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GEAR INSPECTION

- Dedicated vs. CMM
- All-in-One Machines

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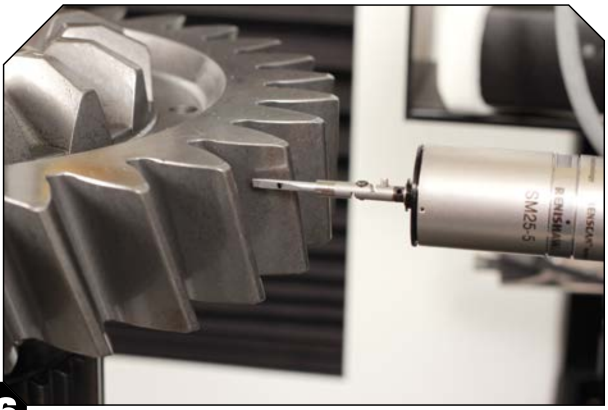

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Vol. 34, No. 5

departments

Cover photo by David Ropinski

THE GEAR INDUSTRY'S INFORMATION SOURCE

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Wenzel Gear Technology

Wenzel offers several solutions for gear manufacturers. WGT, LH Gear, LHF Gear, LH Hybrid are just some of the options available. Check out this video on the GT homepage for additional information (*www.geartechnology.com/videos/Wenzel-Gear-Technology-/*)

Kapp KX 260 Dynamic

A primary advantage of the KX machine concept is the complete integration of automation functionalities. By using the pick-up design, parts are loaded and unloaded from a conveyor without any additional handling of equipment. Moreover, additional functions such as discharging test parts are possible.

(*www.geartechnology.com/videos/Kapp-KX-260-Dynamic-/*)

Event Spotlight: 7th WZL Gear Conference

WZL will give a selection of the most interesting presentations from its research portfolio. The presentation topics will include gear design, manufacturing and testing. (*www.geartechnology.com/news/8182/7th_WZL_Gear_Conference/*)

Gear Talk:

Our resident blogger Chuck Schultz discusses a variety of gear manufacturing topics including leadership roles, infrastructure investments, unwritten rules and the aches and pains of relocation. Read these and other entries at

www.geartechnology.com/blog/

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Go Here. Do This.

Publisher & Editor-in-Chief
Michael Goldstein

Thank you to all of you who have called or e-mailed to congratulate me for receiving the AGMA Distinguished Service Award at the association's annual meeting in March. Your kind words and personal sentiments reaffirm that what we do here at *Gear Technology* matters. Over the years, and especially after receiving this award, I've heard from a lot of people who have told me how important this publication has been to them and their careers.

One of those people was Jim Bregi Jr., newly elected chairman of AGMA's board of directors, who told me he has been reading *Gear Technology* since he was 15 years old. He also stressed how important the publication has been to the industry. Many others have told me they've saved every issue since the very first one, because they represent such a valuable collection of knowledge.

Many of you have told me how you relied on our "Basics" articles as a significant part of your gear industry education. Over the years we've described in detail the various gear manufacturing processes, such as hobbing, shaping, shaving, honing, straight bevel & spiral bevel gearing and the geometry of the hob itself. From 1984 through 1995, we ran those articles in our "Back to Basics" and "Gear Fundamentals" columns. In fact, I've had more than a few requests that we re-run some of those articles, very often from an experienced engineering manager or VP of engineering who wants to pass that knowledge along to the next generation.

The good news is that we don't have to re-run any of them. One of the things I'm most proud of is that we've digitized all of that knowledge, and not just the basics — more than 2,300 articles in total — and we've made them available on our website under the heading "GT LIBRARY." Subscribers and non-subscribers alike can use the library, and you can search it by keyword or subject. This feature alone attracts nearly 11,000 unique visits every month to our website.

But in order to keep providing this free service to the industry, we need your help. We need you to renew your free subscription.

It seems silly, I know, but it really does help. Because you request the magazine, the post office gives us lower postage rates. Your request also gives our advertisers confidence that the magazine is being read by people who are genuinely interested in the subjects we cover.

Just like you, I get requests all the time from various publishers asking me to renew my subscriptions. I get them as cards attached to the magazines, I get them via e-mail, and I get them by telephone. We're all inundated by junk mail, spam and telemarketing. So I get it. The easiest path is often to ignore those requests.

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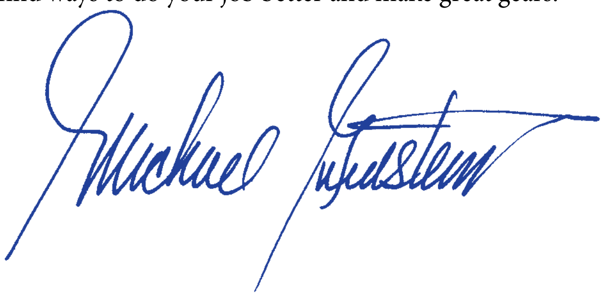
www.geartechnology.com/subscribe.htm

If you're already in the system, it can take as little as 30 seconds. And once you renew, we'll leave you alone for at least a year.

Instead of spending our money to have telemarketers call you or send you postcards, we'd rather invest in things that make a difference to you. We'd rather continue providing you with more and better services. With your help, we promise to continue to invest in more and better resources to help you do your job as accurately and efficiently as possible.

Over the next couple of issues, you'll be reading about some unique offerings that we will be providing at Gear Expo in October, including Ask the Expert Live and some more surprises yet to come. We invite you to stop by our booth to say hello and offer any suggestions you might have about how we can do a better job helping you. Or, if you're not coming to Gear Expo, just drop me a note at michael@geartechnology.com.

I and the whole *Gear Technology* staff are here solely to help you find ways to do your job better and make great gears.



Mahr Inc.

EXPANDS WIRELESS GAGING PRODUCTS

Mahr Inc. has expanded its line of wireless gaging products to include a range of depth gaging products. Digital Depth Gage MarCal 30 EWR, MarCal Specialty Caliper 16 EWR and Universal Caliper 16 EWR all provide wireless data transmission of depth probe measurements.

"Taking measurements on the shop floor and transmitting them wirelessly speeds up the quality assurance process," said George Schuetz, director precision gages for Mahr Inc. "It also adds flexibility and a measure of safety by eliminating troublesome cables. This speeds setup and provides more efficient data processing, especially for quality control in production or incoming goods inspection."

Mahr's Digital Depth Gage Series, MarCal 16 EWR includes several gages designed for a variety of depth gaging tasks, including measuring groove widths and distance between grooves. All MarCal depth gage and caliper products offer IP67 resistance to dust, coolants and lubricants, and are easy to use with high contrast digital display, locking screw, zero reset function, and immediate measurement readout. Built to provide decades of quality service, the units include steel measuring surfaces, hardened steel slide and beam construction, raised and lapped guideways for the protection of the scale, and even include dirt wipers integrated in the slide.

Mahr's MarCal 16 EWR Digital Caliper line includes a universal model and several specialty caliper models. All offer precise depth measurement via an integrated depth rod with measuring ranges of 0 - 6 or 8 in. (0 - 150 or 200 mm) and resolution to 0.0005 in. (0.01 mm). Specialty calipers include jaws for measuring distance between bores and grooves, and stepped workpieces.

Integrated wireless data transmission simplifies the recording and documenting process, especially in the networked factory of Industry 4.0. With the touch of a button on the instrument, or keyboard, a timer, remote control, or foot switch, acquired data is sent from the gage to an i-stick radio receiver plugged into the USB port of the computer.

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

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

Erwin Junker

OFFERS SIMULTANEOUS GRINDING OF ID, OD AND FACES OF GEARS

Junker has introduced the JUMAT 6S 18-20S-18, the latest of Junker's JUMAT series of modular grinding machines, which is capable of grinding the ID, OD and faces of a gear simultaneously. Junker's newest technology features up to four cross-axis systems in one machine, and each grinding spindle operates on its own separate X- and Z-axis, which allows up to four grinding wheels to operate at once.

Another primary feature of the JUMAT 6S 18-20S-18 is its center clamping workholding, composed of a hydrostatic mount and precision chucks, which negates the need to adjust parts to grind other surfaces. Parts are also automatically loaded by the machine's internal loading system, reducing errors in the grinding process.

The obvious benefit of Junker's newest machine is the shortened grinding time by fully grinding a workpiece in a single operation. With up to four wheels operating simultaneously and unobtrusive workholding, the 6S 18-20S-18 can fully grind gears in one operation, cutting down on both setup and grinding time in the shop. Grinding time itself can be reduced down to 45–55 seconds depending on the user's requirements and the size of the gear. This makes Junker's machine ideal for high volume gear manufacturing operations.

As an additional benefit, the 6S 18-20S-18 takes up less floor space due to the reduced amount of equipment needed to grind parts. According to Junker's President and CEO, Horst Zemp, the JUMAT 6S 18-20S-18 can be utilized for numerous different applications, but ring gears are the most common. In addition, the machine is modular and Junker can accept customer-specific requests with a lead time of roughly 12 months.

For more information:
Erwin Junker
Phone: (847) 488-0406
www.junker-group.com

Schunk

INTELLIGENT GRIPPERS MEASURE, IDENTIFY AND MONITOR COMPONENTS

Schunk uses the exposed position of its grippers in the handling process to develop intelligent modules that can do much more than conventional pick and place. Intelligent grippers such as the Schunk EGL Profinet measure, identify and monitor gripped components and the ongoing production process in real-time. The information recorded by the gripper is passed on to the machine control system and can be simultaneously transferred to higher-level internal and external systems as well as cloud solutions for statistical process analyses.

Schunk's aim is to create a more flexible process chain while at the same time providing detailed process data. In other words, the gripper itself detects a faulty component without additional external sensors and decides whether the part should be ejected from the process. If a component is gripped before and after a process step and there is an accumulation of NOK parts, a digital service uses the knowledge of the gripper to automatically analyze whether the fault was already present or whether process changes in the upstream station might have caused the damage to the component.

Schunk illustrates how this can be accomplished using the example of a high-speed de-paneling system from its subsidiary Schunk Electronic Solutions. The system separates small electronic circuit boards from a carrier plate called a panel. After they are separated, the "free" circuit boards are gripped and placed in their destination (e.g. a load carrier) by means of an axis system. Before the components are placed, they are usually measured and checked for quality. For this handling step, Schunk now uses an intelligent gripper, which has built-in sensors/functions for measuring and inspecting the quality of components during the gripping process. The measured data and information derived from it are passed on to the plant cell control system for further process control. The gripper sends the data not only to the cell control system, but also to an analysis tool on the HANA SAP Cloud. The tool continuously collects all data relevant for process optimization.

With a variable stroke and a variable gripping force between 50 N and 600 N, the EGL Profinet parallel gripper covers an extremely wide range of components. In a smart gripping process, the intelligent gripper uses its exposed position directly on the part. Using built-in sensors, it captures the data of the component as well as its size and elasticity. This data is processed in the gripper, making it possible to identify components, detect damage, and decide whether the component is good or bad. After processing, both the recorded information (e.g. good or bad component) as well as the measured data can be transferred via the Profinet interface to the plant control system for process control.This data may in turn be located on the company's own server or in an external location.

For more information:
Schunk
Phone: (919) 767-2013
us.schunk.com

Skiving Machining Center for Gears - GMS450

NACHI

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Turning

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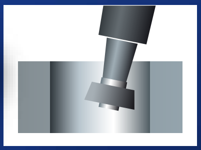
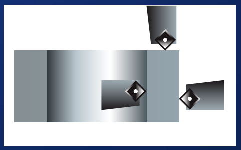
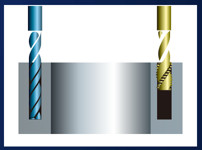


Lathe



Drilling



- High Efficiency Gear Skiving Reduces Work Time up to 1/5 (compared to gear shaping)
- Proprietary Technologies Used
- High Precision Machining of Hardened Gears
- Easy to Control Tooth Profile
- Compact, yet can Machine up to 450mm Diameter Part

Nachi America Inc.

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Nanol Technologies

LUBRICANT ADDITIVE PREVENTS HYDROGEN EMBRITTLEMENT

The Fraunhofer independent research institute has demonstrated that Nanol's lubricant additive has some completely new performance features. The patented lubrication additive, based on nano technology, was originally developed for fuel saving and wear protection in marine engines and industrial applications.

The latest testing now shows that the additive has additional positive properties as well, as it can prevent hydrogen embrittlement. Hydrogen embrittlement is the process by which metals such as steel become brittle and fracture when in contact with hydrogen.

The testing that demonstrated the new effect of Nanol's additive was conducted by a leading manufacturer of ball bearings. Further testing was also carried out at Fraunhofer Institute by Matthias Scherge.

"The latest research has added new features to the scientific picture of Nanol. Nanol must be considered a package with multi-functional properties including viscosity index improvement, friction modification, anti-wear properties as well as protection against hydrogen embrittlement," states Scherge, who has previously conducted several other laboratory tests on Nanol's additive.

Hydrogen embrittlement is a serious issue in several applications, and the newly demonstrated property opens completely new areas of use for Nanol's additive. So far, the additive has mainly been used by shipping companies in marine engines and power plants.

"We are now starting to penetrate new customer segments. Hydrogen embrittlement is a severe problem in for example wind power turbines. By using Nanol, the lifetime of components can be extended and service intervals prolonged," says Johan von Knorring, founder and CEO of Nanol Technologies.

Several other technologies are available to deal with the hydrogen embrittlement problem, including various coatings. According to von Knorring, Nanol's solution is both more reliable and effective in comparison.

For more information:
Nanol Technologies
Phone: +358 40 732 0900
www.nanol.eu

Carbodeon

PLATING IMPROVES ADHESIVE WEAR RESISTANCE

Nanodiamond material specialist Carbodeon has worked with metal finishing specialist CCT Plating to develop a new NanoDiamond enhanced electroless nickel plating with significantly improved performance in sliding applications.

Electroless nickel coatings offer many advantages over other coating types, such as excellent corrosion and abrasion resistance, creating an even coating thickness over complex geometries and at relatively low cost. A limitation to their performance has been that they don't perform well in tribological applications involving moving metal parts, where adhesive wear and galling tend to lead to rapid wear or failure.

Incorporating Carbodeon NanoDiamond into the coating solves this problem. Spherical diamond nanoparticles are specially treated to make them disperse in coating liquids and carry a positive electrical charge on their surfaces. In the plating process, the diamond particles behave similarly to positively charged metal ions and together with the coating material they co-deposit onto the component.

Metal-diamond composite surface treatments have already shown their value in abrasion resistant coatings, but in this latest generation of coatings the process has been optimized to better combat adhesive wear, which occurs mainly when the plated parts are in sliding contact with other metal parts.

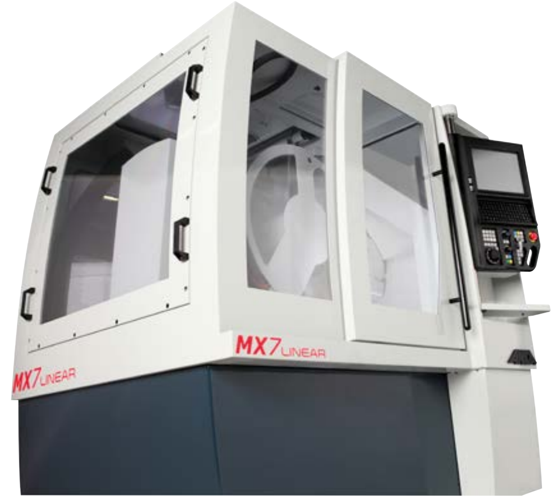
The coating significantly reduces adhesive wear, but does not make the coating abrasive or increase the surface friction. The coatings can be used "as plated," which does not affect the substrate's heat treatment condition, or can be subjected to annealing for maximum performance.

The nanomaterial for the process can be obtained from Carbodeon, who can also implement the complete plating process in existing customer plating facilities. Alternatively, job plating or turnkey solutions can be carried out by CCT Plating in Stuttgart, Germany.

For more information:
Carbodeon
Phone: (358) 40 5566 765
www.carbodeon.net

ANCA

MOTOR TECHNOLOGY IMPROVES CHIP EVACUATION ON GRINDING MACHINES



Highly polished flutes and gash surfaces improve chip evacuation and aid tool performance. The smoother surface enables swarf (or chips) to exit more freely, preventing chip packing and material build up during machining. ANCA has addressed this goal with innovations found only at the ANCA Group.

ANCA has equipped its rigid tool and cutter grinding machines with ANCA Motion's LinX linear motor technology to provide manufacturers a new, higher level of quality tool-making capability.

"Tools ground on our machines have a consistently high-quality cutting edge and surface finish," reports Simon Richardson, ANCA product manager. "Since the LinX motor technology was launched, customers have reported dramatically better results using the duel technologies.

"High quality tool surface finish is a great advantage when machining softer or ductile materials, chips can stick to the carbide. If the chips created are not removed faster than they are being produced, the tool may not perform effectively. However, a better surface finish on the flute prevents the swarf from sticking onto the flute face of the tool while reducing the amount of heat that is generated when machining."

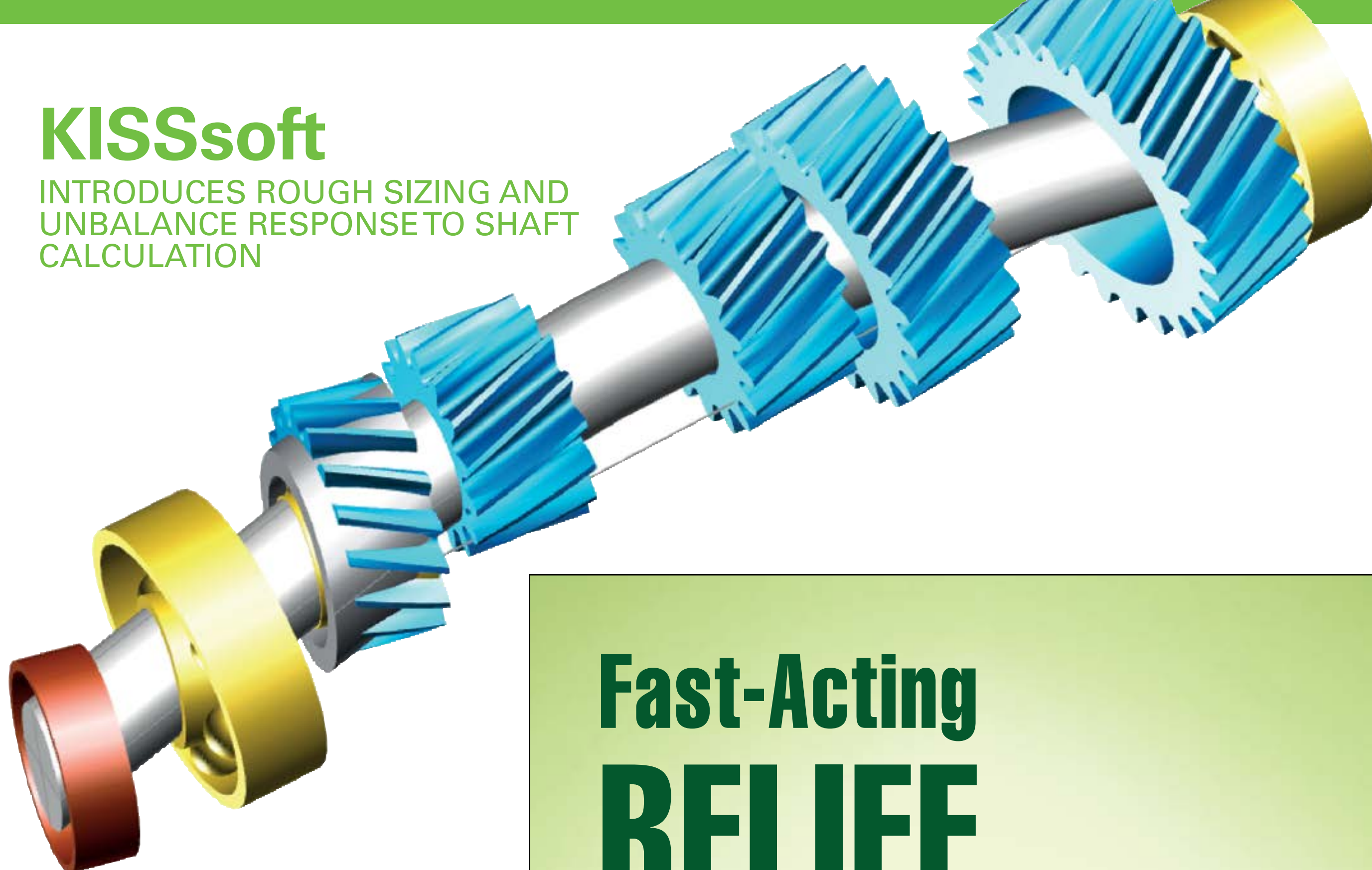
"We realized that having a highly rigid machine with a cylindrical linear motor that assures a smooth axis movement would greatly improve the final surface finish on the tool," Richardson continued. "The research and development team conducted many hours of test grinding to rigorously test our assumption of what surface finish quality we thought was possible."

An Alicona infinite-focus XL metrology machine in ANCA's Grinding Center of Excellence was used to verify the results to nanometer accuracy, finding that a surface finish roughness average as low as 164.7nm (which translates to 0.16 Ra) was achieved.

For more information:
ANCA Inc.
Phone: (248) 926-4466
www.anca.com

KISSsoft

INTRODUCES ROUGH SIZING AND UNBALANCE RESPONSE TO SHAFT CALCULATION



When you are defining dimensions for shafts, KISSsoft now provides options for sizing shaft dimensions with regard to strength, and for sizing the rolling bearings with regard to bearing service life. This really cuts down the time you need to design a gear unit. Here, you can specify which priorities are to apply during sizing. (New functionality within the basic package WPK)

The unbalance response can now be calculated on the basis of an eccentric mass when you're calculating the shaft's vibration. This calculation returns values for the resonating frequencies and the shaft's displacement, along with values for the additional forces to which the bearing is subjected because of the imbalance. To help perform a realistic calculation of vibration, you can now enter the damping values individually. (New module WA11)

For more information:
KISSsoft AG
Phone: +41 55 254 20 50
www.kisssoft.ag

Kadia Inc.

ADDS DEEP HOLE DRILLING SOLUTIONS IN NORTH AMERICA

Brighton, Michigan-based Kadia Inc. has added an extra service to its portfolio by setting up a division to provide deep hole drilling solutions to manufacturers in the US, Canada and Mexico.

The development follows the company's appointment to sell and service the full range of deep hole drilling machines and tooling from TBT Tiefbohrtechnik, which was founded in southern Germany in 1966. Both Kadia and TBT are members of the multinational Nagel Group.

The agreement includes a license for Kadia Inc. to manufacture, stock, resell and regrind carbide-tipped gun drills locally in Brighton. The machines themselves will continue to be built at TBT's factory in Germany and are sold in either US dollars or Euros.

Dennis Tanis, executive vice president of Kadia's North American operation (established in 1984), commented, "We develop deep hole drilling processes for any size of manufacturing project, from firearms through automotive and petrochemical to medical drilling solutions.

In most cases these drilling systems are supplied based on standard TBT gun drilling machines with from one to six spindles. If a machine has more than two spindles, it is often equipped with automated loading and unloading by a gantry-mounted, or pick-and-place robot," he said.

Tanis said the company makes carbide tipped tools here for gun drilling and stock 250 different part numbers for immediate delivery in the size range 0.05 to one inch. TBT's range goes higher, however, to 1.65 inches diameter and also encompasses solid carbide, indexable insert and drills ground with a high speed chip breaker.

For more information:
Kadia Inc.
Phone: (734) 277-4060
www.kadia.com

Hexagon Manufacturing Intelligence

INTRODUCES GLOBAL S CMM PLATFORM

Hexagon Manufacturing Intelligence recently introduced its GLOBAL S Coordinate Measuring Machine (CMM) platform. The Global S measuring solution is the initial offering in Hexagon's Enhanced Productivity Series (EPS) featuring smart technologies such as user experience (UX) enhancements, measurement software and advanced "green" options. The EPS platform is designed specifically to simplify the creation, execution and analysis of measurement routines. The Global S CMM solution is a complete package utilized from start to finish in a Quality program, from the engineer creating the measurement routine to the operator executing the inspection program to the manager analyzing the data and improving processes in the production workflow. The Global S CMM impacts dimensional inspection operations with higher productivity in demand by industries such as automotive, aerospace, general mechanics and precision mechanics industries.

The Global S platform utilizes *PC-DMIS* CMM software for the collection, evaluation, management and presentation of manufacturing data. Leveraging software advancements, common tasks such as the selection of probe tips and importing files are now 3 - 8 times faster than existing solutions. Improvements such as feature sensor mapping allow the user to associate sensors to features more rapidly when importing inspection plans. Operators benefit from faster scanning measurement of non-predefined paths and optimized path trajectories for expedited part-program execution. Another innovation is the new "Inspect" option for program selection and execution. This easy-to-use interface within *PC-DMIS* allows "one click" measurement routine selection.

For more information:
Hexagon Manufacturing Intelligence
Phone: (401) 886-2000
www.hexagonmi.com

Measuring Left and Right

CMM Inspection vs. GMM Inspection

Mariano Marks, Product Specialist, Wenzel America

Speed and accuracy is the name of the game in gear inspection. It's why a Wenzel customer recently purchased a WGT280 that can inspect gears in around eight minutes as opposed to around 18 with the CMM they were previously using. A number of customers are looking for similar results in 2017 regarding gear measurements.

Manufacturing is changing. Parts are getting smaller and smaller. Non-traditional job shops are starting to manufacture and develop gears which change the typical customer demographics. There has also been an increased need for worm gear inspection, presumably due to the addition of robotics in automation.

Utilizing both a coordinate measuring machine (CMM) and a gear measuring machine (GMM) gives the customer two machines that each are good at what they do. This is optimal rather than trying to adapt one to do the other's job. Naturally, two machines can relieve pressure if a large number of parts need to be inspected. It all depends on the types of parts that the customer makes and what they might be making in the future.

While it makes sense to utilize both a CMM and a GMM in the typical gear shop, there are significant differences that will be addressed in this article. We'll look at these differences, discuss quality and inspection trends and report on how gear inspection is evolving.

Durability and Longevity

Since their inception in 1956, CMMs have been a necessary tool in every quality department. Their development has been invaluable in the refinement of precision parts that make for long-lasting and more durable equipment.

When I entered this world, I had no idea that it previously existed, coming face-to-face with a myriad of different components of all different shapes and sizes from all corners of the United States. I then had the opportunity to dive into the unique realm of gear metrology with Wenzel America in 2016.

As CMMs became more sophisticated, gear inspection was also refined from needing three separate pieces of equipment to check profile, lead, and pitch, to becoming full CNC inspection equipment in the late 1970s. Two examples of earlier devices used for gear inspection are the Fellows Microdex for profile and two dial indicators to check pitch.

Wenzel has played a part in this development exhibiting our first gear measuring machine in 2003 to now having the ability to check virtually any gear as well as some cutting tools. Still, there are many differences between gear inspection with a GMM and 3D inspection with a CMM. I will outline three main differences I've experienced during my time using: types of parts measured, parameters that are extracted with each, and speed.

Compare and Contrast

One of the main features that you should see in all modern GMMs is the use of a 4th axis. This, of course, simplifies measurements greatly by minimizing the necessary measurement volume. It is also the best way to inspect a gear since this mimics the generative motion with which gears are made. It is natural, then, for a GMM to use a rotary table since almost all gear-related parts are rotationally symmetric. I've even found myself only locking five out of the six degrees of freedom when aligning these parts due to this characteristic. Racks would be an example of a part that I've measured where it makes no sense to use a rotary table. Of course, gear housings and other 3D parts can be simply fixtured to the rotary table and inspected without using the C-axis as well, but with other metrology software installed on the GMM. It is also worth noting the minor detail that, due to its size, a GMM is more forgiving when loading a part.

Furthermore, the parameters sought from typical parts measured in a CMM vs. those in a GMM could be best represented in a Venn diagram with the most common between both being Geometric Dimensioning and Tolerancing (GD&T) parameters. Profile, lead, pitch, runout, and even dimension over balls are the primary parameters that are not present in regular CMM inspection.

The more common GD&T parameters like flatness and roundness are secondary in a GMM. In this regard, it can be argued that GMMs are easier to program due to the simplicity of the necessary parameters that need to be input. This is not to say that gears are not complex geometries in the least! Nevertheless, it is fair to say that the characteristics that both a GMM and a CMM can evaluate are more common than different.

Finally, since a GMM's primary function is to check gears, it does it quite fast. The advantage in speed can be attributed to the 4th axis motion that practically all of today's GMMs equip. Additionally, if a CMM is not equipped with a rotary table, then a multi-probe stylus system would be necessary to check gear geometries. This also results in added time not just for inspection but qualification as well. At times, these reductions in speed can amount to 50 percent. In the past, a CMM did not inspect gears using the generative method that CNC GMMs started with. However, nowadays, CMMs have made strides in measurement speed due to improved mechanics and integrated rotary tables.

Regardless of where your quality requirements lie, both types of machines are trying to achieve the same goal: to inspect parts accurately with the greatest precision. The way they do it is essentially the same. They are just two different flavors of the same type of tool.

Gear Inspection Then & Now

The pages of this magazine have explored gear inspection for many, many years, highlighting the tighter and tighter tolerance requirements, increased quality demands, and the evolution of gear standards.

Software is one area, in particular, that continues to change the inspection game. Inspection software is becoming easier to use since a more intuitive and logical programming interface is being adapted. Also, the most up-to-date gear standards are being implemented right into the inspection software.

The ability to check virtually any gearing component is now possible. For example, Wenzel just made available a new broaching module to check broaching tools as well as an updated enveloping worm module. We are also able to take advantage of Gear Data Exchange.

Taking this a step farther, I would say that the Industrial Internet of Things (IIoT) will also reveal areas of growth and new developments in gear inspection. Monitoring inspection equipment is something that is underrated and the ability to capture more information never hurts.

There is plenty of information that an inspection machine's controller can provide us, and Wenzel is taking steps to unearth this information for customers so that they understand the health, if you will, of their inspection equipment.

We've developed an Intelligent Machine Interface (IMI) that can collect environmental data like temperature and humidity using integrated sensors as well as the performance of the machine using information from the controller. In this way, using information about actively running programs, warnings, and status reports can be collected and analyzed, by Wenzel as well, with the customer's consent.

This will allow for preventive measures by letting service technicians detect any possible problems with wear or fatigue, for example, to critical parts in the machine before it happens. This means that the customer will have less downtime and interruptions in their production and inspection processes.

Gear Data Exchange

I've written about GDE for our Wenzel America blog (*www.wenzelamerica.com/one-gear-rule/*). It is similar in practice to Part Manufacturing Information (PMI) where GD&T information is built into CAD in order to make programming easier and less error-prone. GDE is a universal format that describes all geometric parameters for cylindrical gears which can then be easily transferred between design, manufacturing, and quality departments.

The format is based on Extensible Markup Language (XML) Version 1.0 which is easily able to be implemented to already existing database applications. The .xml files themselves are so well structured and organized with ASCII text that even novice users can identify mistakes easily. This feature is available in most modern gear software today. It is able to both import and export GDE files.

The *Verein Deutscher Ingenieure* (VDI, Association of German Engineers) has standardized this format in VDI 2610. They also regularly update the GDE format that the .xml files should follow in order to create your own GDE files as you see fit to describe your gear. You can download the latest files at *www.vdi.de/xml/2610/* and you can open them in a simple text editor like Notepad. The benefit of this type of structure is that it makes for fewer errors by the operator streamlining programs and inspection.

Changing Inspection Demands

Whether the customer is interested in CMMs or GMMs it's fair to say that gear inspection is always advancing. The gear industry (as a whole) still suffers when it comes to finding skilled labor. There remains a noticeable amount of the workforce that will be retiring in the next five years. These positions will eventually need to be replaced with qualified candidates that can keep up with the changing demands of our industry. As long as apprenticeship programs remain out there, there is no reason the next wave of workers should miss out on the vast amount of knowledge that workers with decades of experience are actively trying to pass down.

This is why various companies, Wenzel included, participated in Manufacturing Day (*www.mfgday.com*) where local high school students were able to experience what the world of metrology had to offer. The students that came to visit us were actually from a technical school so they were familiar with basic metrology concepts like calipers and a micron! This is an annual nationwide event that benefits every community so make sure to check out a

nearby event near you. We are participating in this event once again this year (*www.mfgday.com/events/2017/wenzel-america-2*) and urge our colleagues in the industry to do the same.

And while the demands of the gear industry change, so too, will the opportunities. Big gears will come back once the mining and energy sectors develop more. A 2017 January/February *Gear Technology* article as well as AGMA supports this increasing trend in manufacturing investments in the United States for the gear industry.

On the flip side, I also see gears becoming smaller and more accurate as the need for light components and automation increases. This includes our customer, Forest City Gear's, tiny gears that will go on the Mars 2020 rover. Finally, I believe smaller shops will focus more on the quality of their products since, as I mentioned earlier, more non-traditional job shops are starting to explore gear manufacturing.

It's an exciting time in the gear shop as data-driven manufacturing takes our industry and our equipment into the future. Here lies an opportunity to examine your inspection needs, plan for future projects and determine what technologies you'll require moving forward.

(Editor's Note: Some information from this article was retrieved from the *International Journal of Emerging Technologies and Innovative Research* here: *www.jetir.org*)

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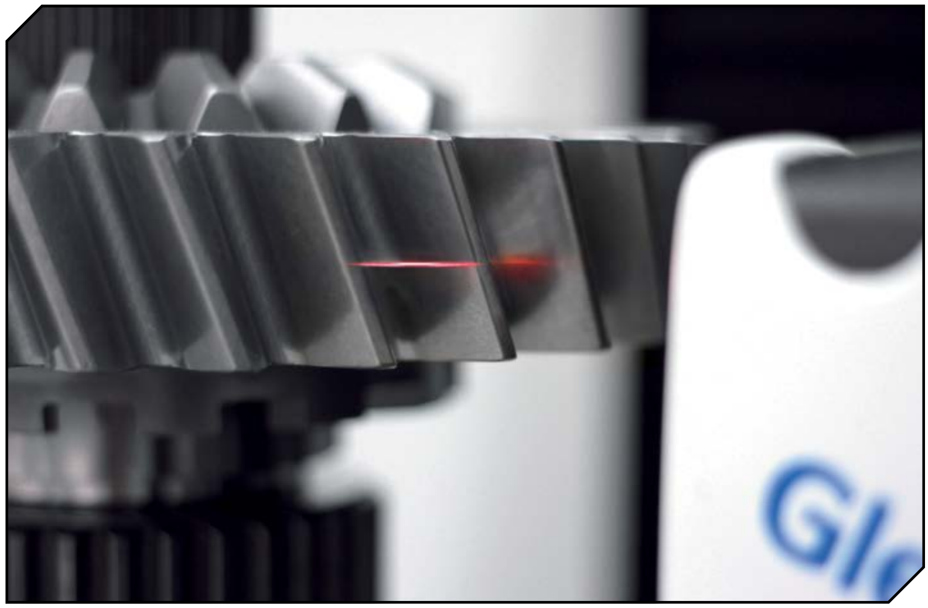
Gear Inspection at Light Speed

Revolutionary new inspection technologies are helping gear manufacturers develop and produce more complex, higher quality gears in a fraction of the time it used to take.

Dennis Traynor, Sales Manager, Gleason Metrology Systems



In the world's gear design rooms and on the production floors, speed is imperative, as manufacturers race to meet stricter vehicle fuel economy and emissions regulations, the weight and efficiency requirements of electric vehicles, and other challenges impacting every product category. No stone is being left unturned in the search for better performance—right down to the transmission gears that account for a small but increasingly significant portion of overall fuel consumption. But the innovative new designs that squeeze more efficiency, less noise, greater strength and longer life out of these gears have also upped the 'inspection ante' in the Quality Room. Conventional tactile probing is highly accurate and reliable—but relatively slow, particularly when something like the entire topography of a tooth flank needs to be analyzed. As gear designers dial in even the most minute improvements in gear performance, they're placing an increasingly heavy burden on the Quality Room—and often adding many precious hours to the time it takes to optimize a new gear design.

Let there be light. With the new Gleason 300GMSL Analytical Gear Inspection System, we're harnessing the power of new non-contact laser technology to take full flank inspection to a completely different level. Never before have gear manufacturers had the ability to record, analyze and validate gear data at the speeds and with the detail that's possible with the 300GMSL. This is particularly important with the recognition that, while traditional lead and profile trace analysis continues to define gear quality classification, gear performance in the real world is determined by how a gear actually meshes with a pinion. Now, in the time it takes a conventional inspection system using tactile probing to do a single lead trace, the 300GMSL can scan a complete tooth flank, a process that, depending on gear size, might require hundreds of individual lead traces when done conventionally. Additionally, the tremendous data density (as many as 685,000 data points might be gathered from a single tooth flank on a typical small helical gear) inherent in non-contact laser scanning enables the technology to 'see' more subtle surface finish conditions such as micro-pitting, scalloping, and waviness patterns resulting from processes like twist-controlled grinding and Power Skiving, but which aren't discernable with tactile probing. This data also makes it possible, in conjunction with the *GAMA* user interface software, for the operator to generate 3D graphical analysis charting of the gear tooth using easily interpretable color changes to show variations from nominal data and where modifications are required—particularly helpful in reverse engineering efforts.

Four machines in one. While its laser scanning capability is particularly well-suited for R&D applications, the 300GMSL also offers the additional features and functionality required for gear measurement and analysis of production parts. These include:

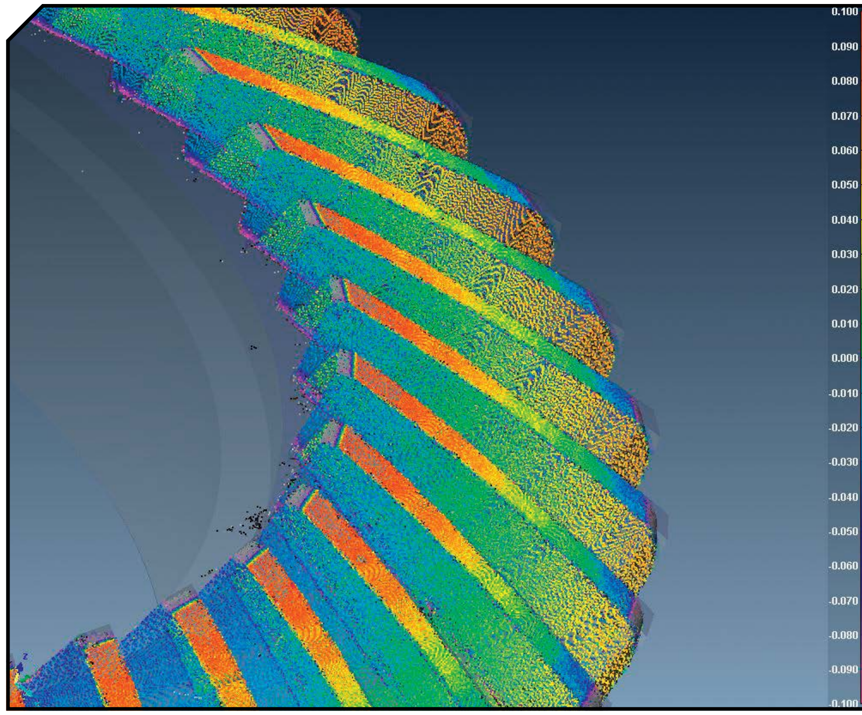
- Tactile probing for traditional gear feature data collection and fast set-up on spur and helical gears, spiral and straight bevel gears and beveloid gears up to 300 mm diameter; and many types of gear cutting tools.
- Surface finish measurement, and the ability to evaluate data for the most common surface roughness measurement parameters.
- Barkhausen noise analysis for residual and compressive stresses after grinding on gear tooth flanks and shaft bearing race features.

All the sensors, including the one used for laser scanning, can be changed arbitrarily and in any random sequence without the need for recalibration. A Renishaw PH10 two-axis indexing probe head is used for the laser scanning sensor, thus providing the additional axes necessary to always position the sensor normal to the work surface regardless of the different positional attitudes required of any workpiece, including spiral bevel gears and worms. Tactile and surface finish testing are both done in conjunction with the Renishaw SP25

probe head; Barkhausen probing connects through the auto-joint function of the PH10 indexing probe head.

Faster to first-part qualification with 300GMSP. Time-saving inspection technology is now available for the production floor as well. This will come as welcome news to the many gear manufacturers who have long had to cope with the wasted time needed to transport finished gears to the lab, and the additional time needed for parts to work their way through the inspection queue. Manufacturers have long sought a truly 'shop-hardened' inspection system — one that could be put in close proximity to the production machines, be extremely resistant to temperature, vibration, and contamination variations, and deliver inspection data almost instantaneously back to the production machines so that first-part qualification could happen almost on the fly. The Gleason 300GMSP does all that, and more. The shop-hardening of the 300GMSP required a completely new design starting with a proprietary machine base material that's well-suited for the sustained higher temperatures experienced on the shop floor. The new base material, coupled with a completely new patent-pending 'H' base design with active leveling system, has proven to be an excellent solution. Air springs detect and automatically compensate for vibratory forces on the fly, such that the machine work platform is both isolated from, and immune to, vibration. The high resolution guidance systems are similarly designed for harsh environments and help to ensure exceptional system accuracies. The 300GMSP also incorporates a system of new software and sensors that work in combination to detect and compensate for typical thermal fluctuations found on the shop floor. In fact, the 300GMSP has proven to deliver exceptional accuracies (2 microns) within a wide temperature range from 15 to 40 degrees C.

Closing the Loop on quality. The 300GMSP can also be interfaced with the Gleason Closed Loop System, which allows measurement data to be networked from the inspection machine directly to the latest Gleason production machines. With Closed Loop, it is no longer necessary to transfer the necessary measured values manually, a process which often leads to costly errors and wasted time during setup. The path to first-part qualification is now much more efficient, enabling the production machine to quickly compare inspection data with nominal values, calculate the corrections required, and produce a qualified first-part.



Advanced technologies, proven platforms. While the 300GMSL and 300GMSP are designed for opposite ends of the gear manufacturing spectrum, both share in common a host of design features that have been proven in hundreds of GMS installations around the world. These include:

- *GAMA*, the object-oriented *Windows*-compatible operating software that puts a host of powerful features right at the operator's fingertips, creating a simpler, more intuitive human/machine interface. With *GAMA*, the process of creating a new program can generally be done in fewer steps and with less reliance on experience level, language requirements, or the gear or application type. *GAMA* supports VDI/ VDE 2120 GDE (Gear Data Exchange) capability as standard, reducing the need for redundant programming and allowing gear data/parameters to be transportable between different machines. This HTML-based standard is just one of the advanced features incorporated into this robust platform.
- An optional Advanced Operator Interface (AOI) with dual display SPC, voice, photo, video, QR code/barcode read/import, and environmental monitoring/recording.
- Equipped with a broad range of styli, a stylus calibration library, and easily accessible probe storage in the storage cabinet at the operator's workstation. A six-position Automatic Probe Change (APC) is also available.

Whatever your needs — R&D or production — gear inspection has never been faster, whether at the light speeds of a laser, or just a few steps away on the production floor.

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Dennis Traynor is Sales Manager for Gleason Metrology Systems. He is responsible for managing the company's sales and marketing efforts globally for metrology products and aftermarket programs. His 30-plus years of metrology experience has encompassed management roles in sales, engineering, product development and customer support.

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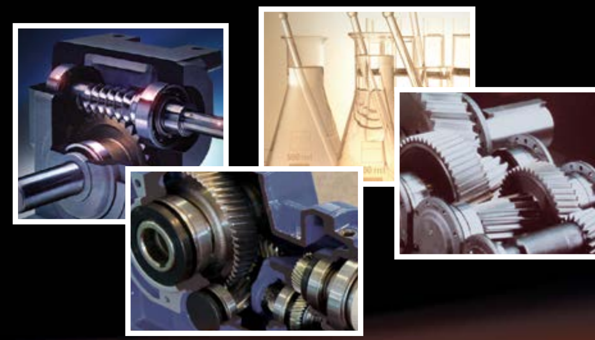

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Ask Not What Your Heat Treater Can Do for You…

When sending gears to be heat treated, manufacturers can end up unwittingly making mistakes that slow down turnaround time. We talked to some heat treaters to get their best advice on how you can help them help you.

Alex Cannella, Associate Editor

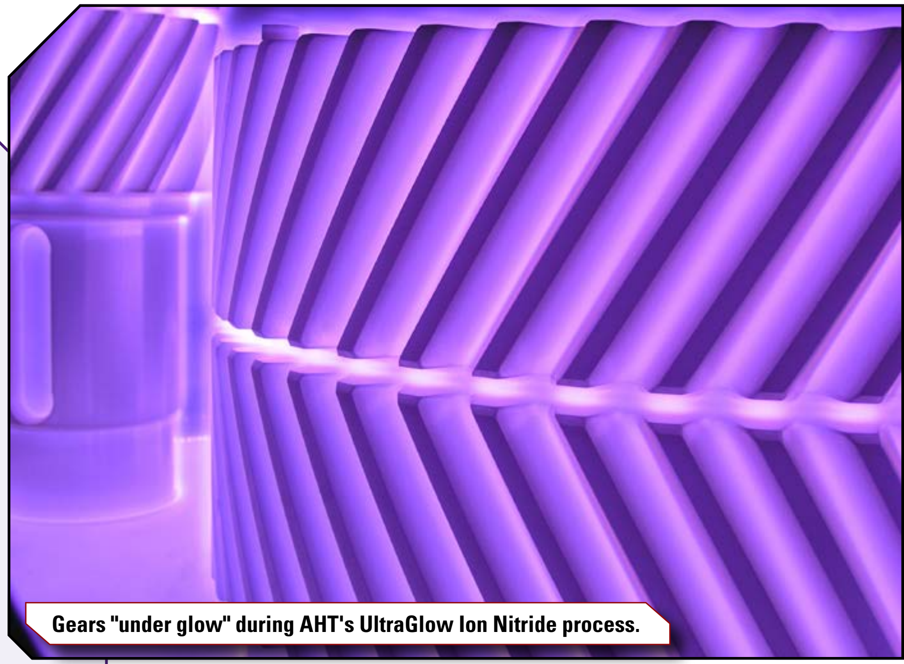
Turnaround time is one of the most discussed facets of manufacturing that we talk about here at *Gear Technology*. Every month, there's always news about a new product or technique that promises to improve that metric, and we're constantly giving advice on how to make your business run faster and leaner. But at the end of the day, there are certain steps of the process that are largely out of the manufacturer's hands.

At first glance, sending gears to be heat treated might seem like one of them. After all, manufacturers can certainly shop around and look for the right heat treater for them, but at the end of the day, giving your gears over to a heat treater requires a degree of trust that the job will be done professionally and expediently, and the reality of the business world is that expectations aren't always met.

But the ball isn't entirely in the heat treater's court, and often when the heat treat process hits a snag, it can actually be due to errors that stem from the manufacturer's side. Every heat treater has nightmare stories; improperly documented or tested gears, gears with different specifications than the treater was expecting and even specification demands that are just plain impossible to meet are all issues that they can and do regularly face.

Every one of these problems complicate a heat treater's job, and by extension slow down work and force an increase in turnaround time. When gears come in with different specifications than previously expected, for example, all the prep work they've already done for the gears is wasted, and they have to invest additional time taking it from the top again. And on the flip side, manufacturers can sometimes, depending on the situation, actually help heat treaters skip steps and work faster just by providing the appropriate information.

We reached out to heat treaters both big and small to ask them about the most common mistakes they see gear manufacturers make and their best tips to avoid making them. Here are some of the best ways you can make your heat treater's life easier, and in doing so, improve your own turnaround time.



Gears "under glow" during AHT's UltraGlow Ion Nitride process.

What Can You Do for Your Heat Treater?

Rule Number One: Communicate!

Every heat treater we talked to, without fail, stressed the importance of communication first and foremost.

"Optimizing turnaround is all about communication," said Phil Harris, marketing manager at Paulo. "The more you let your heat treater know about your process and the next steps in the supply chain, the better. We have seen mutual benefit from coordinating lot sizes with furnace capacity, in some cases holding furnaces for customer delivery times, shipping directly to the next step in the supply chain, or taking on additional processing steps in our facilities."

All heat treaters, be they ion nitriders, vacuum carburizers or otherwise, are willing to discuss the needs and specifications of your application, and their number one piece of advice is to take advantage of that. The more heat treaters know about your gears, the better they can leverage their expertise. They can confirm that your gears can reach the demanded specifications and, in the event that they can't, work with you until they can. The more you're on the same page with your heat treater, the less likely it is you'll run into hiccups when it comes time to send your gears to be treated.

It sounds like painfully obvious advice, but almost every problem a heat treater runs into has to do with a failure of communication in one way or another. Just taking the time to make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sure that you're on the same page as your heat treater can prevent any number of major delays before they have an opportunity to happen.

So, what should you be telling your heat treater? Harris has a few suggestions.

"Ensuring we know what material your gears are and that the hardness specification is achievable is a great start," Harris said. "Remembering to send test coupons can prevent us from cutting a gear, depending on the testing requirements. We need to work together to understand distortion, especially with higher temperature processes. Let your heat treater know about cutting fluids and rust preventative, as those fluids can impact our surface treatments. Lastly, communicating test locations is often missed, but can cause a lot of headache if we end up measuring different areas of the gear."

Test locations are a helpful piece of information heat treaters aren't always provided. It can be important for them to test the same location on the gear that the customer does. If, for example, the gear manufacturer tests the tooth tip but the heat treater tests the tooth root, it's possible to get different results, which leads to delays as the heat treater scratches their head and has to try and get in touch with the customer. And in situations where gears require different case depths at different locations on the tooth, it can become doubly important to specify the test location when you provide your test information.

Midwest Thermal-Vac's ion heat pulse plasma ion nitrider.

Rule Number Two: Start Early and Keep up to Date

While the idea of keeping in touch with your heat treater isn't a revolutionary one, not as many gear manufacturers know when they should start to open that line of communication. The answer is to do so as early as you can. And when heat treaters say early, they mean before you even start manufacturing the gears.

"Gear manufacturers need to incorporate the help they receive from their heat treat facility early in the program," said Frederick Otto, president at Midwest Thermal-Vac. "Thousands of times (and I am not exaggerating) a particular gear ends up at the heat treater with pre-determined specifications that cannot be done. If only this was brought to the table before any gear cutting was started."

"Talk early on and have some head to head meetings and so forth on design," said Gary Sharp, chairman and CEO of Advanced Heat Treat Corp. "Get some development done on prototypes as early as possible so we can get [the gear manufacturer] samples so that they can do some initial testing in case further adjustments need to be made."

Every advantage achieved by talking to your heat treat supplier is compounded by making sure you start talking to them as early as possible and, almost as importantly, keep them informed as your own gear designs change, as that affects their own process.

"Another situation is lack of internal specifications with the correct revision," Otto said. "The correct revision is not sent up front, wasting days of communication and valuable heat treating time, while waiting to receive the requested information. Then only to find out that temperatures, quench media and other specifications that tie a heat treater's hands add unnecessary cost."

A titanium gear after undergoing AHT's ion/plasma nitriding process.

If making sure your heat treat servicer is informed is the number one way to prevent unnecessary delays, then making sure that you talk to them early and often is the best way to make sure they're informed. The more you dedicate yourself to keeping your heat treater apprised of your gears' specifications, the better and faster they can do their job and send your gears on to the next step of production.

Rule Number Three: Vet Your Material Supplier

A mistake can happen anywhere on the supply chain, and that includes with the material supplier. According to Enrique Lopez, sales and marketing director - North America for ALD Thermal Treatment Inc., one of the leading problems ALD encounters is when a gear manufacturer sends gears made of poorly mixed or low quality material. It's also an error echoed by Otto, who described "consistently" getting gears made from the wrong material altogether.

"I know it sounds like a basic thing," Lopez said. "But you would be surprised how often that happens, even with big customers where you're supposed to have high quality materials."

It's a mistake that ultimately rests with the material supplier (or, perhaps, even further up the supply chain), but it's also one that gear manufacturers don't always notice when cutting their gears. But even if low quality materials make it through the gear cutting process without being noticed, the problem will always rear its head during heat treatment when the treater doesn't get the results they're expecting. And when it does, it forces production to halt.

"When we do the heat treatment, of course we will have different results," Lopez said. "And then we will start scratching our heads and figuring out what is happening, wasting a lot of time doing trials, correcting recipes and doing all that, just for the next load coming having again a different situation."

Once a gear manufacturer runs afoul of this problem, it's not necessarily a total loss. According to Lopez, there are a few options going forward to deal with the situation, but they both consume time in their own way.

"In our case, we offer the customer two ways," Lopez said. "They can either have the material back, or we can figure out what to do with this material. Sometimes, the material is so mixed that even within one load, you have good parts and bad parts. Some other times, you can effectively find a breakpoint where you can say 'well, the loads received between [these days] are problematic,' and then you can pull that apart and develop a specific recipe to modify and deal with that usually lower DI. So you can save the materials, you can have good parts, it's just a matter to composite differently."

According to Lopez, the best way to avoid the problem altogether is to just regularly check the materials you're receiving from your supplier.

"I think if a customer relies on their sources, it is still a good idea to have some checks, regular audits, and very good control just to keep a certain level of uniformity in the material they use," Lopez said.


Midwest Thermal-Vac's LPC vacuum carburizing system ICBP 3030.

Rule Number Four: Protect Your Gears in Transit

According to FPM Heat Treating's Vice President, Jim Feltner, one of the most frequent mistakes they see is improperly packaged gears that arrive at the facility damaged.

"Unfortunately [some gear manufacturers] do not realize how much a skid or tub of parts can bounce around on the truck which could lead to potential damage or scrap if the gears come in contact with each other," Feltner said.

Standard shipping companies accidentally damaging gears is one thing, but according to Otto, gears can sometimes be damaged even when they're being transported by heat treaters' own local shipping services.

Gears that show up damaged on arrival are yet another potential snag in production, and as with anything else unexpected that happens in the heat treatment process, requires the heat treater to take time to consult with their customer before they can proceed. To avoid this, Feltner advises making sure your gears are securely packaged with the assumption that the container will be bouncing while in transit.

What Can Your Heat Treater Do for You?

Of course, productivity and turnaround time isn't solely on the gear manufacturer. There are a number of ways that heat treaters have been working to make sure orders are done swiftly and precisely, not least among them being systems like Paulo's Production Information Customer Service (PICS). PICS tracks orders through Paulo's entire facility from the moment they arrive until they leave. When a shipment of gears arrives, they

AHT's UltraOx Layers heat treatment process provides added protection against corrosion as well as the black matte finish you see here.

already have an order number, complete with an already established design process. Coupled with the fact Paulo can hold furnaces for specific shipments, this allows the company to trim a significant amount of setup time.

"PICS stores part numbers and the related heat treatment recipe, so when your order arrives there is no scrambling to design a process and no operator error inputting that recipe," Harris said.

Paulo is, of course, not the only company with such a setup. ALD has a comparable system at their own facilities, including their automatic carburizing lane. According to Lopez, even though ALD specializes in high volume shipments, they can still turn around most jobs in 72 hours.

"You just have to scan it," Lopez said. "And the system will know perfectly what to do...At the end of the line, we'll have a product that didn't have any hiccups or delays at any point."

Midwest Thermal-Vac, on the other hand, offers CMM measuring both before and after heat treatment, which Otto notes

Another gear undergoing AHT's ion/plasma nitride treatment.

also can improve turnaround time, and recipes stay programmed in the company's furnaces after their first use, which guarantees a repeatable heat treatment cycle on subsequent orders. Midwest Thermal-Vac also runs their furnaces 24/7.

"If repeating the CMM measuring process, this would prevent having to ship multiple times from the heat treater to the manufacturer," Otto said. "This would save valuable time and eliminate shipping costs. CMM measuring also provides critical information to be able to move ahead to the heat treating trial. This service edge eventually provides a faster turnaround time with superior quality."

Advanced Heat Treat, on the other hand, opts for the quantity approach. With over 50 nitriding furnaces that the company keeps running 24/7, AHT President Mike Woods is confident in his company's ability to match its competitors in turnaround time while remaining flexible. FPM adopts a similar approach by maintaining a high amount of redundant equipment between three separate locations.

You may have noticed, however, that many of these turnaround-improving processes are still dependent on one thing: that the heat treater knows exactly what they're getting ahead of time. Processes like Paulo and ALD's automatic tracking systems are predicated on the assumption that the gears they receive will be exactly what advance documentation told them they would be. And while companies like Advanced Heat Treat and FPM may pride themselves on their flexibility, differing test results will still force them to spend additional time coordinating with a gear manufacturer before they can proceed. This all drives home just how important the gear manufacturer is in the heat treatment process, even if they aren't the ones performing the actual process, and that if you want a smooth heat treatment with a quick turnaround, the most important thing you can do is remember to talk to your heat treater.

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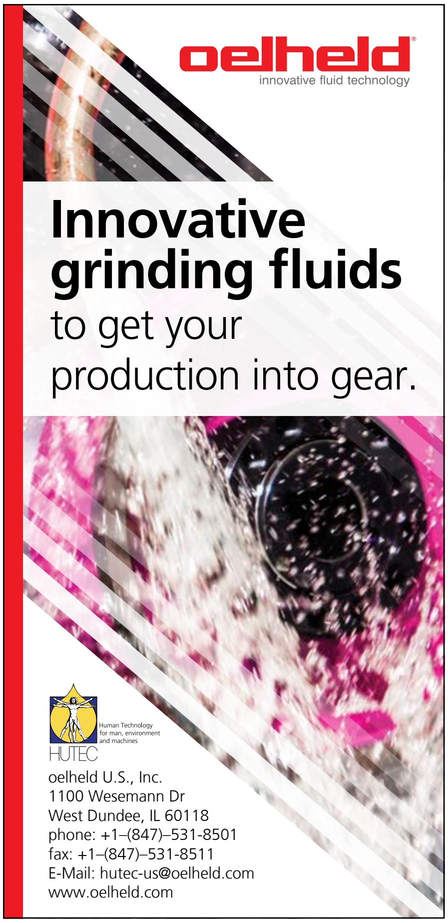
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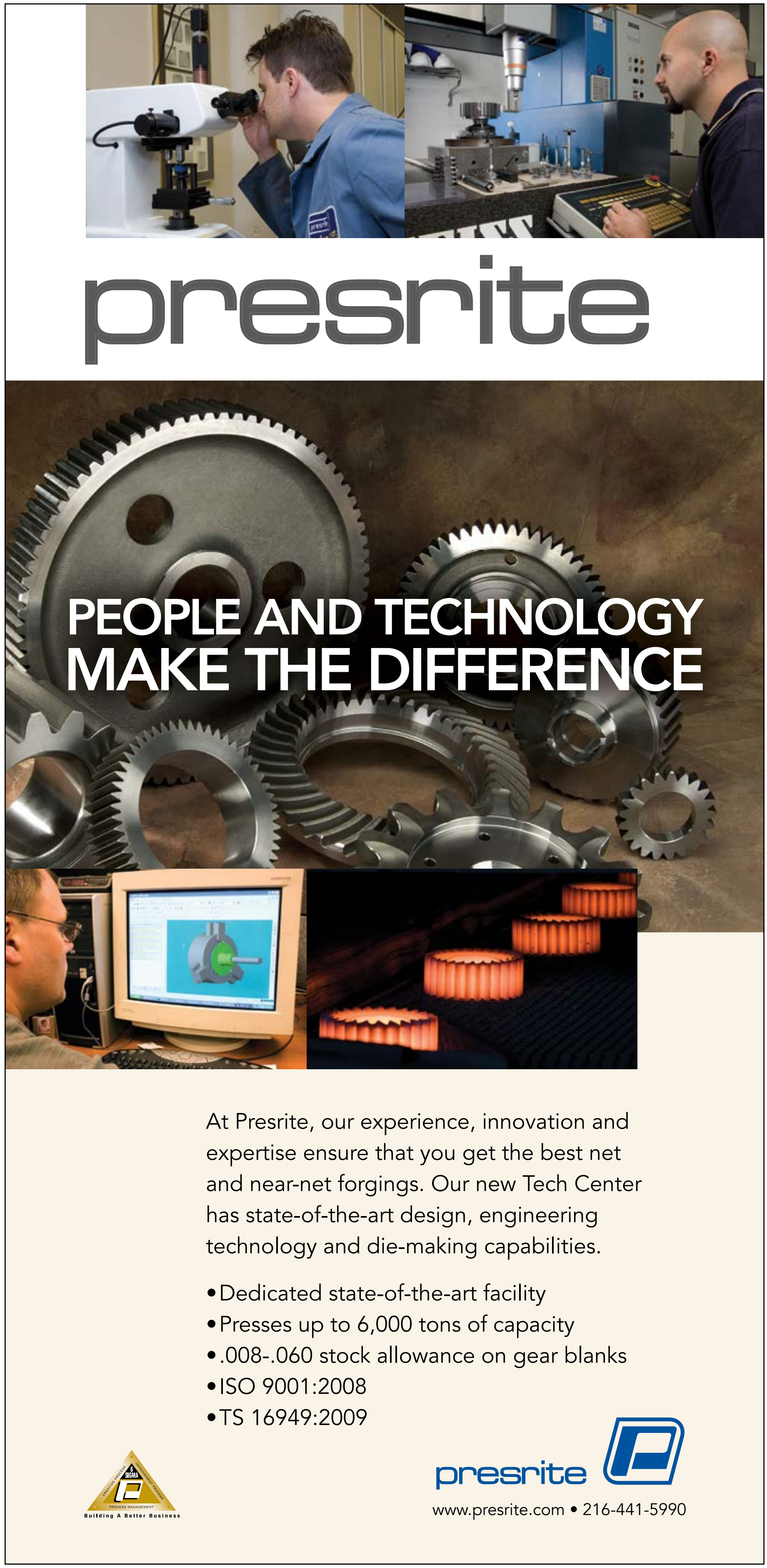
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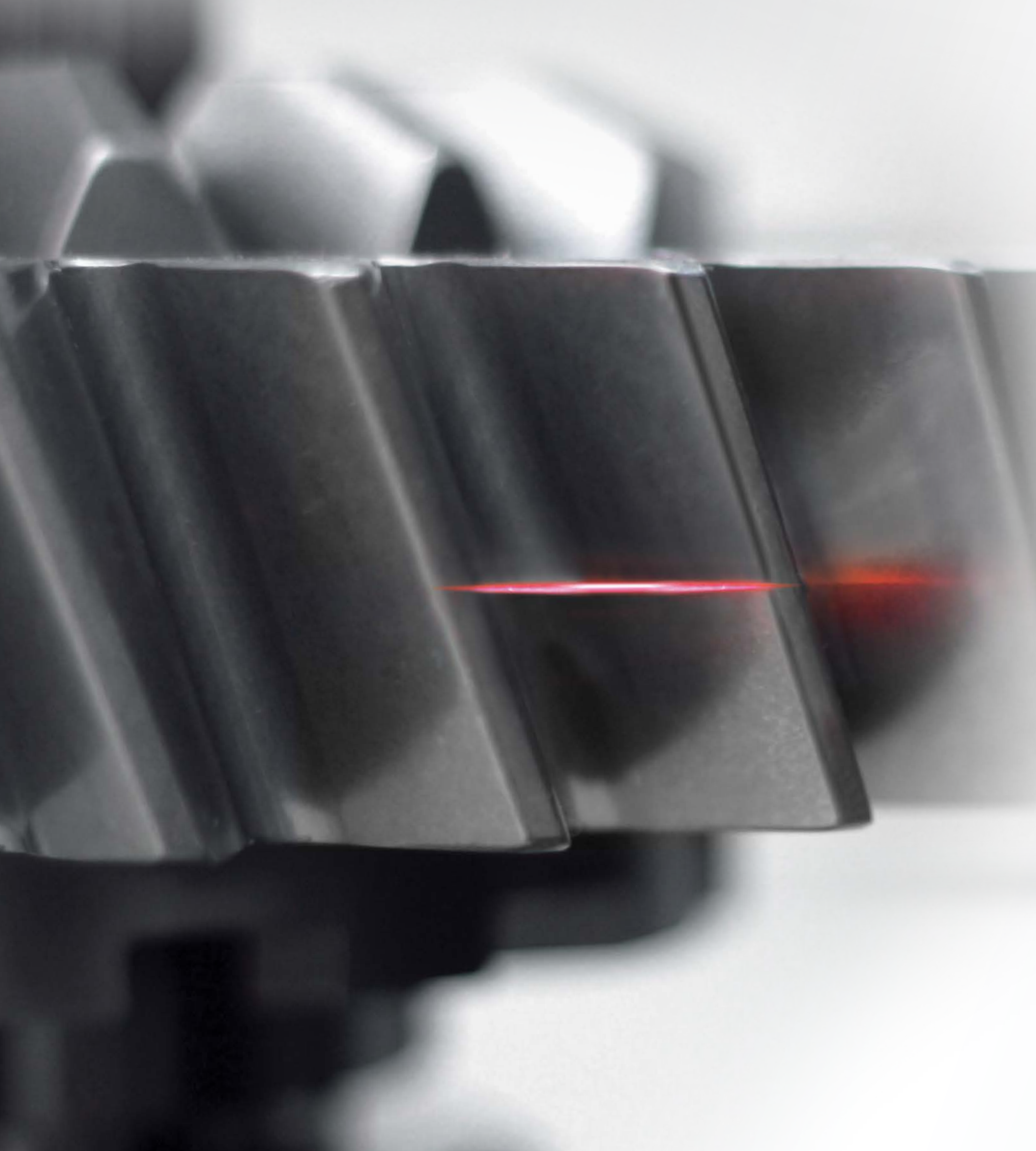


Backlash in Bevel and Hypoid Gears

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

Reader question from Zhao Shenghui, Siemens Mechanical Drive Systems (Tianjin) Co., Ltd.

"I am a research engineer in the R&D department focusing on gear technology. I like the 'Ask the Expert' part of your magazine very much and hope you can help me solve the following question:

"What is the relationship between angular backlash or mean normal backlash change and the axial movement of the ring gear in bevel and hypoid gears?"

Expert response provided by Dr. Hermann J. Stadtfeld. The normal backlash is determined by clamping pinion and gear in a roll tester. First it must be ensured that pinion and gear are rotated to the so called "tight spot." Because of pinion and gear runout, the difference between tight spot and loose spot may be significant. It is important to determine the minimal backlash, because this is the value that must be properly defined for the operation of the gearset. The tight spot can be found on a manual roll tester by setting the pinion cone to the exact mounting distance and rotating the gear by hand until the first metal to metal contact occurs. Further rotation will show if the gear cone has to be increased or reduced in order to maintain a slight metal to metal contact. The angular ring gear position with the largest gear cone adjustment represents the tight spot. Now, the ring gear cone is adjusted to the correct mounting distance and a dial indicator is positioned at the outside in the middle of the profile of a convex ring gear tooth.

Figure 1 displays the setup and indicator position in a 90° roll testing machine. The indicator shaft direction includes a 90° angle to the radius connection between probe contacting point at the flank, and at the center of the ring gear. The probe shaft is also in the plane of the ring gear rotation.

Figure 1 Measurement of normal backlash.

When possible, the pinion rotation should be locked before the indicator is positioned. After completing these preparations the ring gear is rotated in a clockwise direction until the coast side flanks are in firm contact and the indicator is set to zero (pinion convex and ring gear concave = coast side). A slight rotation is then made in counterclockwise direction until a firm contact of the drive side flanks is achieved (pinion concave & ring gear convex = drive side). The indicator reading after this procedure is defined as the "minimal backlash in the plane of rotation" Δt. The relevant value that relates to the normal backlash values in the dimension sheet Δs must be calculated as shown in Figure 2.

where:

Δs = Normal backlash
Δt = Backlash in the plane of rotation
ß,,, = Spiral angle
ß*,,, = Spiral angle projected into plane of rotation
Δts = Backlash normal to projected spiral angle
γ = Pitch angle
α = Pressure angle
h = Backlash perpendicular to pitch cone

Backlash adjustment is done with an axial change of the ring gear position (gear cone). The axial gear cone change between

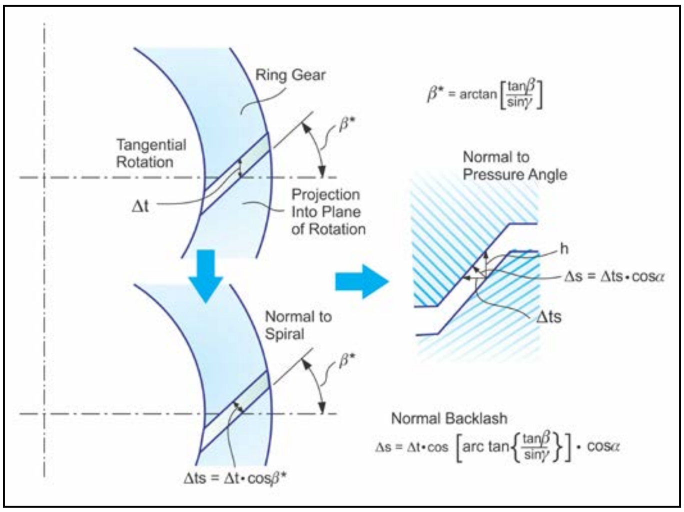


Figure 2 Calculation of normal backlash Δs.

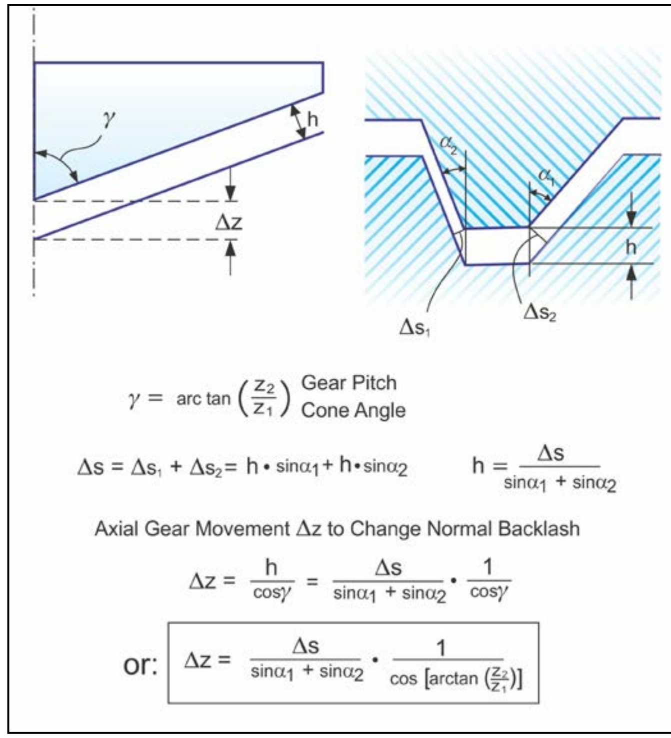


Figure 3 Relationship between withdraw and backlash.

the correct mounting distance setup to the metal to metal condition can therefore be used to determine the normal backlash. Pinion and gear are clamped in a roll tester. First it must to be assured that pinion and gear are rotated to the so called "tight spot." Therefore, pinion and gear cone are set to the exact mounting distance. Then the gear is rotated by hand until the first metal to metal contact occurs. Further rotation will show if the gear cone has to be increased or reduced in order to maintain a slight metal to metal contact. The angular ring gear position with the largest gear cone adjustment represents the tight spot. Ensure firm double flank contact at the tight spot and read the gear cone position on the electronic read out or on the Vernier scale. Now, the ring gear cone is adjusted to the correct mounting distance. The difference in the values of the gear cone at the tight spot metal to metal position to the correct ring gear mounting distance is recorded as "Δz." The schematics and formulae in Figure 3 show the relationship between axial gear movement and normal backlash.

where:

Δz = Axial ring gear move from nominal to metal to metal
z_1 = Number of pinion teeth
z_2 = Number of ring gear teeth
α_1 = Pressure angle convex gear flank
α_2 = Pressure angle concave gear flank

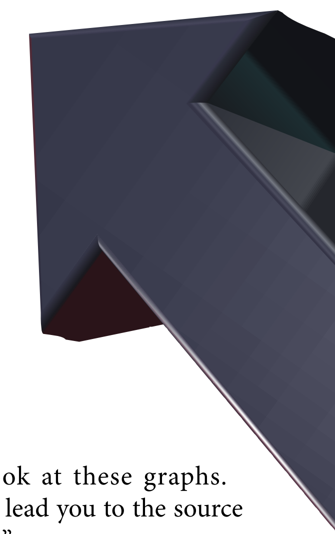
The calculation of angular backlash can be done by dividing Δt by the mean gear radius. The result is in radians and has to be converted to degrees if required. With the relationship between Δs and Δt given in Figure 2, the conversion between angular backlash and the different linear backlash definitions can be quickly be determined. (In addition, see Dr. Stadtfeld's technical paper—"MicroPulse and MicroShift for Ground Bevel Gearsets"—pg. 60.)

Dr. Hermann J. Stadtfeld

received in 1978 his B.S. and in 1982 his M.S. in mechanical engineering at the Technical University in Aachen, Germany; upon receiving his Doctorate, he remained as a research scientist at the University's Machine Tool Laboratory. In 1987, he accepted the position of head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich and, in 1992, returned to academia as visiting professor at the Rochester Institute of Technology. Dr. Stadtfeld returned to the commercial workplace in 1994—joining The Gleason Works—also in Rochester—first as director of R&D, and, in 1996, as vice president R&D. During a three-year hiatus (2002-2005) from Gleason, he established a gear research company in Germany while simultaneously accepting a professorship to teach gear technology courses at the University of Ilmenau. Stadtfeld subsequently returned to the Gleason Corporation in 2005, where he currently holds the position of vice president, bevel gear technology and R&D. A prolific author (and frequent contributor to Gear Technology), Dr. Stadtfeld has published more than 200 technical papers and 10 books on bevel gear technology; he also controls more than 50 international patents on gear design, gear process, tools and machinery.

You Cannot Rely on Labor Efficiency Reporting!

Joe Arvin



Now you might be asking, "Joe, are you nuts? What can you possibly mean by that title of your article? The comparison of Labor Efficiency to Standard Times is vitally important." And you would be correct, but stay with me for a minute to explain.

In manufacturing, we all know that tracking statistics on your operation is essential for understanding how you're doing, as well as identifying areas for improvement. But what does the efficiency metric actually tell you?

First, I need to explain the definition of two key terms used in this article: ***Efficiency*** and ***Productivity***.

Efficiency: This is the actual time reported for setup and run times as compared to the standard times for the specific operation being performed.

Productivity: While there are many definitions of productivity, in this instance, productivity is defined in this way. Of the available paid labor hours, what percentage was used for setting up and running the machines. It's important to keep in mind that this definition of productivity has nothing to do with the number of parts produced. Instead it simply lets you know how many hours were used doing productive work (setup and run).

With that said, the following highlights the importance of not just knowing your efficiency to the standard times, but also knowing the productivity — or the hours used doing productive work.

I received a call from Bob, the president of a manufacturing company, who invited me to lunch. About a week later, we got together at a nearby restaurant and had a good conversation, exchanging stories on what was going on in the industry. Afterwards, as we were leaving the restaurant, Bob asked if I might have some extra time that afternoon to visit his plant. To this I said, "That would be fine."

After a quick tour, we returned to his office, where Bob said, "Joe, I've got a perplexing problem. Our profitability has been declining over the past five years. We've been increasing our prices for inflation every year — plus a little more — but no improvement. Here's what has me stumped. Over that period of time, our shop efficiency has increased from 85% to 90%, but still, the profits continue to slide."

Now, this predicament sounded strangely familiar to a lesson I had learned years before when I was the plant manager at Indiana Gear Works. So I asked Bob what was his plant productivity. "It's good," he quickly responded.

I then took a couple of minutes to explain my definitions of efficiency and productivity. Upon hearing this, Bob said, "Based on those definitions, I guess I'm not sure what my productivity is."

Next I asked Bob about the accuracy of his time standards, stating that if the standards were good and efficiency was increasing, then there should be an increase in profitability. By this time, Bob made a couple of phone calls and asked two others to join us — Phil, the Accounting Manager and Bruce, the Engineering Manager.

Once we were joined by Phil and Bruce, Bob asked me to reiterate my definitions of efficiency and productivity, which I did. Their responses were similar to Bob's in that they weren't exactly sure. Then Bruce stated something interesting: "We do have grievances at least once a week for the time standards being too tight."

"Here's what I would suggest you do," I said. "First, plot on a graph the shop efficiency on a monthly basis over the past five years. Next, for the same time period and interval, plot the actual labor hours spent performing setup and running the machines. And finally, plot the number of actual payroll hours consumed by your shop labor, again for the same time period and interval. Then take a close comparative look at these graphs. They might just lead you to the source of your problem."

They agreed to these tasks and Bob said he'd get in touch with me once they had the information compiled.

About a month later, Bob called and said, "Let's have lunch again." During our meeting Bob said, "The reports you suggested showed our efficiency increasing year over year, just as we thought. However, when we looked at the graphs comparing actual labor hours for setup and running the machines with our total payroll hours, there it was — our productivity had indeed declined."

Continuing, Bob said, "So we started digging into the causes of this increase of non-productive work and here's what we found. Since a lot of our older workers have been retiring, we now have many more new people, and our time for training has really gone up. Speaking of new employees, our top process engineer retired a few years ago, and the two new engineers we brought on to replace him still have a lot to learn. This has caused a significant number of production delays as the operators are waiting for answers to their questions on the engineering routings. Finally, our machines are getting older, and when we looked into it, our down-time for machine maintenance has really hit us."

Bob then explained that this had given them a direction for corrective actions. And while the issues of training new people and being equipped with new or retrofitted equipment are challenges for every manufacturer, having them identified and developing a plan for optimizing these barriers is essential for profitability.

Joe Arvin is a veteran of the gear manufacturing industry. After 40 years at Arrow Gear Company, Joe Arvin is now President of Arvin Global Solutions (AGS). AGS offers a full range of consulting services to the manufacturing industry. His website is *www.ArvinGlobalSolutions.com* and he can be reached by email at *ArvinGlobal@Gmail.com.*

So, in view of the metrics of Efficiency and Productivity, consider these guidelines.

- Efficiency UP and Productivity DOWN = You are probably not making more parts because less time is spent running the machines.
- Efficiency UP and Productivity the SAME = You are producing more parts.
- Efficiency UP and Productivity is UP = You should be significantly more productive, by producing more parts per hour in addition to more hours running the machines.

Now you might be thinking, "But Joe, why screw around with data collection on setup and run hours, and the number of actual paid hours for machine operators. Why not just look at efficiency to the time standards and the number of non-productive hours?

Good question and here's why. Let's say the hours worked by the shop changed due to,

- Increase in hours worked due to working over time
- Reduction in hours worked due to a slow down
- Increase in hours worked due to hiring
- Decrease in hours worked due to layoffs

In these instances the number of non-productive hours could go up or down justifiably because there was a change in the number of hours worked. In other words, this could give false impressions about the increase or decrease of non-productive hours. And we all know there will always be a certain amount of non-productive hours.

Using productivity gives you accurate figures regarding the percentage of time spent doing setup and run compared to machine payroll hours - regardless of the fluctuation of total of hours worked.

The moral of the story is this: You cannot just rely on looking at efficiency as compared to your established time standards. You also need to monitor your productivity — the number of payroll hours spent running the machines — because keeping the machines running is the key to profitability.

A Final Word

If you're having a particular problem or if there is a topic you would like to have addressed in this column, please send me an email at ArvinGlobal@Gmail.com. Be assured that any information you provide will be held in the strictest confidence.

Contact Fatigue Characterization of Through-Hardened Steel for Low-Speed Applications like Hoisting

Dr. Michel Octrue, Antoine Nicolle and Remy Genevier

In several applications like hoisting equipment and cranes, open gears are used to transmit power at rather low speeds (tangential velocity < 1m/s) with lubrication by grease. In consequence those applications have particularities in terms of lubricating conditions and friction involved, pairing of material between pinion and gear wheel, lubricant supply, loading cycles and behavior of materials with significant contact pressure due to lower number of cycles.

The comparison of proven old rating methods [2] with ISO 6336 has shown that ISO is very conservative for through hardened steel gear wheels running with case hardened pinions, specifically in the range of limited life. In order to clarify the situation, an experimental test methodology and a test bench has been developed with representative conditions.

To assess new values of allowable contact-pressure stress numbers, the authors present the concept and the realization of this new test bench in order to satisfy those requirements with the associated procedures of calibration and testing: low-speed tangential velocity and grease lubrication.

Analysis of experimental results and metallurgical analysis of cold work hardening of material on the tooth flank surfaces are analyzed and given on a 42CrMo4 steels. Fatigue SN curves resulting from tests are then compared and discussed with values given in ISO and AGMA gear rating standards.

Context

Open gears are widely used in many industrial applications, such as hoisting devices to drive hoist drums or slewing rings for mobile crane orientations. In those applications, they are driving or driven gears, and the cycle is not always a continuous one.

The other particularities of those gears are the following:

- The tangential velocity is low between 0.1 and 1 m/s;
- It is generally a spur gear set;
- The lubricant is often grease, applied manually or by spray device;
- The gear wheel is finished by hobbing cutting process in quality grade between 7 and 8;
- The face width is between 10 to 12 modules;
- The module is large, between 6 up to 32;
- Gear ratios are between 4 to 6.

As a consequence, and in order to stay in an economic compromise related to the requested power density, those gear sets are often made with a through hardened steel gear wheel meshing with a surface hardened or through hardened steel pinion.

Historically, the rating for those gears has been based on, for a long period of time, calculation methods that were based on experience in the field of applications, such as Henriot [2] or Dudley [8] methods, and more recently, they have been included in gear rating standards such as AGMA [5], DIN 3390 [7], and ISO 6336 [3–5].

Figure 1 shows a comparison among the Henriot 75 method, AGMA and ISO of the different fatigue curves against pitting (allowable stress according to the number of cycles) for through hardened forged steel with a 250 HB hardness, according to different methods.

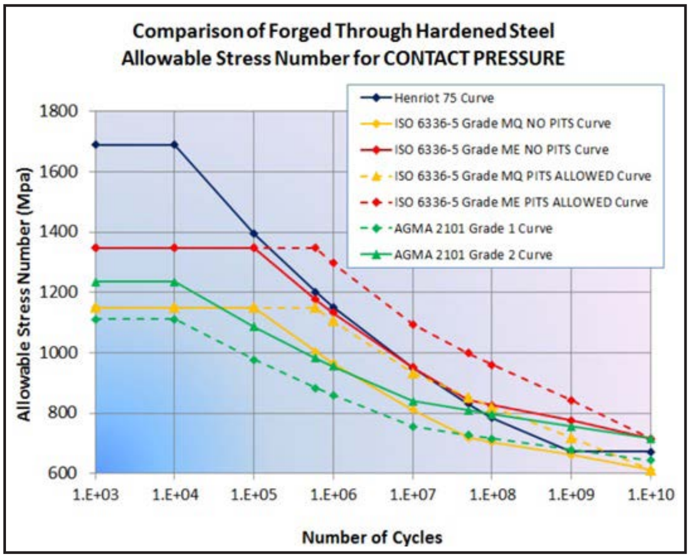


Figure 1 **Comparison of forged through hardened steel allowble contact pressure (in MPa).**

It can be observed that significant differences exist. Those differences correspond to different gear sizing. AGMA seems very conservative, and there is no evolution between the values of AGMA 210-02 and AGMA 2101. Henriot 75, which has been a widely used method by hoist builders, gives relatively high values, which can be reached with a grade MQ ISO steel if pitting is allowed or by a grade ME ISO steel with no pitting allowed.

In order to have a better understanding for open gear, The CETIM Technical Committee for Hoist Machines has decided to build an experiment program in order to:

- Have a better knowledge for low-speed open gears;
- Be able to evaluate the effect of combined hardened surface pinion with through hardened gear wheels;
- Evaluate the type of grease and its mode of application on tooth flanks;
- Evaluate the impact of tooth flank modifications.

Table 1 Gear Geometry of tested specimen 20 × 84

Item	Unit		Pinion		Wheel	
Normal module	m_n	mm	8			
Normal pressure angle	α_n	deg	20			
Helix angle	β	deg	0			
Number of teeth	z	-	20		84	
Profile shit coefficient	x	-	0.3569		-0.3569	
Tip diameter	d_a	mm	181.66	181.71	682.2	682.29
Base diameter	d_b	mm	150.351		631.473	
Form diameter	d_{Ff}	mm	151.22	151.28	652.5	652.7
Face width	b	mm	60		60	
Gear mesh characteristics						
Nominal center distance	a	mm	416			
Working pressure angle	α_{wt}	mm	20			
Contact ratio	ε_α	mm	1.606			
Material and Machining Quality						
Material MQ Grade		-	Case hardened 17CrNiMo6 60 HRc		Through hardened or induction hardened steel, either 42CrMo4 or 30CrNiMo8	
Flank tolerance class according to ISO 1328:2013	Q	-	Class 6 (grinding)		Class 7-8 (hobbing)	
Surface flank roughness	R_a	µm	0.6		1.6	

NOTE: Pinion is finished by grinding and wheel is machined by hobbing.
Pinion is made with case hardened 17CrNiMo6 or 18CrNiMo7-6.
Gear wheels are in through hardened or induction hardened steel, either 42CrMo4 or 30CrNiMo8.

Requirements for Testing

The first step was to define a representative gear specimen on which to conduct the tests; then on that basis, testing conditions have been defined.

Definition of test specimen

The following requirements have been retained for the tested specimen:

- An external spur cylindrical gear set with a pressure angle of 20°, module 8;
- The face width has been limited to 60 mm in order to limit the load force applied by the test bench and consequently its sizing;
- The number of teeth has been selected to 20 for the pinion and 84 for the gear wheel;
- The material could be either through hardened steel or induction hardened steel for the gear wheel. Pinion is case hardened. The gear wheel is the tested gear.
- The profile shift modification will be adjusted in order to balance specific sliding velocity;
- The principle of the test bench should be able to work alternatively in two rotating directions like it is in hoist applications.

Testing strategy

With such geometry and a tangential velocity between 0.1 and 1 m/s, this gives a rotational speed for the wheel between 2.8 rpm and 28 rpm, and the associated frequency for one gear pair is between 4 and 40 teeth per second. This is very low.

In order to accelerate the testing process, and rather than having a continuous motion of the gear set as is usual on a gear test bench, it had been decided to work alternatively on a sector of five teeth. This can be accepted, as in hoist applications, it works like this: a stroke in one direction followed by a stroke in the other direction. By this method, the duration of tests is reduced by a factor 8.

The load to be applied on the gear mesh has been extrapolated from ISO standard, with an increase of 20% in order to take into account that ISO 6336 gives a stress number for 1% of reliability, and rough test results correspond to 50%. This corresponds to a maximum torque to design the test bench of 35,000 Nm applied on the gear wheel, or a tangential load at pitch point of 107 kN.

Test bench concept

Concerning the architecture of the test bench, the requests were:

- An architecture in which the access to the gear mesh was easy to control without disassembly;
- An easy way to remove the tested gear, if possible, by an overhung fixation;
- As the stroke is alternative, it should be necessary that the control system is able to provide steady state conditions concerning load and speed during a significant amount of time, as it should be if continuous motion was applied.

After a compilation of all these requests, several architectures have been proposed with advantages and disadvantages: easy access, easy control of parameter during test, reliability, etc.

It results in the following:

- A compact back-to-back concept using a solid pinion (at the top of Figure 2) meshing with two independent gear wheels on the opposite flanks of the pinion. The loading is obtained by applying two opposite torques on each gear wheel.
- For a simple access to fix the tested gear wheel specimen, the gears will be overhung. The consequence of this is the bearings of the two supporting shafts for the pinion and the wheel should be preloaded, and this assembly should be stiff enough to avoid deflection of axis.
- For the control of motion, a hydraulic motion system has been retained, as the speed is quite low, and in particular, it gives a significant advantage to control the speed during the short stroke on a small number of teeth, in comparison to an electro-mechanic system.
- As the loading is significantly important, a hydraulic loading system is the most appropriate.
- The stiffness of the pinion assembly is increased by a pre-tensioner bolt.

On Figure 3, it can be seen:

- Top left: the static jack by which the two gear wheels are loaded with arm levers. The load is applied manually by controlling the pressure with a pressure sensor in bars.
- Bottom: the dynamic jack by which the alternative motion is

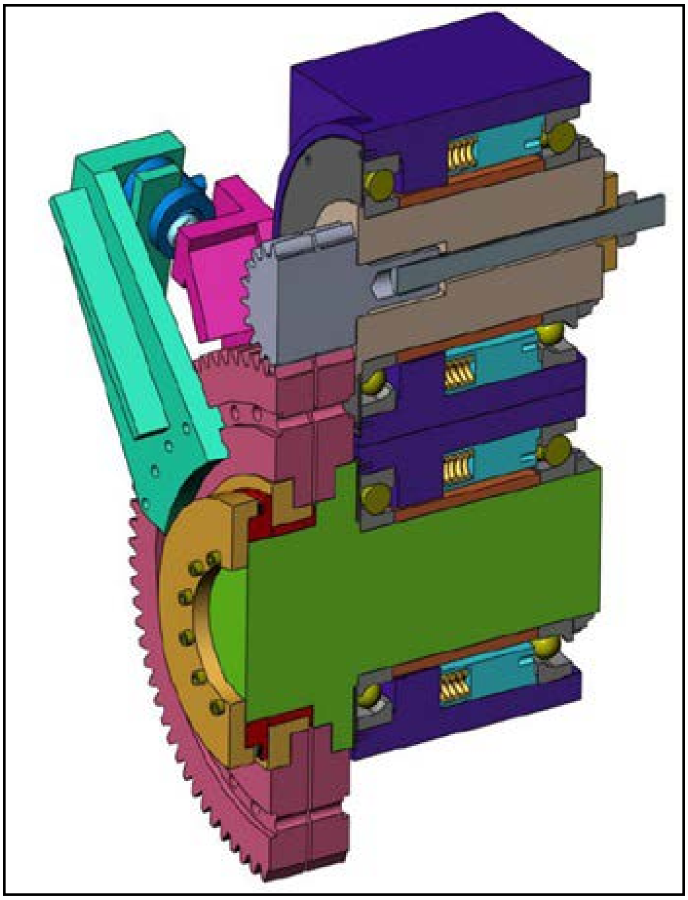


Figure 2 Retained principle for the test bench.

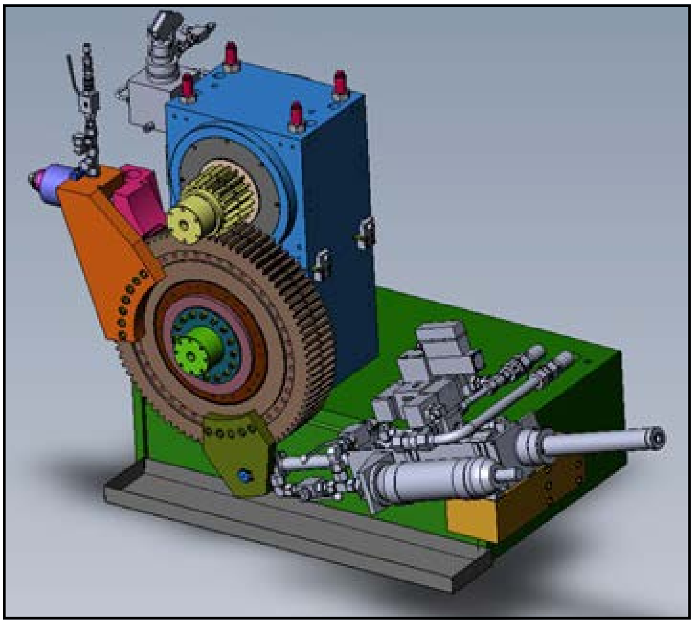


Figure 3 Test bench with hydraulic systems.

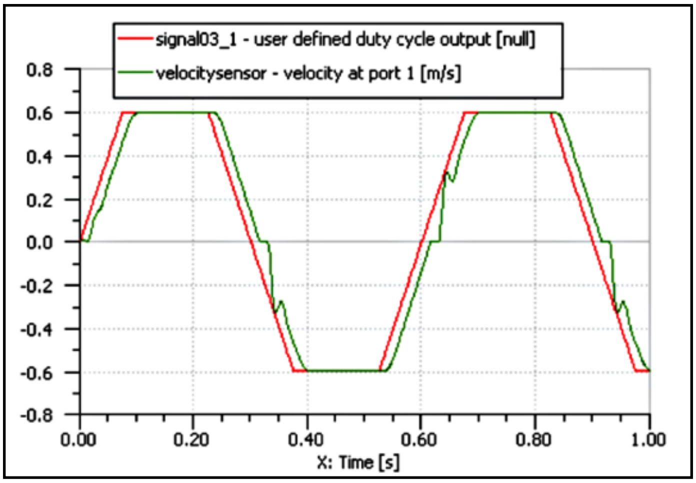


Figure 4 Simulation of speed control system.

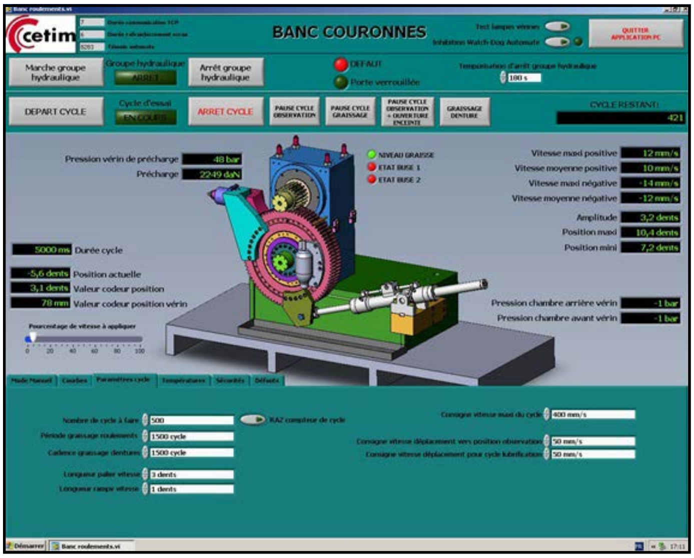


Figure 5 *Man Machine Interface* (*MMI*) of test bench.

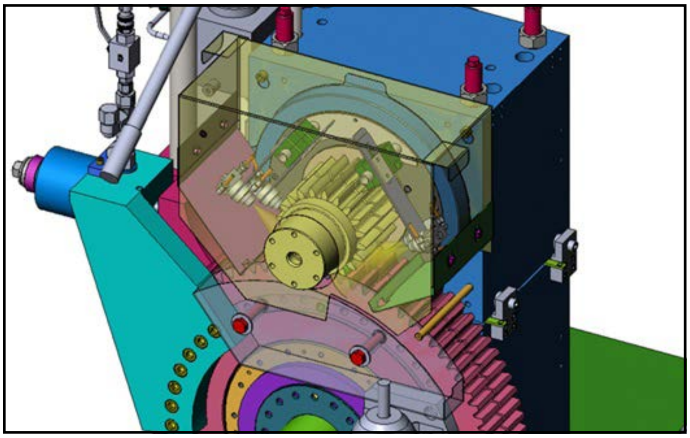


Figure 6 Nozzles of the air-grease spray systems with protector casing.

given for cycles. This hydraulic jack is equipped with a sensor displacement in order to control the speed during the stroke, and also to apply a manual stroke to move the loaded teeth out from the testing sector for observation when the test bench is stopped.

In order to answer the request to keep a constant speed during at least 60% of the full stroke equal to five times the tangential pitch of the teeth, the feasibility of such system has been designed by using *AMESIM* simulation software.

To complete the test bench, a *Man Machine Interface* (*MMI*) (see Figure 5) has been developed with *Labview* (*NI*) in order to set up the parameters for each test and also to control the real motion law applied on the dynamic jack.

During the qualification of the test bench, as the working conditions on a limited sector of five teeth, it has been requested to implement an automatic spray lubrication air-grease flow system in order to assume a correct lubrication (see Figure 6).

Casing has been designed around the gear mesh in order to maintain a clean environment around the test bench and collect sprayed grease.

After several tests, two greases have been selected:

- FUCHS Ceplattyn 300 in first manual application;
- FUCHS Ceplattyn KG10 LC in continuous lubrication by spray application.

Calibration

Displacement system

The first step was to check the hydraulic displacement system. This has been done directly with the *MMI*, where it is possible to represent the setting signal and the real speed, as below in Figure 8. The two other curves show the chamber pressures for the displacement of the dynamic jack; fluctuations are due to the number of gear pairs in contact.

Loading system

The second calibration was to check the linearity and the repeatability of the deformation under loadings. The relation between applied pressure in the loading jack and the relative tangential displacement between the two tested gear wheels.

For this, a non-contact displacement sensor was implemented between the two gear wheels, and strain gages located by laser marking placed in the fillet of the pinion allowed for a complete correlation between the applied loading and deformations (see Figures 9 and 10).

In order to synchronize all the measurements according to the gear wheel rotation, a high-resolution inclinometer has been fixed on the shaft in order to record the angular position of the gear wheel. The relation is nonlinear, in particular, at low loadings because it is requesting a minimum loading value to balance friction forces.

Testing Results and Analysis

The test bench has been in service since the beginning of February 2014, with gear wheels made with through hardened 42CrMo4 steel (202 HBN from the gear wheel certificate),

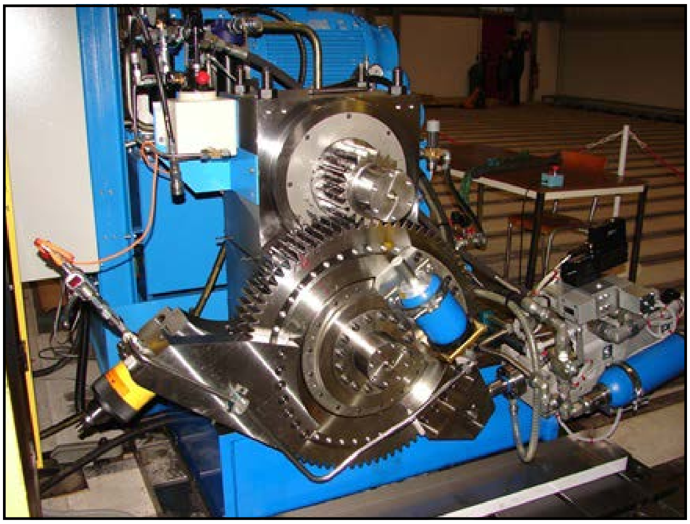


Figure 7 Test bench without casing and lubrication system.

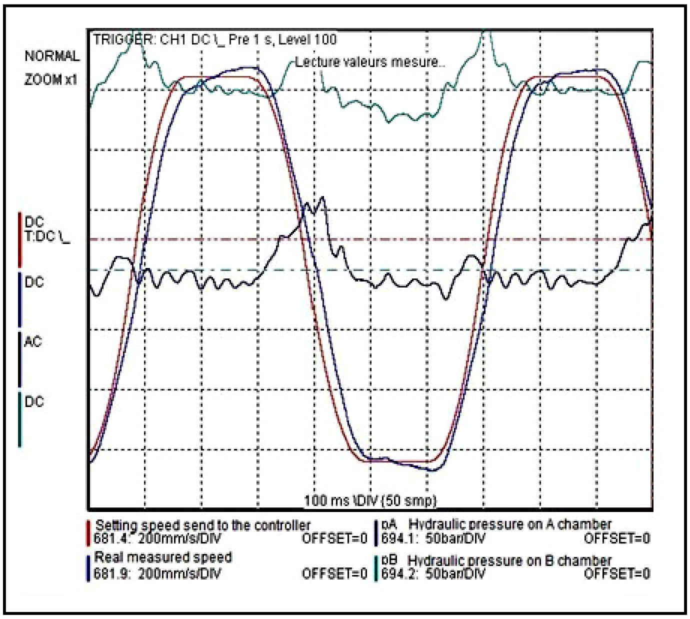


Figure 8 Comparison of speed displacements.

Figure 9 Non-contact displacement sensor.

with a realized flank tolerance class 7 according to ISO 1328:2013.

To conduct the test, and in order to have an idea of the load levels to be set up on the test bench, the following fatigue curves have been evaluated from ISO 6336 with an increase of 20%. The predicted fatigue curve on that basis is represented in Figure 12 by the yellow triangles for the first pits and generalized pitting.

In order to be sure to reach failure by pitting, the first tests have been run lightly above the maximum level predicted by ISO 6336. The first pit has been obtained after 840,000 cycles, and after 1.6 million cycles, no significant progression was observed (see Figure 13). A metallographic analysis has been decided by cutting the tooth and measuring hardness in three areas: filet, close to the pitch point, and tip. In Figure 14, we can observe a cold work hardening of material in the single gear pair contact area with a very important increase of the surface hardness, up to 355 HV1 ≈ 335 HBH (+66%).

Consequently, it means that the material is reinforced in the most loaded area (area with single gear pair in action, with peak pressure at HPSC), so it is necessary to apply a correction to ISO fatigue curve by using a surface hardness of 335 HBN. See dotted lines on Figure 15 (120% of ISO 6336 levels for 335 HBN).

NOTE: Figure 15 is equivalent to Figure 12 with the corresponding surface contact pressure to the torque on the pinion.

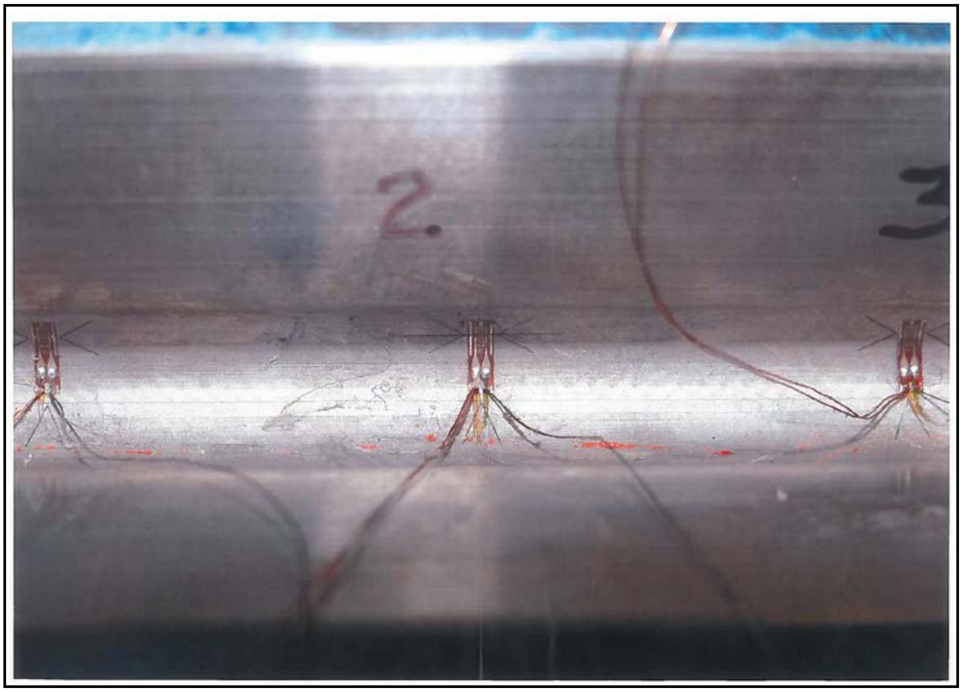


Figure 10 Localization and strain gages in the filet before protection (With laser marks for positioning).

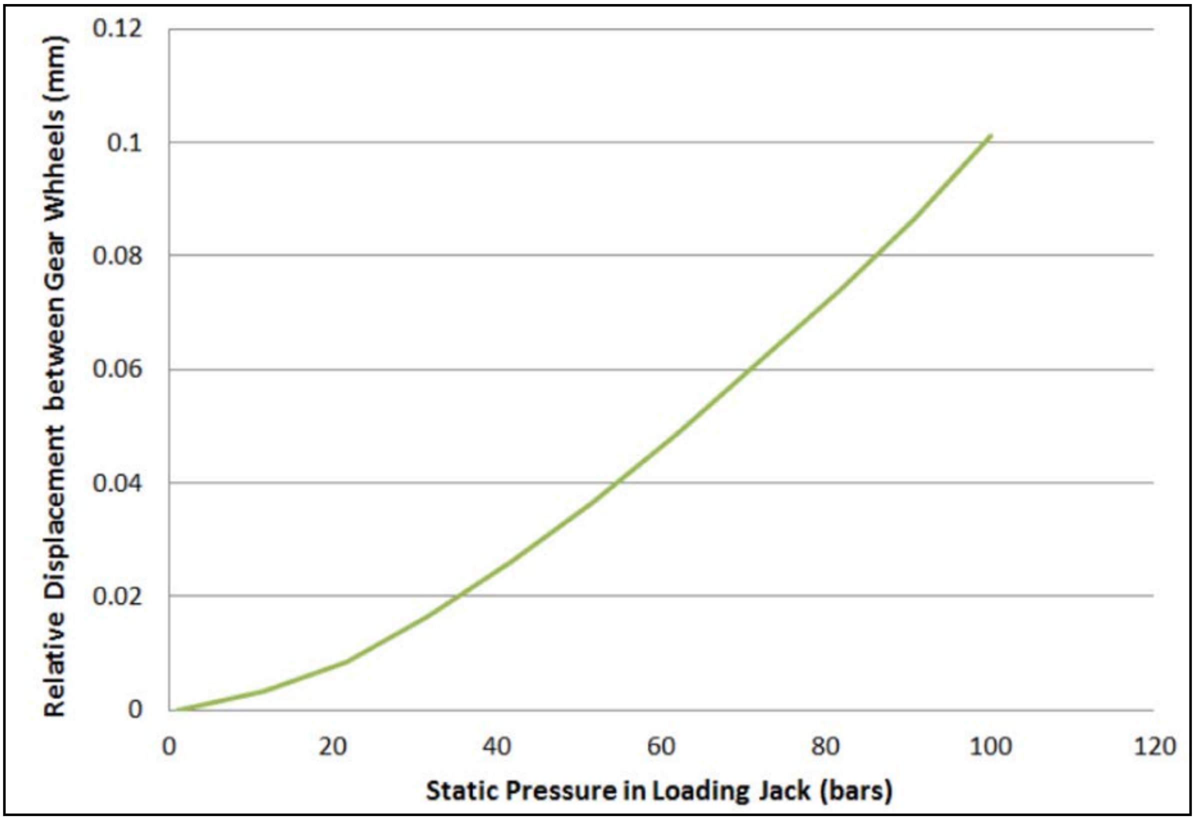


Figure 11 Measured relative displacement between wheels according to loading pressure.

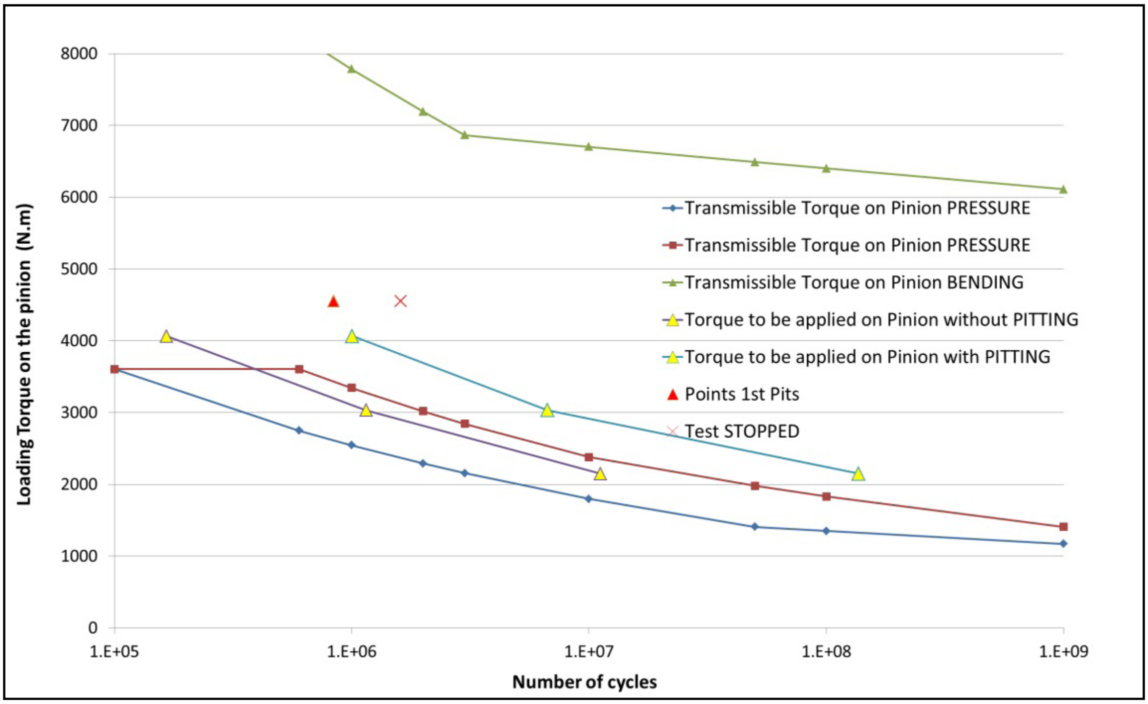


Figure 12 Loading Torque Levels to test 42CrMo4 with contact pressure and bending limits.
NOTE: Figure 12 represents the torque on the pinion according to the number of cycles on one tooth flank. Triangle represents the minimum level to reach for 50 percent of probability of failure. It indicates the real loadings to apply on teeth.

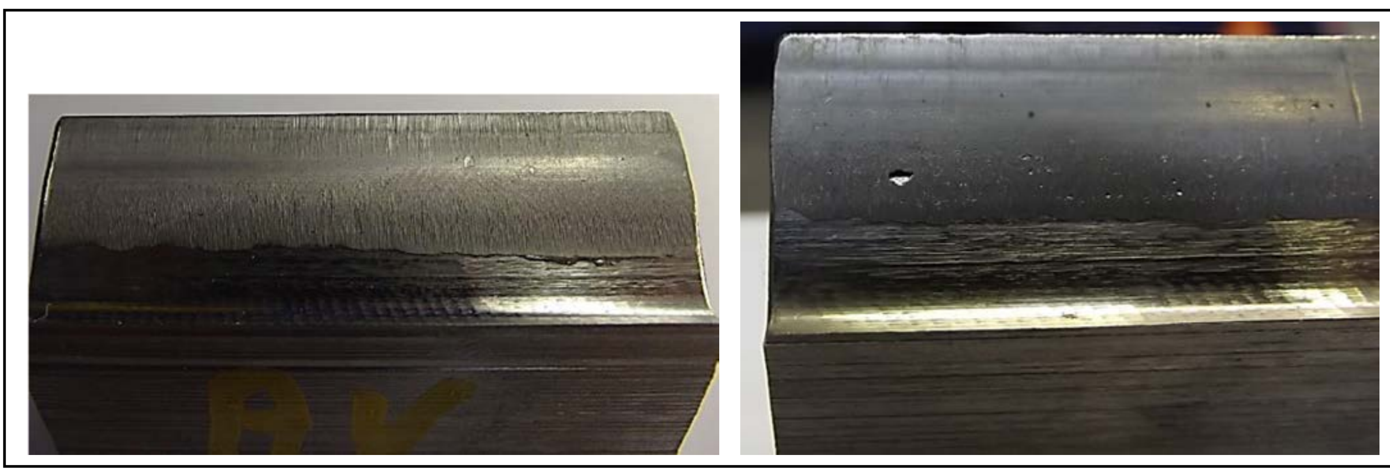


Figure 13 Tooth flank of teeth N° 48 and 50 after 1.6 million cycles.

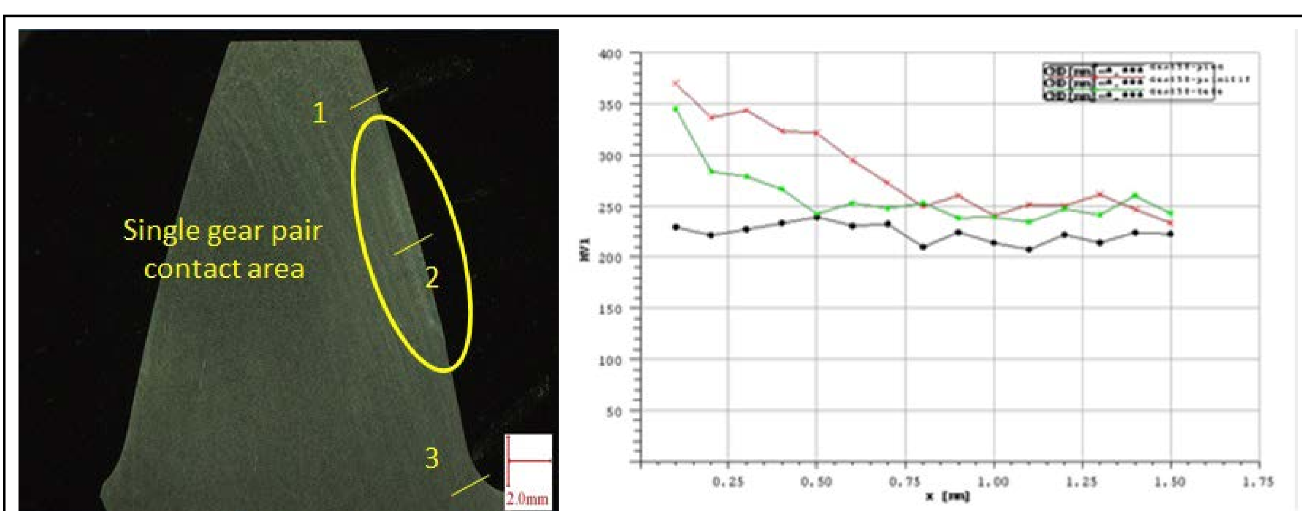


Figure 14 Section of tooth and micro-hardness profile.

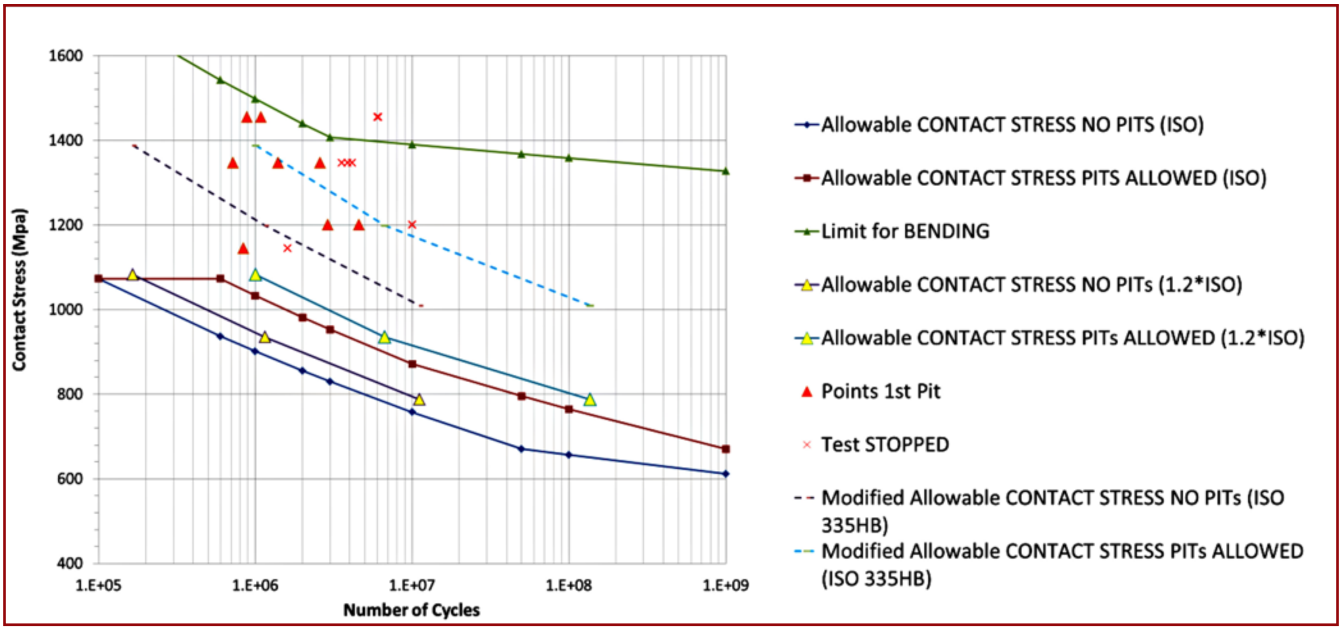


Figure 15 Contact pressure fatigue results for 42CrMo4 with test results.
NOTE: Figure 15 is equivalent to Figure 12 with the corresponding surface contact pressure to the torque on the pinion.

Figure 16 Tooth flank after 4.2 Mcycles at 1347 MPa (left) and 6 Mcycles at 1455 MPa (right).

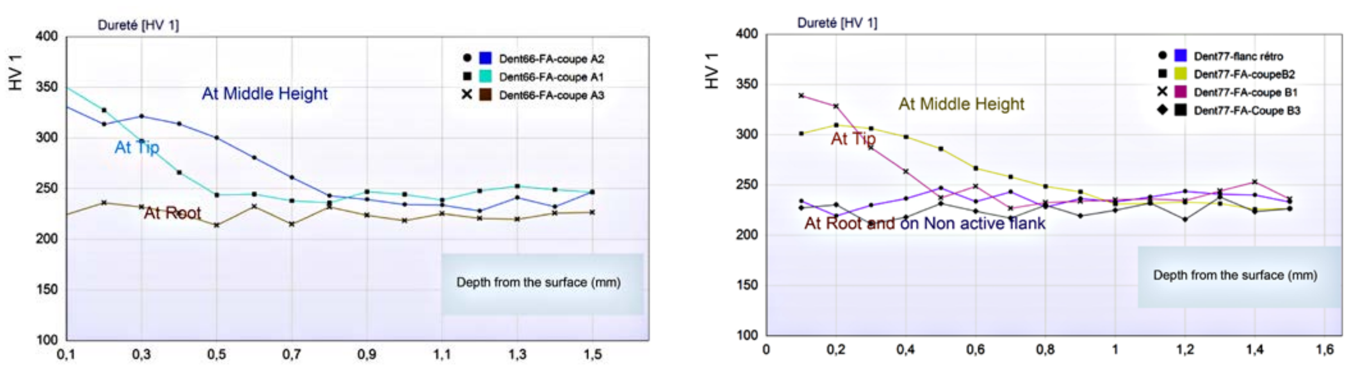


Figure 17 Hardness profile after 4.2 Mcycles at 1347 MPa (left) and 6 Mcycles at 1455 MPa (right).

Figure 18 Tooth flank after 10 Mcycles at 1200 MPa.

On that basis, new tests have been run at a surface contact pressure level of 1347 MPa. Here again, the first pit appeared far away from the prediction, but with a smooth propagation along the face width on the surface close to the highest single point of contact of the wheel, where the contact pressure is maximum. Those tests were continued up to 4.2 million cycles.

In order to see the sensitivity to cold work hardening, we increased the contact pressure up to 1455 MPa in just above the bending fatigue limit of teeth. The first pit appeared a little bit earlier, but the progression on the tooth flanks was not critical. See Figure 16.

In those results, the lubricant factor Z_L has been set to 1, as ISO 6336-2 does not allow extrapolation beyond 500 cSt; the work hardening factor, Z_W, has also been set to 1, as ISO 6336-2 is not established for such working conditions (low speed and grease lubrication).

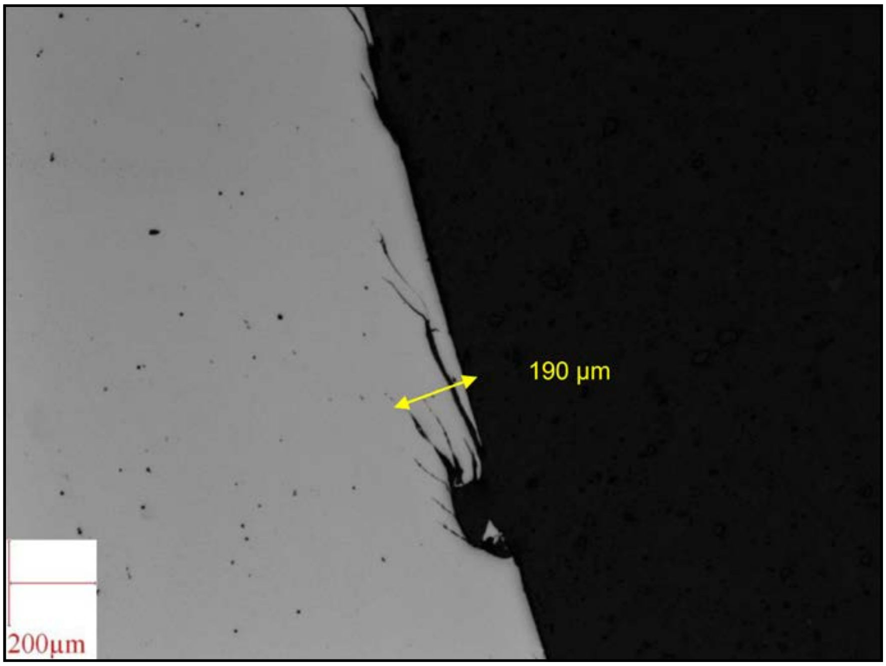


Figure 19 Tooth flank after 10 Mcycles at 1200 MPa.

In order to have an idea of the hardness characteristics of the flank in the area of the single gear pair, contact investigations have been carried out (see Figure 17). We can observe that the area affected by cold work hardening of material is roughly the same on the surface even with the increase of the contact pressure. The hardness is increased up to 300 HV1~285 HBN on a 0.5/0.6 mm depth, which corresponds to one times the half-width of Hertzian contact; a little more depth than the maximum contact shear stress (0.4/0.52 mm).

In order to complete the result, we decided to run two tests up to 10 million cycles, which is significant for such a low-speed application. Figure 18 shows the results of the two tests. Here again, the flanks present a small trace of cracks along the face width located close to the highest single contact point of the gear wheel (corresponding to the area of maximum contact pressure due to minimum radius of curvature of the pinion).

Nevertheless, no cracks have been observed below the surface; only small cracks have been observed from the surface up to a maximum depth of 200 µm for the highest loaded teeth (see Figure 19).

To evaluate wear effect on active flanks during endurance, span measurements have been provided at the end of each test in reference to the non-active flank at different profile diameters: no significant wear has been observed (< 0.05 mm), and it can be concluded that the observed wear effects did not impact the contact pressure results.

Comparison with AGMA

Figure 20 represents the same curve as in Figure 1 but adjusted for 335 HBN, taking into account the cold work hardening effects.

Those curves do not take into account the +20% correction.

We can see that the AGMA values are now crossing the ISO MQ curves.

Comparing with Figure 15, we can see that AGMA, as ISO, indicates conservative values for such working conditions.

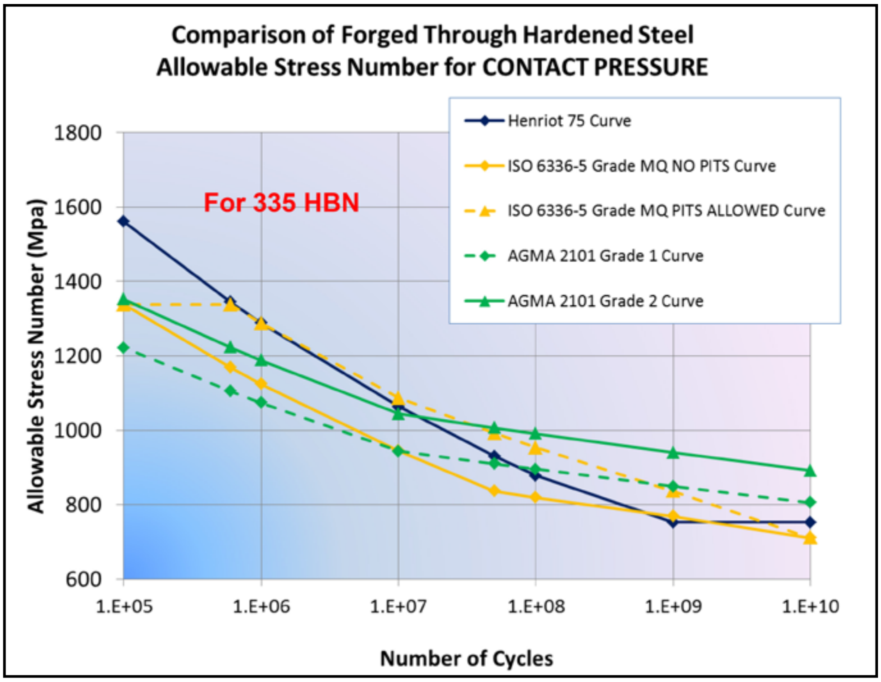


Figure 20 **Comparison of forged through hardened steel allowble contact pressure (in MPa).**

Conclusion

This new testing rig allows us to investigate a low-speed open gear performance under the following conditions, for a 42CrNiMo4 steel gear wheel:

- Running with a ground case hardened pinion with tip and root flank modifications;
- At low speed (tangential velocity < 0.5 m/s);
- With spray lubrication and a good grease;
- After running-in (2h at 25%, 2h at 50%);

The load capacity of 42CrMo4 is significantly improved due to work-hardening.

ISO 6336 seems very conservative and must be improved for such gears with lubricant factor Z_L for grease, and with the work hardening factor Z_W.

Perspectives – Additional Research

At the moment, several tasks are in process and planned:

- Stress and deformation analysis is in process on a new gear wheel set made in forged through hardened 30CrNiMo8 at 265 HBN.
- A new endurance test with the second forged through hardened 30CrNiMo8 is in process with the study of the kinetics of cold-work hardening process.
- An elasto-plastic analysis by nonlinear finite element calculations combined with elasto-plastic fatigue behavior law is in process on the 42CrMo4 steel basis of testing results in order to:
- Check the prediction of the cold-work hardening effect.
- Study the prediction of the cold-work hardening effect on larger module.
- A new testing program is in the study in order to use this test bench to qualify greases in such working conditions.

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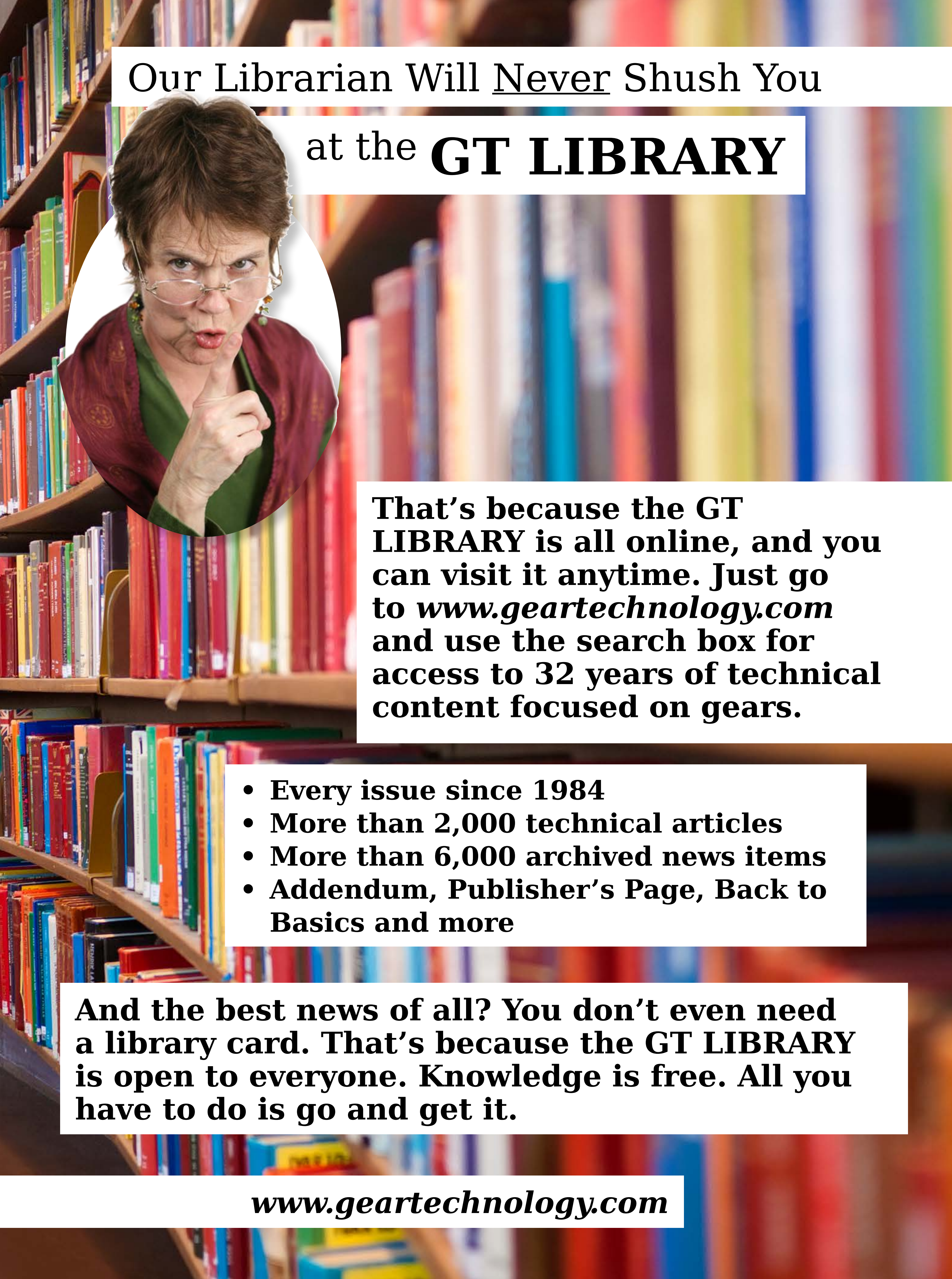
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MicroPulse and MicroShift for Ground Bevel Gearsets

Dr. Hermann J. Stadtfeld

Editors' Note: The June issue of Gear Technology contained the technical paper, "Surface Structure Shift for Ground Bevel Gears," by Sebastian Strunk of Gleason Corp. The following paper, "MicroPulse and MicroShift for Ground Bevel Gearsets," by Gleason's Dr. Hermann J. Stadtfeld, addresses the conclusion subsequently made to combine MicroPulse and structure shift techniques in one package, which were then programmed into summaries and machine controls.

Introduction

Grinding of bevel and hypoid gears creates on the surface a roughness structure with lines that are parallel to the root. Imperfections of those lines often repeat on preceding teeth, leading to a magnification of the amplitudes above the tooth mesh frequency and their higher harmonics. This phenomenon is known in grinding and has led in many cylindrical gear applications to an additional finishing operation (honing). Until now, in bevel and hypoid gear grinding, a short time lapping of pinion and gear after the grinding operation, is the only possibility to change the surface structure from the strongly root line oriented roughness lines to a diffuse structure. Lapping after grinding was never a process combination of choice for several reasons. The additional operation is costly and it causes abrasive grit to penetrate into the surface, just as the case as if lapping were the only finishing operation. Also, for short a time lapping pinion and gears are mated after they leave the lapping machine. This in turn reduces or eliminates some of the advantages grinding would provide over lapping (Ref. 1).

However, the surface structure from lapping superimposed to a precisely ground flank surface presents a combination of accuracy and texture which could significantly enhance the rolling performance of bevel gearsets. In generating grinding for bevel pinions and generated bevel ring gears, the grinding wheel represents a tooth of the generating gear to the work, while the work rolls on the generating gear to finish profile and lead. The contact zones are lines that lie under an inclination angle α_t (Fig. 1).

The regularities in the generating flats and in the roughness lines are the sources of certain noise excitations. The frequencies induced can be high multiples of the tooth mesh frequency, but are often also reflected in the first three mesh harmonics. Figure 2 shows in an exaggerated way the generating flats and the tracks of the tool roughness. In grinding, the generating flats are very small, but the grinding grain tracks are dominating with respect to surface roughness.

Generating flats in grinding, however, are *theoretically* nonexistent because the grinding wheel surface represents a continuum of microscopic cutting edges. But *practical experience* teaches us differently. The explanations for those generating marks are the texture on the grinding wheel surface, run out and imbalance in the grinding wheel, and inaccuracies caused by the wheel dressing cycle. In addition to the wheel-based effects, the machine movements could also cause generating marks. The part program that consists of basic settings is converted into a table of axis positions; i.e. — it can be visualized as several hundred lines, where each line has a position value for each axis of the free form machine (X, Y, Z, A, B and C). As the machine moves from one line of axis positions to the next, the controller software tries to connect the discrete positions with a smoothing function. However, the machine might pause for some milliseconds in each position and generate a "microflat." Figure 1 shows a tooth surface with a number of microflats, which is in reality a factor of 10 higher then shown. Each flat has a cone envelope function that can be modified in different ways (Ref. 1).

Until today, no attention had been paid to the fact that not only are the microflats consistent with the timing of each tooth

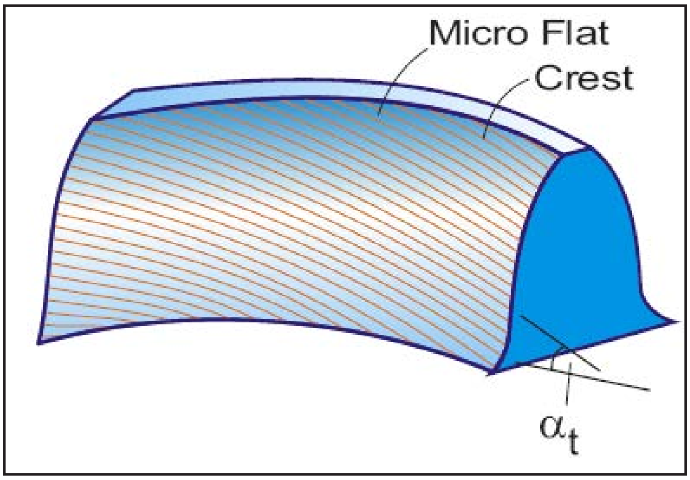

Figure 1 Micro flats on a ground flank surface under inclination angle at.

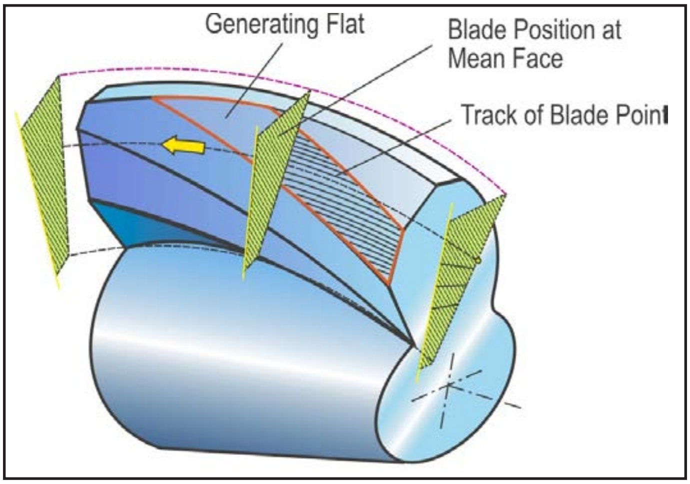

Figure 2 Generating flats and grinding wheel roughness traces.

mesh, but also with each other imperfection as well as desired flank surface modifications such as UMC relief section and, for example, Flankrem are located along the path of meshing at the same roll position. The roll positions of each tooth around the circumference of a gear repeat with a phase shift from tooth to tooth which is equal to one pitch:

$$q_i = q_1 + i * 360°/z \quad (1)$$

where:

q_i particular roll position; e.g. start roll position on tooth i

$q1$ particular roll position on tooth number 1

i number of any chosen tooth on observed gear → $\{1 \leq i \geq z\}$

z number of teeth of observed gear

All disturbances or dynamic events that repeat from tooth to tooth during the operation of a gear set will repeat, depending on the manufacturing tolerances very precisely to one pitch. The consequence of this is, for example, that flats or imperfections will generate audible sound with a frequency equaling the number of their occurrence per tooth mesh, multiplied with the fundamental tooth mesh frequency. It is worth mentioning that such frequencies that are commonly between two and twelve times the tooth mesh frequency will also increase the intensity of the amplitude of the tooth mesh frequency. This phenomenon is called "ghost fundamental" (Ref. 2).

The main topics of this paper are:

- Surface structure caused by generating roll
- Scramble of tooth mesh events
- The principle of MicroPulse
- Surface structure generated by MicroPulse
- The principle of structure shift
- Generic structure shift
- Natural structure generation
- Application of structure generation and structure shift
- Conclusion

Noise Reduction by "Scrambling"

The expression "scrambling" has been used for the determined or random change of geometrical features from tooth to tooth on gears. One example is the introduction of a random spacing error (Fig. 3). The goal of this "tooth position scrambling" was to reduce the fundamental tooth mesh frequency generated by the tooth mesh impact, and precisely repeats with the timing of one pitch — depending on the gear quality. It was expected that the existing tooth impact energy would now be partially re-directed to the side bands and therefore provide an additional masking of all harmonic amplitude peaks. Ground gears show a very high gear quality, which is why the intensity amplitude of the tooth mesh frequency is particularly high. The attempt to break the high intensity down by adding spacing errors failed for several reasons. The random tooth spacing errors reduce the gear quality rating, which makes it difficult to monitor the soundness of a grinding production. Furthermore, tooth spacing variations reduce the effective contact ratio under load, which affects the load carrying capacity of a gearset (Ref. 3).

However, the original goal — to reduce the vibration and noise emission of gearsets — also failed. In the example in Figure 3 the rack is shifted with a constant speed. The gear rotates

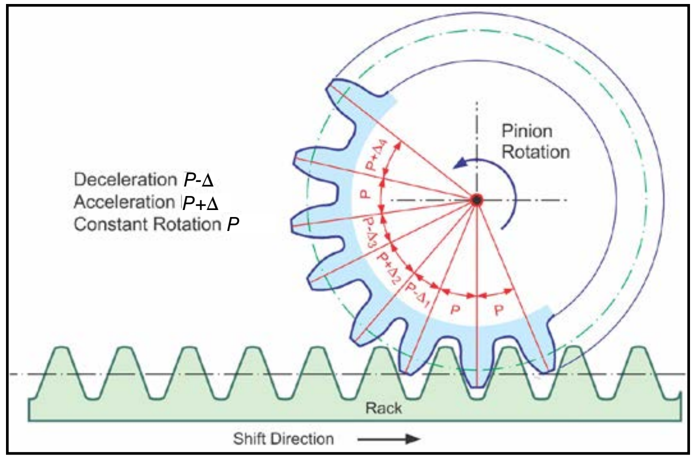

Figure 3 Introduced spacing error.

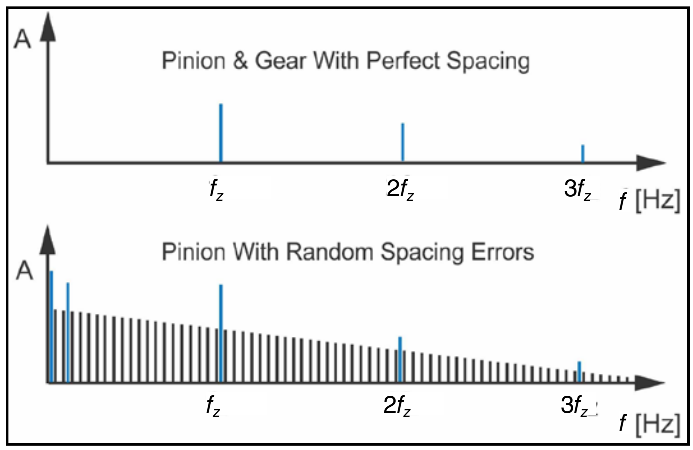

Figure 4 FFT of gear with perfect spacing (top) and random spacing errors (bottom).

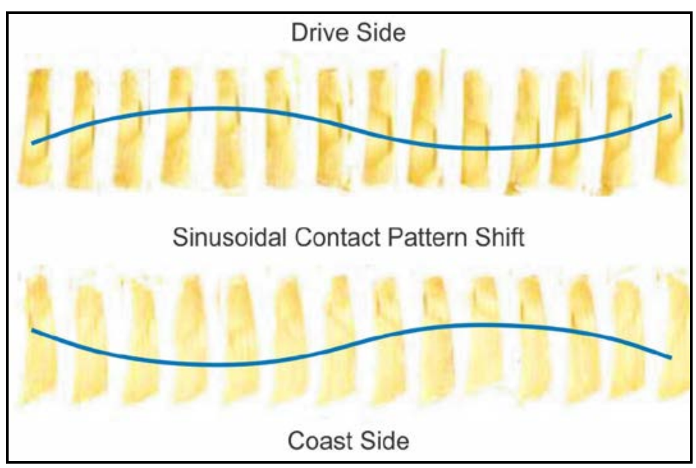

Figure 5 Sinusoidal contact pattern shift (Ref. 3).

with a constant RPM while the teeth with a spacing of p are in mesh. When the first tooth with a lower spacing p-D_1 contacts the rack, an increased meshing impact and an additional deceleration occur. The following tooth with a larger spacing $p+D_2$ causes a lower mesh impact and an acceleration of the pinion rotation. Figure 4 (top) shows the fast Fourier transformation (FFT) of a single flank test working variation in case of a meshing pinion and gear with high spacing quality. Analysis results of trial gears manufactured with spacing errors D of 5 micro-radiant showed increased first harmonic amplitudes, while additional low-frequency amplitudes in the range of the pinion and gear rotational frequency had also been created. Additionally, bars in the entire frequency range that reduce their amplitude with increasing frequency (impulse effect) were present.

The attempt to develop a more sophisticated approach was proposed with the position change of the tooth contact pattern from tooth to tooth, in an either random or, for example, sinusoidal pattern. For the amounts of change, the period of one sine function is used (Fig. 5). The first trial was not successful because the first order corrections, which had been used to realize the contact pattern position change, induced spacing errors. The elimination of the spacing errors also did not lead to a noise reduction. The spacing errors in bevel and hypoid gears are measured in the center of the flank surfaces. With respect to the constantly changing tooth-to-tooth location of the first meshing impact, the spacing errors were still present; and, the frequency spectrum of a single flank analysis post processed with a fast Fourier transformation (FFT) also showed high first harmonic amplitudes and disturbingly low frequency peaks.

The Principle of MicroPulse

The basic idea of MicroPulse grinding is the use of machine motions of different frequencies in order to generate a surface texture that will break up the orientation and the regularities, due to the grain movements on the surface of the grinding wheel relative to the flank surfaces. Micropulsing is the change of one or more axis positions with the frequency of the axis position commands. Since the axes already move simultaneously from one roll position to the next — which takes milliseconds — small amounts of movement can be added or subtracted without causing a vibration like the term "pulse" may suggest. An example for the frequency of the micro modifications is shown below:

$$f = 1/t$$
$$t = 1\text{sec}/299\text{flats} = 0.0033 \text{ sec}$$
$$f = 299 \text{ Hz}$$

where:
f… Frequency
t… Time of machine movement from one flat to the next

The frequency can also be lower (every second or third position command), but not higher. The principle is the modification of the axis position table, which is executed by the free form machine controller allowing movement from one microflat to the next. A line in the axis position table with, e.g., 300 lines of X, Y, Z, A, B and C positions, is modified by adding a linear or angular dimension (e.g., 2 microns or 3 angular seconds) to one of the linear dimensions (e.g., Z-axis or B-axis). The next line of positions is used to subtract the amount previously added from the same axis designation.

The amount added and subtracted can also follow a linear or higher-order function, or can be randomized. This has to happen within certain limits to limit the change from flat to flat below, e.g., 5 microns, and to limit the change between the extreme changes, e.g., first and last flat below e.g. 5 microns in order to assure trueness of flank form and to preserve the effect of a noise optimal surface structure.

Preferred vector directions for micro pulsing:

a. tangential to the flat
b. tangential to the grinding wheel cone (in axial plane)
c. axial movement represents the compromise of b) for outer and inner grinding surface
d. radial movement towards flank (normal to flat)
e. sideways movement tangential to flat (different to a)
f. combination of a), b), c), d) and e), combination can change from flat to flat
g. single movement a) through e) but changing axis from flat to flat
h. combination movement similar to f) but with changing quantity from flat to flat
i. single axis movement with changing quantity from flat to flat, axis designation can also change from flat to flat

The axis movement (micropulsing) is a superimposition of delta values upon the theoretical axis positions. The surface form modification cannot be detected by a regular coordinate measurement, which assures that no sacrifice in measurable part quality is made by applying MicroPulse.

The grinding developments using MicroPulse give the optical appearance of the flank surface of a more irregular structure, compared to conventionally ground surfaces. Figure 7 (right) shows the result of a MicroPulse grinding, using 5 mm pulse amplitude in Z-axis direction (Fig. 6) and a random contents of ±2 µm. Compared to the left photograph of a conventionally ground flank surface, the MicroPulse structure appears to have more wave amplitudes and higher roughness peak amplitudes. This is only an optical illusion, as surface roughness measurements show better results for *Ra* and *Rz* in case of the MicroPulse-treated surfaces (Ref. 1).

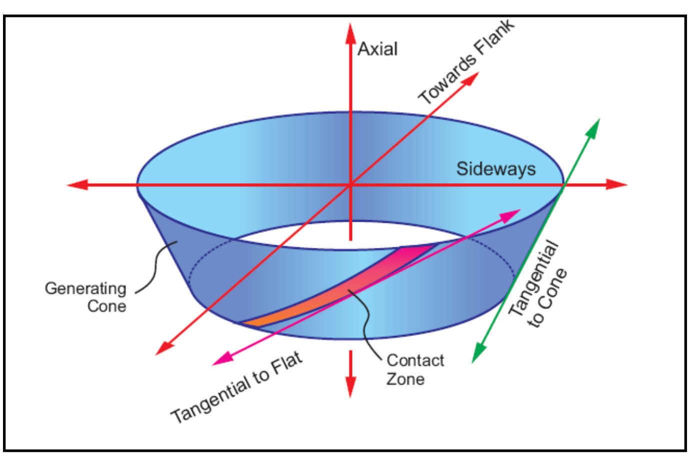

Figure 6 Possible directions of micro motions.

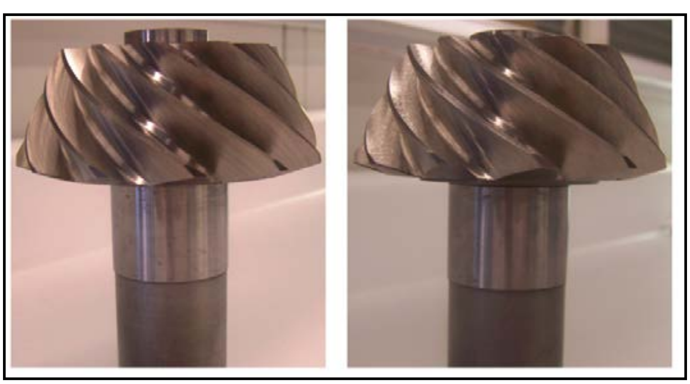

Figure 7 Standard surface structure (left), MicroPulse structure (right).

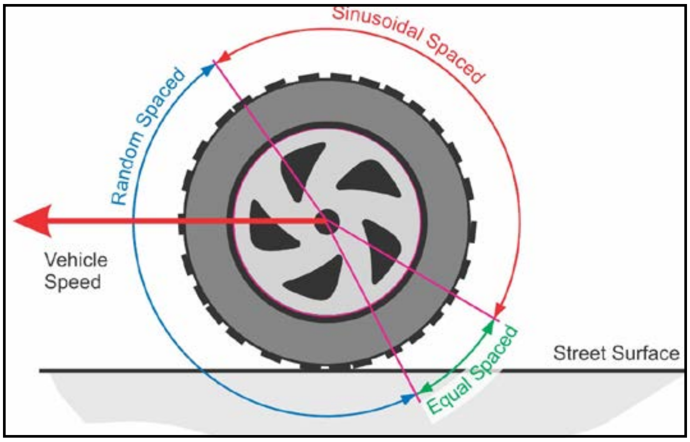

Figure 8 **Differently spaced treads on an automobile tire.**

Controlled Surface Structure Shift

The idea of purposely introduced spacing errors between the teeth was literally taken from the pitch variation of automotive cooling fan blades and the irregular spacing of the pattern on vehicle tires (Ref. 4). Although the tire with its differently spaced treads (Fig. 8) suggests a similarity to the gear with tooth spacing variations in Figure 3, the physical principles that are applied in both cases are quite different. The wheel in Figure 8 will not change its RPM, nor will the vehicle speed change as a result of the random- or sinusoidal-spaced tire treads. The treads merely have an influence on the dynamics and noise generation due to the changing contact frequency between rubber sections and street surface. The analogy in gearing is also the modulation of the contacting surfaces — not the phase location of those surfaces. In other words, this means that the teeth have to be equally spaced in order to assure proper function of a gear transmission but the surface texture should be shifted within each tooth and from one tooth to the next.

Carrying the principle of the tire treads a step further would result in different tread pattern shapes around the tire, in addition to the unequally spaced treads. A useful analogy in gears is shown in Figure 9; the left vertical sequence of pinion flank surfaces of three consecutive teeth shows from tooth to tooth a sinusoidal shift of the first generating flat, which is also mathematically represented in the diagrams on top of each tooth. The right vertical sequence of flank surfaces of three consecutive teeth shows that the generating flats no longer have equal distance. The flat widths follow a sinusoidal function that is phase shifted from tooth to tooth according to the sine-graphs plotted in the diagrams above each tooth.

It appears that a modulation that utilizes both principles according to Figure 9 is redundant. The right column (Fig. 9) has sinusoidal-spaced generating flats where the sine function is phase shifted from tooth to tooth. This modulation function already contains all the elements for variable generating flat spacing, as well as an individual tooth-to-tooth shift of the generated surface.

It has to be considered that tooth flanks are not rolling onto each other like the tire on the street surface. In the case of hypoid gears the contact area moves from entrance to exit point due to a combination of a relative rolling and a relative sliding motion between the contacting pinion and gear flank. Rolling and sliding velocity vectors that indicate the directions of those

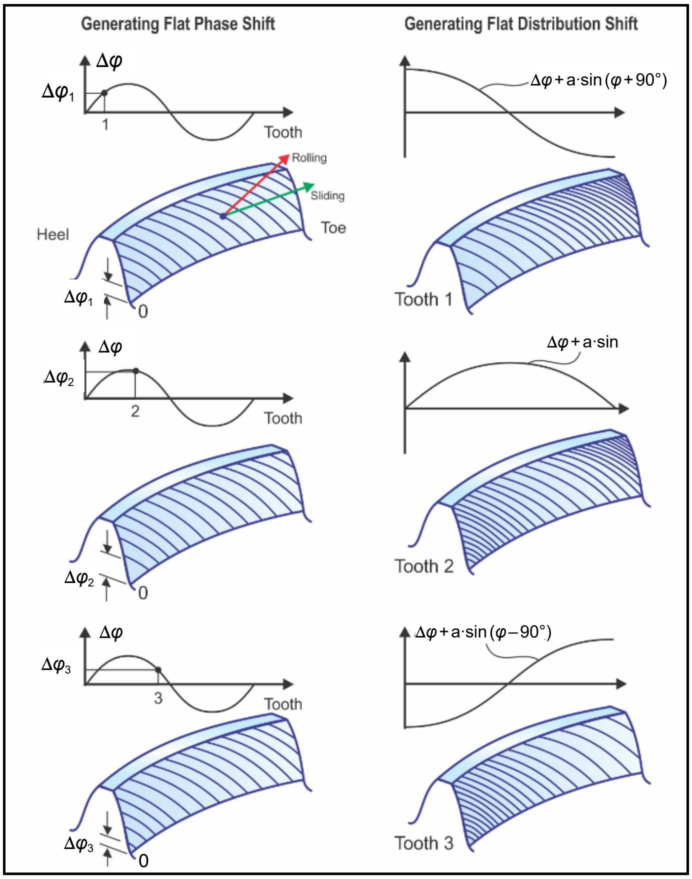

Figure 9 **Structure shift within one flank and from tooth to tooth.**

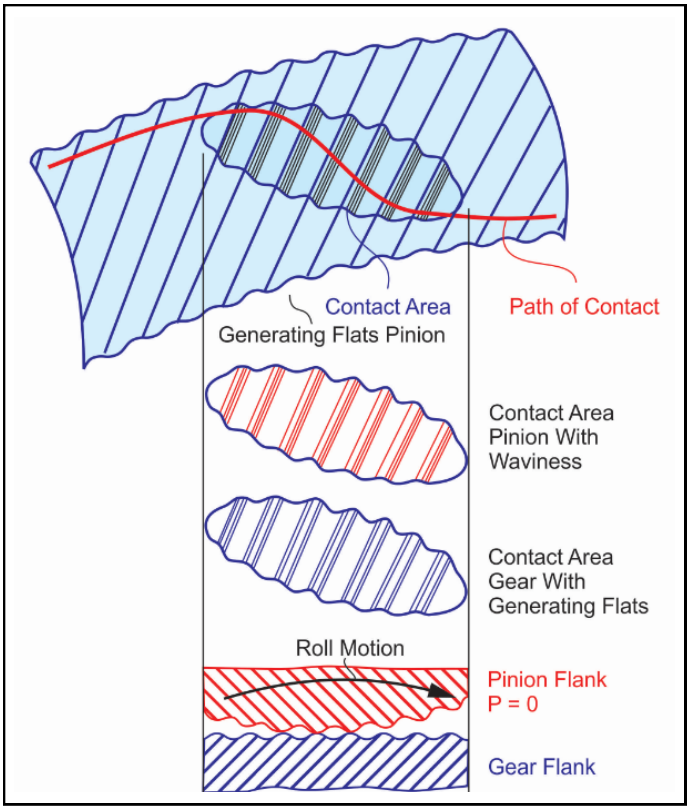

Figure 10 **Generating flat interaction between pinion and gear.**

motions are shown (Fig. 9, upper-left tooth). While the rolling velocity direction is mainly perpendicular to the generating flat direction, the sliding velocity changes its direction between entrance and exit point. If the gear flank surfaces that mate with the generated pinion surfaces are manufactured with the Formate process, then there will be no additional kinematic excitations induced by the gear, excepting some influence from the surface roughness. The sliding in connection with the surface roughness will provide some dampening of the dynamic excitation generated by the rolling process.

If both pinion and gear flanks are manufactured by the generating process, then both members will show some generating flat structures. Figure 10 shows the interaction of two generated flanks within their contact pattern area. The excitations induced by the two surface textures are rather complex. Without any modulation of the generating flat locations and distances, there will already be variations in the distances of the generating flats of spiral bevel and hypoid gears between toe and heel due to the changing spiral angle. There will be additional modulations based on machining tolerances that will influence the phase relationship of the generating flat waves shown in the bottom graphic in Figure 10. It would be difficult and unrealistic to achieve a sophisticated generating flat shift and spacing variation that will sustain its rolling noise significant shape and location due to realistic production conditions and the customary assembly tolerances.

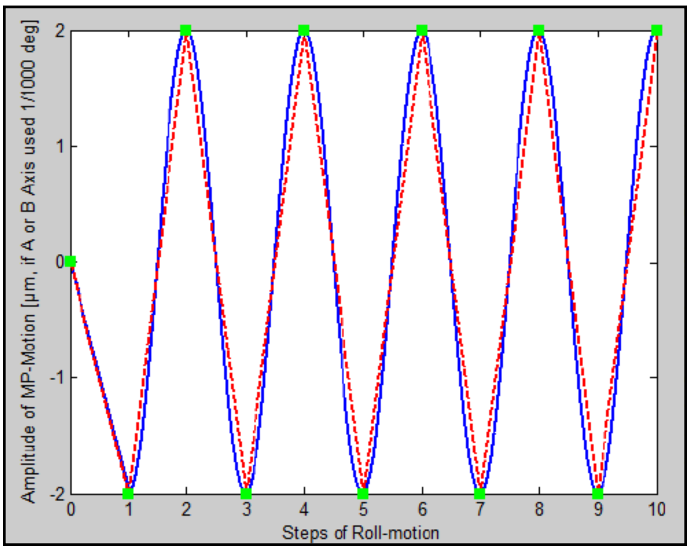

Figure 11 Approximated sine wave with 3 anchor positions N per wave (Ref. 5).

Robust Structure Shift for Productive Grinding Production

The combination of a generated pinion and a Formate gear seems particularly well suited for the application of an advanced MicroPulse and MicroShift process. The gear member will not exhibit any generating flats independent from the speed of plunging. Thus, surface texture form generating flats can be only created on the pinion. Depending on the roll rate, there may not be any existing surface texture on the pinion flanks (except the roughness streaks).

In order to achieve a suitable surface texture, the X-axis is selected as the preferred pulsing axis and the number of generating positions describing one sine period is chosen at three. Three generating positions present the smallest number to guide a complete sine wave from 0° to 360° — as shown (Fig. 11; e.g. point 1 to point 3). The spacing of the points along the abscissa corresponds to the number of axes position lines in the CNC part program and therefore is generally constant. In order to avoid truncated sine waves, the number of sine function anchor points should start at three and always be odd. The finest sine wave along the path of contact is achieved with three anchor points, which means that a minimum of three roll positions (or generating flats) are required to form one sine wave. If for example the number of anchor points is increased to five, then the sine waves are twice as long (on the flank surface) and one wave requires five roll positions. This results in a courser wavi-

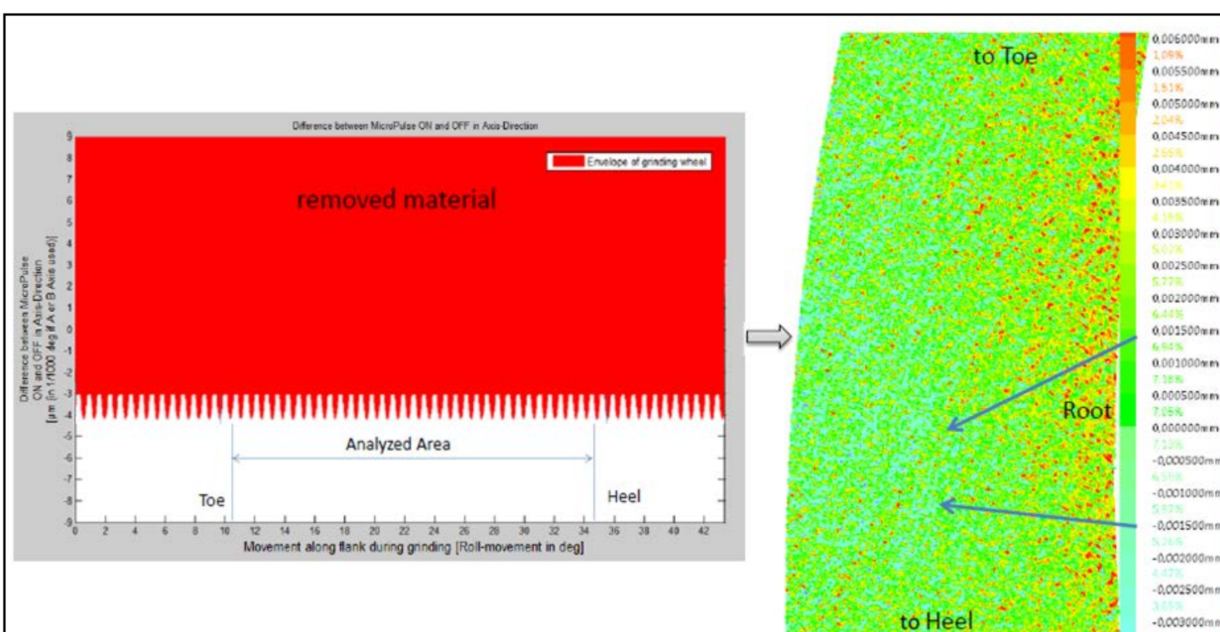

Figure 12 MicroPulse surface modulation, X-axis, 3mm amplitude 3 position sine period (Ref. 5).

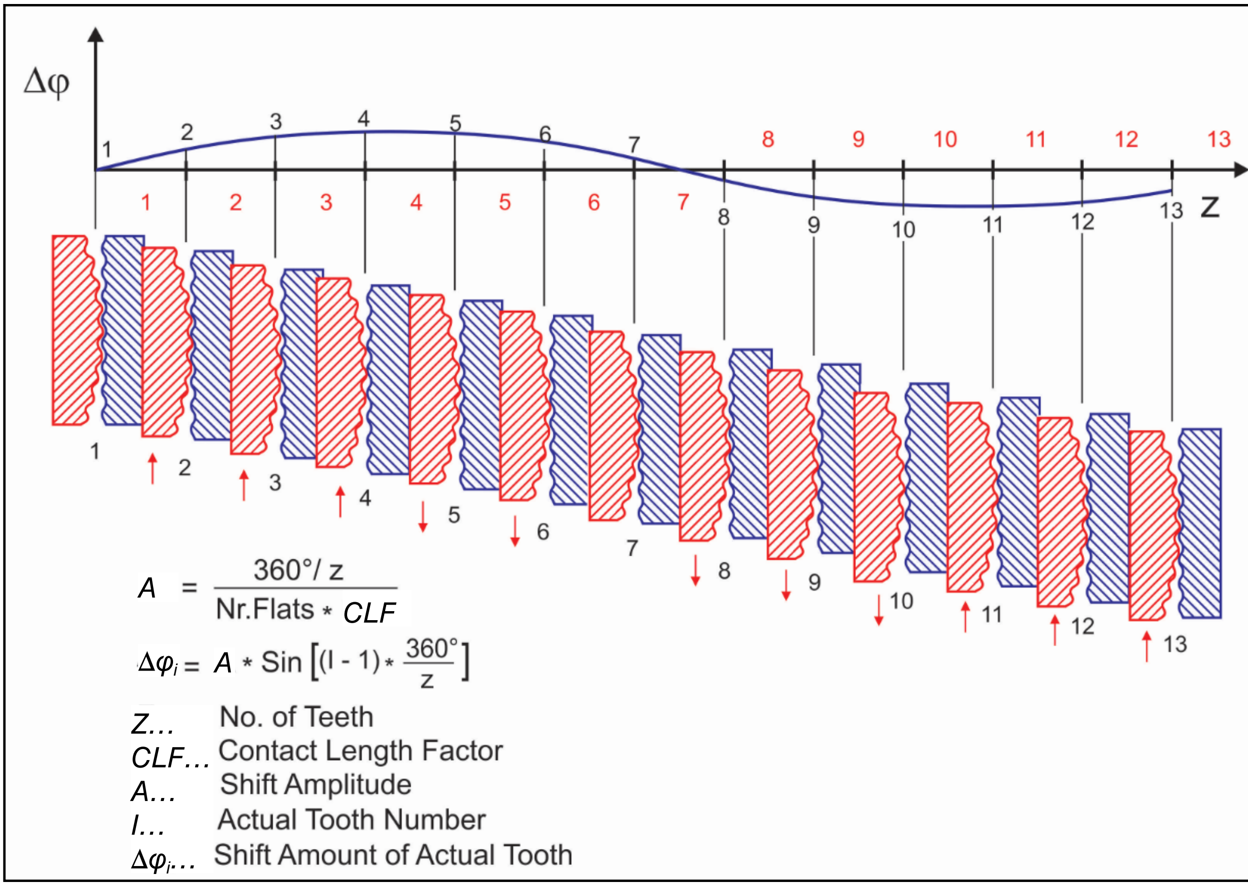

Figure 13 **Structure shifting sine function for 13 tooth pinion with 0.79° texture spacing.**

ness pattern, but the individual sine wave is approximated more accurately with two more anchor points.

If at light load, between 60 to 120 roll positions can be found within the active tooth contact, then 3 anchor positions for one full sine wave will result in 20 to 40 sine waves. Those are realistic numbers for a surface texture. A number of waves below 10 is undesirable because this results in a surface modification rather than a texture.

Figure 12 (left) is a simulation result, using waves with three anchor points and 3 mm amplitude. The enveloping effect of the used 6-inch grinding wheel reduces the effective amplitude of the waves from the initial 3 mm down to about 1.5 mm. Within the analyzed contact area, 35 periodic waves are generated. After a sample pinion with the parameters of the simulation was ground, a surface scan with a laser optical measurement machine was performed. The ISO graphic (Fig. 12, right) reflects the texture, generated with MicroPulse, very well. High areas are orange and low areas are blue.

Although the texture in Figure 12 can be viewed as advantageous for the rolling process between flank surfaces, an excitation with the same or a fractional frequency can be expected in the gear mesh. The structure shift from tooth to tooth (Fig. 9, left) is required in order to assure that the generated surface structure will only generate side bands in the Fourier analysis of the single flank testing results. The answer to the question about the amplitude and the frequency of the shifting sine function can be derived from the characteristic of the texture. In the case of a 13-tooth pinion, one pitch is approximately 27.69°. With 35 periodic waves along one pitch, the angular distance between the waves (equal to the distance between generating flats) is 0.79°. The maximal value that the sine wave has to shift the structure one flat distance equals 0.79°. The shift function should only be one full period per one pinion revolution. This means that the sine function will be split into 13 sections. The first point is at the beginning of section one (with no shift). The second point is at the end of section one, and so on until the thirteenth point is located at the end of section 12. Section 13 connects the thirteenth and the first tooth, which is why the shift value at tooth number thirteen is not back to zero (Fig. 13); because the sine function needs to shift from tooth thirteen to tooth one in order to regain its zero point and start over again.

In the top of Figure 13 it is shown how the shift amounts D_J are gained by the sine function. The black numbers are the points of shift (equal to the location of the teeth) spaced by the angle of one pitch; the red numbers are the 13 sections between the teeth. In the example in the mean (lower section of Fig. 13), the waves in the surface of the first pinion tooth fit exactly into the texture of the first gear tooth. The shift amount is the largest at tooth four, where the peaks of the mating tooth structures are in contact. After that the shift amount is reduced, passes zero at tooth number seven, and develops an increasingly negative amount that reduces after tooth ten — but doesn't reach zero at the last tooth. Doubling the amplitude will shift the structure beyond two surface waves. However, the range of recommended amplitudes is minimally A and maximally 5*A (see equation in Figure 13).

The grinding summary program uses the equations in Figure 13 in order to calculate the default starting point for a MicroPulse development. Only three parameters should be changed — the shift amplitude A; the number of anchor positions N of the structure waves; and the amplitude of the structure waves. Figure 14 shows a section of a pinion grinding summary that lists the MicroPulse and MicroShift settings.

Regarding generated ring gears, it is possible to apply MicroPulse to the gear instead of the pinion. The higher number of teeth will reduce the angular shift amounts between teeth, which allows for larger shift amplitudes. If it is intended to use MicroPulse for both members, pinion and gear, it should be noted that both members should receive different amounts of wave anchor points and only the grinding of one member (preferably the ring gear) should apply a structure shift.

The structure shift from tooth to tooth is accomplished simply with a modification of the start and end roll position, which are now individually calculated for each tooth separately. Even though this is a straight forward and clean approach, it requires the calculation of a separate part program for each tooth. In the presently discussed example, thirteen different pinion summaries are compiled behind each other in order to accomplish the task of a controlled structure shift.

```
COPYRIGHT (c) 2017    GLEASON   R & D  GEAR TECHNOLOGY
GROUND FORMATE HYPOID SUMMARY No. TEST        GLEASON WORKS

PINION   G R I N D I N G   S U M M A R Y

MICRO-PULSE PARAMETERS

MP0. MICROPULSE ON/OFF . . . . . . . . . . .        ON
MP1. AXIS. . . . . . . . . . . . . . . . . .        X
MP2. POINTS PER CYCLE. . . . . . . . . . . .     3.000 mm
MP3. BASE AMPLITUDE. . . . . . . . . . . . .     0.003 mm
MP4. RANDOM AMPLITUDE. . . . . . . . . . . .     0.000 mm
MP5. X-AXIS FEED ANGLE . . . . . . . . . . .     0.000 deg
MP6. Z-AXIS FEED ANGLE . . . . . . . . . . .     0.000 deg
MP7. SURFACE STRUCTURE SHIFT . . . . . . . .        ON
MP8. PERIODS PER REVOLUTION. . . . . . . . .     1.000 mm
MP9. SURFACE STRUCTURE SHIFT AMPLITUDE . .       0.680 deg

  UNDEVELOPED SETTINGS - NOT VERIFIED IN PRODUCTION !
```

Figure 14 MicroPulse grinding summary.

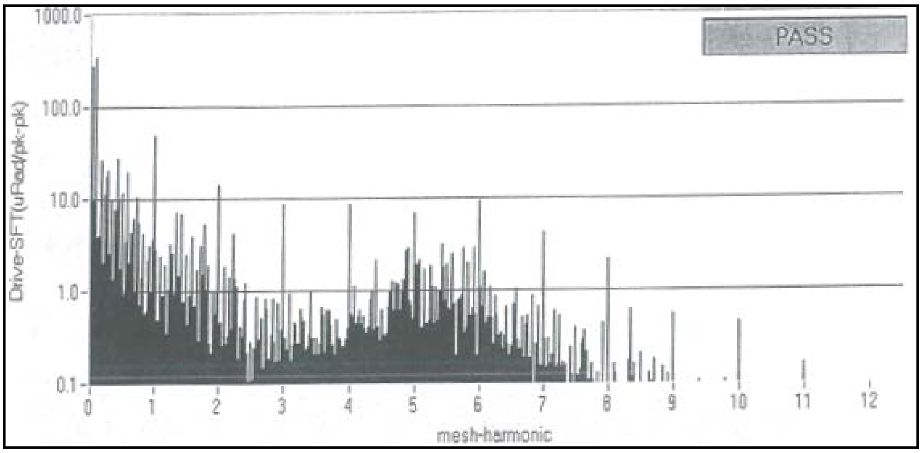

Figure 15 Single flank test Fourier analysis results of baseline gearset without MicroPulse (Ref. 5).

Practical Grinding Results with MicroPulse

In this section the results of one practical example are discussed. Figure 15 shows the results of a Fourier analysis after a single flank test of the automotive hypoid gearset without pinion-MicroPulse. The single flank test was conducted with a pinion speed of 60 rpm and a torque of 12 Nm. Along the abscissa, the fundamental frequency (first mesh harmonic "1") and its higher multiples are shown. The logarithmic ordinate scale shows larger bars at frequencies close to zero, which indicate the pinion and gear runout. All harmonic frequencies from one through 11 have pronounced amplitudes. It is an interesting observation that the amplitudes between the second and the sixth harmonic are almost constant at a value of 10 mrad, which most likely indicates objectionable noise at certain speeds of the vehicle.

The image in Figure 16 shows the surface finish of a 13-tooth pinion that was ground with 3 mm X-axis pulse amplitude and three anchor points per wave. The sinusoidal shift function uses one period-per-pinion revolution (Fig. 13), and the shift function amplitude was A = 0.79°. The pinion flank surfaces in Figure 16 have the earlier mentioned roughness streaks which are parallel to the root and a well visible surface texture with a generating

Figure 16 MicroPulse ground pinion (Ref. 3).

flat orientation, similar to the laser optical image in Figure 12. This pinion is the result of a MiroPulse and MicroShift parameter study, with a complete matrix that was established according to a "design of experiment" (DOE) method.

The blue color in the root is the remaining witness marks of the side grinding technique, which was applied in order to keep the cost of the parameter study down and allow for grinding up to six different MicroPulse parameter sets on one single pinion. Although this procedure changes the backlash, the results of the single flank testing are identical to the results of the original parts with correct tooth thickness and backlash.

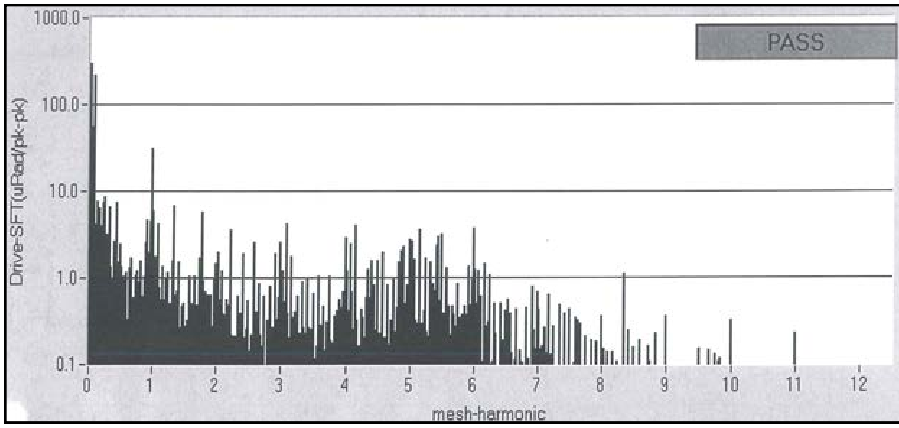

Figure 17 Single flank test Fourier analysis results of gearset with MicroPulse-processed pinion (Ref. 5).

Figure 17 shows the results of a Fourier analysis after a single flank test of the pinion from Figure 15, rolled with the same Formate ring gear from the test shown in Figure 14. The single flank test was again conducted with a pinion speed of 60 rpm and a torque of 12 Nm. At the low frequency the pinion and gear runout bars are identical to the bars in the analysis of the gearset without MicroPulse. The bars of all harmonic frequencies across the chart in Figure 17 are less than 50% of the values in case without MicroPulse. While the first harmonic is lower but still pronounced, the higher harmonic frequency bars are low and imbedded within many raised side bands.

Already the results of the single flank test and the Fourier analysis indicate the highly reduced excitation potential of this MicroPulse-processed gearset. All gearsets with the amplitude frequency characteristic (dominated by side bands) resulted in quieter operating performance during vehicle noise analysis. Presently the evaluated gearset might benefit from a reduction of the fist harmonic excitation bar that has an amplitude of 13 mμrad. Although this is already a low value, compared with the higher harmonics and the side bands, 8 to 10 μrad would give an optimally balanced amplitude frequency plot.

Summary

- This paper described the combination of the existing MicoPulse with a controlled structure shift. The structure shift is calculated, such that a complete sine function around the circumference of a pinion is established that changes the start roll positions of the individual teeth by the ordinate value of the sine function, which is split in a number of sections, equal to the number of teeth. The combination of a surface texture generation and the controlled shift of this texture from one tooth surface to the next is a new technology, which finds many physical analogies in unrelated fields, but a technique to apply this physical principle to gears had not been discovered until now.
- In production grinding with rather aggressive roll rates, it can be noticed that some structure or texture related to generating flats is created. Such a generating flat structure on a ground gear flank is undesirable, which prompts a gear manufacturer to find ways to eliminate this effect. Besides the obvious possibility of a slower roll rate or a dual rotation cycle, some manufacturers have chosen to short time structure lap after grinding. Lapping after grinding might not present the most cost effective solution to achieve flank surfaces with a precise flank form and a desirable surface structure, but this process combination guarantees in nearly each case quiet performing bevel and hypoid gearsets.
- The structure shift principle can be applied to initially undesirable surface textures, generated with fast roll rates and reduce or eliminate the dynamically negative effect of the generating flats. In this case, it is no longer required to use the MicroPulse surface texture generation, because the naturally existing texture is utilized to cancel its own excitation and produce in addition desirable side bands which result in an acoustic gearset quality similar to gearsets manufactured with the combination of MicroPulse and MicroShift. The latter turns a disadvantage to an advantage because it delivers the benefit of a highly productive grinding combined with high quality and quiet gearsets.

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Dr. Hermann J. Stadtfeld received in 1978 his B.S. and in 1982 his M.S. in mechanical engineering at the Technical University in Aachen, Germany; upon receiving his Doctorate, he remained as a research scientist at the University's Machine Tool Laboratory. In 1987, he accepted the position of head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich and, in 1992, returned to academia as visiting professor at the Rochester Institute of Technology. Dr. Stadtfeld returned to the commercial workplace in 1994 — joining The Gleason Works — also in Rochester — first as director of R&D, and, in 1996, as vice president R&D. During a three-year hiatus (2002-2005) from Gleason, he established a gear research company in Germany while simultaneously accepting a professorship to teach gear technology courses at the University of Ilmenau. Stadtfeld subsequently returned to the Gleason Corporation in 2005, where he currently holds the position of vice president, bevel gear technology and R&D. A prolific author (and frequent contributor to Gear Technology), Dr. Stadtfeld has published more than 200 technical papers and 10 books on bevel gear technology; he also controls more than 50 international patents on gear design, gear process, tools and machinery.

Surface Characteristics of Hobbed Gears

Markus Krömer, Deniz Sari, Christoph Löpenhaus and Christian Brecher

Gear hobbing is one of the most productive manufacturing processes for cylindrical gears. The quality of the gears is a result of the tool quality, the precision of the workpiece, tool clamping and kinematics of the machine. The dry gear hobbing process allows machining of gears with a quality according to the DIN standard up to IT 5. To evaluate which gear quality is possible to machine with a given clamping and hob, it is useful to simulate the process in advance. This is also an opportunity to order the required quality of the hob according to its application. The objective presented in this report is to simulate the gear hobbing processes and to calculate the geometry and surface of the workpiece. By a geometric penetration calculation, the resulting gear geometry as well as process characteristic values are determined. By an evaluation of tool and clamping tolerances, these deviations can be used to modify the ideal simulation model. Afterwards a non-ideal hobbing simulation can be performed and the resulting gear geometry can be analyzed using a virtual measurement machine. A virtual measurement machine analyses the geometry according to VDI/VDE 2612/2607 and DIN 3961. The resulting measurements of the flank and lead lines can be used for a classification of the gear quality. An advantage of this non-ideal simulation is also the possibility of calculating the tool load taking tolerances into account and to use the results for further process designs to reduce the risk of tool failure. This method also can be used to design machining processes for gear finish hobbing which has economic advantages because of the shortened process chain. To evaluate the effect of different characteristic process deviations on the operational behavior of the gears, running tests are conducted.

Gear Hobbing: State of the Art

Gear hobbing is a continuous generating process which can be compared to kinematic conditions of worm and worm gear. The workpiece is represented by the worm gear whereas the hobbing tool is designed like the worm (Fig. 1, top left). By a continuous rotation ω_0 of the tool, the cutting movement is realized. An axial feed f_a of the hob across the face of the gear is superimposed upon the tool rotation. Because of the continuous cutting process, the secondary processing times are low which makes gear hobbing to be one of the most productive manufacturing processes for cylindrical gears (Ref. 1).

Due to the kinematic coupling, characteristic cutting deviations occur on the flanks and the tooth root of the workpiece. These deviations are called "feed marks" (Fig. 1, middle) and "generated cuts" (Fig. 1, bottom). The feed marks are oriented in direction of the workpiece width and the generated cuts occur in profile direction.

The height of the feed marks mostly depends on the axial feed and the outside diameter of the hob. Typically, the height of the feed marks is greater than the height of the generated cuts. Generated cuts are mostly depending on the number of gaps and threads of the tool. For both deviations, analytical Equations 1 and 2 exist (Ref. 2). However, these equations only calculate the deviations for an ideal process.

$$\delta_x = \left(\frac{f_a}{\cos\beta_2}\right) \cdot \frac{\sin\alpha_{n0}}{4 \cdot d_{a0}} \qquad (1)$$

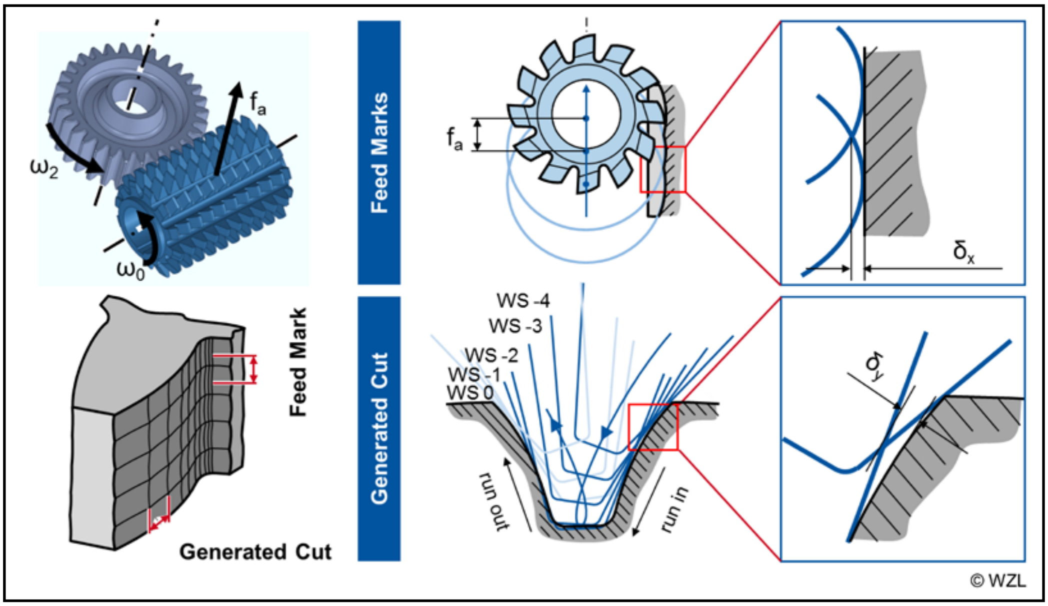

Figure 1 Characteristic deviations due to kinematics of hobbing process.

This paper was first presented at the 6th WZL Gear Conference USA, June 28, 2016.

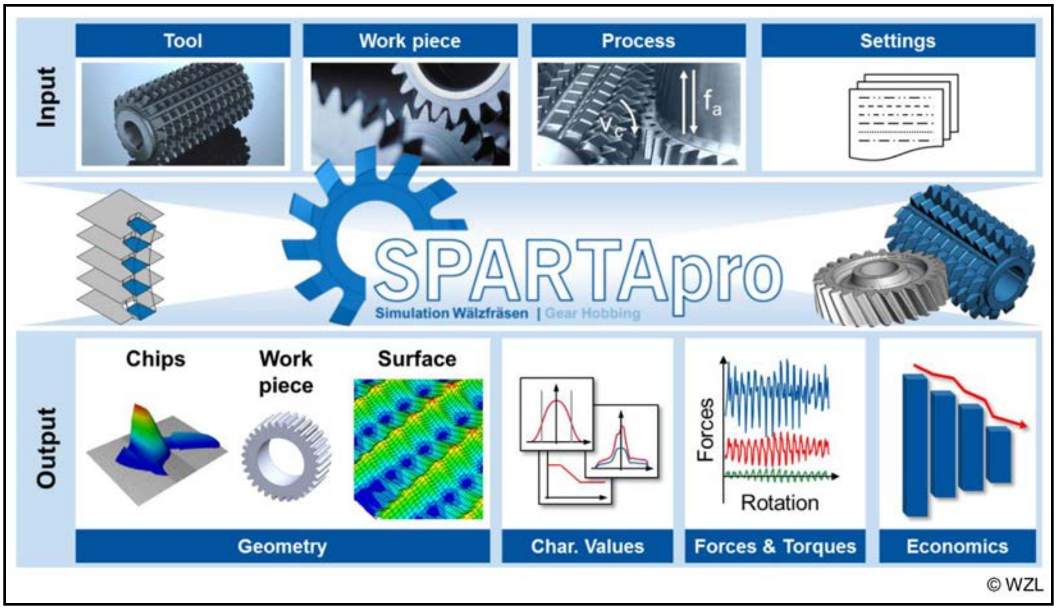

Figure 2 **Process simulation for soft gear machining *SPARTApro*.**

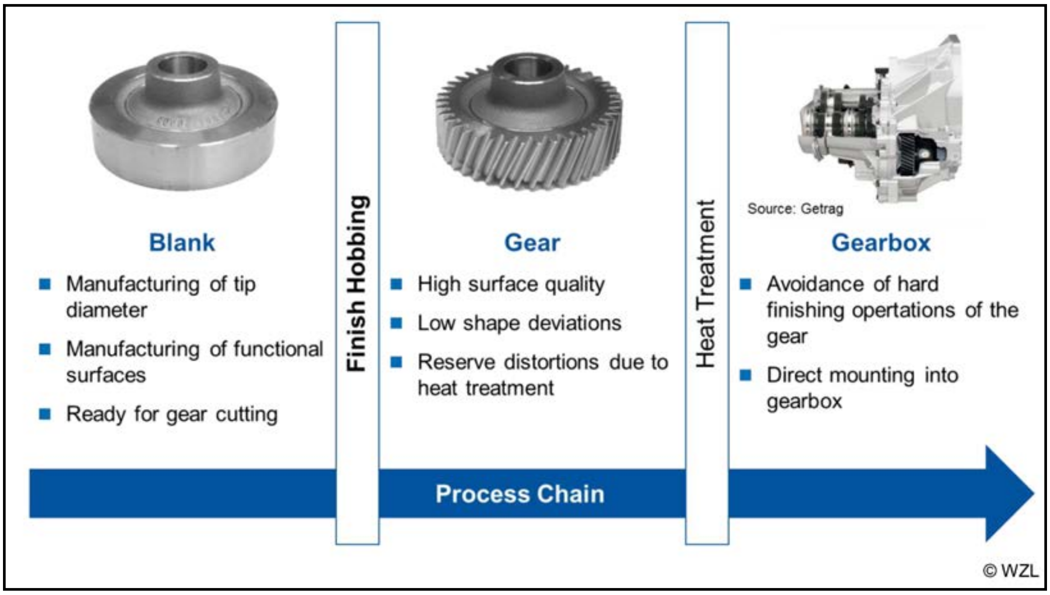

Figure 3 **Process chain of gear finish hobbing (Ref. 9).**

$$\delta_y = \frac{\pi^2 \cdot m_n \cdot z_0^2 \cdot \sin \alpha_{n0}}{4 \cdot n_0 \cdot z_2} \qquad (2)$$

δ_x	(µm)	Generated cuts
f_a	(mm)	Axial feed
α_{n0}	(°)	Normal pressure angle of the tool
m_n	(mm)	Normal module
n_0	(-)	Number of gaps of the tool
δ_y	(µm)	Feed marks
β_2	(°)	Helix angle of the workpiece
d_{a0}	(mm)	Outside diameter of the tool
z_0	(-)	Number of starts of the tool
z_2	(-)	Number of teeth of the workpiece

In general, the deviations of the final hobbed gear are greater because of the characteristic process deviations are superposed by tolerances of tool, clamping and machine kinematics. The total deviation is a combination of the described characteristic deviations as well as the deviations caused by tolerances of tool, clamping and kinematics (Ref. 3). With the knowledge of the total deviation in the process, the resulting gear quality can be determined. The method of gear measuring is defined in different standards. Common standards in Europe are VDI/VDE 2612 (Ref. 4) or DIN 3961 (Ref. 5). Both standards describe the measurement of gears in direction of profile and lead of the workpiece. In addition, the deviations of pitch and radial-run out are measured. As stated in DIN 3962-1 (Ref. 6) the resulting gear quality is calculated for various module sizes and is divided into twelve different quality groups. Gears with a high quality have a low quality group (e.g., IT 1) and low-quality gears have a high quality group (IT 12).

If a certain quality of the workpiece is requested by the design department, the production planner has to select a sufficient tool and clamping for manufacturing process. Because the price of tool and clamping depends on the precision, it is desirable to select only the required combination.

Simulation of the gear hobbing process. In (Refs. 7 and Ref. 8), the simulation software *SPARTApro* for calculating characteristic values for the gear hobbing process was presented. Input parameters are the geometrical information of the workpiece such as module, number of teeth and outside diameter as well as the tool data and its profile geometry. With the given axial feed, a penetration calculation is executed and the non-deformed chip geometries occurring in the hobbing process are determined. Afterwards, these chip volumes are analyzed and characteristic values such as the maximum and average chip thickness $h_{cu,max}$ and $h_{cu,av}$, the specific chip volume V' and the maximum and average cutting length l_{max} and l_{av} are calculated. The values are displayed along the unrolled cutting edge and as maximum and average values for the whole process. Besides these values, *SPARTApro* is capable of calculating the cutting forces of the hobbing process and the economical profitability of the process.

Gear finish hobbing. With the knowledge of characteristic deviations of the machining process, it is possible to design a hobbing process with very low deviations. Figure 3 shows the process chain of gear finish hobbing. First, the blank of the workpiece is machined. The machining includes turning of the blank as well as grinding of functional surfaces. Afterwards the blank is ready for gear hobbing. For gear finish hobbing, characteristic deviations have to be about one µm and lower. These low deviations are achieved using multi cut strategies. The simplest type of multi-cut strategy are two separate cuts. First the roughing cut in which most of the workpiece material is machined. In the following finishing cut only a stock of around $T = 100$ µm is removed. Because of the low volume which is machined in the second cut, high cutting speeds can be used. This gives the process designer the possibility to reduce the axial feed, feed marks and still get economical process designs.

Due to the advantage of low deviations and a low surface roughness, gear finish hobbing offers the possibility to shorten the process chain for gear manufacturing, by eliminating the gear grinding process. However, for gear finish hobbing the deviations coming out of the heat treatment have to be known. These deviations have to be considered and eliminated by flank modifications in the hobbing process. After heat treatment, modifications in the hobbing process and deviations of the heat treatment should eliminate each other and the final workpiece results. After heat treatment, the gear is ready for assembling (Ref. 9).

Special advantages of gear finish hobbing are high cutting speed and low amount of stock. These points were investigated in several research projects at WZL. First, the influence of several cutting materials on tool life was investigated in an analogy trial (Ref. 10). Afterwards, the results of the analogy trial have been transferred on the load collective in gear hobbing (Ref. 11). The potential of several cutting materials for gear finish hobbing was not the only focus of the investigations. Additionally, the possible workpiece quality was a topic. For these, the fly-cutter trial was used. The influence of different process parameters on the possible profile and surface quality was investigated. The deviation from the ideal involute depends on the number of generating cuts. By using more generating cuts (higher number of gashes or reduced number of threads), the straight tool profiles can approximate the ideal involute more accurate (Eq. 2) (Ref. 9).

Simulation of Characteristic Deviations in Gear Hobbing

The presented manufacturing simulation *SPARTApro* was enhanced to be capable of simulating the surface topography of the gear. Therefore, a penetration calculation with the designed process parameters is executed and afterwards the resulting gap geometry is compared with an ideal gear geometry (Fig. 4). The ideal workpiece can be calculated within *SPARTApro* or can be calculated and imported from other software such as *GEARGENERATOR* (Ref. 12), which has been developed at the WZL. *GEARGENERATOR* uses the basic requirements of a gear tooth system (Ref. 13) to calculate the ideal gap geometry. The simulated surface can be measured and analyzed in any direction with a virtual measurement machine based on the VDI/VDE 2612 (Ref. 4) standard.

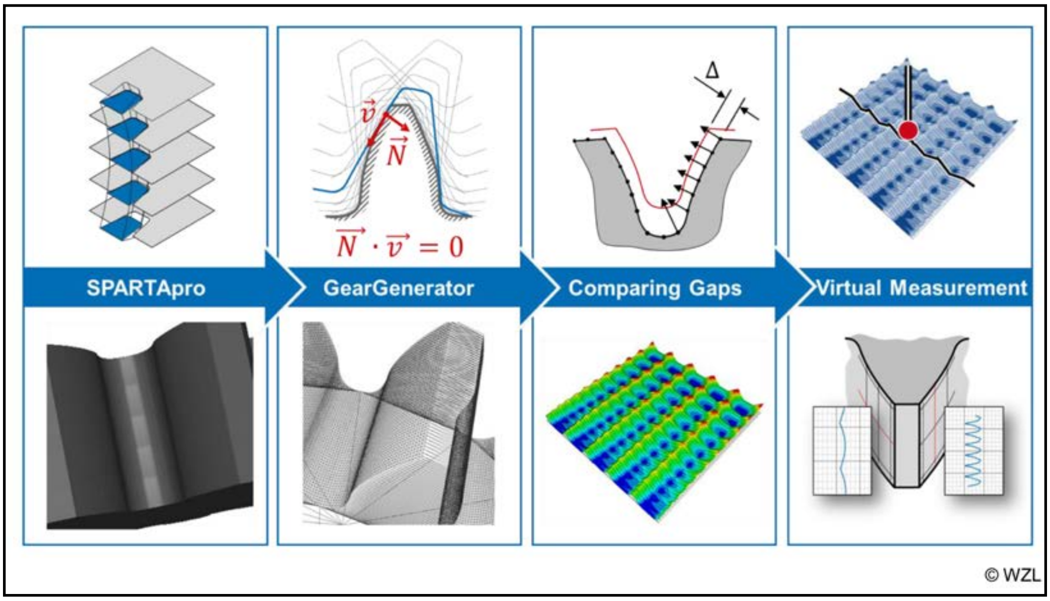

Figure 4 Approach for calculating gear surface topography.

Figure 5 shows an example of the surface topography of a hobbed workpiece. The data of the workpiece, tool as well as process is depicted at the bottom. At the top the surface topographies are shown as a mountain map. The lines plotted on the mountain map represent the lines of measurement in direction of profile and lead. The simulated measurement lines are shown at the right side of Figure 5. The axial feed used in this process is set to $f_a = 2.4$ mm. This value also can be found in the measurement of the lead line as the distance of two peaks. Both, the measurement of the profile as well as of the lead line show a deviation of five µm to the ideal flank. According to DIN 3962 6 this is a gear quality of IT 5 which is close to the best quality which can be achieved economically in the conventional hobbing process.

In the graphical interface of *SPARTApro*, the WZL *GEAR TOOLBOX*, the output of profile and lead lines is based on the design of measurement sheets of gear measurement machines. An example of a simulated measurement is given in Figure 6. At the top of the output three measurements of the profile for left and right flank are shown. While the gear measurement machines measure a specific number of teeth of the gear, the software measures only one tooth on different heights, see left bottom of Figure 6. By analyzing one tooth it is not possible to measure radial run-outs or pitch errors but it is possible to analyze modifications of profile and lead such as crowning or the natural twist. In future versions it will also be possible to analyze a various number of teeth of the workpiece. In the lower half of the graphical output, the measurements of the lead lines are displayed. For each flank, the measurement results are depicted for three diameters of the gear. Below each measurement plot, the numerical values of the profile and lead modifications are plotted.

Simulation of tool and process errors. Deviations in the hobbing process can occur as tolerances of the tool and gear or due to displacements in the clamping of tool and workpiece (Ref. 3). The tolerances of the tool are defined in DIN 8000 (Ref. 14). The top half of Figure 7 shows the devia-

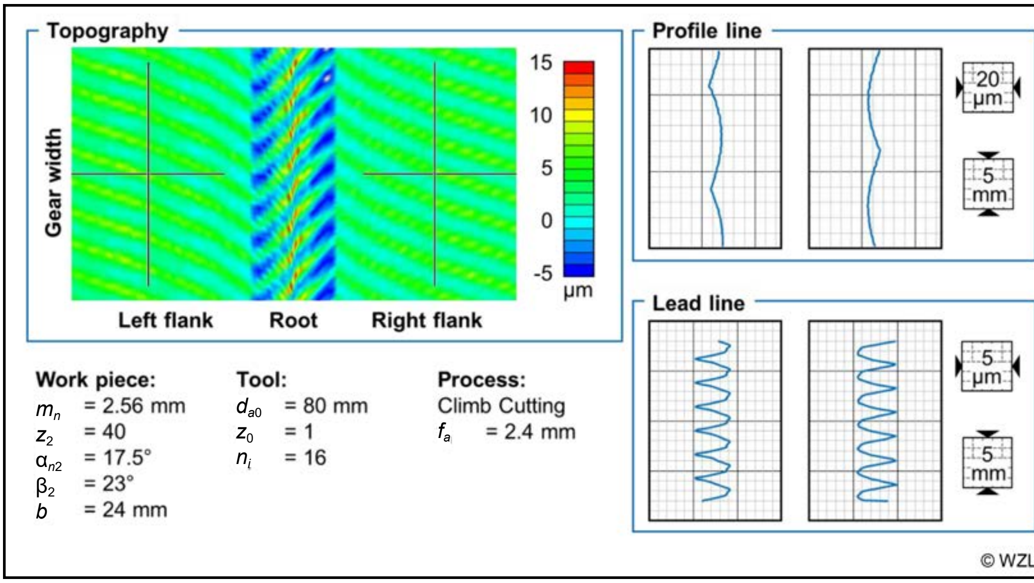

Figure 5 Topography and measurements of ideal gear.

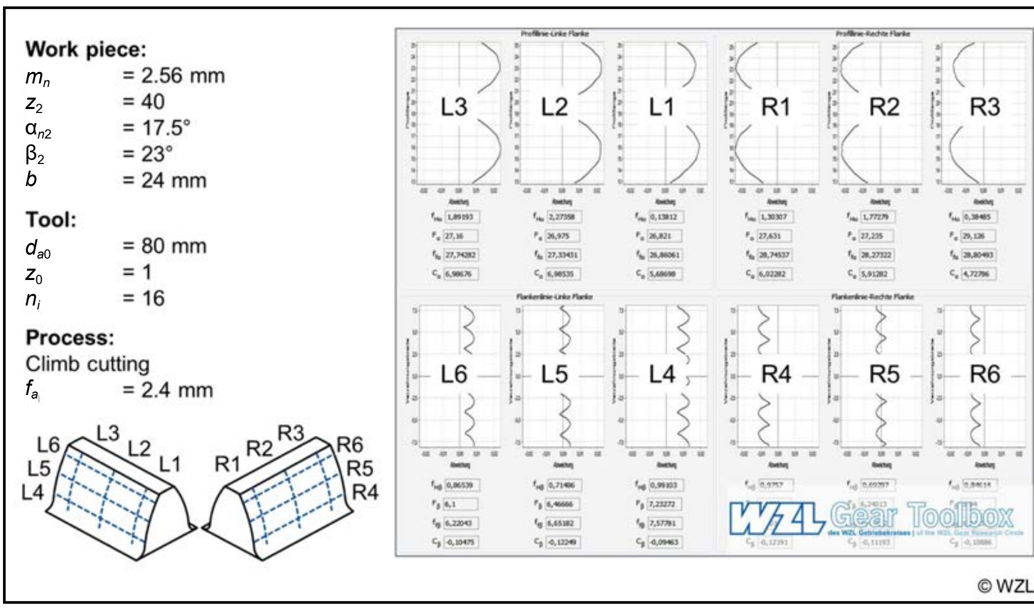

Figure 6 Graphical output of virtual measurement machine.

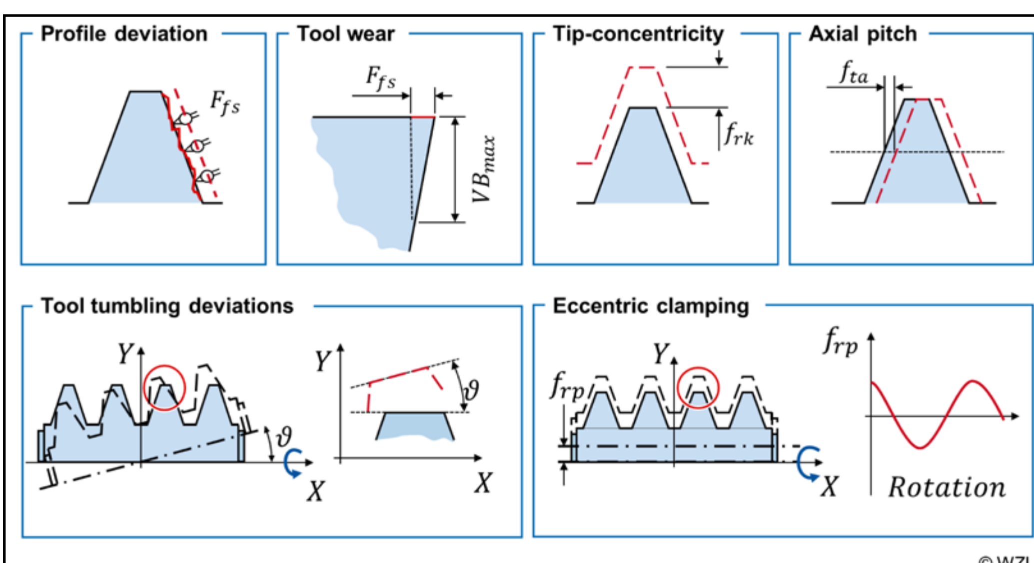

Figure 7 Profile deviations of tool and clamping errors.

tions which can occur at the tool. These are deviations of the pitch, concentricity or flank profile. These three tolerances will be investigated. The flank profile can differ from the ideal profile because of tolerances in manufacturing of the hob or due to tool wear. Besides the height of the tool profile can deviate which leads to a tip-concentricity of a single blade. This is typical if an indexable insert hob is used and a chip is stuck between the mounting and the insert. The third mentioned deviation is a variation of the pitch, which can be consolidated to the axial pitch deviation between two teeth of the hob. On the tool clamping two different types of deviations have to be taken into account. These are tumbling and eccentricity deviations, as shown in the bottom half of Figure 7. While tumbling leads to a tilt of the tool profile and to an eccentricity, which depends on the distance of the hob tooth to the axial hob center, the eccentricity causes an evenly changing radial run out of the tool profile. The described tolerances of the tool clamping also can occur as deviations of the workpiece clamping. However, because only one tooth is simulated in *SPARTApro*, these deviations cannot be evaluated in the latest version of the software and therefore are neglected.

Table 1 Tolerances for hobs with module range of m_n = 2.5 mm – 4 mm

Tolerance	A	AA
Axial pitch [f_{ta}]	19 µm	11 µm
Profile deviation (tolerance) [F_{fs}]	14 µm	8 µm
Profile deviation (tool wear) [F_{fs}]	18 µm	18 µm
Tumbling [ϑ]	5 µm	3 µm
Eccentric [f_{rp}]	25 µm	16 µm

After identifying possible tolerances and deviations of tool and clamping of the tool, the maximum of each tolerance within the tolerance field has to be determined. Tolerances of the tool are defined in DIN 3968 (Ref. 15) and depend on module and quality category of the hob. There are five grades for the quality but only the two best are relevant in practice nowadays. These quality grades are saved in the software and can be selected. In the following a gear with a module of m_n = 2.56 mm is selected. Table 1 shows the maximum of each tolerance class for a hob with this module. For this example, the profile deviation and the eccentricity have the highest maximum values.

First, the effect of an eccentricity will be shown. In Figure 8 the results of a hobbing simulation with an eccentric clamping of f_{rp} = 60 µm are given. This high eccentricity is greater than the allowable tolerance of the tool which is, according to DIN 3968 15 and Table 1, only f_{rp} = 25 µm. However, because of this high eccentricity the effect of the tolerance to the topography as well as the profile and lead lines can be seen directly. As it is shown the surface topography differs from the ideal surface in Figure 5. Again, lines in the mountain map represent the measurement path of profile and lead lines. Analyzing the measurements show nearly the same deviations in direction of the workpiece width as in the ideal simulation but much higher deviations of the profile. These profile deviations have a maximum value of F_f = 32 µm, which is the maximum distance to the ideal flank. A deviation such as the presented results in a gear quality of IT 10. In

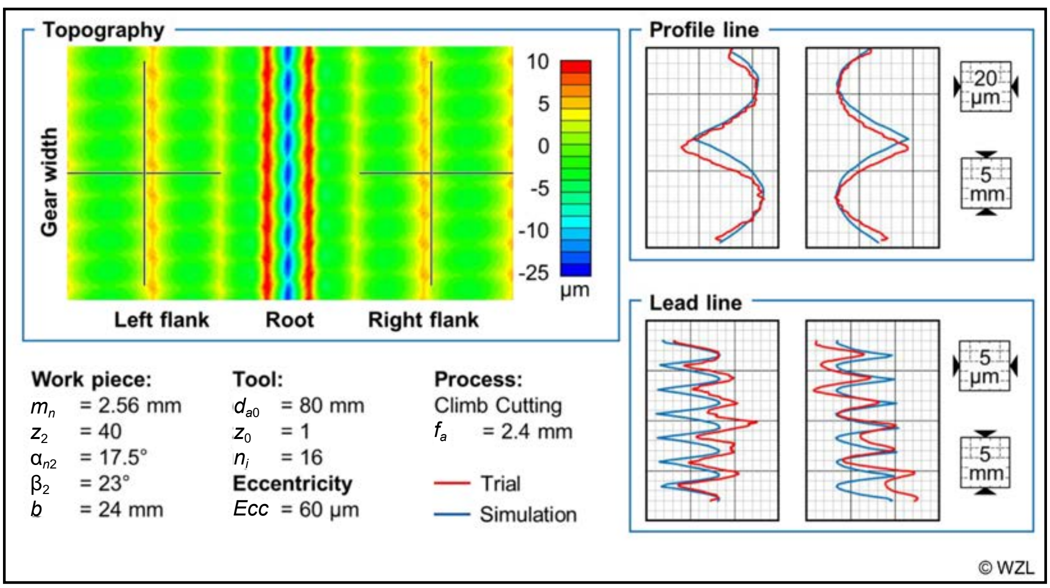

Figure 8 Resultant gear quality of hobbing with deviations.

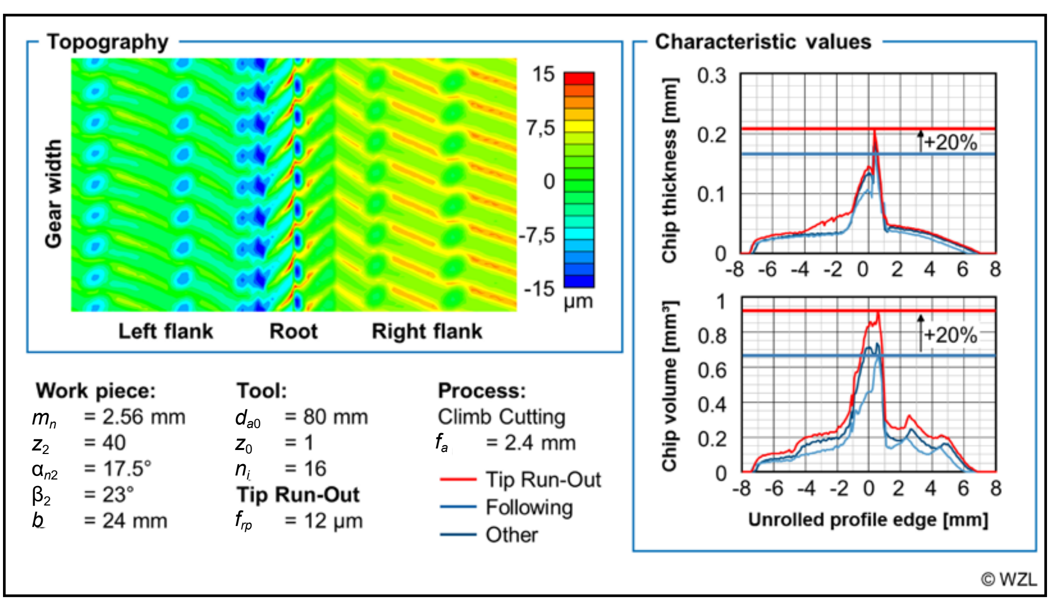

Figure 9 Gear geometry due to tip run-out of tool profile.

comparison to the simulation results (blue line), the measured profile and lead lines of a hobbing trial machined with the same eccentricity are plotted in the same graph (red line). For the profile, simulation and trial are nearly identical and, besides the non-simulated lead error, also the lead lines coincide. This comparison shows that the simulation, as well as the virtual measurement machine, are capable of simulating and analyzing deviations.

Influence of tolerances on characteristic values. After calculating the gear geometry and analyzing the resulting gear quality, the influence of tool deviations to the characteristic values in the hobbing process will be discussed. The focus in this report is the maximum chip thickness and the chip volume. The chip thickness is one of the most important characteristic values for process design in machining with defined cutting edges (Refs. 1 and 16). The chip volume is a combination of cutting length and chip thickness and correlates with cutting forces and tool load.

In the top-left picture of Figure 9, the surface topography of a simulated gear is shown. The characteristic line of contact of hob and gear is visible but the structure of the surface is intermittent by small 'buckles'. These buckles are a result of a tip concentricity at one hob tooth of $f_{rK} = 12\,\mu m$.

In the diagrams in the right section of Figure 9, the characteristic values chip thickness and chip volume are plotted alongside the unrolled cutting edge. In each diagram, three graphs are shown. The solid, dark-red graph has the highest values for the hobbing tooth with a defined deviation of $f_{rK} = 12\,\mu m$. Besides, a second solid-light graph displays the following profile in contact after the first one. The last graph represents all other tool profiles, which have all nearly the same values. As it is shown the values of the tooth with a radial run-out are the highest for both values, while the following tooth has the lowest. The chip thickness as well as the chip volume of the profile with a run-out deviation, is around 20% higher than of all other profiles. As expected, the values of the following profile are in both cases the same amount lower as the values of the deviation profile are higher than the other teeth of the hob. This observation shows that there is a significant influence of tool deviations on characteristic values.

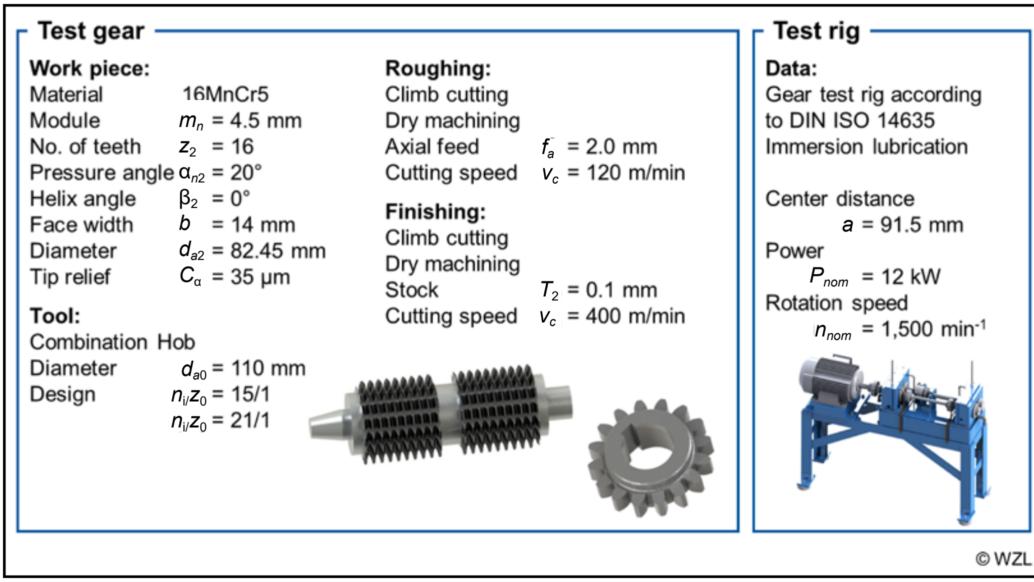

Figure 10 Test gear and test rig for pitting load carrying capacity investigation (Ref. 20).

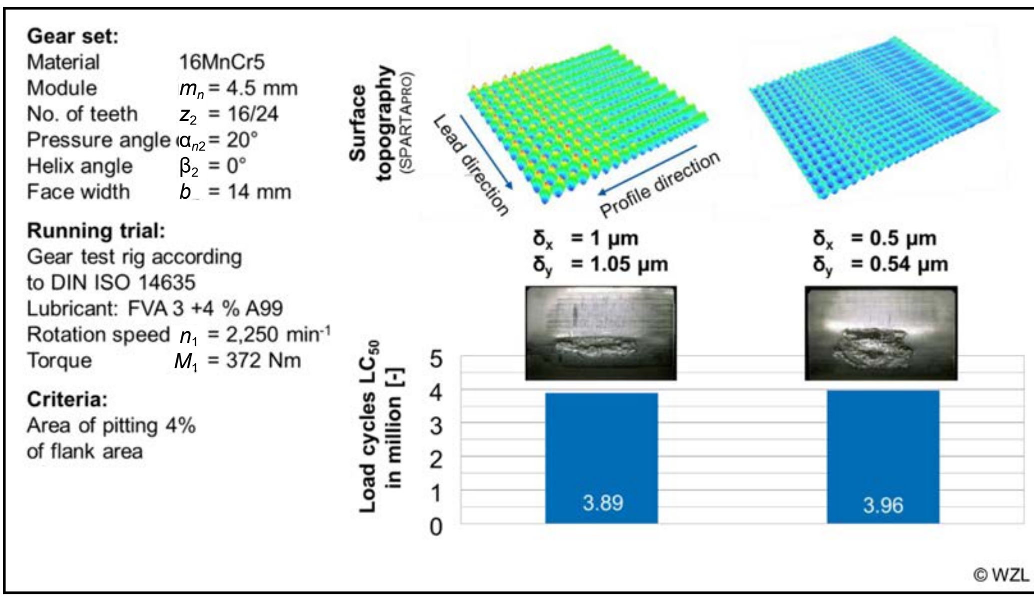

Figure 11 Influence of machining process on pitting strength (Ref. 20).

Operational Behavior of Finished Hobbed Gears

The presented method of calculation of the surface structure can be used in the design of gear finish hobbing processes. By knowing the height of the characteristic deviations for a process and tool design, each parameter can be set to an economical or technical optimum.

In the following, the operational behavior of finished hobbed gears will be discussed. Therefore, two sets of gears with different surface structures are manufactured and afterwards the load carrying capacity regarding pitting is investigated on test rigs according to DIN 14635 (Ref. 17). The geometrical data of the gear is given (Fig. 10). The rough machining of both gear sets is done with an axial feed of $f_a = 2.0$ mm and a cutting velocity of $v_c = 120$ m/min. Afterwards, the stock of $T_2 = 0.1$ mm on the flanks of the gear is removed in a finishing cut. Because of a modified tool profile, the tooth root is not machined in the finishing cut. In both gear sets the cutting velocity during finishing is set to $v_c = 400$ m/min, which is state of the art in gear finish hobbing (Ref. 18).

To investigate the effect of different surface structures, in the first finishing process a one start hob with 15 gashes is used. This tool design, in combination with an axial feed of $f_a = 1.16$ mm, results in a maximum deviation due to feed marks of $\delta_x = 1.0$ µm. The deviation due to generating cuts is nearly the same ($\delta_y = 1.05$ µm). As second, process and tool design an axial feed of $f_a = 0.8$ mm and a hob with 21 gashes is used. This leads to a maximal deviation of $\delta_x = \delta_y = 0.5$ µm. The heat treatment after hobbing of both gear sets is low-pressure carburizing and afterwards high-pressure gas quenching. By using this method of heat treatment, a totally dry manufacturing chain of the gears can be realized (Ref. 18).

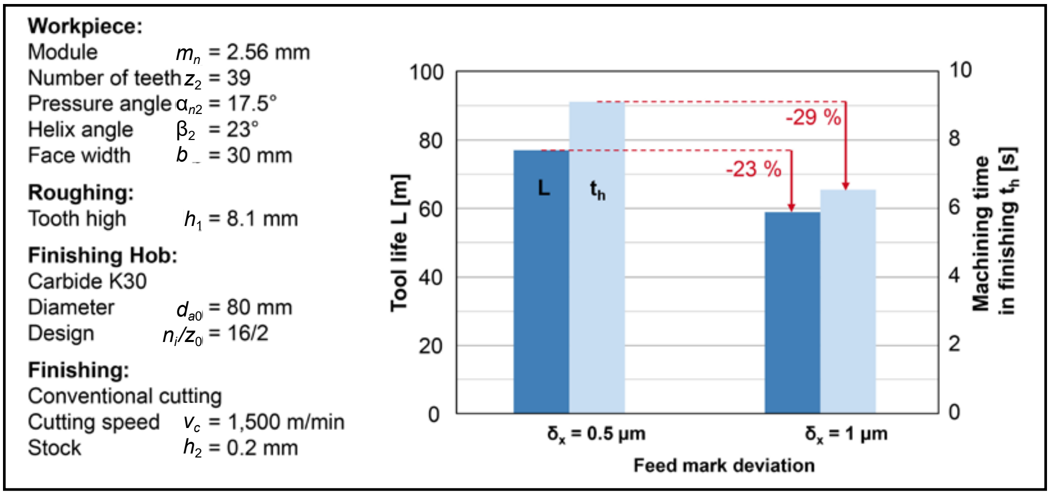

Figure 12 Comparison of tool life and machining time in finishing (Ref. 18).

The investigations regarding the tooth contact fatigue are realized on a gear test rig according to DIN 14635 (Fig. 10, right). The test rig has an axial distance of the gears of $a = 91.5$ mm. By a mechanical load clutch, a defined torque can be applied to the gear set. The friction losses are compensated by a motor with a constant rotation speed of $n = 1{,}500$ min^{-1} and a torque of $T = 480$ Nm. All investigations are performed with the FVA 3 +4% A99 reference oil at a temperature of $T = 90$°C. The end of each load carrying test is reached if the pitting has a surface of more than $V_{EZ} = 4\%$ (Refs. 19 and 18).

The simulated characteristic deviations of both gear sets as well as the lifetime of the gear are shown in Figure 11. The end of lifetime is defined by means of the reached number of load cycles at which 50% LC_{50} of the gears failed. To determine the surface structure of the gears the presented simulation method implemented in *SPARTApro* is used (Ref. 18).

The evaluation of LC_{50} is done with the help of a Weibull distribution grid and the probability calculation according to Weibull and Gabner. After conducting three load cycle tests for each variant, the number of load cycles LC_{50} is nearly the same for both gear sets. The lifetime of the variant with the higher characteristic deviations of around one µm was $LC_{50} = 3.89$ million load cycles and the lifetime of the other variant $LC_{50} = 3.96$ million. In all trials, the size of the flank defects for both variants are nearly the same. In Figure 11 representative pictures of the flanks are shown. These results show that an increase of the process characteristic deviations form $\delta_x = \delta_y = 0.5$ µm to $\delta_x = \delta_y = 1.0$ µm nearly have no effect on the resulting pitting strength of the finished hobbed gear (Ref. 18).

Because the characteristic deviations of the flank surface up to $\sigma_x = 1$ µm have no effect on the achievable load cycles the increase in the axial feed can be used to get a faster and possibly more economical process. Figure 12 shows the effect of the increased axial feed on the tool life and the machining time. During the machining with the lower axial feed of $f_a = 0.67$ mm the maximum chip thickness which can be calculated with the help of *SPARTApro* is $h_{cu} = 13$ µm. Comparing this to the higher maximum chip thickness of $h_{cu} = 20$ µm in the machining with an axial feed of $f_a = 1.0$ mm explains why there is a decrease of the tool life by 23%. But at the same time also the machining time decreases be nearly 30% which is a significant gain in productivity. Finally, the process designer has to choose between low machining times and higher tool life. A change of the pitting strength due to the increased axial feed could not been shown.

Summary and Outlook

Until now, calculating characteristic values for the gear hobbing process has neglected the possibility of inaccuracies and tolerances of the tool as well as of the clamping. To consider these tolerances in early stages of the process design, a simulation has been developed and presented. The model simulates the hobbing process and calculates established characteristic values such as the chip thickness h_{cu} and the cutting length l_e. Furthermore, the topography of the gear flanks and the root geometry is analyzed and depicted. The software can calculate profile and lead lines of the gear. Furthermore, the roughness of the tooth root geometry can be measured. Besides calculating characteristic values, this information can be used to design machining processes, like the gear finish hobbing. Gear finish hobbing enables the implementation of a resource saving and cost effective process chain for gear manufacturing industry. Production-related product properties are resulting from the gear finish hobbing process and can have an influence on the gear's application characteristics. Some of these properties like the characteristic deviations can be predicted with the presented simulation model. But the effect of these on the application characteristics are unknown. Therefore, there is no basis of decision-making in the industrial environment. This knowledge is required for implementing this technology. To gain first knowledge on the operational characteristics of finished hobbed gears, the pitting load carrying capacity of finish hobbed gears, depending on the process-related geometrical deviations, was investigated. The final evaluation states that a high optimizing potential of can be used through an adapted process design of gear finish hobbing.

In conclusion, it remains unclear which impact the increasing tool wear has on the application characteristic of finish hobbed gears. In previous studies, a new tool has always been used for the manufacturing of experimental gearings. Furthermore, an analysis of the maximum permissible process-related deviation of gear finish hobbed gears on the pitting load carrying capacity is useful. Provided that a maximal permissible limit of the process-related deviations is known, the productivity of this process can be increased by a further axial feed.

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Dipl.-Ing. Markus Krömer in 2013 was awarded a degree in mechanical engineering from the RWTH Aachen University. Since that time Krömer has worked first as a research engineer and presently as group leader of the gear design and manufacturing simulation group of the laboratory of machine tools and production engineering (WZL) of RWTH Aachen University.

Dr.-Ing. Deniz Sari in 2012 received his degree in mechanical engineering from the RWTH Aachen University. He began his career as a research engineer and a group leader of the Gear Manufacturing Group of Laboratory of Machine Tools and Production Engineering (WZL) of RWTH Aachen University. In 2016 he earned his Doctorate — with a core emphasis on gear finish hobbing — in Mechanical Engineering (Dr.-Ing./Phd) from the RWTH Aachen University. Also in 2016 Sari began work as gear technology manager for Samputensili (Bentivoglio Italy) and its joint venture, Star SU.

Dipl.-Wirt.-Ing. Christoph Löpenhaus has since 2014 served as Chief Engineer in the Gear Department of WZL, RWTH Aachen / Laboratory of Machine Tools and Production Engineering (WZL), RWTH Aachen. He previously held positions there as (2011–2014) Team Leader, Group Gear Testing Gear Department Chair of Machine Tools Laboratory of Machine Tools and Production Engineering (WZL) RWTH Aachen; (2010–2011) Research Assistant, Group Gear Testing Gear Department Chair of Machine Tools Laboratory of Machine Tools and Production Engineering (WZL) RWTH Aachen: (2007–2009) as Student Researcher, Group Gear Design and Manufacturing Calculation Gear Department Chair of Machine Tools Laboratory of Machine Tools and Production Engineering (WZL) RWTH Aachen; and (2004–2009) as a student in Industrial Engineering RWTH Aachen.

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).

AGMA

ANNOUNCES TWO NEW COMMITTEES

The American Gear Manufacturers Association (AGMA) recently announced two new member driven committees: Emerging Technology and Industry Voice. The Emerging Technology Committee will be led by Chair Brian Schultz, president of Great Lakes Industry. The focus of the Emerging Technology Committee is to determine what technologies are expected to impact the industry, and develop AGMA as a platform for delivering action-oriented information, communications and speakers.

"The Emerging Technology will be one of AGMA's most critically important committees because they will challenge industry by alerting industry to disruptive technologies and market opportunities that they believe will have a considerable impact on industry," notes Matthew E. Croson, AGMA president. "The information they share will come from both a technical and business perspective, allowing companies to understand, and take action on, the opportunities as we see them develop."

The Emerging Technology committee will be tracking four major technologies, as they start efforts to add value to AGMA membership, including; additive manufacturing, industrial Internet of Things (IoT), robotics and new alloys.

"Members should expect to see provocative speakers, white papers, communications and outreach that can be considered internally as AGMA members wrestle with response strategies," notes Croson. "We see the association as serving as a change agent platform where members can get a handle on the emerging technologies from both a technical and business perspective, then do the work they need to respond."

The Industry Voice Committee will be led by Shawn O'Brien, vice president, marketing at McInnes Rolled Ring. The focus of the Industry Voice Committee is to bring the mechanical power transmission supply chain together, and to share how AGMA's members and the association provide innovation to the larger power transmission industry.

Additionally, the Industry Voice Committee is tasked with exploring collaborations with organizations along the power transmission supply chain, and to effectively communicate what our industry is all about to the downstream customer.

"AGMA's strategic plan asks for the association to develop what we're calling the Power Transmission Alliance, and figure out how we can best discuss who we are, what value we deliver, and how best to access the collective knowledge of the supply chain," notes Croson. "This strategy came from the acknowledgement of the customer trend for needing information that covers the full power transmission system, not just the components. We have an opportunity to unite elements of our industry under an Alliance umbrella in order to communicate what we are all about at events such as Gear Expo, or the Fall Technical Meeting, where we bring industry together."

Committee Members for Emerging Technology include:

Committee Chair: Brian Schultz, president - Great Lakes Industry

Committee Members:

- Bill Bennett, metallurgical engineer – Corry Forge Company (Division of Ellwood City Forge)
- Teressa Conlan, assistant manager Spare Parts – Klingelnberg America, Inc.
- Nitin Chaphalkar, product manager – DMG/Mori Seiki USA, Inc.
- Joe Goral, Sr., technical support engineer – Bourn & Koch, Inc.
- David Harroun, sales manager – Koepfer America, LLC
- David Hegenbarth, president – Federal Gear
- Will Li, vice president – Li Gear
- Thomas "Buzz" Maiuri, senior product manager – The Gleason Works
- Jack Masseth, director, Advanced Gear Design and Manufacturing – Meritor Heavy Vehicle Systems, LLC

Committee Members for Industry Voice include:

Committee Chair: Shawn O'Brien, vice president, sales and marketing – McInnes Rolled Rings

Committee Members:

- Darian Ditzler, sales manager – Luren Precision Chicago Co., Ltd
- William Gornicki, vice president, sales and marketing – ALD Vacuum Systems, Inc.
- Matthew Johnston, vice president – Croix Gear & Machining
- Anne Miner, sales manager – Machine Tool Builders, Inc.
- Gregory Moreland, global manager, markets and products – Fairfield Manufacturing Co., Inc.

"AGMA looks forward to working with these industry leaders as we drive new value for AGMA members by bringing thought provoking insight about emerging technologies, and take a leadership position by bringing the industry together to talk about what we are all about," adds Croson. "AGMA is 100 percent focused on creating a bright future for members, and we encourage non-members to join us and be part of the next 100 years of AGMA." (*www.agma.org*)

Star Cutter Company

CELEBRATES 90TH ANNIVERSARY IN 2017

Star Cutter Company is celebrating its 90th Anniversary throughout 2017 by reflecting on its past and looking towards the future.

Founded in 1927 by Howard B. Lawton and Frank Burgess, Star Cutter Company is a fourth generation family owned business and one of the oldest Michigan based manufacturing companies. Star Cutter started its cutting tool operations in Detroit before moving the main facility to Farmington in 1951. In the late 1960's, the company made an extreme change to their operation by splitting up its growing manufacturing offerings into several smaller towns throughout Northern Michigan. The Star Cutter Company headquarters remains in Farmington Hills along with its solid carbide tool manufacturing (Northern Tool), with additional manufacturing taking place in East Tawas (Tawas Tool; Gear Cutting Tools), Ossineke (Ossineke Industries; Gundrills), Lewiston (H.B. Carbide Company; Carbide Blanks and Preforms), Elk Rapids (Elk Rapids Engineering; CNC Tool & Cutter Grinding Machines), and Traverse City (Grand Traverse Construction; Commercial Construction).

Bradley Lawton, chairman of Star Cutter Company, believes a large amount of the company's success is due to the culture created as the result of directing the business "up north" beginning around 1967. "The family has always had a fond attraction to the northern lower peninsula and wanted to invest in the local communities. We set out to develop a skilled workforce and over time have created viable operations that have supported these communities."

In addition to having grown to 500 statewide employees, the company has long been committed to the future of manufacturing through education and training.

"We believe in Michigan manufacturing and it's future and have forged relationships with local colleges including: Alpena Community College, Northwestern Michigan College (Traverse City), Kirkland Community College (Roscommon), MTEC (Gaylord), Delta College (University Center), and Schoolcraft College (Livonia). As a result of these partnerships, we have made access available to hands-on training and apprenticeship programs for students interested in a career in manufacturing."

(*www.star-su.com*)

Mazak

APPOINTS NEW SOUTHWEST REGIONAL GENERAL MANAGER

Mazak Corporation drew from the ranks of its highly capable and experienced management team and promoted **Christopher Papke** to the position of Southwest Regional General Manager. Papke will take over for Dana Scott who is set to retire after 19 years as the head of Mazak's Southwest Technology Center in Houston, Texas.

Papke brings 18 years of Mazak experience to his new position. He started in the company's sales training program after graduating from Indiana University with a bachelor's degree in Liberal Arts and from Cincinnati State Technical College with an associate degree in Engineering Technology. As part of his training, he spent nine months at Mazak's Florence, Kentucky, North American Manufacturing Headquarters where he was submersed in the art of metal cutting and in the production of machine tools.

After six months in Mazak's Field Service Department helping install new machines, 18 months in the Application Engineering Department and another 18 months as a Product Specialist, Papke was promoted in 2004 to the position of Distributor Sales Manager for the Midwest Region. He served in that position for seven years before his promotion to Direct Sales Manager for the Southwest Region in 2011.

"We are extremely confident in Chris's ability to lead the Southwest Region as its new Regional General Manager," said Dan Janka, president of Mazak. "With his extensive Mazak training and sales experience, Chris was the perfect candidate for the position, and we know he'll continue to uphold Mazak's stellar reputation for outstanding customer service and support."

Mazak's Southwest Technology Center and its Technical Center in Dallas, Texas, are part of the company's network of nationwide regional Technology Centers. As a key component of Mazak's comprehensive customer support, the Technology and Technical Centers offer advanced application support, education and training, new technology and manufacturing systems along with on-site training and technology seminars.

(*www.mazakusa.com*)

Sandvik Coromant

APPOINTS NEW PRESIDENT

Nadine Crauwels has been appointed as the new president of Sandvik Coromant, and will be responsible for continuing to develop the company as the leading supplier of tools, tooling solutions, and know-how to the manufacturing industry.

Crauwels has a solid background with Sandvik Coromant, having previously worked as vice president and head of customized solutions and strategic relations. She has had roles within sales, product management and production introduction, and also worked as Sandvik Coromant manager for Switzerland. Crauwels joined the company in 2000, and has more than 22 years' experience in the manufacturing industry.

"I am very pleased that Nadine will take on this new role since she is a solid and modern leader with extensive knowledge and experience from our industry. Her leadership, along with the strong team in Sandvik Coromant, makes me feel highly optimistic for the future development of Sandvik Coromant," says Klas Forsström, president of Sandvik Machining Solutions, who previously held the position as president of Sandvik Coromant.

"This is very exciting, and I am looking forward to this new opportunity to continue to develop this fantastic company. Sandvik Coromant is in a great position already today with leading products and solutions that deliver value to our customers around the world. Sandvik Coromant is driven by highly skilled and committed employees dedicated to supporting our customers. With the Sandvik Coromant Management team, I will make sure we will execute our strategy to lead the industry forward and together shape the future of manufacturing," says Crauwels, "My focus will lie on securing the continuity of Sandvik Coromant's success and strengthening our role as market leader."

Crauwels will report to the president of Sandvik Machining Solutions Forsström and be a member of the Sandvik Machining Solutions Management Team. Born in Belgium, Crauwels has a master of science in mechanical engineering from Catholic University of Leuven, Belgium. (*www.sandvik.coromant.com*)

Oerlikon

PRESENTS PAPER AT CTI SYMPOSIUM USA 2017

High-performance transmission specialist Oerlikon Graziano, brand of Oerlikon Drive Systems Segment, presented its range of hybrid transmission systems at the 2017 CTI Symposium and Transmission Expo USA, in Novi, Michigan. The focus was on the hybrid transmission concept, which promises a step forward on the path to electrification, with a compact and elegant package and full hybrid capabilities.

Oerlikon Graziano presented a paper entitled "Modular P2-P3 Dedicated Hybrid Transmission for 48V and HV Applications." The company has designed and patented an elegant DHT concept, starting from the know-how cumulated in the last years from the concept of the OGeco transmission. This has been achieved by continuous improvement activities ongoing on the demo vehicle and focusing on the market needs. The transmission is a modular concept which starts from a traditional 2-shaft single-clutch transmission. Thanks to a link between two main gears of the gearbox and the direct gearing between the electric machine and this linked gear arrangement, free-mounted on the primary shaft, the concept allows to have a very efficient electric path of the transmission, which presents two different gear ratios between the electric machine and the secondary shaft.

The solution is particularly innovative, because keeping a very simple and well known architecture (so cost effective), it allows the connections to be made with standard transmission components, selectively coupling the electric machine to either the primary or the secondary shaft. This feature, then, represents a mixed P2-P3 hybrid architecture and therefore takes the advantages of both (e.g. powershifting-P3, recuperation-P3, cranking-P2, standstill charging-P2). It allows a performance increase of up to 40 percent on 0–100 kph and up to 25 percent benefit on CO_2 emission with the installed electric power being 30 percent of the total. Thanks to its scalability and to the possibility of having different power-split configurations the system can be used both as a mild-hybrid or as a plug-in hybrid solution, within a 48V or HV system.

Between the products on display the new entry in the electric range products is EMR3, a single speed transmission for battery electric vehicle, designed for a maximum input torque of 270 Nm and max input speed of 14,000 rpm. The lubrication concept is developed to guarantee maximum flexibility in term of installation angle to allow the highest level of compatibility with different vehicle layout. Another remarkable factor is represented by the compact design (150 mm center distance input shaft), for weight optimization.

The 4SED Twin-Drive 4-Speed Electric Drive is a powershifting gearbox with low-cost design that includes two small motors and four ratios to provide a wider range of operation at higher efficiency. (*www.oerlikon.com/drivesystems*)

Cal Poly

EXCELS AT SAE BAJA COMPETITION WITH SMTCL

The California Polytechnic Institute in Pomona, CA competed in the Collegiate Baja Off-Road Competition in Pittsburg, Kansas on May 25–28 and finished in 4th Place. The event sponsored by the Society of Automotive Engineers (SAE) saw over 100 teams competing from Universities all over the world. Students from the United States, Canada, Mexico, India, China, South Korea all participated in the competition. In addition to the Baja Off-Road Competition the SAE also holds Collegiate Design Events for formula cars, aircraft, supermileage vehicles and autonomous driving vehicles.

To compete in the SAE Competition, students must design and build an off-road vehicle and then take part in a variety of events with scoring based on overall design, cost, acceleration, and manueverability and endurance. The event was won by the University of Michigan who finished first in five of the individual competitions. Cal Poly finished 4th with a new vehicle designed and built in their Engineering Lab. Parts on the Cal Poly Pomona vehicle were machined on the SMTCL VMC1000B and VivaTurn Lathe. These machines were provided by SMTCL-Americas to the Cal Poly Pomona Mechanical Engineering Lab.

Clifford Stover MSE PE, professor, engineering director of California State Polytechnic University – Pomona said, "Through the state-of-the-art CNC machines and the ingenuity of our students, we put a great car on the track, but more importantly we are preparing our students for the real world of manufacturing."

Jerry McCarty, chief operating officer of SMTCL, explained that SMTCL. "The CNC Machining Centers we put in the Cal Poly Engineering Lab have Fanuc Controls, which is the CNC Control that these students will likely see when they go out in the workforce." The students use the machine to manufacture engine and powertrain and suspension components. McCarty added, "SMTCL is proud to be a part of the learning experience for these students and the skills they are obtaining will benefit them and their future employers for years to come."

SMTCL produces 80,000 machine tools each year with revenues of $2.9 Billion. SMTCL has over 300 products including CNC (computer numerical control) boring mills, vertical turning centers, vertical machining centers, horizontal turning centers, horizontal machining centers, gantry-type machining centers, pipe threading machines and tapping centers. SMTCL also makes conventional lathes, boring mills, and radial drills. The SMTCL Technology Center is located in the City of Industry, California and stocks machines, replacement parts, and accessories. (*www.smtcl-americas.com*)

Hexagon Manufacturing Intelligence

ACQUIRES VIRES

Hexagon recently announced the acquisition of VIRES, a German-based, leading provider of simulation software solutions that support the development, testing and validation of driver-assisted and fully autonomous driving technology. VIRES's proven simulation solutions have been recognized for their robustness, performance and ease of building simulation environments for over 20 years. Their worldwide customer list spans prominent automotive OEMs and suppliers as well as recent entrants to the automotive market to companies in the railway and aerospace industries and elite universities involved in shaping the future of mobility. "The VIRES acquisition strengthens our CAE (simulation) platform with an industry-proven solution," says Hexagon President and CEO Ola Rollén. "It also supports our overall autonomous X vision to deliver a software-driven, intelligent ecosystem that leverages our expertise in 3D mapping and other essential sensor technologies to make safe, autonomous vehicles a reality." The company's core product VIRES Virtual Test Drive (VTD) supports a wide range of additional tools and services. As a main contributor to the industrial consortia behind interoperability standards, VIRES is a driving force in automotive simulator technology. (*www.hexagonmi.com*)

GF Machining Solutions

OPEN HOUSE TOUTS LATEST WIRE EDM TECHNOLOGY

Gf Machining Solutions introduced seven brand new machines during its recent Solution Days event in Lincolnshire, Illinois. Highlights included the heavy-duty AgieCharmilles Cut P 350/550/850 wire EDMs and the highly precise Mikron Mill P 900 vertical mill. The event also featured the new Mikron high-speed machining center and two new AgieCharmilles die-sinking EDMs. Attendees experienced live part-processing demonstrations as well as a variety of presentations to learn the latest manufacturing strategies.

The Cut P series of wire EDMs handles large, heavy part production for job shops, moldmakers, and manufacturers in the stamping, aerospace and medical industries. The machines provide ample axis travels and cut large, steep tapers and thread wire quickly and efficiently. The Mikron Mill P 900 features a polymer concrete machine base that delivers high dynamic stiffness, while its symmetrical portal design, thermal management, contour accuracy and precise positioning contribute to superior part surface finishes. To reduce cycle times, the machine sports an aggressive high-speed 20,000-rpm StepTec spindle.

The Solutions Days event also showcased a System 3R Transformer cell featuring a high-speed machining center, die-sinking EDM and a coordinate measuring machine.

GF Machining Solutions' open house event celebrated System 3Rs' 50- year anniversary and welcomed students selected to participate in the newly-created 3-year apprenticeship program. This program combines traditional college academic and technical courses with extensive practical experience to create a special opportunity for participants to earn a salary while they learn skills and gain knowledge. (*www.gfms.com*)

Gehring

HOLDS SUCCESSFUL 2017 HONING CONFERENCE

Gehring held its 2017 Honing Conference and Workshops event on May 10–11, 2017 at the Inn of St. John's in Plymouth, Michigan. The conference and workshops brought together experts from the global industry to discuss and propose solutions to advanced manufacturing challenges in surface finish technology applications. A total of 80 attendees, most from the automotive primes and Tier One suppliers, were treated to two days of learning, networking and fun.

President of Gehring in the United States, Roger Cope, gave the opening remarks to kick off the event. He noted this was the 91-year anniversary of Gehring in Germany and that the company has had a manufacturing footprint in the U.S. for 41 years. An R&D facility in Livonia, Michigan was established several years ago to meet the demand for specialized honing process development, consulting and the rapid rise in demand for Gehring contract and prototype honing services. He further mentioned that Gehring has diversified its market focus in the last several years to include the defense sector and, in that arena, Livonia serves as an ITAR-compliant facility. The "One Gehring" theme codifies the global focus of the company, as it seeks to serve a global customer base, Cope said.

Dr. Wolfram Lohse, CTO of the Gehring Group then took the floor and observed, "Part of our new business mission and focus globally is our desire to enhance customer and industry knowledge through the Gehring Academy for honing education, training, consulting and support in helping manufacturers implement and use our advanced honing technologies to their advantage, specifically to meet impending CAFE emissions regulations. We seek a partnership focus with key clients while retaining the highest level of integrity in handling confidential projects." He discussed the drive to sustainability – another Gehring focus for the future. Partnerships with other key market specialists at this event, such as Oerlikon Metco AG, Nanofocus and Siemens, have been developed to produce a comprehensive resource for the market, with multiple sources of expertise relevant to surface finish technology.

Cope concluded his remarks by noting that Gehring is now a "one-stop shop" for all elements of the honing process – machines, tools, gauging, automation, rework, abrasives, R&D – with global support for global production platforms.

Gehring's Director of R&D, Michael Schaefer, commented, "Gehring was honored to host this first unique conference, dedicated to Advanced Honing and Surface Finish technology, in the USA and to provide a high level technical and networking platform for professionals in this field with the leading manufacturers in the automotive and other industry sectors." (*www.gehring.de*)

Solar Atmospheres

ANNOUNCES PERSONNEL CHANGES

William and Myrtle Jones, primary owners of the Solar Atmospheres family of companies, have announced a few organization changes within the Solar companies. Roger Jones has been appointed CEO for Solar Atmospheres' four vacuum heat treating locations: Solar Atmospheres Souderton, PA; Solar Atmospheres Hermitage, PA; Solar Atmospheres Fontana, CA; Solar Atmospheres Greenville, SC. Roger previously held the position of Corporate President of Solar Atmospheres. Roger started the Solar Atmospheres vacuum heat treating business with his father, William Jones, back in 1983.

Also, Jamie Jones has been promoted to president for the Solar Atmospheres Souderton location. Jamie previously served as the vice president of operations at the Souderton location, and has been with the company for over 20 years.

Similarly, Trevor Jones has been promoted to CEO for Solar Manufacturing, Magnetic Specialties, and the newly developed Vacuum Pump Services Corp. Trevor has been active in the furnace operations and R&D department at Solar since 2004, and he previously held the position of principal engineer at Solar Atmospheres. (*www.solaratm.com*)

Exact Metrology

OFFERS PRODUCTS AND SERVICES AT CINCINNATI AND BROOKFIELD LOCATIONS

Exact Metrology held an open house at its facility in Cincinnati and the event was attended by over 100 local area companies, comprising quality assessment, design engineering and management personnel from many of the leading manufacturers in the region. Hosted by company co-president Steve Young, the day included ongoing product demonstrations of the various metrology equipment brands offered for sale, lease and rental by Exact, as well as the testing procedures provided as a service by this unique metrology supplier. Highlight of the event was the company's new partner, EnvisionTEC, a builder of 3D printing equipment for myriad industries, for whom Exact was recently named Midwest dealer. Also on display were a number of the other equipment lines represented by Exact, including Romer arms, GE CT scanning, Leica 3D imaging scanners and a variety of point cloud software advancements for the quality world.

Services on display at the Cincinnati open house included 3D scanning, reverse engineering, quality inspection, instant scan-to-CAD comparison and a full suite of PolyWorks software solutions. Equipment shown at the event included Aicon 3D systems, Breuckmann 3D scanners, Leica Geosystems, Romer and Hexagon brands of scanning devices and related hardware, all of which were available for hands-on use by event attendees. Company representatives from the various equipment lines, as well as Exact Metrology's team of application engineering and testing specialists, were present for demonstrations and technical presentations, throughout the event.

The EnvisionTEC line drew particular attention and Steve Young commented, "This new partner was a natural extension of our service work. We do 3D scanning and were using a 3D printer, so we had that light bulb moment and decided to connect with a 3D printer builder to expand our equipment offerings." Exact represents EnvisionTEC throughout the Midwest. EnvisionTEC is a Detroit-based builder of various 3D printers for the medical, dental, jewelry and various industrial sectors, offering machines to produce parts up to 18" cube.

In addition, the Brookfield, Wisconsin location hosted its open house. Attended by 70 companies in the area, the event was hosted by Exact Metrology co-president Dean Solberg in conjunction with Exact partners EnvisionTEC, Hexagon Metrology, PolyWorks, 3DSystems and ETI.

A variety of scanning equipment was demonstrated throughout two rooms in the facility. One highlight of the open house was the new Leica BLK360 Imaging Laser Scanner, a 360-degree scanner that allows high resolution scans for a full-dome in less than three minutes. Other devices showcased included the Hexagon Metrology Romer Absolute Arm, several Artec3D scanners, the Surphaser 100HSX, several Leica long range scanners and the ProCon CT scanner. While demonstration pieces were available to scan, attendees were able to bring in their own parts to show live 3D scanning on the screen.

(*www.exactmetrology.com*)

Okuma

COMPLETES SECOND SMART FACTORY IN JAPAN

Okuma Corporation recently announced the completion of the company's new Dream Site 2 (DS2) parts factory in Oguchi, Japan. This facility improves the company's ability to respond to customer needs by shortening lead times and adding value through high-efficiency production. Parts produced will be used for machine tool production and also to stock service inventory. The DS2 commenced production in March, 2017.

DS2 is a self-contained start-to-finish production facility for small and medium lathes, and grinders. This is the second smart factory built at Okuma's headquarters, following the Dream Site 1 (DS1), which was completed in May 2013. The DS1 was one of the first self-contained start-to-finish smart factories.

Okuma is building its smart factories based on the goal of building futuristic factories that interweave automation with skilled techniques. These smart factories combine cutting-edge automation, technologies for unmanned operation, advanced IIoT (Industrial Internet of Things), and workplace know-how to achieve high-mix low-volume production while maintaining production efficiency equivalent to that of mass production. DS2 highlights include more advanced automation and robotics, accurate and quick work instructions and enhanced operation monitoring. (*www.okuma.com*)

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

July 18–19—7th WZL Gear Conference Ann Arbor, Michigan. In continuation of a successful tradition to present the research results from WZL Gear Department to the North American gear industry, WZL invites members of the gear manufacturing community to the 7th WZL Gear Conference hosted by Liebherr Gear Technology at the Sheraton in Ann Arbor, Michigan. The conference fee is $260 per attendee. WZL will give a selection of the most interesting presentations from its research portfolio. The presentation topics will include gear design, manufacturing and testing. The two-day conference is devoted exclusively to the presentation of the latest research in gear design, manufacturing and testing. Additionally, the software resources of the WZL Gear Research Circle are available for examination, including solutions for gear design and manufacturing process development. For more information, visit *www.wzl.rwth-aachen.de*.

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

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

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

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

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

September 13–15—VDI International Conference on Gears 2017 Garching, Germany. Supported by national and international associations, the conference brings together over 600 leading experts from the international gear and transmission industry. The 2017 conference will be a unique meeting point for equipment manufacturers, producers and researchers of gear and transmission systems to present their new solutions, latest research results and technical ideas. There is still room for improvement in the field of gears and transmissions, how gears can contribute to increasing energy efficiency, reducing resource consumption and how new technologies will be incorporated in the powertrain. For more information, visit *www.vdi-wissensforum.de/en/event/international-conference-on-gears/*.

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4 What is your primary JOB FUNCTION (check ONLY one)

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- ❏ Manufacturing Production Management (C)
- ❏ Manufacturing Production Department (D)
- ❏ Manufacturing Engineering Management (E)
- ❏ Manufacturing Engineering Department (F)
- ❏ Product Design, R&D Management (H)
- ❏ Product Design, R&D Department (I)
- ❏ Purchasing (L)
- ❏ Marketing, Sales or Communications (M)
- ❏ Quality Control Management (P)
- ❏ Quality Control Department (Q)
- ❏ Other (Please describe) (N) __________

5 My company's principal product or service is:__________

6 How are YOU involved with gears (check all that apply)?

- ☐ My company MAKES gears (20)
- ☐ My company BUYS gears (22)
- ☐ I DESIGN gears (23)
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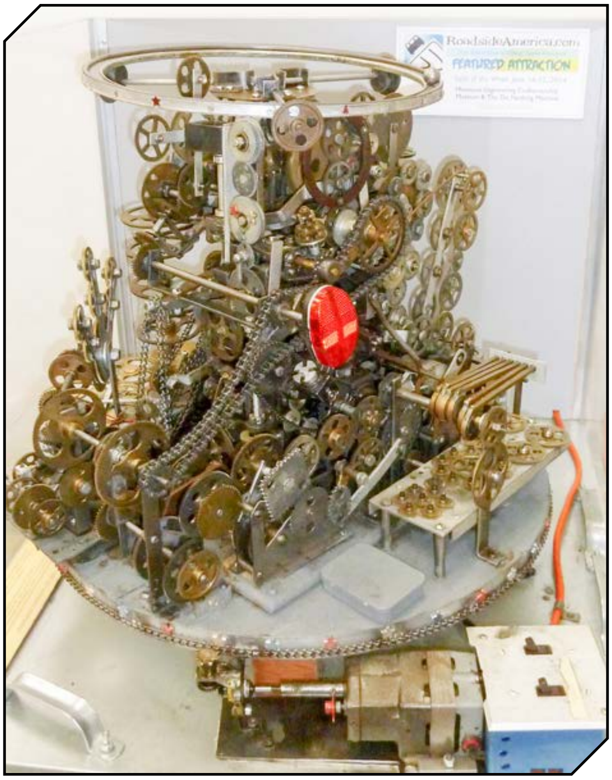
Much Ado About Nothing

For over 50 years, the Do Nothing Machine has entertained the public eye with its complex machinery, a mountain of over 700 gears put together for the express purpose of doing nothing.

Alex Cannella, Associate Editor

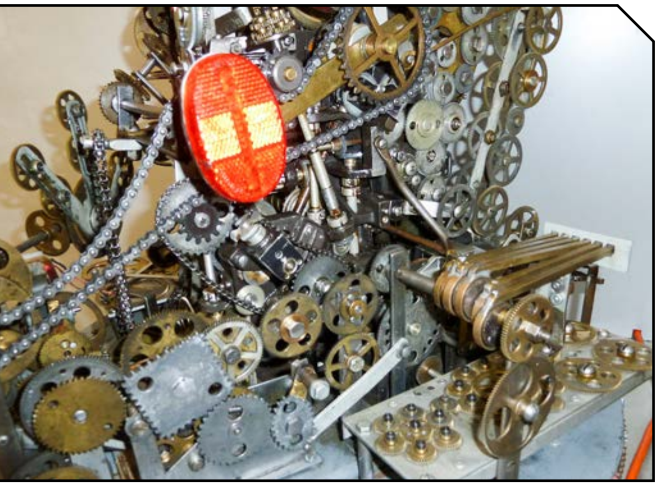


There's an argument to be made that the simplest tool to execute a job is the best one. But we've always been entranced by wild, mechanically verbose contraptions like Rube Goldberg machines, which have always been more about the journey than the destination, so to speak. But even Rube Goldberg machines eventually manage to accomplish something at the end. The Do Nothing Machine? Its creator, Lawrence Wahlstrom, cheekily dubbed it a flying saucer detector, smog eradicator or any number of other fanciful names, but with the official title it bears today, it probably goes without saying what its function is.

Wahlstrom, a retired clock maker, started working on the Do Nothing Machine as a repair job. He found a surplus WWII bomb sight and repaired its complex gear train. Once other people started seeing it, however, he quickly realized that his audience was more interested in being entertained by the device's complexity than studying it.

And so Wahlstrom turned his bomb sight into an art piece. He made the Do Nothing Machine more and more complicated over a 15-year period starting in 1948 with the goal of adding at least 50 gears each year. By the time he was finished with it, Wahlstrom's monster had become a mountain of moving parts that eventually consisted of over 700 gears, dozens of outlandish gear trains and, bizarrely enough, an oil pump from a Volkswagen, a ball bearing on an oscillating track and a red light.

The machine became a minor celebrity of its own in the '50s. It and its creator found their way into the pages of *Popular Mechanics*, *Mechanix Illustrated* and even *Life* magazine, and made more than 25 television appearances, including on the Garry Moore, Art Linkletter and Bob Hope shows. And during that entire time, it continued to grow and evolve until it eventually fell out of the limelight.



Wahlstrom's machine wouldn't resurface until 2003 when it was purchased by Earl Wolf in an auction. Wolf, in a sense, carried on Wahlstrom's legacy, restoring the machine to its former glory and immediately taking it on the road to show off to the public at local fairs and shows. But even restored, the machine took a fair amount of work to maintain, with errant parts constantly breaking down. Ever since, the machine has seemingly required a technician's full attention all on its own to keep it maintained.

Eventually, the Do Nothing Machine changed hands again, this time being gifted to the Miniature Engineering Craftsmanship Museum in Carlsbad, Calif., where it has remained on display today. The machine has gotten long in the tooth and temperamental, but curators and engineers of the museum work persistently to keep the needy beast maintained. Their efforts keep the Do Nothing Machine in working order, and the machine continues to delight those who walk through the museum's doors today.

So perhaps the Do Nothing Machine is a bit of a misnomer. After half a century of entertaining the masses with its inscrutable systems, surely, it's accomplished its creator's original mission.

For more information:
The Miniature Engineering Craftsmanship Museum
Phone: (760) 727-9492
www.craftsmanshipmuseum.com/index.html

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