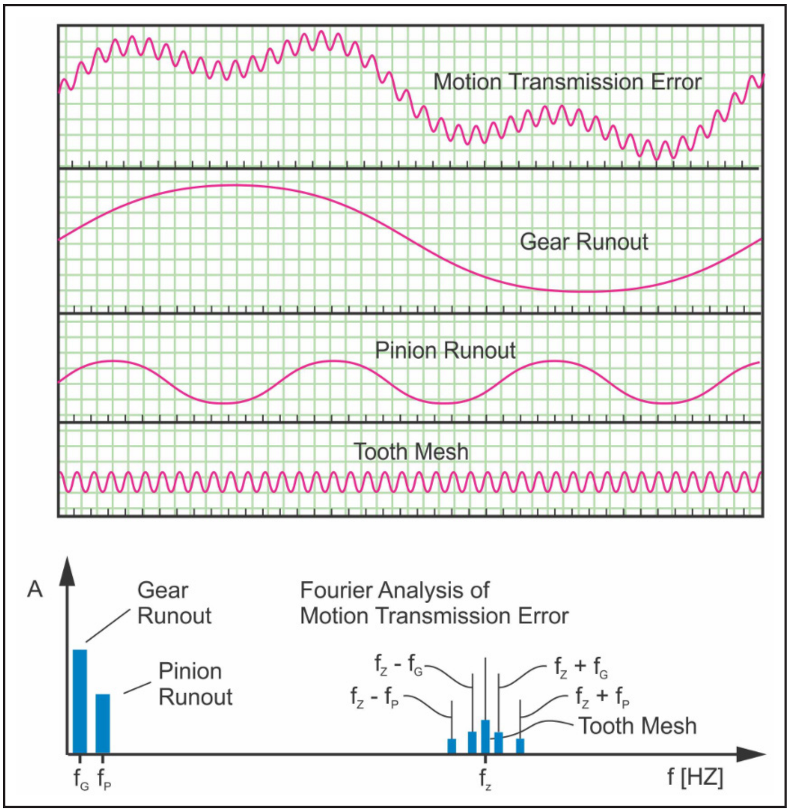

Figure 7 Separation of harmonic motion transmission elements of motion error.

- FFT's are useful if the presence of low frequencies caused by pinion and gear runout should be detected. Those waves are dominated by a sinusoidal content.
- FFT's are useful if higher frequencies caused by surface texture or generating flats should be detected. Also those waves are dominated by sinusoidal contents.
- FFT's are useful in the medium frequency range (first to fourth harmonic) if the measured transmission variations have a dominating sinusoidal content.

A periodic impulse function is impossible to capture with a harmonic Fourier analysis if the width of the impulse and the period of its reoccurrence have largely different amounts as shown on top of Figure 6. The bottom of Figure 6 shows the residual error reflects a high frequency with the amplitude of the original peak. In reality, the FFT will attempt to approximate the function and also interpret the impulse characteristic which will result in side bands in the entire frequency range.

The Physics of Sound Transmission Applied to Gears

In a constructed example, the single flank error signal in the graphic in Figure 7 consists only of sine functions. The top graphic is the recording of one ring gear revolution. In the example, a ratio of 3.00 was chosen, which means the graphs in Figure 10 will be exactly repeated for additional ring gear revolutions.

Figure 7 shows how in three steps, first the gear runout, then the pinion runout and finally the tooth mesh is filtered out. In the example, no residual amplitudes are left. It can be assumed that a listener can clearly hear all three separated frequencies. At the bottom in Figure 7 the FFT result contains bars for the gear runout, the pinion runout and the tooth mesh frequency. The side bands of the tooth mesh frequency originate from the gear and pinion runout. The side bands are spaced away from the tooth mesh frequency by their respective runout frequencies. Although the gear and pinion runout and even the generating flats commonly have a dominating sinusoidal shape, the tooth mesh in most real cases is parabolic resulting in many additional frequency amplitudes which is attributed to the transformation algorithm that is used in Fourier analysis and does not exactly represent the audible frequencies.

In Figure 8 the motion transmission error from Figure 7 is used as an example for the separation of the elements "Gear Runout," Pinion Runout" and tooth mesh. The difference with Figure 7 is the tooth mesh motion error which is parabolic in Figure 8 instead of sinusoidal. Due to the parabolic motion error not only f_z, but also the multiples of f_z are present in the Fourier analysis result. Each of these harmonic frequency bars is surrounded by side bands caused by the gear and pinion runout. Instead of ignoring the differences between parabolic and sinusoidal function, the Fourier analysis expresses the residuals between parabolic motion graph and sine function in additional sine functions of higher orders (Ref. 4).

Summary

The psychoacoustic science teaches that a sound source which initially has a non-harmonic excitation will be recognized as harmonic function with the initial frequency and a superimposition of an infinite number of higher frequencies with fading amplitudes. The reason is the ability of mechanical structure and the ability of air waves to transmit only harmonic signals. This phenomenon is also supported by the human ear which processes received sound with a spectral analysis and therefore only recognizes superimposed harmonic sound signals, even if the sound waves would consist of a pure square function.

It is interesting to mention in this connection, that Jean-Baptiste Joseph Fourier published in 1807 his analysis method which uses an infinite number of sinusoidal frequencies in order to quantify a repeated function even if the function has no sinusoidal elements. Fourier's analysis algorithm is employed since the 1960s as a computerized method and is used today to analyze vibration and sound for its contents of frequencies. Fourier's method is aligned with the sound transmission principle of the airwaves as well as with the function of the human ear. However, it is an approximation of signals like square waves which do not contain any harmonic waves at all, yet the result is a variety of harmonic frequencies and their amplitudes.

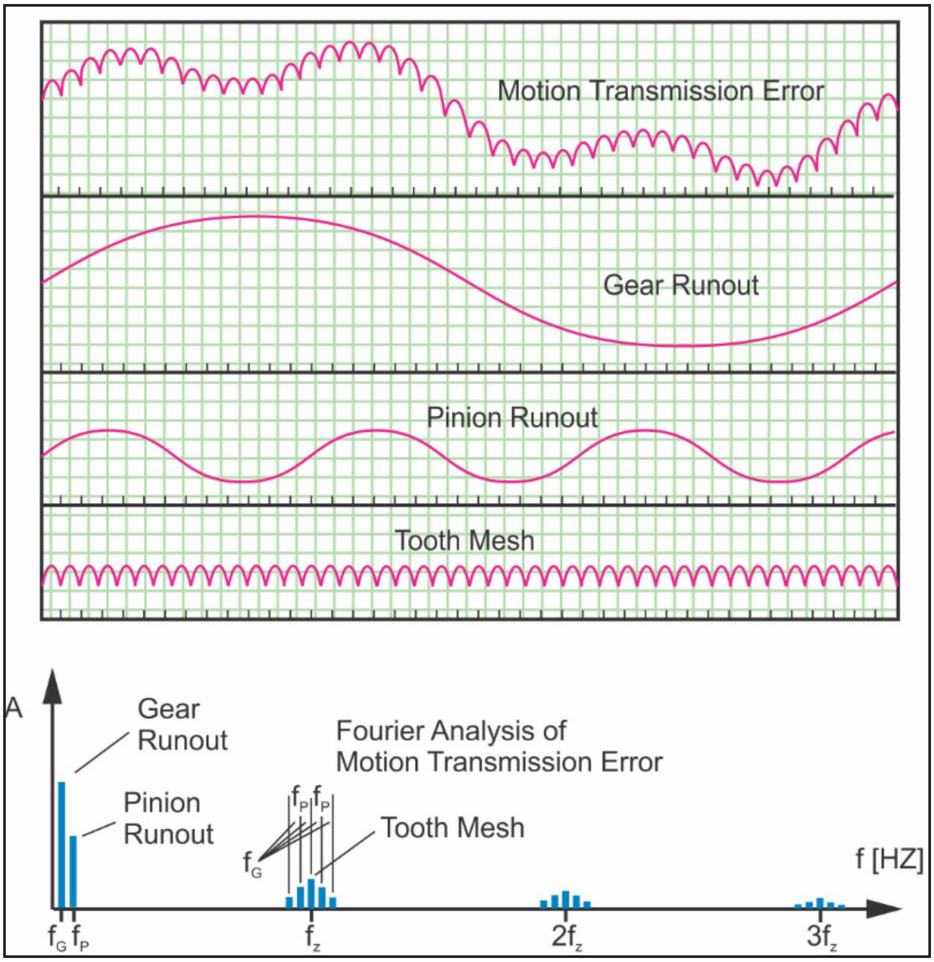

Figure 8 Separation of parabolic and harmonic motion transmission elements.

Conclusion for eDrive Noise Reduction

The higher input speed of eDrives implies that all noise causing disturbances are multiplied by 3 to 10 compared to conventional transmissions. Therefore events higher than the third mesh harmonic would be above the human audible frequency. The conclusion from this would be that higher harmonics and surface structure effects have no influence on the audible spectrum and can therefore be neglected.

This conclusion is incorrect. Only the first stage of an eDrive has the high rotational speed. All conventional criteria like frequencies below and above the third mesh harmonic as well as surface structure borne frequencies are still applicable to the final stages of electric vehicle transmissions. A reason to use surface structure shifts (MicroShift) in addition to flank form modifications is based on the research results from structure shift investigations. A different amount of surface structure shift from tooth to tooth, following for example a sinusoidal function, will generate side bands with different frequency distances from the mesh frequency multiples. The side bands will change sensation of noise recognition from annoying to an un-disturbing, smooth buzzing sound.

All gear noise is caused from the tooth mesh impact, flank form imperfections as well as from generating flats and roughness tracks of the tool (cutting blades or grinding wheel). Generating flats and tool roughness tracks are shown in an exaggerated view in Figure 9. Depending on the direction of the contacting lines between the two mating gears and their interacting with the flank surface effects in Figure 9, medium and high frequency noise can be generated when the mating teeth mesh under certain, mostly low, loads.

If the tooth mesh impact and the surface effects are the cause of excitations of gearbox surrounding structures, two conclusions for their reduction or elimination are possible:

- A modified transmission function can reduce or eliminate the residuals and all higher harmonic multiples of the tooth mesh harmonic.
- Side bands surrounding the harmonic peaks will reduce the annoying character of the emitted noise.

Modifications to the transmission function can be achieved with Universal Machine Motions (UMC). Chapter 10 discusses several possibilities of sophisticated transmission function optimizations which proved to reduce the tooth mesh impact as the major source of all gear noise.

How surface structures can be influenced in their characteristic and then be shifted from tooth to tooth according to sinusoidal functions or applying a Gauss normal distribution is presented in Chapter 11.

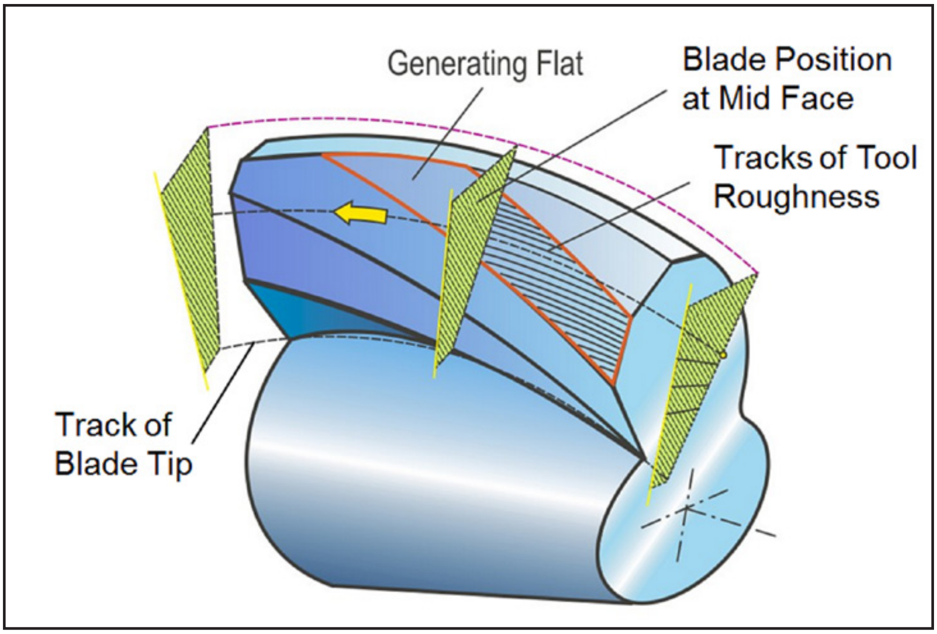

Figure 9 **Noise generating flank surface effects.**

References

1. Deruty, E. "How the Ear Works, Psychoacoustics of the Human Hearing Experience", Article in *www.soundonsound.com*, November 2016.
2. Wilbraham, H. "On a Certain Periodic Function", Cambridge and Dublin Mathematical Journal 3, 1848.
3. Burkhardt, H. "Klein's Encyclopedia, Mathematische Annalen", Review of the Gibbs Phenomenon, Teubner Verlag, Göttingen, 1933.
4. Stadtfeld, H.J. "Psychoacoustic Methodology for the Noise Reduction of Bevel Gears", AGMA, Fall Technical Meeting, Columbus, Ohio, October 2017.

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Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in bevel gear technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems and gear manufacturing methods, as well as cutting tools and gear manufacturing machines. Under his leadership the world of bevel gear cutting has converted to environmentally friendly, dry machining of gears with significantly increased power density due to non-linear machine motions and new processes. Those developments also lower noise emission level and reduce energy consumption.

For 35 years, Dr. Stadtfeld has had a remarkable career within the field of bevel gear technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. He held a professor position at the Rochester Institute of Technology in Rochester, New York From 1992 to 1994. In 2000 as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards—one for his high-speed dry cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year." Between 2015–2016 CNN featured him as "Tech Hero" on a Website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency.

Stadtfeld continues, along with his senior management position at Gleason Corporation, to mentor and advise graduate level Gleason employees, and he supervises Gleason-sponsored Master Thesis programs as professor of the Technical University of Ilmenau—thus helping to shape and ensure the future of gear technology.

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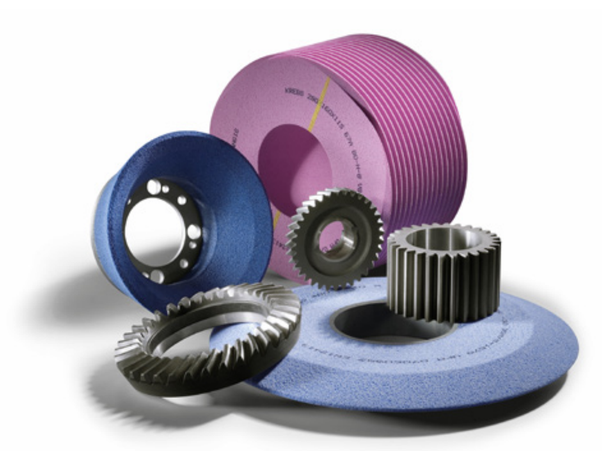
Krebs & Riedel

CELEBRATE 125 YEARS OF GRINDING TECHNOLOGY

The cornerstone of the Krebs & Riedel grinding wheel factory in Bad Karlshafen was laid some 125 years ago. Today the family-owned company operates worldwide as a manufacturer of individually manufactured precision grinding wheels and impresses with innovation and solution-oriented application technology advice. Above all, customers from the automotive, aerospace, mechanical engineering, medical technology and wind power sectors rely upon the high-precision products manufactured by Krebs & Riedel. In addition to conventional grinding wheels, cutting wheels, cup grinding wheels and grinding segments with ceramic and synthetic resin bonds, Krebs & Riedel also manufactures CBN and diamond tools with ceramic bonds, as well as honing rings. The medium-sized family business with over 250 committed employees has an annual turnover of 31 million euros.



Solutions for profile grinding, continuous generating grinding applications.

Krebs & Riedel has subsidiaries in China and India, as well as 30 international distributors. A team of application technology consultants looks after customers worldwide. Krebs & Riedel emphasis the importance of research and development and works closely with several research institutions. Important investments in sustainability management and the expansion of the Bad Karlshafen plant are ongoing.

At Krebs & Riedel, high-quality products are created with special quality standards and maximum safety. Krebs & Riedel is a member of the VDS (Verband Deutscher Schleifmittelwerke e.V.). As a founding member of the oSa (organization for the safety of abrasives), safety comes first.

The production program includes corundum and silicon carbide wheels with a ceramic bond and synthetic resin bond for most industrial grinding applications up to 900 mm outside diameter for round, flat, tool, centerless, gear and rough grinding applications. Cut-off wheels in synthetic resin bond with and without fiber reinforcement up to 800 mm outside diameter for chop cut, pendulum cutting and rotary cutting. Roughing and pendulum grinding with and without fibre reinforcement for the cleaning shop and the foundry industry; Grinding wheels for pendulum grinding machines, grinding wheels for bench grinders and grinding wheels for grinding manipulators. Diamond and CBN grinding media in vitrified bond with a working speed of up to 200 m/s for internal, flat, circular, tool grinding and special grinding processes.

Krebs & Riedel is a specialist in the field of gear applications and supplies top gear manufacturers around the globe. These grinding wheels are used on many gear grinding machines, including those from the manufacturers Gleason, Kapp-Niles, Klingelnberg, Liebherr, Mitsubishi, Reishauer and Samputensili.

For customers in the automotive industry, aerospace, mechanical engineering, medical technology and wind power, Krebs & Riedel offers the right tools for the machining of gears in continuously reliable quality. The company's experience ranges from grinding the smallest gears in the field of medical technology to large planetary gears in wind turbines.

Products include:

Blue Moon 147A and 148A - specifications for increased economic efficiency through extended dressing cycles and increased removal rates in the grinding process. By using special abrasive grain geometries and proportions in connection

Continuous generating grinding with fine and polishing zone.
Picture copyright: Kapp-Niles.

with an optimized pore space design, a very high level of ease of cutting with little heat input and high cutting performance is achieved. Krebs & Riedel produces unprofiled or pre-profiled worm wheels for modules 1 - 12 in the highest quality according to customer specifications up to 80 m/s.

Krebs & Riedel produces a wide range of dressable grinding worms with a ceramic bond for gear machining. All specifications guarantee the highest profile accuracy with the lowest thermal loads on the workpieces. The combination of grinding worms with fine-grain or polishing worms creates powerful tools that enable grinding and polishing in one application.

Krebs & Riedel was also one of the manufacturers who offered a carrier variant for CBN and diamond abrasives. The proportion of carbon fiber guarantees maximum strength with the lowest weight. The body is up to 75% lighter than a comparable steel body. In addition to easy handling during assembly, extremely smooth running is achieved. This means that the load on the grinding spindle is lower. They also offer significantly better damping properties than conventional base bodies. In addition, the carbon base bodies are often used when machining small filigree components. The grinding behavior is more harmonious and leads to improved surface quality. With the new CBN worm grinding wheels, an increase in productivity can be achieved through increased stock removal with an improved service life. Thanks to the fact that the base body can be re-assigned, good economic efficiency is also achieved, despite the higher material price. Therefore, it is not just a short-term thought, but a trend that will also prevail over the long term. The working speeds are up to 100 m/s. Depending on the composition, higher working speeds can also be achieved.

www.krebs-riedel.de

Martin Kapp

ANNOUNCES RETIREMENT

After many years of success at machine tool manufacturer Kapp Niles, Martin Kapp is retiring from the joint management of the company with Helmut Nüssle. His sons Michael and Matthias Kapp will continue the family tradition as of 01.07.2021 and strengthen the new management together with Michael Bär.

The motivation for strengthening the management, combined with a reorganization of the areas of responsibility, was not only the retirement of Martin Kapp but also the increasing importance of global markets. “We have decided to broaden and strengthen the management team. This will allow us to focus more on operational topics and intensify our global orientation, especially towards China,” says Martin Kapp.

In the future, Helmut Nüssle will be responsible for China, the most important single market in the group, the coordination and development of the international offices, and strategic issues. Michael Kapp will cover the value-creating areas, Matthias Kapp the development and sales and Michael Bär the commercial part. Martin Kapp will join the advisory board at this time and take over as chairman.

After studying mechanical engineering, the two brothers Michael and Matthias Kapp first worked for other companies and have now been with Kapp Niles for several years. Michael Kapp was previously responsible for production, Matthias Kapp was previously in charge of marketing. The grandsons of company founder Bernhard Kapp would like to maintain and expand the current business areas and increasingly focus on new business areas such as digitalization and e-mobility.

(Left to right) **Helmut Nüssle, Martin Kapp, Michael Kapp, Michael Bär and Matthias Kapp.**

Michael Bär brings his years of experience in the commercial sector to the management team. The graduate in business administration has been with the group since January 2012, most recently as division manager for controlling, finance and human resources.

Even with the new management, Kapp Niles remains true to itself: the family-run company has always maintained open communication with its employees and attaches highest importance to stability, independence, and security for the future.

www.kapp-niles.com

QuesTek

AWARDED THREE PROJECTS FOR ADVANCED MATERIALS DEVELOPMENT

QuesTek Innovations LLC has received three new Small Business Innovation Research (SBIR) Phase I Awards from The Office of Naval Research, NASA and The Department of Energy to develop advanced materials and technologies across a diverse range of materials systems, industries and demanding end-use applications.

Office of Naval Research SBIR-funded SBIR: QuesTek will develop a software tool leveraging an integrated computational materials engineering (ICME)-based modeling framework to enable optimization of a nickel alloy for Additive Manufacturing (AM). The software tool will enable alloy composition customization for conditions observed in AM, enhancing printability, reducing flaws, and improving mechanical properties of AM Ni components. The software's mechanistic computational models will be calibrated using state-of-the-art experimental techniques to validate predictive models, explaining complex phenomena resulting from AM processing. The developed software tool is expected to improve the understanding of AM technology and harness it to design a new generation of advanced Ni alloys and components for jet engines, industrial gas turbines, and other demanding applications.

NASA-funded SBIR: QuesTek will computationally design calcia-magnesia-alumina-silicate-(CMAS) resistant multi-layer thermal and environmental barrier coatings for ceramic matrix composite (CMC)-based hot turbine components. While CMCs allow for greater operating temperatures and fuel efficiency compared to state-of-the-art Ni superalloys, they are not readily used because current coatings lack long-term protection against molten CMAS attack at high temperature. QuesTek's new ICME-designed coating system will enable increased reliability and performance of CMCs in aircraft propulsion systems, hypersonic combustor panels, commercial turbo fans and industrial gas turbine plants leading to greater fuel efficiency.

Department of Energy-funded SBIR: QuesTek will apply its ICME tools to develop a machine learning (ML)-based, open-source software package enabling reproducible data analysis for multiple electron microscopy systems and data types. This effort specifically addresses the lack of current open-source packages tailored for metallic materials data. The proposed CALPHAD-based thermodynamics and kinetics modeling framework for ML models will increase the accuracy for phase identification across all alloy systems of interest. Such a tool will enable the effective analysis of the large and quickly growing pool of electron microscopy data generated at research facilities, universities and companies.

Dr. Greg Olson, QuesTek co-founder and chief science officer, and the Massachusetts Institute of Technology Thermo-Calc Professor of the Practice, stated "These three projects represent diverse examples of using ICME for concurrent design of material and component, enabling accelerated development of advanced materials across a wide range of material systems and applications."

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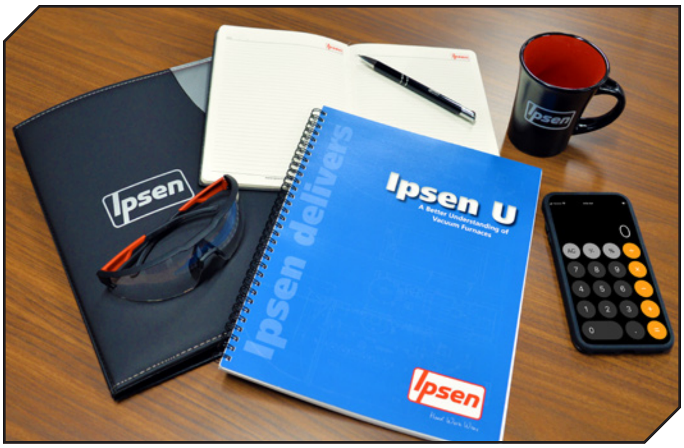
Ipsen

BRINGS EDUCATION DIRECTLY TO CUSTOMERS

In addition to classroom-style trainings at their manufacturing facility, Ipsen offers on-site Ipsen U courses to accommodate large groups at customer facilities. Ipsen U is a course designed to teach heat treatment fundamentals, best practices and new methods. Attendees receive an extensive overview of vacuum furnace equipment, processes and maintenance.



For on-site trainings, customers can choose which topics to focus on, allowing for a customized, hands-on experience that follows safety protocols. Ipsen sends highly qualified technical resources, sometimes those who were directly involved with the build of the furnace they are training on.

The next Ipsen U class is scheduled for August 3–5, 2021, in Cherry Valley, Illinois. Attendees for the 3-day course have the advantage of networking with other heat treaters and seeing how furnaces are built at Ipsen's Vacuum Technology Excellence Center.

www.ipsenusa.com/IpsenU

MSC Software

ANNOUNCES WIND POWER AND SUSTAINABILITY WEBINAR SERIES

MSC Software, a part of Hexagon's Manufacturing Intelligence division, announced it will host an eight-part webinar series covering industry-shaping technology trends for the wind power industry. The Technology Tailwinds series is designed to inform and update design and CAE engineers, quality inspection professionals, and factory managers involved in wind turbine design, manufacturing, operations, and MRO. The upcoming Hexagon series will focus on trending topics in the wind power industry such as the evolution toward large capacity turbines that will require advances in design, analytics, automation, inspection and maintenance. On a monthly basis, MSC Software will present fresh insights to help navigate the current business windscape through the use of touch point technologies

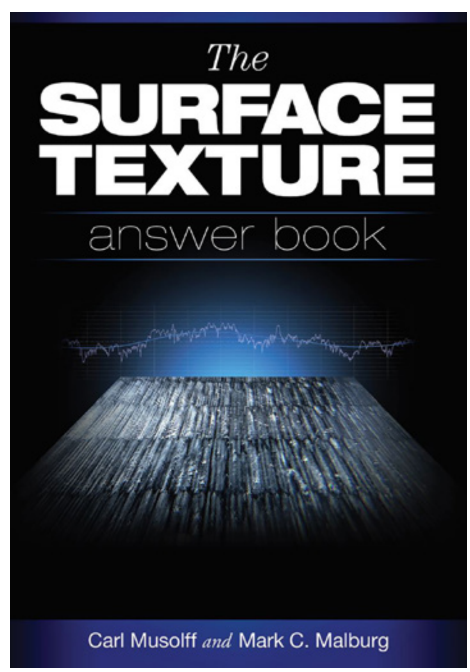
and implementation strategies. Discussions will cover the key technology components and the best practices required to advance this unfolding next-generation of wind turbines systems, and ultimately accelerate clean energy adoption.

www.mscsoftware.com/Wind-Energy-Webinar-Series

Surface Texture Answer Book

EXAMINES CONCEPTS AND APPLICATIONS

A new resource makes it easier to find answers to surface texture related concepts and applications. The Surface Texture Answer Book answers more than 100 commonly-asked questions regarding surface texture measurement, analysis, interpretation, specification, and application.



"Surface texture is more than just a number from a measurement device," said Carl Musolff, co-author. "It's a microscopic world with huge implications for many industries and applications. Our goal with this book is to help technicians and engineers quickly address their questions, regardless of their level of experience with surface analysis. But more than that, we want this book to be a learning resource that will benefit readers far beyond their immediate need."

"Every day in my work I answer questions like, 'What is filtering?' and 'What is waviness?' said Mark Malburg, co-author and president of Digital Metrology Solutions. "These are important questions about measuring and specifying surfaces, most of which are not taught in schools. We found there was a real need for a resource to directly address these kinds of questions in a user-friendly, non-academic way. This book includes hundreds of figures to help make texture visual, which we've found is the best way to help readers grasp and retain these concepts."

The Surface Texture Answer Book draws on information from numerous resources, as well as the authors' combined 70 years of industry experience. Topics focus primarily on two-dimensional measurement techniques, which represent the vast majority of surface texture measurements in industry today. The book also touches on some important aspects of 3-dimensional (areal) measurement, which is becoming more prevalent in development and industrial applications.

"We believe that this book clarifies a lot of the concepts, and misconceptions, relating to surface texture," said Musolff. "We hope readers will be able to come to the book for a particular answer, then encounter other topics along the way that expand their knowledge as well."

The 400-page paperback book is available through *amazon.com* (*amazon.com/Surface-Texture-Answer-Book/dp/1736846825/*) and through the *digitalmetrology.com* website.

Digitalmetrology.com

Star SU's Engineering Manager

ELECTED BY GEAR RESEARCH INSTITUTE TO ITS BOARD OF TRUSTEES

Star SU has announced that **John O' Neil**, its engineering manager for gear tools, has been elected by the Gear Research Institute (GRI) individual members and member companies to its Board of Trustees for the 2021- 2023 term. The GRI is governed by a tripartite board, which includes membership of the Institute as well as the Society of Mechanical Engineers (ASME) and the American Gear Manufacturer's Association (AGMA).

O'Neil has been a member of the GRI since 2010, as well as being actively involved in the AGMA where he has been a Gear Cutting Tool Committee Member since 2009 and Vice Chair of this committee since 2015. Additionally, he was recently appointed as Star SU's representative to AGMA's Electric Drive Committee.

As engineering manager for gear tool at Star SU, a joint venture between Star Cutter Company and Samputensili, O'Neil has been instrumental in aligning the technical resources and manufacturing practices between the two companies. Originally joining Star Cutter Company in 1980, he has served in a multitude of manufacturing and engineering capacities for the company's gear cutting solutions.

www.star-su.com

Index

EXPANDS DISTRIBUTION NETWORK

Index with its Index and Traub brands of precision turning machines are now represented by Great Lakes Machinery, Inc. (Lancaster, NY) in the Northern New York area. According to Cris Taylor, Index USA president and CEO, the new representation part of the company's ongoing sales and service initiative.

"Our distributor network plays a vital role in providing a high level of responsiveness at a local level," said Taylor. "We are very selective in choosing distributors and Great Lakes Machinery meets the high standards we set for our partners. Their addition to our network will be a significant sales and service asset to Index customers in New York State."

Great Lakes Machinery, Inc. is a family-owned firm with more than 30 years of machine-sales experience.

Us.index-traub.com

Felsomat

HOSTS SUCCESSFUL INNOVATION DAY

On Thursday, June 10 Felsomat USA swung open the doors at their USA headquarters in Schaumburg, IL and welcomed more than 40 guests to their Innovation Day. The team was excited to welcome a variety of customers, media, and suppliers to their first in-person event since the beginning of the coronavirus pandemic.

"We've missed our customers, and it was so exciting to show them all the innovations we've been working on over the last year," says Daniel Maerklin, president and CEO of Felsomat USA. He continued, "while as a company we've worked hard to develop and implement the solutions needed to survive, and even thrive during the pandemic, we've really been missing the personal relationships we've developed with our colleagues, suppliers, and customers — so it was very important to us that we host an event that gets everyone together in person, safely."

Throughout the day, attendees experienced a wide variety of live demonstrations on Felsomat's state-of-the-art automation solutions, exciting presentations from expert team members, and experienced networking opportunities that many of us have been so desperately craving over the course of the last year.

A few of the live demonstrations included a state-of-the-art fully automated robotic laser welding line for rear-differential units (RDU) as well as a power transmission unit (PTU), the Felsomat low-cost flexible robotic load cell BAUSTEIN, a modular robotic loading unit that can be easily configured to the specific custom application, as well as a demonstration of the FHC 80 — Felsomat's high speed hobbing machine. "Our goal was to allow guests to see a wide variety of our automation and production solutions. I think we achieved that, and guests seemed very impressed with the technologies on display," says James Petiprin, strategic account manager.

In addition to the machining demonstrations, Felsomat offered a variety of live presentations that highlighted its expertise across a variety of automation and manufacturing systems. Presentations were given by Strategic Account Managers, James Petiprin and Ryan Berman, as well as Vice President of Sales, Matt Skelton, and covered a range of topics including-mobility stator and rotor assembly, FSC Machine Loading, and end of line packout cells.

If you missed the event, don't worry! The team at Felsomat would be happy to give you an individual shop tour. Visit the website below and contact the team to schedule.

www.felsomatinnovationday.com/

Gleason

JOINS UMATI COMMUNITY

Gleason recently joined the Umati Community to develop a common, inter-company, inter-process, inter-model standard which enables production assets to communicate directly regarding production and process data, building a base for advanced diagnostics and efficiency optimization regarding products and processes, and ultimately, the Smart Factory.

umati

Umati with its unified interface will enable customers to overcome current restrictions, choosing equipment more freely, connecting assets than never experienced before. For manufacturers, integration of third party services like automation, tooling or software apps will become much easier. Step by step, initiatives like Umati can be expanded to the entire mechanical engineering industry, not single parts of the manufacturing machine.

Eventually, all elements of the production chain must connect to really optimize processes, maximize product quality, avoid scrap, and gain the best possible efficiency. This initiative goes hand in hand with Gleason's own Closed Loop automatic correction cycle, supported by in-process inspection in parallel to the actual manufacturing cycle.

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Are You Ready for Your Next In-Person Meeting?

Randy Stott, Publisher & Editor-in-Chief

Business travel is back, and if you're serious about impressing your customers, colleagues and co-workers, then you need to look the part. Unlike all those online meetings and conference calls, where you can show up in your pajamas, you're going to need to get yourself cleaned up, dressed for success, and looking your best.

Luckily, there's just enough time before the Motion + Power Technology Expo for you to get everything you need. The Addendum Team has scoured the Internet to find the absolute best attire and accoutrements to make your next gear-related gathering a complete success.

When you're meeting with important people (and anyone in the gear industry qualifies, of course), you want to dress to impress. Nothing completes the look like cheesy — I mean, event appropriate — neckwear. In the old days, they used to say you couldn't go wrong with a brightly colored power tie. We say power ties are out, but power *transmission* ties? Oh yeah, they're in!

www.amazon.com/dp/B0818P6Z3B

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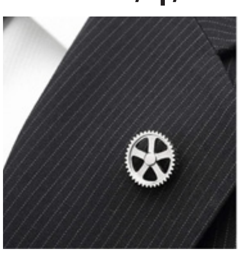
As long as you're going all fancy, you might as well complete the look with some high-fashion accessories. How about some gear-themed cufflinks or a subtle lapel pin?

www.amazon.com/dp/B01DNEA6JE



www.amazon.com/dp/B08KFH8BY4/

Of course, if you want to skip the suit and go for comfort, the Addendum Team highly recommends this custom gear print button-down shirt. You know you could totally pull off this look:

gearfrost.com/products/steampunk-brass-gears-and-cogs-print-mens-short-sleeve-shirt

At a trade show, your feet are going to take a beating. Girding them with gears is a great way to remind yourself that all that walking is worth it.

www.amazon.com/dp/B07KW4V1XL

www.amazon.com/dp/B07MSY1KFT

www.amazon.com/dp/B08F54TPSY

A word of caution: Not all of these looks are meant to go together. Mix and match at your own discretion. Seriously, if you put that shirt with one of those ties, you might scare people.

That being said, we encourage you to experiment. In fact, anyone who shows up at MPT Expo wearing one of our featured items will **WIN A PRIZE**. Just stop by the AGMA booth (#2813) to claim your prize! (Warning! We may take your photo and run it in a future column!)

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