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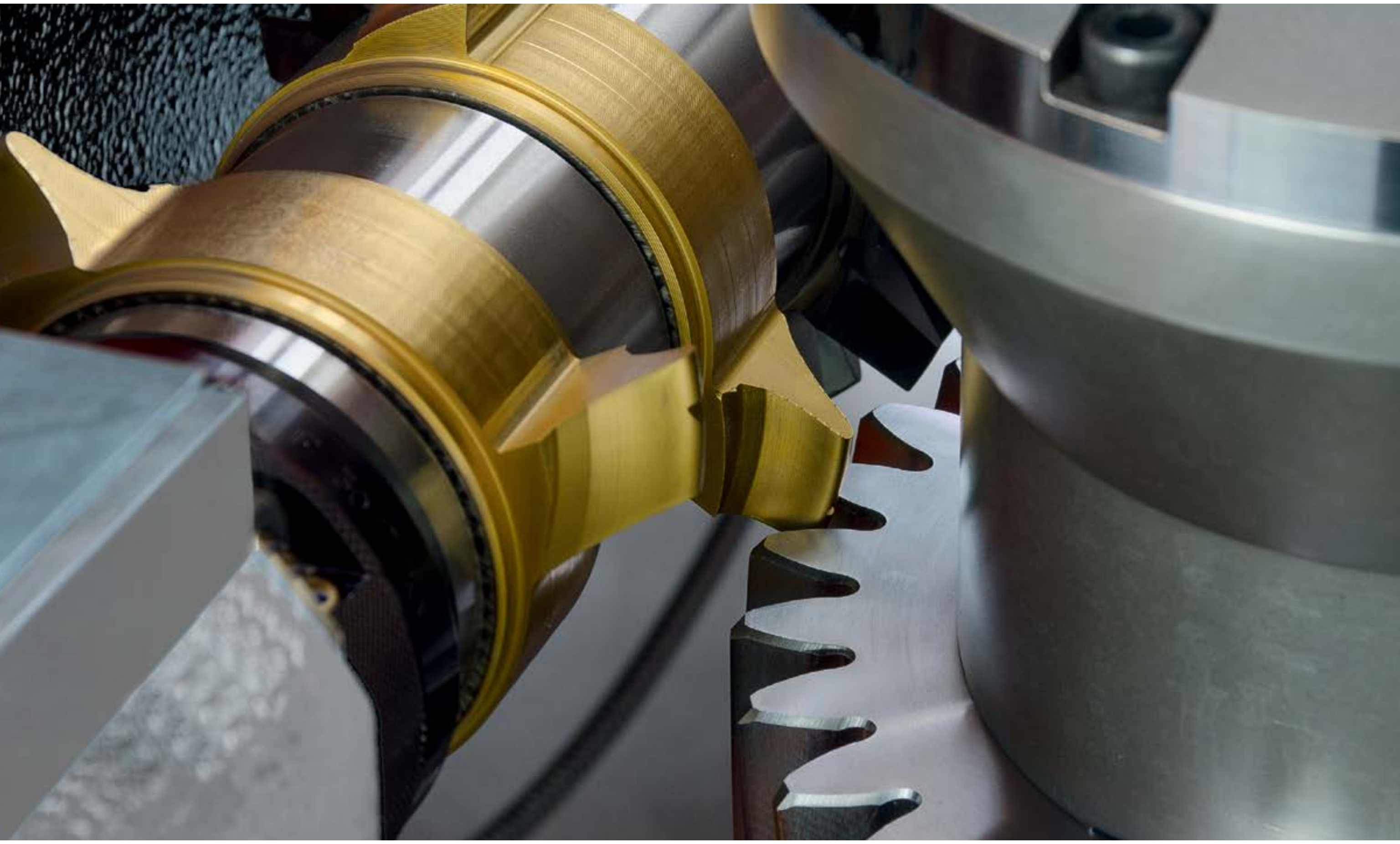
departments

Cover photo curtesy of Liebherr

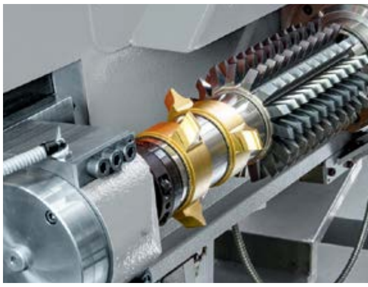
Liebherr Performance.



Gear hobbing machine LC 180 DC

Gear hobbing machine LC 300 DC

Chamfering machines LD 180 C and LD 300 C



Chamfering in the work area

Simultaneous chamfering with ChamferCut – The best and most economical solution

- Established process in gear production
- Very precise chamfer geometry
- Premium chamfer quality and reproducibility
- No bulging or material deformation
- Standard tooth-root chamfering
- Very long tool life
- Lower tool costs compared to alternative processes

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www.liebherr.com

LIEBHERR

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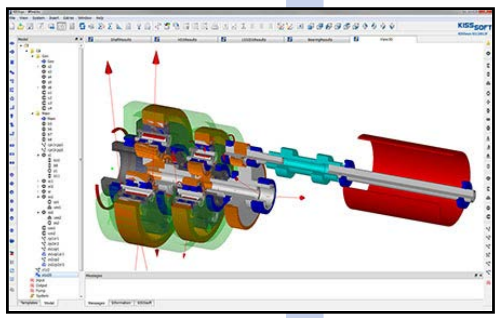
www.geartechnology.com

Gleason Carbide Dry Hobbing:

The 100HiC features an integrated chamfering/deburring unit to eliminate burrs on tooth flanks. The machine handles any geared profile which can be hobbed, up to a diameter of 100 mm (120 mm on request) and module 3 mm (optionally module 4 mm). Check out a video on the process at *www.geartechnology.com/videos/Gleason-Carbide-Dry-Hobbing/.*

KISSsoft Single Stage Gearbox Modeling:

In this short tutorial, *KISSsoft* shows how quickly a user can define a gearbox using KISSsys software. Learn more about the software at *www.geartechnology.com/videos/KISSsoft-2017-Modeling-A-Single-Stage-Gearbox/.*



Event Spotlight: Gear Dynamics and Gear Noise Course

The purpose of this unique short course is to provide a better understanding of the mechanisms of gear noise generation, methods by which gear noise is measured and predicted and techniques employed in gear noise and vibration reduction. Over the past 38 years more than 2,000 engineers and technicians from over 370 companies have attended the Gear Noise Short Course. For more information, visit *www.geartechnology.com/news/7976/Gear_Dynamics_and_Gear_Noise_Course/.*

Gear Talk:

Our resident blogger Chuck Schultz discusses a variety of gear manufacturing topics including new technologies and innovations, company slogans, summer jobs and the importance of taking chances and risks in gear design and development. Read these and other entries at:

www.geartechnology.com/blog/.

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MITSUBISHI
HEAVY INDUSTRIES AMERICA, INC.
Our Technologies, Your Tommorow
Close the Black Hole of Downtime
“What a fantastic bit of kit the GE20A hobber is having run trouble free and 500,000 parts since installation.”
— Ken Manners CEO, SP Metal Forging, South Africa
Downtime is a black hole that impairs productivity, kills the bottom line and simply shouldn’t happen due to breakdowns. With a philosophy of continuous process improvement, in conjunction with an active reliability and maintainability program, Mitsubishi’s gear machine products deliver best in the business quality and predictable production. Experience perfect production systems by visiting www.mitsubishigearcenter.com or contact sales 248-669-6136.
GE20A
ZE15B
MITSUBISHI

Get Smarter at Gear Expo

Publisher & Editor-in-Chief
Michael Goldstein

As I sit here working on this editorial, it's already late Spring. Most days have been under 60° here in Chicago, and rain almost every day is the norm. So, before we get distracted by warm breezes and summer blooms, I want to talk about the Fall.

This is a Gear Expo year, and in October, the American Gear Manufacturers Association (AGMA) will put on its biennial exhibition in Columbus, Ohio. You might think that October is still a long way off, but summer can be fleeting. All it takes is getting busy with a project or a new business opportunity, and months can go by in the blink of an eye. So I want you to start thinking now about Gear Expo and the many benefits you can get by attending.

As always, you can expect all of the suppliers to our industry to exhibit their latest technologies, including new machinery, processes, tooling, workholding and more. Additionally—and perhaps more importantly—this is a unique opportunity for you to meet and interact with a wide variety of people from these exhibitors. These companies are not at Gear Expo just to sell you something. They're there to educate you as well. So you can expect to meet with not only salespeople, but also the dedicated gear industry professionals who are involved with engineering, maintenance and installation of the latest technology, along with the key corporate leaders who provide valuable insight into our industry.

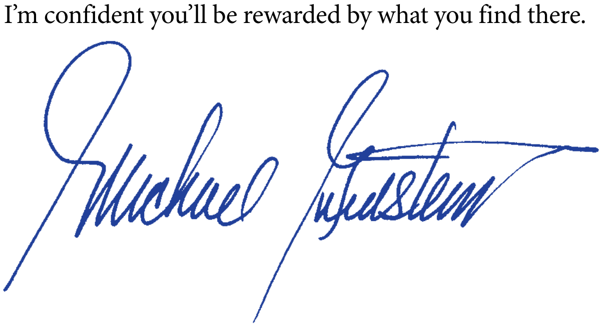
So don't just go to the show thinking about the new machines you might like to purchase. Instead, go there thinking that this is the best and most efficient opportunity you're likely to have to tap into the greatest wealth of gear manufacturing knowledge on the planet. These people work with companies like yours all over the world. They know things about how your peers and competitors operate. They've probably already helped solve problems for others that you've only just recently become aware of. Going to Gear Expo isn't just a shopping trip. It's a learning expedition.

And it's also an important opportunity for those of you who don't make gears, but buy them. It's an often overlooked part of the show, but one that's gaining in importance. More than 50 gear and gearbox manufacturers are slated to exhibit this year, including manufacturers of cut metal, powder metal and plastic gears, as well as manufacturers of custom gearboxes for a wide range of applications and industries. According to AGMA President Matt Croson, Gear Expo will continue its evolution from a gear manufacturing show into a more complete mechanical power transmission show. So, if you design, buy or use gears or gear drives, I think you'll find just as much at Gear Expo as your gear manufacturing counterparts.

We also hope that when you come to Gear Expo, you'll visit us in our booth (#1022). Two years ago, we presented the first ever live edition of our popular "Ask the Experts" column. We had four sessions – Gear Grinding, Cutting Tools, Gear Design and "Ask Anything," – featuring experts such as Dr. Hermann Stadtfeld of The Gleason Works, Dr. Hartmuth Mueller of Klingelnberg, Dr. Andreas Mehr of Liebherr, and Dr. Karsten Stahl, head of the FZG research group at the Technical University of Munich, as well as our own technical editors, Chuck Schultz and Octave Labath. All of these people made themselves available to our live audience to address problems and answer questions. It was such a resounding success, that we're doing it again at the 2017 show. Although we're still finalizing our lineup, you can anticipate a similar level of gear-related technical knowledge and experience among our experts. So, if you're having a particular design, manufacturing or any other type of problem relating to gears, this is a great opportunity to learn more.

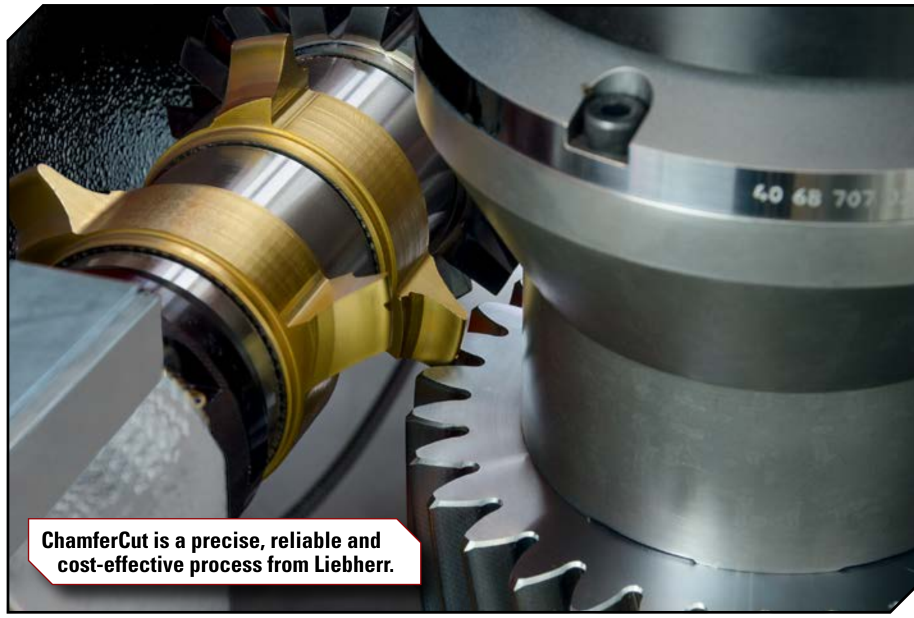
As if that's not enough, there's even more to learn off the show floor. Leading up to and overlapping the first day of Gear Expo, AGMA will be running its Fall Technical Meeting (October 22–24), which is a yearly offering of the latest technical articles, papers and presentations. This year's batch of sessions includes a great mix of cutting-edge technical discussions and basics, so it's a great learning opportunity for both the experienced gear engineer and the newbie.

For more information about the show, including all the educational opportunities available there, visit *www.gearexpo.com*. Register to come to the show. Make plans to stay as long as you're able. I'm confident you'll be rewarded by what you find there.



Liebherr

EXPANDS CHAMFERCUT FOR NEW APPLICATIONS



ChamferCut is a precise, reliable and cost-effective process from Liebherr.

Liebherr has optimized its gear hobbing machine portfolio for the ChamferCut process and now offers enhanced technologies with increased cost-efficiency. Additional machining is now no longer required following chamfering in the Liebherr ChamferCut unit. As a result, chamfering can be performed more precisely, reliably and economically than with competing processes, such as press deburring.

The ChamferCut process enables a complete and even chamfer right down to the tooth root. There is no need for a second cut, which is often required during the deformation-based deburring process for the removal of build-up material. As the exact chamfer shape is generated, there is no effect on the material structure, unlike with deformation-based processes. An optimal starting point is created for downstream hard gear finishing, through grinding or honing. The quality of the chamfer offers not only very precise chamfer geometry, but also high chamfer quality and reproducibility. The tool costs are also lowered, which in turn leads to a low amortization period of the machine.

User-friendly control system with flexible automation capacity

In contrast to press deburring, the advantages for the customer during chamfering include fast retooling and simple adaptation in the case of varying flank modifications, in addition to user-friendly software. Simple adjustments or corrections are also possible via the CNC axes. In general, dry and wet machining is possible with the optimized machines. The machine tools are flexibly automated via a plastic chain conveyor or a palletizing cell. The automatic loading is affected by the flexible ringloader principle. Alternatively, the loading can also be done using a robot or gantry. The following machine types are equipped with the integrated ChamferCut unit:

Gear hobbing machine LC 180 DC

The established LC 180 DC with integrated ChamferCut unit is a very compact gear hobbing machine. This integrated automation solution enables hobbing and simultaneous chamfering of workpieces with a maximum diameter of 180 mm and a module of 3.5 mm.

Gear hobbing machine LC 300 DC

With the LC 300 DC gear hobbing machine workpieces with a maximum diameter of 300 mm can be produced very economically, with a high gear cutting quality and precise chamfer quality. Workpieces up to module 6.5 mm can be hobbed and simultaneously chamfered.

Chamfering machines LD 180 C and LD 300 C

The LD 180 C and LD 300 C are compact stand-alone machines whose main task is the chamfering of gears. They can be integrated easily, quickly and cost-effectively into all existing production/manufacturing lines.

Chamfering in the work area

The classic ChamferCut process with the chamfer cutters on the hob arbor can be retrofitted on all existing Liebherr gear hobbing machines with Siemens 840 D control and higher.

For more information:
Liebherr Gear Technology, Inc.
Phone: (734) 429-7225
www.liebherr.com

The Liebherr LC 300 DC gear hobbing machine with integrated ChamferCut unit for chamfering parallel to machining.

Heller Machine Tools

HF SERIES DESIGNED FOR COMPLEX PRISMATIC PARTS

Heller Machine Tools introduces its HF series 5-axis horizontal machining centers to North America for machining complex prismatic parts from lighter, smaller workpieces to heavier workpieces up to 800 kg table load. In the series of two machines, the fifth axis is provided by the workpiece on a swiveling trunnion with rotary table or a pallet changer for higher volume production. Users can specify from a range of four spindle packages based on the material. Spindle speeds up to 18,000 rpm and torque up to 354 Nm are available.

According to Heller, the main target groups of the HF series are the general machine industry and automotive suppliers. The two new machine models are Heller's entry into a popular size range for these industries. The HF 5500 offers a work area of 900×950×900mm (X/Y/Z), and the smaller HF 3500 has a work envelope of 710/750/710mm (X/Y/Z).

With three linear axes in X, Y and Z and two rotary axes in A and B integrated into a rotary table on a trunnion, the HF machines are designed for 5-sided machining and simultaneous 5-axis machining. The HF machines may alternatively be equipped with a lift-and-rotate pallet changer for series 5-sided production. Standardized pallet automation solutions may be supplied by Fastems or Schuler.

Contrary to conventional 5-axis machining centers, Heller's concept is not only based on single-part clamping but provides the possibility of multiple clamping or the clamping of very large components (transmission cases using 'window-type' fixtures).

The NC toolchanger is equipped with two NC axes for short idle times and consistent operation. The chain-type tool magazines capacities are: HSK63: 54, 80 and 160 or HSK100: 50, 100 and150.

As standard, Heller offers the SC63 SpeedCutting unit (18,000 rpm, 100 Nm) equipped with an HSK-A 63 spindle taper. Optionally available is the PC63 PowerCutting unit (12,000 rpm, 201 Nm), also equipped with an HSK-A 63 spindle taper, as well as the SC100 SpeedCutting unit (12,000 rpm, 201 Nm) and the PC100 PowerCutting unit (10,000 rpm, 354 Nm), both equipped with an HSK-A 100 spindle taper. The HF machines provide a rugged 8000 (HF3500) and 10,000 Nm (HF5500) of feed force for handling even the most difficult materials without interruption or strain.

Recently, Heller demonstrated the capabilities of the HF series. Using a 100 mm diameter face-milling cutter, a chip removal rate of 470 cm^3/min was achieved, machining 1.2312 steel with a feed of ap 3.5 mm and an engagement width of ae 75 mm. An optional Speed Package enables acceleration of up to 10 m/s^2 and rapid speeds of up to 90m/min to be achieved on the HF series. This provides a reduction in chip-to-chip times of approximately 10 percent.

HF series machines are equipped with a Siemens control and a double pivoting main operator panel with a 24-inch touchscreen as well as a newly developed Heller user interface for maximum ease of operation.

For more information:
Heller Machine Tools
Phone: (248) 288-5000
www.heller.biz

Sandvik Coromant

NEW INSERT GRADE DESIGNED FOR TURNING IN UNSTABLE CONDITIONS

Cutting tool and tooling system specialist Sandvik Coromant has introduced its GC4335 insert grade for the turning of steels where unstable conditions or vibration issues prevail. GC4335 is designed to bring about secure and predictable machining as well as shorter cycle times and better machine utilization through reduced stoppages and longer insert life. Customers will benefit from an improved process with less risk of insert breakage as well as reduced cost per component and faster return on investment.

GC4335, which features Inveio coating technology for maximum thermal protection, offers greater steel turning endurance through improved edge-line security in comparison with the previous generation grade, along with greater resistance to flank wear, plastic deformation and crater wear.

"The new GC4335 is particularly suited for uneven forged surfaces, the turning of which can lead to frequent insert changes due to fatigue and failure," explains Bimal Mazumdar, product manager - turning. "Slowing down an operation to replace a broken insert means less production. When production is slower, fewer parts get completed per cycle, and that affects overall profitability."

The introduction of GC4335 will benefit general engineering shops, as well as automotive OEMs and tier suppliers and subcontractors in the oil and gas sector. Typical components include tubes, valves, crankshafts, differential housings, flanges and rings to list a few.

Underlying reasons behind the performance of GC4335 include a new substrate that is well balanced between reliable toughness and resistance to plastic deformation. In addition, a new alumina coating delivers efficient heat transfer from the cutting zone to act as a heat barrier, and the columnar MT-TiCN inner coating offers improved resistance against abrasive wear. A yellow TiN coating on the insert flank allows for easy wear detection.

For more information:
Sandvik Coromant
Phone: (800) 726-3845
www.sandvik.coromant.com

Mahr Federal

OFFERS LATEST VERSION OF MARCOM METROLOGY SOFTWARE

Mahr Federal is now offering its *MarCom* metrology software version 5.2 as a free download from Mahr's website. *MarCom 5.2* is a full-featured metrology software interface for connecting measuring instruments by cable or wireless. It enables direct transfer of measured values into MS Excel, SPC software, or text file, and can manage signals from up to 32 measuring instruments connected by wireless and 128 connected via cables using USB.

"Taking measurements on the shop floor and transmitting them wirelessly speeds up the quality assurance process," said George Schuetz, Mahr Federal director, precision gages. "When measuring on the machine or on larger workpieces, for example, there is no need to run troublesome cables. This speeds setup and provides more efficient data processing, especially for quality control in production or incoming goods."

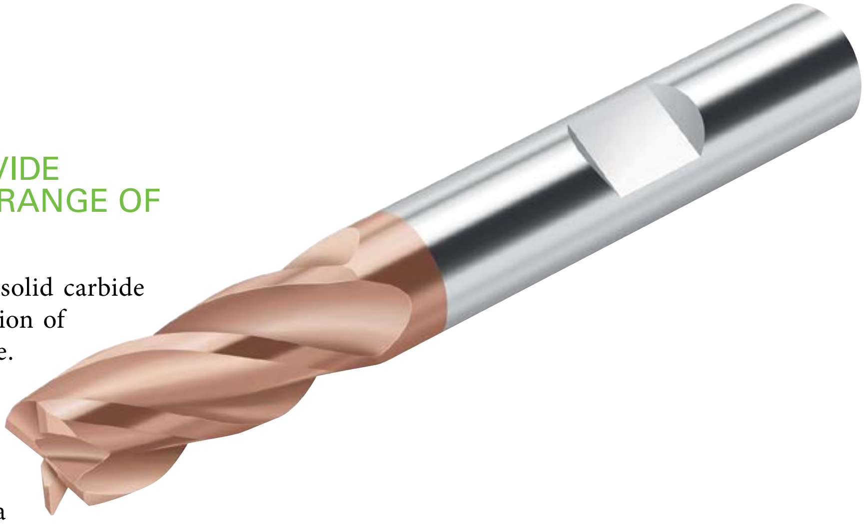
Wireless data transmission also simplifies the recording and documenting process, especially in the networked factory of Industry 4.0. By pressing a button on the instrument or using a keyboard command, timer, remote control or foot switch, acquired data is sent from the gage to an i-stick radio receiver plugged into the USB port of a computer. Each i-stick can receive data from up to 8 gages using "Integrated Wireless." For those measuring instruments that do not have an "Integrated Wireless" interface, Mahr can add an external transmission module.

MarCom 5.2 software enables fast and easy setup of measuring stations with wireless data transfer to the PC. The *MarCom* cell control is highly flexible. Measured values from connected devices can be automatically transferred into separate Excel columns, tables, or files ensuring the reliability of measurement data documentation. At the same time, the *MarCom* software ensures that readings can be passed on through an integrated virtual interface box to an SPC/CAQ software such as Q-DAS or Babtec.

For more information:
Mahr Federal Inc.
Phone: (401) 784-3100
www.mahr.com

Walter

MILLING CUTTERS PROVIDE VERSATILITY FOR WIDE RANGE OF APPLICATIONS



Walter has added to its range of solid carbide milling cutters with the introduction of its MC232 Perform product line. These three versatile, cost effective new cutter types are available with two, three or four teeth, in a diameter range of 0.08 in. to 0.79 in. (2 to 20 mm) from a 0.24 in. (6 mm) shank diameter with a Weldon shank.

This marks the first time that solid carbide milling cutters have been included in the Perform line from Walter, which is designed to be highly economical and suitable for use in a wide range of applications, key advantages for shops that frequently machine smaller quantities. The properties of the new MC232 Perform milling cutters are particularly beneficial for users whose top priority is the universal applicability of their tools, rather than simply tool life.

Universal applicability is also mirrored in the technical features of the MC232 Perform milling cutters. Thanks to their geometry with center cutting edge and 35 degrees spiral, as well as their WJ30ED grade, these new corner/slot milling cutters are suitable for all common milling operations such as lateral milling, full slotting, pocket milling, ramping and helical plunging. They can be used in industries ranging from mechanical engineering, mold and die, to the automotive and energy industries.

For more information:
Walter USA, LLC
Phone: (800) 945-5554
www.walter-tools.com/us

BVL Oberflachentechnik

OFFERS CLEANING SYSTEMS FOR AUTOMOTIVE INDUSTRY

The absolute necessity for clean components in the automotive industry requires reliable cleaning technologies. With longstanding experience in this field, the manufacturer BvL Oberflächentechnik produces suitable cleaning systems which are always tailored to special customer requirements.

The NiagaraDFS basket washing system is BvL's answer to especially high cleanliness requirements. The flood/spray system with revolving wheel technology ensures thorough all-round cleaning through rotation of the parts baskets or parts carriers around the horizontal axis. The inline material flow concept shortens ancillary times to a minimum, significantly reducing cycle times and increasing capacity.

BvL also offers expertise in the field of deburring. For the cleaning of gearbox parts for a large German automotive manufacturer, the Slovenian company LTH Castings invested in the Geyser high pressure deburring system with an integrated industrial robot. The Geyser reliably removes swarf and burrs with a high pressure water jet through multiple rotating nozzles or single lances which are directed specifically at the critical areas of the component. Short cycle times make the system particularly efficient and suitable for series production.

While the component is deburred, the empty workpiece holders in this special application move through a washing unit integrated into the high pressure system. This positions the deburred component on the cleaned workpiece holder, preventing renewed soiling through residue.

Because of its compact design in container form, the high pressure deburring system can be ideally integrated into the production process. BvL offers all required systems from a single source: from pre-cleaning, deburring and fine cleaning to drying and cooling. The machines and components made of high quality stainless steel are perfectly matched and can be individually adapted: the high pressure deburring system from LTH Castings was also combined with a pre-cleaning unit and a final fine cleaning stage.

For more information:
Bernard Van Lengerich Gruppe
Phone: +49 (0) 5903 951-0
www.bvl-group.de

Seco/Warwick

DELIVERS VACUUM HEAT TREATMENT SYSTEM TO GALVAMET

Seco/Warwick is developing a vacuum heat treatment system equipped with a 10 bar abs. gas quenching system, the sixth in a series of systems designed by the company that power the Galvamet industrial park. The new system will increase their production capacity for the heat treatment of components for the aviation sector.

The Seco/Warwick system to be delivered to Galvamet is designed for a wide range of industrial heat treatment applications including quench hardening and tempering, degassing, annealing, solution heat treatment, brazing and others.

"Galvamet has been cooperating with Seco/Warwick for a few years now. Seco/Warwick has been the partner that fully understands our business needs and delivers innovative and state-of-the-art technologies, increasing our production capacity and improving the finished quality of our heat-treated products. With the addition of the Seco/Warwick high vacuum furnace, we aim to deliver excellent and durable parts to our demanding customers in the most cost-effective way," said Ales Slechta, executive manager of Galvamet.

"Seco/Warwick's long term cooperation with the leading manufacturers of components used for production of airplanes, automobile, tools and others, along with the extensive industry knowledge and access to the latest technologies, has made our solutions the solutions of choice. The system which is going to be installed at the Galvamet facility guarantees that our customer will produce the best quality products and meet the requirements of AMS2750E," said Maciej Korecki, vice president, business segment vacuum at Seco/Warwick.

Precision is critical as any deformation in a metal case structural properties can cause tragic aircraft accidents. Seco/Warwick solutions not only enhance the physical properties of the metal, but are also energy efficient and environmentally friendly.

For more information:
Seco/Warwick Corporation
Phone: (814) 332-8400
www.secowarwick.com

LMT Tools

OFFERS PRECISION TOOLS FOR MEDICAL INDUSTRY

The human body is a miracle of nature. In various areas, modern medicine is able to imitate this miracle: Prosthetics, for example, take over important functions. They form human body parts and limbs in precise detail and make natural movement patterns possible. For the complex processing of prosthetics — such as artificial knee joints — LMT Tools offers precise customized tools.

In the field of medicine, authorizations are required for certain machining methods. For the experts at LMT Tools, quick response times and fast request processing are taken for granted. This way, customers benefit from the experience of the LMT Tools experts in every step in the production process.

Sophisticated materials such as titanium or CoCrMo are used to produce artificial joints. LMT Tool's customized tool solutions and portfolio of standard precision tools for medical technolo-

Trico Corporation

LAUNCHES SENSEI LUBRICATION SYSTEM

Trico Corporation, a provider of lubrication management solutions, recently introduced Sensei, a real-time lubrication intelligence system. Sensei wirelessly transmits oil level and ambient air temperature to a customizable, web-based dashboard. As a result, users gain real-time input on machine status and maintenance requirements.

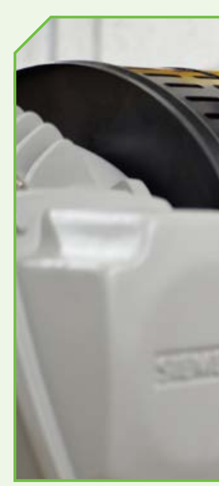
Sensei can:

- Reduce inspection time from hours to minutes per week.
- Reduce requirements for personnel to visit difficult- or dangerous-to-access areas.
- Help avoid downtime by providing alerts and warnings.
- Enable organizations to operate more efficiently by performing proactive, data-driven maintenance.

"The launch of Sensei represents a new ability to generate meaningful data faster and more efficiently than ever before. As a result, we are uniquely positioned to help customers develop cost-saving strategies and reduce the massive pressures of reliability," says Jim Jung, president, Trico. "In combination with the services from the Trico Analysis Center, Sensei enables us to redefine lubrication management strategies for the Internet of Things era."

The first wireless sensors available as part of the Sensei system are oil level sensors designed to accompany Trico's line of 8-oz. Opto-Matic vented and closed constant level oilers. Pumps, motors, gearboxes, fans, blowers and other equipment use constant level oilers to maintain a consistent fluid level.

Industrial and manufacturing applications include those in machining, petrochemical, chemical processing, primary metals, pulp and paper and more. "Sensei has helped us rule out and identify problems," says Mike Walton, ICML, MLT-II, Mechanical Technician at Irving Tissue, St. John, New Brunswick. Irving Tissue tested Sensei on the Yankee Exhaust Fans that assist in the drying process. Walton notes that the reliability team at first thought one fan had an oil leak because it lost so much oil in a short period, but historical data provided



gy have special geometries and coatings. They make precise cutting and processing within narrow tolerances possible.

LMT's DHC Hardline series tools facilitate trochoidal milling. Machining using circular feed motion significantly shortens processing time — while maintaining high quality and excellent process reliability. This means that even the standard tools by LMT Tools provide innovative solutions for sophisticated forming and complex components which are required in the field of medical technology.

For more information:
LMT USA Inc.
Phone: (847) 693-3270
www.lmt-tools.com

by Sensei showed that there were periods as long as four to five months where oil level stayed constant.

"On fan 200-190-21, Sensei enabled us to rule out a leak and look for other causes," says Walton. "Conversely, fan 100-190-53 leaked constantly. On closer examination, we found it had a leaking fitting going to the bearing housing, as well as a bad seal. Work orders were entered to correct those problems."

For more information:
Trico Corporation
Phone: (800) 558-7008
www.tricorp.com

Gear Grinding Today

New divisions, open houses and the continued rise of the Industrial Internet of Things — there's been a lot going on in gear grinding the past year. Here are a few highlights of what people are doing in industry today.

Alex Cannella, Associate Editor

Gear grinding is growing at a steady pace. It continues to be an essential part of the gear manufacturing process, business is on the up and individual markets such as aerospace and automotive are holding strong. While there's no imminent overhaul of the industry or sudden shift in economic fortunes that gear grinders need to brace for, the industry is still moving forward, and different machine manufacturers have come up with a few new ways to compete for your dollar and provide added services for your gear grinding needs. Here are a few of the latest opportunities and new technologies you might want to take advantage of.

Product Spotlight: Samputensili's SG 160 Skygrind

The SG 160 Skygrind from Samputensili is the world's first gear dry grinding machine. This process removes the need for cooling oils during the hard finish grinding of the gear after heat treatment. Roughly 90 percent of the stock allowance is removed in the first pass using a hobbing tool, and subsequently in the second pass, a grinding wheel removes the remaining stock without causing problems of overheating the workpiece, which results in a fully dry process. The structure with two spindles actuated by the linear motors and the use of more channels simultaneously ensures a chip-to-chip time of less than two seconds.

The SG 160 splits the X-axis into two liner slides, each of which carries tool spindles. Both work spindles are in full position control at any time.

The SG 160 Skygrind ensures cycle times at a low comparative cost to traditional manufacturing solutions in the automotive industry.

According to the manufacturer, the SG 160 Skygrind is even faster than traditional dual table grinding machines, featuring a small footprint and lower cost for auxiliary equipment. The most important piece however is the eliminated need for cutting tools, creating an extremely green machine.

To see the SG 160 in action, you can watch the video at *www.geartechnology.com/videos*.

Company Spotlight: Kapp Niles Metrology (KNM)

There's a new Kapp Niles in town named Kapp Niles Metrology GmbH (KNM). According to Bill Miller, VP — sales and service for Kapp Technologies (KTLP), after KTLP acquired controlling interest in U.S.-based Penta Gear Metrology in 2015, it was evident by customer response that a full metrology product line should be offered globally. KTLP already distributed the larger metrology systems (R&P) built in Aschaffenburg, Germany, and extending operations globally was an attractive prospect. Further study indicated that with additional resources and technology from Kapp, founding a new company would yield significant synergies. Hans Rauth and Chris Pumm agreed and become founding partners in the formation of KNM and bring familiar engineering and technical staff with them.

The new division launched on April 1, 2017 and Miller elaborated that demand from the company's established customer base is a primary focus of the new division, but growing demands in the market as a whole for innovative metrology solutions present exciting opportunities especially as part of Kapp's Industry 4.0 initiatives.

"Often we're asked by customers: 'who do you recommend for measuring?' They want to know what we use and how we measure," Miller said. "A couple of times I'd ask if they wanted us to get in this business. And they said: 'would you, please?'"

Kapp Niles has had their own metrology technology built directly into their grinding machines for over two decades so it is a logical step. But while a built-in measuring system offers closed loop corrections for setup time savings for a grinding machine, it isn't certified to use as the final measurement.

"It's been a long time coming in that we've heard this for decades," Miller said. "The customers' message is clear: why don't you build a measuring machine so that we can buy the system from you. And so finally, we had the opportunity and the time was right, and so we stepped into with the new entity: Kapp Niles Metrology."

KNM is not meant to replace Penta Gear, and Miller emphasizes that the two companies are highly complementary. KNM will give Penta Gear's products worldwide reach.

That said, there are more differences between the two companies than just the markets they'll be selling to. They will continue to release metrology solutions that will cover different manufacturing needs and work with different sized workpieces. Penta Gear's products primarily consist of analytical machines capable of measuring workpieces up to 400 mm in diameter, recontrolled used machines up to 650 mm, and gear size (DOB) and double flank functional gages. KNM constructs custom gear analytical machines with up to 5.5 m of capacity, portable checkers, and integrated inspection systems.

"The existing products and unique strengths of these companies together provide a full range of products and services to the market," Miller said.

Hot Topic: Improving Workspeed and Productivity

Hardinge Grinding Group's General Manager — Director of Sales, Daniel Rey, has noted a number of trends amongst the company's customers. Most of them surround a familiar desire: to reduce setup time, and thus put out more product faster. A common method that Rey's noticed is becoming more prevalent is to grind multiple distinct features simultaneously, but notes that the manner in which manufacturers are pursuing that goal can vary depending on how deep their pockets are.

"So we kind of see two trends," Rey said. "One area is for the high-end machines, where cycle time is important, where automation is important, where grinding features simultaneously is of importance. There is another trend with sub-suppliers. They don't have the amount of investments available to be made in these high-end machines, so they are looking basically to adapt certain features to universal grinders so it gets them by, so to speak...These are kind of two contradictory trends, if you will."

Meeting the demands of one of these trends is the Hauser H40-400, a universal jig grinder now being sold by the Hardinge Grinding Group. The H40 comes with numerous base features, including automatic taper grinding, an automatic grinding tool changer and an automatic pallet changer. The machine also features a dual-frame design in which the machining head is positioned in the middle of the machining area. The design is meant to improve the grinder's rigidity, and thus accuracy, as well as improve control of machining and transverse forces and reduce effects from thermal expansion.

Also in an effort to improve workspeed, the Hardinge Grinding Group has incorporated internet connectivity and other technologies that fall under the Industrial Internet of Things' (IIoT) umbrella. IIoT technology has become increasingly relevant in every industry, and gear grinding is no different. What is different is that now we're reaching the tipping point where we see IIoT services become more widely adopted and, with an increasing number of customers, even expected.

"Some of that we clearly see filtering through now and becoming more and more of a requirement for customers in their buying decision," Rey said.

One area of IIoT technology that is seeing wide adoption is in the field of connectivity. Alongside numerous other machine manufacturers, the Hardinge Grinding Group has opted to design all their machines to leave the factory floor capable of connecting to the internet. It's a seemingly simple, almost innocuous upgrade, but it's also one that wouldn't have been widely considered five years ago. Now it's a standard feature. And one can expect that other, more complex concepts related to IIoT — preventative maintenance through self-monitoring products, for example — will follow suit and become standard tools a gear manufacturer can expect to use to improve productivity.

"Some people that are well-read, they expect things to be available today," Rey said. "They don't want to wait until the future is here, so to speak."

One of the primary benefits of internet connectivity is that it allows the Grinding Group to connect to a machine anywhere, even remote regions where they may not necessarily have an engineer on hand. When there's a malfunction or error, Hardinge's team can troubleshoot the machine online instead of forcing the customer to wait an extra day for an expert to arrive on-site, potentially reducing downtime.

"We try to basically become more responsive and faster in our responses..." Rey said. "If a customer calls, whoever is on the other line will tell you a certain set of information, which then the best way for us to verify would be to be in front of the machine. And short of being in front of the machine due to not having a local service engineer available would be to access the machine online."

Rey stressed that the technology is not meant to replace Hardinge's force of service engineers. Instead, it's designed to provide customers more options to get back on their feet as quickly as possible if something goes wrong with a machine. Both avenues will still be available for the customer to utilize at their discretion.

Product Spotlight: Klingelnberg's Cylindrical Gear Machines

During a two-day in-house show on November 9 and 10 at the Ettlingen Oberweier (Germany) works, Klingelnberg presented its wide range of Höfler cylindrical gear machines. A total of 13 exhibition areas at the Ettlingen works were dedicated to showcasing the company's innovative and versatile solutions as well as the very latest technological processes.

The latest development from Klingelnberg enables direct networking of a closed loop cylindrical gear machine with a measuring device. This technology was previously only possible with bevel gear machines. "By transferring the established Klingelnberg closed loop concept for cylindrical gears, we link the machining centers with the measuring machine and are therefore driving digitization of gear manufacturing firmly forward," explains Dr. Christof Gorgels, head of the Precision Measuring Center product line. "The closed loop concept for cylindrical gears is based on an open interface and automates machine correction."

To demonstrate how the latest Industry 4.0 compliant development can be used for practical production, a VIPER 500 cylindrical gear grinding machine was networked with the P 40 measuring machine at the works. "We have been waiting for this interface!" Willi Humbel, chairman of the board of directors of Humbel Zahnräder AG, commented. "This development will help us tremendously to simplify production of our toothed gears and improve the quality of our components at the same time."

Digitization in production was the main topic at the two-day event. Höfler cylindrical gear grinding machines are not only designed to be reliable and highly-developed hardware, but the company's GearPro software also guarantees convenient machining and ensures maximum efficiency in daily use.

In addition, attendees were able to obtain information about the wide range of services of the machine construction company. With the Höfler Service Gate remote maintenance concept, a global communication network will be established in the future from the Ettlingen Oberweier site. At the beginning of the technology show, visitors already marveled at the sight of a customized eight-meter-high Höfler HF 6000 cylindrical gear cutting machine at the plant entrance. The Höfler HF 6000 cylindrical gear cutting machine for workpieces has a diameter of up to six meters.

Product Spotlight: Luren Precision's LVG-100

The LVG-100 is Luren's latest and most advanced 6-axis CNC machine to date. Designed to grind spiral bevel gears efficiently and with high precision, the LVG-100 grinding machine can produce spiral bevel gears up to AGMA class 14 accuracy. It features a cup type CBN grinding wheel and an HSK tool holder designed to maximize stability and provide quick tool replacement. Other physical features include a Siemens controller, separate cooling system for the spindle and direct drive motors and a rigid high-speed spindle. The LVG-100 also has an optional probe for automatic tooth positioning.

One feature not limited to Luren's LV-series machines, however, is the company's software. Designed and created by Luren's software department, it's designed to provide a friendly user interface by generating automatic CNC programs and providing versatility for all types of gear designs, including an automatic path generating compensation feature.

"With our software, minimal CNC code knowledge is needed to run our machines, the operator simply needs to input the specifications right from the gear drawing, and our software actually generates the whole CNC program," Darian Ditzler, north american sales representative at Luren Precision, said. "It will suggest a machining program, generate a grinding path, allow for modification of tip, root, chamfer, and crowning. Our software is intuitive and conversational, making it the best feature of our machines. Designed as a turnkey machine, we can put our machine on your shop floor and within two or three days you can be grinding production parts."

The LV-series machines are part of Luren's ongoing focus on building high quality, advanced CNC machines.

"To make a high-quality machine requires attention to every detail to meet Luren's requirements for high precision grinding and solid long term reliability," Ditzler said. "That has always been our focus on making our grinding machines."

According to Ditzler, the LVG-100 has received a warm reception in the two years it's been on the market. The grinding machine has become a regular part of Luren's booths at trade shows. Luren took the LVG-100 on the road to the last Taipei International Machine Tool Show (TIMTOS) and Japan International Machine Tool Fair (JIMTOF), where it received positive attention, and if you want to get a good look at it yourself, the LVG-100 will be at Gear Expo in October.

Event Spotlight: GrindDate 2017

Amongst the numerous massive trade shows that happen every year, Haas Schleifmachinen (German parent company of Haas Multigrind) put on their own open house show, GrindDate.

The show was designed to give attendees an opportunity to learn about the company's products and latest developments in a calmer setting than the frantic hustle and bustle of mainstay trade shows. Haas organized the show at their headquarters in Trossingen, a small German town on the edge of the Black Forest, to set the backdrop for the show's relaxed tone.

"GrindDate is intended to encourage two-way communication with our customers and prospects, in a much more relaxed, personal, and focused setting compared to the traditional trade shows," David Drechsler, business development manager — Americas at Haas Multigrind, said. "We bring our prospects up to date on recent and planned innovations at Haas and we have time to get more detailed and interactive feedback from our customers."

Amongst their usual established products, Haas used GrindDate to introduce their latest wheel loading station. The station is designed to operate with their Multigrind CA and CB machines, five-axis grinding centers that are built using Haas' Multicube design. The loading station system allows users to load wheels and wheel sets for more part numbers, reducing setup and changeover time, and is capable of storing up to 70 wheel flanges and 20 coolant nozzles.

Alongside the latest technology from the company, 18 presentations were given at the show. English and German presentations covered a full range of grinding and related technologies, including grinding wheels, grinding fluids, wheel dressing, coolant filtration and software, and Haas even brought in speakers from outside companies, including Oelheld, Kaiser and Krebs & Riedel.

2017 was the second ever installment of Haas's show, and according to Drechsler, GrindDate 2017 outstripped its predecessor with double the attendance.

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Industry Spotlight: The Future of Automotive

In automotive, as with many other industries, gear grinding is an unquestioned cornerstone of the gear production process, and according to Walter Graf, Reishauer's marketing manager, it will only continue to grow in importance, particularly with the rise of electric cars. Though electric cars won't be completely taking over the market any time soon, they are expected to grow in popularity, and when they do, it will be important that gear manufacturers are ready to meet new demands.

According to Graf, a primary concern for electric cars will be gear noise. When the usual petrol-based motor is cut from an electric car, one of the loudest remaining noises comes from the gears, and Graf believes that reducing that noise will not only become a matter of concern for automotive manufacturers in the future, but also that reiterating on current gear grinding techniques can provide the solution to that demand.

Just last month, we took an in-depth look at the outlook for the automotive industry. If you want to learn more about upcoming trends gear manufacturers working in the automotive industry should be keeping tabs on, check out "Transmission Throwdown" in the May 2017 issue of *Gear Technology* or online at *www.geartechnology.com*.

To read about Reishauer's latest gear grinding technology, see the technical article, "Twist Control Grinding," on page 48.

Product Spotlight: Liebherr's IG Opal 4.0 Technology

Liebherr has reiterated on past designs and come out with their next generation of internal gear tooth profile grinding technology. IG Opal 4.0 allows users to change over from external to internal gear grinding in under a half hour and is compatable with grinding disks 100 or 125 millimeters in diameter.

Interested in hearing more about Liebherr's new technology? You can find more details in our product new section online at *www.geartechnology.com* or in the May 2017 issue of *Gear Technology*.

Wind Turbine Gearbox Reliability

Modeling, Instrumentation and Testing.

Travis Histed and Chad Glinsky, Romax Technology, Inc.

A high number of wind turbine gearboxes do not meet their expected design life, despite meeting the design criteria of current bearing, gear, and wind turbine industry standards and certifications. This, in turn, increases the cost of energy generated by wind turbines. To investigate the root causes of these reliability issues, the U.S. Department of Energy and National Renewable Energy Laboratory (NREL) established the Gearbox Reliability Collaborative in 2007, now called the Drivetrain Reliability Collaborative (DRC), of which Romax Technology is an active partner. The collaborative is focused on improving reliability by better understanding loads, improving design tools, and refining testing practices.

A series of gearbox designs have been tested on the NREL 2.5 MW dynamometer in Colorado as part of this effort, with each iteration containing strategic design elements used to validate certain assumptions. Romax Technology and Romax InSight have been involved in the modeling, analysis, design, and testing of these gearboxes since 2008. The final iteration of the test program was Gearbox 3 (GB3), which was tested in late 2016.

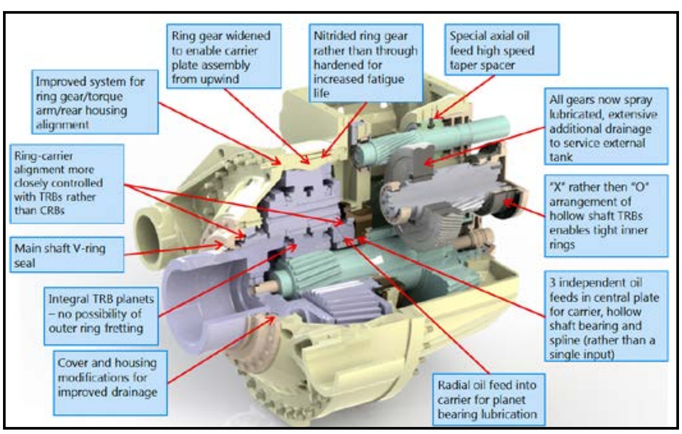

Figure 1 As the wind industry seeks to reduce costs, improvements in gearbox reliability will improve the bottom line.

The 2.5 MW dynamometer at the NREL National Wind Technology Center allows for accurate replication of field conditions encountered by wind turbines such as transient loading, rotor off-axis non-torque loads (NTL), and grid interface conditions. Romax carried out an engineering assessment of the GB3 test article, focusing on the planetary stage modelling, instrumentation, gearbox assembly, and data analysis.

The gearbox was fully modeled in *RomaxWind* as part of the design effort. *RomaxWind* is a drivetrain system modeling tool developed over the last twenty years for wide usage in the rotating machinery industry, particularly in wind turbine gearbox

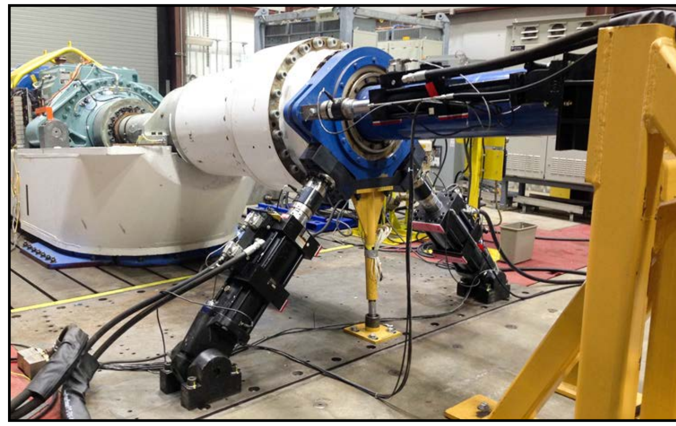

Figure 2 NREL 2.5 MW test stand with GB3 in background, and NTL hydraulic system in the foreground. The NTL system is used to impart non-torque loads into the hub flange of the test article, simulating wind turbine rotor hub loads.

design, automotive and off-highway vehicle drivetrain design. The Romax simulation tools allow the complete gearbox system to be analyzed in a fully coupled 6-DOF environment, including the mechanics and stiffness of gears, bearings, housings, shafts, planet carriers and supporting structures. This allows the prediction of misalignment of the gears and bearings, which is one of the key inputs that affect the durability of these components.

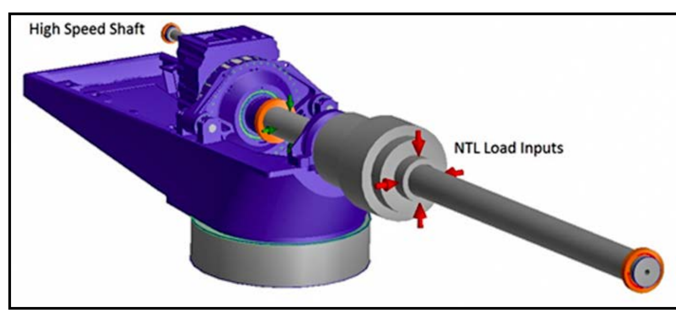

Figure 3 *RomaxWind* analysis model of GB3, including NREL 2.5 MW dynamometer shafting and NTL system.

The test article was heavily instrumented with strain gauges on the ring gear both internally and externally, strain gauges on the planet bearing inner rings, and proximity sensors to measure carrier alignment to the housing as well as housing alignment to the bedplate. The strain gauges placed within the planet bearings (a pair of tapered roller bearings with the outer races integral to the gear blank) were of particular interest, as this is rarely done. Ten gauges were bonded to the inner races of the bearings (both upwind and downwind) in custom machined grooves. This allowed for the analysis of the variation of the load zone during testing, and correlation with *RomaxWind* predictions created in the design phase of the project.

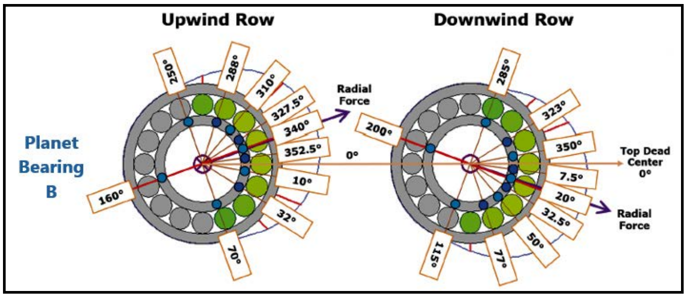

Figure 3 Instrumentation Layout.

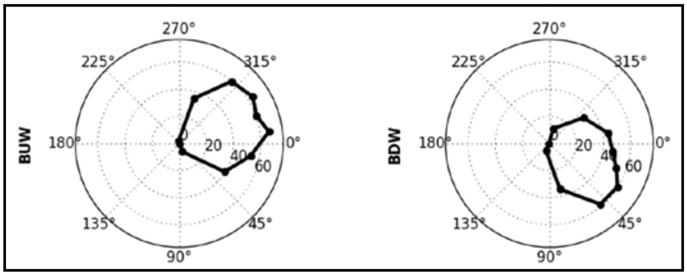

Figure 4 Experimental Results 100% torque (360 kNm), no NTL.

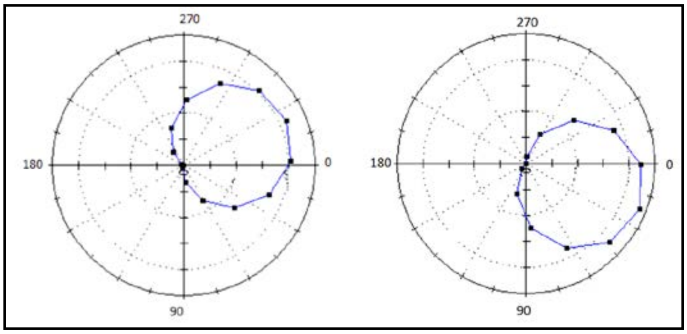

Figure 5 ***RomaxWind*** **Prediction 100% torque (360 kNm), no NTL.**

As can be seen by comparing the experimental results with *RomaxWind* analysis, load zones are shifted 20 degrees between the upwind bearing and the downwind bearing rows as a result of the tipping moment created by the axial thrust generated from the helix angle on the planetary gear set.

By employing this more rigid pre-loaded TRB pair in each planet of GB3, compared to the more traditional double row cylindrical bearings used in the predecessor gearbox GB2, great increases in planet bearing reliability are realized.

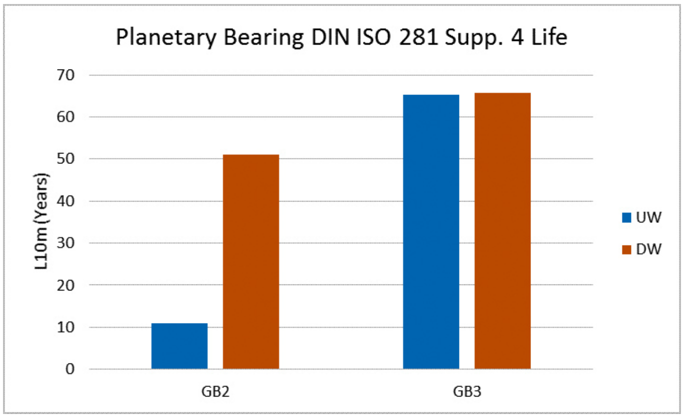

Figure 6 Planetary bearing L10 life predictions show improved life for GB3 planet bearings as a result of improved load share between the upwind and downwind row. This is a result of the increased rigidity of the pre-loaded TRB pair, compared to the more traditional double row cylindrical roller employed in GB2.

This more rigid arrangement allows for better load share between the upwind and downwind bearings, which in turn leads to increased L10 life, as predicted in *RomaxWind* analysis.

It is this combination of advanced analysis tools yielding insight to the design process, backed by innovative testing to confirm these assumptions, that is closing the gap between design-estimated and actual wind turbine gearbox field reliability. Knowledge gained from the Drivetrain Reliability Collaborative is publicly available to facilitate reliability improvements, and ultimately result in improved gearbox design standards and practices.

For more information:

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Travis Histed is an engineering analyst at Romax and is responsible for delivering project work and assisting customers with solutions. Having joined Romax in 2014, Travis' prior experience includes hydro-turbine analysis and design, natural gas engine fuel delivery systems, and manganese mining in South America before joining Romax in 2014. He graduated from Colorado State University in 2011 with a degree in mechanical engineering.

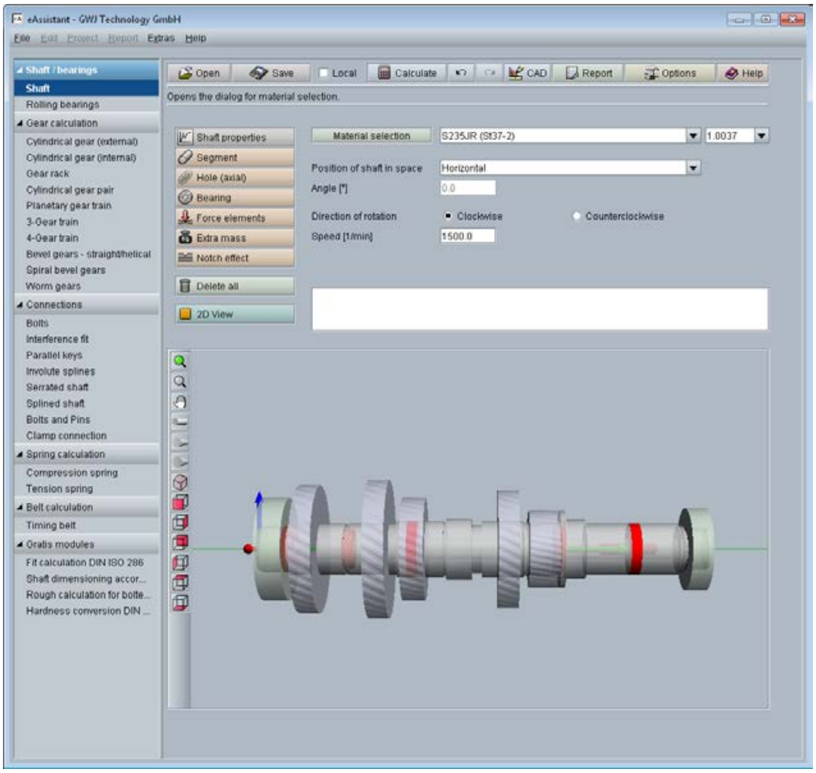
Chad Glinsky graduated from Michigan State University with a master of science degree in mechanical engineering. His research experience is in drivetrain dynamics and controls of continuously variable transmissions. Prior industry experience includes automotive quality engineering, electromechanical design, and noise and vibration testing. He joined Romax in 2012 as an engineering analyst and is now the Engineering Manager for the US.

Testing 1,2,3...

What's New and Noteworthy in Software Applications in 2017?

Matthew Jaster, Senior Editor

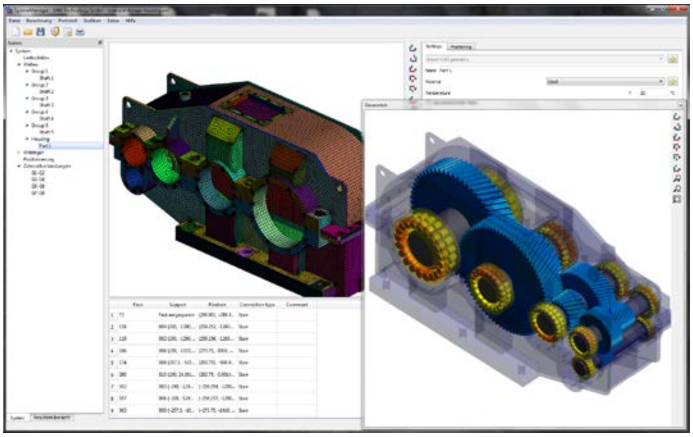
In general, people have a love/hate relationship with the term "update." We certainly don't appreciate updating our smartphones since they potentially cause more problems with each new download. Software can also have its fair share of frustrations, but it can also be an extremely valuable tool if the updates and new product developments make your job easier. Each year, developers like KISSsoft, GWJ Technology and MESYS offer software tools and consulting services for the gear industry. Some are brand new products others are upgrades from previous software packages.



Shaft calculation with GWJ Technology's *eAssistant* software.

GWJ Updates eAssistant Software

GWJ Technology GmbH is constantly working on software enhancements and adding new features to the system in order to keep the applications up-to-date. GWJ recently released a product update for its web-based calculation software *eAssistant*. The new version comes with a variety of new features and functions including a significant improvement of the *eAssistant* framework. The software can now be launched independently of a web browser. There will be no more problems with pop-up blockers and browser zoom. Additionally, all calculation modules now include two unit systems: the metric system and the U.S. customary unit system. The user can quickly switch between the units. There are several more improvements in the software like the addition of the ANSI/AGMA 2104-D04 standard to determine the load capacity of cylindrical gears and planetary gear trains or the implementation of gear qualities according to DIN 58405, ISO 1328 and ANSI/AGMA 2015.



Gearbox with Housing with GWJ Technology's *SystemManager* software.

Furthermore, GWJ has some new developments with *SystemManager*. *SystemManager* is a true software application for complete systems of machine elements, i.e., the software is a coupled FE calculation of multi-shaft systems with gears as non-linear coupling elements. *SystemManager* runs as a desktop application, making it possible to configure and calculate entire systems with just a few mouse clicks. *SystemManager* now allows the import of 3D housings as STEP files. The software meshes the parts automatically to consider deformation and stiffness of the housing throughout the system. A further extension of the 3D elastic parts function is the support of planet carriers and imported shafts. Planet carriers can be imported as CAD models or be defined parametrically; various basic designs are available for the parametric planet carriers.

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KISSsoft Launches 03/2017 at Hannover Messe

The new version of *KISSsoft 03/2017* was released during Hannover 2017 with a number of innovations including:

- Reliability evaluation of gear units on system level
- Simplified modeling using predefined gear stages in *KISSsys*
- Calculation of root stresses with FE for cylindrical gears
- Variation calculation for the inner geometry of bearings
- Determination of the unbalance response during the vibration calculation of shafts Web demos inform users about various subjects in the calculation programs *KISSsoft* and *KISSsys*. Learn more about new developed features, about sizing and optimization strategies, see examples and much more; easily on your work desk. These web demos are free of charge, all you need is 45 minutes to get to know the various applications of the software.
  Additionally, KISSsoft USA is now providing additional support through a YouTube channel (*www.youtube.com/channel/UCPk0PftMUVTfncY657Yr7Sw*). The videos are designed to help users with questions about how the software works and provide some basic engineering knowledge related to gear design. Over 20 videos are already available for viewing and cover topics such as general gear design, reverse engineering, 2D & 3D export of gear forms, shaft construction, contact analysis and report customization.

For more information:
KISSsoft USA LLC.
Phone: (815) 363-8823
www.kisssoft.com

MESYS

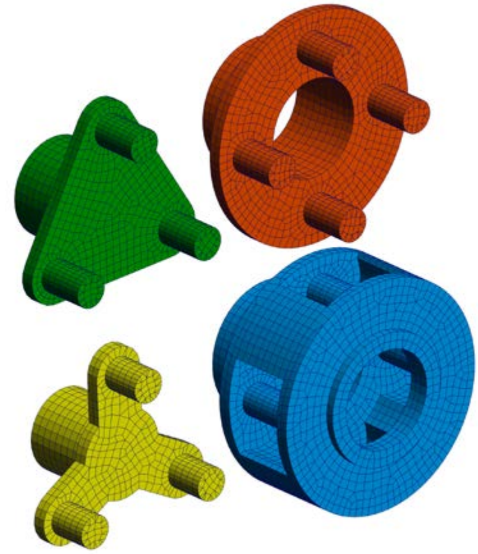
Integration of 3D-Elastic Parts into a Shaft System Calculation

In calculations for shaft systems like gearboxes the shaft are often considered as one-dimensional elements for the calculation of shaft strength, bearing life and safety factors for gears. This has the advantage of short calculation time and easy consideration of boundary conditions. An additional housing stiffness can easily be added by using a stiffness matrix which couples the stiffness at different support positions.

The *MESYS* shaft system calculation software allows the import of 3D-housings as STEP-files since 2016. The software meshes the parts automatically and generates the reduced stiffness matrices which had to be calculated by separate FEA calculations and then to be imported before.

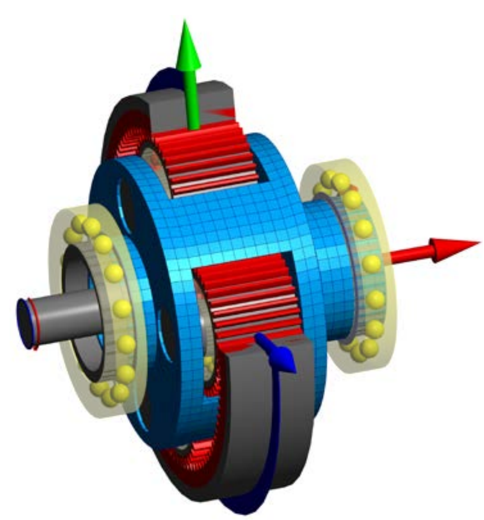
In version *04/2017* the integration of 3D-elastic parts in the *MESYS* shaft system calculation is further extended. 3D-elastic housings can not only be considered in a static calculation, but also in the calculation of natural frequencies by using a modal reduction. The influence of housing elasticity on natural frequencies is much larger than on static deformations.

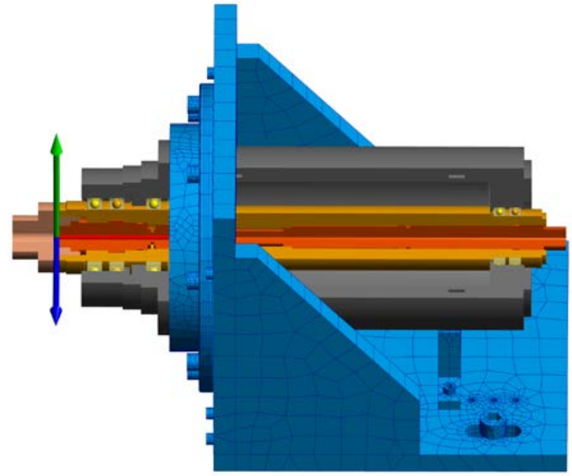
For example a L-shaped spindle test stand without the right support and without considering housing stiffness shows a first natural frequency (an axial mode) of almost 22’000 1/min. Considering the elastic housing the first natural frequency is a bending mode of about 15’200 1/min, which would lead to problem for a planned operating speed of 15’000 1/min. Including the additional right support the natural frequencies of the bending modes rise to 25’000 1/min, die first axial frequency falls to 19’600. The imported CAD-model was the existing CAD-model for manufacturing. This is not optimal because of



many holes and the bolts, but it still can be used. In case the holes and bolts are deleted in the CAD-model memory usage and initial calculation time for the calculation can be reduced.

A further extension is the support of 3D-elastic planet carriers. Compared to housings the planet carries rotate in the system and therefore the calculation has to cope with large rotations. The elastic deformations of the planet carries have an influence on the load distribution of the gears and therefore should be considered at design of tooth trace corrections. The tilting of the planets will also have an influence on the bearing loads and the global torsional stiffness.





Another possibility of an integration of 3D-elastic parts in the shaft calculation is the option of 3D-elastic rotation symmetric parts, which can be defined using a polygon. These 3D-elastic parts define an additional stiffness matrix. As example a flex-pin is considered here. In some older literature equations for the deformations of a flex-pin are given based on the Euler-Bernoulli-beam without consideration of shear deformations. In an example a beam model without shear deformations shows a deflection of 15 µm, including shear deformations the deflection is 23 µm and in case of usage of 3D-elastic parts the deflection is 42 µm. The usage of a 3D-elastic parts will lead to an increase by 80 percent compared to a shear-elastic beam element. The reason is the deformation in the two interference fits where the rigid connection of the beams is much too stiff. The 3D-elastic part is providing a better model for the deformations. As the parts are taken into account like welded in the calculation the real-life deformation should still be a little larger as there could be some sliding in the interference fit.

The integration of 3D-elastic parts into the shaft system calculation allows to consider additional stiffness without the need of external FEA programs. A time-consuming and error-prone transfer of stiffness matrices is therefore not needed any more.

A full calculation in a FEA program would allow more possibilities for defining boundary conditions and would allow nonlinear calculation including contact. The shaft system calculation based on one dimensional shafts has the main advantage of short calculation time in range of seconds, which allows the use of extensive load spectra and parameter variations. With the integration of 3D-elastic parts these advantages are preserved.

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Anatomy of a Rebuild

Nuttall Gear Taps Machine Tool Builders for Shop Floor Upgrades

Matthew Jaster, Senior Editor

Infrastructure engineers continually caution the U.S. government about deteriorating bridges and dams. According to Nuttall Gear, the average age of the 609,380+ bridges in the United States is nearly 42-years-old and the U.S. spends an average of $12 billion annually on repair/replacement costs.

For 60+ years, Nuttall Gear has provided highly-engineered, long-lasting gearbox solutions for the bridge market. It's one of several key heavy industrial sectors that the company provides extensive application expertise and customized solutions.

In order to accommodate these markets, Nuttall Gear (an Altra Industrial Motion Brand) relies on the latest machine tool technology. This includes upgrading and rebuilding some of the equipment.

"We had some pretty old machines on the floor that were manufactured in the late 1960s and early 1970s. It was tough to get service on the equipment and almost impossible to hunt down the necessary replacement parts," said Dan Bogdan, senior manufacturing engineer at Nuttall Gear, a division of Altra.

Instead of investing in all-new equipment, the company developed a rebuild strategy. This centered on a company-wide initiative to have at least one machine rebuilt each year depending on business conditions.

"We had recently purchased a brand new Höfler gear grinding machine and wanted to upgrade our hobbing machines as well," Bogdan said. "We couldn't justify purchasing brand new machines in this area, so we decided to see if we could upgrade/rebuild some of our core equipment to support existing sales and future growth. Machine Tool Builders (MTB) sounded like a good option based on cost, experience and service and support."

A Rich History in Gear Manufacturing

Founded in 1887, Nuttall Gear, Niagara Falls, New York, developed and introduced single helical gears, one of the most significant contributions to the field of gear engineering. Today, Nuttall specializes in providing complete custom packaged drive assemblies combining both mechanical and electrical components to meet specific customer requirements.

Nuttall designs and manufactures a variety of gearing solutions including vertical and horizontal drives, speed reducers and speed increasers, cast iron and fabricated steel housings and flange mounted and scoop mounted gearmotors. Nuttall can provide entire drive packages including reducer, motor mounted on a bedplate with couplings, coupling guards, backstops, chain and/or belt drives, clutches, shoe or disc brakes and auxiliary lubrication consoles.

Custom, heavy-duty Nuttall drives are utilized in a range of key markets including metals, pulp & paper, mining, textile, oil & gas applications such as extruders, crushers, elevators, water screens, briquetting machines, de-barkers, conveyors, drawworks, recoilers/uncoilers and dredges.

Nuttall acquired Delroyd Worm Gear in 1997. Delroyd was founded in 1923. It is recognized worldwide for designing and manufacturing high quality, long-lasting worm gear drives and unique, custom-engineered worm gear products. The company offers a wide range of products and services including single, double and triple worm and helical worm reducers, custom-engineered worm gear reducers, standard and special worm gear sets, reverse-engineered gear sets and gearboxes and gearbox rebuilding services.

Delroyd drives are found in various key markets including power generation, metals, pulp and paper, oil and gas, mining, material handling, food and beverage, textile, wastewater, cement and marine on applications such as pumps, fans, compressors, crushers, mixers, conveyors, stacker/reclaimers, turbines, cranes, winches and propulsion equipment.

The Rebuild Strategy

Ken Flowers and Ron Peiffer at MTB answer plenty of questions on a daily basis. When you're in the rebuild, refurbish and remanufacture business, it's just one-step in a highly-detailed process. Can we automate this equipment? Is there any life left in this machine? How can we make this gear hobber more productive? Bogdan at Nuttall Gear came to MTB with his own list of questions prepped and ready to go.

"Obviously cost is always going to factor into your decision, but you're also looking at service and support, machine tool experience and any additional ideas and concepts MTB brought to the table. There's a lot of back and forth between both companies when you start discussing what you want and what you need out of the rebuild," Bogdan added.

After determining which machines made the most sense for rebuild, the Nuttall team created a strategic plan for the equipment, basically researching and documenting what features and capabilities made the most sense.

After choosing MTB to upgrade a gear hobber, Nuttall Gear has commissioned the company to rebuild a worm gear hobber and a thread milling machine. They plan to continue this in the near future by retrofitting a gear inspection machine and rebuilding an additional gear hobber. Here's a closer look at some of the equipment that has been upgraded:

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Pfauter Turbo 900 Helical Gear Hobber (Rebuilt in 2012)

Before the upgrade, the 900 was a manual machine that was originally manufactured in 1968 and incapable of cutting a lead angle within required tolerances. The 900 was also no longer capable of cutting a crown. Both of these conditions caused additional machining via offsets as well as additional shave and grind time.

Since Nuttall doesn't typically run 20, 30 or 40 pieces one after another, it was important that the setup time was quicker and more efficient.

"We need the machine to be able to set up a part and break it down, set up another part and break it down, etc. We seldom run more than 2 or 3 of the same part. This machine is typically used for pinion shafts, different lengths and different pitches, so we need to be able to setup and change-out very quickly, one job to the next."

MTB converted the manual machine to a CNC machine and it quickly became Nuttall's most efficient and reliable helical hobbing machine. Bogdan was pleased with the modifications MTB made. The upgrades led to improved lead times for both setup and machine cycle time. The crowning capability was restored, and the software was updated and more user-friendly.

"We were also very aware of the parts that were used in the rebuild, including the new pipes, valves, pumps, etc.," Bogdan said. "These were quality parts. The machine is sturdier now and we have the option of using carbide hobs if necessary."

Flowers and Peiffer continued to answer questions and provide additional support after the project was completed. For example, Bogdan said that the company was recently running a part and wanted to perform a machining technique known as opposite hand hobbing (Cutting a right hand gear with a left hand hob).

"This is a fairly straightforward procedure on a manual machine, but when we tried to do it on the CNC machine, it wasn't working quite right. We made a call to MTB and they were able to identify what needed to be done in order to perform the technique on an automatic machine," Bogdan said.

Norton G&E TWG 40 Worm Gear Hobber (Rebuilt in 2014)

The rebuild strategy on the worm gear hobber was to upgrade a 1960s machine that covered the smaller size worm gears (going from a minimum center distance of 2.5"–29". This included upgrading the CNC controls, eliminating several hydraulic leaks that could not be repaired by the maintenance staff and updating machine capabilities in order to improve setup and cycle times.

Bogdan said that Nuttall Gear is a little bit different than other companies because the company does a great deal of custom work and makes all kinds of different gearing. They are heavy into lean manufacturing and prefer not to run too many parts at once and put them in storage. The company philosophy is to run the parts as needed.

Nuttall Gear still makes fly tools for worm wheels. Essentially this is when you take a finishing tooth from a hob and use it to rough and finish the worm wheel in a single pass. The company wanted this worm gear hobber to be able to use tangential hobs, in-feed hobs and fly tools. This requires long, tangential movement on the hobbing machine.

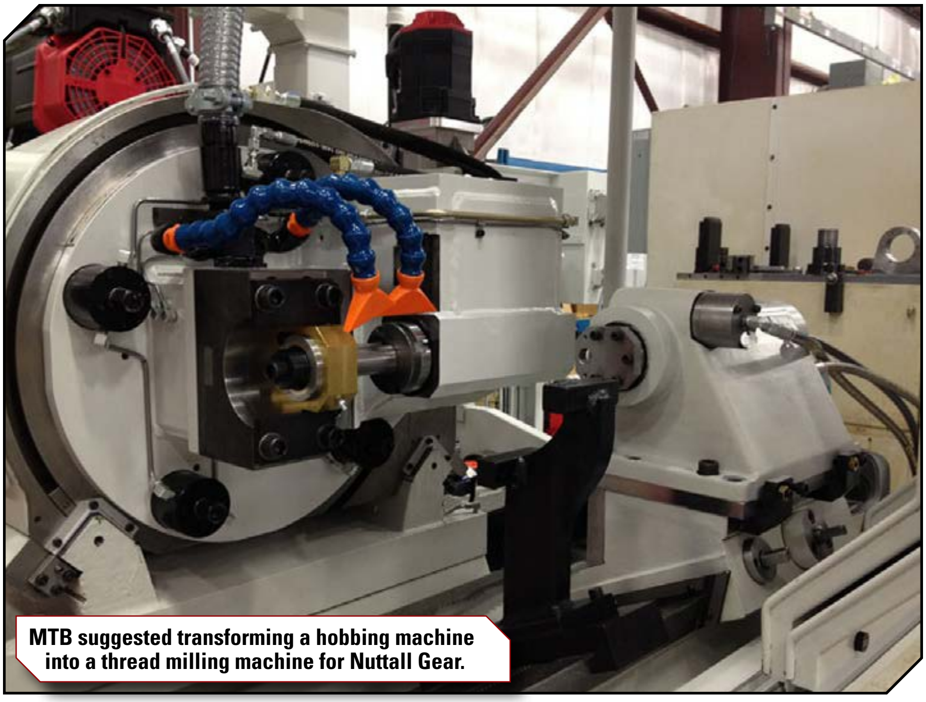
"Side to side movement has to be much longer than a regular hobbing machine," Bogdan said. "You can buy a brand new hobber and it will cut worm gears, helical gears, it will pretty much cut everything. But anywhere I go for a brand new gear hobber, you won't find the tangential movement needed if you're using fly tools."

So this particular capability needed to be custom-made in the rebuild. Nuttall required tangential and radial infeed hobbing. MTB provided both of these capabilities.

MTB also took the helical software and adapted it for use to use on the worm gear hobber. "There's different terminology and you're using different language, so they added all the software to make it easier to use and understand," Bogdan added.

Thanks to these upgrades, the worm gear hobber boasted initial setup reductions greater than 50 percent (down from 2+ hours to less than 1 hour) as well as cycle time reductions between 40 and 60 percent. The gear quality and surface finish were improved, controls were updated to CNC and the rebuilt hobbing head allowed for the use of carbide tooling thanks to the sturdier construction of the rebuilt machine.

"We couldn't consider carbide tooling in the past thanks to the machine vibration," Bogdan added. "Now we have the option if needed and it gives us more flexibility. With the redesign, we get better quality parts, better finishes and we can run parts much faster."



MTB suggested transforming a hobbing machine into a thread milling machine for Nuttall Gear.

Pfauter 250H Horizontal Hobbing Machine into a Thread Milling Machine (2015)

This rebuild was a similar challenge. The company wanted to upgrade a thread milling machine that could provide faster setups and easier changeovers. They were still working with old machines from the 1940s and 1950s that had the same problems as some of the other older equipment.

There was no machine head stability, for example. This prevented engineers from utilizing newer tooling and lowering run times. Bogdan said they were also interested in using insertable blade carbide cutters especially for bigger pitch parts since the older machines couldn't take it due to the vibration.

The game plan was to figure out the main range of parts (pick the sweet spot) and find out if MTB could upgrade one of the machines. As it turned out, MTB had a Gleason horizontal hobbing machine that fit all the criteria. MTB told Bogdan that they could transform the hobber into a CNC thread milling machine by simply changing the cutting head.

"The platform and the base were perfect, they simply needed to make a few simple machine conversions," Bogdan said.

The upgrade offered significant advantages. The old thread milling equipment was all manual. The operator had to be standing in front of the machine to do anything. Bogdan said the time that this took with the manual machines was unacceptable and the old machines (like the other examples) were very difficult to maintain regularly. And forget about finding replacement parts.

With the rebuild, Nuttall Gear now had automatic indexing, the software was easier to use and the machine had the capability to use different size cutters, interchangeable arbors, etc. It basically gave the company the option of doing a majority of parts in a single machine.

"This flexibility gave us the opportunity to get rid of a few machines on the shop floor. It replaces the work done on two of our previous machines, almost three in reality. We just keep the other one around for very small sizes," Bogdan said.

The rebuild let Nuttall Gear utilize carbide cutters that didn't work quite as well on the older equipment. They attempted to use carbide cutters on an older, manual machine and blew the endcap off the back of the machine in the process. "Couldn't handle it until the machine upgrade," he added.

The stability of the machine was one of its greatest perks. By converting a hobbing machine into a thread mill, gear engineers now had a stable, automated, machining cell at their fingertips.

"With the old equipment, the operator had to take a trial cut before the first pass during part setup to establish correct size. MTB updated the software so shorter trial cuts were now built in. Cutting time improved 40 to 60 percent with carbide cutters and 15 to 20 percent with standard cutters. Part setups were significantly reduced.

Nuttall Gear now had automatic indexing, software upgrades and the ability to utilize different size cutters on the thread milling machine.

Future Upgrades

While the purchase of the Höfler gear grinding machine certainly opened up new markets and new opportunities for Nuttall Gear, the rebuilds and upgrades served an entirely different purpose.

"Each of these upgrades simply enhanced and optimized the day-to-day business we already conduct in these heavy industrial sectors," Bogdan said. "This is a cost-effective way to upgrade your plant on a set budget and think outside the box a little when you're looking at the older equipment you're still running on the floor."

Nuttall Gear still has its strategic rebuild plan in place. They plan to target another gear hobber to rebuild in the near future as well as retrofit a Maag SP-160 Gear Inspection Machine. These upgrades will most likely occur between 2017 and 2018. The company will continue to work with MTB on these and additional projects.

The markets Nuttall Gear specializes in, particularly bridge drives, is starting to pick-up according to Bogdan. "We have a lot of quotes for bridge drives and there's still plenty of work available to upgrade some of this equipment. We're hopeful that there will be plenty of new opportunities to test the gearboxes in bridge drives and offer our services and expertise."

Bogdan also sees some more opportunities in transportation, particularly light rail applications. "We're getting more work in subway systems as well as some activity in oil and gas. When the oil industry starts picking up, we'll be much busier and we'll need to make sure the equipment we're using is up to speed. Timing is everything in this business!"

For more information:

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www.nuttallgear.com

The Rebuild/Remanufacture Checklist

With each rebuild project, Dan Bogdan, senior manufacturing engineer at Nuttall Gear, a division of Altra, gains more experience and learns more about the rebuild process. Here's a quick checklist of things to consider when upgrading your equipment:

#1 Know Exactly What You Want From the Rebuild Up Front

It's better to go to corporate with a number in mind for the total cost of the project instead of coming back asking for more money during the rebuild. "If you miss certain elements in the planning phase, it might cost your company an additional $10,000 to $20,000. You don't want to be halfway through the rebuild and find out you need more money to complete the project," Bogdan said.

#2 Experience is Important

Machine Tool Builders (MTB), located in Machesney Park, Illinois, provides top quality, reliable machine tool solutions thanks to its highly-experienced staff, innovative ideas and customer service and support. Bogdan did his research and had a pretty good idea about the expertise MTB provided. "If there's familiarity and knowledge of the machine and a thorough understanding of what you want to accomplish, it makes the entire process so much easier," he said.

#3 Walk and Talk

While initial rebuild discussions begin over the phone or via e-mail, the real legwork is done right on the shop floor. "Ken Flowers and Ron Peiffer at MTB didn't just rattle off potential ideas for our project," Bogdan said. "They toured our facility, looked at all our equipment, and learned all about our machining processes before offering some suggestions for the rebuild project."

#4 Outline and Document Everything

Corporate has to approve the cost of the project and they never like surprises. It's in the best interest for both parties to keep communication open with your rebuilder, make sure everyone is on the same page and write everything down. "You should take all of your own considerations as well as the rebuilder's considerations before going to corporate for project approval," Bogdan said.

#5 Don't Forget the Add-Ons

It's rarely just about putting a new cutting head in a machine or updating the controls. There are always other expenses to consider including new arbors, safety enclosures, software upgrades, etc. "Think about every aspect of the equipment and remember that many of the older machines don't have the safety features and automation capabilities that might be available after the project is completed," Bogdan said. "These are areas that will cost much more money down the road. It's better to prepare for these expenses at the beginning of the project."

#6 Get Complicated

When you're testing parts on the machine in question, it's pointless to select the most common part you typically produce. Bogdan suggests you pick the part that is going to be the most challenging and use that for the testing phase of the project. "If you select a part that has given you the most headaches in the past and it runs smoothly, you'll be much better off in the long run," Bogdan said. "Why not cover every possible outcome right from the very beginning?"

#7 Phone a Friend

There's always going to be something you miss or something you might need the machine to do down the road. Service and support is vital for the success of the rebuild. Bogdan states that MTB typically follows-up on a question or comment the very same day. "They will get back to you as quick as they can and determine what they can do on their end to solve whatever problem you're having with the equipment. It's nice to know we can call them up immediately with any technical issues or questions," Bogdan said.

#8 Communicate Early & Often

Bogdan believes this is just as important at the beginning of the project as the end. Keep the communication line open with your rebuilder, let them know what you might be looking for down the road and what machines you might upgrade next. "This is the most useful part of the entire process," Bogdan said. "Keep talking about what you need and what areas would benefit from additional upgrades. Conversations generate great ideas for the shop floor."


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Ground and Hobbed Globoidal Worm Sets

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

QUESTION

Are profile ground and hobbed, globoidal worm sets better than multi-axis CNC-generated globoidal worm gear sets for reduction of noise and vibration?

Expert response provided by Prof. Dr. Karsten Stahl. Aspects of the question can be answered by applying the results from a research project within the German Research Association for Power Transmissions Engineering (FVA). Therefore, the noise and excitation characteristics of worm gears have an exceedingly different noise and vibration behavior against cylindrical or bevel gears. Worm gears generally show a homogeneous sound power level distribution within a frequency range of 50 Hz and 5 kHz, and can be characterized as broadband noise.

Reasons for this are the high sliding velocities and the running in effect of the worm wheel — usually made from soft material, like bronze.

Therefore the manufacturing method will play a secondary role regarding the noise and vibration behavior.

Prof. Dr. Karsten Stahl is Chair, Machine Elements, Mechanical Engineering, at TUM. He leads and conducts research in the area of mechanical drive systems, with particular interest in investigating the load capacity, efficiency and dynamics of all gears types.

Twist Control Grinding (TCG)

Walter Graf

This paper introduces the latest process developments for the hard-finishing of gears, specifically in regard to controlling the so-called flank twist. The purpose of twist control grinding (TCG) is to either eliminate twist, to introduce a counter-twist on purpose, or to add a specific twist to counteract the deformation of gears under load. By controlling twist, the contact bearing surfaces of meshing gear sets can be fully optimized, and therefore, the forces acting on the bearing surfaces can be ideally distributed. This leads to more efficient gears, both in terms of power density and fuel consumption. Today, in terms of grinding times, twist control grinding is on par with the standard continuous generating grinding which is well-established in the industry. High volume TCG production of twist-free gears, or gears with a defined twist, is now standard production practice at several automotive gearbox manufacturers.

(The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.

Introduction

This paper introduces the latest process developments for the hard-finishing of gears, specifically in regard to controlling the so-called flank twist, also known as bias. This paper only mentions twist control in reference to continuous generating grinding. Flank twist also occurs in profile grinding of helical gears with crowning. Demands on gears have always included the reliable transmission of high torque and the need for increased power density, low weight, and minimal noise emissions. Over recent years, greater efficiency, lower fuel consumption, and CO_2 output have been added to the growing list of demands. Emissions and fuel efficiency are becoming more stringent in all major market regions such as the USA, Europe, and China (Ref. 1; Fig. 1), and the car companies are facing huge technological and economic challenges to comply. These requirements can only be met by improvements in all aspects of motor vehicles, and specifically to the powertrain, i.e., the engine and the transmission. Additionally, research by Ford and Ricardo has shown that a reduction in fuel costs — via improved gearbox design — costs only half as much as similar economies realized by improvements to the internal combustion engine. According to one of many studies (Ref. 2), weight reduction can contribute a major share of the total fuel consumption reduction. Hence, modifying the flank twist by TCG allows modification to the contact pattern of gear teeth, thus leading to higher power density and a reduction in the overall weight of gears in general and, by extension, a weight reduction of the transmission itself. Furthermore, TCG-ground gears have shown noise reductions in transmissions of 2 to 3 decibel (dB).

Flank twist occurs as a matter of course when machining helical gears that feature lead modifications such as crowning. This phenomenon is brought about by the geometries and kinematics inherent in the continuous generating grinding of helical gears. Incidentally, profile grinding with a single rib wheel will also lead to flank twist, but this paper will focus on generating grinding only. Simply put, the purpose of twist control grinding is to either eliminate twist, to deliberately introduce a counter-twist, or to add a specific twist to counteract the deformation of gears under load. More often than not, twist has some negative connotations attached. However, with TCG grinding the word "twist" should be seen in a positive light, as it allows gear designers to use this phenomenon to fine-tune the gear geometry. Furthermore, the process, as presented in this paper, allows separate TCG on the left and right flank in the same grinding pass. By controlling twist the contact bearing patterns of meshing gear sets can be fully controlled and, therefore, the forces acting on the bearing surfaces can be ideally distributed, which leads to higher power density, more efficient transmission of power, and an increased longevity of gears. The TCG method gives gear design engineers a high degree of freedom to design gear flank geometries to match the demands made on automotive gears and to translate desired design features into an economical manufacturing process.

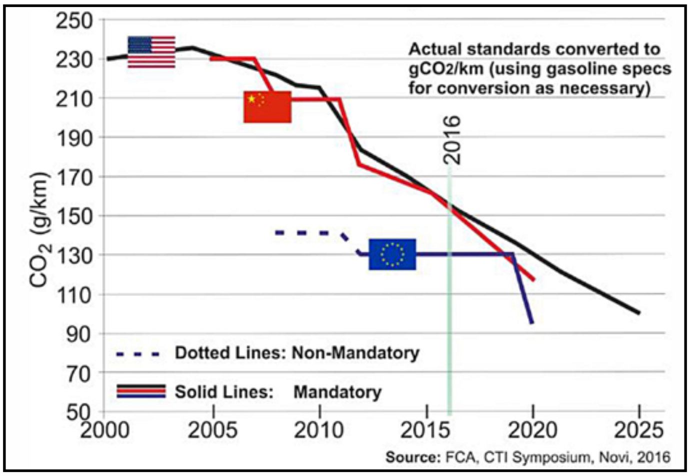

Figure 1 Legislation for CO_2 reduction.

TCG is an added feature of the well-established, continuous generating gear grinding process. In principle, the kinematics of this process can be understood as a worm drive (Figs. 2 and 3), with an additional abrasive machining process consisting of an infeed X, a vertical feed-rate Z, and a lateral shifting motion Y — all working together simultaneously. The main difference to the standard continuous generating is that the grinding worm

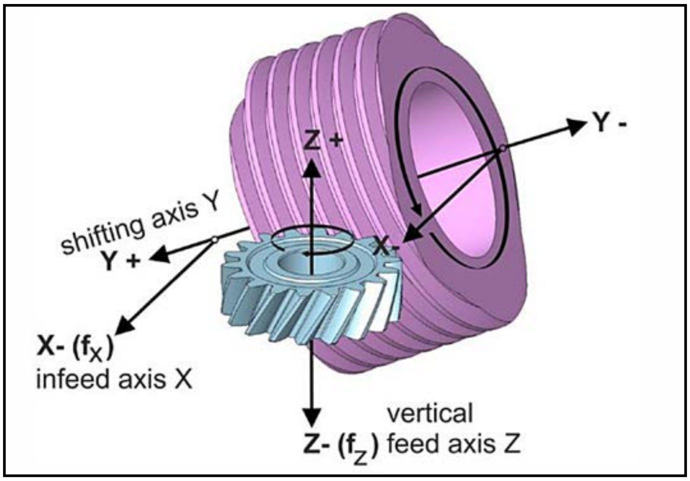

Figure 2 Continuous generating grinding principle.

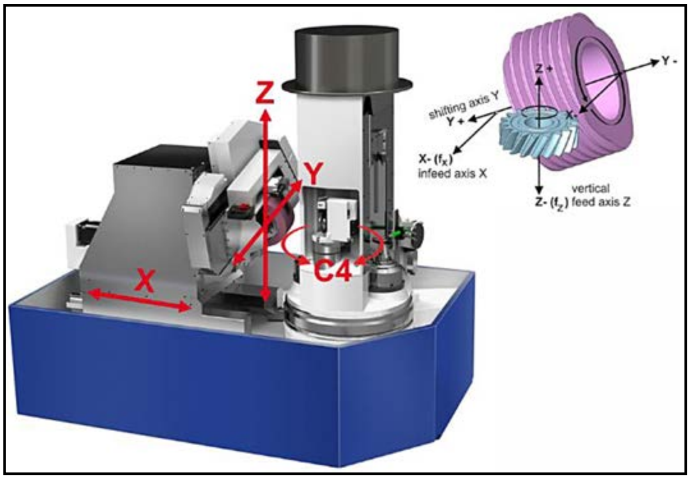

Figure 3 Machine axis movements.

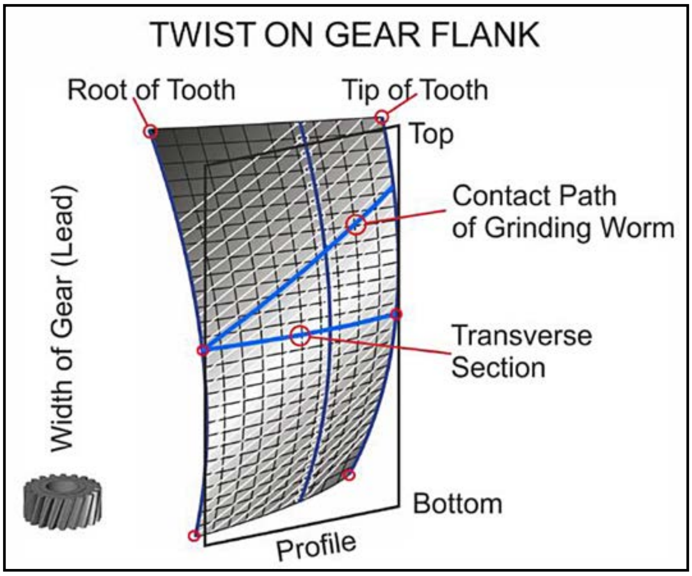

Figure 4 Flank twist.

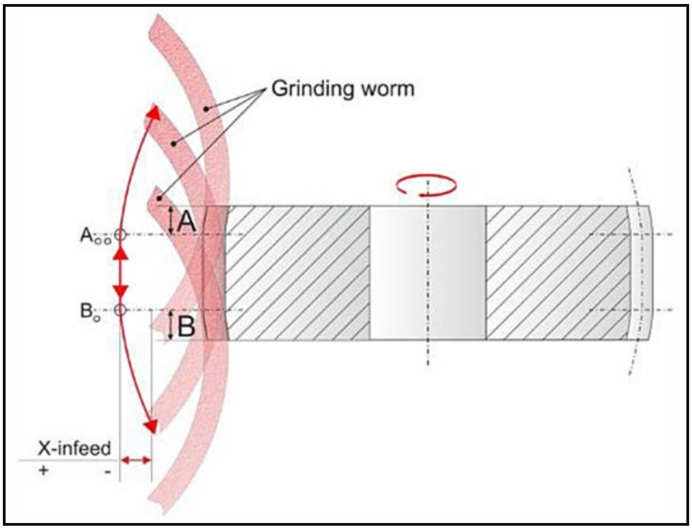

Figure 5 Crowning and changing center distance.

has to be modified across its width in terms of its pitch and/or its pressure angle. For this purpose the dressing unit (C4 axis) needs to be swiveled continuously as it moves laterally across the width of the grinding worm.

Defining Grinding Twist

Grinding twist is a continuous change of the profile angle ($f_{H\alpha}$) of the gear flank over the full width (Fig. 4). As previously mentioned, flank twist occurs as a matter of course when grinding lead-modified helical gears. The change in the profile angle $f_{H\alpha}$ occurs across the face width of the gear. Depending on the amount of lead crowning, twist can be minimal and often ignored, as the profile $f_{H\alpha}$ measurement is taken only across the transverse section in the middle of the lead (Fig. 4). For this reason the gear's teeth are produced within specified tolerances, despite some residual flank twist.

As Figure 4 illustrates, when grinding helical gears the contact path between the grinding worm and the part's tooth flank does not run on the transverse section of the part. (The transverse section is a cross-section perpendicular to the gear axis). The required modification of the tooth trace is defined and measured at the nominal base cylinder of the gear. The base cylinder corresponds to the base circle and is the cylinder from which the involute tooth surfaces are developed. When grinding the flank, depending on the helix angle and the direction of the stroke, the tip and root of a tooth flank's transverse section are not ground simultaneously. Modifications in lead direction, such as crowning or end relief (Fig. 5), are generally created by changing the center distance (*X*-infeed) between the grinding worm and the workpiece axes during the grinding process.

The change of the center distance between the grinding worm and the gear is also relative to the nominal base cylinder. The tooth's root and tip of a transverse section are ground at different revolutions of the gear. The contact paths are visible as feed marks (Fig. 6), so that between the grinding of the root and grinding of the tip, several revolutions of the gear to be ground have occurred. In generating grinding, this twisting effect is exacerbated by a more pronounced crowning or end relief, or by a greater helix angle of the gear flank. Particularly in the case of end relief configurations, in which the center distance changes radically over a relatively short distance, process-related tooth twist will occur.

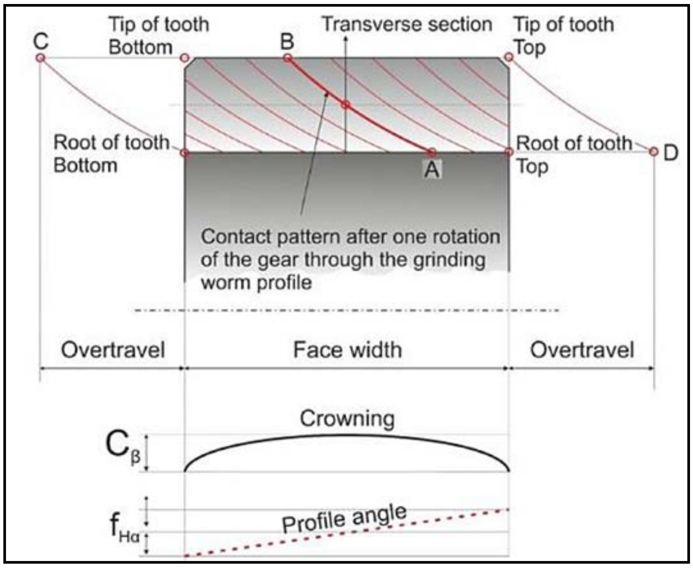

Figure 6 Crowning and profile angle.

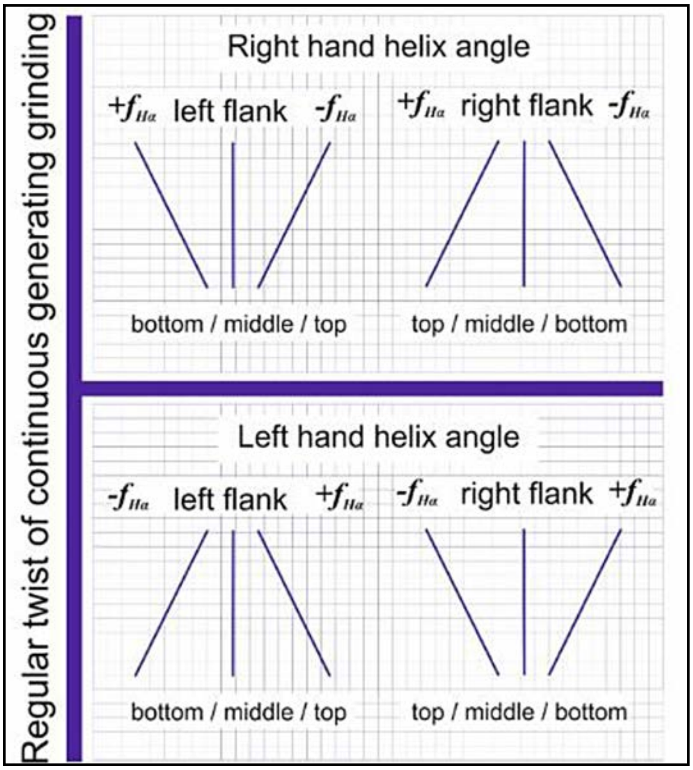

Figure 7 Twist on opposing helix angles.

While grinding crowning and end relief, the center axis distance changes during the grinding of the gear. Consequently, during one grinding stroke, while crowning and/or end relief has been generated, the direction of the center distance has been reversed. The resulting effect is that the tip on one side is in plus (+), and of the root on the opposite side is also in plus (+), creating the described flank twist effect (Fig. 7), which also shows this effect on opposing helix angles such as present on right- and left-hand gears. The measurements are always on one flank, in three locations across the face width of the gear.

Controlling Grinding Twist

TCG grinding takes place on modern existing continuous generating gear grinding machines that possess the necessary kinematics to control twist. Modification to the gear's base pitch can serve to compensate for any resulting twist, or serve to create a deliberately produced target twist. This modification is made possible by changing the pitch and/or the pressure angle across the width of the grinding worm (Fig. 8).

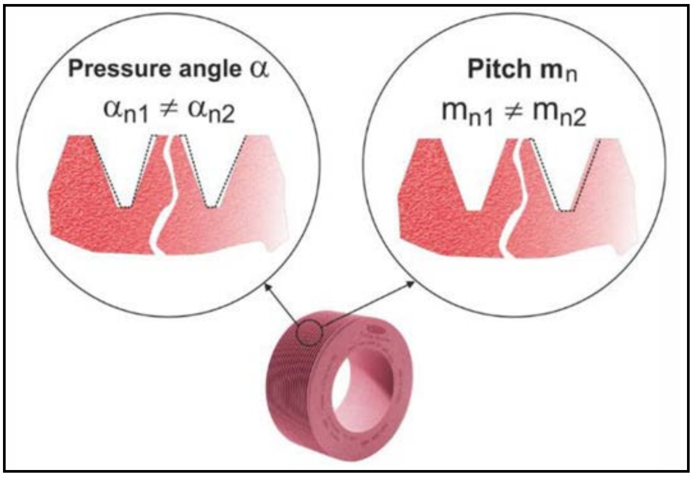

Figure 8 Modification of the grinding worm.

To control the twist that occurs in continuous generating grinding, a continuous change of the pressure angle on the grinding worm (Fig. 8) must be introduced across the shifting distance on the grinding worm width. This correction is only possible by applying diagonal generation grinding, such that the gear has a dedicated position on the width on the grinding worm in line with the changes of the pressure angle and the pitch across the grinding worm width. As mentioned previously, this can either occur by continuously changing the pressure angle or the pitch across the width of the grinding worm. TCG utilizes both modifications simultaneously, thus TCG can shorten the distance of the diagonal grinding pass in comparison if only one of the modifications were used at any one time. There are also machine tool builders that use only either pressure angle adjustments or pitch adjustment across the width of the threaded wheel. However, using both adjustments simultaneously has proven itself as the most effective TCG method in the automotive industry.

Figure 9 shows a typical layout of the grinding worm which, in this particular case, is divided into three distinct sections — one for roughing and two for finishing. The narrow ramp sections, $s_{\_1}$ to $s_{\_4}$, that are located in between the individual grinding sections, are not used and represent a safety area to ensure that the cycle start of finishing, for example, will not be in a transitional area between the roughing and finishing stroke.

Diamond Dressing of Grinding Wheel

TCG requires a double-taper diamond disc for the dressing of the grinding worm profile. Generating a defined tooth twist requires part-specific dressing tools, which, at any one time, dress only with one single flank due to the different geometries used for the right- and left-hand flanks (Ref. 4). This, of course, increases the overall dressing time, in comparison to conventional grinding in which both flanks are dressed in the same dressing stroke. In contrast to line dressing, profile dressing involves a linear contact between the grinding worm and the dressing tool, resulting in far shorter dressing times than line dressing. For line dressing, a flexible universal diamond dressing tool with defined radii dresses the profile of the grinding worm by using the machine axes on a line-by-line basis (Ref. 5). As there is only a point contact between the grinding worm and the dressing tool, the dressing times required for line profiling are relatively high. Line dressing is only relevant for prototyping gears, and so will not be further addressed in this paper. In addition to modifications and corrections of the twist and the profile angle, the profile dressing method also permits changes in profile crowning. Using the same dressing tool, the TCG process also allows separate profile crowning and flank twist corrections on each individual flank. To generate varying pressure angles on the grinding worm, the tool is swiveled during the dressing process using the machine's C4 axis (Fig. 10). So-called profile roll sets are available for outside diameter dressing or rounding off the tip of the grinding worm. These roll sets generate the required tooth tip profile of the grinding worm after both grinding worm flanks have been dressed.

Manufacturing Twist-Controlled Gears

An exemplary definition of twist-relevant data on a manufacturing drawing is shown (Fig. 11). In contrast to conventionally ground gears, TCG-ground gears need a precise indication as to the three measuring locations across the face width of the gear. In the case of the gear shown in Figure 11, the locations where the measurements have to be taken are as follows, starting from the top of the gear: 2.75 mm, 10.75 mm, 18.75 mm, with angle profile deviation ($f_{H\alpha}$) on the drive side being +10 µm at location 2.75, 0 at location 10.75, and −10 µm at location 18.75.

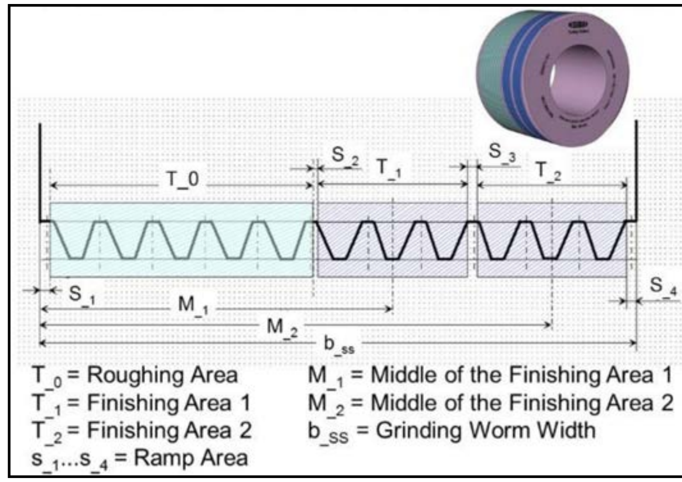

Figure 9 **Grinding worm layout.**

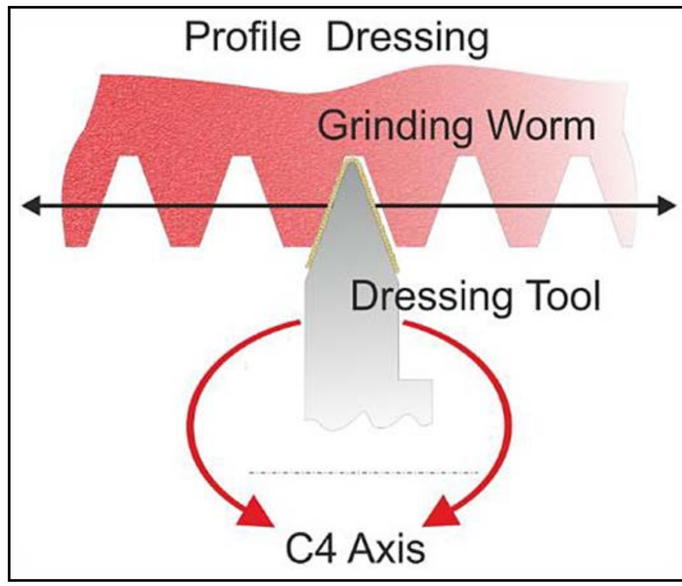

Figure 10 **Dressing the grinding worm.**

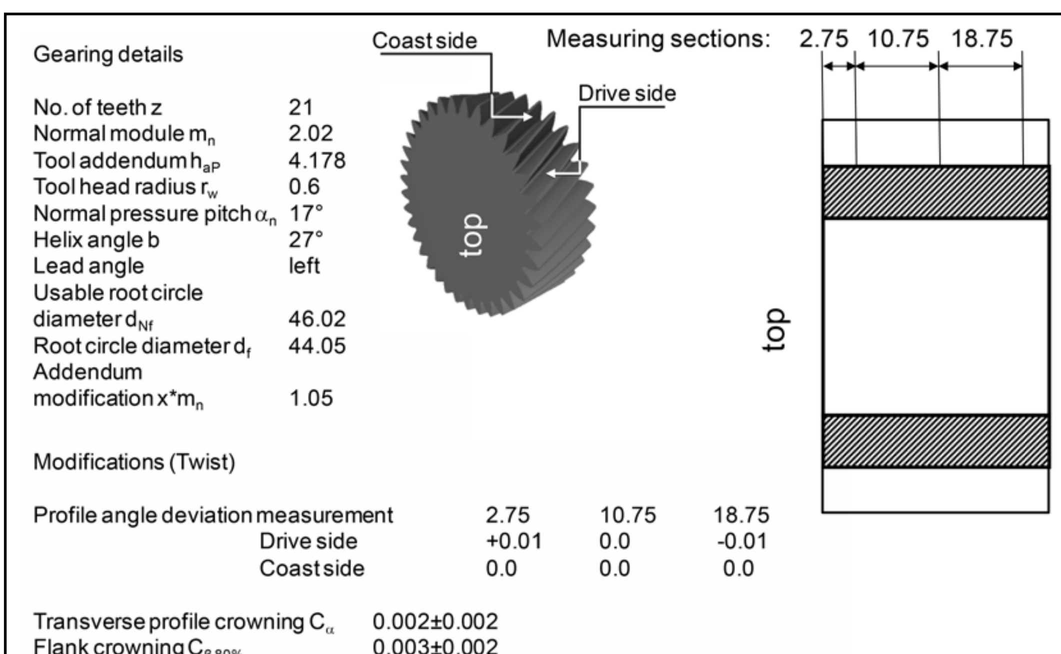

Figure 11 **Exemplary definition of twist.**

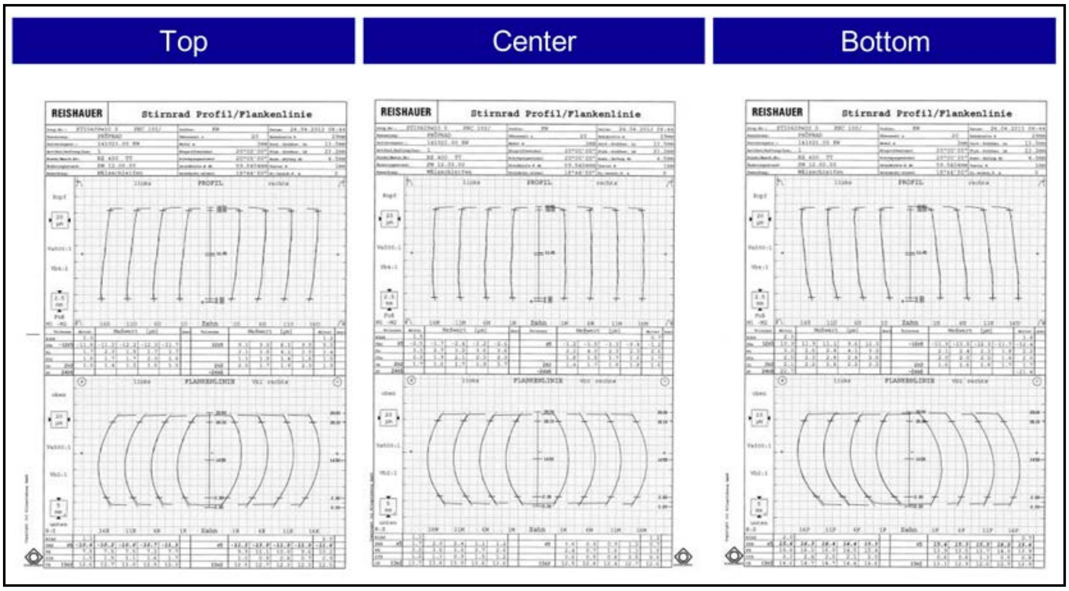

Figure 12 Gear ground with natural twist.

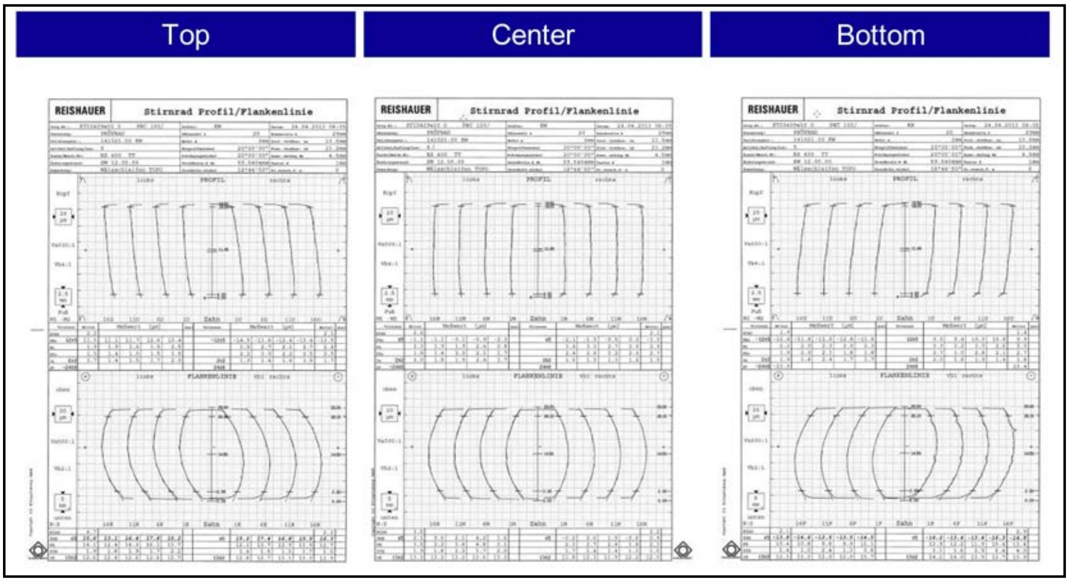

Figure 13 Gear ground with counter twist.

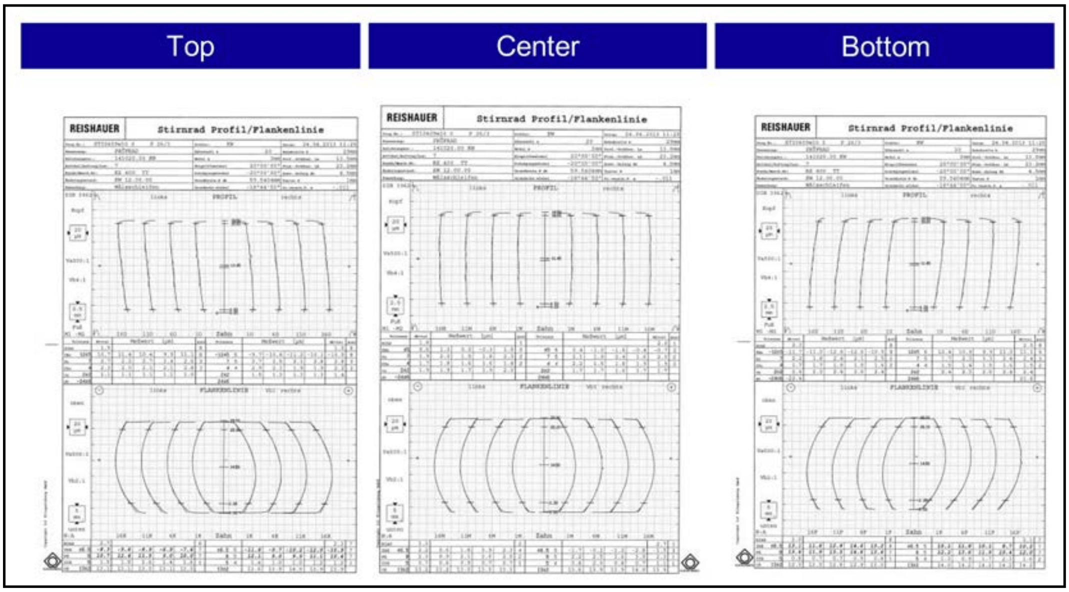

Figure 14 Mating gear ground with natural twist.

Effects of Twist

In order to show why grinding with a specified and controlled twist is worthwhile to pursue, the contact pattern of a gear wheel has been examined more closely (Ref. 6). A gear with the natural twist resulting from continuous generation grinding (Fig. 12) and one ground with TCG (Fig. 13) have been ground for this purpose. These gears have both been paired separately with the same mating gear, which had been ground with continuous generating grinding with a natural twist (Fig. 14). The resulting, different contact patterns are shown (Fig. 15). It can be seen that the contact pattern is less sloping in the pairing variant with the applied TCG. Furthermore, in this pairing the contact pattern is spread wider across both tooth flanks. Due to this wider contact pattern the torque load of the gear pair can be spread over a larger flank surface area. For this reason individual points of the flank would be subject to a lesser load which, correspondingly, would lead to an increased load-bearing capacity.

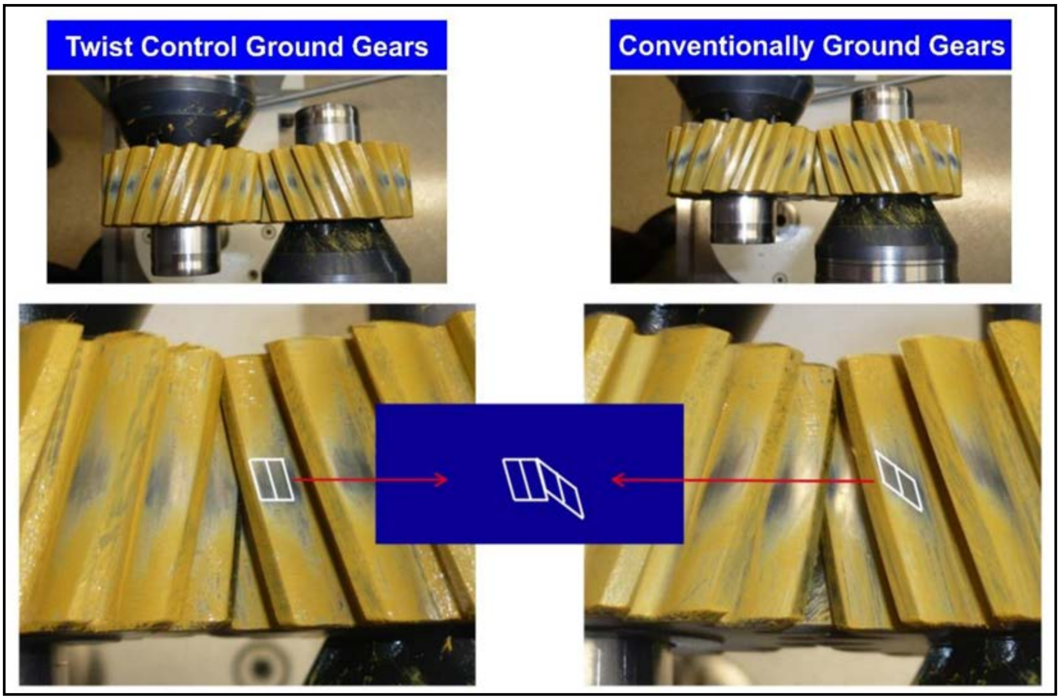

Figure 15 **Contact patterns of mating gears.**

Economic Considerations and Conclusion

The direct integration of TCG into the conventional continuous generating grinding process translates into minimal investment costs if customers already have Reishauer continuous generating gear grinding machines that feature a dressing unit with swivel capability. Furthermore, the diamond dressing tools remain the same as for many existing conventional processes. In addition, the TCG process requires minimal additional operator training if the operators already have experience with standard continuous generating grinding. Today, in terms of grinding cycle times, twist control grinding is on par with the standard continuous generating grinding which is well established in the industry. The number of workpieces per dress is also on par with standard continuous generating grinding. The benefits gained from controlling twist justify the small software investment and the influence of additional wheel dressing time. Following intensive research work and several years of industry application, Twist Control Grinding technology has proven itself in the marketplace and has, in many cases, eliminated gear honing, often thought to be the only method for large-scale twist-free hard finishing of gears. High volume TCG production of twist-free gears, or gears with a defined twist, is now standard production practice at several automotive transmission manufacturers. The higher process costs over conventional gear grinding are outweighed by the benefits of the reduction in torque loss, the increase in bearing capacity of TCG-ground gears, and higher resulting power density in transmissions. The main challenge which is presently addressed for TCG is the user friendliness of setting up the machine. Setting up a TCG process, or making corrections, must be simple and fast.

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After completing his toolmaking apprenticeship in 1974, **Walter Graf** worked for ten years in tool and mold making workshops. He subsequently he continued his studies in Australia and the UK and was awarded a Bachelor of Science Degree (Honors). In 1992, he began as a Product Manager for super-abrasive grinding and dressing tools at Winterthur Technology Group, Switzerland, and before the purchase of Winterthur by 3M in 2011, he held the position of Chief Marketing Officer for the entire Winterthur Group. At 3M, his role changed to Global Segment Leader for bonded abrasives. Since January 2014, he holds the position of Marketing Manager for gear grinding machines at Reishauer AG, Switzerland.

Surface Structure Shift for Ground Bevel Gears

Sebastian Strunk

(The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.)

Ground bevel and hypoid gears have a designed motion error that defines parts of their NVH-behavior. Besides others, the surface structure has an effect on the excitation behavior. This surface structure is defined by the hard finishing process. Grinding shows the advantage of high repeatability, defined flank forms with closed-loop corrections, and subsequently very low reject rates. However, it is known that for example lapped gear sets show, at least at low loads, a lower excitation level, including the lower as well as the higher mesh harmonics. The generation of a ground pinion is realized with a generating motion of a cup-shaped grinding wheel that follows a path given by the axis position table. Machine motions itself in combination with resulting machine vibrations, and imperfect grinding wheel roundness during a standard grinding process can lead to a distinct surface structure with facets parallel to the contacting lines. These lines, including their waviness, are crossed while the contacting zone passes along the path of contact and leads to excitations when rolling the bevel gear set. The MicroPulse process (Refs. 1–2), as it is implemented at present, gives the possibility to influence each axis position in each line of the axis position table with small, predetermined or random amounts. The presented development is a process which improves the excitation behavior of a ground bevel gear set by altering the surface structure of a generated member along the path of contact from slot to slot. This process can include the use of the MicroPulse motions, but it is not required. Rather than using the same axis-position-table for every ground slot — the current state of the art — every slot receives changes to its specific axis-position-table. The changes from slot to slot are calculated to address the objectionable harmonic excitation. For this reason the objected harmonic excitation is predictably addressable based on a closed-loop iteration calibrating the chosen process parameters.

Introduction / State of the Art

Ground bevel and hypoid gears have a designed motion error that defines parts of their NVH-behavior. In addition to other dynamic effects, the surface structure has an effect on excitation behavior. This surface structure is defined via the hard finishing process. The most common hard finishing processes are, for example, lapping, grinding, and skiving. Grinding shows the advantage of high repeatability, defined flank forms with closed-loop corrections, and, subsequently, has very low reject rates (Ref. 3). However, it is known that lapped gear sets show — at least at low loads — a lower excitation level at lower and higher mesh harmonics.

Originally, the motions between tool and work gear are derived from a rolling process of the work gear and the generating gear. After the transformation of the rolling motion into a five- or six-axis free form machine, the motions of the single axes are basically third order functions with a dominating first order content. The coordinates for all axes are written into an axis position table that is read in by the machine controller of the free form machine.

The generation of a ground pinion is realized via the rolling motion of a cup-shaped grinding wheel that follows a path given by the axis position table. Some excitations in ground gear sets are caused by the production process itself. The machine follows each line in this axis position table and interpolates between the lines. At low roll rates, a high number of lines are given in the axis position table, and the machine can follow these lines very accurately because of the slow motions and their continuous functions. With low roll rates the machine inertia also contributes to smooth transitions between the lines in the axis position table.

At high roll rates, fewer lines are generated in the axis-position-table. The machine has to follow these lines at a higher speed while the grinding wheel RPM, determined from a given surface speed, remains the same. This results in fewer revolutions of the grinding wheel between the axis positions of the part program, creating surface pattern similar to generating flats. The minimal time increment between two axis positions is limited by the controller-specific block time, which presents the upper limit of axis positions for each given roll rate. An additional cause of certain surface pattern at high roll rates is the degrading synchronization accuracy between the three linear and two rotational axes.

The above described effects can basically be summarized as influences where machine motion, in combination with resulting machine vibration and imperfect grinding wheel roundness during a standard grinding process, will lead to a distinct surface structure with facets parallel to the contacting lines. These lines, including their waviness, are crossed while rolling along the path of contact and lead to excitations when rolling the bevel gear set. Depending on roll rate and machine dynamics, these effects can be found at lower mesh harmonics (fast roll-rates) or at higher mesh harmonics (slow roll-rates).

The MicroPulse process (Ref. 2), as implemented at present, offers the possibility to influence each axis position in each line of the axis position table with some small predetermined

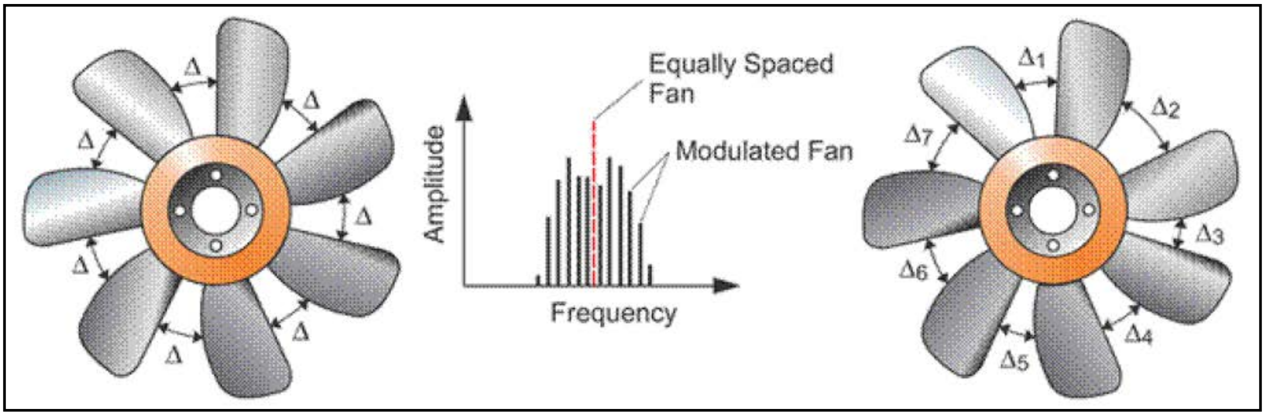

Figure 1 Cooling fan with unequally spaced blades.

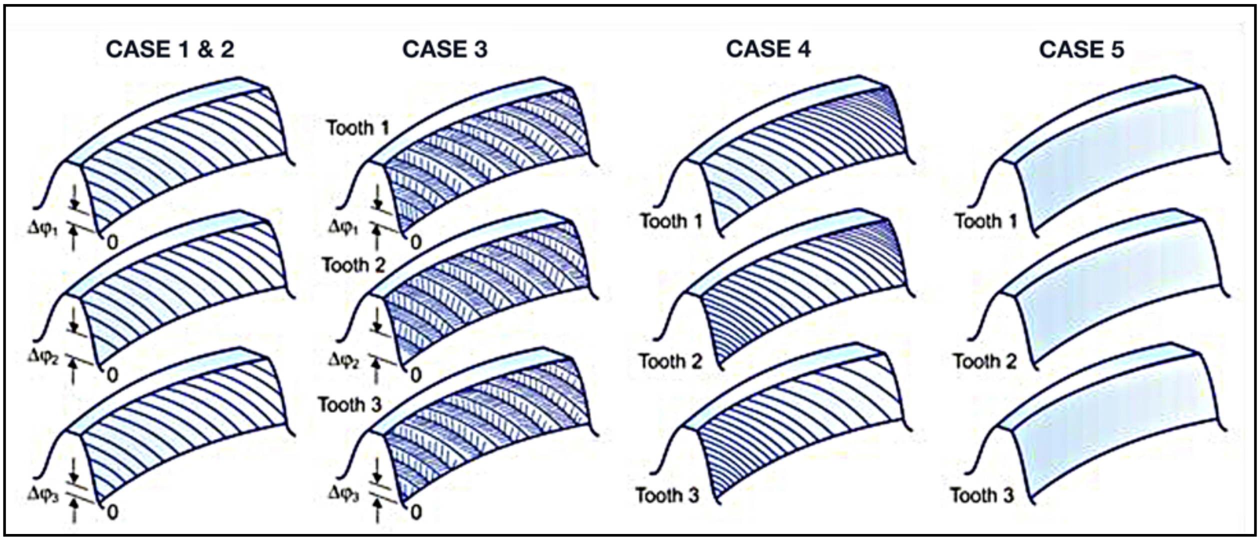

Figure 2 Tooth mesh surface structure and excitation change.

or random axis motion amount. In previous research (Ref. 2) MicroPulse was used to introduce a predictable and/or random surface structure on the flank to influence the NVH behavior of the ground gear set. In the standard grinding process the same axis-position-table is used for every tooth slot, leading to a similar appearance of the surface structure for every flank, if the process affected wear of the grinding wheel from the first to last slot is neglected.

Additional literature research in the field of application and inventions utilizing principles of (frequency-) modulation in the field of mechanical engineering present the separation to the inventive idea. For example, in fans (U.S. 3006603 A) (Ref. 4), torque converters (U.S.20110289909 A1) (Ref. 5), and turbines (U.S. 1502903 A) (Ref. 6), an unequal spacing of the blades leads to a changed excitation behavior. Figure 1 shows the exaggerated example of a cooling fan with unequally spaced blades. The results of these spacing variations lower the peak harmonics (e.g. — blade impact frequency of a fan) and introduce additional sidebands. The energy of the peak harmonic is distributed from the peak to the sidebands, leading to a lowering of the peak harmonic. This idea applied to the spacing of gear teeth has been part of several research projects, but showed only limited success (Ref. 7).

The above stated properties of the standard grinding process including the MicroPulse repeat precisely from one tooth to the next and lead to excitations of discrete harmonics that correlate to the machined existing surface structure, including the surface waviness, leading to measured NVH-behaviors that are not acceptable in the final application of the ground gear sets.

Theoretical and Practical Background

The idea behind the "surface structure shift" was the development of a process that improves the excitation behavior of a ground bevel gear set by altering the surface structure of a generated member from slot to slot. This process can include the use of the MicroPulse motions, but it can also be applied without MicroPulse. Instead of using the same axis-position-table for every ground slot — today's state of the art — every slot receives changes to its specific axis-position-table. The changes from slot to slot are calculated to address the objectionable harmonic excitation. For this reason, the objected harmonic excitation is predictably addressable based on a closed-loop iteration calibrating the chosen process parameters.

The following general cases (Fig. 2) are possible to change the excitation behavior using this process:

1. Shifting the roll-positions so that not every facet (waviness) is positioned the same way on each flank combined *with* a MicroPulse-motion.
2. Shifting the roll-positions so that not every facet (waviness) is positioned the same way on each flank *without* additional MicroPulse-motion.

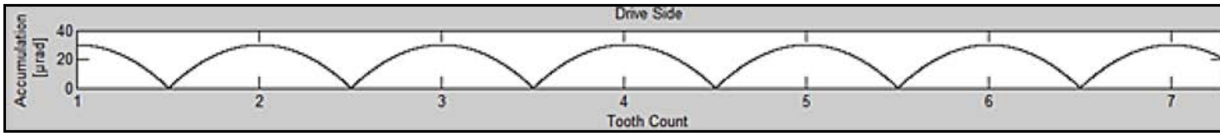

Figure 3 Simulated transmission error without any surface structure and waviness.

3. Changing the position of every facet (waviness) on every flank *only* by applying the MicroPulse motions.
4. Changing the distances of the roll angle increments in the axis position table along a slot (from start-roll position to end-roll position) with and without a different function from slot to slot.
   - Changing the position for every facet/waviness for every flank with the same amount of shift (every flank has the same pattern, only shifted versus the original pattern), utilizing roll-position shift and/or MicroPulse. This change is targeted to counteract dynamic events during the grinding process, leaving a surface without significant surface effects, eliminating higher harmonic excitations.

The amount of roll-position shift in cases 1) and 2) is a result of a calculation based on:

- An analysis of the results of a single flank test (SFT) of the evaluated gear set.
- An analysis of the original axis position table (within the part program) that would be used in a standard grinding process for a particular part, especially the relation between the number of lines in the axis position table and the roll angle.
- An analysis of the existing contact pattern.

The simulation in Figure 3 shows the transmission error caused by a designed motion error, without any surface structure influence. Desirable is a low transmission error leading to a low excitation level, by means of low motion error amplitudes. Note that a certain amount of crowning in profile and face width direction of the flanks is required in order to maintain a good contact pattern under high load situations. Crowning is a deviation from conjugate flank surfaces and will cause correlating amplitudes of motion error.

A fast Fourier transformation (FFT) of this transmission error (Fig. 3) leads to the results in Figure 4. This figure shows the most desired result of an FFT of a single-flank test (SFT) of a gear set showing only an excitation due to the designed motion error.

The FFT of an SFT of a measured real gear set (Fig. 5) shows a different behavior than the analysis of the theoretical gear set (Fig. 3), especially in the higher mesh harmonic range.

The amplitude of the 6th mesh harmonic is pronounced, which is not obvious in the analysis of the designed motion-error. In this case the amplitude of the sixth mesh harmonic is at 9.4 µrad. It is assumed that surface structure effects/waviness on the standard ground flank lead to the effects of a higher sixth mesh harmonic. To trace back these effects, they are replicated via simulation with a purposely introduced surface structure (Fig. 6). Here the simulated transmission error does not only consist of the designed motion error, but also of a surface structure with a pattern of six-grooves-per-motion error parabola.

An FFT of the transmission error (Fig. 6) leads to the results in Figure 7; Figure 7 shows the result of an FFT of a simulated SFT of a gear set, including an additional surface structure (waviness); and due to that, an additional excitation of the sixth mesh harmonic, correlating to the measurement of the real gear set.

The simulation including the surface structure represents a simple model leading to the wanted replication of the effects of a higher sixth mesh harmonic measured during an SFT of the real gear set.

The most efficient way to lower the amplified excitations in Figure 7 would be the elimination or reduction of the effects that take place during the standard grinding process itself. This is desirable, but the possibilities are generally limited by machine stiffness and dynamic behavior in the grinding process.

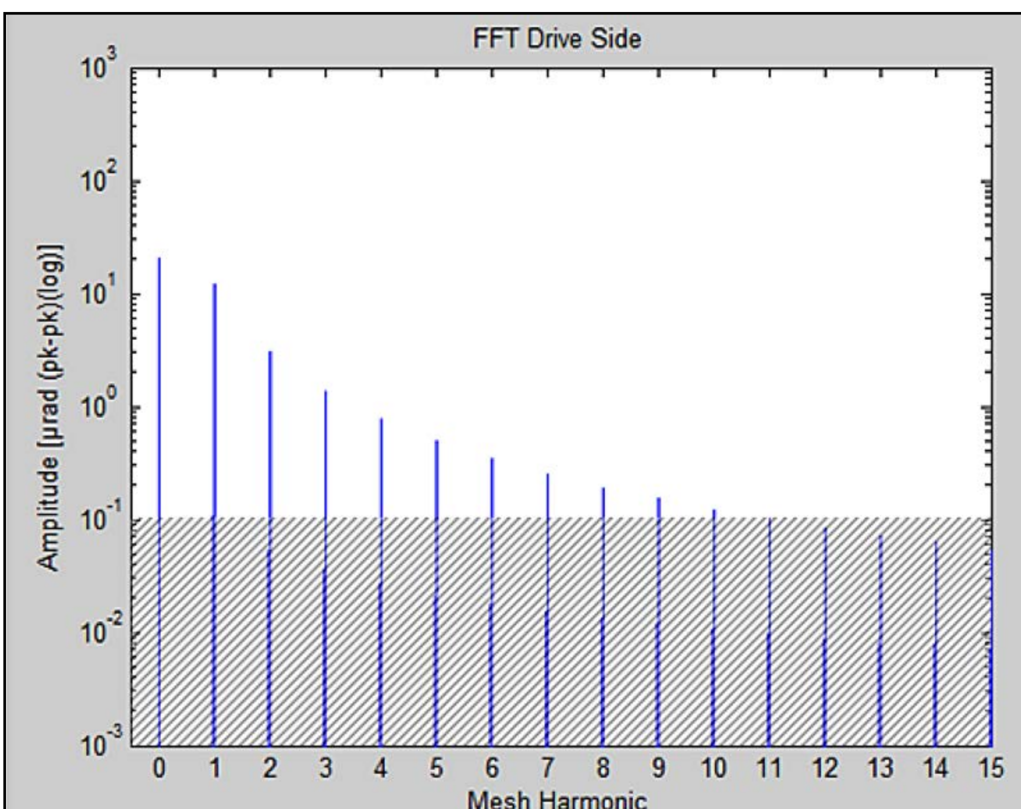

Figure 4 FFT of transmission error caused by designed motion error without any surface structure (waviness).

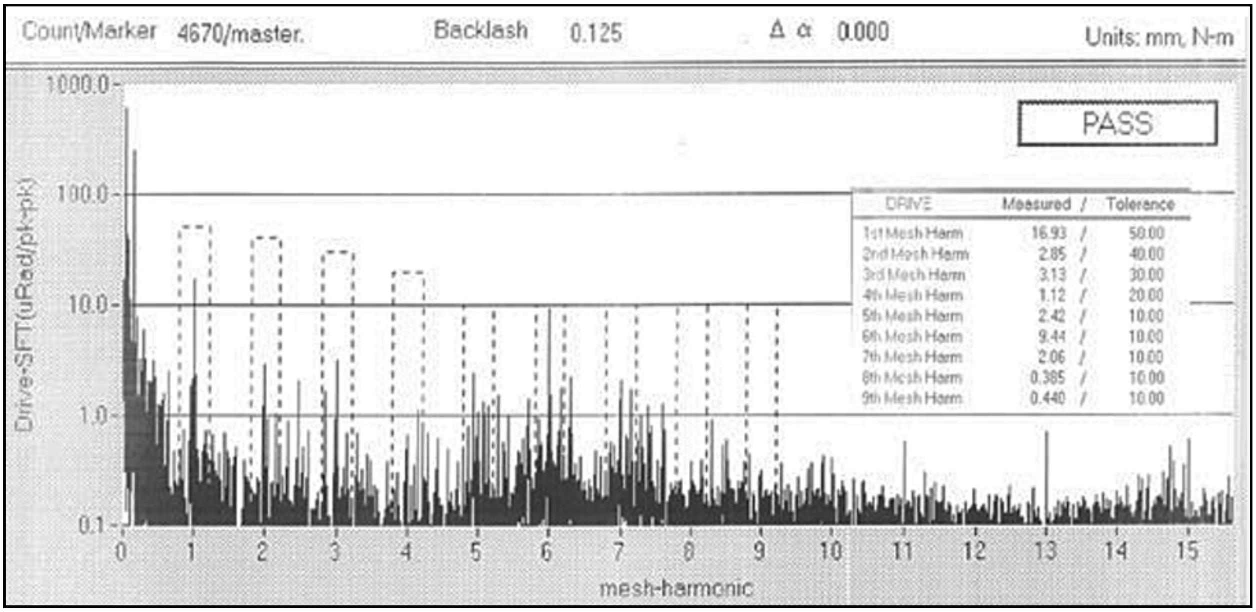

Figure 5 FFT of SFT of a real gear set (baseline) with high 6th mesh harmonic.

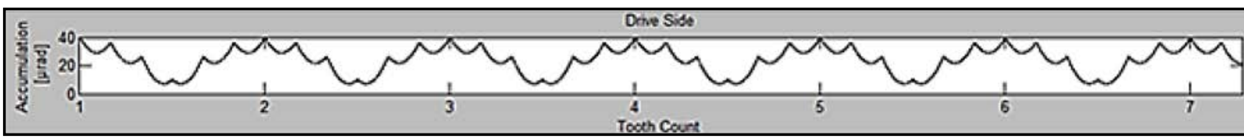

Figure 6 Simulation of transmission (motion) error — including anticipated surface structure (waviness) — leading to a high 6th mesh harmonic excitation.

Other ways to change the excitation behavior are to change several parameters of the standard grinding process. One example is to grind with lower roll rates. If the machine vibrations during grinding are independent of the roll rate and keep their frequency, then the resulting surface structures will become finer. This will lead to a shift of the excitations from lower to higher mesh harmonics.

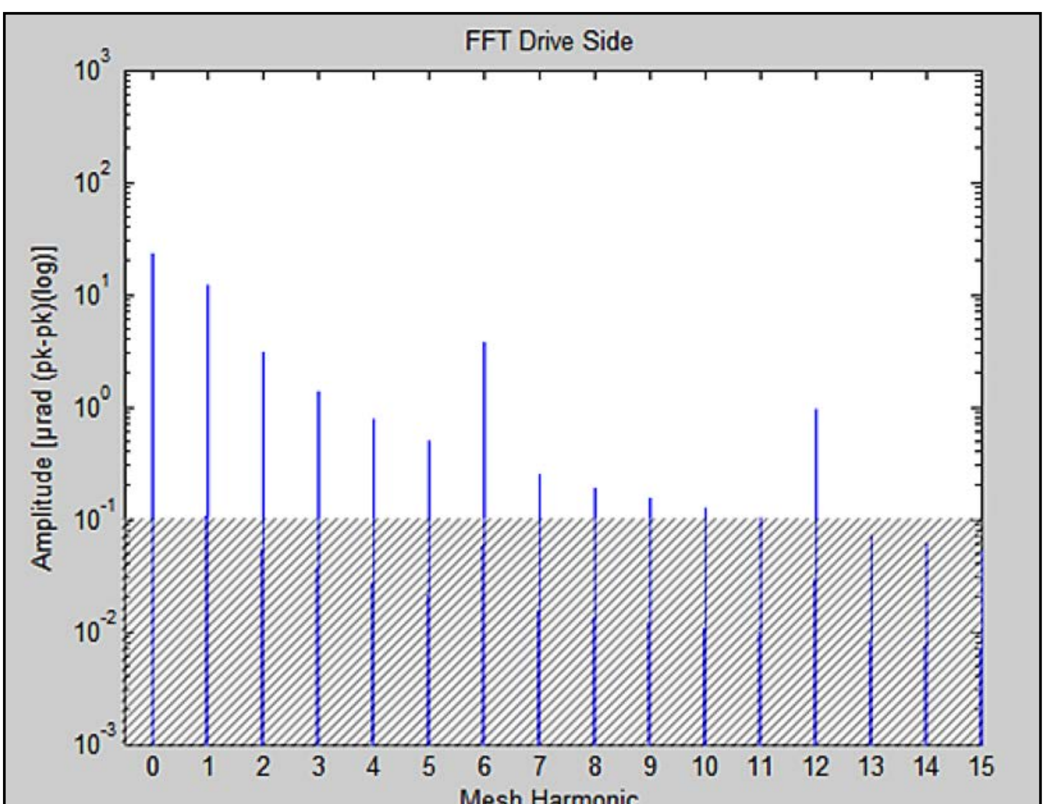

Figure 7 FFT of transmission error, including waviness leading to increased amplitudes of 6th and 12th order mesh harmonics.

Excitation problems can always occur on both members of the gear set. If one member is already ground in a certain quantity, then counteractions can only be applied to the other member. A purposely introduced waviness to offset the problems of the opposite member (EP 20130006061) seems impractical — in bevel gear grinding in particular — if this requires dressing waviness in the grinding wheel profile. The roll motion in generated pinions and gears and the plunging motion in non-generated gears will not allow certain grinding wheel profile waves to be transferred to the flank surfaces. The process, affected by relative sliding between grinding wheel profile and flank surfaces, would wipe out sinusoidal or similar wave forms with maxima, minima, and inflection points. Therefore the inventive process does not use modifications to the grinding wheel profile, but strictly uses machine motions (MicroPulse) and process parameters (roll-positions) to introduce and alter surface structures, and is therefore limited to the generated member.

The theoretical idea is to change and improve the excitation behavior by changing the position of the surface structure (waviness) on each flank (structure shift), which is fundamentally different from the ideas of unequal tooth spacing that are referenced as state of the art. A change of the spacing in a defined or random way will lower the gear quality according to the internationally defined standards. Spacing variations cause also negative side effects like low frequency rumbling, which is not the case in the inventive process.

In case of a structure shift, only the surface structure is addressed in a defined way. Depending on the case, the surface structure in the entire generated flank area is positioned differently, e.g. — from slot to slot. In all cases this is done via roll-position-shifts and/or roll-increment-changes and/or via utilizing the MicroPulse motions.

Case 1. To change and improve the excitation behavior, the following steps are applied according to Case 1), which utilizes

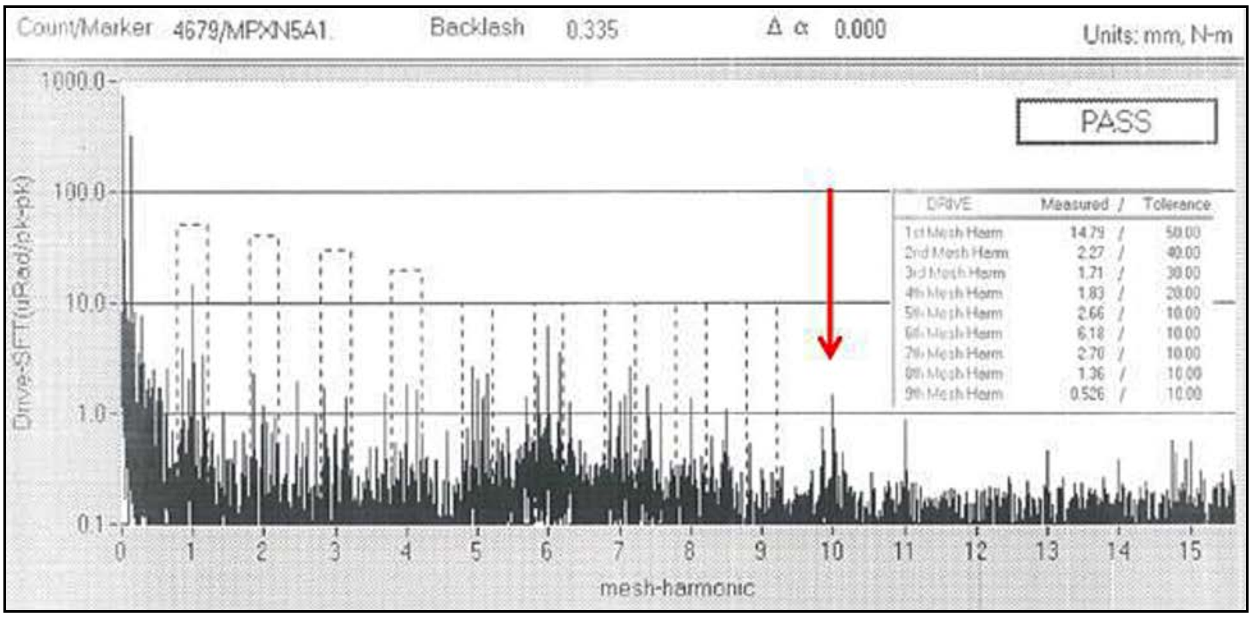

Figure 8 FFT of transmission error with MicroPulse leading to increased amplitude of 10th and 11th order mesh harmonics.

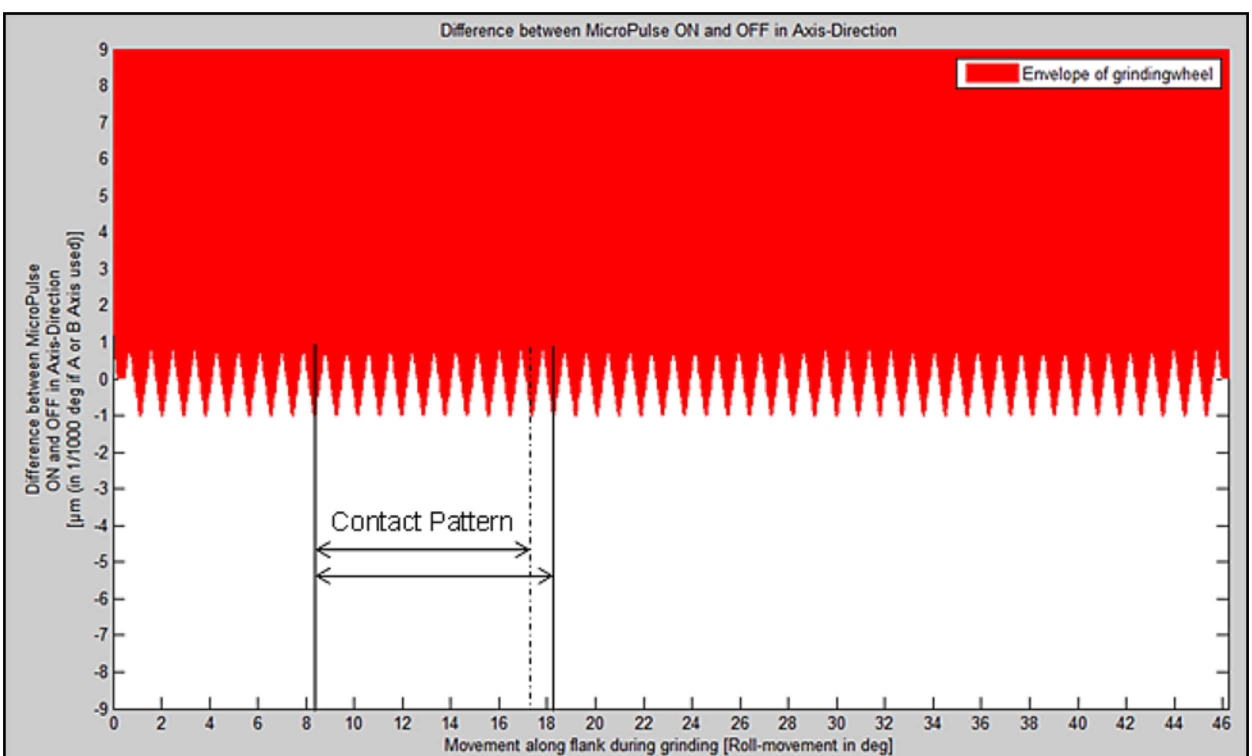

Figure 9 Theoretical effect of MicroPulse on surface structure, leading to an excitation of 10th and 11th order mesh harmonic (here N=5).

MicroPulse motions and a predetermined change of the roll positions per slot.

The objected harmonic is identified via an SFT or similar test (Fig. 5), possibly using a master gear for the uninfluenced member. In this example the sixth mesh harmonic is the objected harmonic.

The iteration process is started to identify the correct MicroPulse parameters and to correlate them to the objected mesh harmonic. In a first grind of the generated member, the MicroPulse division-factor (parameter) N is chosen via educated guess. The amplitude A is chosen within the range of one 1 µm to alter the X axis motions. This axis moves the grinding wheel almost perpendicular into the flank surface.

The SFT of the newly ground part rolling with the master gear delivers a distinctly higher excitation of a certain harmonic (Fig. 8).

Based on the artificially excited harmonic (Fig. 8), a correlation can be established between the division-factor N of the MicroPulse and the introduced surface structure, leading to a distinct higher harmonic (Fig. 9).

In this case the chosen division-factor of $N=5$ leads to a higher 10th and 11th mesh harmonic.

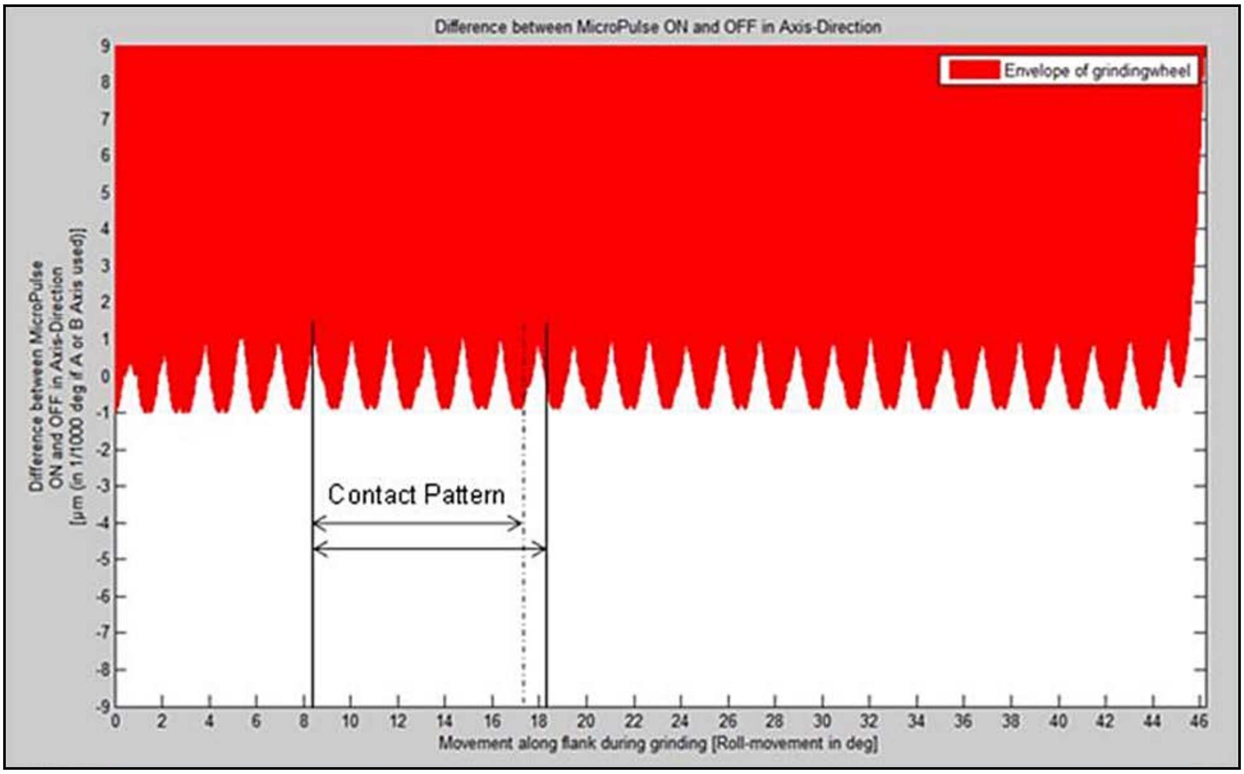

Figure 10 **Theoretical effect of MicroPulse on surface structure with iterated and correct parameter *N*; predicted to lead to an excitation of the 6th mesh harmonic (here *N*=8).**

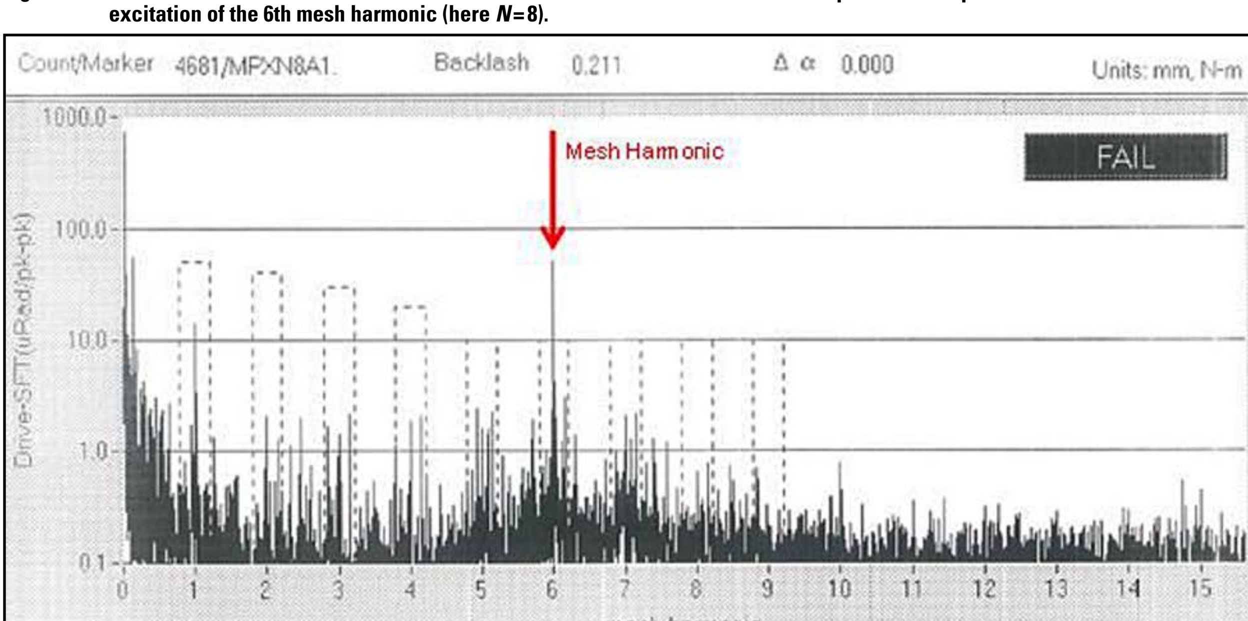

Figure 11 **Measured FFT of real SFT with higher 6th mesh harmonic due to MicroPulse.**

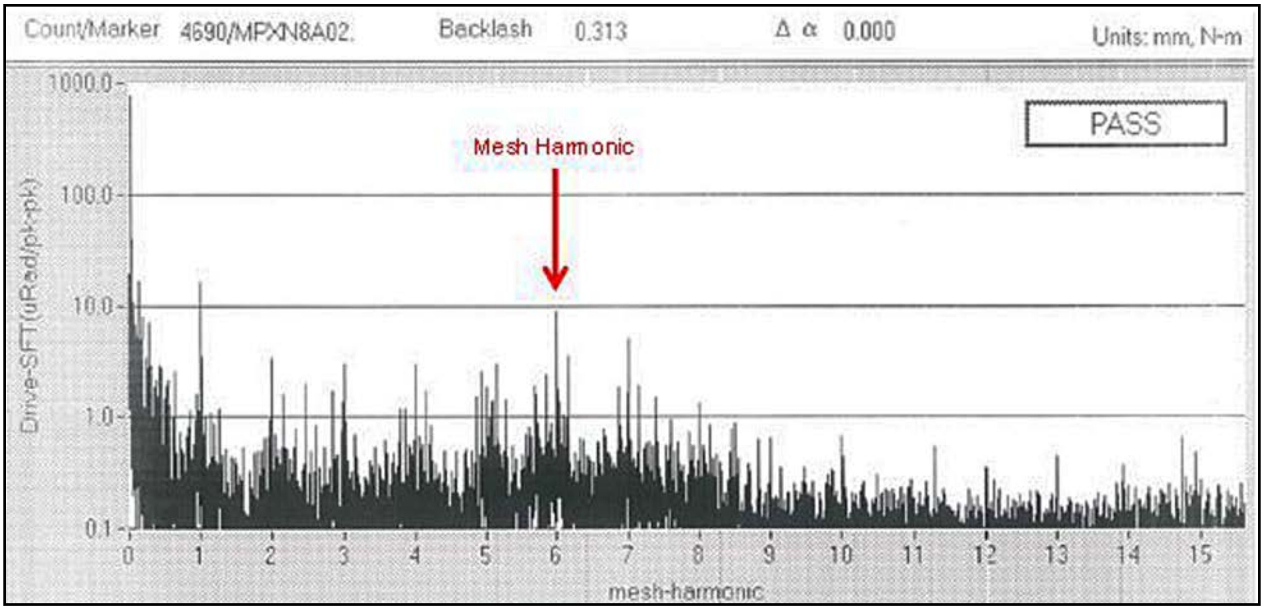

Figure 12 Measured FFT of real SFT with higher 6th mesh harmonic (8.8 µrad) due to MicroPulse with $N = 8$ and $A = 0.2$ µm.

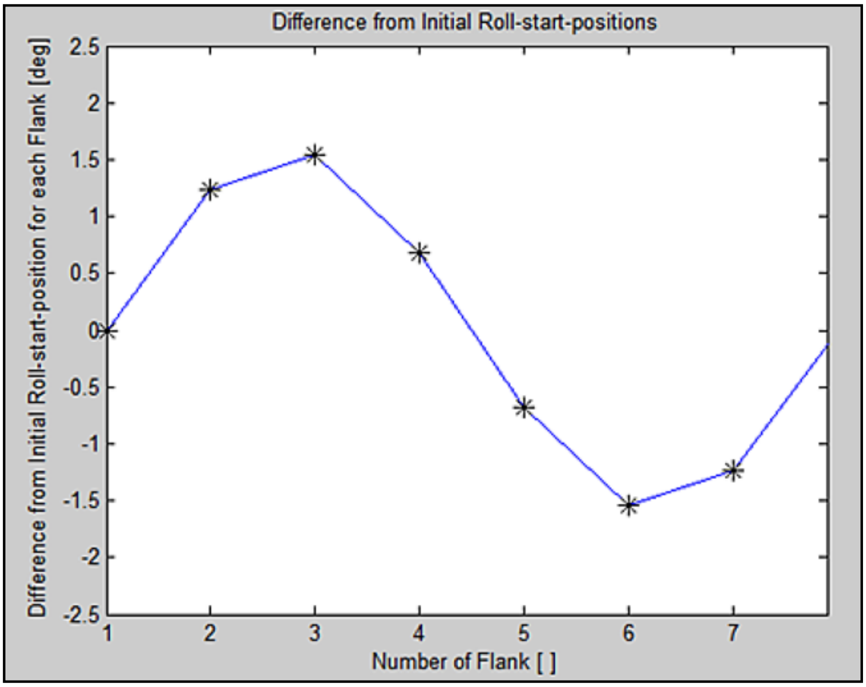

Figure 13 New start roll-positions for every slot with $N_R = N - 1$ (here $N = 8$).

With this correlated MicroPulse parameter N the new correct parameter N^* is calculated via simulation of the MicroPulse process (Fig. 10), which leads to an excitation of the objected mesh harmonic (Fig. 11). If required, after having the part ground with the new parameters, additional iterations must be conducted to address the objected mesh harmonic. This leads to the correct final parameter N.

The amplitude A of MicroPulse is lowered to an amount where the influence is still measurable and influencing the objected harmonic. The amounts will be in the lower tenth of a micron range (Fig. 12).

The shift of the pattern from flank to flank is calculated via the following procedure:

The amount of roll angle per line (RAPL) of the original axis-position-table is calculated:

$$RAPL = \frac{(Toe-roll-position)-(Heel-roll-position)}{Number\ of\ lines\ in\ axis-position-table} \quad (1)$$

The parameters triggering the shifted surface structure counteract the effects of the original surface structure, and are calculated from the MicroPulse parameters. To calculate the correlating shift in the roll-position for every slot (ΔRP_j) to change the surface structure from slot to slot, the previously determined division-factor N of MicroPulse is utilized. The shift-amplitude-factor N_R is calculated for a shift that is organized via a sine function:

$$\Delta RP_{j=i+1} = A_s * \sin\left[\left(\frac{2*\pi}{z_1}\right)*i\right] \quad (2)$$

with,

$$A_s = N_R * RAPL \quad (3)$$

with,

$$N_R = N - 1 \quad (4)$$

This formula will lead to a shift utilizing the maximal amount of amplitude. This means that when organizing the shift via one sine-wave, patterns that are maximally shifted will theoretically line up with the original non-shifted surface structure.

Alternatively

$$N_R = N - (1 + 0.1 * N) \quad (5)$$

This will lower the maximal amount of utilized shift-amplitude so that, theoretically, no alignments with the original structure will occur.

The shift-amplitude-factor in this case correlates to MicroPulse parameter *N* but can also be a factor calculated and chosen in a different way.

The shift-amplitude A_s is calculated via this formula:

$$A_s = N_R * RAPL \quad (6)$$

To calculate the amount and distribution of shift of the roll-position for each slot (ΔRP_j), a single sine-wave is utilized.

$$\Delta RP_{j=i+1} = A_s * \sin\left[\left(\frac{2*\pi}{z_1}\right)*i\right] \quad (7)$$

with i going from 0 to (z_1-1) and with z_1 being the number of teeth of the part.

The newly calculated ΔRP_j are added to the toe-(dwell) and heel-(dwell)-roll-positions for every slot, whereas the slot number $j=1$ has the untouched baseline roll-positions, thus leading to changed roll-positions (Figs. 13 and 14).

Also, other shift-patterns are possible; for example, a linear shift with a manually chosen amount of shift for every slot; the center of roll is not changed.

This leads to a pattern-shift $\Delta\varphi_i$ for every flank. Figure 15 shows the pattern shift for

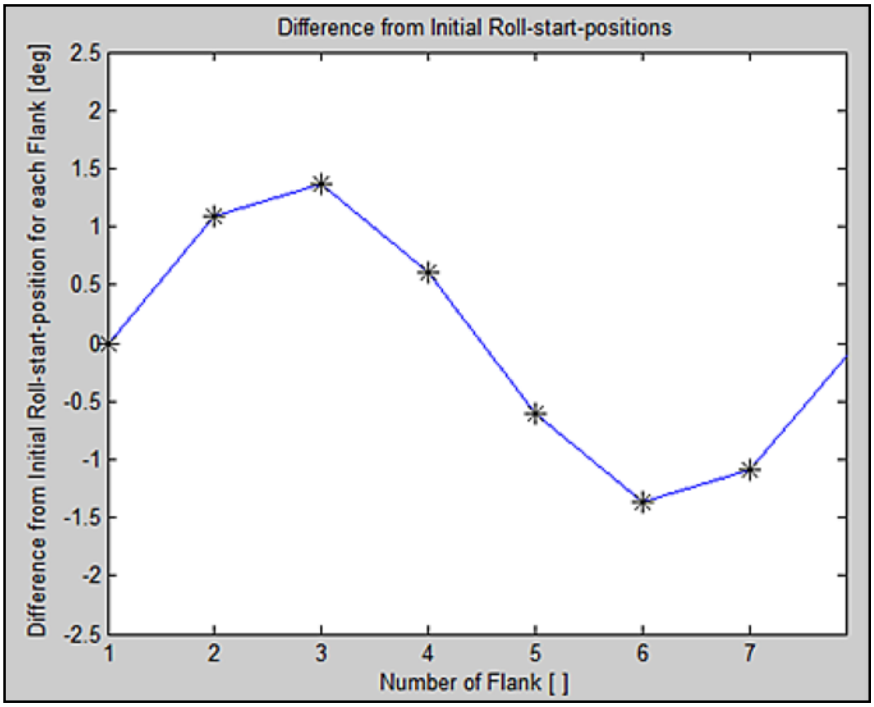

Figure 14 New start roll-positions for every slot with $N_R = N-(1+0.1*N)$ (here $N=8$).

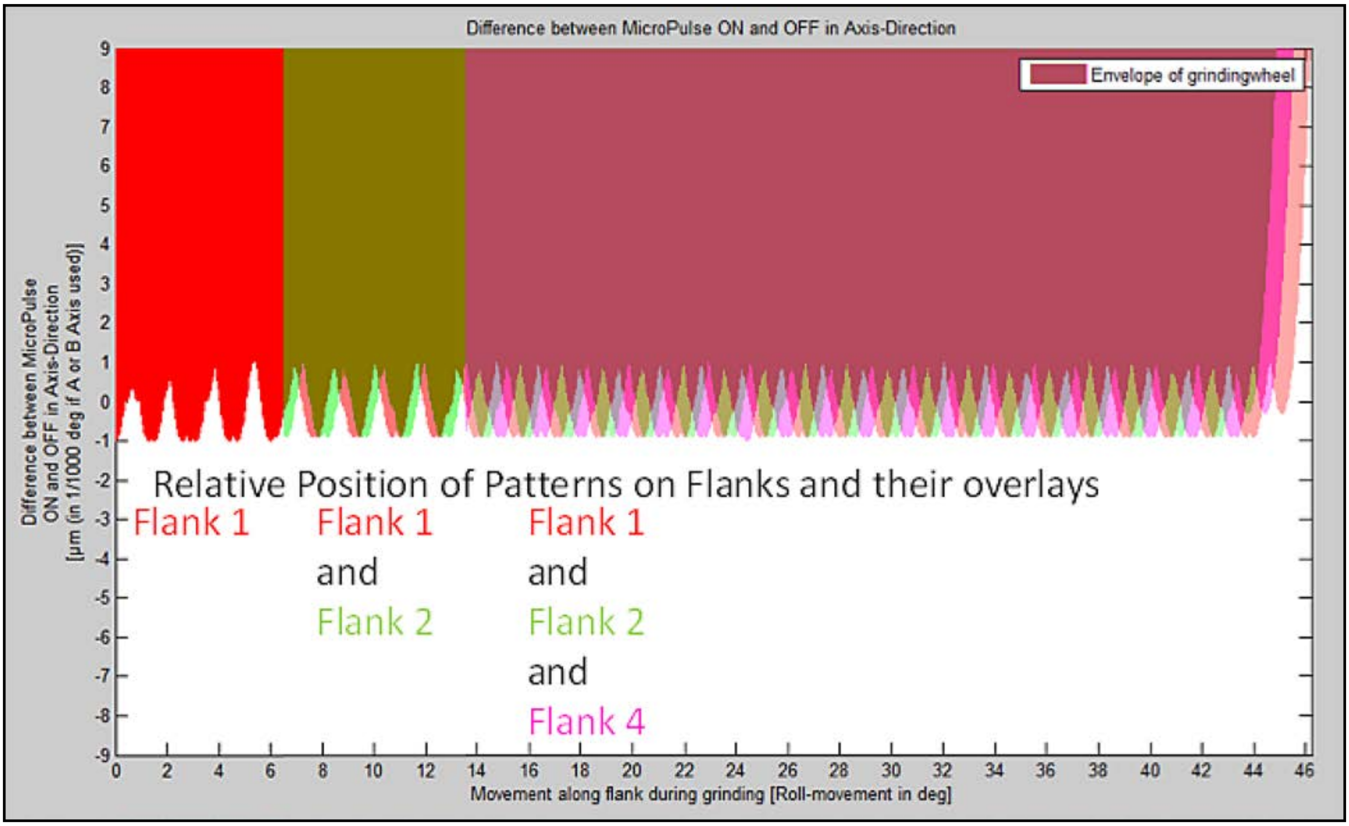

Figure 15 Relative position of patterns on flanks in regard to the new roll-positions for every slot (here $N=8$, $A=1$ µm).

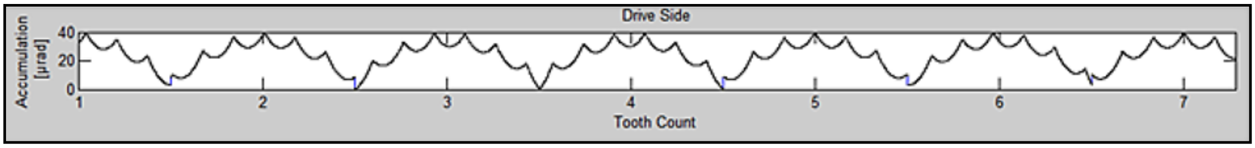

Figure 16 Simulation of transmission (motion) error, including anticipated surface structure.

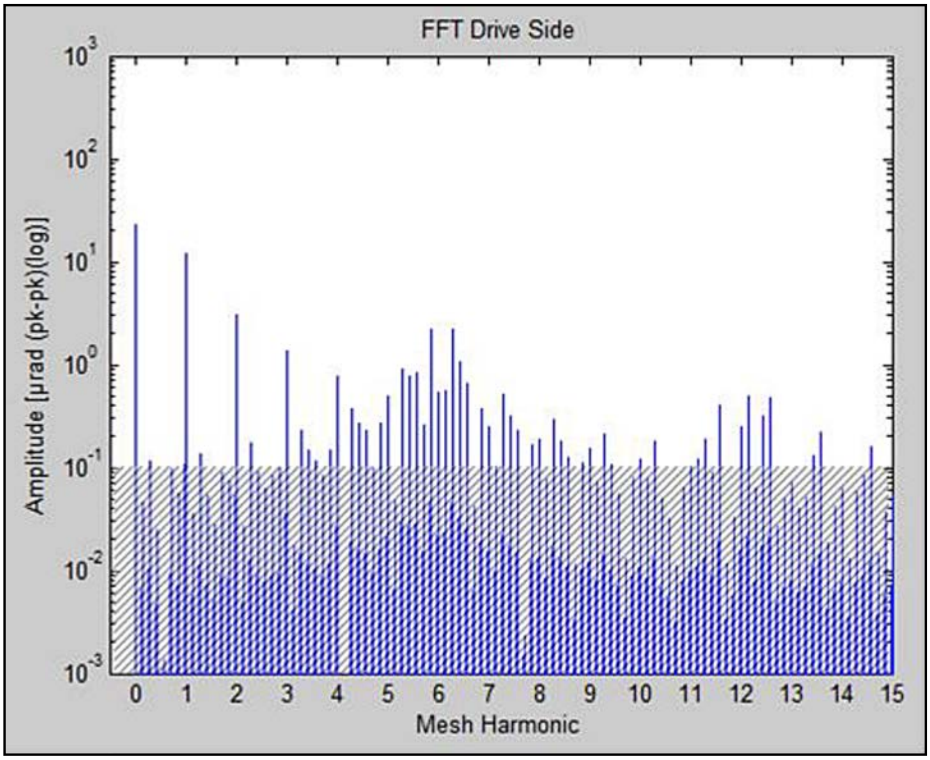

Figure 17 FFT of transmission error, including introduced surface structure with shift of structure from flank to flank, leading to lowered peak harmonics and to introduction of sidebands around 6th- and 12th-order mesh harmonics.

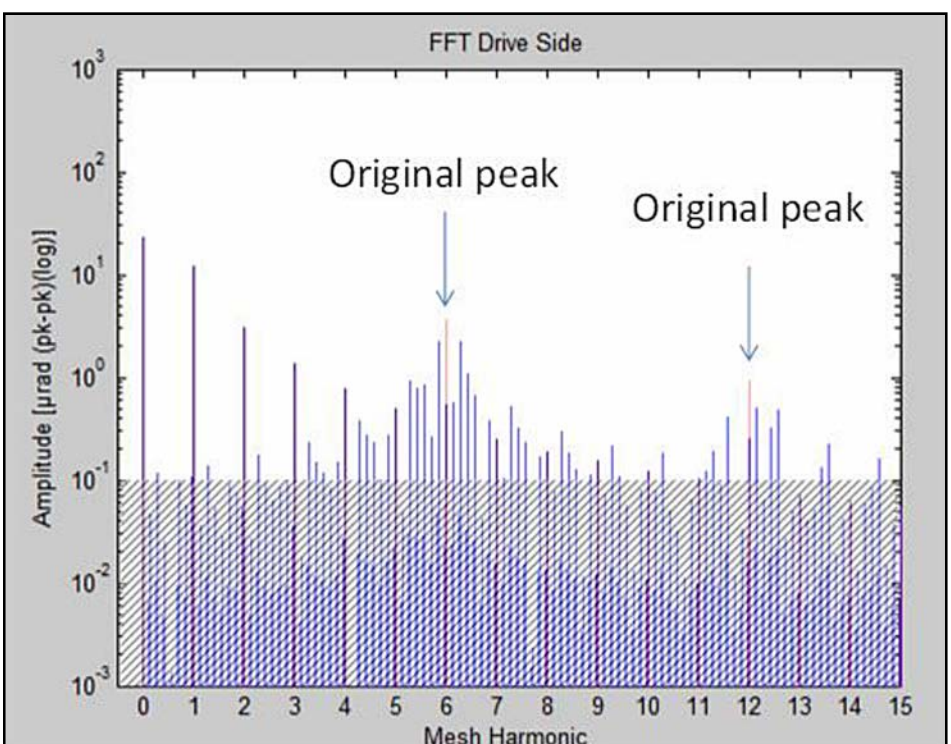

Figure 18 Comparison of FFT of transmission error, including introduced surface structure with (blue) and without (red, Fig. 7) shift of structure from flank to flank, leading to lowered peak harmonics and introduction of sidebands around 6th- and 12th-order mesh harmonics.

three flanks using $N_R = N - 1$. For better visibility, the amplitude is chosen with $A = 1\,\mu\text{m}$.

Applying the pattern shift to the simulation of the transmission error results in the surface structure shown (Fig. 16); every flank shows a differing position of the surface structure, leading to the simulated FFT of SFT (Fig. 17).

The comparison of the simulation with introduced surface structure and no shift (Fig. 7) — with the shifted surface structure (Fig. 17) — is shown (Fig. 18). The red graph shows the original non-shifted FFT of the simulated SFT (Fig. 7), whereas the blue graph shows the FFT of the SFT of the shifted surface structure.

By applying factors for the surface structure shift that were gleaned — via simulation to real-world grinding process — we learn that this approach leads to a following of actual-measured FFT of SFT (Fig. 19), and can be compared to the results of the original FFT of the baseline SFT (Fig. 5). The 6th mesh harmonic amounts to 1.4 µrad; maximal amount of the sidebands is 4.5 µrad.

Case 2. In this case, only a roll-position-shift is utilized without any additional micro-motions via MicroPulse. Facets at high roll rates can correlate to the lines in the axis-position-table and to the excited mesh harmonics. To improve and change the excitation behavior in these situations, the already-existing surface structure is shifted on the flank surface.

The shift-amplitude A_{SR} in roll-position for every slot is calculated via this formula:

$$\Delta RP_{j=i+1} = A_{SR} * \sin\left[\left(\frac{2*\pi}{z_1}\right)*i\right] \tag{8}$$

with,

$A_{SR} = RAPL$ and i going from 0 to $(z_1{-}1)$ and with z_1 being the number of teeth of the part.

Figure 20 shows the FFT of SFT using unmodified roll-positions, and Figure 21 shows the FFT of SFT using modified roll-positions.

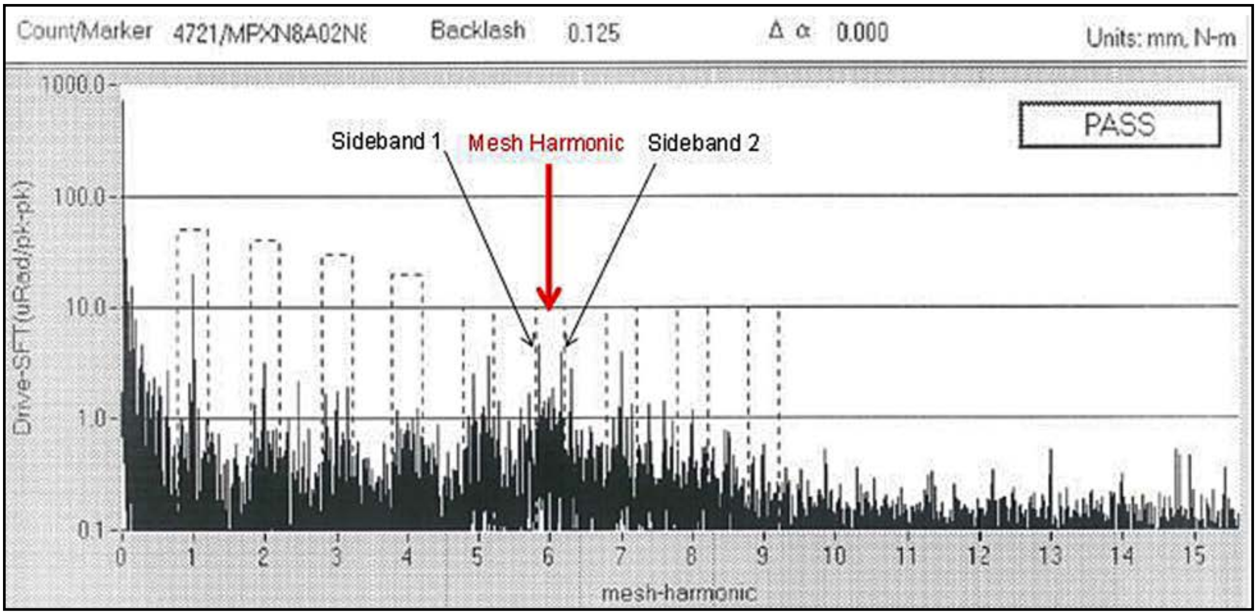

Figure 19 Measured FFT of real SFT with introduced and shifted surface structure via MicroPulse ($N=8$, $A=0.2\,\mu m$).

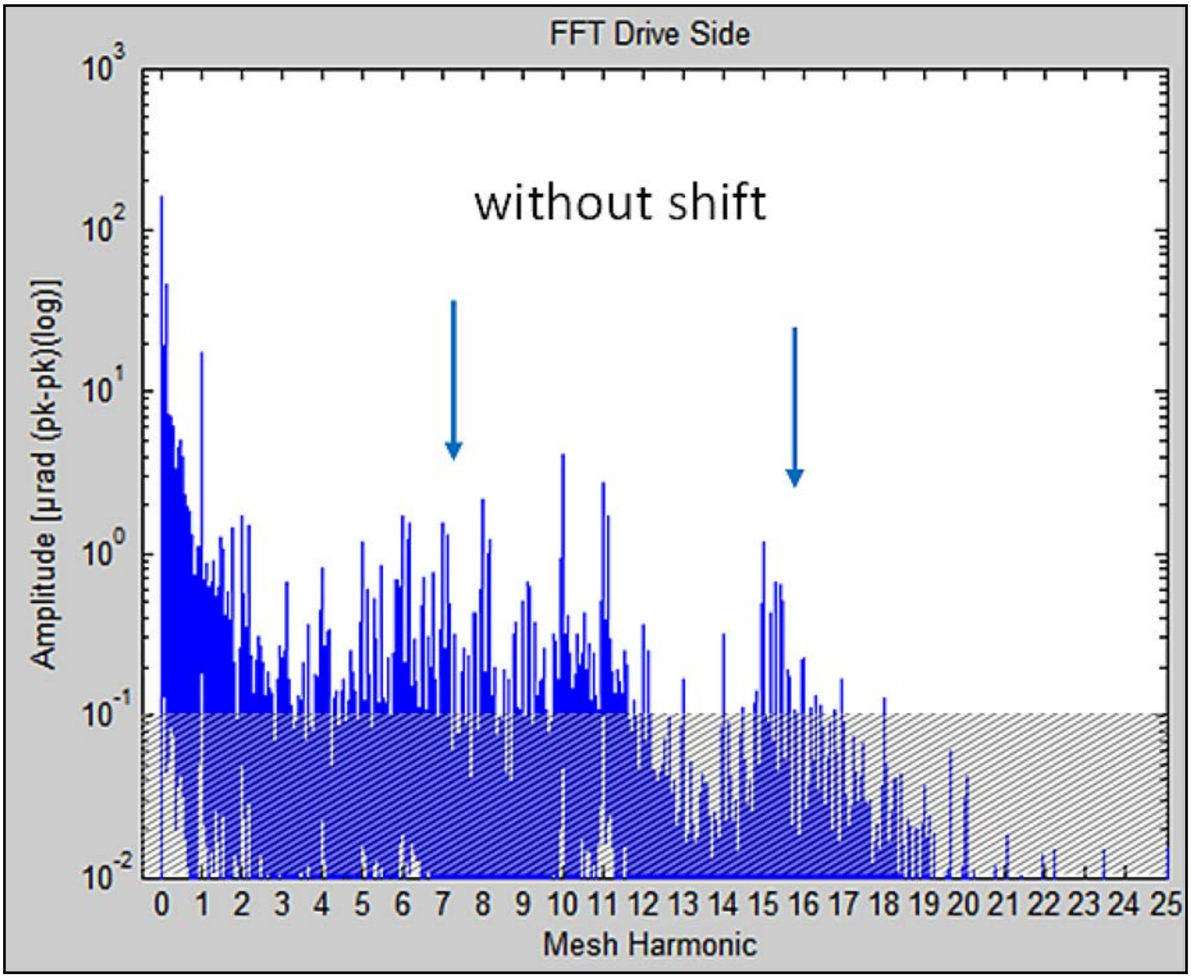

Figure 20 Measured FFT of real SFT with ground at a roll-rate of 20°/s without any roll position-shift.

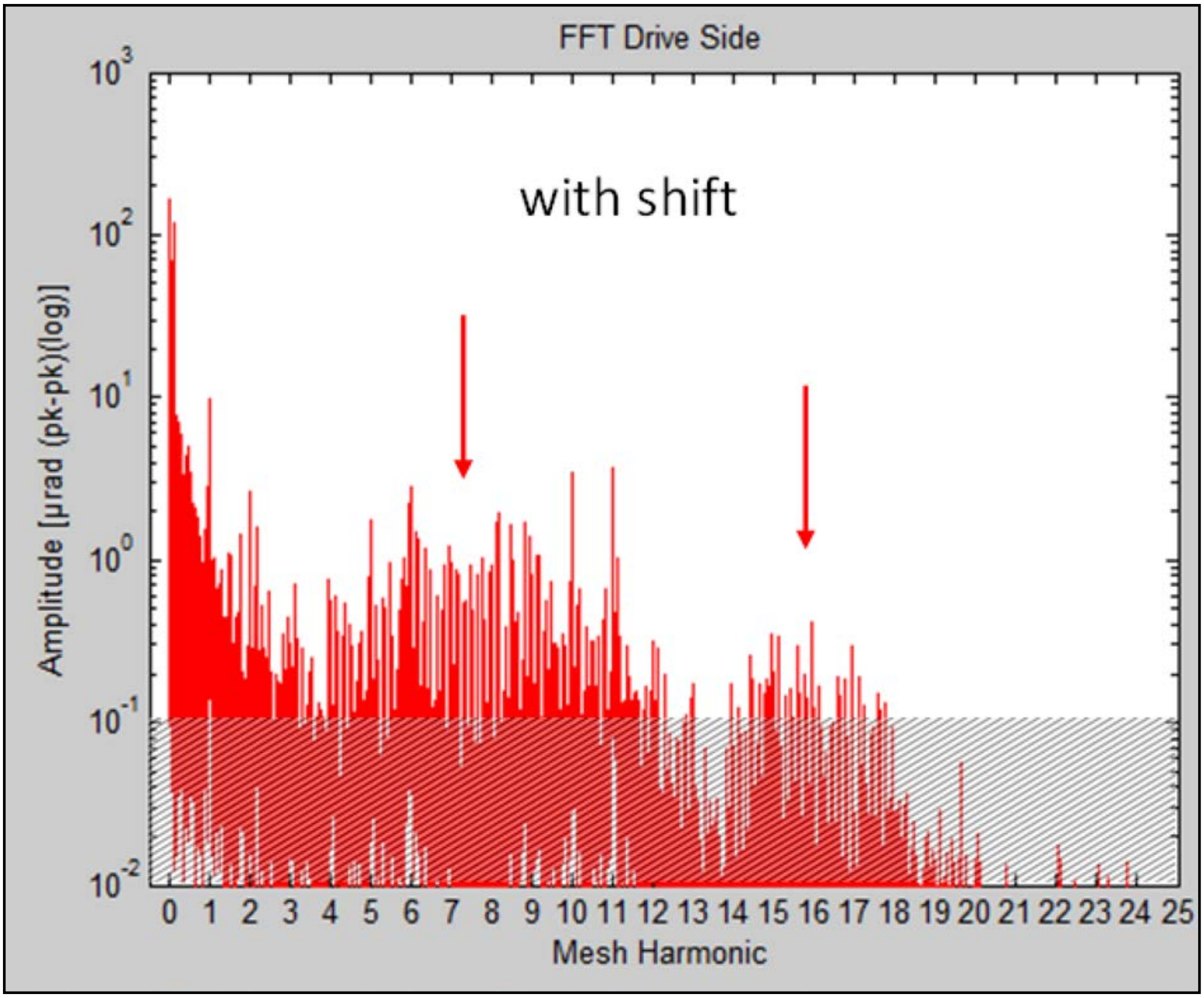

Figure 21 **Measured FFT of real SFT with ground at a roll-rate of 20°/s with roll-position-shift.**

Visible are the high peak harmonics in the area of 7th to 8th mesh harmonic, as well as in the area of the 14th to 16th mesh harmonic.

Visible is the lowering of peak harmonics in the area of 7th to 8th mesh harmonic as well as in the area of the 14th to 16th mesh harmonic.

The 10th and 11th mesh harmonic were identified as machine-introduced harmonics.

Case 3. In this case only the MicroPulse motions are utilized to introduce and alter the position of the facets on each flank. Patterns can only be realized if the resolution of the axis position table is sufficient.

Case 4. In this case, the distances of the roll angle increments in the axis position table along a slot (from start-roll position to end-roll position) are changed with or without a different function (for example, sine-function) for every slot. This process can also include additional MicroPulse axis movements.

Case 5. Changing the position for every facet/waviness for every flank with the same amount of shift (every flank has the same pattern, only shifted versus the original pattern) utilizing roll position shift and/or MicroPulse. This change is targeted to counteract dynamic effects during the grinding process.

Discussion and Future Work

Today, basic calculation tools for the "surface structure shift" are used to optimize gear sets, starting with an educated guess, calculation of the addressed mesh harmonic, and a guided optimization, as shown in this paper.

An alternative to the iteration process could be to calculate the exact division-factor *N* via the theoretical analysis of the contact pattern — assuming that theoretical and practical contact have a high correlation for the objected gear set. This means that if the objected gear set is far away from the original design, a "fresh" development or a reverse engineering via CMM to obtain the actual TCA is required. The first and last roll positions for the beginning and end of the contacting area at low load are obtained via analytical tooth contact analysis, e.g. — *Unical.*

The existing surface structure within this roll angle has a certain pattern, based on the SFT result, which is then replicated with the correct choice of the division factor *N* of the MicroPulse process. This should be done via simulation tools leading, e.g., to a MicroPulse pattern with six peaks within the contacting area.

In addition, future developments regarding the surface structure should focus not only on generated, but also on the non-generated members.

The tool of the "surface structure shift" is relatively new and needs further investigation and practical studies. This should include testing not only of gear sets on the test rig, but also end-of-line tests as well as vehicle testing.

Conclusion

- The results show that there is an effect of the "surface structure shift" as a tool to address a targeted reduction of excitation of higher harmonics in ground bevel gear sets.
- The theoretical background of "surface structure shift" and MicroPulse are explained at the beginning of this paper. After this, several cases are shown, on how to influence the surface structure with these tools. The two most relevant cases are explained in detail. Case 1 utilizes additional machine motions (MicroPulse) to influence the surface structure on the generated ground bevel gear flank surface, in combination with the "surface structure shift," predictably altering the surface structure from flank to flank. This leads, as shown via practical example, to the capability of lowering higher mesh harmonic excitations while introducing sidebands.
- Case 2 only uses the surface structure shift, without additional machine motions, and is preferably used under high-speed machine motions, leading to an improved higher mesh harmonic behavior.
- In general, the processes presented here aim at predictably introducing more sidebands while lowering higher mesh harmonic peak amplitudes.

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Sebastian Strunk, upon completing an apprenticeship as automotive mechatronic technician at Mercedes-Benz in Bremen, Germany, began his bachelor studies in automotive engineering at Ilmenau University of Technology in 2009. He completed his Bachelor thesis, i.e.—efficiency improvements of newly designed, automatic transmissions—during an internship in the R&D department of Mercedes-Benz in Stuttgart, Germany in 2013. His passion for transmissions and gears prompted him to apply for an internship at The Gleason Works in Rochester, New York. The intership began in April, 2014, during which time he wrote his Master Thesis about the roll-optimization of ground bevel gears. After finishing both his thesis and a brief stint working in Ludwigsburg, Germany for Gleason-Pfauter, Strunk in late 2015 returned to the U.S. to begin work in the R&D department of The Gleason Works.

Designing Very Strong Gear Teeth by Means of High Pressure Angles

Rick Miller

The purpose of this paper is to present a method of designing and specifying gear teeth with much higher bending and surface contact strength (reduced bending and surface contact stresses). The primary means of achieving this is by specifying gear teeth with significantly higher pressure angles. This paper will show calculation procedures, mathematical solutions, and the theoretical background and equations to do this. The required user input factors for the method described in this paper are: numbers of teeth, pinion and gear; diametral pitch; center distance; desired minimum top land, pinion and gear; desired contact ratio; and maximum backlash. The desired pressure angle can then be entered and another value re-entered to make comparisons. The output factors would be the outside diameters of the pinion and gear, and other gear data, based on the entered pressure angle. In the past, higher pressure angle gears have not been commonly designed and specified because of the relative difficulties involved in designing them and the lack of appropriate and easy-to-use tools to evaluate them. This paper contributes to making it easier to accomplish this task.

(The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.)

Introduction and Background

By convention, commonality of cutting tools, and familiarity, several pressure angle choices have become industry standards for gear designs. These include 14.5, 20, 22.5 and 25° pressure angles. Twenty and 25° pressure angle gears are typically the most commonly used today, although pressure angles as high as 28° to 30° have been used on occasion for maximum-strength applications.

Higher pressure angle designs were typically not considered or used because of the limitations listed above, the most significant being reduced gear teeth top lands and fillet radius. Standard gear tooth proportions and universal rack geometry are based on the pressure angles listed above and do not lend themselves to designing gears with pressure angles above around 30°.

For higher pressure angle gear designs, numbers of teeth and other gear tooth macro-geometry items must be considered carefully so that the natural limitations of high pressure angle gearing are avoided while exploiting their benefits.

If not carefully designed, manufacturing the gears can be difficult and more expensive. Gear cutting tools will usually be non-standard. Gear noise will usually be higher due to the decreased contact ratio and reduced root/tip clearance, which can entrap oil.

Separating force from the gear teeth increases directly with the tangent of the pressure angle. In parallel shaft assemblies, this needs to be considered, as the increased forces arising from high pressure angle gears may unacceptably shorten shaft or bearing life. In planetary gearboxes, the net separating force is theoretically zero: the sun/planet separating force is canceled out by the planet/ring separating force. Therefore, planetary applications offer an excellent opportunity to utilize higher pressure angle gear teeth.

The advantage of the methods described in this paper is that gear teeth and gear tooth data of various different pressure angles can be calculated, compared and evaluated quickly and easily, and high pressure angle gears can be designed and specified. Gears can be designed based on desired top lands, contact ratio, and hob tip radius.

Discussion

As stated above, two of the primary attributes of high pressure angle gears that are potentially limiting factors and therefore must be considered, calculated, and accounted for are: 1) circular tooth thickness at the outside diameter of the gear (top land thickness); and 2) hob tip radius and the resulting generated tooth root fillet radius; both of these are considered — each in a separate section.

In this report four separate gear tooth pairs are evaluated and described:

1. Traditionally designed gearset with 25° pressure angle serving as reference design
2. High pressure angle gearset with hob tip radius of zero and 36° pressure angle
3. High pressure angle gearset with a 0.007 inch hob tip radius and 35° pressure angle
4. High pressure angle gearset with a 0.020 inch hob tip radius and 33.5° pressure angle

To ease in the evaluation and comparison, and to isolate the pressure angle influence on the results so that pressure angle is the main variable, the following inputs remain the same for both the traditional 25° pressure angle design and the high (maximized) pressure angle design:

Numbers of gear and pinion teeth; diametral pitch; center distance (standard center distance); the circular tooth thickness of pinion and gear for the high pressure angle gears is equal and is set by the backlash. The 25° pressure angle reference design uses 15% long addendum pinion and 15% short addendum gear tooth proportions and the resulting gear tooth circular tooth thicknesses to provide close to equal bending stresses for the pinion and gear. This represents a typical relatively standard gear design.

Program user inputs

- Number of teeth, pinion and gear: z_1, z_2
- Diametral pitch: P_d
- Center distance (default = standard): a
- Desired minimum top land, pinion and gear: T_{oP}, T_{oG}
- Desired contact ratio: m_c
- Maximum backlash: B

Summary of user inputs for example of high pressure angle gear set run

- 16 tooth pinion, 29 tooth gear
- 6 diametral pitch
- 3.75 inch center distance (standard)
- Desired minimum top land, pinion and gear: 0.030 inch
- Desired contact ratio: 1.15
- Maximum backlash: 0.0120 inch

Definition of terms (Note: Subscripts P = pinion; G = gear, where necessary.)

z_1, z_2 = Number of teeth
D_{bP} = Base diameter, pinion
D_{bG} = Base diameter, gear
P_d = Diametral pitch
D_{oP} = Outside diameter, pinion
D_{oG} = Outside diameter, gear
d = Pitch diameter
t_o = Circular tooth thickness at outside diameter (or any known diameter)
a = Center distance
p_b = Base pitch
D_R = Root diameter
Z = Length of line of action
m_c = Contact ratio
ϕ = Pressure angle
ϕ_o = Pressure angle at outside diameter (or any known diameter)
s = Circular tooth thickness at standard pitch diameter

Calculations for pressure angle corresponding to input top land (tooth thickness at O.D.) and contact ratio, m_c

Mathematical solution:

$$D_o = \frac{d\cos\phi}{\cos\left(\text{arcinv}\left(\frac{s}{d} - \frac{t_o}{D_o} + \text{inv}\,\phi\right)\right)} \quad (1)$$

$$M_c = \frac{P_d\left(\sqrt{\left(\frac{D_{oP}}{2}\right)^2 - \left(\frac{D_{bP}}{2}\right)^2} + \sqrt{\left(\frac{D_{oG}}{2}\right)^2 - \left(\frac{D_{bG}}{2}\right)^2} - a\sin\phi\right)}{\pi\cos\phi} \quad (2)$$

Standard gear equations used:

$$d = \frac{z}{P_d}$$

$$D_b = d\cos\phi$$

$$p_b = \frac{(\pi\cos\phi)}{P_d}$$

$$s = \frac{\pi}{2P_d} - \frac{B}{2}$$

Calculation procedure. Using input information and standard gear equations above, calculate d, D_b, and s for pinion and gear. Since pressure angle is the unknown, create an initial trial value and substitute Equation 1 (above). Because the D_o term appears in the denominator as well as being the unknown variable solved for, the denominator value is set to the standard D_o value. Because the contribution of this term is small, the potential "error" that this causes is negligible to the end calculation. Calculate the outside diameter D_o for both pinion and gear from Equation 1.

Next, substitute the D_o values calculated from Equation 1 into Equation 2, and calculate the contact ratio at that pressure angle. Iterate the pressure angle and calculate using Equations 1 and 2 to converge on the desired contact ratio that was input. The result is the pressure angle necessary to achieve the desired contact ratio, top land, and also meet other input conditions.

Derivation of Equations

Outside diameter. Since top land is known by user input and circular tooth thickness s is known by calculation from inputs or as a separate input, Equation 3 can be solved for D_o:

$$t_o = D_o\left(\frac{s}{d} + \text{inv}\,\phi - \text{inv}\,\phi_o\right) \quad (3)$$

Solve Equation 3 for inv ϕ_o:

$$\text{inv}\,\phi = \frac{s}{d} - \frac{t_o}{D_o} + \text{inv}\,\phi \quad (4)$$

The involute function is $\text{inv}\,\phi = \tan\phi - \phi$ radians. If the numeric value of $\text{inv}\,\phi$ is known and the angle is desired, this contains a transcendental term, and the solution must be iterated using the Newton method; the result is called "ARCINV." Look up or solve for the angle of the ARCINV.

$$\cos\phi_o = \left(\frac{d\cos\phi}{D_o}\right) \quad (5)$$

$$\therefore D_o = \left(\frac{d\cos\phi}{\cos\phi_o}\right) \quad (6)$$

Substituting Equation 4 into Equation 6:

$$D_o = \frac{d\cos\phi}{\cos\left(\text{arcinv}\left(\frac{s}{d} - \frac{t_o}{D_o} + \text{inv}\,\phi\right)\right)} \quad (7)$$

Contact ratio:

$$m_c = \left(\frac{Z}{P_b}\right) \quad (8)$$

But Equation 9:

$$p_b = \left(\frac{\pi\cos\phi}{P_d}\right) \quad (9)$$

and Equation 10:

$$Z = \sqrt{\left(\frac{D_{oP}}{2}\right)^2 - \left(\frac{D_{bP}}{2}\right)^2} + \sqrt{\left(\frac{D_{oG}}{2}\right)^2 - \left(\frac{D_{bG}}{2}\right)^2} - a\sin\phi \quad (10)$$

Combining Equations 8, 9 and 10 gives:

$$m_c = \frac{P_d\left(\sqrt{\left(\frac{D_{oP}}{2}\right)^2 - \left(\frac{D_{bP}}{2}\right)^2} + \sqrt{\left(\frac{D_{oG}}{2}\right)^2 - \left(\frac{D_{bG}}{2}\right)^2} - a\sin\phi\right)}{\pi\cos\phi} \quad (11)$$

Any other pressure angle can be entered and another value re-entered to make comparisons.

A spreadsheet or computer program can be created from the equations and formulas included in this paper to automate the mathematical calculations.

As stated above, the result of this convergence routine shows the pressure angle for the gearset above with the design input values, considering the input value for top land thickness.

However, as also stated above, the second important consideration is the hob tip radius and the root fillet radius it generates for both the pinion and gear. The pressure angle for this consideration is almost certainly different from the pressure angle considering the pinion and gear top land only. So, in order for a gear design to meet both design criteria (matching the top lands and hob tip radius/tooth root fillet radius), the smaller of the two pressure angle values must be used in the design of the gear teeth.

All gear data and stress calculations were performed using the *AGMA GRS 3.1.7* gear rating suite program. Due to the length of the program data outputs, the data was summarized and shown in a more abbreviated format.

Result of calculation for pressure angle from example from top land consideration:

Pressure angle from top land input = 35°

Calculations for Pressure Angle Corresponding to Input Hob Tip Radius Consideration

Mathematical solution. Program inputs in addition to the inputs from the example above:

CSW = (circular space width of gear) which is also the circular tooth thickness of the hob tooth

b = dedendum of gear (addendum of hob tooth)

r = (hob tip radius)

Summary of User Inputs for Example of High Pressure

Angle Gearset Run for Hob Tip Radius Calculations

CSW = 0.2663 inch

b = 0.1833 inch

r = 0.020 inch

$$2\left(\left(\frac{r}{\sin\phi}\right)-r+b\right)\tan\phi=\mathrm{CSW} \qquad (12)$$

$$r\left[\frac{1-\sin\phi}{\cos\phi}\right]=\left(\frac{\mathrm{CSW}}{2}\right)-b\tan\phi \qquad (13)$$

$$r=\frac{\left[\left(\frac{\mathrm{CSW}}{2}\right)-b\tan\phi\right]\cos\phi}{1-\sin\phi} \qquad (14)$$

$$r=\frac{\left[\left(\frac{\mathrm{CSW}\cos\phi}{2}\right)-b\sin\phi\right.}{1-\sin\phi} \qquad (15)$$

When $r=0$:

$$\text{numerator}=\left(\frac{\mathrm{CSW}\cos\phi}{2}\right)-b\sin\phi=0$$

$$\frac{\mathrm{CSW}\cos\phi}{2}=b\sin\phi \qquad (16)$$

$$\tan\phi=\frac{\mathrm{CSW}}{2b} \qquad (17)$$

$$\phi=\tan^{-1}\left(\frac{\mathrm{CSW}}{2b}\right) \qquad (18)$$

This is the pressure angle for a hob tip radius of 0 (sharp corner).

Calculation method: using the values for r, b, and CSW, iterate the pressure angle and find the pressure angle that matches the input hob tip radius using Equation 15. Also, Equation 18 can be used to find the pressure angle that matches a hob tip radius of zero.

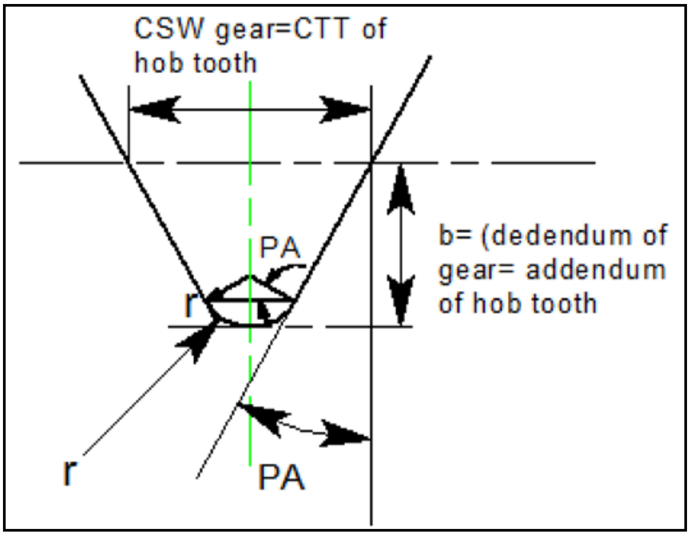


Figure 1 Hob tooth details.

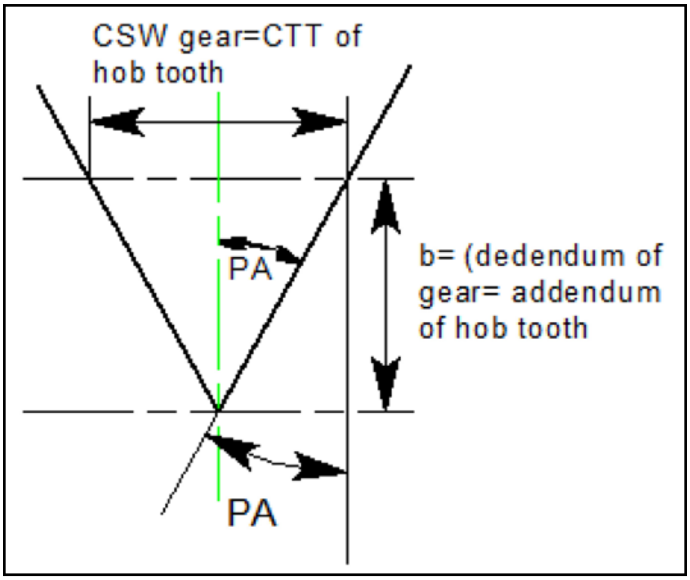


Figure 2 Hob tooth details for sharp corner (zero hob tip radius).

Once a pressure angle is calculated for the desired hob tip radius, enter this pressure angle into Equation 1 to determine the outside diameters for the pinion and gear, and into Equation 2 to determine and calculate the new contact ratio — which most likely will differ from the earlier input value. The remaining gear data and stress analysis calculations can be performed using these new values of pressure angle and outside diameters.

Result of calculation for pressure angle from example for hob tip radius:

For this example we want to avoid a zero hob tip radius, and we will set the hob tip radius to 0.020 inch and calculate the pressure angle of the gear teeth that will produce this 0.020 inch radius. A pressure angle of 33.5° is the calculated number, so a 33.5° pressure angle will be used for the further calculations of the remaining gear data and stress and rating analysis.

For a hob tip radius of zero (sharp corner), the pressure angle for the gear teeth is 36°.

SPUR GEAR SPECIFICATIONS

oerlikon fairfield

PART NUMBER	25 PA Pinion		25 PA Gear
---BASIC DATA ---			
NUMBER OF TEETH	16		29
RATIO		1.813 -- Hunting Tooth Ratio	
DIAMETRAL PITCH NORMAL		6.000	
CIRCULAR PITCH NORMAL		0.5236	
PRESSURE ANGLE NORMAL		25.000°	
HELIX ANGLE AND HAND	SPUR	0.000°	SPUR
LEAD	∞		∞
DIAMETRAL PITCH TRANSVERSE		6.000	
CIRCULAR PITCH TRANSVERSE		0.5236	
PRESSURE ANGLE TRANVERSE		25.000°	
PITCH DIAMETER (CUT)	2.6667		4.8333
BASE CIRCLE DIAMETER	2.4168		4.3805
OUTSIDE DIAMETER	3.0500		5.1167
ANGLE OUTSIDE DIAMETER	44.1071°		34.5851°
ROOT DIAMETER	2.2667		4.3333
ROOT CLEARANCE	0.0583		0.0583
ADDENDUM MODIFICATION	15.000%		-15.000%
ADDENDUM	0.1917		0.1417
WHOLE DEPTH (STANDARD)	0.3917		0.3917
FACE WIDTH	2.0000		2.0000
----TOOTH SIZE----			
CIR TKS OPERATING NORMAL	0.2821 -- 0.2791		0.2355 -- 0.2325
CIR TKS CUT TRANSVERSE	0.2821 -- 0.2791		0.2355 -- 0.2325
CIRCULAR TKS CUT NORMAL	0.2821 -- 0.2791		0.2355 -- 0.2325
CIR TKS AT OD NORMAL	0.0670 -- 0.0640		0.0930 -- 0.0900
MEASUREMENT OVER PINS	3.1018 -- 3.0965		5.1760 -- 5.1699
FMC STANDARD PIN/BALL	0.28800 PINS		0.28800 PINS
PIN/BALL CONTACT DIAMETER	2.6777 -- 2.6733		4.7736 -- 4.7682
CIR SPACE WIDTH NORMAL	0.2445 -- 0.2415		0.2911 -- 0.2881
----OPERATING DIMENSIONS----			
CENTER DISTANCE OPERATING		3.7500	
CENTER DISTANCE STANDARD		3.7500	
PRESSURE ANGLE TRANS. OPERATING		25.0000°	
ANGLE OPERATING PITCH DIA		26.7175°	
PITCH DIAMETER OPERATING	2.6667		4.8333
DIAMETER SAP	2.4733		4.5719
ANGLE SAP	12.4574°		17.1232°
DIAMETER TIF	2.4639		4.5589
ANGLE TIF	11.3616°		16.5186°
DIAMETER HPSTC	2.8311		4.9283
ANGLE HPSTC	34.9574°		29.5369°
DIAMETER LPSTC	2.5830		4.6970
ANGLE LPSTC	21.6071°		22.1713°
BACKLASH NORMAL OPERATING		0.0120 -- 0.0060	
INVOLUTE CONTACT RATIO		1.4067	
HELICAL CONTACT RATIO		0.0000	
TOTAL CONTACT RATIO		1.4067	
SLIP RATIO SAP	-1.7763		-1.5759
SLIP RATIO OD	0.6118		0.6398
APPROACH / RECESS RATIO		45.06% / 54.94%	

Figure 3 Spur gear specifications: 25° pressure angle.

SPUR GEAR STRESS ANALYSIS

œrlikon fairfield

PART NUMBER	25 PA Pinion		25 PA Gear
NUMBER OF TEETH	16		29
DIAMETRAL PITCH NORMAL		6.000	
PRESSURE ANGLE		25.000°	
HELIX ANGLE	SPUR	0.000°	SPUR
CENTER DISTANCE OPERATING		3.7500	
FACE WIDTH	2.0000		2.0000
ADDENDUM	0.1917		0.1417
WHOLE DEPTH (STANDARD)	0.3917		0.3917
HOB EDGE RADIUS	0.0429		0.0429
CIRCULAR TKS CUT NORMAL	0.2821		0.2355
--- FACTORS CALCULATION & APPLICATION ---			
J FACTOR (AGMA 908)	0.4051		0.3948
I FACTOR (AGMA 908)		0.1103	
AGMA 2000 QUALITY		8	
APPLICATION FACTORS		1.0000	
Km MOUNTING FACTOR		1.0000	
Kv DYNAMIC FACTOR		1.0074	
PITCHLINE VELOCITY (fpm)		1	
--- STRESS ALLOWABLES ---			
BENDING (psi)	65,000		65,000
SURFACE (psi)	225,000		225,000
--- STATIC TORQUE RATING ---			
BENDING (in-lbs)	11,704		20,670
SURFACE (in-lbs)	7,571		13,723
--- DYNAMIC TORQUE RATING AT PINION 1 RPM ---			
BENDING (in-lbs)	11,617		20,518
SURFACE (in-lbs)	7,515		13,621
--- STRESS AT PINION 16000 in-lbs TORQUE, 1 RPM ---			
BENDING (psi)	89,522		91,873
SURFACE (psi)		328,302	
--- LIFE IN CYCLES TO 1% FAILURE ---			
BENDING	283,613		228,177
SURFACE	11,742		11,742
--- LIFE IN HOURS TO 1% FAILURE ---			
BENDING	4,727		6,893
SURFACE	196		355

--- GEAR GEOMETRY ERRORS ---

-- NO ERRORS --

Figure 4 Spur gear stress analysis: 25° pressure angle.

SPUR GEAR SPECIFICATIONS

oerlikon fairfield

PART NUMBER	33.5 PA Pinion		33.5 PA Gear
---BASIC DATA ---			
NUMBER OF TEETH	16		29
RATIO		1.813 -- Hunting Tooth Ratio	
DIAMETRAL PITCH NORMAL		6.000	
CIRCULAR PITCH NORMAL		0.5236	
PRESSURE ANGLE NORMAL		33.500°	
HELIX ANGLE AND HAND	SPUR	0.000°	SPUR
LEAD	∞		∞
DIAMETRAL PITCH TRANSVERSE		6.000	
CIRCULAR PITCH TRANSVERSE		0.5236	
PRESSURE ANGLE TRANVERSE		33.500°	
PITCH DIAMETER (CUT)	2.6667		4.8333
BASE CIRCLE DIAMETER	2.2237		4.0304
OUTSIDE DIAMETER	2.9820		5.1592
ANGLE OUTSIDE DIAMETER	51.1928°		45.7844°
ROOT DIAMETER	2.3000		4.4800
ROOT CLEARANCE	0.0204		0.0190
ADDENDUM MODIFICATION	-5.400%		-2.240%
ADDENDUM	0.1577		0.1629
WHOLE DEPTH	0.3410		0.3396
FACE WIDTH	2.0000		2.0000
----TOOTH SIZE----			
CIR TKS OPERATING NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS CUT TRANSVERSE	0.2588 -- 0.2558		0.2588 -- 0.2558
CIRCULAR TKS CUT NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS AT OD NORMAL	0.0300 -- 0.0260		0.0300 -- 0.0270
MEASUREMENT OVER PINS	3.1554 -- 3.1513		5.3190 -- 5.3148
FMC STANDARD PIN/BALL	0.32000 PINS		0.32000 PINS
PIN/BALL CONTACT DIAMETER	2.6488 -- 2.6452		4.8234 -- 4.8195
CIR SPACE WIDTH NORMAL	0.2678 -- 0.2648		0.2678 -- 0.2648
----OPERATING DIMENSIONS----			
CENTER DISTANCE OPERATING		3.7500	
CENTER DISTANCE STANDARD		3.7500	
PRESSURE ANGLE TRANS. OPERATING		33.5000°	
ANGLE OPERATING PITCH DIA		37.9232°	
PITCH DIAMETER OPERATING	2.6667		4.8333
DIAMETER SAP	2.4061		4.5693
ANGLE SAP	23.6748°		30.6021°
DIAMETER TIF	2.3967		4.5577
ANGLE TIF	23.0375°		30.2505°
DIAMETER HPSTC	2.8559		5.0399
ANGLE HPSTC	46.1748°		43.0159°
DIAMETER LPSTC	2.4869		4.6642
ANGLE LPSTC	28.6928°		33.3707°
BACKLASH NORMAL OPERATING		0.0120 -- 0.0060	
INVOLUTE CONTACT RATIO		1.2230	
HELICAL CONTACT RATIO		0.0000	
TOTAL CONTACT RATIO		1.2230	
SLIP RATIO SAP	-0.9339		-0.6728
SLIP RATIO OD	0.4022		0.4829
APPROACH / RECESS RATIO		51.78% / 48.22%	

Figure 5 Spur gear specifications: 33.5° pressure angle.

SPUR GEAR STRESS ANALYSIS

oerlikon fairfield

PART NUMBER	33.5 PA Pinion		33.5 PA Gear
NUMBER OF TEETH	16		29
DIAMETRAL PITCH NORMAL		6.000	
PRESSURE ANGLE		33.500°	
HELIX ANGLE	SPUR	0.000°	SPUR
CENTER DISTANCE OPERATING		3.7500	
FACE WIDTH	2.0000		2.0000
ADDENDUM	0.1577		0.1629
WHOLE DEPTH	0.3410		0.3396
HOB EDGE RADIUS	0.0203		0.0285
CIRCULAR TKS CUT NORMAL	0.2588		0.2588
--- FACTORS CALCULATION & APPLICATION ---			
J FACTOR (AGMA 908)	0.5487		0.6168
I FACTOR (AGMA 908)		0.1273	
AGMA 2000 QUALITY		8	
APPLICATION FACTORS		1.0000	
Km MOUNTING FACTOR		1.0000	
Kv DYNAMIC FACTOR		1.0053	
PITCHLINE VELOCITY (fpm)		0	
--- STRESS ALLOWABLES ---			
BENDING (psi)	65,000		65,000
SURFACE (psi)	225,000		225,000
--- STATIC TORQUE RATING ---			
BENDING (in-lbs)	15,853		32,297
SURFACE (in-lbs)	8,733		15,828
--- DYNAMIC TORQUE RATING AT PINION 1 RPM ---			
BENDING (in-lbs)	15,770		32,128
SURFACE (in-lbs)	8,687		15,745
--- STRESS AT PINION 16000 in-lbs TORQUE, 1 RPM ---			
BENDING (psi)	65,949		58,672
SURFACE (psi)		305,358	
--- LIFE IN CYCLES TO 1% FAILURE ---			
BENDING	1.184E+07		8.437E+09
SURFACE	42,816		42,816
--- LIFE IN HOURS TO 1% FAILURE ---			
BENDING	394,752		5.097E+08
SURFACE	1,427		2,587
--- GEAR GEOMETRY ERRORS ---			
-- NO ERRORS --			

Figure 6 Spur gear stress analysis: 33.5° pressure angle.

SPUR GEAR SPECIFICATIONS

PART NUMBER	35 PA Pinion		35 PA Gear
---BASIC DATA ---			
NUMBER OF TEETH	16		29
RATIO		1.813 -- Hunting Tooth Ratio	
DIAMETRAL PITCH NORMAL		6.000	
CIRCULAR PITCH NORMAL		0.5236	
PRESSURE ANGLE NORMAL		35.000°	
HELIX ANGLE AND HAND	SPUR	0.000°	SPUR
LEAD	∞		∞
DIAMETRAL PITCH TRANSVERSE		6.000	
CIRCULAR PITCH TRANSVERSE		0.5236	
PRESSURE ANGLE TRANVERSE		35.000°	
PITCH DIAMETER (CUT)	2.6667		4.8333
BASE CIRCLE DIAMETER	2.1844		3.9592
OUTSIDE DIAMETER	2.9651		5.1405
ANGLE OUTSIDE DIAMETER	52.5898°		47.4469°
ROOT DIAMETER	2.3000		4.4800
ROOT CLEARANCE	0.0297		0.0275
ADDENDUM MODIFICATION	-10.480%		-7.838%
ADDENDUM	0.1492		0.1536
WHOLE DEPTH	0.3325		0.3303
FACE WIDTH	2.0000		2.0000
----TOOTH SIZE----			
CIR TKS OPERATING NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS CUT TRANSVERSE	0.2588 -- 0.2558		0.2588 -- 0.2558
CIRCULAR TKS CUT NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS AT OD NORMAL	0.0330 -- 0.0300		0.0330 -- 0.0300
MEASUREMENT OVER PINS	3.1564 -- 3.1526		5.3197 -- 5.3157
FMC STANDARD PIN/BALL	0.32000 PINS		0.32000 PINS
PIN/BALL CONTACT DIAMETER	2.6438 -- 2.6404		4.8178 -- 4.8141
CIR SPACE WIDTH NORMAL	0.2678 -- 0.2648		0.2678 -- 0.2648
----OPERATING DIMENSIONS----			
CENTER DISTANCE OPERATING		3.7500	
CENTER DISTANCE STANDARD		3.7500	
PRESSURE ANGLE TRANS. OPERATING		35.0000°	
ANGLE OPERATING PITCH DIA		40.1189°	
PITCH DIAMETER OPERATING	2.6667		4.8333
DIAMETER SAP	2.4122		4.5772
ANGLE SAP	26.8370°		33.2385°
DIAMETER TIF	2.4027		4.5660
ANGLE TIF	26.2473°		32.9131°
DIAMETER HPSTC	2.8827		5.0623
ANGLE HPSTC	49.3370°		45.6523°
DIAMETER LPSTC	2.4673		4.6407
ANGLE LPSTC	30.0898°		35.0331°
BACKLASH NORMAL OPERATING		0.0120 -- 0.0060	
INVOLUTE CONTACT RATIO		1.1446	
HELICAL CONTACT RATIO		0.0000	
TOTAL CONTACT RATIO		1.1446	
SLIP RATIO SAP	-0.7680		-0.5822
SLIP RATIO OD	0.3680		0.4344
APPROACH / RECESS RATIO		51.57% / 48.43%	

Figure 7 **Spur gear specifications: 35° pressure angle.**

SPUR GEAR STRESS ANALYSIS

oerlikon fairfield

PART NUMBER	35 PA Pinion		35 PA Gear
NUMBER OF TEETH	16		29
DIAMETRAL PITCH NORMAL		6.000	
PRESSURE ANGLE		35.000°	
HELIX ANGLE	SPUR	0.000°	SPUR
CENTER DISTANCE OPERATING		3.7500	
FACE WIDTH	2.0000		2.0000
ADDENDUM	0.1492		0.1536
WHOLE DEPTH	0.3325		0.3303
HOB EDGE RADIUS	0.0074		0.0164
CIRCULAR TKS CUT NORMAL	0.2588		0.2588
--- FACTORS CALCULATION & APPLICATION ---			
J FACTOR (AGMA 908)	0.5846		0.6581
I FACTOR (AGMA 908)		0.1292	
AGMA 2000 QUALITY		8	
APPLICATION FACTORS		1.0000	
Km MOUNTING FACTOR		1.0000	
Kv DYNAMIC FACTOR		1.0053	
PITCHLINE VELOCITY (fpm)		0	
--- STRESS ALLOWABLES ---			
BENDING (psi)	65,000		65,000
SURFACE (psi)	225,000		225,000
--- STATIC TORQUE RATING ---			
BENDING (in-lbs)	16,889		34,460
SURFACE (in-lbs)	8,866		16,069
--- DYNAMIC TORQUE RATING AT PINION 1 RPM ---			
BENDING (in-lbs)	16,801		34,279
SURFACE (in-lbs)	8,819		15,985
--- STRESS AT PINION 16000 in-lbs TORQUE, 1 RPM ---			
BENDING (psi)	61,902		54,990
SURFACE (psi)		303,063	
--- LIFE IN CYCLES TO 1% FAILURE ---			
BENDING	4.156E+08		3.216E+11
SURFACE	48,990		48,990
--- LIFE IN HOURS TO 1% FAILURE ---			
BENDING	1.385E+07		1.943E+10
SURFACE	1,633		2,960
--- GEAR GEOMETRY ERRORS ---			

-- NO ERRORS --

Figure 8 Spur gear stress analysis: 35° pressure angle.

SPUR GEAR SPECIFICATIONS

oerlikon fairfield

---BASIC DATA ---			
NUMBER OF TEETH	16		29
RATIO		1.813 -- Hunting Tooth Ratio	
DIAMETRAL PITCH NORMAL		6.000	
CIRCULAR PITCH NORMAL		0.5236	
PRESSURE ANGLE NORMAL		36.000°	
HELIX ANGLE AND HAND	SPUR	0.000°	SPUR
LEAD	∞		∞
DIAMETRAL PITCH TRANSVERSE		6.000	
CIRCULAR PITCH TRANSVERSE		0.5236	
PRESSURE ANGLE TRANVERSE		36.000°	
PITCH DIAMETER (CUT)	2.6667		4.8333
BASE CIRCLE DIAMETER	2.1574		3.9102
OUTSIDE DIAMETER	2.9602		5.1350
ANGLE OUTSIDE DIAMETER	53.8317°		48.7700°
ROOT DIAMETER	2.3000		4.4800
ROOT CLEARANCE	0.0325		0.0299
ADDENDUM MODIFICATION	-11.940%		-9.500%
ADDENDUM	0.1468		0.1508
WHOLE DEPTH	0.3301		0.3275
FACE WIDTH	2.0000		2.0000
----TOOTH SIZE----			
CIR TKS OPERATING NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS CUT TRANSVERSE	0.2588 -- 0.2558		0.2588 -- 0.2558
CIRCULAR TKS CUT NORMAL	0.2588 -- 0.2558		0.2588 -- 0.2558
CIR TKS AT OD NORMAL	0.0290 -- 0.0260		0.0300 -- 0.0260
MEASUREMENT OVER PINS	3.1572 -- 3.1535		5.3203 -- 5.3164
FMC STANDARD PIN/BALL	0.32000 PINS		0.32000 PINS
PIN/BALL CONTACT DIAMETER	2.6406 -- 2.6373		4.8142 -- 4.8106
CIR SPACE WIDTH NORMAL	0.2678 -- 0.2648		0.2678 -- 0.2648
----OPERATING DIMENSIONS----			
CENTER DISTANCE OPERATING		3.7500	
CENTER DISTANCE STANDARD		3.7500	
PRESSURE ANGLE TRANS. OPERATING		36.0000°	
ANGLE OPERATING PITCH DIA		41.6278°	
PITCH DIAMETER OPERATING	2.6667		4.8333
DIAMETER SAP	2.4126		4.5784
ANGLE SAP	28.6827°		34.8947°
DIAMETER TIF	2.4032		4.5674
ANGLE TIF	28.1213°		34.5849°
DIAMETER HPSTC	2.8928		5.0709
ANGLE HPSTC	51.1827°		47.3084°
DIAMETER LPSTC	2.4589		4.6310
ANGLE LPSTC	31.3317°		36.3562°
BACKLASH NORMAL OPERATING		0.0120 -- 0.0060	
INVOLUTE CONTACT RATIO		1.1177	
HELICAL CONTACT RATIO		0.0000	
TOTAL CONTACT RATIO		1.1177	
SLIP RATIO SAP	-0.7003		-0.5427
SLIP RATIO OD	0.3518		0.4119
APPROACH / RECESS RATIO		51.47% / 48.53%	

Figure 9 **Spur gear specifications: 36° pressure angle.**

SPUR GEAR STRESS ANALYSIS

oerlikon fairfield

NUMBER OF TEETH	16		29
DIAMETRAL PITCH NORMAL		6.000	
PRESSURE ANGLE		36.000°	
HELIX ANGLE	SPUR	0.000°	SPUR
CENTER DISTANCE OPERATING		3.7500	
FACE WIDTH	2.0000		2.0000
ADDENDUM	0.1468		0.1508
WHOLE DEPTH	0.3301		0.3275
HOB EDGE RADIUS	-0.0019		0.0076
CIRCULAR TKS CUT NORMAL	0.2588		0.2588
--- FACTORS CALCULATION & APPLICATION ---			
J FACTOR (AGMA 908)	0.6096		0.6876
I FACTOR (AGMA 908)		0.1311	
AGMA 2000 QUALITY		8	
APPLICATION FACTORS		1.0000	
Km MOUNTING FACTOR		1.0000	
Kv DYNAMIC FACTOR		1.0053	
PITCHLINE VELOCITY (fpm)		0	
--- STRESS ALLOWABLES ---			
BENDING (psi)	65,000		65,000
SURFACE (psi)	225,000		225,000
--- STATIC TORQUE RATING ---			
BENDING (in-lbs)	17,612		36,005
SURFACE (in-lbs)	8,993		16,300
--- DYNAMIC TORQUE RATING AT PINION 1 RPM ---			
BENDING (in-lbs)	17,520		35,817
SURFACE (in-lbs)	8,946		16,214
--- STRESS AT PINION 16000 in-lbs TORQUE, 1 RPM ---			
BENDING (psi)	59,363		52,630
SURFACE (psi)		300,910	
--- LIFE IN CYCLES TO 1% FAILURE ---			
BENDING	4.369E+09		3.783E+12
SURFACE	55,642		55,642
--- LIFE IN HOURS TO 1% FAILURE ---			
BENDING	1.456E+08		2.285E+11
SURFACE	1,855		3,362
--- GEAR GEOMETRY ERRORS ---			

-- NO ERRORS --

Figure 10 Spur gear stress analysis: 36° pressure angle.

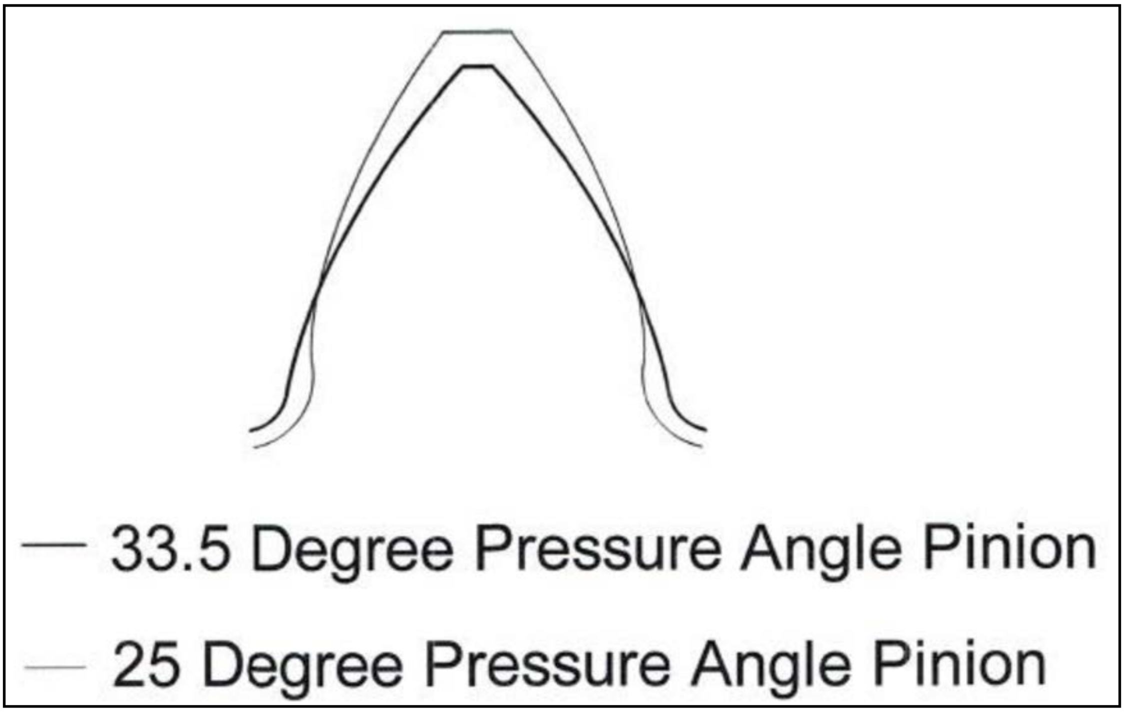
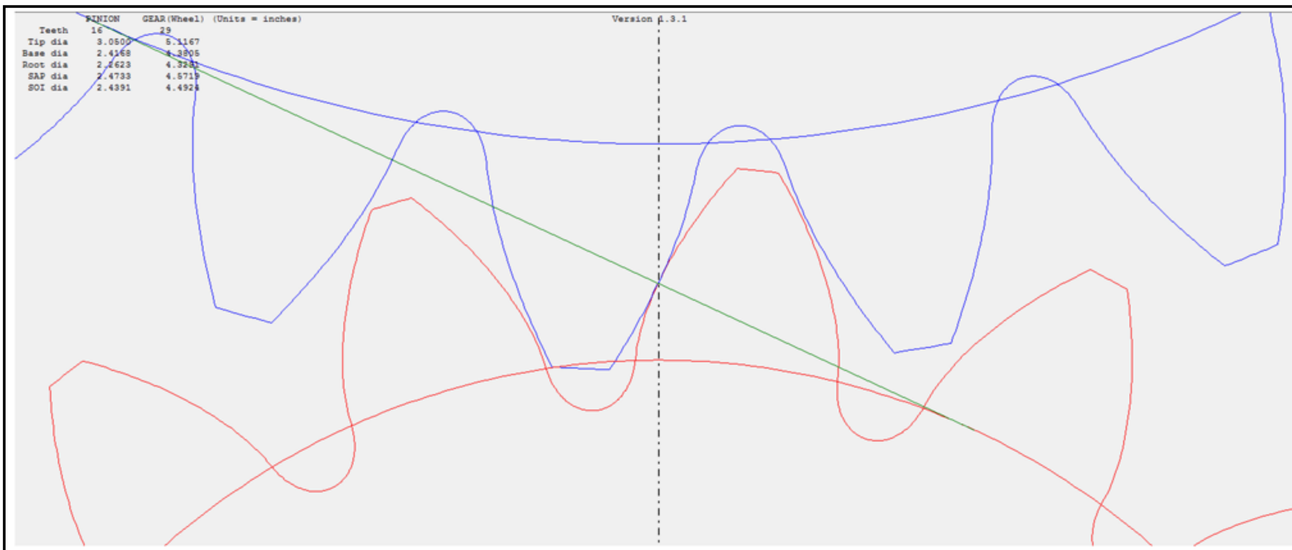


Figure 11 Reference 25 PA and 33.5 PA gear tooth profiles.



	PINION	GEAR (Wheel)	(Units = inches)
Teeth	16	29	
Tip dia.	3.0500	5.1167	
Base dia.	2.4168	4.3805	
Root dia.	2.2623	4.3291	
SAP dia.	2.4733	4.5719	
SOI dia.	2.4391	4.4924	

Figure 12 25° pressure angle gear teeth.

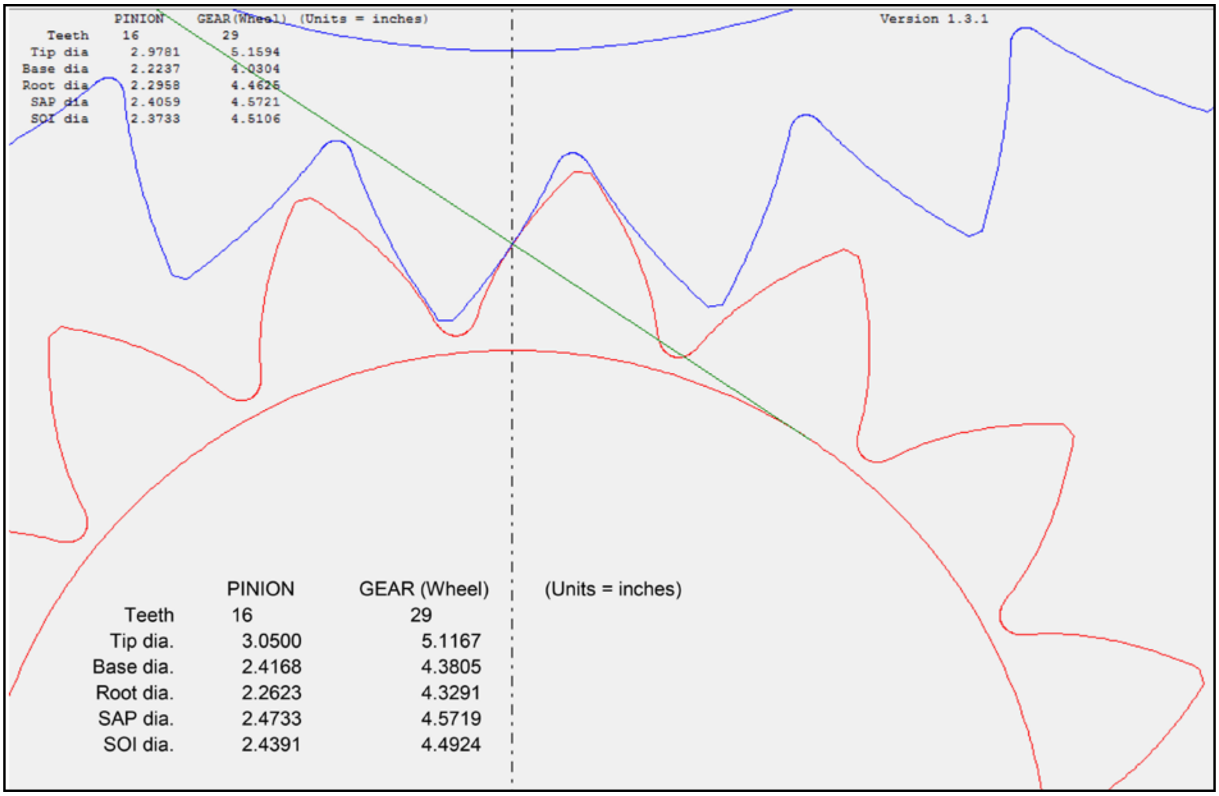


Figure 13 33.5° pressure angle gear teeth.

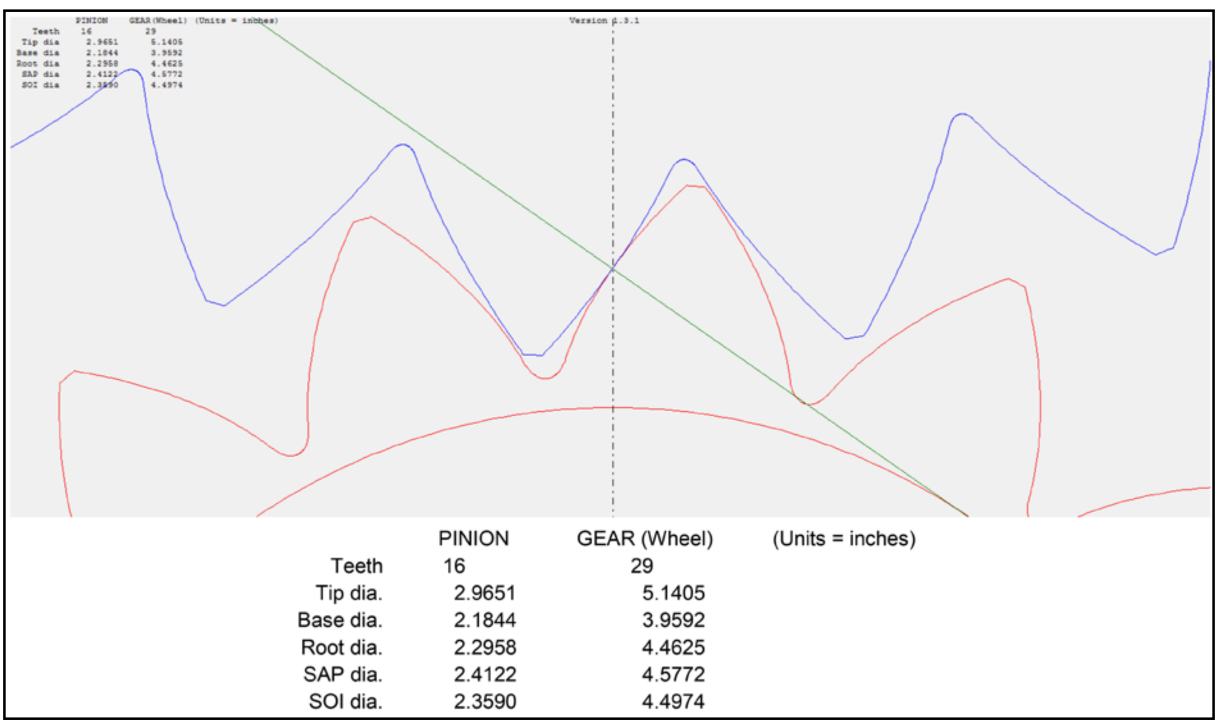


Figure 14 35° pressure angle gear teeth.

Review of Results and Commentary

All gear trials were run with the following common gear data attributes:

- 6 DP, 3.75 inch center distance,
- 0.012 inch maximum backlash,
- 16,000 in-lb pinion torque,
- 1 RPM pinion speed.

As stated above, the 25° pressure angle gearset uses 15% long addendum pinion and 15% short addendum gear tooth proportions, and the resulting circular tooth thicknesses.

The first trial was for the 25° pressure angle design; this serves as the benchmark. Following are the relevant results:

- Bending stress, PSI, pinion/gear is 89,522/91,873; static torque rating bending, (in-lb): 11,704/20,670
- Surface contact stress, PSI, pinion and gear: 328,302; static torque rating surface P/G: 7,571/13,723

***The second trial was to determine the pressure angle at the following conditions*:**

0.030 inch top land; 2.1/DP whole depth, 1.15 contact ratio.

- The calculated outside diameters (Eq. 1) are 2.965 inches pinion and 5.141 inches gear
- The calculated pressure angle to match these conditions is 35°
- The hob tip radius at these conditions is 0.007 inches pinion / .016 inches gear.
- Bending stress, PSI, pinion/gear is 61,902/54,990; static torque rating bending, (in-lb): 16,889/34,460
- Surface contact stress, PSI, pinion and gear: 303,063; static torque rating surface P/G: 8,866/16,069
- This represents a bending stress reduction from the 25 PA gearset of 31% pinion and 40% for the gear
- The increase in static torque rating for bending strength is 44% pinion and 67% for the gear
- The increase in static torque rating for surface contact strength is 17% for both pinion and gear

***The third trial was to determine the pressure angle at the above conditions for the second trial: 0.030 top land, 2.1/DP whole depth, 1.15 contact ratio — but with the following additional requirements*:**

Hob tip radius equal to 0.020 inches

- Calculated outside diameters are 2.982 inches pinion and 5.159 inches gear
- Calculated contact ratio is 1.22
- Calculated pressure angle to match these conditions is 33.5°
- Bending stress, PSI, pinion/gear: 65,949 / 58,672; static torque rating bending, (in-lb): 15,853 / 32,297
- Surface contact stress, PSI, pinion and gear: 305,358; static torque rating surface P/G: 8,733 / 15,828
- This represents a bending stress reduction from the 25 PA gearset of 26% pinion and 36% for the gear
- The increase in static torque rating for bending strength is 35% pinion and 56% for the gear
- The increase in static torque rating for surface contact strength is 15% for both pinion and gear

Summary and Conclusion

A method has been presented to calculate the pressure angle for gear teeth when the top land, contact ratio, and backlash are specified as inputs. This method does not consider hob tip radius, which may be a small value or even zero for this calculation. A zero or very small hob tip radius is probably not a good or acceptable design. So another example was shown where a given hob tip radius was used as an input, and another set of equations and calculations were shown separately to evaluate the pressure angle that matches the given hob tip radius in addition to the other input variables as before. This pressure angle would be smaller than either the zero hob tip radius value or the 0.007 inch hob tip radius value in the proposed example and is a preferred design, and the resultant gear data was calculated.

Gear tooth circular tooth thicknesses were standard in all of these high pressure angle examples but could have been specified as non-standard values if desired and used in the existing calculations. Likewise, the top land values for the pinion and the gear were the same (0.030 inch), but could have been different from each other.

All mathematical formulas and their derivation were shown. The results for the examples shown are a much higher pressure angle than is currently used in gearing and produces significantly reduced bending and surface contact stress for the higher pressure angle gearing. Note that there are other items to be considered, such as ease of manufacturing, and that pressure angles this high have other considerations to take into account. The purpose of this paper is to determine and quantify the use of high pressure angles for gear teeth and to calculate them and not to suggest good design practice.

A typical application for this type of high pressure angle gearing would be one with slow speed, large, coarse pitch teeth, and lower quality level, although other conditions could also be considered for these gears. Applications where a high power density and high gear tooth strength are required should consider this type of gearing.

Note that these methods can also be used for more typical pressure angle designs where the user simply wants to design gear teeth and gearsets based on top lands, contact ratio and hob tip radius as inputs.

All gear data and stress calculations were performed using the *AGMA GRS 3.1.7* gear rating suite. Due to the length of the program data outputs, the data was summarized and shown in more abbreviated format.

In order to ensure further validation of the gear tooth stresses, it is suggested that alternative FEA (finite element analysis) be performed on the gear teeth and the results of this be compared to the results from the above analysis.

Dolan and Broghamer (Ref.6) discuss the applicability of their work and stress correction factors to different pressure angles.

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Rick Miller is president and sole member of Innovative Drive Solutions LLC, a mechanical engineering consulting business that specializes in gear and geared power drive systems, design and analysis. Based in Indianapolis, Indiana, Miller helps clients in the United States and around the world with his technical expertise. Miller is well-known for helping customers solve their technical problems by successfully adhering to the tenet, "For every problem, there is a solution." Miller has created over 300 original gearbox designs used in a variety of industries. He is the inventor on two patents granted and one pending — a testimony to his creativity and out-of-the box thinking. Prior to leading his consultancy business he was chief engineer of Oerlikon Fairfield in Lafayette, Indiana. Miller is a member of SAE International and ASME, and is Vice Chairman of the AGMA Vehicle Gearing Committee.

Toyoda Americas

OPENS GREAT LAKES TECHNICAL CENTER

JTEKT Toyoda Americas celebrated the grand unveiling of their Great Lakes Technical Center April 19 and 20. Nestled at the heart of the U.S. automotive industry and just under 40 miles from the Canadian border, Toyoda's Wixom, Michigan based tech center will provide local sales application, turnkey and service support to manufacturers in the Great Lakes region.

Attendees caught a first look at the tech center's four machines: FH500J horizontal machining center, Stealth 965 vertical machining center and recent additions to the Toyoda lineup, Takisawa Taiwan's NEX-105 and Stealth EX-108 turning centers. All four machines were set with varied application demonstrations showing off high speed machining and dynamic milling applications.

"Toyoda customers will benefit from the (Great Lakes) facility, which will serve as our service hub for Michigan as well as an area for current and future customers to view the machine capabilities we offer," said Michigan and Windsor Regional Manager, Austin Sievers. "Our doors are open for all area manufacturers, please coordinate visits with your local distributor representative or myself. We will also be hosting training seminars in the near future for grinding, gear skiving and specific machining applications."

There will be no shortage of Toyoda expertise in service and engineering as the tech center shares the 75,000 sq. ft. facility with Toyoda's Remanufactured Products Division (RPD). Dedicated much to the repairing and remanufacturing of machines since the 1970's, RPD will continue to specialize in returning overworked machining centers to OEM specifications.

Toyoda would like to offer a special thank-you to their local distributors KM Industrial Machinery, Network Machinery, industry partners Seco Tools, Kennametal, Mastercam, Schunk and master BBQ-er, 'Q It Up. (*www.toyoda.com*)

Mazak

ANNOUNCES PRECI FACILITY GRAND OPENING

Mazak customers in Mexico will soon benefit from enhanced levels of localized customer service and support with the grand opening of the Preci facility in Queretaro. The brand new building will house applications and service technicians, offer training to customers and demonstrate some of the most advanced Mazak machine tool and automation technologies, including those specifically geared toward the area's well-entrenched aerospace and automotive industries.

"The new building gives Mazak's customers in the Queretaro area and surrounding regions even more access to the technical, engineering and applications expertise they need to thrive and succeed," said Brian Papke, chairman of Mazak Corporation. "We continue to expand and strengthen our capabilities in Mexico - thanks to Preci - as well as throughout all of North America while other OEMs typically trim customer service, support and sales initiatives to keep overhead costs in check."

The Preci facility encompasses nearly 6,000 square feet, including training space and a 3,200-square-foot showroom that will house some of Mazak's most advanced multi- tasking, full 5-axis, horizontal and vertical machining systems. Six employees will provide technical and sales support to keep customers competitive and productive. (*www.mazakusa.com*)

ANCA

CONFIRMS GRAEME BILLINGS AS BOARD CHAIRMAN

ANCA has announced its board has confirmed the appointment of an independent, non-executive chairman for the ANCA group board.

Pat Boland, joint co-founder said: "After a rigorous interview process, with several high-quality applicants, the board has appointed **Graeme Billings** to this role."

"Graeme comes from an impressive business background as both a senior manager, independent director and chairman for several of Australia's best companies," he concluded.

After his appointment, Billings said: "The ANCA Group is a great success story. I look forward to working with the board and management in pursuit of the company's long term growth strategy."

Formally a senior partner at PricewaterhouseCoopers, as well as leading the firm's Global Industrial Products sector, Graeme has extensive experience in assurance, transaction and consulting services with multinational and Australian companies in the automotive, construction and general manufacturing industries, spanning a 34-year period.

Billings also draws on his experience with acquisitions, mergers and other business investigation areas, including succession planning. In addition, he was a regular media commentator on the industrial products sector.

Billings lives in Melbourne with his wife and they have three children. He is a passionate sports fan and particularly enjoys AFL, cricket and golf.

This position is effective immediately. (*www.anca.com*)

AGMA

WELCOMES NEW BOARD MEMBERS

The American Gear Manufacturers Association (AGMA) recently announced the election of Jim Bregi, president of Doppler Gear as the new AGMA chairman of the board, at the AGMA Annual Meeting held March 30–April 1 in Palm Springs, California.

Other changes to the board include a new chairman emeritus, treasurer, business management executive committee (BMEC) chairman and technical division executive committee (TDEC) chairman.

The new AGMA executive committee is: Jim Bregi, chairman, and president of Doppler Gear; John Cross, treasurer, and president, ASI Technologies, Inc.; Todd Praneis, TDEC chairman, and director of product development, Cotta Transmission; John Grazia, BMEC chairman, and president, GearTec, Inc. and Dean Burrows, chairman emeritus, and president of Gear Motions, Inc.

Additionally, AGMA welcomes four new members to its

(Left) Jim Bregi, Doppler Gear and Dean Burrows, Gear Motions, Inc.

board of directors. These directors will serve a three-year term (2017–2020), effective April 3, 2017. The new board members were elected by AGMA corporate members in the first quarter of 2017, and announced during the AGMA Annual Meeting.

The newly elected board members are: Michael Engesser, president, Reishauer USA; Mike McKernin, president, Circle Gear and Machine Company; Cory Ooyen, president, Global Gear and Machining, LLC; and Greg Schulte, president, Bonfiglioli USA.

"AGMA is a member driven organization and these industry leaders will join our dynamic board at an exciting time in its history," noted Matthew E. Croson, president of AGMA. "I look forward to working closely with them as we execute on our strategic plan and add value into the second century of AGMA's history." (*www.agma.org*)

Sandvik Coromant

SIGNS RESEARCH AGREEMENT WITH PARC TO DEVELOP DIGITAL MANUFACTURING TECHNOLOGY

Sandvik Coromant is strengthening its digital manufacturing capabilities by signing a strategic research agreement with PARC, a Xerox company, world-renowned innovation center. PARC will provide Sandvik Coromant with a footprint in Silicon Valley and expert resources for research and development in the field of digital manufacturing.

PARC will allocate resources to conduct research and develop digital manufacturing technologies for Sandvik Coromant under the terms of the agreement. Sandvik Coromant will also acquire all intellectual property (IP) and technology related to PARC's software for high-level process planning and automated manufacturing cost estimation for subtractive manufacturing.

"This partnership is a natural step and in line with Sandvik Coromant's long-term strategy to develop attractive solutions in the field of digital manufacturing and Industry 4.0," said Magnus Ekbäck, vice president and head of business development and digital machining for Sandvik Coromant. "With this cooperation we will significantly strengthen our capabilities within digital machining."

"Manufacturing is entering a dynamic new phase as the cyber and physical worlds converge, and the complex and diverse industry needs significant innovation to truly progress," said PARC CEO Tolga Kurtoglu. "The missing piece for complete design automation and manufacturing of complex products has been the integrated coupling of design and manufacturing, which we have been developing at PARC for many years. We're pleased to partner with Sandvik Coromant to see these innovations come to life on the global stage."

PARC has been developing technologies for government agencies and commercial clients in the field of digital manufacturing for almost a decade. Its digital manufacturing suite of technologies helps designers and manufacturers understand real-world manufacturing process constraints during digital product design and identifies potential limitations of a supply chain early in the design phase, ultimately minimizing time-to-market and improving overall product quality.

The strategic research agreement will be governed by a Joint Steering Committee with representatives from both PARC and Sandvik Coromant. (*www.sandvik.coromant.com*)

Photo Caption: Saigopal Nelaturi (Area Manager, Computation for Automation in Systems Engineering) PARC, Janni Weber (Senior Project Manager) Sandvik Coromant, Mats Bergstrom (Managing Director, Global Business Operations and Program Manager for Digital Design and Manufacturing) PARC, Magnus Ekbäck (Vice President and Head of Business Development and Digital Machining) Sandvik Coromant, Tolga Kurtoglu (CEO) PARC, Markus Larsson (Vice President of Global Business Operations) PARC, Mats Allard (Project Manager Virtual Machining) Sandvik Coromant, Michael Waltrip (Senior Director, Intellectual Property Management and Commercialization) PARC.

Kapp Niles

FOUNDS METROLOGY DIVISION

Kapp Niles has announced the expansion of its product portfolio by adding high-end metrology solutions. The new-found division Kapp Niles Metrology GmbH, based in Aschaffenburg, Germany, leverages the wealth of experience and technology from R&P Metrology GmbH, whose employees and management are joining the new company. Kapp Niles Metrology designs and builds customized large 4- and 5-axis analyzers built to VDI/VDE class I. A derivative of the technology is a transportable 3-axis device for analyzing gears in the shop on cutting machines or even in a gear box. An expansion into the metrology sector complements the Kapp Niles product portfolio for gear and profile grinding up to 8 meters. The new company will also provide sales and support in Europe and Asia for the smaller gear analyzers and products of Penta Gear Metrology of Dayton, OH (pentagear.com), which joined Kapp Technologies in 2015. Both Kapp Niles Metrology GmbH and Penta Gear Metrology are innovators in their respective sectors and now join forces for further advancements. Industry 4.0 is just one of the areas customers will benefit from these extensive integrated solutions to the gear industry. (*www.kapp-niles.com*)

Seco/Warwick

AWARDED PRODUCTION COMPANY OF THE YEAR

Seco/Warwick has won a Production Company of the Year title in the Leaders of the Manufacturing World Competition.

The title given to Seco/Warwick is a recognition of a company's expertise, innovative technologies and solutions in the manufacturing sector while achieving significant growth dynamics.

"Seco/Warwick is not afraid to reach for IT solutions from the world's top shelf, which captured the attention of the competition jury. With our knowledge and experience we contribute to the development of the manufacturing market and the most interesting solutions for Industry 4.0. We know what breakthrough technologies are and have a vision for their creation and application in industrial production," says Paweł Wyrzykowski, CEO of the Seco/Warwick Group.

Innovative metal heat treatment solutions by Seco/Warwick have revolutionized the world's metallurgical industry. Seco/Warwick is among the top five companies in this field thanks to the use of disruptive technology and constant cooperation with universities in Europe and abroad. Today, Seco/Warwick can boast about 30 trademarks and 50 patents, dozens of awards and technical certifications and nearly 4,000 solutions in operation with customers in 70 countries.

At the III Innovative Manufacturing Forum, during the presentation of "Mixed-reality in Industry 4.0 - Redefining Reality in Industrial Production" Seco/Warwick presented its latest innovation - Seco/Lens, an application utilizing augmented reality technology, based on the latest HoloLens holographic computer. It is the first such application in Poland and one of the first in the world used in heavy industry.

"Digital technology is the basis for the development of the fourth industrial revolution we are currently witnessing. The driving force behind these concepts are concrete solutions that utilize the Internet of Things (IoT), cloud computing, augmented reality, and advanced analytics. Seco/Warwick is at the forefront of the digital revolution in the manufacturing industry, demonstrating how to effectively leverage digital tools to create innovative solutions and models. Based on Microsoft technology, the company has created an integrated ecosystem of data, applications and systems that support its growth and improve the efficiency of processes, especially those of an innovative nature," emphasizes Dariusz Piotrowski, member of the board at Microsoft in Poland.

"This is a new era of Seco/Warwick equipment application - the interaction era. Cyber-goggles, so far associated more with the gaming world than the industry, have been embedded in the real world. The implementation of virtual technology to our production, maintenance and service of Seco/Warwick systems, has become reality and is going to result in substantial benefits for us and our clients, for example by increasing the mobility, effectiveness and shortening our technicians' reaction times," specifies Katarzyna Sawka, Seco/Warwick global marketing director. (*www.secowarwick.com*)

June 27–29—Power-Gen Europe 2017 Cologne, Germany. Power-Gen Europe and co-located Renewable Energy World Europe, is where a rapidly-evolving power industry meets to gather information and compare views on shared opportunities and challenges. Attracting a worldwide audience, it is a key event for advancing Europe's energy future. Featuring the leading suppliers, sub-suppliers, service providers and end-users across the entire power generation value chain, the trade show encapsulates all aspects of today's centralized and distributed power generation sector. Together they combine strategic and technical presentations with the largest trade show exhibition of power equipment and services in Europe. Conference topics include renewable energy, energy storage, plant management, digital tools, and strategies for change. For more information, visit *www.powergeneurope.com*.

July 5–6—International VDI Congress-Drivetrain for Vehicles Bonn, Germany. The electrification of the powertrain implies one of the mega trends in transmission development. This technical advancement has impacted the entire automotive industry and affects everyone from the manufacturers, the suppliers and subcontractors up to the drivers themselves. This conference examines the predicted impact and influence of the new electric and hybrid vehicles on the market in terms of suitability for mass production. Here the focus is placed on the requirements that electrified drive systems have to fulfill and how they inspire manufacturers and suppliers in engineering and mechatronics to propel innovative developments to new heights. One of the highlights in Bonn is the accompanying trade show, which over the years has grown to become a major marketplace. More than 100 organizations from around the world present their solutions covering all aspects of the automotive transmission and its components. For more information, visit *www.transmission-congress.com*.

July 17–21—Coordinate Metrology Society Conference Snowbird, Utah. The Coordinate Metrology Society (CMS) has announced that attendee registration is now open for the 2017 Coordinate Metrology Society Conference (CMSC). The CMS will convene this year at the Snowbird Meeting and Convention Center in Snowbird, Utah, July 17–21, 2017. The eminent membership association for 3-D measurement professionals gathers annually to learn about technology achievements, network with industry experts and get a pulse on the metrology industry. Weekly registration includes entry to more than 20 technical sessions, workshops, the ever-popular Measurement and Education Zone, CMSC Exhibition Hall and networking events, as well as post-conference access to all technical papers and presentation materials. CMSC 2017 affords an educational opportunity for anyone interested in 3D measurement and inspection solutions utilized in manufacturing, research and development, and various scientific fields. For the 33rd year in a row, the CMS has connected with metrologists through education and technology. For more information, visit *www.cmsc.org*.

July 31–August 3—CAR Management Briefing Seminars Grand Traverse Resort, Traverse City, Michigan. Initiated by the University of Michigan in 1965, the first Center for Automotive Research Management Briefing Seminars (CAR MBS) hosted only 30 people. When the industry was at its highest number of employment, the event grew to attract more than 1,400 attendees annually from more than 35 states and 15 countries–representing industry, academia, media and the government. CAR MBS leads the industry in providing a context for auto industry stakeholders to discuss critical issues and emerging trends while fostering new industry relationships in daily networking sessions. Seminars include targeted sessions on manufacturing strategy, vehicle lightweighting, connected and automated vehicles, advanced powertrain, supply chain, sales forecasting, purchasing, talent and designing for technology. For more information, visit *www.cargroup.org*.

August 1–3—Ipsen U 2017 Cherry Valley, Illinois. Continuing Ipsen's long-standing tradition of offering training that teaches best practices and help improve the performance and lifespan of your equipment. Ipsen's newly remodeled, state-of-the-art space offers an ideal arena for attendees to build and refresh their knowledge of heat-treating equipment, processes and maintenance through applied learning. For those that prefer to stay close to home, Ipsen will also be providing additional one-day courses throughout the United States. Specific topics that will be covered during these local seminars include vacuum and atmosphere furnace maintenance best practices, optimizing operations with predictive maintenance and achieving and maintaining aerospace compliance. Overall, both training opportunities will teach best practices for regaining control of your equipment and offer expert insight into specific maintenance issues you might be experiencing on a daily basis. For more information, visit *www.ipsenusa.com*.

August 10—The Changing Landscape of Additive Manufacturing Materials Youngstown, Ohio. SME and America Makes come together to bring you this one-of-a-kind seminar. 3D Printing has significantly grown in recent years and is expected to quickly grow over the next few years. Discover which materials and filaments are most durable, what types of machines to use, certification/qualification standards as well as how to reduce cost, and increase profitability. Participating companies include GE, the U.S. Army, Northrop Grumman, and more. Topics include new materials, aerospace production, material implementation, expanding design space and the future of additive manufacturing. For more information, visit *smartmanufacturingseries.com*.

August 21–22—Design and Production Engineering 2017 Birmingham, U.K. The Design & Production 2017 Conference brings together experts, researchers, scholars and students from all areas of mechanical engineering including design engineering, manufacture engineering, production engineering, vehicle engineering and other related areas such as mechatronics, bio-inspired robotics, prosthetic design and bio-inspired design. This conference offers an opportunity to attend the presentations delivered by eminent scientists, researchers, experts from all over the world. Topics include reshoring, manufacturing innovations, material science, aerospace, maintenance and more. For more information, visit *www.design-production.conferenceseries.com*.

September 6–8—AGMA 2017 Bevel Gear System Design San Diego, CA. Learn how to design and apply bevel gears systems from the initial concept through manufacturing and quality control and on to assembly, installation and maintenance. Engage in a practical hands-on guide to the bevel gear design, manufacture, quality control, assembly, installation rating, lubrication and, most especially, application. Engineers, technicians, and others involved in the selection, application and/or design of bevel gear systems should attend. Ray Drago is the instructor. For more information, visit *www.agma.org*.

Babbage's Engines

Though we think of the computer as a distinctly 20th century invention, Charles Babbage designed several precursors way back in the early 1800s.

Alex Cannella, Associate Editor

Today, we use electronic mathematical tables for everything from astronomy to finance. But when Charles Babbage was born all the way back in 1791, these tables were all done by hand, and that meant they were susceptible to human error. Babbage spent a portion of his early life double-checking these tables, and was often frustrated by just how many he found.

That frustration drove Babbage to invent the Difference Engine, a behemoth machine designed to calculate polynomial tables, in 1821. The machine could only use addition, but could still calculate tables utilizing the method of differences. The Difference Engine was run with a simple hand crank, with the idea being to literally plug and chug the numbers. It was essentially a room-sized calculator, but a thirst for the infallible calculating power of exacting machinery inspired the government to fund the machine's construction.

Just designing the Difference Engine was no small feat of genius, but Babbage found that actually building the machine was an even more difficult proposition. The design called for a staggering 25,000 parts, including numerous gearwheels, and each needed to be cut to exacting specifications. Even after £17,500 of funding from the British government and 12 years of work, all Babbage had to show for his effort was a prototype for a single section of the machine. While the prototype drew plenty of attention, patience and funding eventually ran out, and the Difference Engine was never completed.

But Babbage had already moved on to a new project: The Analytical Engine. Unlike the Difference Engine, this newest design has been hailed as a full-on precursor to the modern computer due to the way it pioneered many design concepts that are still used for computers today. It was structured in two parts, with one being a "store" where much of the setup or intermediate solutions could be temporarily kept and results could be printed, the other a "mill" where the actual number crunching happened. The design mirrors how computers work today, with memory storage and a processor separate from each other.

The Analytical Engine also utilized a punch card system to program its calculations. Babbage borrowed the idea for the punch card system from the Jacquard loom. The idea would, in turn, later become a necessary part of early modern computer systems. It was also capable of a much wider range of calculations than the Difference Engine, now able to subtract, multiply and divide.

Much like with the Difference Engine, Babbage moved on to new ideas before the Analytical Engine was ever built, this time redesigning his original project. The Difference Engine No. 2 required only 8,000 parts, a fraction of what the original called for, and could calculate polynomials up to the seventh order. The machine also took Babbage's earlier idea for a separate printer and added it to the Difference Engine.

Ultimately, however, the Difference Engine No. 2 met the same fate as Babbage's earlier inventions. Either because of the complexity of the machines or his unyielding personality and dedication to perfection, Babbage never finished any of his machines before moving on to his next idea. To this day, only one full Difference Engine based on the 2.0 model has ever been completed, and work on it didn't even start until 1985, well after it had been obsoleted by computers.

The Science Museum in London set out to build a Difference Engine No. 2 by following Babbage's design both to prove that it had been a technologically feasible machine and to honor the 200th anniversary of Babbage's birth.

Just one of the countless gearwheels used to make Babbage's engines function. Photo by Marcin Wichary, originally posted to flickr.com (licensed under CC BY 2.0).

But even with modern manufacturing techniques, recreating Babbage's Difference Engine No. 2 was a 17-year effort fraught with technical and financial challenges. While the calculating half of the machine was completed in 1991 just in time for the anniversary, the rest wouldn't be completed until 2002. But eventually, the team managed to put it together without deviating from Babbage's design, and the Difference Engine is still on display at the Science Museum in London today.

Several other artifacts of Babbage's work are on display elsewhere in the world. The Smithsonian displays a single segment of the full machine that was made in 1853, and there's a replica that was created for a Microsoft executive, but the only original, full Difference Engine to ever be completed resides in London.

ATLAS

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