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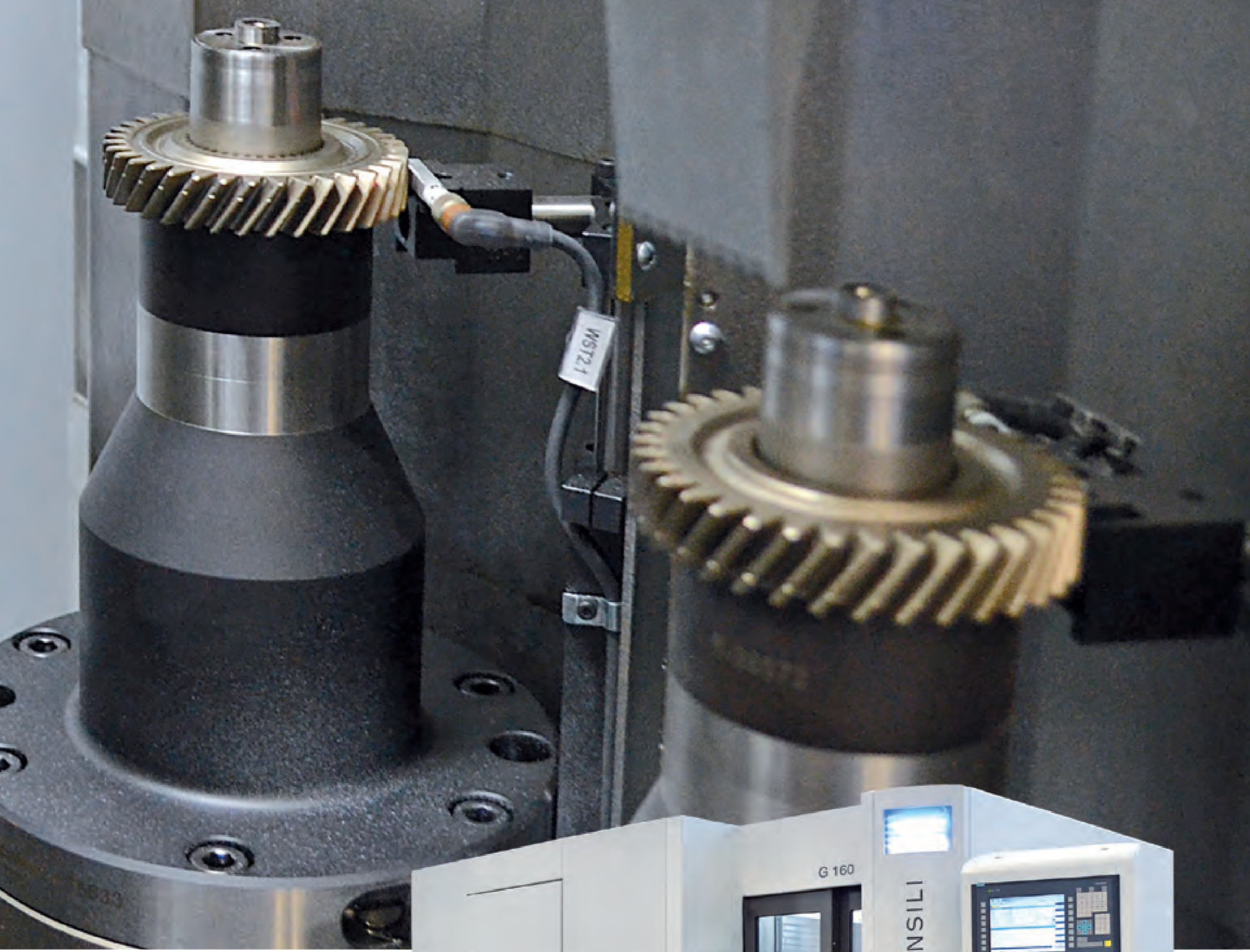
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Mazak Integrex i-200S AG

Integration of Integrex multi-tasking machine with gear cutting and gear measurement provides high accuracy gear cutting and reduced in-process time. Learn more here:

www.geartechnology.com/videos/Mazak-Integrex-i-200S-AG/

Seco Tools Spur Gear Power Skiving

This Seco Tools video shows the machining of a spur gear M3.5 (DP 7.26) Z+60 Profile DIN3972/II. The material is CK45. Machining time totaled 174", and the component was completed in 6 passes.

www.geartechnology.com/videos/Spur-Gear-Power-Skiving-/

Event Spotlight: EMO Hannover 2019

Under the motto "Smart Technologies Driving Tomorrow's Production," the EMO will be showing what modern-day production technology looks like and who is offering it. A new exhibition area IoT in production underscores its claim to position itself as a platform for networking in production. Learn more at: *www.geartechnology.com/news/4394/EMO_Hannover/*.

Gear Talk

Catch up with the gear origin stories and hear some of our resident blogger's musings on the history of the gear industry here:

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FOREST CITY GEAR

Gear Show 4.0

Publisher & Editor-in-Chief
Michael Goldstein

There have always been plenty of reasons to attend Gear Expo. For decades, it's been the best place to see all of the technology, vendors and solutions in the gear industry, all under one roof. You can talk to the people who develop the technology for designing, manufacturing, processing and inspecting gears. You can find any number of highly qualified gear manufacturers, whether you're looking for open gearing, standard speed reducers or custom, one-of-a-kind gearboxes. I've always said that Gear Expo was the greatest collection of gear knowledge under one roof all at one time that you could find anywhere in the world.

And that's still true. You can still see the newest and latest offerings from the major gear machine tool manufacturers. You still have the opportunity to interact with the engineers who develop, build and install the technology, so you can quickly and easily get the answers you want, resolve any manufacturing problems you're having and get a glimpse into your manufacturing future.

Also, as in year's past, the show is co-located with ASM's Heat Treating Society Conference and Exposition.

But now that it has evolved into the Motion + Power Technology Expo (taking place October 15–17 at the Cobo Center in Detroit), it's become much more than just a trade show. This event has grown into a one-stop educational, networking and buying event, and it's expanding its reach into other types of power transmission products as well. In particular, the AGMA has announced an increased focus on electric drives and fluid power as key elements of MPT Expo moving forward. That increased focus begins this year with the fluid power pavilion, which is being produced in partnership with the National Fluid Power Association.

That expansion of focus is taking place off the show floor, too, with greatly expanded educational offerings. For the first time ever, attendees can also take part in the MPT Conference, which includes seminars in two tracks: "Know Your Business" (the business track) and "Be Prepared for the Future" (the emerging technology track). The business track will include topics such as cybersecurity, supply chain and workforce development, while the emerging technology track will include seminars on 3-D printing, electric drives, IIoT and Robotics.

Those topics may seem a little bit removed from traditional gear industry fare, and there's a reason. The gear industry is changing, and only those who change with it will be ready for the future. The AGMA has put together a lineup of speakers designed to get you thinking about your company's future.

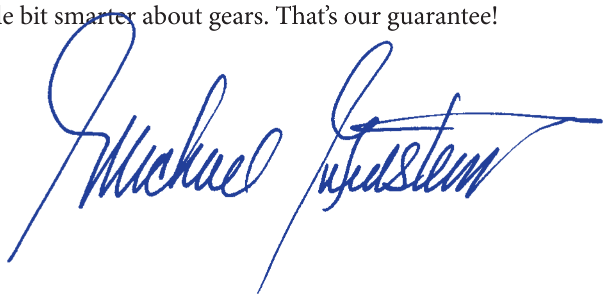
But that doesn't mean they're abandoning the good, old-fashioned gear-themed education you've come to expect. MPT Expo overlaps with the AGMA Fall Technical meeting (Oct. 14–16), where you can hear 26 presentations from the world's foremost experts on the latest research and technology related to gearing. In addition, there are in-depth educational sessions throughout the three days of MPT Expo, everything from the basics of gearing to heat treatment, lubrication, fluid power, bearings, electric drives and much more.

I don't have enough space here to tell you about everything MPT Expo has to offer, so I'll refer you to our full coverage on pages 26–37 and to the show website at *motionpowerexpo.com*.

As always, we'll be at the show. We hope that when you come, you'll stop by and see us in Booth #3826. We promise that our booth will be full of activity and educational opportunities as well, including four sessions of *Gear Technology TV*'s popular "Ask the Expert LIVE!" show. In fact, if your company is experiencing any gear-related problems (whether they be design, manufacturing, heat treating or anything else), why not send us your questions? Even if you're not there, we'll ask our panel of experts for help, and you can see the answers on *Gear Technology TV*.

In addition, we'll be recording live sessions of our "Revolutions" feature, where we interview leading experts in the gear industry about the latest technology, how it works, and why it's important.

Between "Ask the Expert LIVE!" and "Revolutions," you can't help learning something just by sitting in the audience. In fact, all you have to do is come by our booth and listen in to get a little bit smarter about gears. That's our guarantee!



TimkenSteel

TOUTS AUTOMATION AND ROBOTICS IN FORGING APPLICATIONS

The forging industry is a key link between critical manufacturing segments — metal suppliers (both ferrous and nonferrous) and end user industries. Forgings, which appear in 20% of the products representing the Gross Domestic Product of the United States, are essential to the U.S. industrial economy, to its society, and to its national security, according to the Forging Industry Association (FIA).

In recent years the U.S. forging industry has undergone significant shrinkage associated with intense global competition, technological changes, and environmental and economic factors. Those companies that survived the industry downsizing emerged stronger and better equipped to face the competitive challenges of manufacturing today — escalating demands from customers, changing markets, global competition, and threats from competing manufacturing processes.

The forging industry looks forward to the business and technical challenges that will shape its future. Some of these challenges include higher levels of quality, a greater return on investments and a push toward smart manufacturing initiatives. 20 years ago, it would have been highly unlikely to find automation, robotic, and sensor technologies in the forging industry. In the last five to ten years, however, huge steps have been taken to radically change existing processes and optimize process modeling, controls, sensors and preventative maintenance in these areas.

In-Line Forge Press

One example of this is TimkenSteel, a producer of alloy steel products and services including standard steel grades as well as customized solutions. The company offers solutions in special bar quality (SBQ) bar sizes from 1" to 16" and seamless mechanical tube sizes from less than 3" to over 13". They engineer hundreds of carbon and alloy steel grades to meet the severe service requirements in oil and gas.

One area that the company has invested in recently is its automation capabilities. Ron Honaker, senior reliability/maintenance specialist at TimkenSteel, says that the in-line forge press at the Faircrest Steel Plant is completely automated.

“Most forgers use an operator to physically run their press; in contrast, our operator monitors both the bloom mill and the forge press from a pulpit and only intervenes if a problem occurs,” Honaker says. “Our in-line forge press makes our work area safer because we do not have an operator directly involved with the forging process. Further, this technology allows us to be more efficient because we can run automatic cycle times at the press that match up with cycle times for the mill.”

This kind of automation technology would not have been possible 15 to 20 years ago, according to Honaker. It allows TimkenSteel the luxury of achieving results at the plant that the organization couldn’t have reached in the past.

Modern forge lines are tasked with not only handling the product from one stage to the next, but also with creating the most efficient and effective production process. “Sensors, for example, are critical for material placement while processing the cast blooms and ingots,” Honaker says.

The forge press only requires one operator to do what would take 4–5 employees to do with older technology. When facing industry challenges like skilled workforce shortages, this technology allows TimkenSteel to get the job done faster and more efficiently.

In turn, the logic built into the forge press keeps product being manipulated from damaging any equipment and does not require any human interaction with the actual product. This is critical in making the manufacturing facility safer and more efficient.

Another area that continues to advance for TimkenSteel is the company’s modeling technology.

“We currently use modeling to look at possible end results when forging new products or chemistries. This technology also allows us to show customers how we can process the blooms or ingots for higher quality and enhanced sound centers,” Honaker says.

Future Growth

The FIA believes that new knowledge must be developed and applied industry-wide through specific research and development that focuses on bulk deformation sciences and engineering technologies so that more cost efficient and higher performing products and processes are developed.

In addition, partnerships between the forging industry, federal laboratories, universities, and vendor companies must be formed to share information on integrated computational tools, advanced modeling, and automation techniques. It’s obvious that automation and robotic technologies will continue to play a pivotal role in the future of forgings, gear blanks and raw materials.

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www.timkensteel.com


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Solar Atmospheres

INSTALLS ALL-METAL HOT ZONE VACUUM FURNACE AND 14-FOOT AIR FURNACE

Solar Atmospheres recently installed another unique, all-metal hot zone vacuum furnace at its 1969 Clearview Road facility in Souderton, PA.

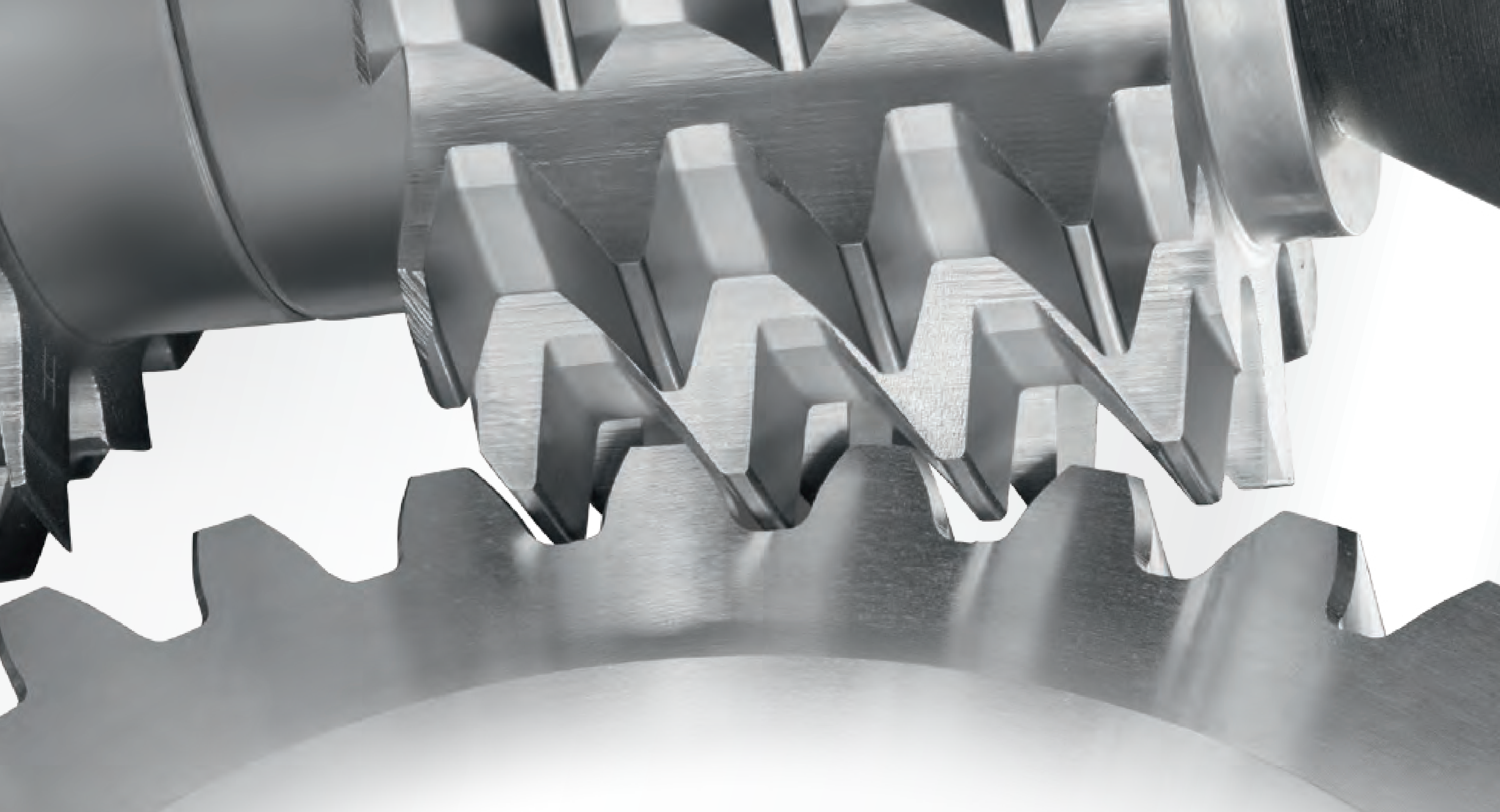
This is Solar's third all-metal hot zone furnace installation for their climate-controlled room. The additional furnace increases Solar's capacity for processing sensitive materials such as PH stainless, nickel-chrome based superalloys, titanium, and ferritic and austenitic stainless steels.

The unique placement of isolation valves, an all-metal moly/stainless steel hot zone, and a stainless steel chamber allows this furnace to attain the level of cleanliness mandated by the demanding aerospace and medical markets. The ability to achieve vacuum levels lower than 5×10^{-6} Torr produces clean, bright results without contamination. Additionally, this furnace incorporates Solar Manufacturing's latest SolarVac Polaris HMI control system for complete process automation.

Jamie Jones, president of Solar Atmospheres states, "The increasing demands for cleanliness levels in critical aerospace and medical applications, and the growth in these markets, paved the way for Solar Atmospheres to add capacity through this investment."

Additionally, the company recently installed a brand new, 14-foot long car bottom air furnace. The furnace was surveyed in accordance with AMS2750 Rev E and is uniform within ±10°F (Class 2). With a working zone measuring 60" wide × 54" high × 168" long, the furnace will be capable of handling workloads up to 30,000 pounds. A maximum operating temperature of 1400°F allows this furnace to accommodate the tempering of large tool steel components, as well as the age hardening processes of nickel-based alloys and precipitation hardenable stainless steels.

For more information:
Solar Atmospheres
Phone: (844) 982-0660
www.solaratm.com



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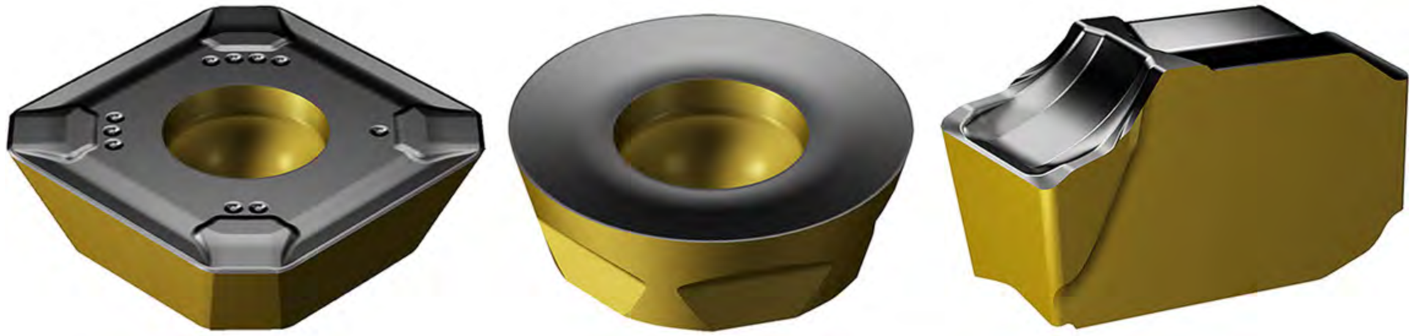


Sandvik Coromant

EXTENDS INSERT GRADES TO ADDITIONAL MILLING CONCEPTS

GC4330 and GC4340, which feature a specially developed substrate, Inveio coating and enhanced post-treatment technology, allow users to enjoy substantially increased tool life and process security. Now, the extension of these grades to additional Sandvik Coromant milling concepts brings their advantages to even more machine shops looking to optimize the milling of steel workpieces.

"GC4330 and GC4340 have been purpose-designed to overcome certain issues when machining steel components," states Karl Emil Holmström, global product application manager grades at Sandvik Coromant. "For instance, some hard and abrasive steels can promote wear along the insert's flank face, particularly at elevated speeds and longer time in cut. What's more, machining in unstable conditions as a result of compromised fixturing or long overhang increases the risk of chipped inserts. A further risk is thermal fluctuation during machining which, especially in wet conditions, can lead to crack formation and sudden breakages."

Among the many design attributes of GC4330 and GC4340 is the optimized Inveio coating. Inveio is the technical breakthrough of uni-directional crystal orientation in the alumina coating layer that gives inserts a new level of wear resistance and tool life. Furthermore, the substrate of the grades delivers highly controlled grain size distribution for more reliable and predictable insert behavior.

GC4330 is a medium-hard grade

for roughing to semi-finish face milling, with the tough GC4340 grade preferred for rough shoulder milling and groove milling. Both grades are now extended to the aforementioned CoroMill 245 and CoroMill 300, as well as the CoroMill 360 heavy-duty face mill, CoroMill 419 high-feed mill, and LPMH-PM plunge-cutter inserts.

In addition, GC4330 is available for the CoroMill 365 high-security face mill, while GC4340 can be applied to the CoroMill 216 ball-nose end mill and CoroMill 415 small-diameter high-feed face mill, along with the CoroMill QD cutter.

This list adds to the existing availability of both grades for CoroMill 390 and CoroMill 490 shoulder mills, CoroMill 345 face mills, CoroMill 210 high-feed cutters, CoroMill 200 profile mills and CoroMill 331 for grooving and parting off.

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

KISSsoft

INTRODUCES 2019 RELEASE

The new *KISSsoft Release 2019* contains numerous new features, including *KISSdesign*, which provides the user with a tool that allows intuitive concept design on a system level. So, in addition to the elementary components (gear pair, bearing or shaft/bearing system), complete gears can now be designed in a separate module (Module KSD).

The main focus here lies on fast concept building, which is a great advantage — especially in the initial phase of a project. Further information about this new system program is available in a short video and web demo in September 2019.

Would you like to build different drivetrain concepts by yourself using the modeling tree and sketch functionality? Then register for the workshop on *KISSdesign* as part of KUM International 2019 on October 24 and create several kinematics together with our experts — starting from industrial gearboxes up to shifted transmissions.

For more information:
KISSsoft AG (A Gleason Company)
Phone: (585) 494-2470
www.kisssoft.ag

NUM AG

HELPS AUTOMATE PRODUCTION OF INVOLUTE AND CYCLOIDAL GEARS FOR ROBOTICS

NUM is helping the Taiwanese machine tool company Chien Wei Precise Technology to develop innovative CNC grinding machines for manufacturing specialist gears used in robotics applications. Based entirely on NUM's latest-generation Flexium+ 68 CNC platform, Chien Wei's new machines are designed to speed the production of both involute and cycloidal profile precision gears. They are believed to be the first gear grinding machines on the market that are capable of handling both types of gear profile. There are two versions of the grinding machine, one for internal gears, the other for external gears.

According to Chien Wei's President, Mr. Lee, "We quickly decided that what we needed was a CNC system that fully supported gear grinding from the outset, so that our customers could simply input the parameters of the gear they wanted, with the CNC then controlling all aspects of the machine's dressing and grinding processes in real-time. NUM was an obvious choice, because of its proven expertise in CNC gear grinding applications. The company was also willing to collaborate in the joint development of the CNC system, which includes an application-specific HMI (human-machine interface) and various dedicated control functions."

For more information:
NUM Corporation
Phone: (630) 505-7722
www.num.com

Taking the Wait Out of High Quality Gear Blanks

Forest City Gear makes the investment to bring gear blanking in-house, giving it complete control over quality and delivery: because failure's not an option.

"You can't send a repairman to Mars."

Forest City Gear Turning and Milling Supervisor Mike Miller sums it succinctly when asked about the company's decision to bring most of its critical gear blanking operations in-house, rather than outsourcing. Today, Forest City Gear has a state-of-the-art 8,500 sq. ft. facility in close proximity to the company's main plant in Roscoe, IL dedicated almost entirely to the precision turning, milling and inspection operations needed to produce its gear blanks.

The investment gives Forest City Gear complete control over the quality and delivery of the blanks that are the 'near net shape' starting point for the fine- and medium-pitch cylindrical gears and shafts the company produces. And that's good news for the 400 or so Forest City Gear customers that are active at any one time.

"Whether it's for the Mars Rover or an application closer to home, our customers have quality and delivery requirements that are increasingly hard to meet when you outsource gear blanking to the turning houses," Miller explains. "The typical process can take weeks and stretch out even further when blanks are rejected.

"Bringing this work in-house is paying dividends every day. For example, we had a customer recently that needed an emergency order of high-precision pinion shafts for a power tool application. Fortunately, we had this facility up and running, cutting turn-around time from a typical ten or 12 weeks to just two."

Invest in the Best. The decision to in-source gear blanking wasn't made lightly. Some valuable lessons were learned in 2012, when Forest City Gear originally built the facility and launched Roscoe Works, a division created for gear blanking, but eventually re-purposed to meet a long-term high volume gear production contract. Today Roscoe Works has come full circle — only better.

"We couldn't have gotten to where we're at today without the learning experience of Roscoe Works," says Forest City Gear Director of Operations Jared Lyford. "Since 2012, we've expanded the core competencies — people, training and technology — necessary for the production of gear blanks that can't easily be outsourced, while recognizing that there's still commodity work here that's more efficient to outsource."

The typical blanking operation for a gear or shaft seems simple enough: start with bar stock or forging, rough and finish turn the part to remove excess material, perform the necessary milling and drilling operations — everything short of producing the gear teeth. It's easily manageable in a gear production environment running the same commodity parts day after day. But at Forest City Gear, blanks on any given day might be needed for several dozen different customer orders, with gears ranging from 1/8" to 8" in diameter, shafts up to 16" long — all in lot sizes as small as one or as many as a thousand.

"We responded to this challenge the way we always do at Forest City Gear: invest in the best, most productive technology for the job," says Lyford. "For example, we've just added four advanced Mazak Quick Turn Turning Centers with multi-tasking capability so both turning and milling can be done in just one setup for shorter lead times and greater accuracy. We've also upgraded our CAD/CAM design and manufacturing software to *Mastercam*, thus giving us a more powerful, yet simple and intuitive 5-axis parts programming capability in support of these milling and turning operations."

The 8,500 sq. ft. facility includes Mazak Quick Turn Turning Centers with multi-tasking capability so both turning and milling can be done in just one setup for shorter lead times and greater accuracy.

In addition to the integral main turning spindle, the Mazak Quick Turns are equipped with both milling spindle (and a 12-position turret for tool changing) and Y-axis capability to create multiple tool positions, as well as a second turning spindle so that particularly complex parts can be machined complete in a single setup to save time and help hold tight tolerances. As a result, each do the work of multiple machines, helping Forest City Gear add greatly to its existing turning and milling capacity, while reducing floor space and manpower requirements, machine and tooling costs.

More Quality, Less Queue Time. Once the blanks are machined, they're ready for completion at Forest City Gear's main facility. But first comes inspection.

"Starting off a project with blanks out of tolerance can create a devastating production bottleneck when operations downstream are sitting idle waiting for good parts to finally arrive," says Mike Miller.

That's why, according to Miller, CMM-level inspection is today the norm, rather than the exception, for the majority of the gear blanks produced at this facility. That means that fully 75% of these jobs require that a sample lot be inspected by a CMM for true position, profile and the other critical features to ensure they're made to part print. While Forest City Gear has a dedicated quality lab, inspection of gear blanks in the lab would require transport to the main plant, and then queuing up for inspection in competition with parts being completed in the main plant. All of this takes precious time. Forest City Gear's solution? Bring the lab to the new facility. The company just purchased a new Zeiss Accura CMM for the quality lab at the main plant, thus freeing up its existing Zeiss Contura CMM. This system now resides at the gear blanking facility, in close proximity to the production floor (the entire facility is temperature controlled), and dedicated to gear blanking inspection.

The facility has its own dedicated Zeiss Contura CMM, putting inspection in close proximity to the shop floor to reduce queue time.

Beyond Blanks: What's Next. With the new operation now running two 10-hour shifts, Forest City Gear is already looking at expansion. The company has the land to add an additional 10,000 sq. ft. to the facility and, according to Jared Lyford, is looking at purchasing new equipment to completely machine products such as gear housings and small planetary carriers.

For more information:

Forest City Gear
Phone: (815) 623-2168
www.forestcitygear.com

Forest City Gear can produce its own blanks for gears ranging from 1/8" to 8" in diameter, shafts up to 16" long – in lot sizes from one to a thousand.

Super Skiving Cutter

An Innovative Process Modification for Gear Skiving

Tetsuji Monden, Toshimasa Kikuchi, Keisuke Yoshikawa, Noritaka Fujimura, Adrianos Georgoussi

In recent years, the skiving process has been attracting attention as an internal gear cutting method, and many gear cutting users in the automotive and construction machine industries have been adopting it as a cutting method for mass production.

The gear skiving process allows for high precision and high efficiency cutting. However, significant challenges, such as the high dynamic load on the tool during cutting and thus a shortened tool life, inhibit the large-scale industrialization of the process. To overcome these challenges, Mitsubishi Heavy Industries, Ltd. (MHI) conducted a comparison test between the super skiving cutter and the pinion skiving cutter used in the conventional skiving process and the test results are reported here. The test was conducted in cooperation with the WZL of RWTH Aachen University, Germany, as a third party organization.

Introduction

Internal gears are mainly used for planetary gear devices for automotive automatic transmissions and reducers of construction machines. The conventional internal gear cutting processes are mainly limited to gear shaper cutting using a pinion cutter and broaching using a broach cutter, and these cutting processes have both advantages and disadvantages in terms of productivity, processing accuracy, production cost, etc. In recent years, the development of a skiving process, as an alternative to the conventional processes, which allows high precision and high efficiency cutting, has been promoted along with the increase in machine rigidity/performance and the progress in tool material/coating technologies. However, the industrialization of the process on a large scale is being inhibited by a shortened tool life.

As shown in Figure 1, in the skiving process, a crossed axes angle is formed, and so the effective rake angle of the tool becomes negative during cutting. As a result, the cutting sharpness of the tool is reduced, the cutting resistance is increased and the load on the tool cutting edge is increased, causing a rise in tool wear and chipping on the cutting edge of the tool. MHI developed a proprietary super skiving cutting tool with the objective of improving the cutting conditions and increase the tool life, thus enabling a productive an economical process.

Figure 2 presents the appearances of the pinion skiving cutter (hereinafter, PSC) used for the conventional skiving process and the super skiving cutter (hereinafter SSC) developed by MHI. The SSC is a skiving tool consisting of multiple blades. Each blade represents a pinion skiving tool with a specific amount of cutting teeth. Thus, the cutting volume can be further distributed and the cutting load per tooth can be reduced.

In addition, Figure 3 displays the general internal gear manufacturing process. SSC was developed, from the beginning, targeting workpieces falling under Figure 3-(1) and mainly used by domestic automotive manufacturers. In this case, the workpiece hardness is HB230

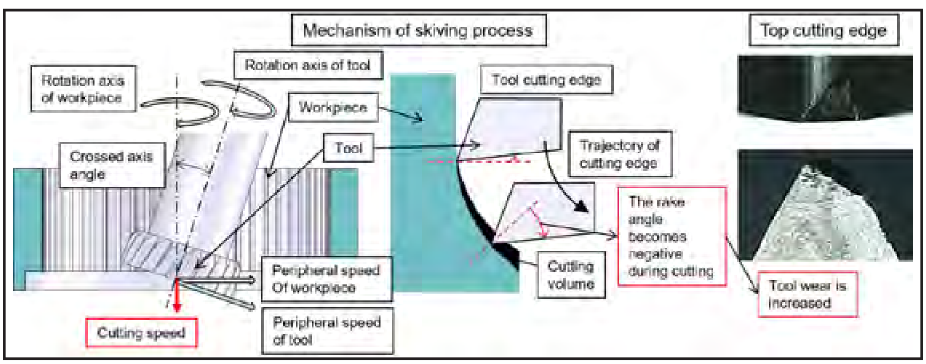


Figure 1 Effective rake angle in skiving process.

Figure 2 Appearance of pinion skiving cutter (PSC) and super skiving cutter (SSC).

Figure 3 Manufacturing process of internal gear.

(≈HRC20) or less, which is relatively easy to cut. Figure 4 gives the results of continuous cutting in which each PSC and SSC tool was used to cut a workpiece with HB200 falling under Figure 3-(1), until the tool wear amount reaches 250 µm. This test was conducted under the same cycle time (hereinafter C/T). The results indicated that the number of workpieces processed by SSC was about 6 times larger than that by PSC. Some users, however, require a skiving process for a workpiece material with a hardness of HRC45 or less as can be seen in Figure 3-(2), which is something that overseas users often require. Therefore, in this test, we requested the cooperation of WZL of RWTH Aachen University in Germany as a third party organization and evaluated the performance of SSC for a workpiece material with a high hardness.

Features of Super Skiving Cutter

Development concept of super skiving cutter

For a skiving cutter, which has the problem of a shortened tool life, we needed to realize improved productivity and increased tool life in continuous cutting using multiple blades in a manner similar to hobbing. Therefore, in order to provide a tool with multiple blades, we developed a tool with an increased thickness compared with that of the conventional PSC. As shown in Figure 5, in the skiving process, a crossed axes angle is formed. If a tool with an increased thickness is used with the crossed axes angle being formed, interference occurs between the tool and the workpiece. To avoid this interference, the tool must be barrel-shaped. Based on the barrel shape, the multiple-blade tool was realized. As depicted in Figure 6, SSC is formed with the finishing blade at the maximum outside diameter of the barrel shape and the rough blades set based on the finishing blade.

Specification of workpieces

Material	SCM415 (HB200)
Module	1.5
Number of teeth	70
Helix angle	20° LH
C/T	60 s

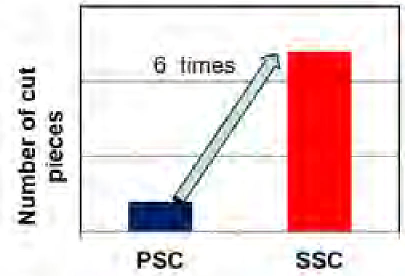


Figure 4 Comparison of performance between PSC and SSC (workpiece material: SCM415).

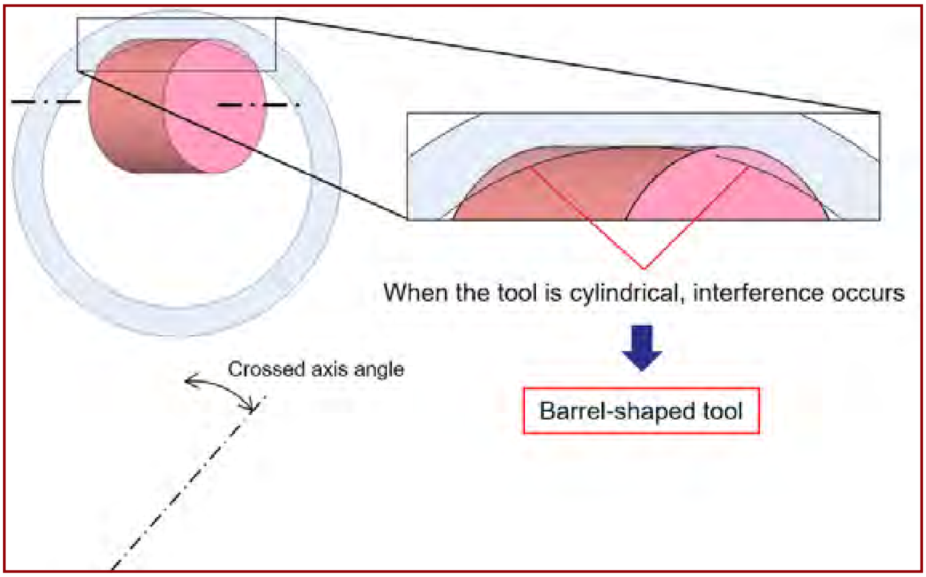


Figure 5 Shape of SSC (1).

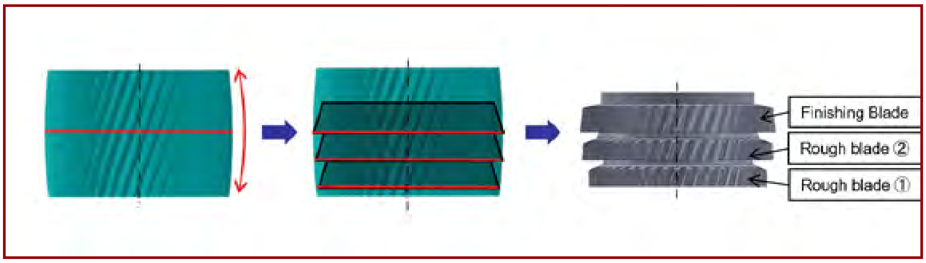


Figure 6 Shape of SSC (2).

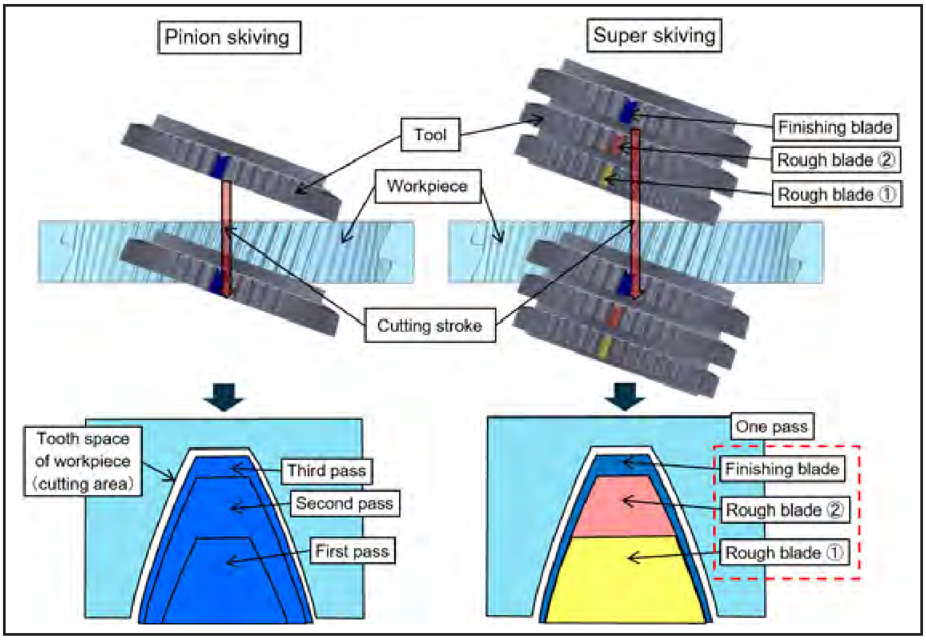


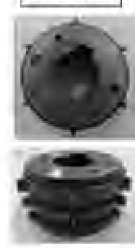
Figure 7 Cutter blades of tool used in the cutting area.

Specifications of workpiece		
Module	1.25	mm
Number of teeth	85	
Pressure angle	20	deg
Helix angle	20 (RH)	deg
Material	1.7225 (42CrMo4)	
Hardness	30-35 35-40	HRC

Specifications of tool	
Type	PSC SSC
Number of teeth	6 (equivalent 54) ※1
Helix angle	SPUR
Material	Powder high-speed steel, carbide

Cutting conditions		
Cutting speed	120	m/min
Feed speed	0.1~0.2 mm/rev	
Number of cuts by cutter blade	13	times ※2

Test cutter



※1 The test cutter with evenly spaced 6 teeth was made by reducing the teeth from a 54-teeth cutter.
※2 In PSC, the number of cutting strokes is13 passes (In one stroke, one cutter blade cuts (once).)
In SSC, the number of cutting strokes is 5 passes (In one stroke, three cutter blades cut (three times), but in the final stroke, only one finishing blades cuts (once).)

Table 1 Specifications of test pieces.

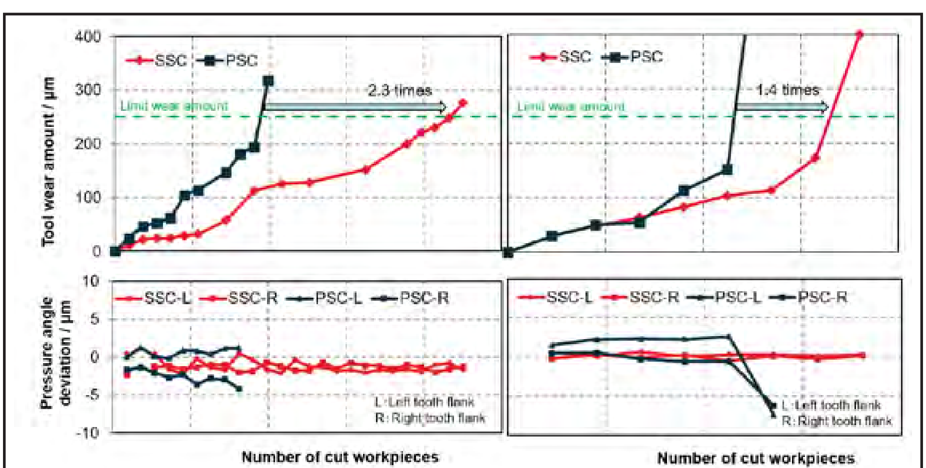


Figure 8 Comparison of performance between PSC and SSC (workpiece hardness difference).

Advantages of super skiving cutter

As illustrated in Figure 7, the advantages of SSC are as follows:

PSC cuts the tooth space of a workpiece using the same finishing blade (Figure 7 presents the case of cutting in 3 passes), while SSC has three cutter blades (rough blade (1), rough blade (2), finishing blade) so that it can cut the tooth space of a workpiece in one pass using different cutter blades. The cutting load on one cutter blade of SSC was reduced to one third of PSC, and SSC achieved a longer tool life.

The two rough blades are independent from the finishing blade. The precision of the workpiece depends on the tooth profile of the finishing blade, and the tooth profile of the rough blades can be changed freely. The tooth profile of the rough blades can be adjusted according to the state of wear of each blade or the shapes of chips, and a further increase in tool life can be expected. In addition, depending on the state of wear, different tool materials may be used for the finishing blade and the rough blades.

Test Results

Test specifications

The workpiece, tool, and cutting conditions used in this test are shown in Table 1. In the test, a cutter with only six teeth was used to reduce the number of workpieces needed. With the use of this cutter, the machining of 9 workpieces can be made equivalent to the machining of one workpiece. The number of cuts under the given cutting conditions is a result of the cutting amount of one cutter blade being the same, rather than the C/T being the same. That is, when the number of cuts of the cutter blade is 13, PSC uses one cutter blade (only the finishing blade) in one cutting stroke and the total number of cutting strokes corresponds to 13 passes (cut with one cutter blade × 13 passes = 13 cuts). SSC uses three cutter blades (rough blade (1), rough blade (2), finishing blade) in one cutting stroke. In the final cutting stroke, however, only the finishing blade is used for the purpose of increased precision. Therefore, the total number of cutting strokes corresponds to 5 passes (cut with three cutter blades × 4 passes + cut with one cutter blade × one pass = 13 cuts). In this case, the C/T of SSC is shortened by about 40%. The cycle times of PSC and SSC do not simply correspond to the number of passes, because the cutters have different thicknesses and their cutting strokes are different, as can be seen in Figure 7.

Under these conditions, the tool life for PSC and SSC was evaluated with the following comparison items:

- Influence of workpiece hardness: Comparison between HRC30-35 and HRC35-40
- Influence of cutter material: Comparison between powder high-speed steel and carbide

For the test, the MSS300 Skiving Machine developed by MHI was used.

Test results

Figure 8 gives the results of the cutting of workpieces with different hardnesses, HRC30-35 and HRC35-40, by the powder high-speed steel cutter. The upper graphs show the changes in tool wear. When the limit wear amount is 250μm, the tool life of SSC is 2.3 times longer than that of PSC for the workpiece hardness of HRC30-35, and the tool life of SSC is 1.4 times longer for HRC35-40. The lower the workpiece hardness is, the larger the performance difference between PSC and SSC becomes. The lower graphs illustrate the pressure angle deviation of the workpieces. Compared with PSC, SSC maintains almost the same pressure angle deviation in any wear amount.

Figure 9 presents the results of the cutting of the HRC35-40 workpieces by the carbide cutter. As is the case with Figure 8, the upper graph shows the changes in tool wear. When the limit wear amount is 250 μm, the tool life of SSC is 3 times longer than that of PSC, which substantially exceeds the 1.4-times increase in the results of the test using the powder high-speed steel cutter under the same conditions.

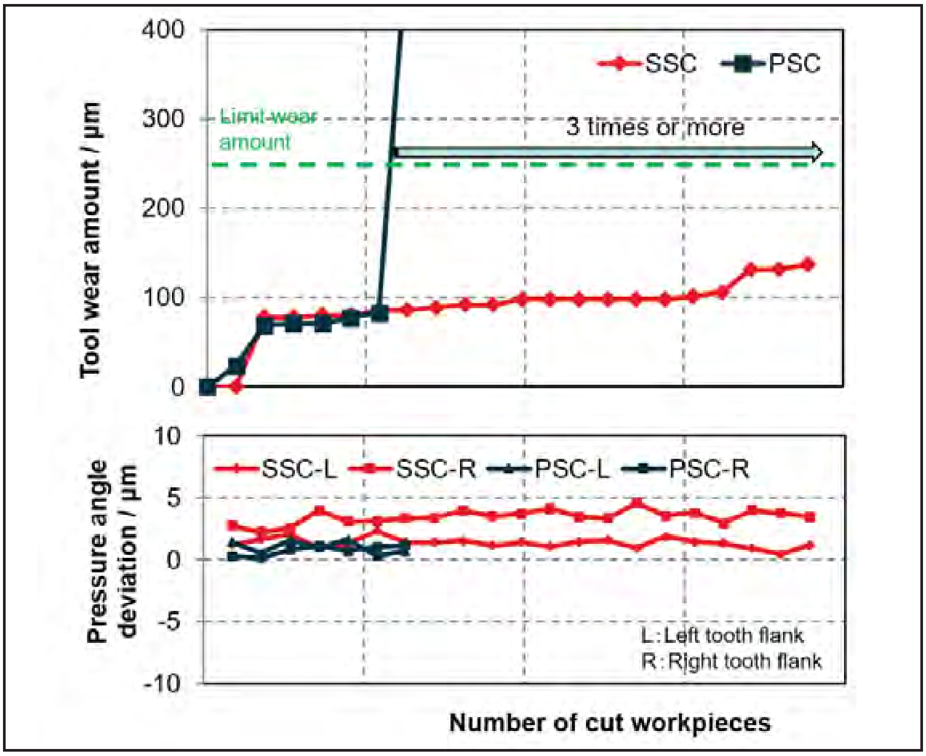


Figure 9 Comparison of performance between PSC and SSC (cutter material: carbide).

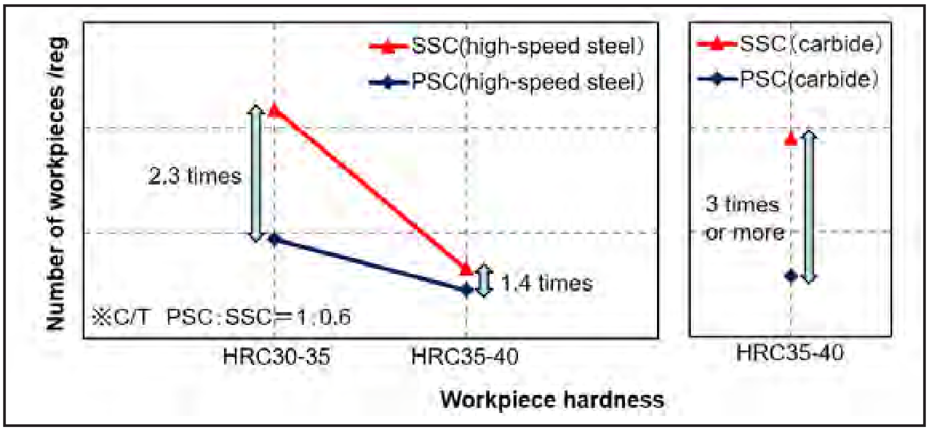


Figure. 10 Comparison of performance between PSC and SSC.

Consideration

In this test, the results of the performance comparison between PSC and SSC showed the following:

1. As can be seen in Figure 10, the difference in tool life between PSC and SSC depends on workpiece hardness.
2. As shown in Figures 8 and 9, under the conditions where the workpiece hardness is high, HRC30-40, and the C/T is shortened by about 40%, the tool life of SSC can be 1.4 to 3 times or longer than that of PSC.
3. As illustrated in Figure 4, under the conditions where the workpiece hardness is HB200 and the C/T is same, the tool life of SSC can be 6 times longer than that of PSC.

Accordingly, we think it is important to select appropriate tool materials and determine optimal cutting conditions according to workpiece hardness for SSC to deliver higher performance than PSC.

Conclusion

In this test, the superiority of SSC in a wide range of workpiece hardnesses including high hardness was verified. In the future, we will continuously develop SSC for further improved performance. In particular, we are going to optimize the cutting conditions, evaluate workpieces with different specifications and expand the verification scope. MHI has also developed and sells the ZI20A internal generating gear grinding machine for finishing, and we are making efforts to provide total and optimal proposals in the manufacturing process of internal gears from skiving to finishing grinding.

For more information

Mitsubishi Heavy Industries America, Inc. - Gear Machine Tool Division
46992 Liberty Drive
Wixom, MI 48393
Phone: (248) 668-4140
www.MitsubishiGearCenter.com

MPT Expo is all about Learning

OCTOBER 15–17, 2019, COBO CENTER, DETROIT, MI

MOTION + POWER TECHNOLOGY EXPO

The Motion + Power Technology Expo (formerly Gear Expo) connects manufacturers, suppliers, buyers, and experts in the mechanical power, electric power, and fluid power industries.

No matter which industry you represent, you will gain best practices and new ideas from like-minded colleagues as well as cross-sector collaboration.

Show Floor

Visitors will see more than 300 exhibitors from across the supply chain, including all the usual gear industry suppliers, from the major machine tool manufacturers to suppliers of workholding, inspection equipment, cutting tools, lubrication and more. Of course, there will also be pleny of gear manufacturing companies, including open gear manufacturers as well as suppliers of custom and standard gearboxes. In addition, visitors will see the new fluid power pavilion (provided in conjunction with the National Fluid Power Association).

For a full listing of exhibitors at MPT Expo, visit *motionpowerexpo.com*. But also, stay tuned! Our comprehensive coverage will continue in the September/October issue, including booth previews of many top exhibitors!

OFFICIAL SHOW HOURS

Tuesday, October 15
9:00 am – 6:00 pm

Wednesday, October 16
9:00 am – 5:00 pm

Thursday, October 17
9:00 am – 4:00 pm

HOW TO REGISTER

ONLINE
Visit MotionPowerExpo.com and enter your guest pass registration code (at right) to pre-register for an expo-only admission.

OR

IN PERSON
Present this pass at the Motion + Power Technology Expo registration counter in the Cobo Center. This guest pass saves you $50 in on-site registration fees.

When issued by an exhibitor at Motion + Power Technology Expo, this Guest Pass entitles the bearer to one complimentary expo-only addition, good during the official show hours.

MOTION + POWER TECHNOLOGY EXPO

FREE GUEST PASS

GEAR. ELECTRIC. FLUID POWER. ALL UNDER ONE ROOF.

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BOOTH #: 3826

GUEST PASS REGISTRATION CODE: MEX210

With the latest demands for efficiency and power density, often the solution is a choice combining power transmission technologies. At MPT Expo, you'll see the entire power transmission supply chain — with mechanical, fluid power, electric, and hybrid solutions.

Owned by: American Gear Manufacturers Association | Sponsoring organization: NFPA | Co-located with: HTS Heat Treating Society ASM International

OCTOBER 15–17, 2019 | DETROIT, MICHIGAN | COBO CENTER | **MotionPowerExpo.com**

A Learning Experience

In addition to learning from the exhibitors all about the latest technologies related to gears, gear manufacturing, fluid power and more, the show has a lot to offer in terms of seminars, classes and organized educational sessions.

Ask the Expert LIVE!
Booth #3826

Gear Technology and *Power Transmission Engineering* will be hosting live sessions of our popular series "Ask the Expert LIVE!" throughout MPT Expo. Be a part of our engaging educational shows by joining our live audience. You can listen in and learn, or you can try to stump our experts with your toughest questions!

- **Gear Manufacturing – Tuesday, October 16, 10:30 a.m.** Our experts will answer your questions on hobbing, shaping, skiving, grinding, bevel gear manufacturing and much more. Whether your questions are about the machine, cutting tools, workholding or general troubleshooting, our experts will have the answers you need!
- **Gear Design – Tuesday, October 16, 2:30 p.m.** Have questions about software? Standards? Material specifications? This is the place to learn from our panel of experts!
- **Lubrication – Wednesday, October 17, 10:30 a.m.** Learn more about viscosity, EHL film thickness, synthetic lubricants and their effects on gearbox efficiency, micropitting resistance and more.
- **Bearings – Wednesday, October 17, 2:30 p.m.** We all know that gears operate as part of a system, and some of the most crucial components in those systems are the bearings. Learn more about bearing selection, why bearings fail and some of the critical issues facing gearbox designers and manufacturers today.

Do you have questions on any of these topics? You don't have to be present to get answers! Send your questions now to Jack McGuinn, Senior Editor, *jmcguinn@geartechnology.com,* and we'll submit them to our panel of experts for you!

Education Courses

The education courses at the Motion + Power Technology Expo offer exclusive access to a wide-ranging series of technical seminars taught by industry leaders and insiders. From novice to expert, there are courses for all career-levels. Each course is conveniently situated just steps from the Expo floor — so you can combine classroom learning with hands-on experience with the equipment. Admission to the exhibit hall is included with your seminar registration. See *motionpowerexpo.com* for information on registration and pricing (but don't wait, because prices go up after Sept. 13).

Hydraulic Fluid Properties, Efficiency, and Contamination Control
8:00 am – 12:00 pm, Tuesday, Oct. 15
Paul Michael, Research Chemist, MSOE

Supply Chain Management
8:00 am – 12:00 pm, Tuesday, Oct. 15
Dr. Justin Jones and Keyvan Gerami, Ranken Technical College

Technical Overview of Automotive Differentials
8:00 am – 12:00 pm, Tuesday, Oct. 15
William Mark McVea, KBE+, Inc.

Overview of Fluid Power Components and Systems
1:00 pm – 5:00 pm, Tuesday, Oct. 15
Thomas Wanke, CFPE Director, Fluid Power Industrial Consortium and Industry Relations, MSOE

Technical Overview of Automotive Powertrain Lubricants
1:00 pm – 5:00 pm, Tuesday, Oct. 15
William Mark McVea, KBE+, Inc.

Why Bearings Are Damaged
1:00 pm – 5:00 pm, Tuesday, Oct. 15
ABMA

Fundamental Understanding of Electro Fluid Power Technology
8:00 am – 12:00 pm, Wednesday, Oct. 16

Gearbox Field Inspection — Load Distribution, Lubrication, and Condition Monitoring
8:00 am – 12:00 pm, Wednesday, Oct. 16

Basics of Gearing
8:00 am – 5:00 pm, Wednesday, Oct. 16
William Mark McVea, KBE+, Inc.

Reverse Gear System Engineering—Why, When, and How
8:00 am–5:00 pm, Wednesday, Oct. 16
Raymond Drago, P.E., Drive Systems Technology

Taming Tooth Deflections: The Case for Profile Modifications
8:00 am–12:00 pm, Thursday, Oct. 17
Raymond Drago, P.E., Drive Systems Technology

Basics of Gearing
8:00 am–5:00 pm, Thursday, Oct. 17
William Mark McVea, KBE+, Inc.

Materials Selection and Heat Treatment of Gears
8:00 am–5:00 pm, Thursday, Oct. 17
AGMA and ASM International

Loaded Tooth Contact
1:00 pm–5:00 pm, Thursday, Oct. 17
Terry Klaves

Fall Technical Meeting

Take a deep dive into the gear industry at AGMA's Fall Technical Meeting. This meeting brings together top researchers from across the globe who will provide the latest information on their peer-reviewed gear industry research. Network with the industry experts, academics, and engineers; ask your burning questions; and see what is in the future of this industry.

Fall Technical Meeting Networking and Events Schedule

Monday, October 14: 1:00 pm–8:00 pm
Tuesday, October 15: 7:00 am–5:00 pm
Wednesday, October 16: 7:00 am–5:00 pm

Presentation Sessions

Each session will showcase five to six presenters sharing their highly technical knowledge of specific topics within the following research areas:

Session 1—Application, Design, and Rating

Monday, October 14, 1:00 pm–5:00 pm

- Design of a Double Spiral Bevel Gearset
- Electric Vehicle Transmissions with Hypoid Gearset
- Misalignment Compensation Splines Design
- Optimal Polymer Gear Design: Metal-to-Plastic Conversion
- Specific Dynamic Behavior of Planetary Gears
- Spline Centering, Piloting and Toggle: Torsional Stiffness, Shaft Bending, and Centering of Moment Loads

Session 2—Efficiency, Lubrication, Noise, and Vibration

Tuesday, October 15, 8:00 am–12:00 pm

- Computing Gear Sliding Losses
- IPhase Management as a Strategy to Reduce Gear Whine in Idler Gear Sets
- Leveraging the Complementary Strengths of Orbitless and Planetary Drives
- Opportunities of Efficiency Improvement by the Use of Hydro Lubricants
- Reduction of the Tonality of Gear Noise by Application of Topography Scattering for Ground Bevel Gears

Session 3 — Materials and Heat Treatment
Tuesday, October 15, 1:30 pm–5:00 pm

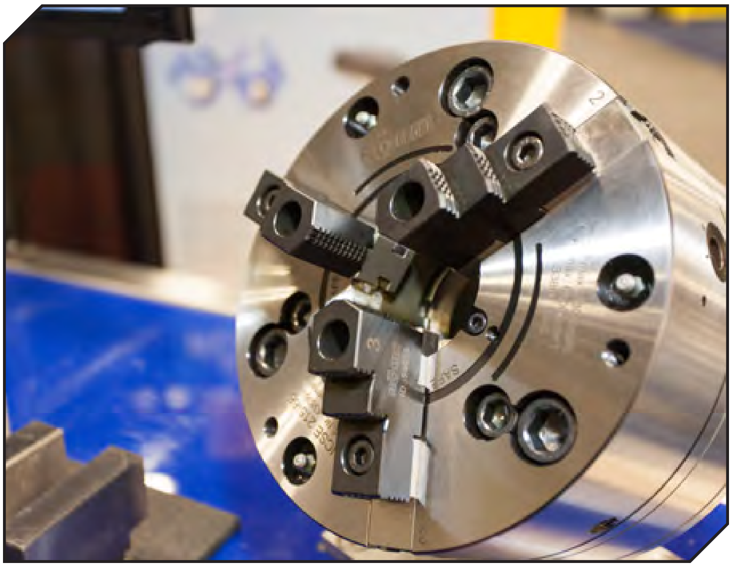
- 4D High Pressure Gas Quenching: A Leap in Performance vs. Press Quenching
- Evaluation of Steel Cleanliness by Extreme Value Statistics and its Correlation with Fatigue Performance
- Material Properties and Tooth Root Bending Strength of Shot Blasted, Case Carburized Gears with Alternative Microstructures
- Performance and Properties of New, Alternative Gear Steel
- Tooth Root Testing of Steels with High Cleanliness

Session 4 — Manufacturing, Inspection, and Quality Control
Wednesday, October 16, 8:00 am–12:00 pm

- A Comparison of Surface Roughness Measurement Methods for Gear Tooth Working Surfaces
- Chamfering of Gears — New Innovative Cutting Solutions for Efficient Gear Production
- Influence of Manufacturing Variations of Spline Couplings on Gear Root and Contact Stress
- Micro Skiving — (r)evolution of a Known Production Process
- Rapid and Precise Manufacturing of Special Involute Gears for Prototype Testing

Session 5 — Optimization, Gear Wear, and Failure
Wednesday, October 16, 1:00 pm–5:00 pm

- Calculated Scuffing Risk: Correlating AGMA 925-BXX, AGMA 6011-J14, and Original MAAG Gear Predictions
- Effects of the Load-dependent Shift of Gear Center Distance on Calculated Load Capacity and Excitation Using Analytical Mesh Stiffness Approach
- Layout of Profile Modifications for Asymmetric Gears
- New Standardized Calculation Method of the Tooth Flank Fracture Load Capacity of Bevel and Hypoid Gears
- Optimum Carburized and Hardened Case Depth



FTM Fun and Games Reception

MPT Expo attendees are invited to join AGMA Fall Technical Meeting attendees at our FTM Fun and Games Reception at Punch Bowl Social Detroit. Enjoy food and drinks with your colleagues while participating in fun activities such as bowling, darts, karaoke, and arcade games. A great way to kick off a busy week at MPT Expo!

Fall Technical Meeting Pricing

Prices range from $295 for a single session, up to $1,395 for the full meeting, depending on AGMA membership status and whether you meet the early-bird pricing deadline (full details available at motionpowerexpo.com).

MPT CONFERENCE

Motion + Power Technology Expo gathers thinkers and doers in the power transmission industry. Our conference is designed for these thinkers and doers. We are bringing you speakers who will provide you current information in two tracks: Business and Emerging Technology. Each session has a 45-minute presentation with an additional 15-minute Q&A portion. The MPT Conference runs from 9:30 a.m. until 4:30 p.m. on Wednesday, October 16 and Thursday, October 17. The Price includes admission to all 16 presentations, plus admission to the Expo Hall. $295 ($395 after Sept. 13).

IIoT — Simplifying Industrial IoT for Discrete Manufacturers
9:00 am–10:00 am, Wednesday, October 16
Stacy Pease, Director of Customer Success, MachineMetrics

Market Info — Economic Outlook and Trends within the Industrial Fluid Power Market
10:30 am–11:30 am, Wednesday, October 16
Chloe Parkins, Fluid Power Specialist, Oxford Economics

Electric Drive Technology — The Future of eMobility in the Commercial Vehicle Space
10:30 am–11:30 am, Wednesday, October 16
John Bennett, VP and CTO, Meritor

Blockchain — Blockchain: The Future of Manufacturing
2:00 pm–3:00 pm, Wednesday, October 16
Joel Neidig, CEO and Co-Founder, SIMBA Chain

3D Printing — Processes and New Machines for 3D Printing Metal
2:00 pm–3:00 pm, Wednesday, October 16
Kirk Rogers, PhD, Senior ADDvisorSM, The Barnes Group Advisors

Supply Chain — Effective Contract Negotiations: The Path to Commercial Success with Large OE Customers
3:30 pm–4:30 pm, Wednesday, October 16
Tom Rouse, Founder, Rouse Contract Consultants, LLC

Robotics — The End of Fear: How Collaborative Industrial Robots Will Change Durable Goods Manufacturing
3:30 pm–4:30 pm, Wednesday, October 16
Alberto Moel, PhD, VP, Business Development, Veo Robotics

Market Info — The Evolution of the Automotive Powertrain
9:00 am–10:00 am, Thursday, October 17
Casey Selecman, Director – Advisory Services, IHS Markit

IIoT — Standards for IIoT Interoperability
9:00 am–10:00 am, Thursday, October 17
Russ Waddell, Director, MTConnect

Workforce — Workforce Development Using a Farm Team Approach
10:30 am–11:30 am, Thursday, October 17
Tony Velotta, Organizational Development Leader, Scot Forge

Electric Drive Technology — Losing Teeth? The Future of Gear Trains in the Age of Electrification
10:30 am–11:30 am, Thursday, October 17
Jeff Hemphill, CTO, Schaeffler

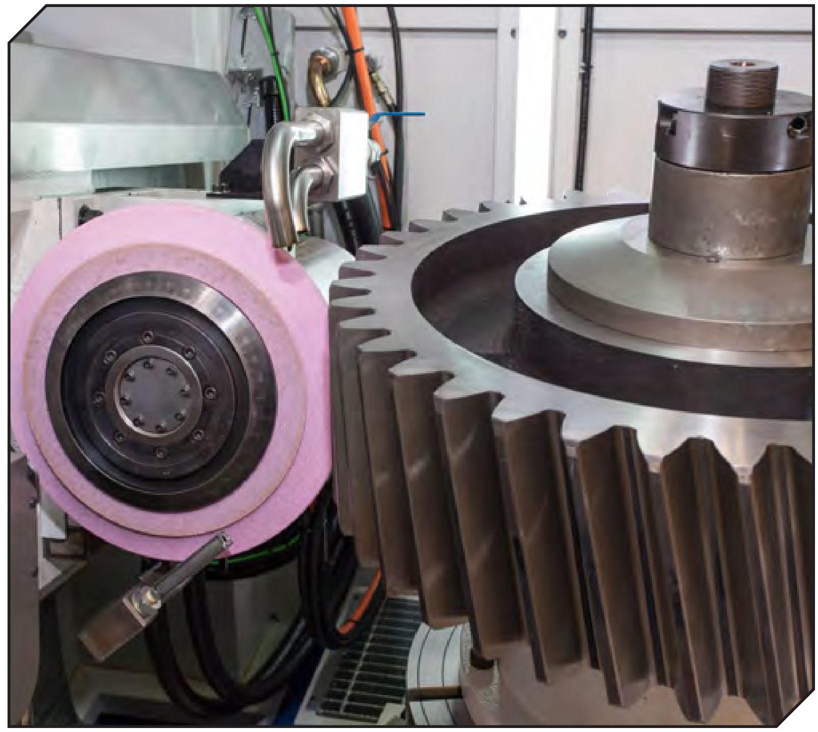
Cybersecurity — Cybersecurity Hygiene in Motion
2:00 pm–3:00 pm, Thursday, October 17
James McQuiggan, CISSP, Chapter President, (ISC)2 Central Florida Chapter

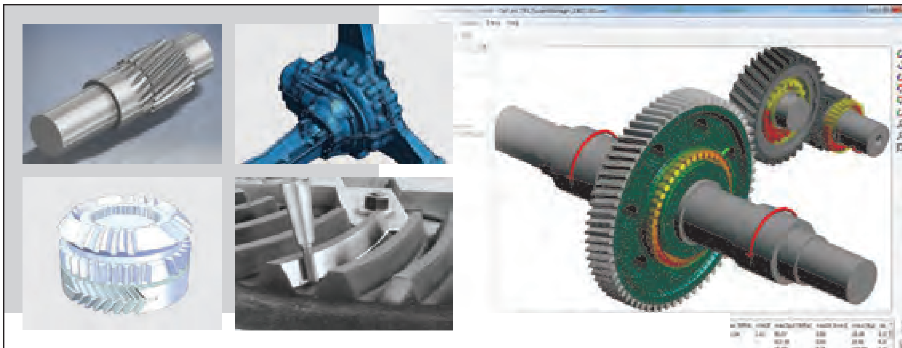
3D Printing — Materials Challenges and Solutions in Additive Manufacturing
2:00 pm–3:00 pm, Thursday, October 17
Jeff Grabowski, Materials Specialist, QuesTek Innovations, LLC

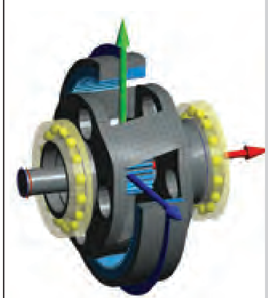
Workforce — Hire Like Nobody's Business
3:30 pm–4:30 pm, Thursday, October 17
Todd Palmer, Founder and President, Diversified Industrial Staffing

Robotics — Collaborative Operation in Industry Today
3:30 pm–4:30 pm, Thursday, October 17
Rick Maxwell, Collaborative Robot Team, FANUC America Corporation

For more information:
MotionPowerExpo.com







Heat Treat 2019

Bigger and Better Than Ever

As the way things are manufactured continues to evolve, manufacturing trade shows are keeping pace with that evolution. A perfect example of that can be found at this year's biennial Heat Treat 2019 (Oct. 15–Oct. 17, COBO Center, Detroit) — the 30,000-member ASM Heat Treating Society's (*asminternational.org*) signature event. The ASM's mission statement is summed up in just two words, i.e. — "Everything Material" — and the group is "dedicated to serving the materials science and engineering profession." Through their network of 30,000 members worldwide, ASM "provides authoritative information and knowledge on materials and processes — from the structural to the nanoscale."

These shows are no stranger to the Motor City; the city has a long history of hosting the event. And as technology advances, the city is keeping pace. How so?

As the ASM explains:

Technology. From automotive, to aviation, and defense, Detroit is changing the way the world moves. Their unmatched automotive research, design and advanced manufacturing resources make this region the leader in next-generation mobility and technology development.

Automobile capital of the word. Detroit is second-largest source of architectural and engineering job opportunities in the U.S., with the domestic auto industry primarily headquartered in Metro Detroit.

Global. Why do 1,300 firms from 38 countries call the Detroit region home? Detroit is the perfect location when you're looking to access U.S. and Canadian markets. The city is home to one of the world's most valuable border crossings and Detroit Metro Airport schedules non-stop flights to more than 160 destinations.

Sustainability. Michigan's business climate is stronger than ever. Nearly two-thirds of Michigan businesses surveyed describe the state as having a positive business climate and would promote Michigan as a place to work, start and conduct business.

From automotive, to aviation, and defense, Detroit is changing.

With this year's 30-year anniversary show, the heat treating industry is co-exhibiting with what used to be AGMA's Gear Expo and is now that association's much more manufacturing-inclusive Motion + Power Technology Expo. The show is now a one-stop-shopping trifecta — heat treat, gear and motion technology — guaranteed to cast a wider net for attendees and dress a wider stage for exhibitors. And in practical terms, it is logistics-friendly — attendees now may need attend only one show for their needs — not three—saving time *and* money.

What hasn't changed is that, as with past shows, this year's event will be both technical conference and exhibition.

Heat Treat 2019 will feature:

- Three days of one-on-one networking opportunities with approximately 200 heat treat exhibitors/companies. That group includes the industry's top companies and biggest names in the heat treating industry.
- Latest industry research is provided by more than 125 technical sessions and technical papers, and presenting special symposiums on induction heat treating.
- The This is Heat Treat free college student program. (Given the complexity of heat treating, which easily rivals that of gear manufacture, there is little wonder that solid young talent is needed — yet lacking. The show is a perfect venue for programs like This is Heat Treat and other youth-oriented presentations intended to help address that need.)

Indeed, in co-locating with the newly expanded Motion + Power Technology Expo, HT 2019 attendees will now have access to an additional network of 4,000 attendees and 250 exhibiting companies. What's more, joint initiatives with Motion + Power Technology Expo 2019 include educational programming, networking events and more.

Heat Treat 2019 will also host post-doctoral researchers, lecturers and professors for a competition-based award and recognition program, dedicated to encouraging increased participation of academic institutions in the ASM Heat Treating Society (HTS), and to provide attractive offers and opportunities in the worldwide materials and thermal processing communities. The winner will receive $2,500 that can be used to support research activity at the academic researcher's institution. The award can also be used for travel expenses (researcher or student), conference fees, scholarship money, or laboratory equipment.

Presentation/technical paper topics include:

- Additive Manufacturing / 3-D Processing
- Applied Technology / Processes and Applications
- Atmosphere Technology and Surface Engineering
- Automotive Lightweighting
- Induction Heat Treating
- Internet of Things
- Low Temperature Surface Hardening of Stainless Steel
- Materials Durability / Mechanical Testing
- Microstructural Development / Characterization
- Powder Metallurgy
- Quenching and Cooling
- Residual Stress
- Thermal Mechanical Processing
- Thermal Processing of Non-Metals (ceramics, composites, polymers)
- Vacuum Processes and Technology
- Welding / Joining

And there's more — much more.

Of particular interest:

Inductoheat Plant Tour
Monday, October 14

Ford Rouge Factory Tour
Monday, October 14

Women in Engineering Networking Breakfast:

"Don't Stop – Five Lessons I Have Learned, So You Don't Have To"
Thursday, October 17

The speaker for the event is Stacey M. DelVecchio, F. SWE, Additive Manufacturing Product Manager Innovation & Technology Development Division Caterpillar, and an advisor with the Society of Manufacturing's additive manufacturing community.

Some Education Courses Details:

Tuesday, October 15: General Heat Treating
Wednesday, October 16: Introduction to Gear and Bearing Materials
Thursday, October 17: Basics of Non-Destructive Evaluation for Gears and Bearings
Thursday, October 17: Materials Selection and Heat Treatment of Gears Presented by ASM Heat Treating Society and AGMA

Of special interest to young attendees: Current college students studying materials science and engineering are entitled to completely free conference registration for the 29th ASM Heat Treating Society Conference and Exposition

Thursday, October 17 (am – 5pm):
This Is Heat Treat

The This Is Heat Treat program includes a special student reception and opportunities to connect directly with companies that students might want to work for by spending one-on-one time with them in their booths. Students need only register as a student and bring their Student ID with them to the show.

More Student Activities, Awards and Competitions

ASM Heat Treating Society Emerging Professionals Reception in the Expo Hall

Tuesday, October 15

Young Professionals Reception (joint with Motion+Power Technology Expo)

Tuesday, October 15
Cost: $15

This special networking event, for young professionals age 35 and under, will feature drinks, hors d'oeuvres and the opportunity to network with peers in the industry.

One-on-One Demos in Exhibitor Booths

Students can acquire relevant knowledge and insight directly from the major players in the heat treat world by signing up to shadow with them in their booth. See workshops, live demos, and learn about the companies first-hand from the people that work there. Beginners can choose from the list of exhibiting companies that they'd like to learn more about and receive a date and time to meet with them on the floor.

Fluxtrol Student Research Competition

October 15th & 16th

Heat Treat 2019 will offer the young innovative scientists/professionals competition-based award and recognition program, seeking to encourage participation of young scientists in ASM

HTS, and to provide attractive offers and opportunities in the worldwide thermal processing community.

Comprehensive Technical Programming

Learn the latest research and development in your field on such topics as advancements in heat treating, advanced processes, quenching and cooling, processes and applications, vacuum process and technology. Visit and network with more than 200 companies from the heat treating industry. Attendees will once again have access to over 300 additional companies at Motion + Power Technology Expo (formerly Gear Expo).

Special Keynote Presentations

Also available are important updates from an exciting line-up of well-known industry experts, including:

Dr. George Krauss, Professor Emeritus, Colorado School of Mines

Jack Harris, Chairman, IMS International

Prof. Marco Taisch, Vice President, World Manufacturing Foundation, Politecnico di Milano

VIP Guided Industry Tour

Attendees can sign up for the 2nd VIP Guided Industry Tour at Heat Treat 2019. This tour is limited to the first 150 attendees. You'll have exclusive access to 10 companies showcasing their industry products and services. Pre-registration and prequalification are required to receive your ticket. Tours will be on Tuesday, October 15 from 3:30 p.m.–4:30 p.m.

SOLUTIONS CENTER

The Solutions Center in the Exhibit Hall provides opportunities to meet the product experts, get answers to your questions and discover the latest in heat treating innovations. Presentations will be 15–20 minutes in length and will be held all day Tuesday — Thursday.

"BASICS OF HEAT TREATING"/ EDUCATION COURSES

Improve your knowledge by taking an ASM Education short course. Taught by industry experts, these interactive learning experiences will help you stay up-to-date and competitive. This year's courses will include Metallography Insights; General Heat Treating; Intro to Gear and Bearing Materials; Basics of Non-Destructive Evaluation for Gears and Bearings; as well as a special joint course offered with AGMA — Materials Selection and Heat Treatment of Gears.

"THIS IS HEAT TREAT" FREE STUDENT PROGRAM

If you have an intern or know a current college student studying materials science and engineering, let them know about the "THIS IS HEAT TREAT" program, where registration for Heat Treat 2019 is free. This special student registration includes access to the full technical program, a student/young professional networking reception, as well as the opportunity to meet major players in the heat treating world.

For complete details visit *www.asminternational.org/web/heat-treat-2019/*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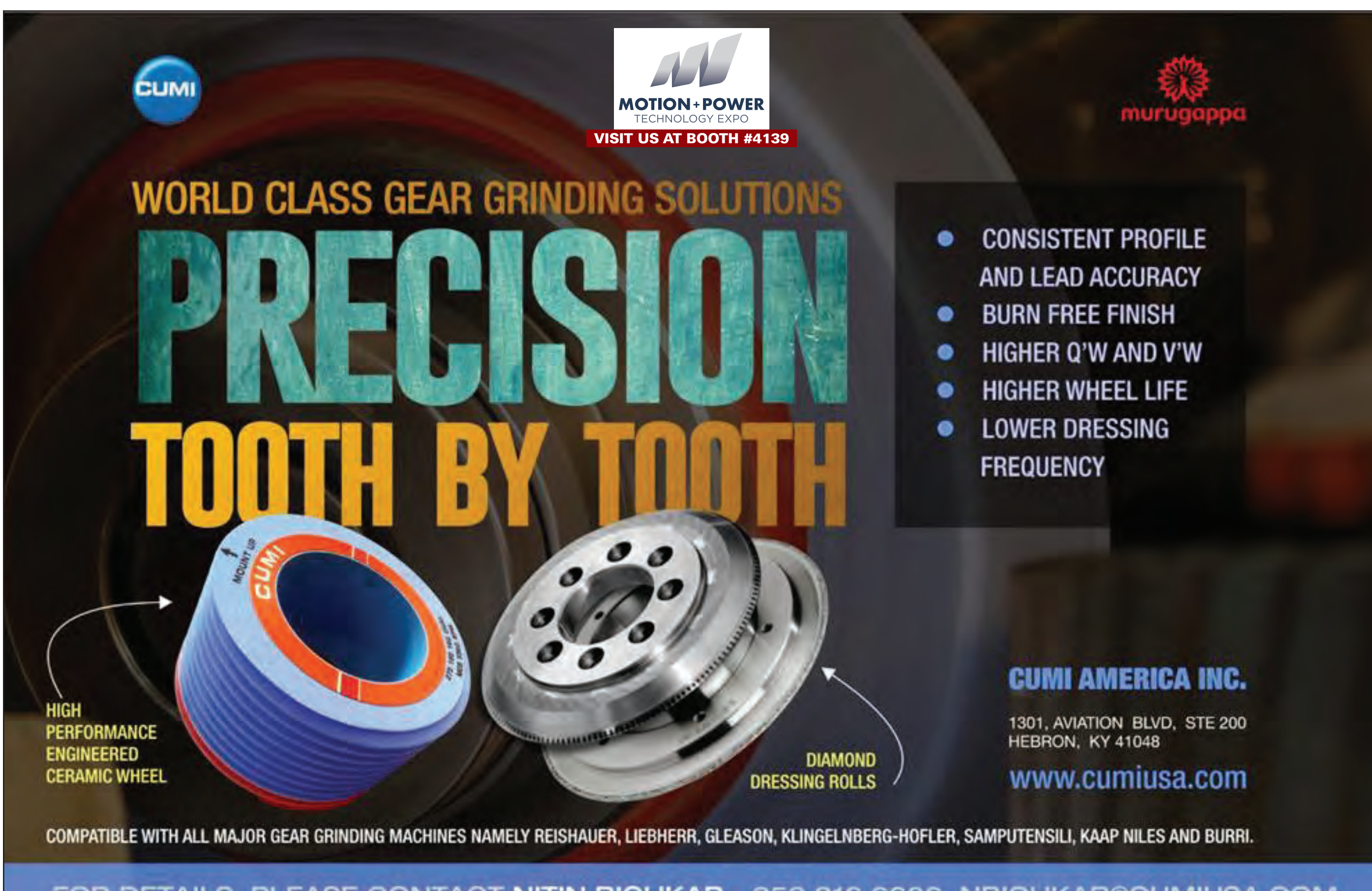

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Overcoming Barriers

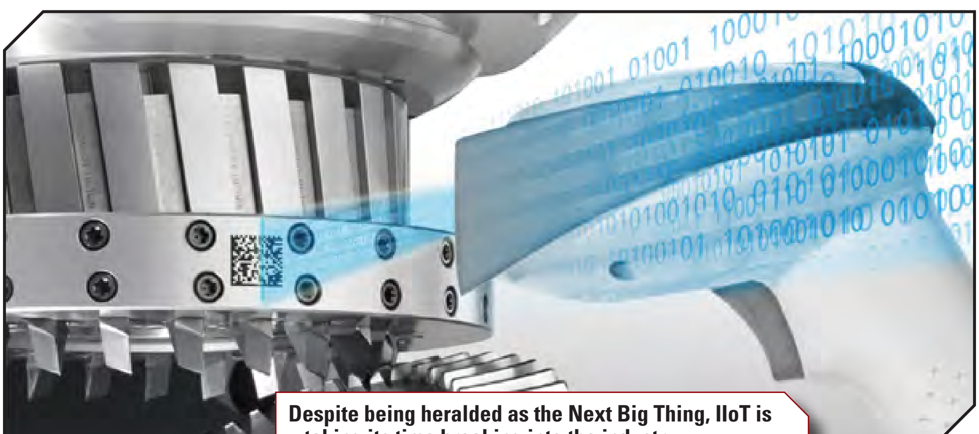
Depending on who you ask, the Industrial Internet of Things is growing more slowly than anyone predicted. Why is that, and what does that mean for the gear manufacturing industry?

Alex Cannella, Associate News Editor

IIoT, Industry 4.0, whatever you want to call it: Ever since it came onto the scene, the Industrial Internet of Things was supposed to be the next big advance in manufacturing technology. Even from the start, it was hailed as the Fourth Industrial Revolution, and accordingly with that name, was supposed to completely upend how we did business. That's how it got its slightly more marketing-savvy Industry 4.0 moniker in Europe, after all.

And here's the thing: IIoT technology does have the power to be everything it's been promised to be and more. But the future that many, myself included, have been hailing as just around the corner for a few years now is...very much still somewhere around that corner. Massive industry shifts such as the one that would be predicated by IIoT advances don't happen instantaneously, but the more I talk to people about how this particular field is advancing, the more mixed the signals I get, and the critical point always revolves around one thing: adoption rates.

Before anyone starts thinking it's all doom and gloom, it's not. Depending on who you ask, IIoT is a booming business that's expanding just fine. Governmental push from multiple countries, including here in the U.S., all but ensures that the field will continue to grow and most market forecasts are plenty optimistic. IIoT as a field doesn't look like it's at much risk of failing.



Despite being heralded as the Next Big Thing, IIoT is taking its time breaking into the industry.

But bring the topic up at a trade show, and you might be surprised by how many manufacturers have cooler expectations compared to those forecasts. That's not to say that IIoT isn't growing—just that it isn't the sweeping revolution everyone speculated it would be, or at least not yet.

"In general, IIoT has not spread with the speed that a lot of people had expected it to catch on everywhere in the world," Rakesh Kulkarni, director of digital manufacturing solutions at Gleason Corporation, said. "There are a number of factors that need to come together to make IIoT successful, and we see that happening relatively slowly."

So what are those factors that need to come together? What's slowing IIoT down from being the juggernaut of industry everyone thought it would be?

Part of it is a lack of infrastructure and the industry's still-fledgeling state, part of it is a lack of skilled talent, and part of it is baked into IIoT's very nature as a more forward-looking, long-term technology with comparatively fewer upfront benefits. Those first two are understandable speed bumps for any bold new endeavor that has yet to be widely adopted, and the third makes sense the moment you look at how most businesses are actually run. From energy efficiency to the benefits IIoT promises, delayed gratitude and profits stemming from savings over time are both tough sells for a business world run on year-over-year profits and shareholders expecting a return on their investments.

The easiest to talk about is the infrastructure issue, or namely, as Kulkarni put it, the need to set up the foundation to make IIoT "scalable, secure, and future proof."

"The ability of companies to do this is quite often limited considering the challenges in developing IIoT solutions – long pilots, value based pricing, long/risky implementation cycles, vendor lock-in/high switching costs," Kulkarni said. "On the other hand, the lack of vision and roadmap of future use cases makes the return of the initial investment dependent on only a few initial IIoT use cases. This makes it a barrier to get going on the right infrastructure investments."

That issue is particularly poignant in our gear industry, where some feel that those limited use cases don't always cover the specific pain points that might bring value to your average manufacturer.

Though not in the same words, Daniel Meuris, engineering director for digitization and virtualization for Klingelnberg GmbH, echoed that sentiment. That lack of vision and dearth of case studies make actually showing off the benefits of IIoT to would-be users a challenge.

"Until now, if you look at the market of IoT solutions, then many solutions exist because there's technology that makes it possible, but there's not a real value that is delivered," Meuris said. "So you have these MES systems and big data approaches and machine learning and all this stuff, but really the value that makes your production more efficient, especially in the gearing world, is hard to find. Companies are waiting for the suppliers to give us something that gives us value and makes us more efficient, but this proof is still missing to a certain amount for many solutions."

The challenge, according to Meuris, largely stems from the gearing industry's specific local concerns. As with most any sweeping change, the high level theoretical benefits IIoT brings are easy to list off. Prime among them is the fact that digital twins and other solutions provide unprecedented transparency into your own manufacturing line, which in turn allows manufacturers to make all kinds of corrections to their production to improve both quality and efficiency. Getting noisy gears? Go backwards through your process one step at a time until you find the reason and you can solve the problem. Want to change your cutting process to something more efficient? Trace the consequences of how that will affect your gears with a digital twin. In this matter, Kulkarni and Meuris agree.

"One of the most important parts of IIoT technology that U.S. manufacturers like is their ability to make better data driven decisions in their plants with IIoT," Kulkarni said. "In the past, there were a lot of black boxes in the plant that were not fully understood and led to suboptimal decisions. With IIoT, one is able to connect key metrics in the plants to root causes, solve those problems and see their effects at the plant level."

"There are many dependencies in this long process chain," Meuris said. "The only way to get transparency of all these dependencies is to use digital technology."

However, according to Meuris, it's also necessary to look at specific applications in different industries. IIoT can promise plenty in the abstract, high-level sense, but you still need to investigate how to apply it to each local industry, and in gear manufacturing's case, IIoT technology still hasn't quite reached out to make that connection.

In some cases, as with smart tooling, that connection's beginning to form, but according to Meuris, this is largely because the tech is concrete. It's easy to show off. The lion's share of IIoT solutions don't have that benefit.

"There are other topics like this whole big data stuff and machine status analytics," Meuris said. "This is not so concrete. Of course, they are still very interested in it, but we need to walk some steps to get this final value that we can deliver that makes it easy to explain to customers. That's still a challenge."

This, in turn, connects the issue of the industry's nascent infrastructure with both of IIoT's other roadblocks, the first being the more long-term, esoteric benefits of most IIoT solutions. As Kulkarni noted, many of IIoT's most powerful advances have a long gestation period or require substantial up-front effort before they start realizing any of their promised returns. Pair that with the lack of concrete case studies, and you sometimes have an uphill battle convincing a manufacturer that fields like, say, big data analytics will give them a better return on investment when they could allocate that money on a newer, more efficient gear grinding machine with demonstrable returns.

"The second barrier is understanding how artificial intelligence can be applied effectively in companies," Kulkarni said. "AI typically needs rich data to be able to analyze it and provide valuable insights. In the short term, this data may not be available and the value from some of the use cases do not get easily extracted."

Then there's the final roadblock: skilled talent. That's an endemic issue that's faced the gear industry specifically for years. But more specifically, according to Meuris, there need to be more people reaching across that gap. Tying back into IIoT's need to focus on individual industries, Meuris believes that the gearing industry needs, at bare minimum, more communication between gearing specialists that can trade their industry-specific knowhow with software specialists that develop the actual IIoT products that can help that industry.

"With IoT solutions, if you talk to [customers], we could talk for five months and both have a different idea of what we're talking about. You really need to bring something on the screen or give somebody a mouse to click something, and then you can start talking and...come to an iterative solution."

According to Kulkarni, this is specifically important for predictive maintenance solutions, one of IIoT's most important cornerstones, and also one of the solutions with the longest arm to translate into benefits.

"Although manufacturers struggle to reach to predictive maintenance in early stages of their IIoT journey, it is important to develop the data monitoring and storage capabilities to make use of human knowledge in this stage," Kulkarni said. "So in these early stages, manufacturers are using the domain knowledge gained by experts and combine it with the data collected to get to valuable insights."

Bridging the Gap

So how does the IIoT industry overcome these barriers? For Kulkarni and Gleason, it's all about breaking adoption down into steps, first providing more upfront value before graduating to more long term, data-hungry solutions.

"This is a digital journey," Kulkarni said. "And we have broken it down into phases where we are developing offerings for short term along with the infrastructure for long term benefits."

As an example, Gleason is developing a new predictive maintenance solution they've dubbed Gleason *Fingerprint*. *Fingerprint* is designed specifically to tackle one of those critical infrastructure problems that IIoT faces: Predictive maintenance requires a vast stream of existing data in order to work. And that's data that a company wouldn't have if it hasn't jumped onto the IIoT bandwagon yet.

"IIoT products today monitor and visualize signals from the machines without a proper reference," Kulkarni said. "The challenge is the amount of data that gets monitored is limited in duration and [has] a lot of noises within it."

Without reams of already recorded data, an AI algorithm will struggle with that noise — variables in the process such as different tooling, job settings, and so on. But according to Kulkarni, the data itself can also be just as difficult for a flesh and blood person to parse.

So *Fingerprint* tries to make up the difference with its own prepackaged data. Before a new machine is shipped to the customer, this software takes a "*Master Fingerprint*," essentially a dry run of one machine cycle. And for every test after that, the *Master Fingerprint* is held up as a control group to compare the machine's current parameters against. And through this method, any drift in the machine's parameters over time can be detected and diagnosed from there, giving advance warning on when a machine might be in need of repair or getting long in the tooth.

Fingerprint's main selling point is its ability to provide a preventive maintenance solution, but it also combats two of IIoT's woes. It gives the user something concrete they can hold up next to any data they generate while also handily solving one of IIoT's main stumbling points by providing immediate benefit for a solution that formerly took far more work and time to achieve.

"*Fingerprint* can generate an accurate analysis in far less time, with a fraction of the cost and effort, and without requiring a skilled technician as the first step," Kulkarni said. "Ultimately, checking on the machine's status, performing self-checks, and recommending actions can all be done proactively."

The Gear Engine is part of Klingelnberg's ongoing efforts to tackle IIoT's growing pains.

Klingelnberg has their own similar product in the *Machine Status Analyzer*, a condition monitoring program that works by first recording a test run of a job without the workpiece, then using that data to monitor the actual cutting process and check for errors. While older and more concerned with specific manufacturing jobs than preventative maintenance across a machine's full lifetime, the product draws some striking similarities, and according to Meuris, it's just the start of a longer strategy.

Central to that ongoing strategy is an effort to bridge that talent gap, and they've started that process at home with their own company. The hope is that by getting the gearing experts in the company talking with their software side, Klingelnberg can tailor its IIoT solutions to what the gear manufacturing industry needs.

"If our guys here know nearly everything about bevel gears, and they say 'this thing, you really can solve a customer's problem,' and we can also put that into software, that's our approach," Meuris said. "That's the best we can do."

Doing so tackles the issue of a lack of case studies. But instead of just producing more concrete and numerous case studies to try and sway gear manufacturers to use already-established solutions, this method works in reverse, instead looking for pain points the industry is suffering from that Klingelnberg can specifically build IIoT solutions around solving.

And in order to support this effort, another component of Klingelnberg's strategy is to focus on responsiveness and become more "agile," to basically iterate faster and start a project as a bare functional, more open-ended prototype, then fill in and finalize the details based on customer feedback to those early ideas.

"If you look at software solutions today in the production field, they are really slow," Meuris said. "And with this gear engine approach, we really try to change this. We really try to bring on a solution where we can really be agile, so if customers have ideas and want to have changes on this platform, that we are really able to deliver fast. That's a core idea."

More advances are doubtless to come, but the most recent fruits of this strategy are Klingelnberg's *Gear Engine Platform*, which is essentially their centralized software suite that allows them to easily provide new programs and updates to existing machines, and some smart tooling solutions.

What Does This Mean For Us?

But all of this has been a lot of talk about the trials and tribulations that IIoT's sellers face, and not as much about what it all means for the gear industry, the buyers in this equation. One IIoT vendor's roadblock is another gear manufacturer's excuse for not being interested.

But frankly, the reason to care is the same as it's ever been: IIoT still remains a technology that could potentially do everything it's promised and completely overhaul how we manufacture everything from phones to cars to, yes, even gears. And right now, that technology is a bit of a hard sell thanks to its nascent state — certainly harder than anyone in the IIoT industry expected it would be — but that's probably going to change over time.

While there are still plenty of stumbling blocks that IIoT needs to clear before it can become the revolutionary force it envisions itself as, those issues are being targeted and whittled down one after another. As each kink in the system gets worked out, IIoT is going to become an increasingly attractive and, more importantly, accessible product to consider buying. And even if you aren't in the market for an IIoT solution today, it's worth asking yourself: at what point would you be? As the industry continues to work to broaden its appeal, we might reach that point sooner than you think.

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A Tale of Two Gear Companies

Ross Wegryn-Jones, Mitsubishi Heavy Industries America, Inc.

Experiencing a Dickensian dilemma in its essence, a Los Angeles based manufacturing company was faced with the good fortune of ever increasing orders for steel gears from a good customer with a new recreational product in very high demand. Confronting the possibility of an untold number of lonely late nights tending to the whims of a 1950s era manual hobber was an unpalatable prospect no one desired.

Meanwhile, another company nearby had recently designed their first stainless steel helical gear set for a new compact fishing reel and they were having an unexpectedly difficult time producing gears of the quality they needed to make the reel a success.

One company desired greater throughput without losing quality. The other desired quality and consistency they'd never yet produced in order to make their product work. Both companies were doing their best to utilize older, manually operated equipment that had always been well-kept, loyal companions. The possibility of sourcing suitable gear sets from outside vendors in a timely fashion was a bleak prospect as demand and resulting lead times everywhere were high at the time.

Both of these family-owned manufacturing companies have been in the Los Angeles valley for three generations. Brothers Glenn and Sean Eberlein had been visiting their family-owned machine shop Mercury Broach Company, Inc. of South El Monte, CA since they were mere urchins. Founded in 1961 as a production broaching company, Mercury Broach branched into gear production in 1988 when Mark Eberlein took over the business from his father, Leo. The seeds of this latest revolution were planted in the mid 2010s when the young brothers arrived to gain knowledge of manufacturing under the watchful eye of Mark. Serving a long list of customers with unique needs the brothers learned the business from the inside out.

Twin brothers David and Douglas Nilsen of Accurate Fishing Products of Corona, CA incubated their business from within Accurate Grinding & Manufacturing Corporation, owned by their father, Jack Nilsen. Founded in 1950 by Jack's father-in-law, Michael DeMarco, the AS9100C certified company serves the aerospace and defense industry with extremely tight-tolerance turned, milled and ground workpieces using state-of-the-art machine tools and an outstanding, experienced and talented production staff. Revolution from within the company actually started in the 1990s during the brothers' college years after Jack came up with an idea to produce a 'gaff,' a bloody big fish handling hook, out of aerospace materials so it wouldn't bend or deform under load. Jack tasked his young sons whilst on summer break with refining the design and manufacture of this unique gaff. Not only did the Nilsen brothers find a receptive sport fishing industry at local fishing shows whilst selling the gaff, but in conversations with customers they identified other needs as well; which they eventually developed into their own line of ***Accurate Fishing*** branded reels.

David and Douglas Nilsen of Accurate Fishing Products, with the company's first fishing reels, in 1997.

Both companies independently found a solution to their respective plights using what could now be called an "old-school" method: They phoned up a few experienced local gear makers, who directed them to take a closer look at the Mitsubishi line of gear machine tools. Mercury and Accurate each chose the 150 mm/6" diameter Mitsubishi model GE15A 5-Axis Hobbing Machine with skiving and robot integration for eventual lights-out operations. Both companies wanted an immediate solution to the bottlenecks in their shops, but did not wish to be guillotined with a machine tool that would limit their future plans. Each company produced or adapted their own workholding tools to suit their immediate needs in time for the arrival of their new hobbers, for which delivery, installation and training only required a few short weeks.

Up and running within hours of installation, Mercury Broach requested training on helical, spur and stacked gear changeovers. Within a few short days, they had not only learned how to operate the machine, but they had managed to eliminate their backlog of gear orders as well. Short work was made of all the jobs by quickly modifying or adding programs through a machine programming interface easily learned and understood. Having been 'voluntold' to work the prior

"It was the best of times, it was the worst of times."

thirty days in a row with 10 to 12 hour days and over a beautiful Labor Day holiday weekend as well, to say the Eberlein brothers were quite pleased to have quelled rebellion in their shop would be a vast understatement.

Accurate Fishing Products experienced a similarly short machine installation timeline but were primarily concerned with having complete control of and to be able to produce the best possible stainless steel helical gears they could for their new fishing reel design in time for Christmas deliveries. Apparently there are few consumers as finicky as sport and charter fishermen who demand both zero backlash **and** smooth action in their fishing reels and are quite willing to invest in high quality fishing tackle to realize this. After a few trial parts and assembly of a few 'TERN' reels; imagine the surprise and delight of the quality department who were very pleased to report the reels just produced were unlike any others before seen and precisely what they had been pursuing for months!

With more than 2,000 machines in the field, the Mitsubishi 'G' series hobbing machines are a well executed, extremely refined and flexible machine tool honed by more than 30 years of kaizen manufacturing techniques. With a suite of standard features including a straightforward and easy-to-understand interface, wet or dry operation, flexible workholding options and a fully adjustable tailstock; Aristocrat, Bourgeois, and Jacobin alike will be able to quickly and accurately produce billable workpieces in a job, batch or production machine shop environment.

A machine delivered from Mitsubishi's stock machine program can be gainfully employed in your village almost as rapidly as Madame Defarge's ire. While the machines were sought after by each company for different reasons, both companies expected immense reductions in cycle times, which were realized. But the real shock was in the ease of changeover and the exceptional first article inspection results. The fear factor from the establishment within each shop simply vanished once everyone had their turn with the new hobbing machine.

It was found during an initial meeting between the two companies for this profile that the first generation of ownership more than likely did business with one another in the 1960s as there were very few precision machine shops like theirs in the valley at that time — so a lost connection has been restored. Accurate Fishing Products is now configuring a collaborative robot to their new hobber and broadening the scope of work to include their legacy spur gears. Mercury Broach continues to serve an ever expanding list of customers at the same address since 1961. They are still growing their family, having recently welcomed a Mitsubishi Programmable Helical CNC Shaping machine to their portfolio and more importantly, welcoming Sean's new bride Nicole to the company this past September. She keeps the Eberlein rebels of the production department in line by knitting her administrative skillset into the operation...

Ross Wegryn-Jones (center) with Glenn Eberlein (left) and Sean Eberlein (right) of Mercury Broach & Machine standing in front of their new 5-axis hobbing machine

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Defining the Spline Pressure Angle

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

QUESTION

I am a mechanical engineering student at the University of Kansas. I have a sprocket that has an internal spline. I am trying to design a mating gear with this internal spline.

After buying a sprocket online, I was able to make a CAD model with the help of someone who does reverse engineering on gears. From this CAD drawing, how do I calculate the pressure angle of this gear? And how do I design the mating gear (external splined gear) for this part?

***Expert response provided by* Dr. Hermann J. Stadtfeld:** (*Editor's note: For a more detailed presentation on this topic, look to the Sep–Oct issue for "Design Parameters for Internal Splines," by Dr. Stadtfeld.*) If the splines are being designed, then one of the preferred pressure angles from the standards should be used. ANSI and DIN offer the choice between 30°, 37.5° and 45°. In the JIS standard a pressure angle of 20° is also proposed.

If the spline is designed for an aftermarket product (for example, a sprocket or a spline shaft), then a simple measurement, preferably on a CMM or with a Vernier caliper as shown in the Figure, can be conducted to obtain a first pressure angle estimation. If the aftermarket product is the sprocket (not the shaft), then it would be desirable to obtain the measurement explained in the Figure on the spline shaft.

The measurement results are used together with the depth of the spline tooth to calculate the approximated pressure angle:

$$\alpha_{approx} = \arctan[2 \times \text{Depth}/(t_1 - t_2)]$$

In case of a topland $t_2 = 2.60$ mm, a root width $t_1 = 7.30$ and a Depth of 2.0 mm the approximated pressure angle is:

$$\alpha_{approx} = \arctan[2 \times 2.00/(7.30 - 2.60)] = 40.39°$$

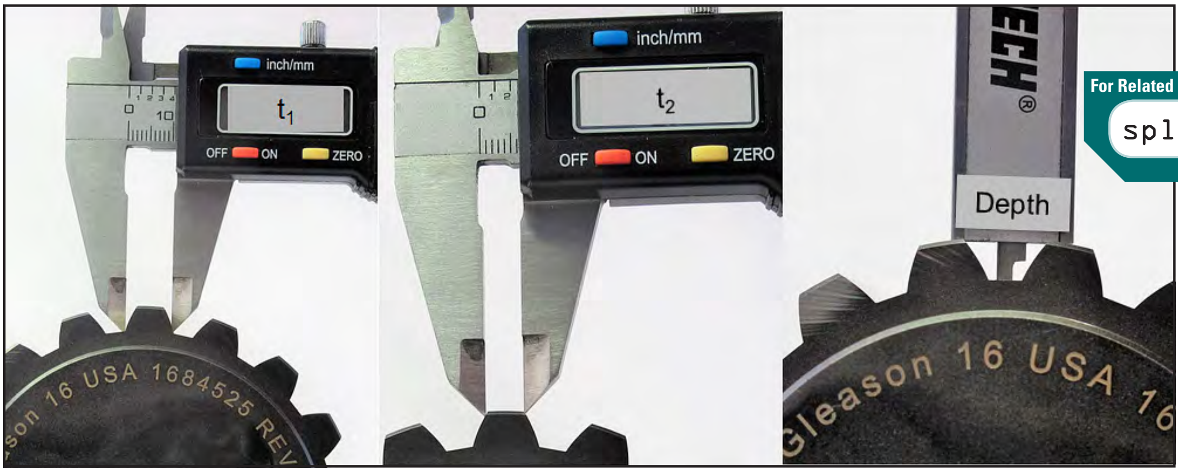
The approximated angle is between the preferred angle 37.5° and 45° from the standards. The difference to 45° is 4.61° and the difference to 37.5° is only 2.89°. The decision therefore is 37.5°:

$$\alpha_{External} = \alpha_{Internal} = 37.5°$$

37.5° is a popular pressure angle for splines which also indicates, that the result of measurement and calculation is realistic. It is recommended that the major diameter of the sprocket is equal to the outside diameter of the spline shaft to assure a major diameter fit. If the sprocket is the transmission output of a unidirectional unit, then the flanks can receive a small backlash (e.g. sprocket spline tooth thickness tolerance ISO 7H and shaft spline tooth thickness tolerance 7f). If sprocket and spline have to transmit torque in frequently changing direction, then a transition fit or a press fit of the spline teeth is recommended (sprocket ISO 7H, shaft ISO 7n.

The tolerance of the major diameter of the internal spline should be a selected as a transition fit for example ISO H7 (the outside diameter of the spline shaft should be ISO j7).

Dr. Stadtfeld is Gleason Vice President - Bevel Gear Technology - R&D.



Measurement of topland root and depth.


REISHAUER

Microgear Measurement Standards: Comparing Tactile, Optical and Computed Tomography Measurements

Stephan Jantzen, Martin Stein, Andreas Dietzel, and Karin Kniel

Introduction

Microgears are widely used in industry, as they are essential components of gearboxes used in precision engineering, medical technology, and robotics. In these industries, miniaturization is an ongoing goal, entailing fewer material costs, smaller sizes, and more efficient operation. However, the inspection during the production of microgears is *challenging* because the required measurement uncertainties are small, and because measuring the small workpieces requires special probes (Ref. 12).

The measurement technology used in this context faces the challenge of developing reliable measuring machines and established evaluation routines. However, microgear *measurement standards* are rare, even though adequate quality control of gears requires gear-like measurement standards. Therefore, the Physikalisch-Technische Bundesanstalt (PTB), Germany's national metrology institute, has developed two microgear measurement standards.

Measurement standards are a user-friendly instrument for checking and selecting adequate measurement technology (Ref. 2). Measurement standards benefit industry when substitution measurements are performed. Measuring calibrated workpieces allows systematic errors to be corrected that arise in measuring machines and task-specific measurement uncertainties to be estimated.

Comparison measurements are useful for evaluating the performance of laboratories, finding problems, confirming measurement uncertainty claims, and checking the performance characteristics of a given method (see ISO 17043).

In the following chapter, we will present PTB's two microgear measurement standards. Their analyses using seven measurement methods are then presented, evaluated and compared with each other.

Overview of the Two Involute Microgear Measurement Standards Developed at PTB

This section gives an overview of the two microgear measurement standards developed at PTB (internal and external microgear). In both workpieces, four gears are embedded (1 mm, 0.5 mm, 0.2 mm, and 0.1 mm modules); each gear has four teeth realized (Table 1). The wide range of modules suits different applications. Additionally, measuring the four modules may reveal size-dependent effects of the measuring machine used.

Both measurement standards were manufactured from carbide and titanium. Carbide yields better machinability and higher mechanical stability. Titanium features a small absorption coefficient, which allows computed tomography (CT) measurements to be performed. Both workpieces have a tip diameter of 20 mm, which facilitates handling and clamping.

External microgear measurement standard. The external microgear measurement standard consists of an upper datum reference, a gear disk, and a lower datum reference (Fig. 1) (Refs. 2, 13). These three parts are joined by pinning and gluing.

Internal microgear measurement standard. The most

Table 1 Properties of the two microgear measurement standards

	External microgear	Internal microgear
Facewidth	4 mm	2 mm
Outer diameter	22 mm	40 mm
Profile	Involute	
Normal modules mn	1 mm, 0.5 mm, 0.2 mm, and 0.1 mm	
Teeth realized per module	4	
Pressure angle a.	20°	
Tip diameter	20 mm	
Helix angle #	0°	
Profile shift coefficient x	0	
Material	Carbide and titanium	
Machine process of the profiles	Wire electric discharge machining (Wire EDM)	
Calibrated features	Profile and helix	

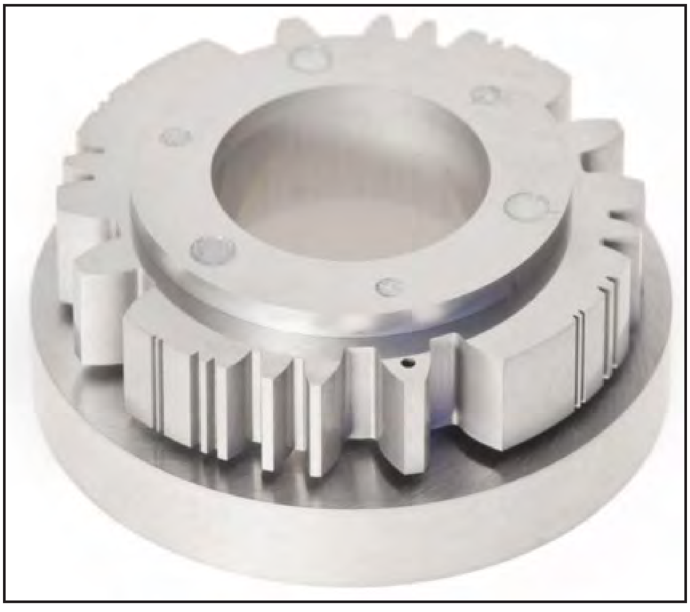


Figure 1 External microgear measurement standard. The bore hole denotes Tooth 1. The inner bore reduces the length to be penetrated by X-ray when measuring with the CT system.

prominent characteristics of the internal microgear measurement standard are its facewidth of 2 mm and its custom clamp (Fig. 2) (Ref. 6). The clamping can be loosened, which allows the gear disk to be measured separately from the clamp (for example, for CT or optical measurements). Furthermore, the design allows the workpiece to be measured in a flipped state. The facewidth of 2 mm matches the shaft length of the tactile probe in the µCMM used for calibration. Accordingly, the µCMM can characterize the whole flank for calibration.

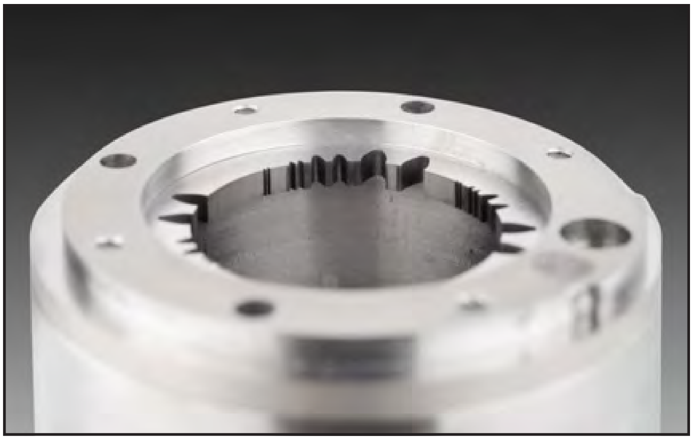


Figure 2 Internal microgear measurement standard with custom clamp.

Comparison Measurements

The comparison measurements featured seven measurement methods (see Table 2). The following sections give details of the different measurement parameters.

Tactile calibration on a µCMM. The calibration measurements were performed on the Zeiss *F25* micro coordinate measuring machine (µCMM). The µCMM calibrated both measurement standards with measurement uncertainties in the sub-micrometer range (Table 3). The probing force was 1 mN.

The tactile calibration provided the reference values for the comparison measurements. The calibration values refer to the deviations of the profile and the helix (see ISO 1328 and ANSI/AGMA 1012-G05). The calibrated gear parameters were evaluated in the software of the measuring machine (Zeiss *Gear Pro* (Ref. 8).

The smallest module embodied ($m_n = 0.1$ mm) was not calibrated because the probing element, whose sphere diameter is 125 µm, is too large for the tooth spaces. Figure 3 shows the measurement setups.

Table 2 Overview of measurement methods we compared (the abbreviation GMI stands for gear measuring instrument)

	Measurement of external microgear	Measurement of internal microgear
Tactile calibration on a µCMM	Except 0.1-mm module	Except 0.1-mm module
Tactile measurement on a GMI with standard probe	Except 0.1-mm module	Except 0.1-mm module
Tactile measurement on a GMI with custom microprobe	Yes	Not yet
Computed tomography (CT) measurement	Yes	Yes
Optical measurement: focus variation	Yes	Yes
Optical measurement: transmitted light	Not possible	Yes
Tactile-optical measurement	Yes	Not yet

Table 3 Measurement uncertainties of the tactile calibrations. The measurement uncertainties are equal for all three modules (1 mm, 0.5 mm, and 0.2 mm)

Parameter	Internal microgear, titanium U_{cal} ($k=2$) in µm	Internal microgear, carbide U_{cal} ($k=2$) in µm	External microgear, titanium and carbide U_{cal} ($k=2$) in µm
Profile slope deviation $f_{H\alpha}$	0.6	0.5	0.4
Profile form deviation $f_{f\alpha}$	0.5	0.5	0.3
Total profile deviation F_α	0.7	0.6	0.5
Helix slope deviation $f_{H\beta}$	0.5	0.4	0.4
Helix form deviation $f_{f\beta}$	0.5	0.5	0.3
Total helix deviation F_β	0.6	0.6	0.5

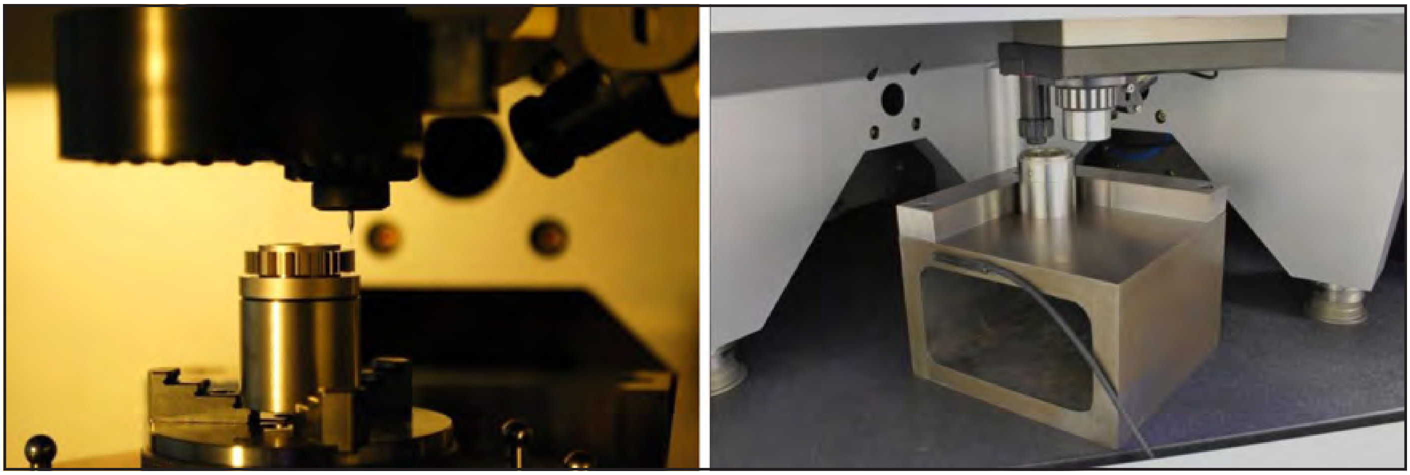


Figure 3 Measurement setups of the microgear measurement standards on the µCMM. The left side of the figure shows the external measurement standard (Ref. 2)]. The right side of the figure shows the internal measurement standard and its custom clamp.

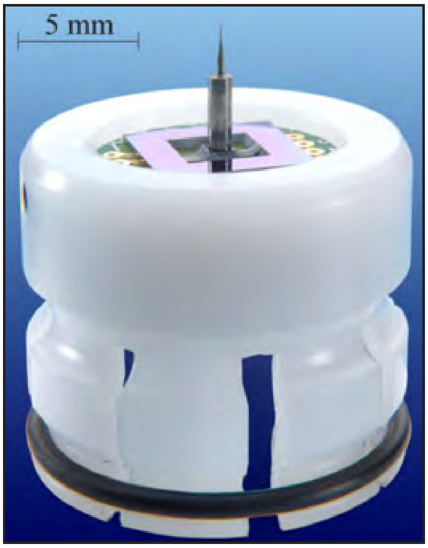


Figure 4 Detailed view of the IMT/PTB microprobe with sphere diameters down to 50 µm. The microprobe is integrated into our GMI.

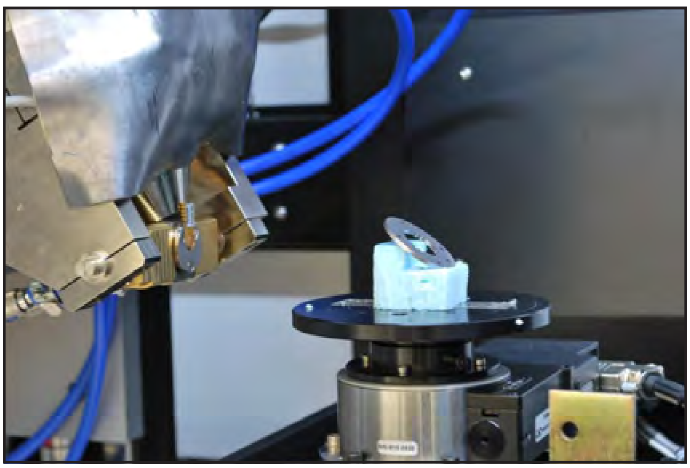


Figure 5 Measurement setup of the CT system. The X-ray source can be seen on the left-hand side of the image above. The measurement standard, positioned on the rotary table, can be seen on the right. The detector is situated on the far-right side and is not depicted in the image above.

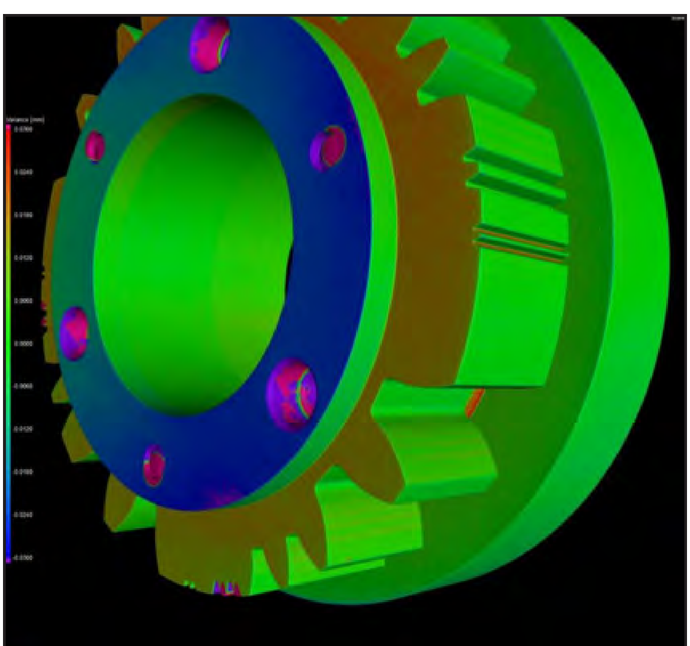


Figure 6 Target/actual comparison of the CT measurement regarding the CAD model.

Tactile measurements on a gear measuring instrument (GMI). Gear measuring instruments (GMIs) feature a rotary table for measuring cylindrical workpieces. On our Klingelnberg *P40* GMI, we used two different probes: a conventional probe with a 300-micrometer ruby sphere and a custom microprobe with a monolithic shaft and 100-micrometer sphere (Fig. 4). This microprobe was developed by TU Braunschweig and PTB (Refs. 1, 10). The probing force was between 15 mN (with the microprobe) and 825 mN (with the standard probe).

Computed tomography (CT) measurements. The CT measurements were performed on a Nikon *MCT 225* (cone-beam CT). This measurement method can check internal dimensions and "combine dimensional quality control with material quality control in one single quality inspection run" (Ref. 7).

The measurement standards were tilted 45° for measurement (Fig. 5). The CT measurement of the internal microgear used an invar foil with accurately known dimensions as the reference object (Ref. 3). The invar foil was measured before and after the microgear measurement standards were measured. Comparing the CT results of the invar foil with the reference value from the tactile calibration yielded a scaling factor that was applied to the measurement results of the microgear. Evaluations of CT measurements may include:

- Comparison with the CAD model (see Figure 6)
- Areal evaluation
- Conventional, line-based evaluation

For comparison with the line-based tactile calibration, we extract line features from the volumetric CT data.

The CT measurement generates a file containing the spatial coordinates of every measurement point. For this reason, the *gear* parameter analysis required additional software to separate points and to extract ine elements (profile lines and helix lines, see also Figure 12). In this study, we used a line-based evaluation for comparison (see ISO 1328).

Table 4 compares the CT measurement parameters of the external and internal microgears.

For CT measurements, the overall size of the workpiece determines the largest magnification that can be achieved. The internal microgear measurement standard has an outer diameter of 40 mm, whereas the external microgear measurement standard has an outer diameter of 22 mm. This explains the difference in the resulting voxel sizes: $(22.7\ \mu m)^3$ voxel size for the internal microgear, compared to $(17.5\ \mu m)^3$ voxel size for the

Table 4 Overview of the CT measurement parameters of the external and internal microgears

		External microgear	Internal microgear
Measuring data	Voltage	185 kV	190 kV
	Power	12.4W	17.5 W
	Pre-filter	0.8 mm Cu	1 mm Cu
	Measuring time	120 min	167 min
	Projections	1800	2500
	Magnification	12.9×	8.8×
	Resolution detector	2048×2048 pixels	
	Exposure time	2×2.8 s	4 s
	Voxel size	$(17.5\ \mu m)^3$	$(22.7\ \mu m)^3$
Reconstruction	Beam hardening filter	2	2
	Reconstruction filter	2	2
	Median filter	3×3 pixel	No median applied

external microgear, which could have been further decreased by reducing the distance between the workpiece and X-ray source. However, algorithms of the CT software achieve sub-voxel resolution. Additional key parameters are the penetration length and the material permeability. Both parameters influence the X-ray power needed for the measurement, which itself influences noise in the measurement results. The maximum penetration length of the external gear is ~12 mm and ~20 mm for the internal microgear. Thus, measuring the internal microgear yielded more *noise*. As a result, the form deviations measured by CT are on average *twice as high as the calibration values*. Furthermore, the limited resolution of the CT measurements (mainly due to the large voxel size) leads to rounded edges. Thus, the gear parameter analysis shows negative profile slope deviations (tip relief).

The data generated by means of a CT measurement are several gigabytes depending on the detector resolution and on the number of projections.

Optical measurements. We used two optical measurement methods: a focus variation method and a transmitted light method (Fig. 7).

Focus variation method. The focus variation measurements were performed on an Alicona InifiniteFocus G4 (external microgear) and InfiniteFocus G5 (internal microgear). The workpiece was clamped at a 45° angle (between the optical axis and the gear axis, Fig. 8) with the Rotation Unit.

We used two lenses featuring different magnifications and, thus, different resolutions (see Table 5).

We tested four different settings for the external microgear measurement standard. The 3-D view obtained with Setting 1 showed several measuring artifacts that may be caused by sub-optimal exposure time and reflections. Setting 4 showed the best results due to the high magnification. However, the 0.1 mm module could not be evaluated because too many artifacts were on the teeth. Moreover, the focus variation measurements took a long time to perform (Table 6). However, the measurement time could have been reduced by optimizing the settings, as we did with the Alicona InfiniteFocus G5 and the internal microgear.

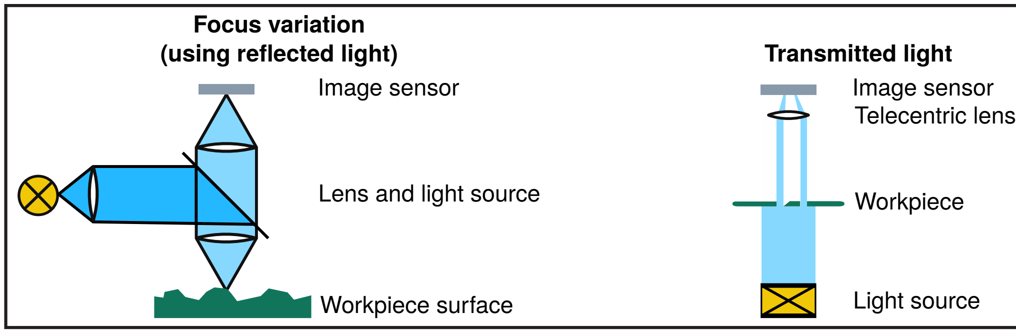


Figure 7 Simplified visualization of the two optical measurement principles.

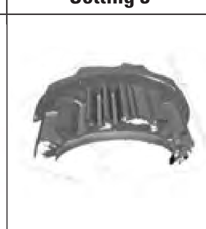
Figure 8 Measurement setup of the Alicona InifiniteFocus. The measuring machine allows roughness measurements and 3-D measurements to be performed.

Table 5 Specifications of lenses used for focus variation

	5× lens	10× lens
Image area	2.9 mm × 1.4 mm	2.2 mm × 1.1 mm
Numerical aperture	0.15	0.3
Maximum resolution (lateral)	2.2 µm	1.1 µm
Resolution (vertical)*	0.4 µm–8.36 µm	0.1 µm–2 µm

* The vertical resolution depends on the scanning speed

Table 6 Overview of measurements performed using the Alicona InifiniteFocus G4

	Setting 1	Setting 2	Setting 3*	Setting 4
3D view				
Measuring time	24h	400h	20h	50 h
Resolution (lateral)	7.8 µm	7.8 µm	3.9 µm	3.9 µm
Resolution (vertical)	0.25 µm	0.25 µm	0.25 µm	0.25 µm
Exposure time	80 ms	automatic	40 ms	20 ms
Magnification	5×	5×	10×	10×
Polarization	Active	Active	Active	Active

* Not a full measurement

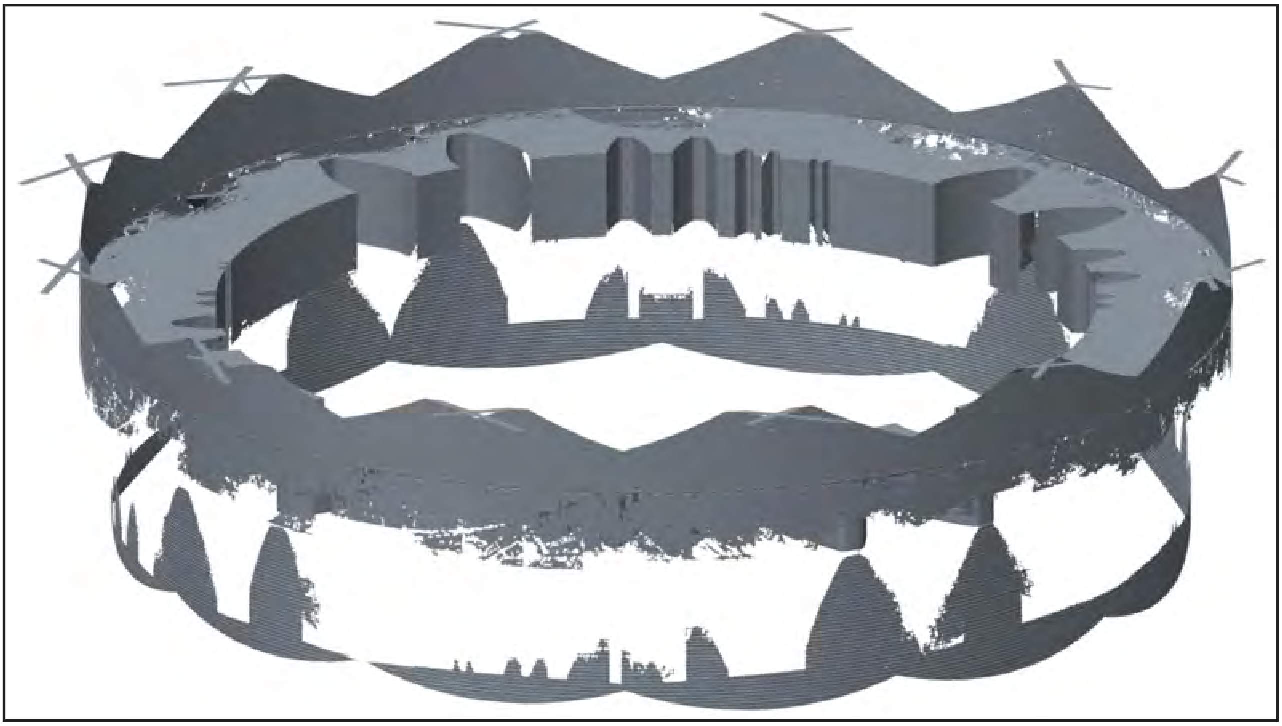


Figure 9 Reconstruction of the internal microgear measurement standard with focus variation.

On the InfiniteFocus G5, what worked best for the internal microgear was 10× magnification, no polarizer, 0.15 seconds exposure time, 8.5 µm lateral resolution, and 0.35 µm vertical resolution. The measuring time was 106 minutes. It was not possible to capture the whole measurement standard, but all gear teeth (Fig. 9). Thus, we had to change the definition of the workpiece coordinate system for evaluations of this measurement. Nearly every tooth space shows small artifacts, but they mainly occurred at the edges, which did not impair the *traditional* line-based evaluation.

Transmitted light method. The optical transmitted light measurements were limited to the *internal* microgear. It was not possible to measure the external microgear because the lower datum reference diameter is larger than the tip diameter. Therefore, the lower datum reference would have blocked the light (Fig. 1).

The measuring machine used was a Werth Videocheck UA. As shown in Figure 7, the transmitted light method yields 2-D point data (x- and y-coordinates). Thus, it was only possible to analyze profile lines (without helices). Additionally, the imaged profile lines are an *envelope* of the whole facewidth, which leads to systematic errors. Accordingly, this measurement method is commonly used to characterize thin or 2.5-dimensional objects. The systematic error when measuring gear profiles depends on the:

- Helix deviations
- Twist (Ref. 15)

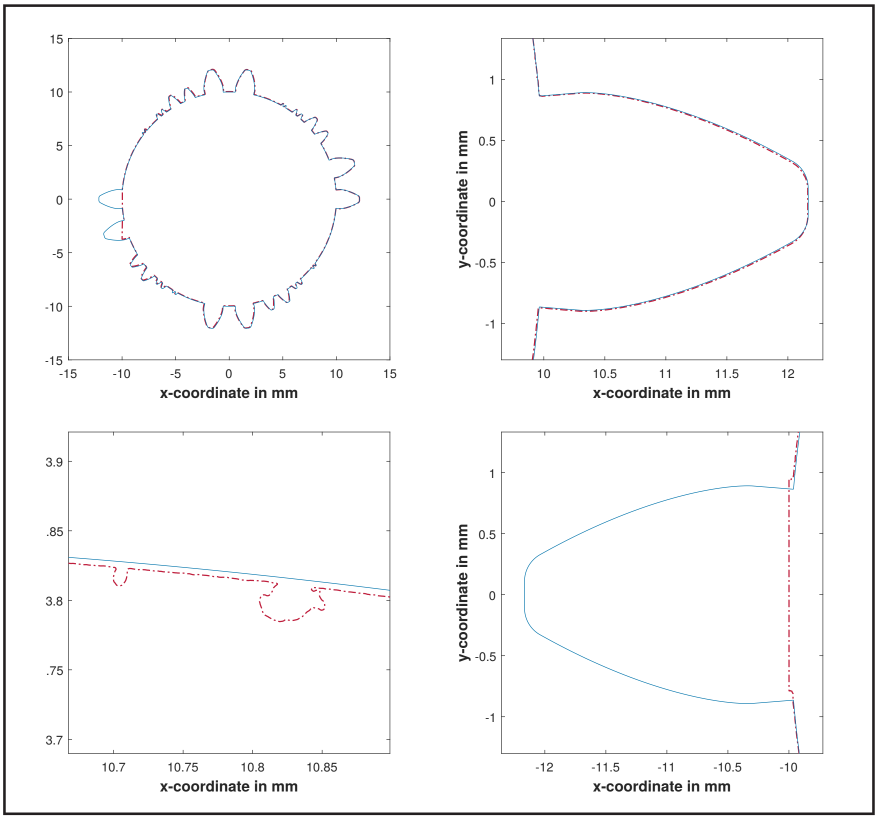


Figure 10 Visual analysis of the transmitted light measurement. In all the above figures, the red dashed and dotted line represents the measurement and the blue solid line represents the contour of the CAD model, which is the target geometry. Upper-left plot: overview of the measured inner contour of the microgear. Upper-right plot: Detailed view of a tooth with a 1 mm module showing good agreement with the CAD model. Lower-left plot: Detailed view of two particles on the tooth surface (information on their z-coordinate cannot be provided using this measurement method). Lower-right plot: Here, the automatic edge detection has failed and skipped the tooth.

- Alignment of measurement standard and measuring machine
- Contamination

When measuring with transmitted light, every particle on the tooth surface alters the measurement result (Fig. 10, lower-left plot). By contrast, it is unlikely that these particles would alter the *tactile* measurement result; either the particles are not positioned on the scanned line or the tactile probe would push away loosely adhering particles.

The measurement program was created by means of automatic edge detection. Here, the software requires only a starting position with the optics focused on the inner contour and does not require information on the real gear geometry. However, using this algorithm led to teeth being skipped (Fig. 10, lower-right plot).

Tactile-optical measurement. The tactile-optical measurements were performed on the multi-sensor CMM Werth Videocheck UA quipped with the fiber probe developed at PTB (Fig. 11) (Ref. 11). Probing forces were as low as 1 μN.

Comparison and discussion of the measurement results. In summary, the two workpieces were characterized by seven measurement systems. For comparison purposes, we focused on the deviations of the gear parameters from the calibration values, the measuring time, and the measurability of the smallest module (Table 7).

Tactile measurements are the most established approach in gear metrology. Thus, the standard-compliant evaluation of the deviations (see ISO 1328) is based on line elements, which are the output of tactile measurements (instead of surface data). The high level of development of such elements makes tactile measuring machines favorable.

To ensure comparability of the measurement results obtained by means of the different principles, it was necessary to process the data and extract the line-based features of the standard evaluation (Fig. 12).

The focus variation method relies on light reflections of the

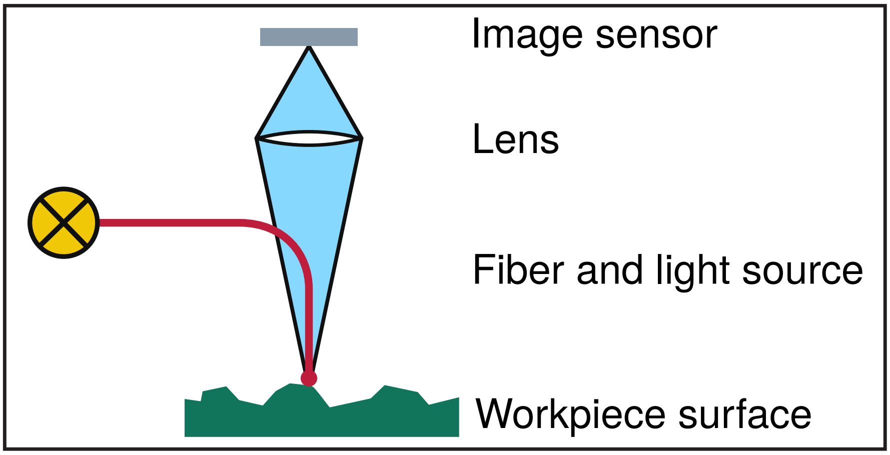


Figure 11 **Working principle of the fiber probe. The light merges into the fiber (depicted in red) and the image sensor detects deflections of the fused sphere at the tip of the fiber.**

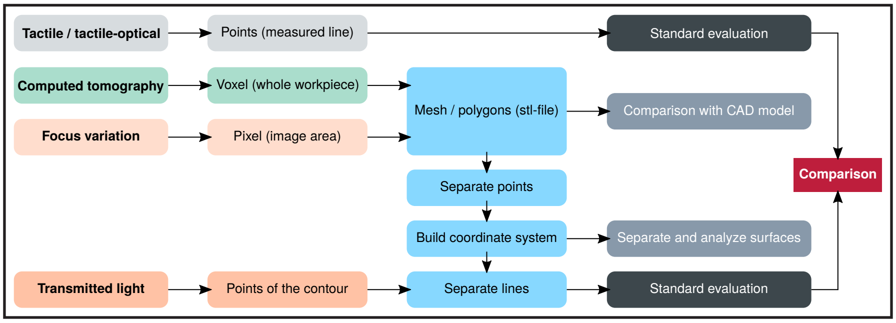


Figure 12 **Process flow of the evaluation in the comparison measurements. Standard evaluation refers to the ISO 1328-1.**

Table 7 Comparison of measurement parameters

Measurement method	Measuring machine	Measurement time	Parameters
Tactile (CMM)	Zeiss *F25*	2 min per tooth for scanning, up to 10 min for single-point probing	**Gear parameter evaluation:** Zeiss Gear Pro **Sphere diameter:** 125 μm **Strategy:** Scanning (single-point probing used additionally for the external microgear)
Tactile (GMI with standard probe and custom microprobe)	Klingelnberg *P40*	2 min per tooth	**Gear parameter evaluation:** Klingelnberg software **Sphere diameter:** 300 μm (standard probe), 50 μm and 300 μm (custom microprobe of PTB and TU Braunschweig) **Strategy:** Scanning
Computed tomography (CT)	Nikon *MCT 225*	120 min per workpiece	**Voxel size** (depending on the workpiece size): $(17.5\ \mu m)^3$ for the external gear, $(22.5\ \mu m)^3$ for the internal gear **Gear parameter evaluation:** Hexagon 3D Reshaper and Gear, evaluation takes up to **five hours per tooth to perform** (400 points per millimeter, 1 mm module)
Optical (focus variation)	Alicona *InifiniteFocus G5*	106 min per workpiece	**Lenses:** 5× and 10× **Gear parameter evaluation:** Hexagon 3D Reshaper and Gear, evaluation takes up to **five hours per tooth to perform** (400 points per millimeter, 1 mm module). There is an additional software module from Alicona for gears, which might reduce evaluation time
Optical (transmitted light)	Werth Videocheck *UA*	1 min per tooth	**Gear parameter evaluation:** Zeiss Involute Pro **Lens:** 10×
Tactile-optical measurement	Werth Videocheck *UA*	5 min per tooth	**Gear parameter evaluation:** WinWerth with gear module **Sphere diameter:** 125 μm **Strategy:** Single-point probing

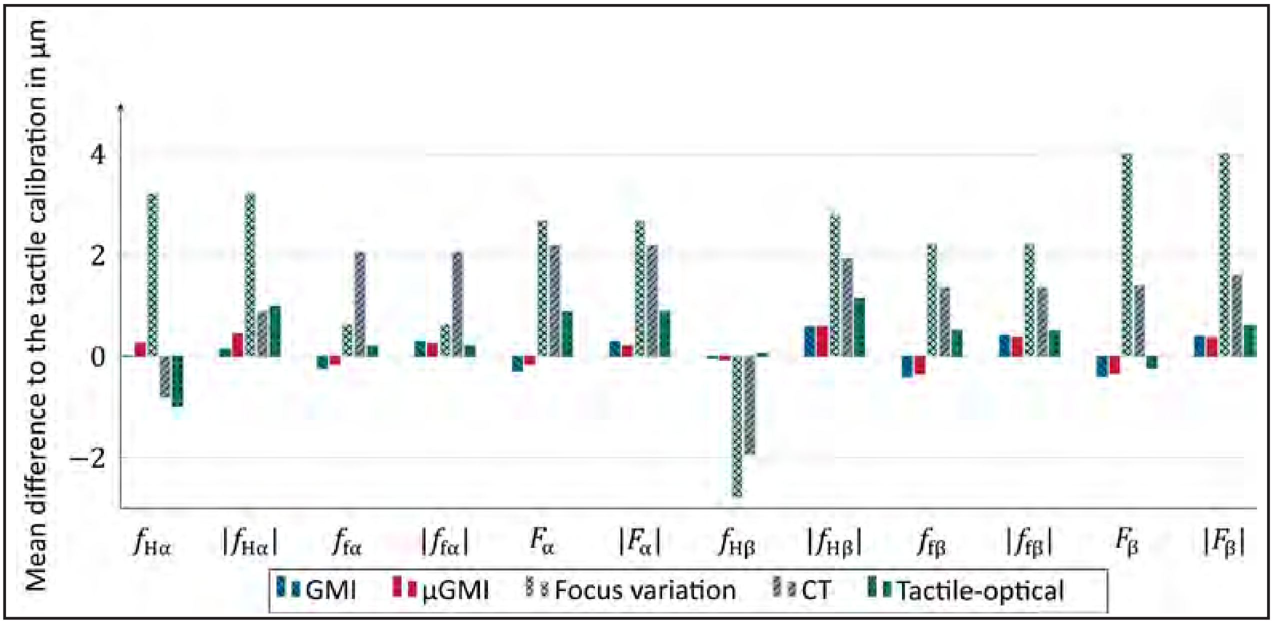


Figure 13 Comparison measurements of the external microgear measurement standard.

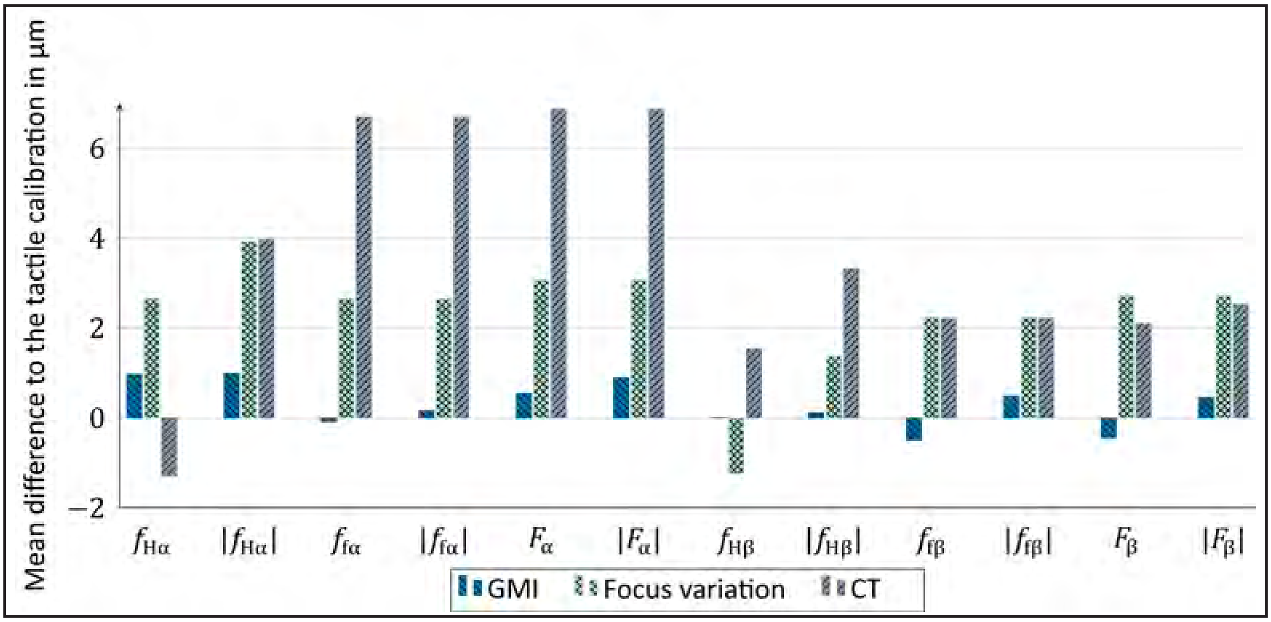


Figure 14 Comparison measurements of the internal microgear measurement standard.

Table 8 Evaluation of the measurement methods regarding microgear metrology		
Measurement method	**Advantages**	**Disadvantages**
Tactile (µCMM and GMI)	Fast, accurate, easily traceable	Line-based characterization of the workpiece, special probes required, sphere diameter must match the tooth spaces, most probes are fragile, probing may alter the workpiece due to high Hertzian stress
Computed tomography (CT)	Fast measurement, volumetric characterization of the workpiece, contactless, can check internal dimensions, measurement of very small modules, unaffected by contamination of the workpiece	Differences of several micrometer from the calibration values, resolution depends on the overall size of the workpiece and length to be penetrated by the X-rays, calibrated reference object needed to achieve highest available accuracy (scale correction), strong noise, data analysis requires considerable processing power and time
Optical (focus variation)	Fast areal characterization of the workpiece, contactless	Differences of several micrometer from the calibration values, occasional artifacts, sensitive to contamination, measurability depends on surface finish and on the angle between workpiece surface and optical axis, data analysis requires considerable processing power and time
Optical (transmitted light)	Fast, contactless, information on the target geometry is unnecessary due to the edge detection	Systematic errors due to the measurement principle (only 2D data, compared to 3D data from all other measurement methods, envelope contour from all z-coordinates), sensitive to contamination, line-based characterization of the workpiece
Tactile-optical	Lowest probing force (1 pN), smallest probe spheres available (40 µm) [14]	Line-based characterization of the workpiece, sticking effects due to the small stiffness of the fiber, measurability depends on surface finish

workpiece surface onto the image sensor. In this study, measuring gears required that the workpieces be tilted to ensure an adequate angle. Furthermore, the fixed focal length of the lenses limits the reconstruction internal gears — in the case of the internal microgear measurement standard, we were not able to completely reconstruct the workpiece.

CT systems allow contactless measurements that yield a complete 3D representation of the workpiece. However, the resolution depends on the workpiece size (in contrast to all other methods described in this work). Accordingly, CT measurements yield low resolutions for gears whose ratios of the outer diameter to the module are high.

The following two figures show the measurement results. Measurement results of the 1 mm, 0.5 mm, and 0.2 mm modules are stated in mean differences to the tactile calibration (regarding all modules and teeth). First, we computed the single differences (measurement result minus the corresponding result of the calibration). Afterwards, we computed the mean of these differences for every gear parameter ($f_{H\alpha}$, $f_{f\alpha}$, F_α, $f_{H\beta}$, $f_{f\beta}$, F_β) because the differences between the modules are mostly negligible, whereas the differences regarding the gear parameters are decisive. The term "abs" in the following figures states that the mean was computed using the absolute value of each difference.

The best agreement with the calibration values comes from *GMI* and µ*GMI*. Most of the Focus Variation and *CT* results differ markedly from the calibration values.

Analyzing the CT measurements of the internal microgear, we found out that the reason for the large differences in the profile form deviations is the virtual tip relief due to limited structural resolution. Shortening the evaluation range of the profiles at the tip end would have halved the differences to the calibration values.

In general, the form deviations of the CT and focus variation measurements are large due to limited resolution and noise — applying filters could decrease the differences to the calibration values. The comparison measurements using the GMI were successful because the results are within the measurement uncertainties.

Based on this study, we checked the applicability of the measurement methods used regarding microgear measurements (Table 8). The results show that each measurement method has shortcomings.

For industrial measurements, the combination of measurement time, cost, and quality can be a helpful key value to evaluate measurement methods. In the context of measurement technology, "quality" can be, among other things, influenced by accuracy, precision, measurement uncertainty, holistic characterization of the workpiece (3-D-reconstruction of the workpiece), robustness, and reliability. In terms of quality, the tactile measurements featured the smallest measurement uncertainties but generated only line data. CT measurements generated a holistic digital representation of the workpiece. The focus variation method was the most cost- and time-efficient measurement method. High-precision coordinate measuring machines and CT systems cost about two to five times as much as most optical systems.

Conclusion and Outlook

PTB successfully conducted comparison measurements of two microgear measurement standards using seven measurement methods. The following goals were pursued:

- Verification of the measurement standards and their calibration
- Performance evaluation of the measuring machines involved *regarding microgear measurements*
- Comparison of the measuring machines *based on actual measurement data*

Since a reasonable number of measurement results are within the measurement uncertainty of the calibration, we infer that the measurement standards are adequate and that their calibration is correct.

Industry and research may benefit from the workpiece-like measurement standards by testing and evaluating measuring techniques and machines. Using different techniques and machines to measure a calibrated workpiece reveals their individual advantages and disadvantages.

Small and medium-sized enterprises (SMEs) could take advantage of the comparison measurements by using the independent and comparable measurement data provided here. This will allow SMEs to have increased confidence when investing in measuring machines.

Ultimately, only some of the measurement methods were adequate for measuring the 0.1 mm module, namely: tactile measurement with the IMT/PTB microprobe, CT, optical measurements, and tactile-optical measurement with the fiber probe.

Currently, PTB and TU Braunschweig are further developing the custom microprobe (Ref. 9). Our goal is to expand the measurement capabilities of conventional GMIs and CMMs by integrating our microprobe. This allows the use of smaller probing sphere diameters and yields higher sensitivity. The microprobe is supplemented by a *microenvironment*, which is a portable separative device that protects and monitors the direct measurement environment and includes clamping and cleaning solutions (Refs. 4–5).

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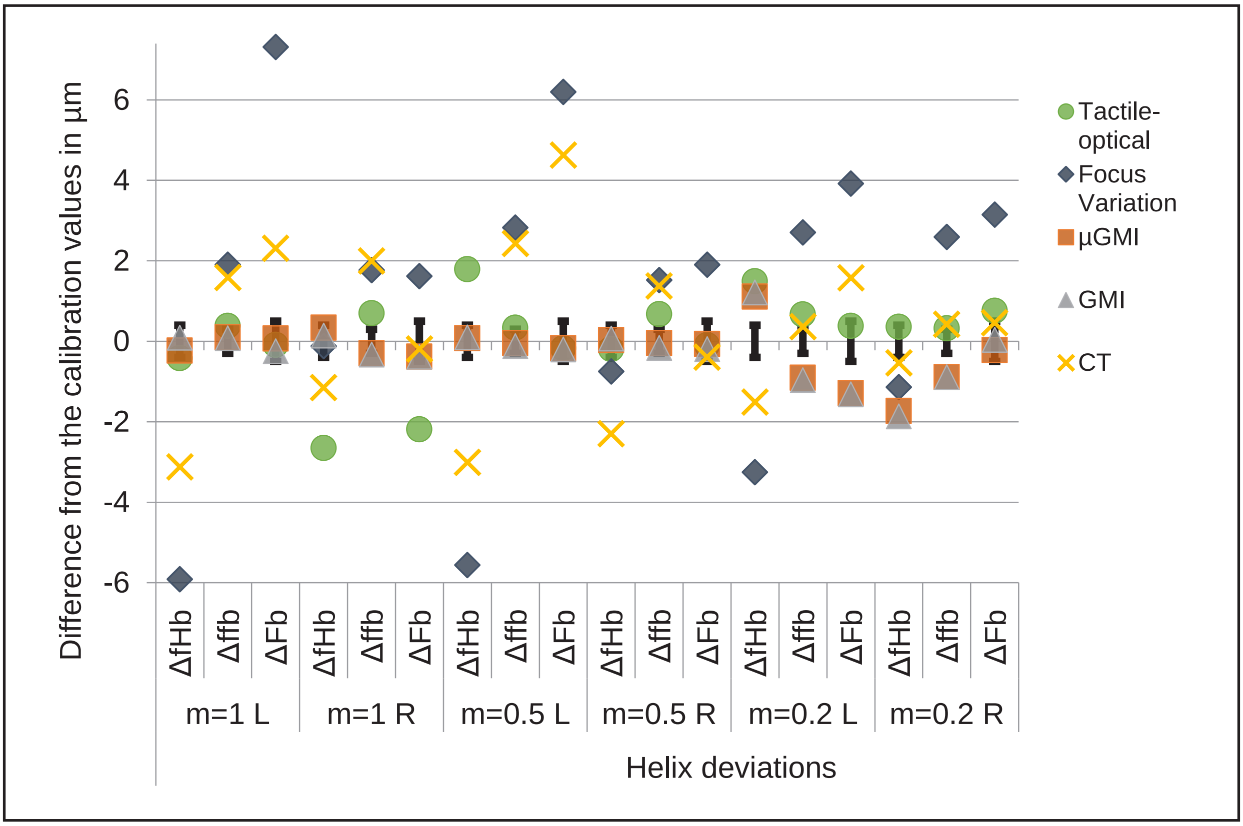

Figure 15 **Comparing the helix deviations for the modules from 0.2 mm to 1 mm of the external microgear. µGMI means a measurement using a custom microprobe integrated into our GMI. The best agreement with the calibration values comes from GMI and µGMI. Most of the Focus Variation and CT results differ markedly from the calibration values.**

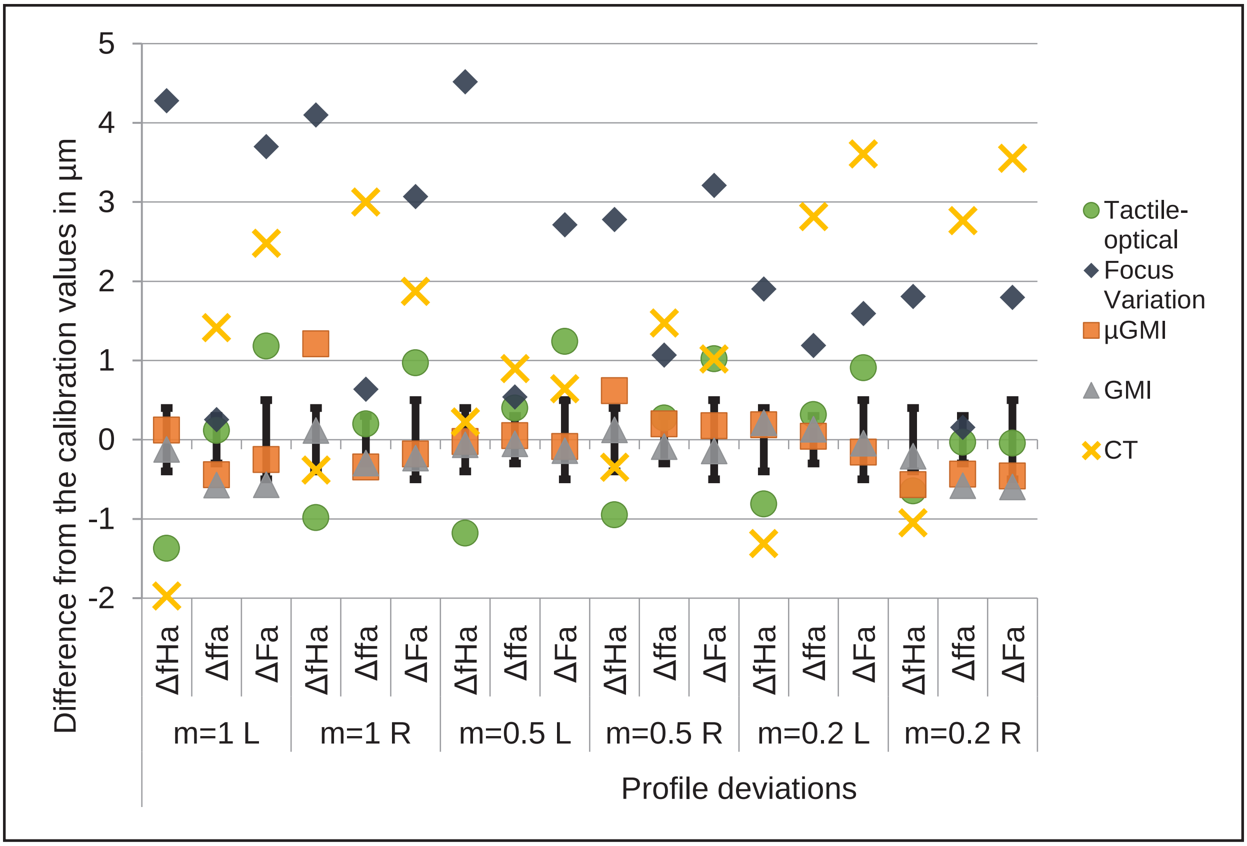

Figure 16 Comparing the profile deviations for the modules from 0.2 mm to 1 mm of the external microgear. µGMI means a measurement using a custom microprobe integrated into our GMI. The best agreement with the calibration values comes from GMI and µGMI. Most of the Tactile-optical and CT results differ markedly from the calibration values. The largest differences can be found in the Focus Variation measurements, which are consistently too large.

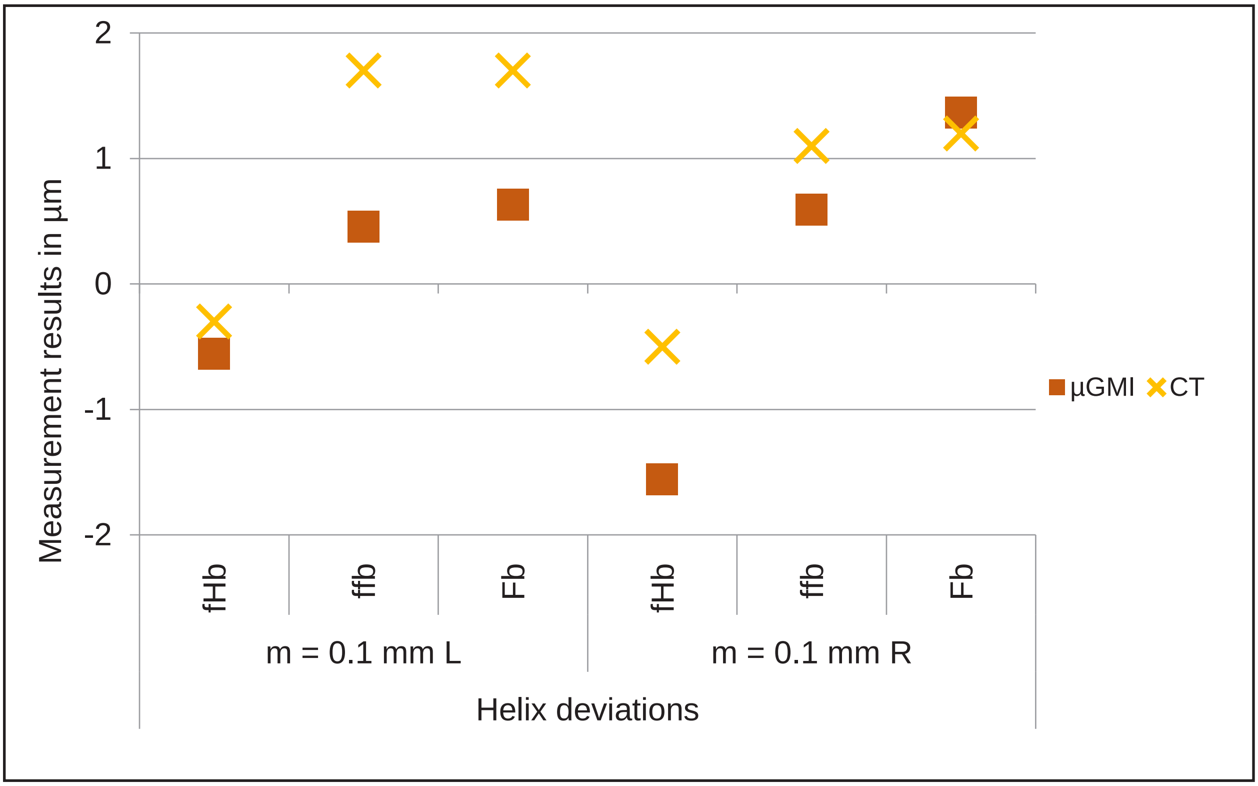

Figure 17 Comparing the helix deviations for the 0.1 mm module of the external microgear (CT and tactile measurement with custom microprobe on the GMI). Overall, the results agree.

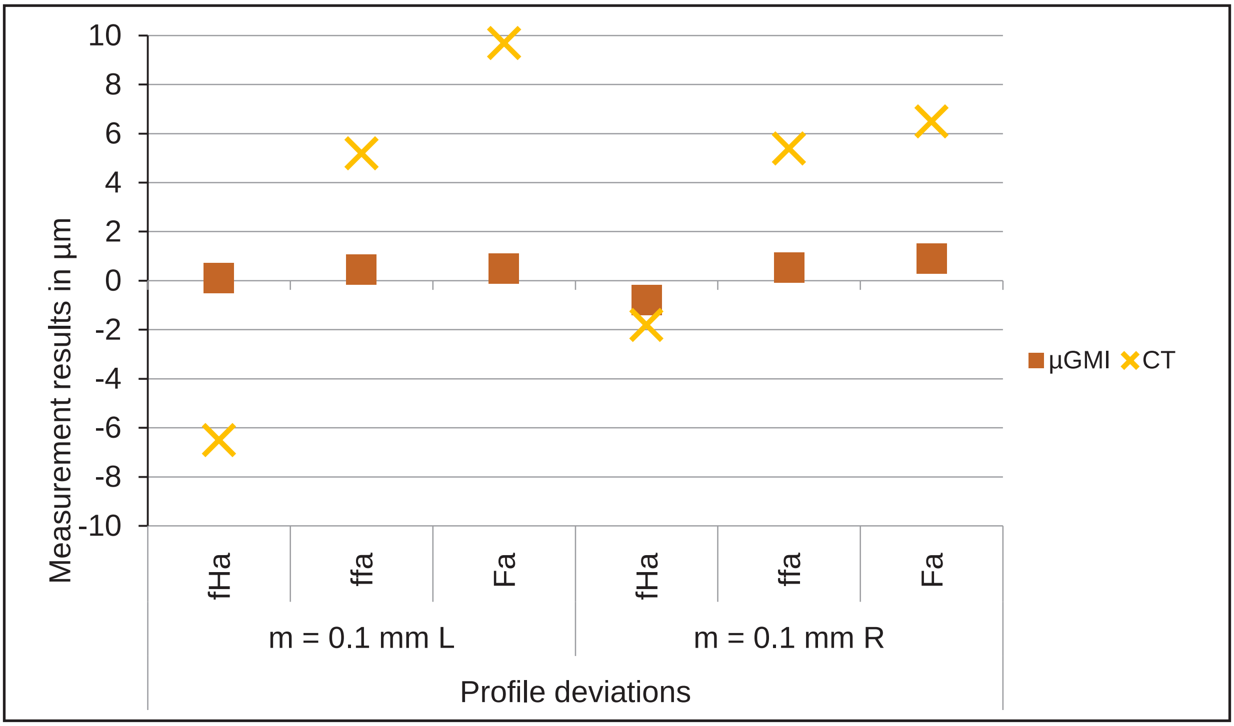

Figure 18 Comparing the profile deviations for the 0.1 mm module of the external microgear (CT and tactile measurement with custom microprobe on the GMI). The length of the profile is short, which might explain the large deviations of the CT measurement.

Supplemental Material

References

1. Ferreira, N. and T. Krah, et al. 2014, "Integration of a Slicon-Based Microprobe into a Gear Measuring Instrument for Accurate Measurement of Mcrogears," *Measurement Science and Technology*, 25(6), pp. 064016.
2. Härtig, F. and K. Kniel, K. et al. 2009, Messung von Mikroverzahnungen: Entwicklung von Verfahren zur Eignungsprüfung von Messgeräten für die Mikroverzahnungsmessung; Forschungsvorhaben Nr. 567 II; Abschlussbericht (English translation: Measurement of microgears: Development of Procedures for Qualification Tests of Measuring Instruments for Microgears*)*, Forschungsvereinigung Antriebstechnik e.V., Frankfurt.
3. Illemann, J. and Neuschaefer-Rube, U. et al. 2018, "Determining Spectrum-Dependent Source and Dtector Psitions in Cone-Beam CT," *8th Conference on Industrial Computed Tomography*.
4. Jantzen, S., T. Decarreaux, et al. 2018, "CO2 Snow Cleaning of Miniaturized Parts," *Precision*
5. *Engineering*, 52 (2018), pp. 122–129.
6. Jantzen, S., R. Meeß, et al. 2017, "Clamping of Microgears with a Compliant String,"
7. *MacroScale 2017—Recent Ddevelopments in Traceable Dimensional Measurements*, Helsinki.
8. Jantzen, S., M. Neugebauer, et al. 2018, "Novel Measurement Standard for Internal Involute Microgears with Modules Down to 0.1 mm," *Measurement Science and Technology*, in revision.
9. Kruth, J.P., M. Bartscher, et al. 2011, "Computed Tomography for Dimensional Metrology," *CIRP Annals*, 60 (2), pp. 821–842.
10. Zeiss Industrial Metrology. 2018, "GEAR PRO", from
11. *www.zeiss.co.uk/metrology/products/software/gear-pro.html.*
12. Metz, D. and A. Dietzel, A. 2017, "New Parallelogram 3-D Displacement Sensor for Micro Probing and Dimensional Metrology," *19th International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS)*, pp. 982–985.
13. Metz, D., N. Ferreira, et al. 2017, "3-D Piezoresistive Silicon Microprobes with Stacked Suspensions for Tailored Mechanical Anisotropies," Sensors and Actuators A: Physical, 267 (2017), pp. 164–176.
14. Petz, M., R. Tutsch, et al. 2012, "Tactile-Optical Probes for Three-Dimensional Microparts,"
15. *Measurement*, 45 (10), pp. 2288–2298.
16. Thalmann, R., F. Meli, et al. 2016, "State of the Art of Tactile Micro Coordinate Metrology," *Applied Sciences*, 6 (5), pp. 150.
17. Wedmann, A., K. Kniel, et al. 2014, *VDI-Berichte 2236: Rückführung von*
18. *Mikroverzahnungsmessungen*, *VDI-Verlag*, Düsseldorf.
19. Werth. 2018, "3-D Fiber Probe," from *http://werthinc.com/products/3d-fiber-probe/*.
20. Winkel, O. 2010, "New Developments in Gear Hobbing," ***Gear Technology***, 3 (4), pp. 47–55.

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Impact of Root Geometry Manufacturing Deviations from a Theoretical Hob Rack on Gear Bending Stress

Rahul V. Nigade and Carlos H. Wink

Introduction

High reliability, superior efficiency, and light weight are key requirements of mechanical power transmission systems, such as automotive transmissions. The competing design requirements pose a challenge to gear designers. Rigorous engineering analysis and sophisticated computational tools might be needed to help in finding the best compromise of design parameters and product performance requirements. One important aspect to be considered during the gear design phase is the manufacturing process. Different manufacturing processes can be used to produce gears, such as hobbing, shaping, and milling (Ref. 1). Each one of them has its advantages and limitations. Gear hobbing is a cost-effective and widely used method of cutting gear teeth (Ref. 1).This generating process makes both the tooth involute flanks and root fillet. The involute flanks can be finished by a post-process such as shaving, grinding, or honing (Ref. 1). In the hobbing operation, root fillets are generated by the hob rack tip corner. The generated root fillet is not a true radius, but a trochoid form (Ref. 2). An undercut root fillet is formed when the "trochoid lies inside a line drawn tangent to the involute profile at the point of intersection of the involute and the trochoid" (Ref. 3) (Fig. 1). Under certain conditions the trochoid form may intersect the tooth involute flanks above the start of active profile, resulting in undercut (Ref. 4). Undercut is generally considered an undesired result of the generating process because it may affect load distribution and reduce gear load capacity (Refs. 3, 5). Undercut was comprehensively investigated by Su and Houser (Ref. 4), and Pedrero et al. (Ref. 5).

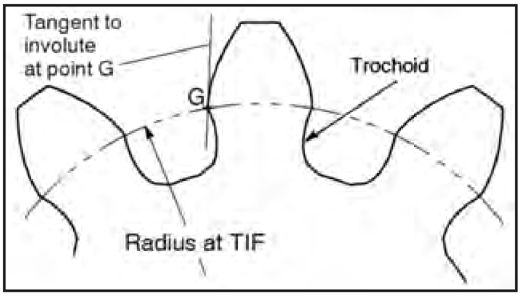


Figure 1 Root fillet shape of undercut teeth (Ref. 3).

The root fillet shape is a leading element for determining tooth bending strength of gears, which is the resistance to cracking (Ref. 6). The root fillet is particularly susceptible to fracture because it is where the highest tensile bending stresses are found (Ref. 7). ANSI/AGMA 1010 (Ref. 7) recommends the use of tools with fully rounded tips and protuberance for reducing bending stresses in the root area. Hob racks with fully rounded tip generate full fillets and reduce stress concentrations, and protuberance tools minimize risks of stress risers, such as notches or steps on the root fillet of gears that are finished after hobbing (Ref. 7). Industry standards, such as ANSI/AGMA 2101 (Ref. 6) and ISO-6336-3 (Ref. 8), provide methods for calculating bending stresses that use stress correction factors derived from basic geometry of the generating tool. However, computational tools for gear analysis, such as *WindowsLDP* (Ref. 9), should be employed for accurate bending stress prediction. Lastly, bending stresses and reliability are determined during the design phase and under the assumption that an equivalent design hob rack will be used for making the gears in production. Chaphalkar et al. (Ref. 10) pointed out gaps on gear drawings, and between design and manufacturing — which may jeopardize gear strength. In general, gear drawings contain complete specifications of involute profile, lead, and other micro-geometry parameters, but typically this is not the case for root fillet shapes, where in some instances only a minimum radius is specified in the root area (Ref. 10). As a result of that, the geometry of the hob cutter actually used to cut the gears in production may deviate from the intended hob rack, which may result in differences of root fillet shape and eventually affecting root bending stress. Also, the root fillet shape is not usually part of quality control and gear inspection, which are mostly focused on tooth contact area — such as involute form and lead (Ref. 10). The objective of this study is to investigate the impact of manufacturing deviation of root fillet

Table 1 Basic gear data

Parameters	Units	Values
Number of teeth	-	66
Module	mm	2.5
Pressure angle	deg	20
Helix angle	deg	0
Outside diameter	mm	171.40
Pitch diameter	mm	165.98
Base diameter	mm	155.97
Root diameter	mm	157.15
Face width	mm	33
Load intensity	N/mm	750

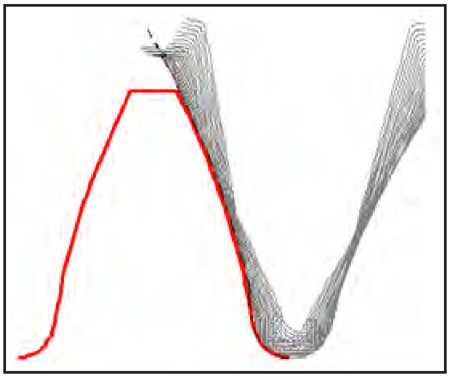


Figure 2 Gear tooth generated by a hob rack.

shape from the intended hob rack on bending stresses. Three gear samples were brought to the gear lab for root fillet inspection. The root fillets were scanned on a gear measurement machine. The measured root fillet data were imported into *WindowsLDP* (Ref. 9) for accurate bending stress calculation using a custom finite element model option available on the program. The results were compared to bending stresses from the intended hob rack. The differences were quantified and causes of deviations were identified. The overall results of this study emphasize the importance of a closed-loop approach of gear design and manufacturing to assure designed root fillet shapes are attained in production, and gears meet the design intent.

Bending Stress from Design Generating Rack

Several methods for calculating bending stress are available through industry standards and gear programs. Some of the key elements of determining the maximum tensile stress at the tooth root are the load distribution of meshing teeth and the generated root fillet shape. The *WindowsLDP* program (Ref. 9), developed by the Gear and Power Transmission Research Laboratory of The Ohio State University is a well-known gear program widely used on gear research projects and in the gear industry. It uses a finite element model for calculating bending stresses accurately, which was validated experimentally and well documented (Refs. 11–12). The program was used to calculate bending stress of the selected case study.

Gear data was entered to *WindowsLDP* along with hob rack geometry that was used for designing the gears. Basic gear geometry information is provided in Table 1. Figure 2 shows the generated tooth in the program. All analysis was done at a single load condition and under no misalignment. The default program setting was used for number of mesh cycle positions and multiplier across the face width, that is, 21 and 4, respectively.

The bending stress calculation was done and the maximum principal tensile root stress from the finite element stress analysis was recorded. Figure 3 shows the bending stress results. The picture on the left depicts a cross section of the gear where the highest bending stress was found along the root fillet. The picture on the right shows the principal stress distribution across gear face width and root fillet. The arrow points to the location of maximum tensile stress.

Bending Stress from Measured Root Fillet Shape

Three samples of the gear case study were inspected. Root fillet shapes were measured on a Wenzel gear measurement machine model WGT400 using Wenzel's *TShaft* program (Ref. 13) (Fig. 4).

The entire tooth was scanned, and 50 points were measured between the start of active profile and root radius. An example of the inspection report of root fillet measurement is shown (Fig. 5).

The measured root fillet points were loaded into *WindowsLDP* as an external file through the user defined XY shape

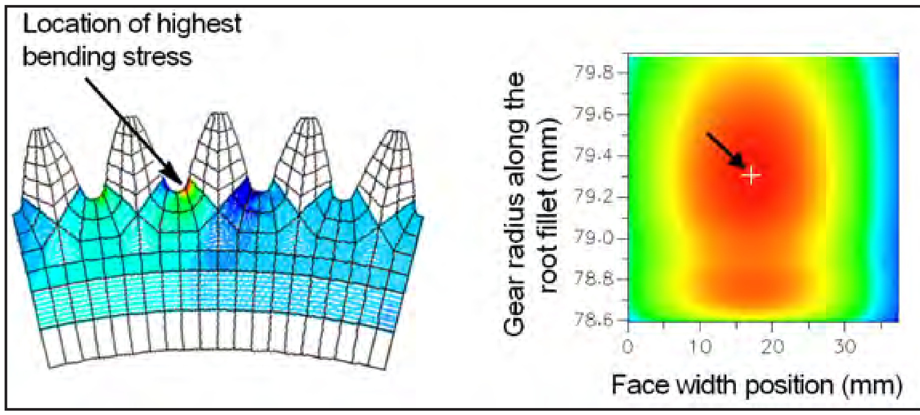


Figure 3 Example of bending stress distribution.

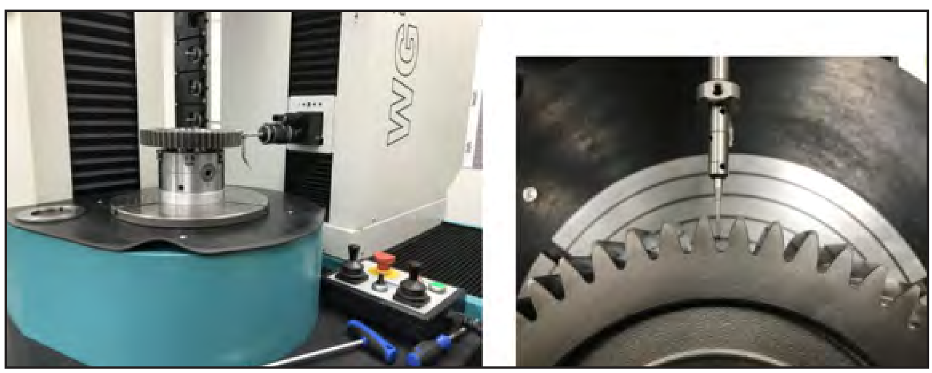
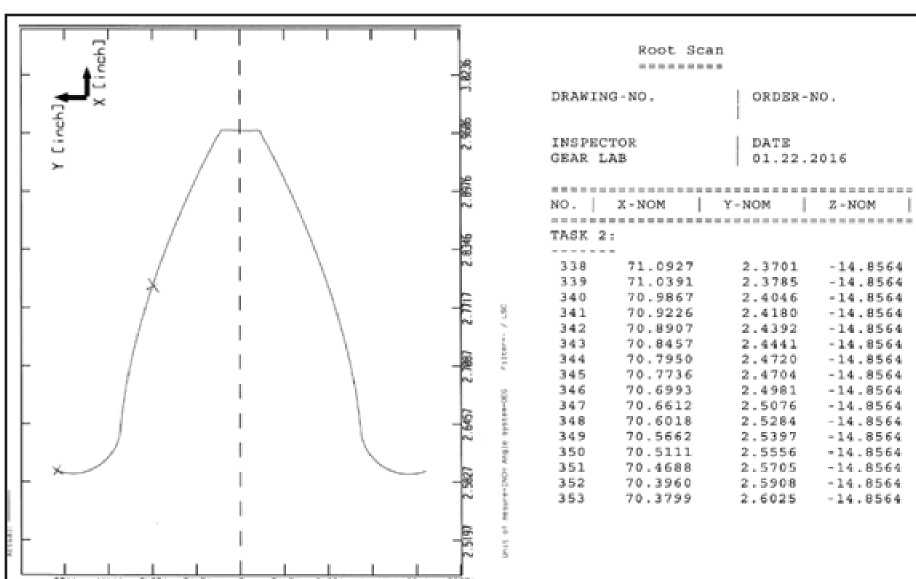


Figure 4 Gear root fillet measurement.



NO.	X-NOM	Y-NOM	Z-NOM
338	71.0927	2.3701	-14.8564
339	71.0391	2.3785	-14.8564
340	70.9867	2.4046	-14.8564
341	70.9226	2.4180	-14.8564
342	70.8907	2.4392	-14.8564
343	70.8457	2.4441	-14.8564
344	70.7950	2.4720	-14.8564
345	70.7736	2.4704	-14.8564
346	70.6993	2.4981	-14.8564
347	70.6612	2.5076	-14.8564
348	70.6018	2.5284	-14.8564
349	70.5662	2.5397	-14.8564
350	70.5111	2.5556	-14.8564
351	70.4688	2.5705	-14.8564
352	70.3960	2.5908	-14.8564
353	70.3799	2.6025	-14.8564

Figure 5 Example of measurement results of a gear root fillet.

option. In that case, the generated root fillet shape by the hob rack is replaced with the actual measured root fillet shape. Interpolation of measured points and finite element mesh are done automatically through a couple of program's routines. Lastly, bending stress was calculated using the finite element analysis module of the program and the maximum principal tensile root stress was recorded.

Results

Bending stress results of generated root fillet shapes by the design hob rack and actual measured root fillet shapes were compared for all three cases. The results were normalized by dividing bending stress of actual root fillet shape by bending stress of design root fillet shape. Thus, results greater than 1 mean increased stress with actual measured root fillet. The normalized results are shown in Table 2.

Table 2 Normalized bending stress results

Gear	Values
Design	1.00
Sample #1	1.22
Sample #2	1.21
Sample #3	1.13

The maximum deviation found among the three gear samples was 1.22, or 22%, over the design bending stress. Figure 6 shows a comparison of the designed root fillet and the measured root fillets. The key reasons for the differences in bending stress results are: root radius of the manufactured gears, and the root fillet curvature. Gear samples #1 and # 2 had slightly undersize root radii and smaller fillet curvatures compared to the designed root fillet shape. Gear sample #3 shows the smallest bending stress deviation to the design bending stress, 13%. Root radius of gear sample # 3 was in good agreement with the designed root radius, but root fillet curvature was smaller.

Further investigation revealed that the hob cutter used to manufacture those particular gear samples had been designed with a different pressure angle, as compared to the design hob rack. The design hob rack was a short-lead hob (Ref. 2) of 17 deg. pressure angle, while the production one was a 20-deg. pressure angle hob. Also, the production hob cutter was not fully rounded at the tip, leaving a flat root condition of the gear, which can be noticed in Figure 6. The normal hob rack profile is shown (Fig. 7), along with a comparison of the two hob cutter parameters.

Discussions

Three gear samples of a case study were investigated. Root fillets were scanned using a gear measurement machine. The data was imported into *WindowsLDP* for bending stress calculation using a finite element option of the program. The results were compared to the bending stress, with the hob rack used to design the gear. Deviations from 13% up to 22% were found. Further investigation revealed differences in root radii and root fillet curvatures, which caused bending stresses of manufactured gears to be higher than the one with a hob rack of the gear design. The reasons for such differences in root fillet shape were attributed to the actual hob cutter used to manufacture the gears that had different pressure angle and tip radius, compared to the intended hob rack. The results of this paper highlight that the root fillet shape is an essential element of gear design, and emphasizes the importance

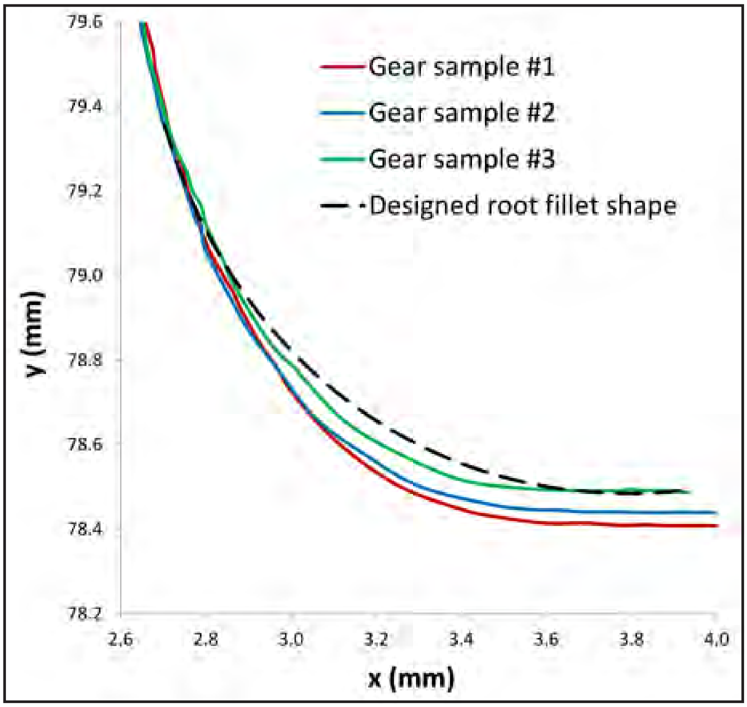
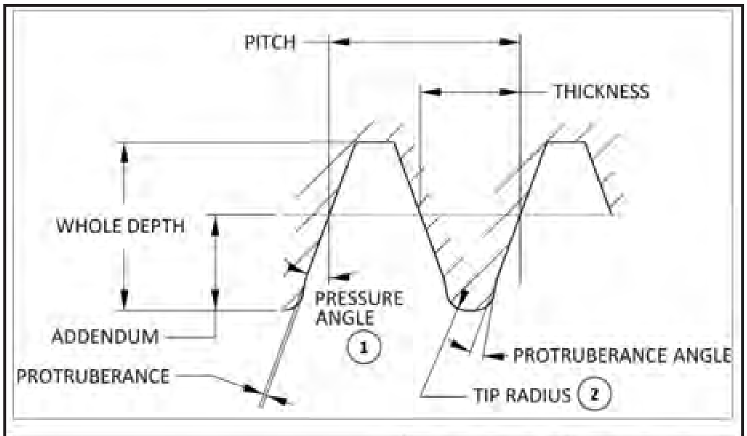


Figure 6 Comparison of root fillet shapes.



	Design	Production
1. Hob pressure angle (deg.)	17	20
2. Hob tip radius (mm)	1.016	0.584

Figure 7 Comparison between design and production hob racks.

of a complete root fillet shape specification or hob rack on gear drawings, along with a robust gear manufacturing control plan for attaining high gear reliability. Establishing a closed-loop approach of gear design and manufacturing helps assure that designed, root fillet shapes are obtained in production — and gears meet the design intent.

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For more information. Questions or comments regarding this paper? Contact Rahul V. Nigade at *RahulNigade@Eaton.com*.

Bibliography

1. Townsend, D. P. 1992, *Dudley's Gear Handbook*, 2nd ed., McGraw-Hill.
2. AGMA. 2013, "Tolerance Specificiation for Gear Hobs," ANSI/AGMA 1102-D03.
3. AGMA. 1999, "Design Manual for Parallel Shaft Fine-Pitch Gearing," AGMA 917-B97.
4. Su, X. and D. Houser. 2000, "Characteristics of Trochoids and Their Application to Determining Gear
5. Teeth Fillet Shapes," *Mechanism and Machine Theory*, 35, pp.291–304.
6. Pedrero, J., M. Artes and C. Garcia-Masia. 2004, "Determination of the Effective Path of Contact of
7. Undercut Involute Gear Teeth," *Proc. Instn. Mech. Engrs Part C J. Mechanical Engineering Science*,
8. 218, pp. 751–760.
9. AGMA. 2010, "Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical
10. Gear Teeth," ANSI/AGMA 2101-D04.
11. AGMA. 2014, "Appearance of Gear Teeth — Terminology of Wear and Failure," ANSI/AGMA 1010- F14.
12. ISO. 2006, "Calculation of Tooth Bending Strength," ISO 6336-3:2006(E).
13. Gear and Power Transmission Research Laboratory of The Ohio State University. n.d., from *gearlab.osu.edu/windowsldp*.
14. Chaphalkar, N., G.Hyatt and N. Bylund. 2014, "Analysis for Gear Root Forms: A Review of Designs, Standards and Manufacturing Methods for Root Forms in Cylindrical Gears," *Gear Solutions Magazine*, pp. 48–56.
15. Talbot, D. 2007, "Finite Element Analysis of Geared Shaft Assemblies and Thin-Rimmed Gears,"
16. M.S. thesis, The Ohio State University.
17. Roesti, B. 2000, "Refinements in Root Stress Analysis, Modeling, and Simulation of Several Spur
18. and Helical Gear Sets," M.S. thesis, The Ohio State University.
19. Wenzel America. Powerhouse GMM, n.d., from *www.wenzelamerica.com/powerhouse- gmm/*.

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Optimizing the Operational Behavior of Bevel Gears Using a Tolerance Field-Based Approach

M. Trippe, A. Lemmer, C. Löpenhaus, C. Brecher

Introduction

In the design process of gears, several criteria must be considered, such as a sufficient durability, a low noise excitation, and a robust design in terms of manufacturing and assembly deviations (Ref. 1). Bevel gears present a challenge in the design, due to the complex contact geometry and the operating-dependent contact conditions. In practice, deviations resulting from the manufacturing process as well as the assembly of the gears also influence the operational behavior of the gears. A comprehensive consideration of these expected deviations in the design process for bevel gears by varying the topography parameters as well as the mounting tolerances has not yet been conducted. (Ref. 2)

As Figure 1 shows, the Ease-Off generated in the design is influenced by manufacturing-related flank deviations and assembly related position deviations. In addition, load-related displacements during the operation have a major influence on the operational behavior. Since the reduction of manufacturing and assembly tolerances leads to increasing costs in the production, it is important to generate an optimal micro-geometry regarding deviations in the design. Optimal does not only refer to the quality of the operational behavior but especially to the robustness of the design against deviations (Refs. 3–4).

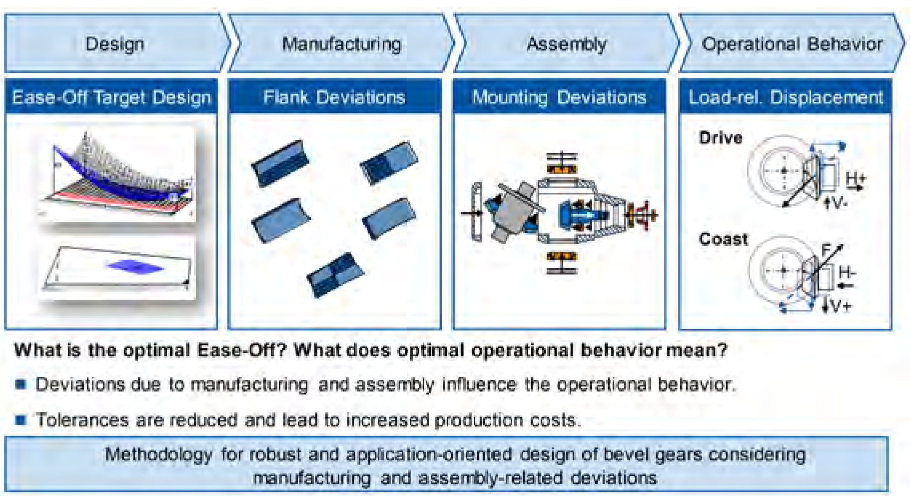

Figure 1 Motivation for robust microgeometries.

For cylindrical gears, robust microgeometries are designed using variant calculations. This way, production costs can be reduced. For bevel gears, such a design method is presented in this report and applied on a near-series pair of bevel gears. Following, the calculation and design method is described and the optimization potential is shown. The optimization method was developed within the IGF research project 18450 BG/1 (FVA 739 I) and validated by means of test-rig investigations.

Method for Optimizing the Microgeometry

The operational behavior of bevel gears is significantly influenced by deviations to the ideal micro-geometry. With the help of the variant calculation, it is possible to consider and examine the influence of micro-geometry and position deviations in the design of the target geometry. The procedure developed within the scope of the research project for the optimization of the micro-geometry by means of a variant calculation specifying the tolerance and load range is shown in Figure 2. Using a methodological tool, an input data set is created for each variant, a calculation with the bevel gear tooth contact analysis *BECAL* is started and the results are merged and evaluated in the

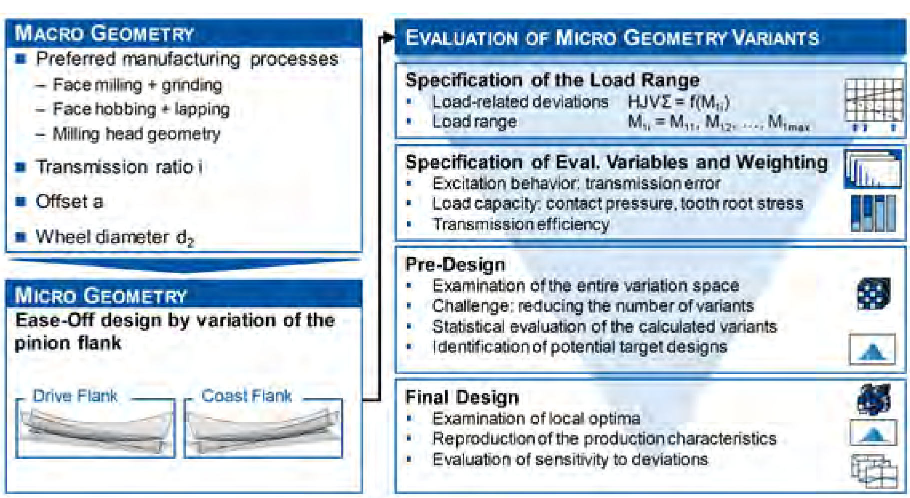

Figure 2 Method for optimizing the microgeometry by variation calculation.

This paper was presented at the 2018 Lyon International Gear Conference and his republished here with permission of the Conference and the authors.

methodological tool (Ref. 5).

In the beginning, the macrogeometry is determined based on the preferred manufacturing process, the transmission ratio, and other constructionally specified parameters. In the next step, the microgeometry of the pinion flank is varied and designed. Regarding the design of the microgeometry it is important to ensure the manufacturability and measurability for the production. Therefore, the tooth contact analysis *BECAL* is coupled with a manufacturing simulation to create the geometry data for the calculation (Refs. 5–6). Within the scope of the evaluation, the robustness of the micro-geometry design is evaluated regarding manufacturing and assembly related deviations. The quality is evaluated regarding the operational behavior. The considered tolerance parameters include flank and position deviations as well as load-dependent misalignments, which are specified by the user together with the calculated load range. In addition to the tolerance parameters, evaluation variables (e.g. loaded transmission error, flank pressure) and load-dependent weighting factors for each of these evaluation variables are specified. The excitation behavior is evaluated based on the loaded transmission error, the load-carrying capacity based on the tooth root stresses as well as the flank pressure. The gear efficiency is used to evaluate the performance of the gear set. The introduction of grading scales in combination with the weighting factors makes it possible to summarize different evaluation variables and load levels for each variant (Ref. 7). Based on the overall grades of each variant, the different variants can be evaluated and compared with each other regarding their robustness against deviations and their quality of operational behavior. A full factorial calculation with 14 varied parameters in three steps already results in 4.78 million calculations. Due to a calculation time of ≈10 sec. per variant, this procedure is particularly unsuitable in industrial practice.

Accordingly, the optimization was divided into a pre- and final-design. Simplifications are made for the first assessment of a design in the pre-design to save calculation time. In the subsequent final-design of one or more potential target designs, all topographical and positional deviations are considered.

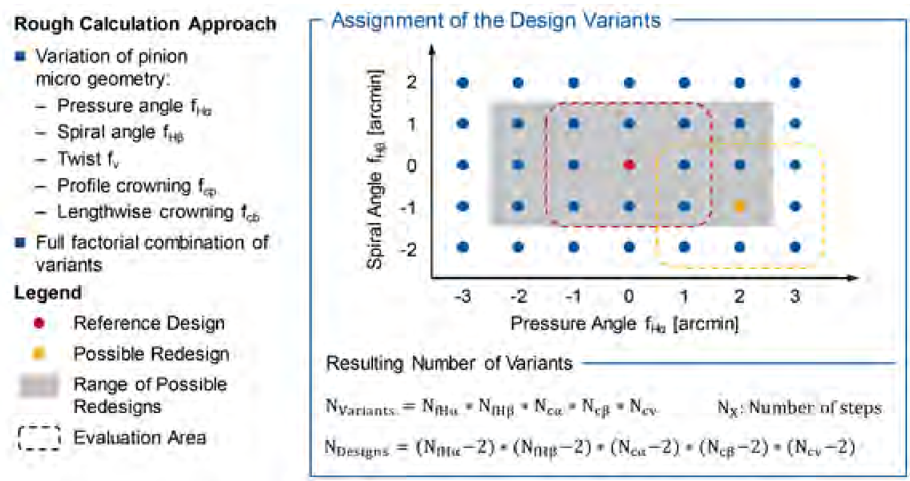

Figure 3 Assignment of the variants to target designs in the pre-design.

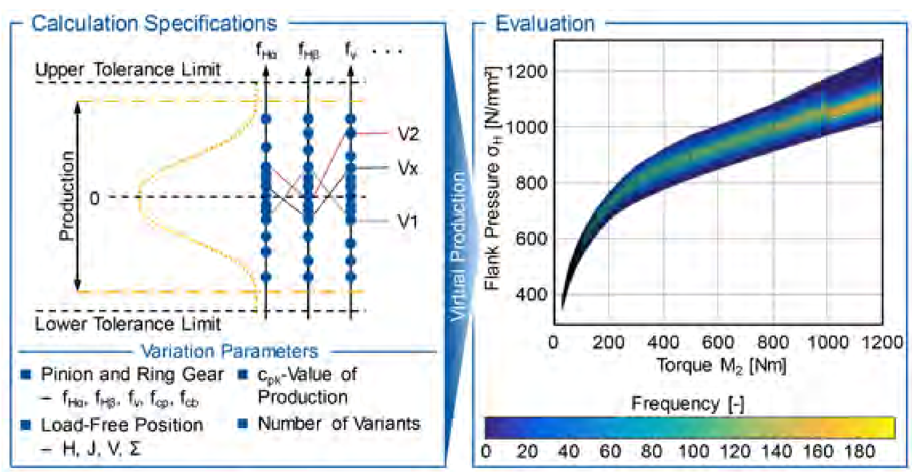

Figure 4 Calculation approach and evaluation of the final-design.

The aim of the pre-design is to identify potential target designs within a given tolerance field, considering all possible variants. For this reason, only the five micro-geometry parameters of the pinion flank shown in Figure 3 are varied to reduce the necessary calculation time. Based on the defined variation values, the microgeometry variants are generated and then calculated in *BECAL*.

The evaluation of the calculated variants is also based on the defined variation steps. For this purpose, the calculated micro-geometries are divided into target designs as it is shown in Figure 3. The maximum number of calculated variants $N_{Variants}$ results from the number of steps of each deviation parameter N_X. The number of designs $N_{Designs}$ results from the reduction by the boundary values of the variation space (N_X-2). In the next step, the variants of the specified evaluation area are assigned to the corresponding target design. This assignment of the microgeometry variants is the basis for the grading, weighting, and evaluation of the calculated variants.

In the final-design calculation, no simplifications are made to represent the influence of manufacturing-related and assembly related deviations of the gear set as precisely as possible. The five topography parameters of the pinion and gear flank are varied as well as the load-free mounting position. These 14 parameters are randomly varied according to the Monte Carlo method using a given process variation and tolerance limits. The user specifies the number of calculated variants and the process variation by the process capability index c_{pk}. For the valuation of the final-design, the algorithm provides the opportunity to evaluate the sensitivity of the calculated variants using statistical parameters. The microgeometry variants of the final-design calculation correspond to a "virtual production." so that the operational behavior of the gear set can be assessed under realistic production and assembly variations.

Application of the Method

The presented method for optimizing the microgeometry was applied to a near-series automotive gear set. The individual work steps are shown in Figure 5. The reference design corresponds to the near-series gear set. The load-related displacements are approved by measurements in the real application and considered in the calculations. In the first step, a pre-design calculation for the five load levels $M_2 = 100$, 200, 300, 400 and 500 Nm was carried out. The parameters $f_{H\beta}$, f_v, f_{cp} and f_{cb} were varied in seven steps. The parameter $f_{H\alpha}$ was constant for the calculations.

From the calculated variants, the optimal redesign regarding the excitation behavior was selected and transferred to a new microgeometry. The redesign then was examined in the final-design regarding the variance of the loaded transmission error in case of realistic manufacturing and assembly deviations. In all calculation steps, only the drive flank was examined, and the loaded transmission error was used to evaluate the variants. The reason for these limitations is the predominant use of the method for optimizing the noise and excitation behavior of bevel gears.

Pre-Design

The simulation parameters used in the pre-design calculation and the results are shown in Figure 6. The range between minimum and maximum values was divided into seven steps for the calculation. Except the profile crowning f_{cp}, the tolerance limits were assumed symmetrical around zero. All five calculated load levels were equally weighted for evaluation. Four varied parameters in seven steps each result in a total number of $N_{Variants} = 7^4 = 2{,}401$ variants and $N_{Designs} = 5^4 = 625$ redesigns. The calculation time for the calculation was ≈33 h. For each new design, the quality of the operational behavior and the robustness of the design against deviations were evaluated. The quality rating evaluates how good the operational behavior of the design is regarding the evaluated parameters. In this case, this is equivalent to the magnitude of the loaded transmission error of a variant. The stability rating evaluates how robust a design is regarding deviations on the pinion tooth flank. In the present case, this means how large the variance of the loaded transmission error is when the pinion micro-geometry is varied. A quality rating of $q = 1$ indicates the lowest or the best loaded transmission error. Whereas, a quality rating of $q = 6$ indicates the highest or worst loaded transmission error. The assignment of the rating scales to the values of the loaded transmission error considers all calculated variants. To determine the overall quality score of a variant, the quality scores of the individual load levels are summarized using the predefined weighting factors.

To determine the stability rating of the redesigns, all variants of the corresponding evaluation are considered. The variance of the evaluation parameters is rated using the standard deviation. The standard deviations of the different redesigns are converted into the stability ratings based on a given rating scale. The evaluation of the pre-design calculation and the selection of the optimal redesign are based on the representation of quality and stability ratings (Fig. 6). In the diagram on the right, the reference design is marked, which was used as input for the pre-design. An equal weighting of all load stages results in numerous redesigns, which, on the one hand, have an improved operational behavior and, on the other hand, are more robust against deviations than the reference design.

The optimal microgeometry found in the pre-design strongly depends on the selected weighting for the evaluation; Figure 7 compares the optimal variants for three different weightings with the reference design. With the same weighting of all load levels, the loaded transmission error of the optimal variant is always lower than the reference design, except for $M_2 = 500$ Nm. If only the two load levels M2 = 100 and 200 Nm are used for the evaluation the loaded transmission error is considerably lower for these two load levels compared to the reference design. However, the loaded transmission error at $M_2 = 400$ and 500 Nm is higher than the

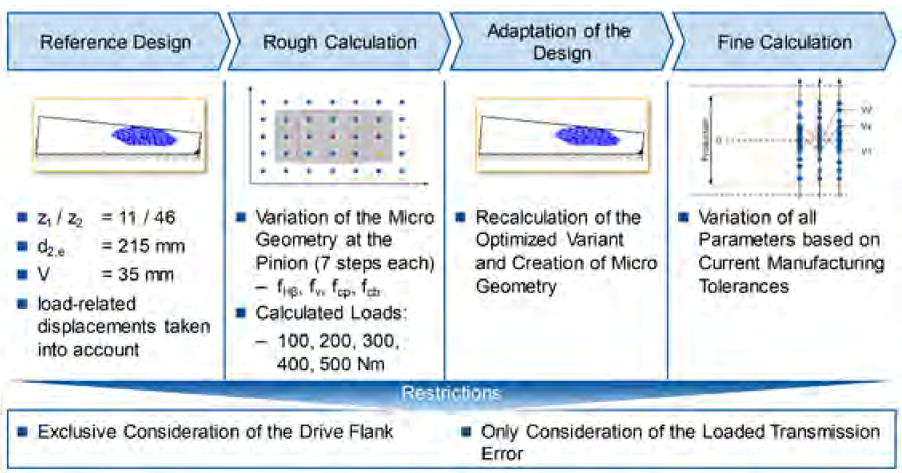

Figure 5 Calculation approach for the optimization of the reference design.

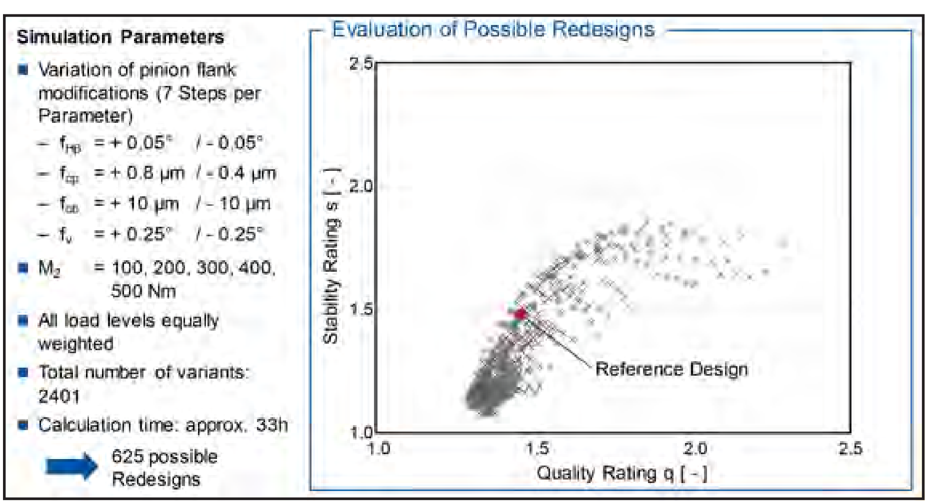

Figure 6 Evaluation of the pre-design calculation.

loaded transmission error of the reference design.

A comparable result is obtained if only the upper-three load levels are weighted in the evaluation. A load-dependent weighting of the evaluation variables to determine the overall grade of a variant is necessary in practice to meet the various design criteria. On the one hand, the designer must ensure that the gear set has a high efficiency and low noise excitation at low loads. On the other hand, the load carrying capacity of the tooth root and the tooth flank must be ensured under high loads, while efficiency and excitation behavior are of secondary importance.

The comparison of different weightings in the evaluation of the calculation results shows that it is possible to consider different load-depended design criteria in the evaluation method for the pre-design calculation. The optimization potential depends significantly on the selected weighting. Therefore the weighting of the considered load stages and evaluation variables must be tailored exactly to the final application to find an optimal microgeometry design. For the next step of the final-design, the microgeometry variant with an optimum at $M_2 = 100$ and 200 Nm was selected and converted into new geometry data for *BECAL*.

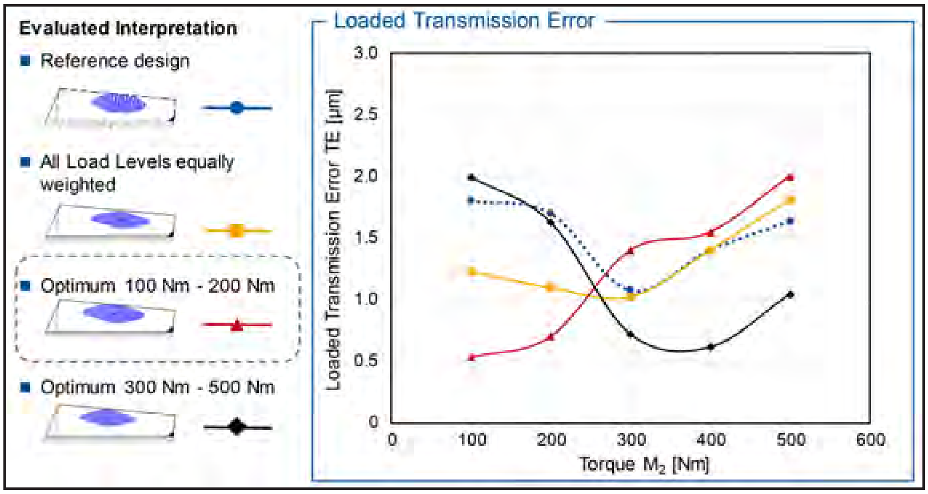

Figure 7 **Comparison of the loaded transmission error for different weightings.**

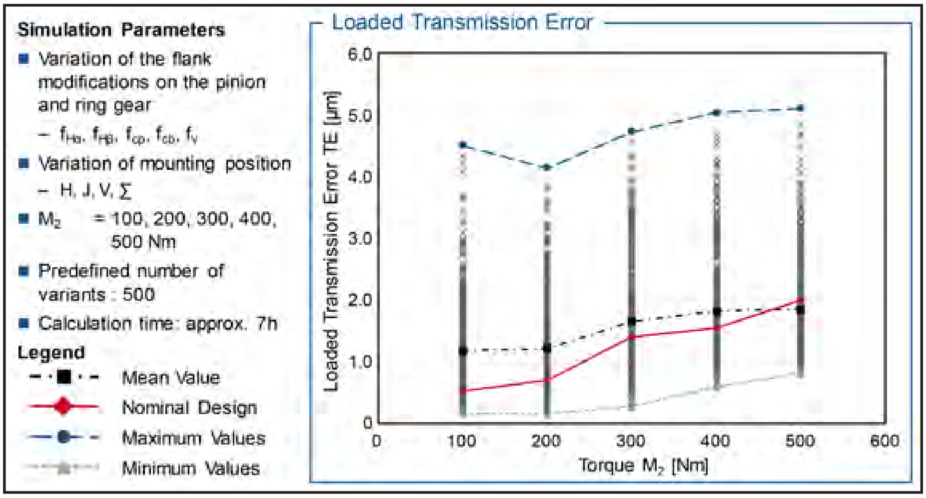

Figure 8 **Statistical evaluation of the final-design calculation.**

Final-Design.

The microgeometry variant optimized in the pre-design calculation was simulated under consideration of realistic process scattering and deviations. The process capability index was set to $c_{pk} = 1.33$. The tolerance limits for the deviation parameters were assumed production-related values. All flank deviations on the pinion and gear as well as the four deviation parameters of the mounting position were considered in the calculation. The calculation in *BECAL* was done for the loads $M_2 = 100$, 200, 300, 400 and 500 Nm as in the pre-design. 500 micro-geometry variants were generated and calculated according to the "Monte Carlo" method assuming a normal distribution (Ref. 8). The research project has shown that a range of 500 variants is sufficient for estimating the spreading of the evaluation variables in the final-design; the calculation time is 7 hours.

Figure 8 shows the calculated loaded transmission errors of all variants over the considered load stages. The maximum transmission error is up to $TE = 5\,\mu m$. The minimal occurring transmission error is $TE = 0.16\,\mu m$. Both the minimum and maximum loaded transmission error increase with the torque and show a local minimum for $M_2 = 200$ Nm. Furthermore, the transmission error of the nominal design without manufacturing and assembly deviations is highlighted in the diagram. A comparison of the nominal design with the minimum and maximum transmission errors shows that the scatter range of the occurring transmission errors is very large.

For the statistical evaluation of the calculation results, the mean value of all variants was calculated for each load level and displayed in the diagram. The mean value of all calculated variants is very close to the values of the nominal design. Most of the variants of the "virtual production" thus show the loaded transmission error defined in the design. The design must be rated as robust against deviations. However, it is also evident that there are "worst case" variants, which have very high transmission errors and lead to the wide range of loaded transmission errors. A further reduction of the resulting scatter of the loaded transmission error is possible on the one hand by selecting a new target design in the pre-design calculation and evaluating it using the final-design calculation. On the other hand, it is possible to use the final-design to identify critical deviation parameters regarding the evaluation parameters. These critical tolerance limits, as well as the process scatter, can be adjusted in a new final-design calculation to analyze and understand the influence of the deviation parameters on the scatter.

One possibility to determine critical tolerance parameters is the multi-variant data analysis (MVDA). The results of the first final-design calculation are statistically examined and the main influencing variables on the respective evaluation parameters are calculated. The corresponding procedure is shown in Figure 9. The results of the first final-design calculation already presented are analyzed with the help of MVDA. The main variables influencing the loaded transmission error are the lengthwise crowning at pinion and gear $f_{H\beta,1}$ and $f_{H\beta,2}$ and the twist at the pinion $f_{v,1}$. The influence of the other deviation parameters on the loaded transmission error is small compared to these three parameters.

Based on these results, the tolerance limits for the lengthwise crowning of the pinion and gear were reduced by 40%. Furthermore, the tolerance limits of the twist on the pinion have been reduced by 30%. The tolerance limits of the other deviation parameters and the process capability index remained unchanged. Using these values, a new final-design calculation with 500 variants was carried out and evaluated. In the lower part of Figure 9 the results of the first and second final-design calculations are compared. The adjustment of the tolerance zones leads to a significant reduction of the scatter of the loaded transmission error. At a load of $M_2 = 100$ Nm, the maximum transmission error is reduced by ≈44%. For $M_2 = 400$ Nm the decrease is ≈27%. The adjustment of the tolerance limits leads not only to a reduced scatter but also to a changed mean value of the occurring transmission errors. The mean transmission errors in the second final-design calculation decrease for all load levels. For the loads $M_2 = 100$ and 200 Nm, the difference between the new mean value and the nominal design is $\approx TE = 0.27$ µm. For the loads $M_2 = 300$ and 400 Nm, the mean values almost exactly match the values of the nominal design. For the load stage $M_2 = 500$ Nm, the mean value of the transmission error is even lower and thus better compared to the nominal design. The consideration of the tolerance limits within the "virtual production" of the final-design calculation shows that a simulative tolerance engineering is possible with the help of the developed procedure. Besides the restriction of tolerance limits to reduce the scatter of the evaluation variables, the method also offers the possibility of estimating the influence of an expansion of individual tolerance limits on the production result. This results in an additional potential to reduce production costs.

Summary and Outlook

Bevel gears have operation-dependent, complex contact conditions that pose a design challenge. Furthermore, in practice, production and assembly related deviations influence the operational behavior. A consideration of the effects of manufacturing and assembly tolerances on the variation of the characteristic values for the operational behavior within a variant calculation has not yet taken place. This deficit was considered in this presented research project IGF 18450 BG/1 and a method for the design of flank topographies robust against deviations for bevel gears was developed, considering manufacturing and assembly related deviations as well as load-related displacements.

Within the scope of this report, the method for optimizing the pinion micro-geometry is presented and applied on a near-series bevel gear set. The method is divided into two sub-calculations. The pre-design calculation makes it possible to optimize the pinion micro-geometry regarding the quality of the operational behavior and the robustness against deviations. In the second calculation step, the final-design, the micro-geometry selected in the pre-design is examined and evaluated in the environment of a "virtual production." Based on the calculation results, the expected variation of the operational behavior can be considered, and the influence of manufacturing and assembly tolerances can be analyzed.

The evaluation of the presented pre-design shows that different load-dependent weightings lead eventually to different excitation characteristics. This allows the designer to adapt the optimization to the specific requirements of the final application. The statistical evaluation of the calculation results of the final-design calculation shows that the mean value of the loaded transmission error of all variants is close to that of the nominal design. However, the scatter of the transmission error is large. A multi-variant data analysis is used to determine the tolerance parameters with the greatest influence on the loaded transmission error. The tolerance limits of the corresponding parameters are then restricted, and the detailed calculation is repeated. The adjustment of the tolerance limits leads to a significant decrease in the scatter of the transmission error and thus to a better result of the "virtual production."

The results of this report show that the developed method makes it possible to optimize the pinion micro-geometry regarding quality and stability as well as tolerance limits in the production. In this way, production costs can be reduced by widening suitable tolerance limits and by an increased material utilization.

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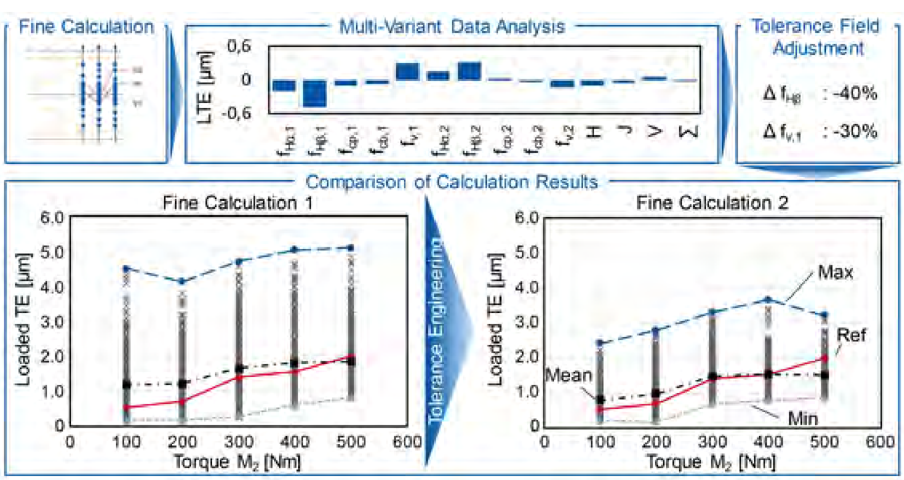

Figure 9 Tolerance engineering using the final-design calculation.

References

1. Aniol, J. and A. Dlugosch. "Optimization of Tooth Flank Geometry by Measurements and Calculations," 4–6 October 2010 Dusseldorf, VDI Verlag.
2. Klingelnberg, J. (Hrsg.). Kegelräder, Berlin: Springer, 2008.
3. Gorgels, C. Umfeldgerechte Kegelradauslegung, Tagungsband zum Seminar Innovationen rund ums Kegelrad. Aachen, 14.-15. März 2012.
4. Radev, T. Geräuschoptimierung von Kegelradgetrieben in der Praxis, Tagungsband zum Seminar Innovationen rund ums Kegelrad, Aachen, 14.-15, März 2008.
5. Schlecht, B., et al. Benutzeranleitung zum FVA-Programm *BECAL* 3.0., TU Dresden, 2002.
6. Thomas, J. "Closed Loop in Production of Bevel Gears," VDI (Hg.): *International Conference on Gears*, Garching 13–15, March 2008, Düsseldorf, VDI Verlag.
7. Brecher, C, C. Löpenhaus and J. Brimmers. "Function-Oriented Tolerancing of Tooth Flank Modifications of Beveloid Gears," *Proc. CIRP* 43, May 2016.
8. Lemieux, C. *Monte Carlo and Quasi-Monte Carlo Sampling*, New York, Springer, 2009

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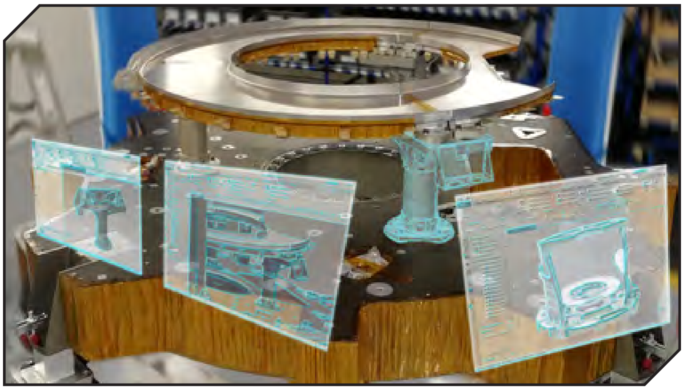
Prof. Dr.-Ing. Christian Brecher has since January 2004 been Ordinary Professor for Machine Tools at the Laboratory for Machine Tools and Production Engineering (WZL) of the RWTH Aachen, as well as Director of the Department for Production Machines at the Fraunhofer Institute for Production Technology IPT. Upon finishing his academic studies in mechanical engineering, Brecher started his professional career first as a research assistant and later as team leader in the department for machine investigation and evaluation at the WZL. From 1999 to April 2001, he was responsible for the department of machine tools in his capacity as a Senior Engineer. After a short spell as a consultant in the aviation industry, Professor Brecher was appointed in August 2001 as the Director for Development at the DS Technologie Werkzeugmaschinenbau GmbH, Mönchengladbach, where he was responsible for construction and development until December 2003. Brecher has received numerous honors and awards, including the Springorum Commemorative Coin; the Borchers Medal of the RWTH Aachen; the Scholarship Award of the Association of German Tool Manufacturers (Verein Deutscher Werkzeugmaschinenfabriken VDW); and the Otto Kienzle Memorial Coin of the Scientific Society for Production Technology (Wissenschaftliche Gesellschaft für Produktionstechnik WGP).

Siemens Digital Industries Software and Sonaca

TAPPED TO DESIGN ADDITIVE MANUFACTURING APPLICATIONS FOR THE EUROPEAN SPACE AGENCY

The European Space Agency (ESA) has selected Siemens Digital Industries Software to develop aerospace design applications for metal additive manufacturing. The applications will leverage Siemens' end-to-end software solution for industrial additive manufacturing that combines generative engineering, topology optimization, predictive analytics, process simulation, build preparation and production execution. The two-year long project, named Design4AM, is built on a strong collaboration between Siemens and Sonaca, a specialist in aerospace structures, with financial support from ESA and the Belgian Federal Science Policy Office (Belspo). The Design4AM project will result in a validated process for using Siemens' comprehensive additive manufacturing software to design and produce highly optimized, light-weighted structural parts for space applications, such as, among others, fittings (structurally bonded to CFRP panel), supports, and bipods for improved performance and cost.

"The Siemens and Sonaca partnership combines the power of a leading additive manufacturing software solution with the expertise from a leading aerospace manufacturer," said Pedro Romero Fernandez, Sonaca General Manager Space BU. "With our deep aerospace knowledge and Siemens' software technologies such as generative design, automated topology optimization and additive manufacturing process simulation, engineers will be able to explore hundreds of design options in a fraction of the normal time, then virtually test them against a variety of physical conditions to arrive at the best design solution for their performance requirements that 3D print correctly the first time."



Additive manufacturing (AM) is an important tool for the space industry because it can meet structural and multi-disciplinary requirements for space applications at a much lower weight than conventional space structures made through traditional manufacturing methods. Weight is a particularly critical concern for space applications; according to industry reports, one pound of payload equates to $10,000 in launch costs. Additive manufacturing techniques can be used to lightweight nearly any kind of complex structure in launchers, propulsion, satellites and various spacecraft components.

Design4AM will leverage the Siemens Digital Innovation Platform with the support of Sonaca's experience in space applications, manufacturing features, material and process, testing and numerical methods for the validation of the chain. Siemens' NX™ software and Simcenter™ software enable engineers to explore a wide range of design concepts in an automated closed-loop process that takes into consideration engineering performance, manufacturing process and operation cost requirements. These tools can account for manufacturing constraints such as thermo-mechanical part distortion, the structural part orientation in the building chamber or the design of supporting structures. The integrated software environment can shorten the part conceptual design and optimization process, helping enable higher performance structures to be manufactured.

"Additive manufacturing can help ESA reshape everything for optimal performance at reduced cost, in comparison to traditional manufacturing methods that require multiple steps, tools, and treatments to achieve the desired outcome," said Didier Granville, RTD projects Manager for Siemens in Liège. "Working with Sonaca, we will be able to help ESA take advantage of additive manufacturing to deliver high-performance structures capable of withstanding the extreme forces that occur during space satellite launches." (*www.siemens.com/plm*)

Bourn & Koch

INCLUDED IN NEW HOLDING COMPANY CALLED PRECISION CUTTING TECHNOLOGIES

Bourn & Koch, an American manufacturer of new precision machine tools, has announced that its parent company, Alleghany Capital Corporation, has acquired Coastal Industrial Distributors LLC, (doing business as CID Performance Tooling); and has formed a new holding company for its subsidiaries in the machine tool and consumable cutting tool sectors. Headquartered in Saco, Maine, CID Performance Tooling ("CID") is a leading manufacturer of high-performance solid carbide end mills. The new holding company formed by Allegany Capital, called "Precision Cutting Technologies" will include Bourn & Koch, Inc. ("Bourn & Koch"), Diamond Technology Innovations, Inc. ("DTI"), and CID.

David Van Geyzel, president and chief executive officer of Alleghany Capital, commented, "This transaction furthers Alleghany Capital's growth strategy in the machine tool and consumable tooling industries. While the formation of Precision Cutting Technologies will not change the management of Bourn & Koch, DTI, and CID, it places these companies under a single platform so that they can share resources and leverage their combined capabilities to provide an enhanced product and service offering to their customers. Alleghany Capital is pleased to welcome CID to the Precision Cutting Technologies group of companies and looks forward to supporting Bourn & Koch, DTI, and CID as they continue to serve their markets."

Terry Derrico, president of Precision Cutting Technologies and Bourn & Koch, added, "We are excited to partner with Jay Lowery, founder and president of CID, as well as his experienced team, and believe that the employees, customers, and suppliers of all the companies within the Precision Cutting Technologies platform will benefit from this acquisition. CID enhances Precision Cutting Technologies' portfolio of consumable cutting tools, while expanding our business in the aerospace, defense, and medical end-markets. With Jay continuing to lead the company post-transaction, CID's day-to-day operations will not be impacted. However, we believe CID will be well positioned to accelerate growth and augment its geographic reach by leveraging the experience, capabilities, and support of Bourn & Koch, DTI, and Alleghany Capital."

"Over the past thirty years, CID has become a leader in producing the highest quality custom tooling solutions for customers serving the most demanding end-markets," stated Lowery. "As we build on our proven track record of quality, innovation, and service, we are pleased to have found a long-term home for the company and are excited about the opportunities that will result from this transaction." (*www.precision-cutting.com*)

Ipsen

EXPANDS SALES ENGINEERING PRESENCE

Ipsen USA recently embarked on an initiative to double the number of Regional Sales Engineers (RSEs) by year-end. Ipsen's RSEs engage customers with the objective of improving furnace performance and increasing service life.

"The North American market has proven the need for a strong and technically diverse field support team," said Ipsen President and CEO **Patrick McKenna**. "We believe that quality product designs are born from investment in supporting customers."

Recent hires include Midwest RSE **Joyce Paliganoff,** Southeast RSE Patrick Heiser and West/Northwest RSE **Larry Gomez**.

"We know the importance of helping our customers with aftermarket products and services on Ipsen and non-Ipsen equipment," said Ipsen Vice President of Sales Pete Kerbel.

The expanding group of RSEs will continue to include individuals with diverse skills and backgrounds, many with experience in engineering, machine repair and metallurgical processes. They perform furnace inspections, develop system health reports, and offer solutions through their expertise in parts, service, retrofits, and repairs. (*www.ipsenusa.com*)

SMT

ANNOUNCES GLOBAL USER FORUMS

This October, SMT is inviting all existing and potential new users to its 2019 Global User Forums. These events are a perfect opportunity to learn about new and emerging technologies of the company and industry trends as well as getting up-to-speed on the latest developments with our computer-aided engineering software, MASTA. Current MASTA users as well as SMT engineers and developers will be imparting their technical knowledge and experiences, providing users a great prospect to enhance their understanding of SMT's products. In addition, our User Forums provide a fantastic platform to network with other delegates.

Extending our global reach, this year's User Forums take place in:

- Sterling Heights, Michigan, USA (October 10)
- Hangzhou, China (October 17–18)
- Munich, Germany (October 23)

The User Forums are free to attend and they are a terrific opportunity to exchange knowledge and interaction for engineering directors, executives, analysts and engineers across various driveline development industries.

Rob Forrest, customer support manager, states, "Now an established feature on SMT's events calendar, I'm excited that we are now able to announce further details of our three 2019 regional User Forums. With previous events having attracted large attendances and following great feedback from delegates, we are, once again, planning a number of informative and stimulating technical presentations along with the opportunity to meet with SMT colleagues and network with other delegates." (*www.smartmt.com*)

Varvel

REWARDS TOP STUDENT IN RACING MOTORCYCLE ENGINEERING COURSE

Commitment, competence and excellent performance are some of the key characteristics of the Varvel Group, the Bologna-based company that has been designing, manufacturing and supplying industrial gearboxes since 1955. The socially responsible Varvel Group has always invested in young people. For a number of years now, the group has also supported projects promoting collaboration between centers of scientific learning and the manufacturing sector. As part of this commitment, this year again, Varvel is rewarding the best performing student in the masters degree course in Racing Motorcycle Engineering organized by the Bologna-based Professional Datagest higher education organization.

This partnership dates back to 2012, when Varvel helped finance two students from towns in Emilia affected by the earthquake of that year. This year, Varvel has made a tangible contribution to the seventh edition of the course, rewarding Marco Radaelli, the student who has demonstrated the greatest talent and passion, commitment and determination. Marco has excelled over intense months of theory and practice sessions, exams and tests to finish in pole position ahead of his colleagues in the masters course.

"Life is a challenge, and the real race is yet to begin," commented Mauro Cominoli, the Varvel Group's general manager, "but Marco has certainly shown a determination to be first across the finishing line and we are delighted to help him continue his race. We see it as our duty to support tomorrow's professionals and help them achieve their ambitions. Passion is the driving force behind the creation of a prosperous future. Education and training are essential if we are to produce new talents and develop qualified human resources with the potential to succeed. Young people are our most important asset in building a better future. They need our support and encouragement if we are to develop motivated human resources able to achieve growth for our company and for the whole system."

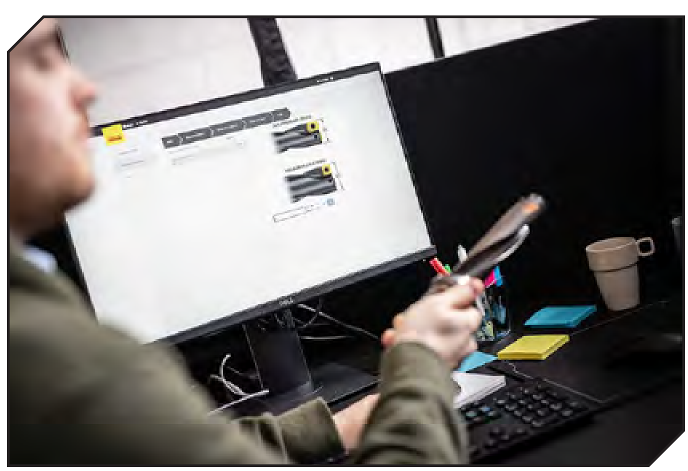
The masters course is delivered by experts from "Motor Valley," an area so called for its high concentration of excellent mechanical engineering companies. It is aimed at graduates and undergraduates in mechanical, electronic and aerospace engineering interested in acquiring the specialist technical competences needed to design and construct racing motorcycles. The course covers dynamics, electronics, track-side data analysis and racing team management and offers over 300 hours of lessons by experts from motor racing teams and constructors plus in-company and track-side practical training sessions. (*www.varvel.com*)

Sandvik Coromant

OFFERS ONLINE SERVICE FOR CUSTOMIZED TOOLING

Sandvik Coromant introduces thousands of new tools, holders, and inserts every year. Yet, sometimes that exact dimension you require might be missing. If so, the company offers services for customized tools. Customers can expect quick quotations, easy ordering, performance guarantee for product and cutting data as well as competitive delivery times. You need to be registered on the Sandvik Coromant website to use this online service.

All major product groups within metalworking, e.g. turning, milling, and hole making, are available for customization, giving users the freedom to specify their own dimensions without having to pay the price of a special tool. The result is tailor-made tooling, designed for specific component manufacturing needs. (*www.sandvik.coromant.com*)



September 9–13—AGMA Basic Training for Gear Manufacturing (Fall) Hilton Oak Lawn, Illinois. Learn the fundamentals of gear manufacturing in this hands-on course. Gain an understanding of gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. Utilizing manual machines, develop a deeper breadth of perspective and understanding of the process and physics of making a gear as well as the ability to apply this knowledge in working with CNC equipment commonly in use. This course is taught at Daley College. A shuttle bus is available each day to transport students to and from the hotel. Although the Basic Course is designed primarily for newer employees with at least six months' experience in setup or machine operation, it has proved beneficial to quality control managers, sales representatives, management, and executives. Course instructors are Dwight Smith, Allen Bird and Peter Grossi. For more information, visit *www.agma.org*.

September 11–12—Digital Industry USA 2019 Louisville, Kentucky. Digital Industry USA 2019 has partnered with leading industry associations to provide educational content for conference sessions and expert panels during the inaugural event. Leading industry association partners include, CSIA (Control System Integrators Association), ISA (International Society of Automation) and MESA (Manufacturing Enterprise Solutions Association) International. During the trade show's on-floor conference program, industry visionaries will showcase field experiences and case studies that feature real IIoT (Industrial Internet of Things) integration across their organizations. For more information, visit *digitalindustry.com*.

September 16–21—EMO Hannover 2019 Hanover, Germany. A new exhibition area IoT in production underscores its claim to position itself as a platform for networking in production. Dr. Wilfried Schäfer, managing director of EMO organizer VDW (German Machine Tool Builders' Association), explains: "IoT in production pro-vides a complete overview of the central aspects of networking, including data security, data analysis, process monitoring, predictive maintenance, smart data management and much more." Robotics and automation are among the key technologies for ensuring lasting international success. Cobots interact directly with humans and give manufacturing companies a competitive edge in the market. At EMO Hannover 2019, trade visitors will find countless automation solutions and collaborative robots aimed at enhancing productivity. Automation and digitalization can be used to make manufacturing processes more efficient. For more information, visit *www.emo-hannover.de*

September 17–19—AGMA Fundamentals of Gear Design and Analysis Hilton Oak Lawn, Illinois. Gain a solid and fundamental understanding of gear geometry, types and arrangements, and design principles. Starting with the basic definitions of gears, conjugate motion, and the Laws of Gearing, learn the tools needed to understand the inter-relation and coordinated motion operating within gear pairs and multi-gear trains. Basic gear system design process and gear measurement and inspection techniques will also be explained. In addition, the fundamentals of understanding the step-wise process of working through the iterative design process required to generate a gear pair will be reviewed. Learn the steps and issues involved in design refinement and some manufacturing considerations. An explanation of basic gear measurement techniques, how measurement equipment and test machines implement these techniques, and how to interpret the results from these basic measurements will also be covered. The instructor is William "Mark" McVea. For more information, visit *www.agma.org*.

September 17–19—CTI Symposium China Shanghai, China. The next International CTI Symposium "Automotive Drivetrains, Intelligent & Electrified" will gather in China for the sixth time to exchange ideas on transmission technology developments. With lectures, presentations, keynote speeches and the satellite exhibition "Transmission Expo," the event will provide a powerful framework for high-ranking Chinese and international automobile and transmission manufacturers and suppliers. The focus will rest on strategies, new components and development tools for conventional and alternative drives. China is now by far the world's largest market for plug-in hybrid and electric vehicles. Supported by state programs and directives, NEVs (New Energy Vehicles) aim to cut emissions in urban conglomerations and make the land less dependent on oil imports. By 2020, the plan is to get more than five million electric automobiles on Chinese roads. For more information, visit *drivetrain-symposium.world/cn/registration/*.

October 7–10—Gear Dynamics and Gear Noise Short Course Ohio State University, Columbus, Ohio. 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 37 years more than 1,950 engineers and technicians from over 360 companies have attended the Gear Noise Short Course. A popular feature of this course is the interspersing of demonstrations with lectures. The extensive measurement and computer software capabilities of the Gear and Power Transmission Research Laboratory allow instructors to do this in a simple and non-commercial manner. The Case History Workshop (Day 3) allows course instructors and participants to interact and to discuss gear noise and dynamics case histories presented by course attendees. Throughout the course, laboratory and computer software demonstrations are used to illustrate gear noise measurement and analysis techniques. The facilities of the Gear and Power Transmission Research Laboratory and the Acoustics and Dynamics Laboratory are used for these demonstrations. For more information, visit *www.nvhgear.org*.

October 15–17—Motion+Power Technology Expo Cobo Hall, Detroit, Michigan. The Motion+Power Technology Expo (formerly Gear Expo) connects the top manufacturers, suppliers, buyers, and experts in the mechanical, electrical, and fluid power industries. Over three action-packed days in Detroit, end-users can shop the latest technology, products and services, and compare benefits side-by-side. Prominent exhibitors will conduct demos and host information-rich seminars as well as offer-up technical expertise. The education courses at the Motion+Power Technology Expo offer exclusive access to a wide-ranging series of technical seminars taught by industry leaders and insiders. From novice to expert, there are courses for all career-levels. Each course is conveniently situated just steps from the Expo floor—so you can combine classroom learning with hands-on experience with the equipment. Admission to the exhibit hall is included with your seminar registration. For more information, visit *www.motion-powerexpo.com*.

Repairing a Stone Gear

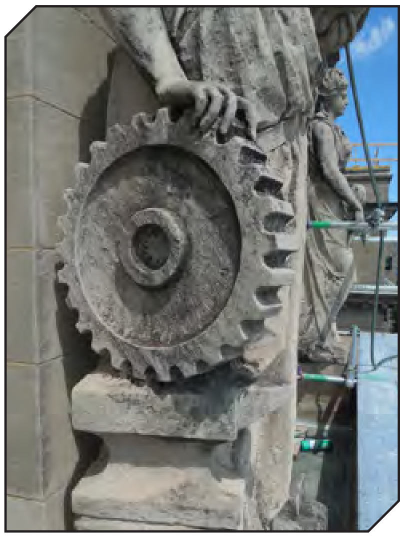
Joseph L. Hazelton, Contributing Editor

How do you fix a stone gear that has a chipped tooth and has surfaces roughened by acid erosion and covered in black grime?

You bring in an art conservator.

That was the decision made by Iowa State University, Ames when it was renovating Marston Hall. Originally the engineering building, the hall is more than 100 years old and is decorated with statues that include a stone spur gear.

The gear is part of a statue that's 8 feet tall. The statue is of a woman with her right hand on the gear. It's one of four statues that adorn the outside of Marston Hall. The other three are also of women. Called the Marston Muses, all four were made in the Greco-Roman style, with each woman wearing a toga.



Part of a statue, this stone gear was damaged by acid erosion, creating a more porous surface on which black grime accumulated.

Each statue represents a field of engineering. One statue is holding surveying equipment; it represents civil engineering. The statue with the spur gear represents mechanical engineering.

Being outdoors, the statues were exposed to wear and tear from weather. However, the wear and tear included damage that had been done in the past, damage likely done by a local, coal-fired power plant. The damage was acid erosion and black carbon deposits on the statues, including the gear.

The damage came from the chemical interaction between the statues' limestone and sulfur dioxide in the air. The limestone, the sulfur dioxide, and their interaction are described by Francis Miller, founder and directing conservator of Conserve ART LLC, Hamden, CT.

Miller and his assistants were brought in to repair the statues.

Each statue was carved from a block of limestone. The limestone consists of calcite shell fragments cemented by fine calcium particles. However, the fragments and particles are susceptible to acid erosion, like from sulfuric acid.

Present in the air, the sulfur dioxide mixed with moisture and created a mild sulfuric acid. Then, acid and limestone interacted, starting with the acid dissolving an amount of the limestone and ending with the creation of calcium sulfate: gypsum. However, gypsum deposits are relatively porous, so they can accumulate airborne particles, like pollutants. The result on the statues: "Black scales," Miller says.

With their surfaces roughened, the statues also accumulated organic growths: small plants.

To restore the statues, Miller and his team loosened the grime with a mist spray, then removed it with a light power washing. Next, they applied an ammonia solution to kill the organic growths and rinsed it off with water, then applied a special gel to dissolve the gypsum, then another gel to dissolve the organic growths that were deeper in the limestone.

However, the second gel included sodium hydroxide: lye. To dissolve the growths without damaging the stone, Miller and his team followed the second gel with a mildly acidic solution. Gel and solution neutralized each other.

With the cleaning done, Miller and his team strengthened the limestone by applying a pre-consolidant and a consolidant. The consolidant seeped into the limestone's pores and created silica gel bonds between its particles.

The two applications didn't change the limestone's appearance, and they help protect the stone from future erosion and pollutants. Also, the silica gels didn't completely seal the limestone. They allow water and water vapor to migrate and evaporate from the stone. "The last thing we want to do is seal the sculpture and then possibly have freeze-thaw damage from any trapped moisture," Miller says.

Like the rest of its statue, the gear was restored by art conservator Francis Miller. Free of grime, the gear can be better appreciated as a sculpture. "It's just beautifully carved" Miller says.

After the gels cured, Miller repaired the statues' cracks and chips, like the chip in the gear tooth. The cracks were repaired with grout.

The chips were repaired with a material that matched the limestone's color, porosity, and strength. However, the new material's bond with the original limestone is weaker than the limestone's bond with itself. So, if the material fails, it would fall off without taking any original limestone with it. That way, the material won't create new damage in the statues.

When the work was done, the statues looked pristine. Miller says the mechanical engineering statue is "dynamically designed" and its gear is very eye-catching: "That design element is very prominent."

Photos by Francis Miller, Conserve ART LLC. Marston Muses, 1903, Proudfoot and Bird Architects, Limestone. Commissioned by Iowa State College. In the Art on Campus Collection, University Museums, Iowa State University, Ames, Iowa. Location: Iowa State University, Marston Hall. U2011.472a-d.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