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HEAT TREATING 4.0?

Big Data and Multi-Axis Machining

Shifting Fortunes in Energy Industries


Profilator
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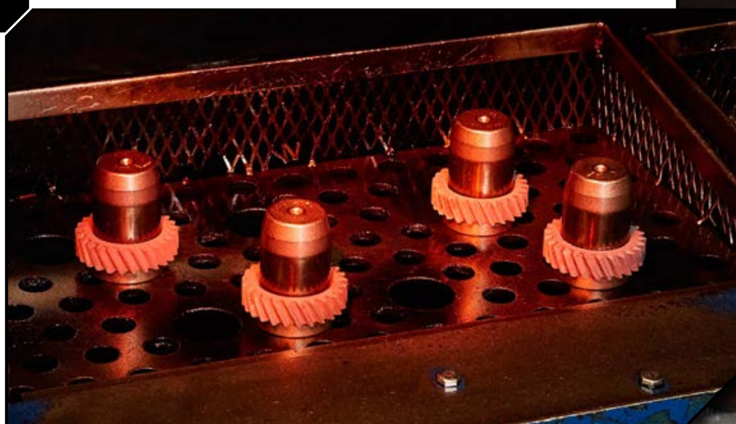

SPECIAL FOCUS: HEAT TREATING

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features

technical

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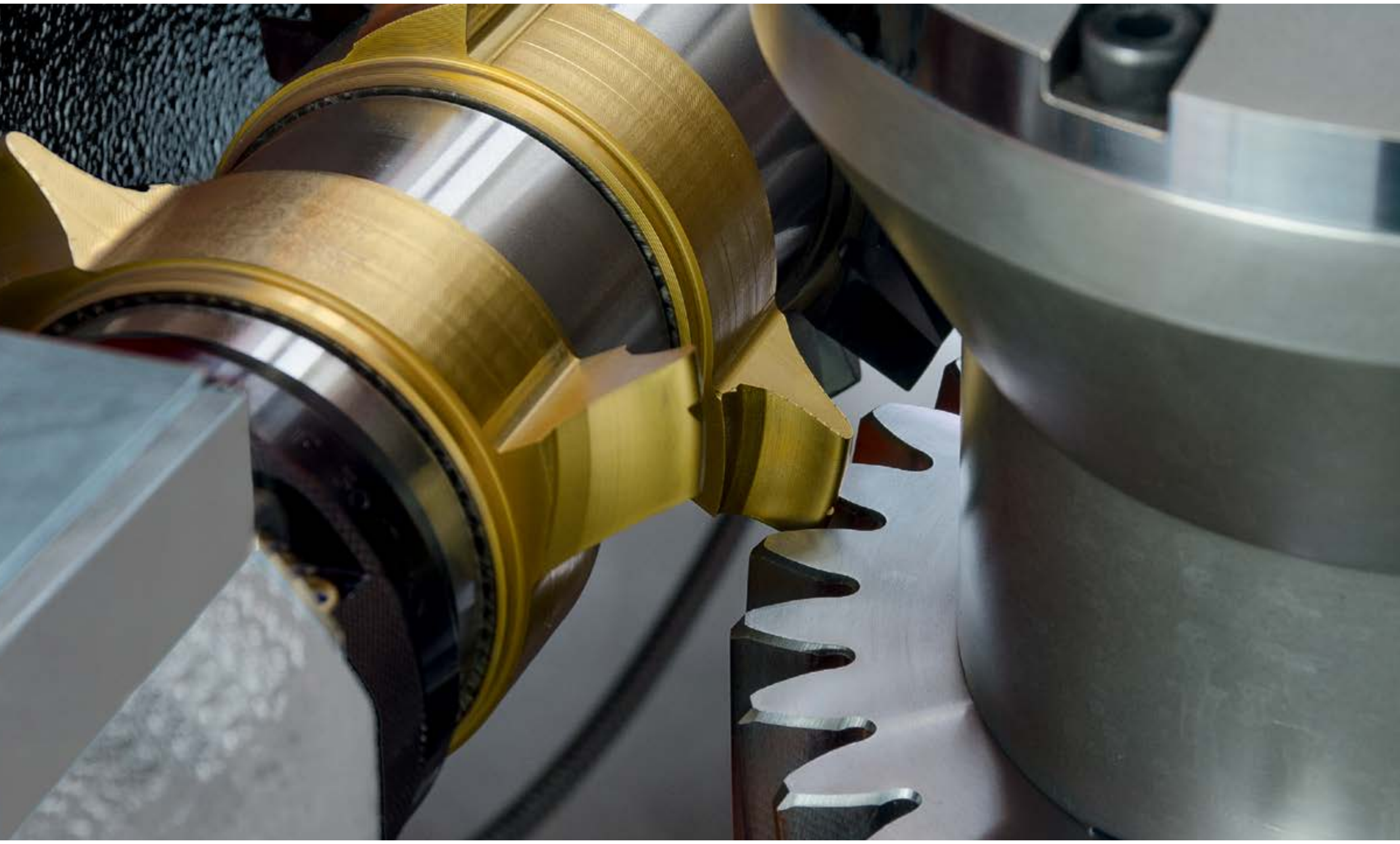
Photo courtesy of Paulo

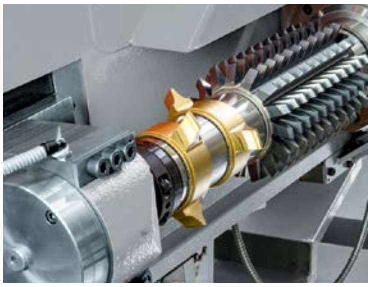
Liebherr Performance.



Gear hobbing machine LC 180 DC

Gear hobbing machine LC 300 DC

Chamfering machines LD 180 C and LD 300 C



Chamfering in the work area

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LIEBHERR

THE GEAR INDUSTRY'S INFORMATION SOURCE

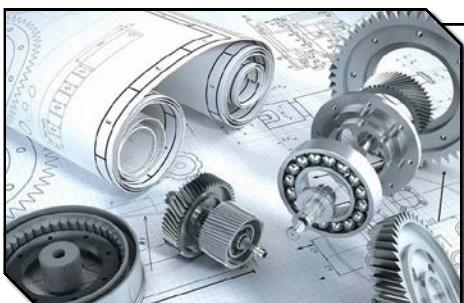
www.geartechnology.com

Gleason Corp

Shaving of gear tooth flanks is an economical process for the large-scale production of gears. In shaving, the cutting tool runs in mesh with an unhardened workpiece with the axes of tool and work crossed in space. See the video here: *www.geartechnology.com/videos/Gleason-Examines-Plunge-Shaving-/*

Koepfer America

Check out this video featuring a wide range of CNC machine tools for hobbing, shaping and milling gears, worms and rotors (*www.geartechnology.com/videos/CLC-Gear-Shaping,-Hobbing-and-Thread-Milling/*)



Gear Talk

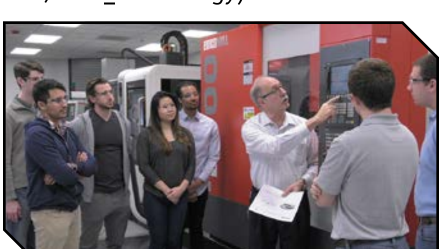
Gear Technology technical editor and resident blogger Chuck Schultz weighs in on these important topics on the *www.geartechnology.com* homepage:

In *Shared Knowledge*, Schultz discusses why offering engineering knowledge with the gear community is beneficial and the role the Internet plays (good and bad) in distributing this information. (*www.geartechnology.com/blog/shared-knowledge/*)

In *Why Not Teach?* Schultz asks those with a gear manufacturing background to join the conversation and become a positive influence on young engineers in our industry. (*www.geartechnology.com/blog/why-not-teach/*)

Social Media

Check out our Twitter page for the latest news and product innovations from companies like Siemens, Solar, Marposs, Gear Research Institute, Sandvik and ECM-USA. (*https://twitter.com/Gear_Technology*)



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RANDALL PUBLICATIONS LLC
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
(847) 437-6604
FAX: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief
Michael Goldstein
publisher@geartechnology.com

Associate Publisher & Managing Editor
Randy Stott
wrs@geartechnology.com

Senior Editor
Jack McGuinn
jmcguinn@geartechnology.com

Senior Editor
Matthew Jaster
mjaster@geartechnology.com

News Editor
Alex Cannella
alex@geartechnology.com

Editorial Consultant
Paul R. Goldstein

Technical Editors
William (Bill) Bradley, Robert Errichello, Octave Labath, P.E., John Lange, Joseph Mihelick, Charles D. Schultz, P.E., Robert E. Smith, Mike Tennutti, Frank Uherek

DESIGN

Art Director
David Ropinski
dropinski@geartechnology.com

ADVERTISING

Associate Publisher & Advertising Sales Manager
Dave Friedman
dave@geartechnology.com

Materials Coordinator
Dorothy Fiandaca
dee@randallpublications.com

China Sales Agent
Eric Wu, Eastco Industry Co., Ltd.
Tel: (86)(21) 52305107
Fax: (86)(21) 52305106
Cell: (86) 13817160576
eric.wu@eastcotec.com

ON-LINE

Digital Content Manager
Kirk Sturgulewski
kirk@geartechnology.com

CIRCULATION

Circulation Manager
Carol Tratar
subscribe@geartechnology.com

Circulation Coordinator
Barbara Novak
bnovak@geartechnology.com

RANDALL STAFF

President
Michael Goldstein

Accounting
Luann Harrold

BPA WORLDWIDE BUSINESS

Transferring Tribal Knowledge

Publisher & Editor-in-Chief
Michael Goldstein

Our annual *State of the Gear Industry* survey (published last issue) once again revealed that the difficulty of finding skilled labor remains one of our industry's most pressing concerns. This is not a surprise, nor is it really news.

Most everyone realizes that we're dealing with an aging manufacturing and engineering workforce, and as those employees with the most knowledge and experience retire—either to sunnier climes, or to that great machine shop in the sky—their knowledge and experience go with them.

We're also dealing with a workforce that's far more mobile than ever before. People change cities or even countries for the right opportunity. They'll also take a job across the street if it pays a little more. Many companies deal with the problem of lost knowledge and experience by simply hiring it away from their competitors. And while this might slow the bleeding at your company, it exacerbates the problem at somebody else's, and it certainly doesn't help the industry as a whole.

What we need, then, is education. Not just a one-time effort, but a concerted, continuous effort to invest in our employees—both young and old—in order to pass on and continue to grow our industry's knowledge.

Last issue, AGMA President Matt Croson told you about some of the new seminars and other educational initiatives the association is putting together. One of the new courses, "Fundamentals of Gear Design and Analysis," takes place April 19–21 in Indianapolis. Another, "Steels for Gear Applications," will be offered October 4–6 in Alexandria, VA. A complete list of AGMA educational offerings is available at *www.agma.org*.

Of course, there are also gear schools and seminars offered by many of the major gear machine tool suppliers. The Gleason Gear School at Gleason Cutting Tools in Loves Park, IL, is scheduled for April 10–13, June 12–15, August 7–10, October 9–12 and December 4–7 this year. The Koepfer Gear School will be held May 23–25 in St. Charles, IL. There are always plenty of educational events like these listed in our events calendar at *www.geartechnology.com*.

Also, Arvin Global Solutions just held its first ever gear seminar in March, and from what I hear, it was a resounding success. "An Introduction to Gear Process Engineering" took place March 7–9 in Naperville, IL. Presenters at the seminar included industry veterans Matt Mondek, Bruce Roberge, Mike Steele, Al Swiglo, Kevin Walsh and our own technical editor and resident blogger, Chuck Schultz. You can read a little bit about the seminar in his blog posts "Shared Knowledge" and "Why Not Teach" (*www.geartechnology.com/blog*).

Here at *Gear Technology*, we believe very strongly in education. It is, after all, the core of what we do. Although we don't host the type of seminars these other organizations present, we do offer educational technical articles, and columns like "Ask the Expert." More than 10,000 visitor per month come to the *Gear Technology* Library to learn from the more than 2,100 technical and feature articles in our archive.

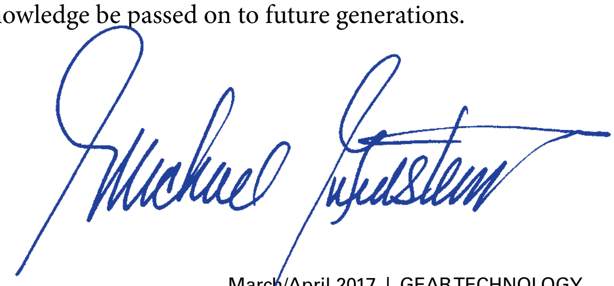
Also, I'm pleased to announce that we'll be hosting the second installment of "Ask the Expert Live" at Gear Expo in Columbus. We had a great turnout at our event in 2015, both in terms of experts on our panel and show visitors who stopped to listen. I strongly recommend you view last year's sessions to see not only the quality of the presenters, but also the questions asked and the depth of answers given, so you can think about what questions you'd like to ask our experts this year. Check out the videos by visiting *www.geartechnology.com/videos*. You'll hear from some of the top technical gurus at Gleason, Klingelnberg, Liebherr, Star-SU, FZG and more.

We're busy putting together a similar lineup of experts and topics for "Ask the Expert Live" at Gear Expo 2017. Having all of these experts gathered in one place is rare, and having them ready to answer your questions is rarer still, so I invite you to submit your gear-related technical questions to senior editor Jack McGuinn (*jmcguinn@geartechnology.com*). And if you come to Gear Expo, I hope you'll come ask your questions in person as well as learn from the answers to others' questions.

We all know that manufacturing is no longer an industry fueled by strong backs and arms. Machines and technology are increasingly doing the work, and these are driven by knowledge and experience. Not investing in them is done at your peril.

So whatever you do, please take advantage of as much education as you're able. If you're in a management position, don't forget that educating and training your employees is an investment in your company that will pay off in terms of increased productivity, quality and profitability.

Investing in iron is only one part of your future success. Investing in knowledge and experience is every bit as important. In fact, it's imperative for your success, for the success of our industry, and the success of our nation that our tribal knowledge be passed on to future generations.



Vomat

INTRODUCES FILTRATION TECHNOLOGY FOR METALWORKING INDUSTRY

For grinding modern cutting tools, all parameters that are involved in the manufacturing process must be optimally coordinated with each other. Only in this way can drills or milling cutters be produced in large quantities with consistent high quality as expected by the market. An important part of the puzzle is microfiltration technology. The filtration technology must not only ensure very high purity of a variety of lubricants over a long period of time but also must be of a design that is flexible enough to grow easily with production capacity expansion.

The filtration specialist Vomat from Germany provides high-performance filtration technology – from small stand alone to large industrial central systems – which are designed to meet customer specific requirements and are of modular design. As a result, they can be quickly and easily adapted to changing requirements in the company.

Vomat systems operate in full-flow mode and separate dirty and clean oil 100 percent thanks to a high-performance pre-coat filter design. This results in utmost purity of the cooling lubricants to NAS 7 or 3-5 µm particle size. In addition, the systems adapt automatically to varying production volumes and initiate the filter backwash cycle depending on the contamination level of each filter element. The back-flushing of each individual filter cartridge instead of the whole filter bank at the same time allows the system to operate with very high energy efficiency while keeping in optimal synchronization with the customer's grinding machines. The Vomat FA standalone models offer filtration capacities of 70 to 960 liters (18–254 gallons) and are extremely compact; much smaller than comparable filtration solutions on the market. This keeps the transport costs low, minimizes building modifications and saves precious production floor space.

Steffen Strobel, technical sales manager with Vomat, states: "Vomat filtration systems grow with the success or needs of our customers. Thus, standard systems can be adapted to increased or changed production requirements by means of additional modules such as digital displays for visualizing the filtration process, frequency-controlled machine supply pumps or internal and external pre-filters as well as a variety of cooling systems. In addition systems can be designed for individual plant configurations and can be integrated seamlessly into any workflow. This includes large-scale industrial plant-wide central systems with optimal cooling and disposal concepts. Even if there are changes in production requirements, with our help the customer is ensured that his filtration system is adapted to current conditions."

For more information:
Oelheld U.S. Inc. (Vomat Distributor)
Phone: (847) 531-8501
www.vomat.de

Emuge

INTRODUCES SOLID CARBIDE COOLANT-FED MICRO DRILLS

Emuge has expanded its EF-Series of high penetration rate drills with a new line of sub-micro grain carbide coolant-fed micro drills. The EF High Performance Micro Drills range from 0.0295 in. (0.75 mm) up to 0.1181 in. (3.0 mm) in diameter, are all coolant through design, and are ideal for aerospace, medical and precision automotive applications designed for producing very small deep holes in steel, cast iron, stainless steels and non-ferrous materials. All tools are 6xD length and can accommodate most production applications.

The unique face geometry of the EF Micro Drills generates short chips in the drill operation, ensuring high drill hole accuracy. The micro face point and flute geometry, in addition to the coolant-fed design enable excellent chip evacuation for the highest possible drilling speed, while reducing the need for peck cycles or clearing chips. The drills have a TiALN T99 multi-layer PVD coating designed for added heat and wear resistance. This significantly reduces built-up edges and edge chipping, substantially increasing tool life. In addition, the large central tool shank channel guarantees maximum coolant intake capacity, allowing optimal coolant transfer.

The internal coolant supply enables economically efficient, high performance machining down to even the smallest drilling diameter of 0.75 mm. Drills also feature a double margin design for added stability and superior hole surface finish.

For more information:
Emuge
Phone: (800) 323-3013
www.emuge.com

Marposs

OPTOQUICK 3.0 DELIVERS TACTILE AND OPTICAL MEASUREMENT TECHNOLOGY

Marposs announces the introduction of Optoquick 3.0, its latest addition to the industrial gauging solutions portfolio. Optoquick is a high precision gauging solution designed for the shop floor environment and integrating Marposs multi-sensing technologies for the widest variety of gauging requirements. Optoquick helps line operators with fast and precise quality control of shafts, directly beside the manufacturing machines, eliminating any waste of time in operations and increasing productivity.

Thanks to the combination of tactile and optical technologies, the Optoquick measuring unit delivers superior gauging capabilities and flexibility at the highest levels of its category. In addition to any typical optical measurements such as diameters, radii or run-outs, the Optoquick can easily inspect key-slots and concave profiles not available through shadow casting analysis.

Optoquick has several features designed for flexible manufacturing: broad measuring range, part capacity up to 1200 mm in length and motorized tailstock for part change, as well as manual and automatic loading options. Multiple gauging programs can be loaded into a single machine, enabling the operator to measure different parts in sequence with the maximum simplicity, as scanning a barcode to automatically activate the right measuring setup.

"In design, we targeted the most demanding requirements for precision gauging controls in the shop floor," says Roland Lang, sales and marketing manager of the flexible gauging systems. "We have worked hard on the core gauging technologies with the goal to overcome traditional trade-offs and to develop a superior solution for the industry."

For more information:
Marposs Corp.
Phone: (248) 370-0404
www.marposs.com

Swiss Precision Gear Grinding

Cars, aircraft and industrial machinery all require high-accuracy gears for their transmissions. Worldwide, Reishauer gear grinding machines play a major role in the manufacturing process of grinding gears used in such transmissions. Demands placed on these transmissions include the reliable transfer of high torque and power density, low weight and minimal noise emissions. Reishauer precision ground gears ensure that the demands placed on transmission gears are fully met.

Reishauer AG, Switzerland
www.reishauer.com

Reishauer Corp. / 1525 Holmes Road / 60123 Elgin
Tel. +1 847 888 38 28 / email: usa@reishauer.com

REISHAUER

Gear Grinding Technology

Mitsui Seiki

OFFERS HIGH-PRECISION MILLING WITH THE PJ812

The new Mitsui Seiki PJ812 Precision Profile Center is a three-axis CNC vertical jig mill engineered to perform high-precision contour machining and ultra-precise boring of components with critical tolerances. It is ideal for processing parts for the mold and die, optical, aerospace and medical industries.

The PJ812 machining center provides positioning accuracy and repeatability of ±1μm. A thermal compensation system employs sensors on the machine faceplate and inside the spindle to minimize the effects of temperature changes on part accuracy and cut temperature-generated displacement by 60 percent. This system also reduces Z-axis thermal growth and deflection by 30 percent. Cooling systems for slideway lubrication and ball screw cores stabilize axis feed precision.

Mechanical design features that maximize machine rigidity and accuracy include hardened and ground tool steel box slideways as well as contact elements that enhance acceleration, reduce stick-slip, and allow for feed accuracy of 0.1µm. Another proprietary engineering detail drastically improves the static rigidity of the Z-axis to more than six times that of conventional Z-axis arrangements.

The PJ812 machining center spindle choices include 10,000 rpm with 50-Taper with 30/15 kW (40/20 hp) direct drive motors and up to 30,000 rpm, 18/15 kW (24/20 hp) with 40-Taper. X-, Y- and Z-axis travels are 1,200 mm (48 in.), 800mm (32 in.) and 500 mm (20 in.) respectively. The machine table can accommodate a maximum load of 1,500 kg (3,300 lbs) on its 1,200 mm (48 in.) × 800 mm (32 in.) work surface. Overall machine footprint is 4,720 mm (189 in.) by 3,000 mm (120 in.). A 40-tool capacity ATC is standard.

The fully enclosed machine enclosure allows for complete containment of chips and coolant, while affording excellent work loading and set up ergonomics. The PJ812 possesses an energy saving circuit that reduces electric power consumption by up to 90 percent and compressed air consumption by up to 40 percent. The latest FANUC 31iM-B CNC is equipped with a new HMI and a 500 mm (19 in.) LCD touch screen for ease of operation for set up and at-machine programming.

For more information:
Mitsui Seiki
Phone: (201) 337-1300
www.mitsuiseiki.com

Mitutoyo

TEST INDICATORS DESIGNED FOR IMPROVED DURABILITY

Mitutoyo America Corporation announces the release of lever-type dial test indicators with increased durability, sensitivity and readability. A wide array of styli and ruby tips allows for probing of many applications. Stylus length is marked on the dial face to assist customers when ordering replacement styli. To improve readability, a glare-free, flat crystal face has been incorporated to allow for easy viewing of graduations. In addition, the font and dial face color were changed. Multiple layers of hard, smudge-resistant coatings on the crystal prevent scratches and contamination. An O-ring seal on the bezel provides smooth rotation and prevents oil and dust from contaminating the dial face. A flange was added to prevent the bezel from becoming detached during use. Optional limit hands can be attached to the bezel, allowing for easy identification of tolerance limits. Improved impact-resistance and a one-piece internal assembly protect your indicator. The one-piece assembly also makes replacement of internal components simple, should service be required. A unique sub-plate structure has been incorporated into all models to prevent the stylus from becoming loose. Redesigned mounting of the gears allows the indicators to maintain good trackability even with prolonged use. Choose from a variety of dial positions: horizontal, horizontal with a 20-degree tilted face, vertical and parallel.

For more information:

Mitutoyo America Corporation
Phone: (630) 820-9666
www.mitutoyo.com

Walter

EXPANDS TITEX PERFORM TAP SERIES

Walter has expanded the productive and cost effective Walter Titex Perform lineup of TC115/TC216 taps with an array of new sizes. The Perform lineup of products is one of three categories to Walter Titex threading tools. 'Perform' tools are products that provide an economical solution with focused importance on price.

The others are 'Supreme' indicating the highest level of technology and performance available and the 'Advance' which indicates product efficiently balanced between price and performance.

The new sizes include UNC thread styles, giving these highly flexible taps an even wider range of application in a variety of materials. New dimensions for the line include metric fine (MF) M8 × 1 to M18 × 1.5; and UNC #6, 8, 10, plus ¼, 5/16, ⅜, ½, ⅝, ¾.

The versatile TC115 (blind-hole) and TC216 (through-hole) taps tackle material ranging from steel to aluminum (ISO material groups P, M, K and N), and because of this versatility can help save on inventory costs by reducing the number of taps needed. The TC115 blind-hole tap has a 45° helix angle (for thread depth of 3×D) and a C-form chamfer. The TC216 through-hole tap features a spiral point for forward chip evacuation and a thread depth capability of 3.5×D. Both taps have HSS-E bodies and are available with either TiN or vaporized coating. The vaporized option increases process reliability with tough ISO-M materials while the TiN coating provides longer tool life and higher cutting speeds among its benefits.

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

Mecof

PORTAL-STYLE 5-AXIS MILLING CENTER PROVIDES HIGH PRECISION

The large Powermill machining center from Mecof, part of EMCO Group, provides users precision, high dynamics, operational flexibility, and cost-effectiveness in a massive travelling gantry 5-axis milling center. Powermill with its moving bridge structure, permits loading of large, heavy workpieces on the stationary work table from overhead or from either end of the machine making it ideal for handling aerospace components. Simple overall design makes possible easy positioning, set up, and clamping of huge workpieces of practically unlimited weight.

Users may specify travel in X/Y/Z: basically unlimited longitudinal, X-axis travel, and from 4,5,-6 and even 7 meters of Y- axis stroke with vertical ram stroke from 1.5 to 2.5 m plus several milling head options, automatic head exchange systems are available to create a suitable solution for a wide range of large parts. Double CNC platforms on each column with vertical adjustment, 120 pocket or more tool changer, laser checking of tool and workpiece to assure precise setup, high pressure tool cooling system, volumetric compensation and more are available. Axes feed rate is 30 m/min.

The mechanical universal milling head provides 6000 rpm, 38 kW (S1), 1000 Nm (S1), or users can choose a milling head with a straight head or with high-Speed motorized spindles, or indexed or full 5-axis contouring milling heads, to suite the material being machined and the geometric shape.

The Mecof machines are popular for aerospace machining as they are designed for the accurate production of assembly and lay-up tooling, long structural parts such as stringers, larger bulkheads and aircraft engine components such as discs and casings (through the application of rotary turning tables in front of or under the machine axes. Along with the EMCO turning machines, the company can offer a wide range of aerospace machining solutions from hydraulic components, actuators and even landing gear.

The box-in-box structure of Mecof machines assures machine structure rigidity, supporting high precision work over long axis travels. The massive structure combined with agility allows flexible, productive machining of many different types of parts.

For more information:
Mecof (Part of EMCO Corporation)
Phone: (248) 313-2700
www.emco-world.com

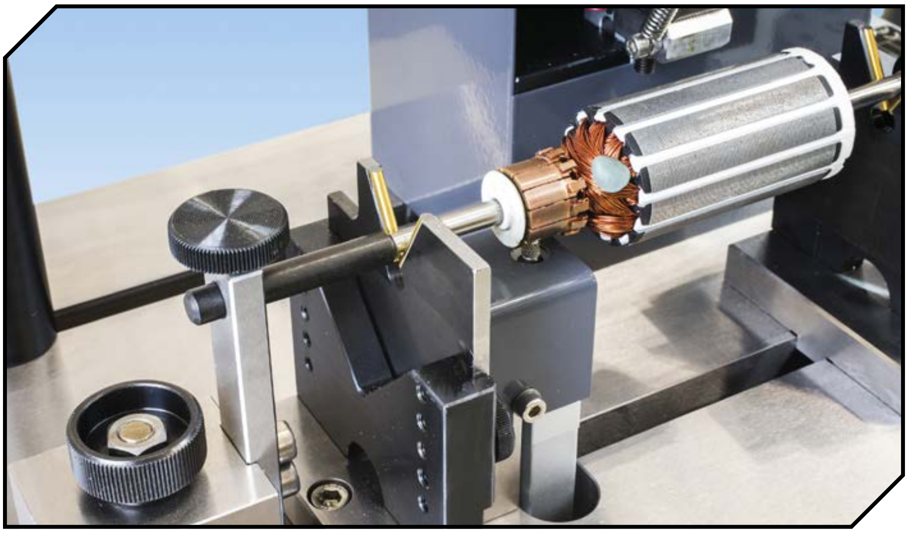
Mahr Federal

INTRODUCES CUSTOM RPM GAGE FOR CYLINDRICAL PARTS MEASUREMENT

The MarSolutions team at Mahr Federal has developed a customized rpm gage for the dynamic measurement of cylindrical parts such as commutator shafts, turbocharger turbine shafts, and other precision shafts in electric motors. The gage incorporates precision Vees and adjustable end-stops to support the shaft and define its axial position and a motion belt to rotate the shaft at up to 20 rpm.

The MarSolutions group was recently established to augment custom gage development directly with customers in response to increased demand for custom gaging solutions for dimensional metrology. Operating worldwide from a number of facilities, the MarSolutions Engineered Metrology Team will help customers analyze the gaging requirements of their application, then design and build a customized gaging solution to meet those requirements.

The MarSolutions Commutator Gage can be used in the lab or on the shop floor to measure multiple dimensional parameters, including diameter, roundness, runout, segment gap, and segment height to height and profile. The gage can be dedicated for a specific shaft size or made adjustable by the user to measure shaft lengths from 130 to 300 mm, shaft diameters from 4 to 20 mm, and winding diameters from 25 to 80 mm. A DC motor drives the motion belt from 2 to 20 rpm while the gaging computer collects data for analysis.



The user customizable software allows results to be displayed as bar graphs, polar graphs, or XY graphs with measuring values or mean values. The D1200X software interface optimizes gage use and allows quick, easy creation of customized forms and programs, and provides integrated functions for measuring system analysis, repeatability and reproducibility. SPC functions allow analysis of X/S and X/R, Pareto and histograms, and data can be exported in QDAS, QUASAR, ASCII and EXCEL formats.

As a customized design, the MarSolutions rpm measuring gage can easily be adapted for other part dimensions and/or shaft designs.

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

Message Received

Big Data Expands Process Capabilities for Multi-Axis Machining

Matthew Jaster, Senior Editor

Shop floor conversations are becoming so one-sided. Instead of some witty banter or charming political debates, the manufacturing floor is getting less personable and more productive. Years ago, you'd find four or five operators sandwiched between two workstations. It's become increasingly common to find one or two individuals responsible for several pieces of equipment during a shift. The direction this is going appears that the machines will be doing most of the talking while the operators simply listen to what they have to say. We have big data to thank for this.

Big data (machine tool data in this context) can provide everything from sensor readings, machine behavior and security threats to machine analytics, troubleshooting and part production. The possibilities for big data (in the industrial sector) are mind boggling and constantly in-flux. The process of collecting and distributing shop floor data (in real time) has changed significantly since MTConnect was first introduced in December 2008 as an open communication standard between shop floor equipment and software applications.

What began as a simple machine tool monitoring operation has significantly flourished in the metalworking industry providing new technologies in areas like mobility, tool management, metrology, automation and controls. Today, a manufacturer can connect its equipment to examine machine processes, cutting tools and inspection capabilities via data reporting and analysis that keeps getting faster, more efficient and more reliable. Here are few examples of companies utilizing the Industrial Internet of Things (IIoT) to enhance machine tool technology in 2017:

Okuma Focuses on Customization

The Okuma OSP controls are designed to integrate the latest software and hardware technology on the market. Okuma designs OSP controls for all of its machine tools and the control architecture allows the company to easily collect data tags no matter what machine is being polled.

Tha Mazak SmartBox connects machines and devices for the collection and distribution of shop floor data.
Photo courtesy of Mazak.

"That being said, we've taken steps to make the process of data collection and transfer easier than ever before. On OSP-P series controls (100, 200, 300), you can download the MTConnect *Agent & Adapter* application for free from our app store (*https://www.myokuma.com/mtconnect-agent-adapter*)," said Brad Klippstein, controls product specialist at Okuma.

Other builders are charging for the MTConnect software interface. Okuma will soon be embedding the MTConnect *Agent & Adapter* software onto the control, saving customers the extra step of downloading the app and installing it onto the machine. MTConnect allows users to access the machine's conditions and status then converts that data into a data stream that can be read by a PC or device application.

"We understand that end-user productivity strategies are endless, so we've made the process even easier to accomplish for customers wanting to take that route of data collection and analysis. The process is easy, and free, for our customers to accomplish," Klippstein said.

Many of Okuma's latest machine tool advancements play on the idea of the factory of the future and the benefits of utilizing data collection on the shop floor. These include numerous time-saving strategies such as new widgets and apps that make it easier to gather the required information at the control or from a connected network.

Okuma's built-in ECO functionality can be used to conserve energy that isn't needed from the machine tools. This now comes standard on new machines with the OSP suite platform. "This function automatically shuts off non-essential pumps, motors, conveyors and other equipment after the machining process to save energy and maintenance costs," Klippstein said.

The Tool Life Management feature (which is standard on Okuma controls) is another well-received update on the company's machine tools. "You can track insert life and tell the machine how to handle situations when the tool life runs out. This saves time and money when you eliminate operator intervention and automate the consumable insert change process,“ said Klippstein.

Regarding gear manufacturing (a subject near and dear to our hearts), Okuma

Okuma has come up with more efficient ways to manufacture gears with its hobbing and skiving functions. Photo courtesy of Okuma.

has come up with more efficient ways to manufacture gears with its hobbing and skiving functions for lathes as well as mills. Okuma offers a gear machining package along with the GUI interface for easy program input. The menus guide the user through the process in an intuitive application that runs on the OSP control. Designing hobbing and skiving programs is made easy with this new Okuma function.

On the metrology side, Okuma continues to improve its capabilities. "As metrology advancements continue to improve, we will need the flexibility to change tool paths and wear offsets in creative manners. The quality and accuracy of parts will be improved if this process can be made relatively easy and fed back to the machine tool," Klippstein added.

All of the OSP controls support application interfaces, according to Klippstein. "Okuma, our distributors, vendors, partners, and customers all have the ability to write custom applications and add them to our OSP interface. Anyone with savvy programming skills can write an app. We offer free dashboards in our app store like MTConnect Mobile Display for connecting your equipment to your smart phone or tablet. You could also download the Machine Alert app and get emails or text messages whenever your Okuma machine is in an alarm state. It tells you what happened and when, and provides a screenshot of the control."

The company's showroom called the Aerospace Center of Excellence (Charlotte, North Carolina) focuses on 5-axis capabilities. "We are always demoing features such as 5-axis auto tuning, dynamic tool load control, cryogenics, tool center point control, and other concepts that can aid in simultaneous 5-axis machining. We've posted blogs and whitepapers on certain applications such as cryogenics and turn-Cut. We try to showcase these machines and processes as much as possible," Klippsten said.

Customer and distributor feedback is imperative to Okuma's success. "We continue to improve the look/feel/functionality of our control by directly communicating with our software engineers at Okuma Japan," Klippstein said. "They

value our input, and have continued to provide us with great products and innovative software solutions."

Mazak Manages Big Data with the SmartBox

Manufacturing engineers continue to approach Neil Derosiers, application engineer and developer at Mazak, with a series of "But can it do this? …" type of questions regarding the company's Smartbox.

"One engineer after another," he said in a recent phone interview. "The first guy will ask if the technology is capable of performing a specific task and then it will be followed by a completely different request. The answer to these questions, however rarely changes. Yes it can probably do that."

Using MTConnect, the Mazak SmartBox connects machines and devices in order to capture a variety of monitoring, security and analytical capabilities. It was developed with Cisco, and will be a key strategy as Mazak moves its manufacturing base toward the digital factory of the future.

As shop floor monitoring and analytics grow in importance, Derosiers says it's vital to not only consider what the Smartbox can accomplish on the shop floor today, but how it can accommodate new technologies and solutions in the future.

"How do we create some kind of launch platform that allows us to have a unique connection that meets shop floor requirements today, but also make it as future-proof as possible so when new technology is introduced five to ten years down the road, it can handle it? This is essentially what the SmartBox is."

The ongoing list of IIoT capabilities including vibration, temperature, positioning, and inspection analysis is evolving in multi-axis machining. Mazak's SmartBox is an effective way to securely manage data like this.

With this product, Mazak has put the security of its machine network in the hands of the people that should be in charge of it, the I.T. department. "We needed I.T. to take the edge of the network from the office to the factory floor and provide the same kind of security and analytics but separate it," Derosiers said.

In short, the SmartBox is a condensed, "three-layer managed switch" similar to what is typically found in a computer room. In manufacturing, the Smartbox can protect up to 10 machine tools on a single box. The user can even isolate groups or cells and allow only the data he or she wants to go through the system.

For example, let's say you get a virus on a machine in the network from a USB jump drive. Not only does that machine tool get infected but every other machine on the network is potentially at risk. "The last thing you want to happen is someone comes into the shop with a laptop (and malware) and takes down your entire network," Derosiers said. "So we're doing more than just data acquisition, we're isolating machines not just from the office, but from each other."

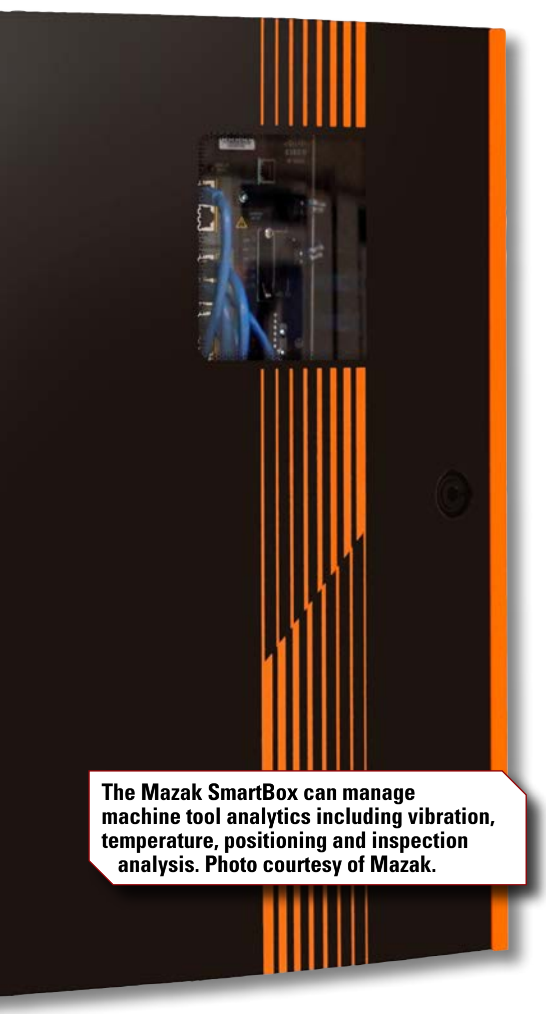
This technology is a spinoff of Mazak's iSmart Factory, the complete digital integration of its Kentucky plant with state-

of-the-art equipment, automation and IIoT capabilities. In fact, Derosiers says that the SmartBox is now a part of the daily tours that take place at the facility.

"We're talking about all of this highly-critical information and analytics moving around the shop floor and whether or not our customers feel they have a secure, trouble-free network that connects it all. It's really a risk assessment, and something every manufacturer should pay close attention to moving forward."

DMG MORI CELOS Platform Creates New Opportunities

The drive for Industry 4.0 is causing a paradigm shift in the machine tool industry that has never been seen since the advent of CNC. Jeff Wallace, general manager, 5-axis Center of Excellence at DMG MORI USA, says that the push for getting machines "online and accessible" is being pushed by customers and the quest for real-time information during the manufacturing process is critical.



The Mazak SmartBox can manage machine tool analytics including vibration, temperature, positioning and inspection analysis. Photo courtesy of Mazak.

"DMG MORI's CELOS control platform is allowing us to develop our next generation of machines incorporating many of the i4.0 requirements. In fact, many of our existing machining platforms already incorporate many of the i4.0 technologies," Wallace said.

Almost all DMG MORI machines are being offered with its CELOS control platform, and the company has the ability to incorporate its machines into almost any MRP and/or ERP system infrastructure, either existing or in the future.

"Our machine platforms are being designed with "intelligent" systems to self-diagnose problems, either mechanical or the cutting processes, and notify the shop manager or the maintenance engineers of existing or potential problems. Armed with this information we are helping the customers avoid costly problems before they arise," Wallace added.

With the ability to monitor the machining process, Wallace said the company can give engineering teams critical information for the production of their components. With the ability to evaluate the quality of the gear geometry on the machine, they can make dynamic adjustments and produce quality components every time.

Enhanced metrology is one area that is greatly improving for machining centers. Wallace said that the ability for closed-loop-feedback during the manufacturing process allows the machines to compensate for cutting conditions that are out of the "normal" range or compensate for tool wear. Systems like high-speed 5-axis scanning, blue light or laser systems make on-machine metrology easier to justify.

According to Wallace, the great debate has always been, "Should you use your machine as a CMM?" "With the speed of the new systems and the machines ability to make closed-loop adjustments, the need for the machine to check the part is critical to the success of i4.0 and much easier for the customer to realize."

Another area of improvement is the evolving technology of human-machine interfaces (HMI). "As we have seen over the past decade, the HMI (smart phone technology, for example) has moved to a predominately touch based system and humans are re-teaching themselves to take advantage of the new HMI. For the most part, the technology exists to make a very sophisticated HMI, but the (re) training of the human and the paradigm shift is a significant challenge."

The CELOS control platform allows the development of DMG MORI's next generation of machines incorporating many of the Industry 4.0 requirements. Image courtesy of DMG MORI.

This comes down to breaking bad habits and bad behavior that has been learned in the past 50 years in manufacturing. Wallace said that the new generation of machinists and manufacturing engineers are growing up with the new

HMIs, so their adoption of the new technology is much faster. "It's the legacy that we have to deal with and incorporate," he added.

And where will some of these new innovations show-up in terms of gear manufacturing? DMG MORI's Mill Turn series is an interesting platform for gear milling today. The company's CTX, NTX and DMU series incorporate milling functionality as well as turning capability.

"Our *gearMILLING* software and our technology cycles with advanced HMIs make gear production much easier than the old gear table based "black-box" machines of the past," Wallace said. "These are quickly going the way of the whale oil industry as customer's demand multi-tasking platforms that can produce more than just gears."

And remote monitoring is becoming more the norm across manufacturing industries. Working with several metrology companies, DMG MORI is developing remote monitoring apps to evaluate the data as the parts come off the machine or monitor during the manufacturing process.

"Another "app" gives us the ability to monitor and adjust high pressure coolant systems in real-time, allowing the user to control their process much closer. The possibilities are limitless; it will be the customer who drives the need for the technology," Wallace said.

DMG MORI plans to cultivate this technology not just with help from its customer base, but also through partnerships with the National Institute for Metalworking Skills (NIMS) and with the control manufacturers.

This gives the company the ability to design systems that work with today's engineers and operators, but also allows the design of new systems that will work in the future.

"We have the ability to work with the schools so they can prepare the training courses for the next generation of users," Wallace added. "This way, we all win."

For more information:

DMG MORI USA
Phone: (847) 593-5400
us.dmgmori.com

Mazak Corporation
Phone: (859) 342-1700
www.mazakusa.com

Okuma America Corporation
Phone: (704) 588-7000
www.okuma.com

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5-Axis Gear Manufacturing Gets Practical

Exciting new machine, cutting tool and software technologies are compelling many manufacturers to take a fresh look at producing their larger gears on machining centers. They're faster than ever, more flexible, easy to operate, highly affordable – and for any type of gear.

Uwe Gaiser

Larger bevel gears have typically been produced on dedicated machines or, less frequently, on standard 5-axis machining centers using end mill cutters. But neither solution has been ideal for a relatively small, but significant number of large gear jobbers and vehicle and equipment manufacturers. Dedicated machines are remarkably productive, but prohibitively expensive for low volumes; standard machining centers are inherently flexible, but too slow to be practical for even the lowest of volumes and lot sizes.

In 2011, Gleason moved to fill this void by forming an alliance with Heller, a leading manufacturer of 5-axis machining centers used for rigid, 5-axis simultaneous machining. By drawing on the collective strengths of both companies — Heller's 5-axis processing capabilities and the stability and rigidity of its machining center platform, and Gleason's bevel gear processing expertise and *CAGE* gear design software — the newly formed Gleason-Heller partnership significantly narrowed this age-old performance gap. The new series of Gleason-Heller 5-axis machines that resulted could indeed produce bevel gears much faster than their 5-axis counterparts, while maintaining typical machining center flexibility.

Mission accomplished? Not quite. The marketplace wanted more. For many, the ability of the machining center to produce larger bevel gears many times faster than what was possible on other standard machining centers wasn't quite enough to justify a purchase. In day-to-day, practical application, what these users really needed was a machine that could easily produce all types of gears and gear tooth geometries: everything from spiral and hypoid bevel gears, straight bevel gears to spur, helical, double-helical and herringbone cylindrical gears. And, of course, all the other general machining tasks that you could throw at it. The end result would be the nearest thing yet to a universal 5-axis machine — a machine designed to be so versatile and easy to use that it would rarely sit idle.

More productivity — start to finish. Several 5-axis horizontal-spindle machining centers now comprise the Gleason-Heller line, ranging from the 6000 series for workpiece diameters up to 1,000 mm, to the FT 16000 for workpiece diameters as large as 2,500 mm. The inherent static and dynamic stability of the Heller machine platform and its extremely robust, high-torque/high-power spindle design provide the ideal platform for the application of a wide range of highly productive inserted-blade disk-type cutters. Heavy milling of a forged raw part, profiling, protuberance machining, flank finishing and profile finishing of the hardened gear — essentially machining the gear complete from a blank — can now take place in as little as two to three hours, vs. the two to three days needed with a standard 5-axis milling machine using end mills. And for those that have

Figure 1 New technologies have converged to finally make it practical to apply 5-axis machining for production of many different gear types, all with high quality.

experienced the less than optimum surface finishes and quality that often result from the use of end mills, it's important to note that DIN 5 or better quality is now achievable on these new machines.

Empowering the operator. But the real "game changer" for the end user is the power that comes from the application of the new suite of Gleason-Heller software. Producing gears complete in just a few hours will look good on paper to many customers — but almost all will ask the question: Can my machine operators really produce high-quality gears of all types as easily as they would the much simpler "prismatic" parts they're used to? After all, skilled personnel are in short supply and gears have never been more complex. To make this technology truly practical, every operator will, with just a few easy steps and minimal knowledge of gear design, be able to automatically generate the optimum parts program and 3D models for

Figure 2 Gleason-Heller's product offering includes models for workpieces as large as 2,500 mm in diameter, with various worktable and pallet changer options.

even the most complex gear designs — bevel and cylindrical. Furthermore, the system will also need to automatically make the first-part corrections, which are so vital to prototyping and small lot production, thus eliminating the costly and time-consuming trial and error common to traditional gear development and production.

The same powerful and highly automated *CAGE* gear design software capabilities that allow Gleason's dedicated bevel machine customers to produce finalized gear designs with optimized contact patterns with minimal trial and error is available to Gleason-Heller users. But that's not the half of it. *CAGE* functionality is just one part of the new *Gleason 5-Axis Gear Studio* (*G5S*) software system. *G5S* seamlessly interfaces with the Heller *uP-Gear* CAM system, providing all the input data, corrections and flank modifications needed for *uP-Gear* to generate a 3D geometry model of the gear for visualization, and the optimum NC parts program needed to produce it. The process is further facilitated through the use of Siemens *NX* software, which runs on the machine's standard Siemens 840D SL CNC. *NX* is one of the most powerful and versatile 3D CAD modeling tools available — and a vital component in the optimization of the gear design and all the required machining operations. On a Gleason-Heller, all the heavy lifting is ultimately done by the software, and the operator's role is one that almost any competent machine operator can perform, with minimal gear design knowledge required up front.

Nor is the use of *G5S* and *uP-Gear* confined to just spiral and hypoid bevel gears, with face milling and face hobbing tooth geometries. The software now fills the long-standing void that has existed for the automated design, optimization and production of many types of different cylindrical gear designs. Even straight bevel gears, and the desirable tooth geometries produced on conventional two-tool generators or by Gleason Coniflex technology, can be replicated. In every case, this powerful suite of software, and an expanding array of pre-existing routines and modules, enable the end user to quickly and easily optimize gear design and important features and characteristics such as flank geometries, contact patterns and profiles on a wide range of gear types.

Closing the loop on quality. For many jobbers and vehicle and components manufacturers, optimizing the designs of prototypes and parts produced in lots as small as one involves slow, costly and painful trial and error, as parts are cut and inspected, designs and programs are refined, and the process starts anew. With a Gleason-Heller machine, this time-consuming process is all but eliminated. Instead, newly developed *Gleason Correction* software, working in conjunction with the customer's CMM or a Gleason GMS gear inspection system, generates inspection files and transmits the new machine settings needed to correct flank form deviations and other important characteristics back to *G5S* so that production of even single-part lot sizes is fast and efficient.

A total solutions approach. A "total solutions" approach was taken in developing this new generation of Gleason-Heller machines so that users would have, at their fingertips, all the components needed to simplify setup and operation, reduce costly non-productive time, and speed production. In other words — everything required to take cost out of the workpiece. For example:

- The machines are capable of running the right cutting tool for the job: inserted blade disk-type cutters for all the typical gear roughing, semi-finishing and finishing operations, and

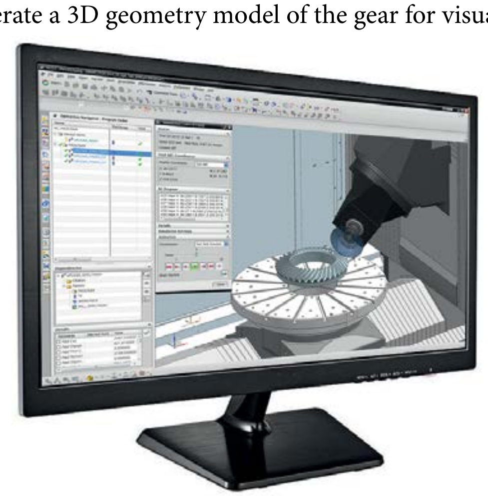

Figure 3 Design inputs from Gleason's new 5-Axis Gear Studio (G5S) software to Heller's uP-Gear CAM system allow the user to easily, and quickly, generate a 3D geometry model of the part, and the optimum NC parts program needed to produce it.

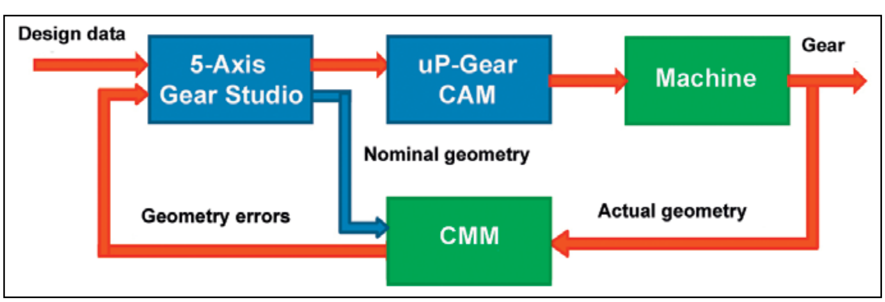

Figure 4 The suite of Gleason-Heller software "closes the loop" on quality and eliminates typical gear development trial-and-error time and cost by using gear inspection data to automatically correct parts programs.

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Figure 5 Gleason-Heller machines can accommodate a wide range of larger bevel and cylindrical gear types, including herringbone and double-helical.

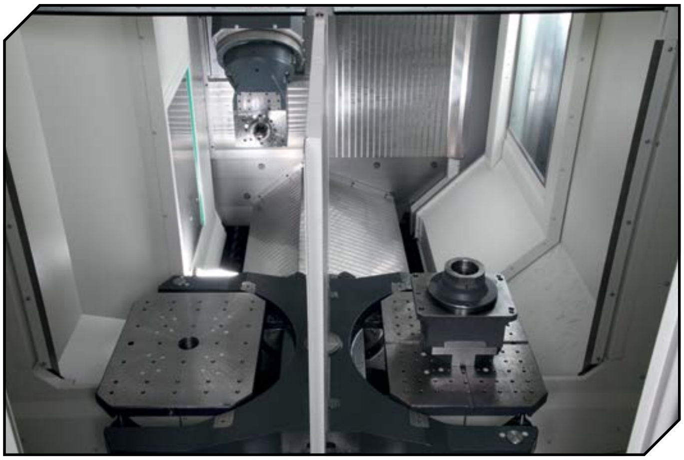


Figure 6 P-type machines are equipped with automatic pallet changers to allow workpiece setup in parallel with machining.

Figure 7 Even true turning operations can be performed on C-type machines equipped with high-speed worktables.

Gleason's new inserted blade SlimLine cutter, for gears with more complex tooth geometries. Automated tool changing of all the different tools is standard.

- The machines are equipped with the Gleason zero-point workholding system, which greatly reduces non-productive workpiece setup time by simplifying typically tedious manual workpiece setup and alignment. A first-part checking probe also is integrated in the machine to automate that critical step in the setup process.
- Models are available with different worktable designs: F-type for orthogonal turn-milling operations, or C-type with higher speeds for real turning operations.
- Models are available as simple table machines (T-type), or with automatic pallet changer (P-type) to set up workpieces in parallel with machining.

The new Gleason-Heller machines are indeed making a strong case for more 5-axis machining of larger, high quality gears in low volumes. It's never been faster or more affordable. For those gear jobbers seeking to expand their markets, or the manufacturers of vehicles and machines for construction, marine propulsion systems, mining, energy and transportation searching for lower cost and more control over quality, Gleason-Heller provides a new option.

For more information:

Gleason Corporation
Phone: (585) 473-1000
www.gleason.com/5axis.

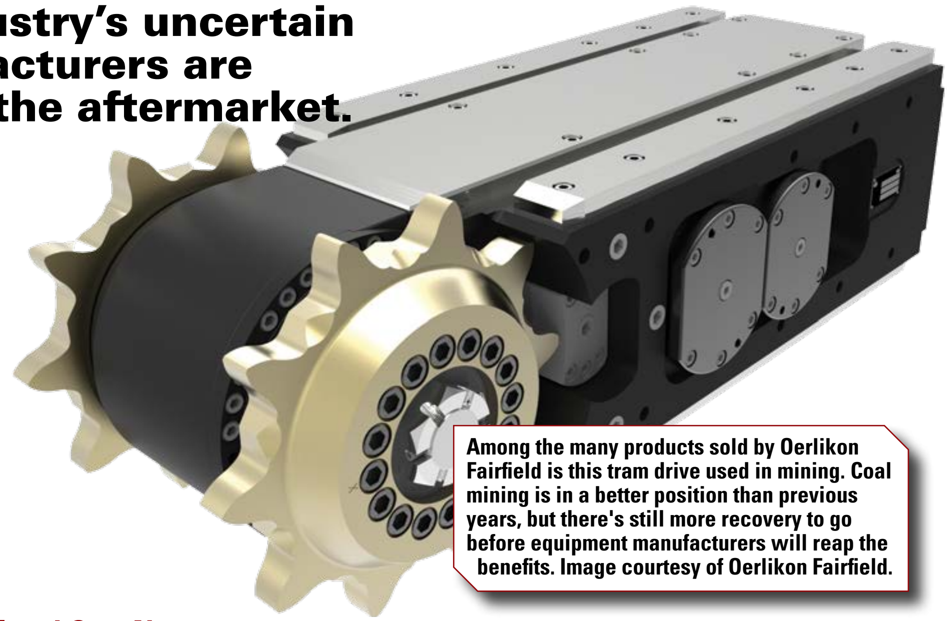
Dipl.-Ing.(FH) Uwe Gaiser is Director Product Management Bevel Gears and Director Gear Technology at the Gleason Corporation. Starting as an Application Engineer for Bevel Gears 28 years ago, he has become expert in every aspect of Gear Design and Development, from drawing concept all the way to vehicle gearbox assembly.

During studying mechanical engineering, Uwe Gaiser was instrumental in the development of first-correction-capabilities of 3D-measurements of bevel gears with the Gleason G-AGE software releases worldwide. His final diploma topic at the University was Single-Flank testing of automotive bevel gears at a well-known luxury car manufacturer. Since then, working for Gleason Corporation, he has filed several bevel gear related patent applications in the area of bevel gear grinding, blade geometry and production methodologies.

Shifting Fortunes

Amidst the energy industry's uncertain future, gearbox manufacturers are focusing on supplying the aftermarket.

Alex Cannella, News Editor



Among the many products sold by Oerlikon Fairfield is this tram drive used in mining. Coal mining is in a better position than previous years, but there's still more recovery to go before equipment manufacturers will reap the benefits. Image courtesy of Oerlikon Fairfield.

The future of the energy industry is a hard one to divine. Whether it's governmental policies like clean energy grants for wind power and restrictions on fracking or larger, global concerns such as the market price of oil, the industry's fortunes have always been sensitive to the bigger picture, and that bigger picture has gotten a little blurry. Politically, the United States has become an anything-goes maelstrom, and what the end result will be when the dust settles is anyone's best guess at the moment.

Perhaps more importantly, the industry is also in flux economically. Alternative energy sources are becoming more commercially viable, and while oil isn't going away anytime soon, just being able to compete is an improvement for alternative energy options that could place those markets in a position to expand.

"The market is in the middle of a transformation," Dipeshwar Singh, global director of strategic marketing at Rexnord, said. "Traditional energy sources are slowly reducing in their share within the energy market, and we are realizing an increase in new forms of energy. We are seeing larger shares of gas, wind, clean coal and solar, and some of the factors that are driving these changes go well beyond the clean, environmental aspect of it. A majority of these new energy sources will continue to be driven by economics. It is becoming increasingly more economical to produce energy through solar, gas or wind, and as it becomes less expensive to produce, the adoption of energy will continue to grow."

In uncertain, changing times, U.S. manufacturers the wind and oil/gas sectors are dealing with very different problems. But before you start breaking out your inner nihilist, there are signs of stability on the horizon.

Oil and Gas: Not out of the Woods Yet

According to the President of Brad Foote Gear Works, Dan Schueller, the oil/gas sector is "all about the price per barrel of oil." And on that front, the message is still mixed.

Some, such as Wikov's Strategic Marketing Manager, Lukas Steiner, are braced for a few more years of uncertainty for oil, citing continued volatility in the weak oil prices. In the meantime, Wikov is shifting its strategy to focus on low carbon sectors and alternative energy opportunities mostly in the aftermarket and strengthening its position by supplying more gearboxes to those marine applications which are up when oil prices result in significant capex cuts.

"We expect volatility in the oil prices while having a price of a barrel still weak," Steiner said. "We think this will last for some years on. We count on the fact we learned from the history that the oil market takes an awful lot longer to adjust to supply shocks than it does to cyclical demand shocks."

But others like Schueller believe that the industry has finally bottomed out and might be able to expect some stability, though perhaps not a return to the prices of a few years ago. After the industry's lowpoint of $30 per barrel back in Jan. 2016, the cost of oil managed to claw and scrape its way up to $54/barrel. Seeing the price of oil trend (mostly) positively for a full year is no doubt heartening news for the industry, and improved confidence in the strength of oil could in turn lead to a stronger industry. It could well be the start of a recovery.

But even if there's more cause for celebration than in past years, the oil barrel still has a few hurdles left to leap before anyone can truly start breathing a sigh of relief. Oil's recent rise can, at least in part, be attributed to the Organization of the Petroleum Exporting Countries (OPEC), which issued a six-month cut on oil production in the hopes of raising prices, and the move has at least inspired confidence in some.

"This was the moment not only gear manufacturers but other OEMs were waiting for in hope of later higher capex into a new drilling equipment," Steiner said.

While the price of oil has been going up, the cut's expiration date is also coming quickly, slated for June 2017, and uncertainty over whether or not the production cut will be extended is already starting to show in the latest market turn for oil, a dip down to $47/barrel.

Oil's greatest hurdle may well be the renegotiation of the production cut, namely getting other heavy hitters like Russia that aren't a part of OPEC, but are part of the deal, to extend it for another six months. And then there's the potential for U.S. shale production to pick up and throw a wrench in the works, anyway, which even industry analysts can't seem to agree on what the potential effect of might be.

While we don't usually get in the habit of waxing at length about an industry's political situation, politics are inextricably intertwined with the price of oil. An oversupplied market naturally driving the cost of oil down leaves artificial cuts in production like OPEC's, which require a great deal of diplomacy and politicking, as the market's current hope for stabilizing.

Schueller's optimism, on the other hand, lies in the industry's ability to adapt to its new circumstances by becoming more streamlined and efficient, which he believes will help the industry stay afloat.

"Oil and gas developers have done a good job lowering their costs over those periods so they can be more efficient," Schueller said. "They can be profitable at oil even though it's in the upper 40s, lower 50s. I think a few years ago, they would have said the oil price would need to be higher, but everybody's done a good job cutting costs and trying to become more efficient, so they're able to be profitable at a lower dollar per oil barrel."

Coal: Still Facing Headwinds

According to Greg Moreland, global manager of market and product research at Oerlikon Fairfield, the coal industry is still facing its own difficulties related to the low cost of natural gas, a competitor for many of the same wallets as the coal industry.

"Despite the recent firming in commodity prices, for equipment manufacturers, the market is still operating at a low point," Moreland said. "There is a lot of surplus equipment available, and that is impacting replacements for new machinery."

There is some relief on that front, however, as natural gas has climbed in price. Moreland believes that the market's already weathered the worst, and personally believes that the coal may even see some small growth by the end of the year.

"The good news is that these markets have reached a bottom," Moreland said. "The year over year double digit declines are passed."

According to Dipeshwar Singh, global director of strategic marketing - energy, at Rexnord, there's also been a shift in the industry as a whole to look at clean coal.

"There is currently an enormous focus on clean coal as an identifiable source of new energy," Singh said. "Much of the older infrastructure that previously focused on the use of coal will likely be retired. However, there is also the likelihood that a new infrastructure will be developed that is based on the newer, more efficient and cleaner coal technologies."

Wind: The Big Crunch

The wind market is looking at better prospects. The wind market is looking at better prospects. Late in 2015, Congress passed a 5-year production tax credit for wind power producers that phases down over that time period. This has provided the U.S. wind industry with the longest outlook in its history, adding stability where there used to be little. And the industry's focus on cutting down the cost of wind energy and becoming economically competitive with oil and gas is already bearing fruit. According to the AWEA, the fourth quarter was the second strongest ever for wind power installations. But according to Martin Sychrovsky, Wikov's marketing director, the industry isn't likely to stop there.

"There will continue [to be] a huge pressure to reduce costs and further reduction in prices of the turbines," Sychrovsky said.

For the wind market, this is healthy. There's no telling if or when the government might bless the industry with more tax credits, and after years of governmental hemming and hawing over funding nascent wind energy efforts, making commercial sense is going to be just as important for the industry to expand as any environmental argument.

For manufacturers, however, it's just one of many factors that are leading people to expect a big crunch in the industry moving forward. As prices are driven down in an effort to compete with oil, the ability to build and sell in bulk will become an important factor in staying competitive in the industry.

"Nowadays the market suffers from excessive overcapacity," Steiner said. "And for us, a smaller player, [there] is less space in there."

"Increasingly, this business will pay off only for the big players which are able to achieve economies of scale," Sychrovsky said.

For U.S. gear manufacturers in particular, the problem is compounded by the strength of the dollar. When faced with a competitive global market in which competitors are actively trying to drive down prices, it's doubly difficult to match foreign prices with the added weight of a strong U.S. dollar. Though the wind market is doing well, smaller players may have difficulty competing with larger companies, particularly foreign ones.

In the meantime, Schueller's best advice to anyone still looking to make gears for the front-end wind market is to look at reducing material costs and increasing productivity.

"The two major buttons to push are how do you reduce your material costs and how do you make your factory more productive to produce that gear?" Schueller said.

It's standard advice, and perhaps easier said than done for small manufacturers, but it's also proven. Brad Foote has focused intently on reducing costs and increasing efficiencies over the past several years.

According the Schueller, "Brad Foote is focusing more on the aftermarket where lead-time and responsiveness are important."

A Single Solution

Despite wildly different woes between each industry, everyone seems to have come to the same solution on how to stay profitable in uncertain times: the aftermarket.

For the wind industry, the aftermarket looks like the most lucrative opportunity in the market today. While smaller gear manufacturers may have trouble finding business for brand new gearboxes, the aftermarket is still wide open for their services.

"The boom occurs in the aftermarket," Sychrovsky said. "Conventional wind turbine gearbox life is 6-7 years. Even the first Chinese offshore parks look around after the first exchanges. There is a very promising future in repairs and replacements business."

With the wind turbine industry being overtaken by the big players, the aftermarket is a logical place to migrate to. With a turnaround that short, old wind turbines will always be hungry for new gearboxes.

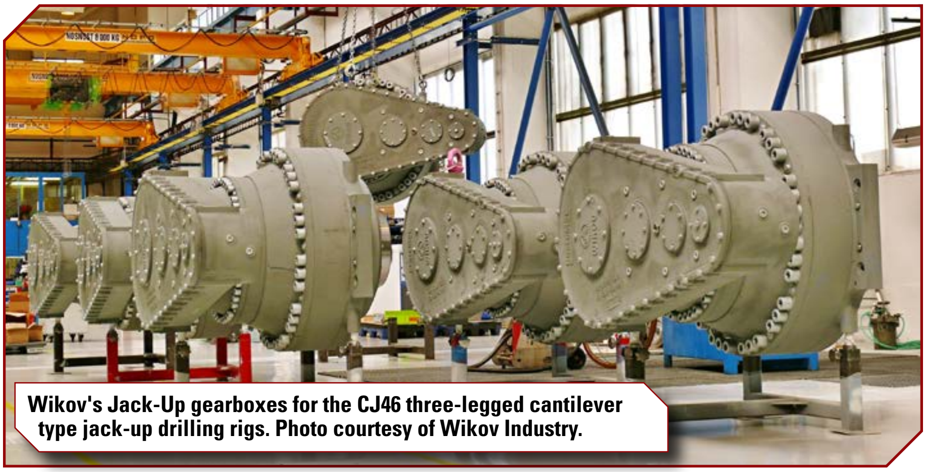
According to Schueller, however, wind turbine gearboxes have seen a wealth of improvements in the past decade. From new designs to sensors that can detect potential mechanical problems early, Schueller believes that U.S. gear manufacturers have come far in improving the design of wind turbine gearboxes. Those advances have made gearboxes stronger and longer-lasting.

"It would be hard to point to one particular thing that would say 'hey, this is what has really caused it to get better,'" Schueller said. "As with most times, it's a combination; combination of better designs, combination of better gear manufacturing by the gear manufacturers, better repair, better monitoring and better early detection of potential problems. Where I think the first gearboxes ran into failure, I think now the early detection is catching problems before a major failure occurs."

One might think that the existence of better, more durable gearboxes would put a damper on the aftermarket, but Wikov and Brad Foote are expecting that the improved gearboxes will actually be a selling point in their favor. At the same time as old, less sophisticated gearboxes are in need of replacement, this new wave of gearboxes are hitting the aftermarket along with assurances such as Wikov's that the gearbox won't have to be replaced again:

"We are confident about extended lifetime of our solution so with the installation of Wikov gearbox, the customer will not have to replace it until the end of the wind turbine lifetime," Sychrovsky said.

It stands to reason that these higher quality gearboxes would be snapped up. And according to Schueller, improved gearboxes will increase demand for aftermarket services such as gear regrinding, as well. Schueller has found that some of the more recent gearboxes don't always need gears fully replaced, but instead just require some regrinding to touch them up. This results in cheaper repair costs and a win-win for both Brad



Wikov's Jack-Up gearboxes for the CJ46 three-legged cantilever type jack-up drilling rigs. Photo courtesy of Wikov Industry.

Rexnord offers their gear manufacturing services to all three industries: oil and gas, coal and wind. Photo courtesy of the Rexnord Corporation.

Foote and gearbox users.

For industries like oil and coal, the basic hope is that once the markets pick back up, coal and oil miners alike will be hungry for more equipment after skimping on replacement parts and utilizing other cost-cutting methods during leaner years.

"Our optimism lies in the hope that sooner or later some of the existing equipment will reach the end of its lifetime and will have to be replaced," Steiner said. "This will be the moment for us to say it was a good decision to stay in this market segment and not to leave it for other segments Wikov serves."

"During this last cycle, many mines were not only delaying new equipment purchases, but they were also cutting back on maintenance," Moreland said. "Spare parts were being cannibalized from existing used machinery. When the markets turn upward, there is going to be increased demand for not only replacement parts, but also for new equipment. There is going to be a 'bullwhip' effect that will challenge manufacturers. Those who will benefit will be the ones with strong supply chains which can be ramped up to meet higher volumes."

Flexibility could be important going forward. If markets continue to remain low, it will be important to maintain low operating costs to stay buoyant, but if conditions improve, a wave of demand brought on by mining companies with more spending money won't wait for businesses to reestablish themselves. But until the day those conditions improve and the energy industry sorts itself out, there's always the aftermarket.

For more information:

Brad Foote Gear Works, Inc.
(708) 298-1100
www.bradfoote.com

Oerlikon Fairfield
(765) 772-4000
www.oerlikon.com/fairfield

Rexnord Corporation
(414) 643-3000
www.rexnord.com

Wikov Industry
+420 244 016 862
www.wikov.com

Heat Treating 4.0

Bringing Mature Technology into the 21st Century

Randy Stott, Managing Editor

The basic concept of heat treating has been around for a long, long time. And even though the technologies have changed considerably, and even though our understanding of the various processes continues to improve, many in our industry still view heat treating as something of a black art.

You take great care cutting your parts to spec. Then you send them out to heat treat, close your eyes, cross your fingers and hope for the best, right?

Well, not so fast. Suppliers are working hard to make sure their equipment is controllable, repeatable and efficient, and manufacturers continue to incorporate technology that gives heat treaters—and their customers—more information about what's going on inside the magic box.

We interviewed several of the leading equipment suppliers for heat treating gears, in order to give our readers a feel for how the technology is changing. Participating in the interview were William "Bill" Disler, president and CEO of AFC-Holcroft; Anne Miner, sales and marketing manager for Diablo Furnaces; Dennis Beauchesne, general manager for ECM USA; Jim Grann, senior technical manager for Ipsen; Aymeric Goldsteinas, product development manager for Ipsen; and Janusz Kowelewski, director of business development for Ipsen's ARGOS brand.

What are the most significant recent advances in heat treating technology for gears?

(ECM-USA) — "Recent" is to be defined. If you are looking at the last 15 years, than you have to point to low pressure vacuum carburizing and high pressure gas quenching, as it has dominated the automotive industry for high production systems. However, if you are talking about the last year or two, this technology is such that it is now bringing products to the market that offer "in-line" heat treating. This subject is bringing the world of heat treating into the reality of processing smaller loads to customers on an in-line basis. Low pressure carburizing, while utilizing higher temperatures and lower processing times, can satisfy the high demand for in-line processing by supplying completely heat treated gears at the speed of associated machining with very little work-in-process.

(Ipsen) — There is a growing share of low-pressure carburizing (LPC) technology for heat-treating gears. One such LPC technology is our AvaC process (acetylene vacuum carburizing), which produces excellent carbon transfer into the parts, thus helping ensure extremely homogenous carburizing – even for complex geometries and high load densities. Ipsen has also developed new technology for multi-chamber LPC: the ARGOS heat-treating system. This vacuum furnace represents a significant milestone in the growing trend to operate LPC lines in combination with inert gas quenching. One of its many benefits is that it provides enhanced temperature uniformity throughout the hot zone, resulting in minimal part distortion.

(AFC-Holcroft) — Although there has been considerable focus regarding low pressure carburizing and gas quench processes for smaller gears throughout the last decade, we have seen a significant increase in manufacturer interest in alternative technologies. Over time, as many users have become more experienced with these technologies, concerns regarding cost and the ability to reliably deploy this technology in evolving markets as needed to be part of a true global bill of process seem to have become more common conversation points. Many gear manufacturers justified the added cost of LPC and gas quench with the assumption that hard machining would be totally eliminated. Since in most situations this is not the case today, the overall cost-to-benefit model takes on a new look. We see considerably more interest in alternative methods of achieving the results needed to meet the strength and distortion objectives of the gear manufacturers. One specific area that has significantly renewed interest is quenching in salt. Although salt has an old-school, dirty image, the reality is that new processing methods make salt a viable alternative that provides single-phase quench benefits like gas but with superior heat

This ring-type furnace helps provide an even temperature uniformity for all parts throughout the process. Courtesy of AFC-Holcroft/Aichelin.

transfer. It is arguably the best quench solution available when it comes to gears, and salt can be 99% recovered. It is much less expensive than gas quench and more forgiving, hence better for evolving markets, and much safer and more environmentally friendly than oil. As manufacturers package heat treat equipment in new ways to handle salt cleanly, it continues to gain attention.

(Diablo) — Although we only concentrate in atmospheric technology, the advancement of one-piece flow allows us to process small batch sizes, while keeping a continuous product-flow between soft-machining, heat treatment and hard-machining.

How are heat treating equipment providers adopting Industry 4.0?

(AFC-Holcroft) — In my opinion, heat treat equipment manufacturers tend to be much slower moving on the higher tech side of things than many other industries such as automation and machine tools. Some heat treat equipment suppliers seem to be engaging with new ideas, while others seem slow moving in this area. Within AFC-Holcroft and the Aichelin Group we have many progressive activities in motion. Our equipment now provides much higher fault diagnostic data than ever before via new networking tools and technology. We also provide a cloud service for our customers where equipment events and fault data are automatically retrieved from furnace equipment and then filtered and organized to provide high-level reports to help our engineers improve our equipment as well as help our customers improve how they operate it. Pareto charts indicating top downtime offenders and mean-time-to-repair become powerful tools and are automatically generated for customers on each piece of equipment monitored. This is only part of our initiative to provide advanced services to our customers via our web-based, secure customer portal. As we continue to better utilize the advanced fault data that is avavilble on devices, such as VFD drives, our web service tools will become more and more powerful. We have the foundation blocks in place and the pyramid is growing.

(Diablo) — Requests for smart industrial ovens and furnaces occur regularly with new equipment quotations. From our standpoint, the ability to control and monitor the heat treating equipment remotely through dial in from engineer or operator is a feature being built into our controls for safety and ease of monitoring productivity. Alerts can be e-mailed or texted, and reviewed and remedied on-line based on the situation. A robust PM operating manual on-line with intuitive questions and answers guides an operator to debug and solve a problem prior to calling an OEM service technician.

(Ipsen) — As Industry 4.0 and other digital technologies continue to grow and advance, we have begun to see the development of heat-treating systems that can manage process variables, enhance productivity and optimize heat treatment operations. Here at Ipsen, our *PdMetrics* software platform for predictive maintenance uses the Internet of Things (IoT) and Big Data to optimize equipment performance and production efficiency. The *PdMetrics* platform securely connects to a network of integrated sensors on your furnace to gather data, run algorithms and provide real-time diagnostics that help improve the health and integrity of your equipment. Overall, the adoption of Industry 4.0 can decrease the cost of heat treatment, as well as improve safety and production efficiency.

(ECM-USA) — Industry 4.0 is nothing new to heat treating equipment, as many manufacturers have provided systems that can monitor and maintain themselves as well as feed key information to other processes downstream. It allows gear manufacturers to have better understanding and control of the process parameters used in heat treating the precision gears produced today. All high production low pressure vacuum carburizing systems in use today in capacity automotive plants have the ability to interact with other portions of the assembly lines and maintenance personnel on that line.

How has heat treating equipment changed to adapt to smaller batch sizes?

(AFC-Holcroft) — Heat Treat equipment has always had the ability to run smaller batch size loads. In the past, the issue has been that the smaller the batch size load, the more expensive it is to heat treat. This has not changed. Depending on the mix of production, any number of technologies can be scaled to larger or smaller load sizes. A smaller load size tends to be easier to quench if the quench media has limited heat transfer rates, such as gas. Having said that, I think that most people have forgotten some of the basics with heat treating in batch loads vs. continuous operations as they relate to uniformity and quality. The simplest way to look at this is to consider carburizing. Carbon diffuses into steel at a rate that is very dependent on temperature, regardless of LPC or conventional process. In fact, for every 100°F increase in carburizing temperature, the time needed to reach a desired case depth is cut in half. Consider, then, a small batch load in a furnace with a temperature uniformity spec of +/- 10°F. That means from one corner of a load to the other you could have up to a 20°F total temperature spread and be within the furnace specifications. In a batch process, the load never moves, so you will definitely have parts throughout the load carburizing at different rates. The effect of 20°F on carburizing case depth at a given cycle time can be verified via simple calculation or via published charts. I believe that it will surprise many people how significant this can be. In a continuous system, or the Ring Furnace system that is becoming much more popular in Europe, the temperature uniformity of the furnace will be the same but the load is moving throughout the process. This means that the load never sees the same non-uniformities of the furnace for very long. The continuous movement though a non-batch system provides a self-averaging effect that ultimately leads to parts having much tighter temperature uniformity throughout the carburizing process. So although small batch loads are desirable to many, to others who process larger volumes, I suggest looking closely at the alternatives. With batch equipment it is also important to look beyond the standard temperature uniformity specification that all suppliers offer – in addition, ask to see temperature uniformity survey (TUS) results from installed equipment. Some equipment may survey at much tighter uniformity, providing it is maintained properly.

(ECM-USA) — In the last few years, the ECM Nano furnace has been developed to adapt smaller batch sizes. This design allows for smaller loads with much better part-to-part deviation for case depth, core hardness and distortion results. This system uses a 20-bar high pressure gas quench system that is very efficient in quenching most steels used in carburizing. This allows the customer to provide small batch sizes based on their production runs. The system can be turned on and off like a CNC and can also be maintained on the fly by a method where half the system can be shut down and the other half can maintain processing gears or parts.

How has heat treating equipment changed to bring the process closer to the manufacturing cell?

(AFC-Holcroft) — The movement to LPC and gas quench has allowed equipment to be nested into manufacturing areas. The clean aspects of the equipment make this more viable than with older style equipment. The equipment is also perceived to be safe to install in the middle of a manufacturing floor; however some recent events with vacuum and pressure vessels have prompted a few more questions in this area. Everyone is interested in smaller, cell-compatible units, but real-world challenges may be difficult to overcome. Heat treat equipment is different than other machines in cells such as gear cutting machines, automation and washers. The mean-time-to-repair (MTR) is much longer due to the internal temperature that the equipment operates at. Not that we plan on equipment failing, but if it does, then cell manufacturing requires short MTR since the entire work cell is down when any part of the cell faults. The time it takes to cool a system furnace to gain access, assess problems and do the repair is going to be a difficult part of this cellular equation of needed uptime availability. True repair and maintenance numbers may be difficult to achieve, or manufacturers may have to decide to accept slightly lower cell uptime in trade for the integration of the heat treat. I think that it will be interesting to see companies explore the benefits and downsides of bringing heat treat into cellular manufacturing. It is very desirable, but the basic nature of the processes may make this solution costly and complicated. We are watching the evolution closely and exploring options within our group.

(Ipsen) — The development of a one-piece flow concept with better traceability allows production to be organized according to the cell manufacturing principle. The ARGOS heat-treating system, for example, is a multicell system with a modular structure and software flexibility that makes it adaptable to a variety of plant configurations and changing production processes. The multi-chamber ARGOS furnace line also offers several distinct operational advantages in manufacturing. With synchronized movement between each process and real-time sensors implemented in each process stage, the intermediate buffers between heat treatment operations can be eliminated and the transfer of loads between different modules (e.g., washing, carburizing, hardening, tempering) can be monitored.

(ECM-USA) — Over the last 20 years, low pressure vacuum carburizing has done just that. In many automotive and some aerospace plants, the heat treat is lost in the sea of CNC machines on the open floor. This helps with lean manufacturing flow, and the furnaces can be dedicated to particular gear manufacturing cells. The heat treat cells can be validated or de-validated as needed for daily heat treating capacity. It is no longer necessary to keep a long pusher furnace running 24/7 in the back corner of a building to shuttle parts to and from the machining cells and have to keep it running for 365 days a year.

What is the next thing coming in terms of heat treating technology?

(AFC-Holcroft) — Hybrid solutions.

(Diablo) — From our standpoint, the ability to control and monitor the heat treating equipment remotely through dial-in from engineer or operator has been a large request. The other key aspect of these furnaces is safety due to oil deployment for cooling, and ensuring that safeties and alarms are deployed in every major component of the furnace.

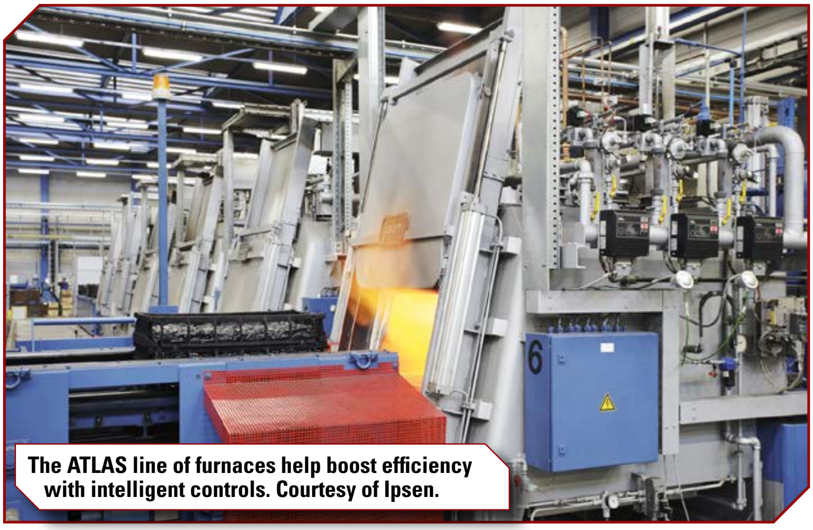
(ECM-USA) — The next thing is here with the ECM Nano in-line processing system. This is where the future of heat treating is going. Processing parts in-line at the speeds of your machining cells is the new requirement in the industry. The industry can no longer sustain the large batching of parts, as this is a costly process with so much work in progress waiting to be heat treated. In addition to the in-line versatility, the process gives precise case depths, load after load, along with reduced distortion through the possibility of gas quenching. This is the future.

(Ipsen) — We will see better materials with improved hardenability and lower quenching pressure requirements. We will also continue to see the development of advanced, innovative heat-treating systems, such as the ARGOS multicell system and the ATLAS atmosphere furnace. In addition, with the increased focus on connectivity and integrating heat-treating equipment with Industry 4.0, we will continue to see new digital technologies emerge. Take our *PdMetrics* predictive maintenance software platform, for example. This innovative system utilizes the Internet of Things (IoT) to provide real-time monitoring and diagnostics. Yet we are continuing to push the boundaries of what is possible by incorporating augmented reality into the platform, transforming the way operators experience their equipment and perform maintenance.

What are the biggest concerns gear manufacturers have about bringing heat treating in-house?

(Ipsen) — The biggest concerns gear manufacturers tend to have about bringing heat treatment in house are the availability of skilled workers and the logistics of heat treatment. To help address these concerns, we offer comprehensive training both on-site at Ipsen U and at customers' facilities. This three-day course provides attendees with a broad, hands-on overview of furnace equipment, processes and maintenance. Our *VacuProf* controls software on our heat-treating systems also allows a user without any special prior knowledge to select the correct process for the type of steel to be treated. The user simply needs to enter the characteristics of the steel, the load geometry and a few other details, such as desired hardness or the heating and quenching characteristics. The *VacuProf Expert* software will then recommend a possible heat treatment recipe for the entered material.

(ECM-USA) — Mostly, safety, operating costs and maintenance of the equipment are of the main concerns for the gear manufacturer bringing heat treating in house. However, the most decisive reason to bring heat treating in-house is to have control over the timing of the parts to be processed. Transportation costs run a hard second to this aspect. Looking back over the years, the only solution was to have a furnace that used a flame curtain and had to be watched by an employee 24/7. With the latest equipment supplying low pressure vacuum carburizing and high pressure gas quenching, the safety concerns are minimized. This technology doesn't require these systems to be monitored 24/7, nor do they require open flames as flame curtains did. In addition, in most cases, the advancements made in high pressure gas quenching and the advancements in quenching capabilities of modern steel products, allow the use of gas as the quenching media. This provides a much safer, cleaner and much more capable of distortion control. Overall, the combination of low pressure carburizing and high pressure gas quenching makes perfect sense for the gear manufacturer to bring heat treating in-house now. The systems



The ATLAS line of furnaces help boost efficiency with intelligent controls. Courtesy of Ipsen.

can be shut off on the weekends and can be idled over holidays with no risk of explosion or need of supervision. The lack of oil quenching provides a clean installation, and the parts are clean as well. The smaller "in-line" system also lend themselves to be the stepping stone for gear manufacturers to start slowly with smaller product to begin with while allowing for optimum control of heat treat design specifications such as tighter case depths and core hardness control.

(Diablo) — The cost of the equipment and talent to maintain it. Diablo Furnaces is manufacturing equipment at a lower price point. Efficiencies are gained with newer methodologies and savvier approaches. Working on a team level basis, all employees have value and input to mitigate costs and waste.

(AFC-Holcroft) — I believe that some are concerned about having the expertise to support the equipment, as it tends to be much different than other traditional gear machining equipment. Providing manufacturers select a strong supplier of heat treat equipment, I believe that the support that manufacturers can provide can significantly lessen the risks and concerns. In addition, with many of the new automation and process monitoring tools such as those described above, the old world of heat treat equipment has changed considerably. We have deep engineering and support capabilities within our global group. We have to make our customers successful. Our future depends on it.

Do you have anything else to add regarding the technology of heat treating gears?

(AFC-Holcroft) — There are many alternatives and methods to optimize the heat treatment of gears. It is not one-type-fits-all. Our group provides a large range of equipment for heat treating everything from windmill gears to gears for Swiss watches and everything in between. I suggest that everyone take the time to evaluate all their options and seek advice from the many quality heat treat equipment suppliers in the marketplace. The right supplier can openly discuss the options that are best for each unique situation. Suppliers with experience in the full range of process alternatives will be the most objective. Often you may have to weigh the pros and cons of multiple solutions, but always take the time to evaluate your options.

(Diablo) — Nowadays, all heat treatment technologies have incorporated modern controls. This in turn offered opportunities for gear design and manufacturing engineers to specify more precision heat treat requirements without added cost, be it hardness range, carburizing depth, timing, or other specs.

(Ipsen) — According to a recent study, there will be tremendous consolidation in the gear industry. This trend is connected with consolidation in the car industry and changing customer evaluations of car utility. The cost of gear heat treatment will influence who will be a survivor of this consolidation. Ipsen's *PdMetrics* software platform is key to lowering the cost of operation by analyzing performance and efficiency and minimizing unplanned downtime. As the gear industry looks at heat treatment, they should consider not just the physical equipment design, but process cost, connectivity and repeatability.

(ECM-USA) — Heat treating gears has come a long way even in the last 10 years with the advance of higher hardenibilty steels and the use of high pressure gas quenching. It's no longer the smoky, soot riddled oily floor, wear your lucky shirt industry. Reducing distortion and making stronger gears are always at the center of gear manufacturing, and that is what low pressure vacuum carburizing has brought to heat treating of gears. Heat treating is not only about the furnace system and how it works for you, but it starts with the design and processing of the material at the design level. Annealing, heat up rates and fixturing are all aspects of the heat treating process that are mostly overlooked and yet these are critical items for gear manufacturers.

A batch of ring gears coming out of the furnace. Courtesy of Ipsen.

For more information:

AFC-Holcroft
49630 Pontiac Trail, Wixom, MI 48393
Phone: (248) 624-8191
sales@afc-holcroft.com
www.afc-holcroft.com

Diablo Furnaces
7723 Burden Road, Machesney Park, IL 61115
Phone: (815) 636-7855
info@diablofurnaces.com
www.diablofurnaces.com

ECM USA
9502 72nd Ave, Suite 400
Pleasant Prairie, WI 53158
Phone: (262) 605-4810
info@ecm-usa.com
www.ecm-usa.com

Ipsen
984 Ipsen Road, Cherry Valley, IL 61016
Phone: (815) 332-4941
sales@ipsenusa.com
www.ipsenusa.com

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It doesn't matter how efficient your plant is!

What matters is the accuracy of your quote

Joe Arvin

To ensure profitability and avoid losses, accurately quoting jobs is the first line of defense.

The importance of accurate quoting for YOUR plant

The reality is this: When you are quoting, it really doesn't matter how efficient or inefficient you are, or how new or old your equipment is. What really matters is how accurate your quoting is to make a profit running that job in *your* plant. Accurate quoting is paramount. And once you start production on a non-profitable job, it's all over but the shouting!

So you might be saying, "Ok Joe, I agree that an accurate quote is essential, but how in the world can I predict the problems which *can* occur?" The primary challenge with quoting is trying to account for the "unforeseen" variables that may arise. Here are a few tips that I've learned to minimize the unpleasant surprises.

The Disclaimer

First, it's a good idea to have some type of disclaimer on your quote to keep you from getting blindsided—especially important for long-term agreements (LTAs). Consider something like this:

Price is based on data and information furnished at the time of quotation. Any changes or additions in specifications could affect the quoted prices. Any escalation or de-escalation in the material cost can require adjustments to the quoted prices.

Who to Involve in Quoting

A common question is, "Which resources should be involved in quoting?" Should it be one person, the president, sales manager, engineering manager, plant manager, or a team from engineering, purchasing, quality, and/or sales?

The answer to this question depends on two key issues: the size of your company and the size of the order. For a smaller company, when one person is quoting, I would suggest that they consult with the sales (for market intelligence), quality, and/or engineering departments. In larger companies with more resources, it is reasonable to have a quoting team. However, regardless of the company size, when it comes to large, complicated orders, or LTAs, it's prudent to involve everyone who could add a valuable perspective.

Quoting by Similar Jobs

Obviously, the best method for quoting is to use information from a previous run of the same part. A word of caution here—don't rely on your memory.

I always felt that I had a good memory for parts and part numbers we had made. However, several years back, we quoted one job and after being released to the shop, I was talking to Lou, the manufacturing manager, who said, "Oh no, we've got *this* job again!" Surprised, I said "What?" To which Lou replied, "Don't you remember this job? It was a big loser because of heat treat distortion!"

After that experience, I made sure the first step was to ensure all quotes were thoroughly reviewed for matching part numbers. And for the occasions when there was not a matching part number, we developed an identifying characteristic part code.

Do you have an identifying characteristic part code? If you don't, it can be a costly and laborious process looking for a similar job. For example, such a code will represent all the key characteristics, telling you if the part is a spur gear, helical, bevel, spline, or combinations, ground teeth or not, number of teeth (± range) OD (± range), overall length (± range), or any other characteristic you'd like to track.

Quoting by Processing

Another good method for quoting accurately is to develop a rough process; however, this is costly if you don't get the job. For large volumes, LTAs, or very complex parts, you may want to do a rough process.

Market Intelligence

There is one more step that can mean the difference between not getting the job and getting it with a reasonable profit. While I'm certainly not suggesting any type of corporate espionage, it doesn't hurt to talk to people. What have your sales people heard on the street?

Even the customer can provide market intelligence. One time I remember having some technical questions about a part we were quoting. So, I called the buyer and he said, "You're going to have to talk to Ted; he's the engineer on this project." Later, during the discussion with Ted, he said, "You do know the EB Welder charges $275 for each part, and we require 17 x-rays of the weld." Previous welds on similar parts were $165 with only five x-rays. These additional costs came as news to me, and obviously were essential in the pricing. So, keep in mind that talking to the customer can be vitally important.

Aerospace Quoting

As some commercial gear markets have contracted, many gear companies have looked at the prospect of pursuing aerospace work. Accurate quoting for the aerospace market is especially critical to ensure profitability. The following are some points to keep in mind.

Contract Review—I learned the hard lesson about contract review years ago when my company had first expanded into aerospace work. After receiving several parts from the same customer, we got an order for a new part. We based our quote on the previous orders. After getting the job we discovered that we had overlooked an additional SPEC that required dynamic balancing. Had we performed a contract review, this costly error would have been avoided.

Contract review is a must. This will help you spot cost risers found in the SPECS which refer to "other SPECS" that are not detailed on the blueprint, such as shotpeening, various surface coatings, or the requirements to only use

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approved sources that might be located on the other side of the country.

Other Aerospace Costs — The hidden costs of aerospace work are well-known to gear makers experienced in supplying this sector. For example, it's a typical requirement that one part will need to be cut up after heat treat. There was, however, one occasion that caught me by surprise. The customer not only required a cut-up part after heat treat, but also one after gear grinding and another before final inspection. Being a small order, and at $1,275 per part, losing an additional two parts made the job non-profitable.

There are other hidden costs. Don't be surprised if the customer requires 100 percent inspection reports for involute, lead, tooth spacing, and runout. You need to charge for these costly activities. Are you also charging for first article inspection? Are you charging for 100 percent magnetic particle inspection and surface temper inspection?

The bottom line is that missing any of these requirements can transform an otherwise accurately quoted job into one that is a loser.

Keeping the Machines Running

"So Joe," you might be asking, "If I quote accurately, can I say goodbye to non-profitable work?" Consider this.

Frank Pielsticker, one of the founders of Arrow Gear, always used to say, "If the machines aren't running, we're not making money." Through the years I have come to believe that "break-even" work is better than having idle machines. It may be in your best interest to take some break-even jobs, as this pays for some overhead. Remember, if your total direct and indirect cost remains the same, it is better to have some money coming into the till, than to not. However, this cannot be your standard operating procedure! When you take this type of work, be sure you communicate to your customer this is a special discounted price.

And don't forget that having an operator running two machines will make this type of work even more attractive. Over my working career I've had accountants and consultants come in and say to get rid of all non-profitable jobs. But they might be looking at a standard rate for each machine that covers all costs and overhead. And if an operator runs one machine, they're right. That job needs to be quoted to account for the standard rate. But if the same operator runs two machines, the second machine is almost free in terms of overhead. If I knew a job was to be run on a second machine by the same operator, I would comfortably quote less for the job. Accounting would say we lost money on that job, but we didn't.

Tracking Your Record

It is important to know your quote win rate. Hopefully you communicate this to your sales people. Are you promoting this specialty in your ads on your website? Are you keeping your light under a barrel?

Conclusion

Quoting is generally not an exacting science and is generally more of a game of chance. But using a few carefully considered guidelines, you can turn more opportunities into profitable jobs.

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.

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*.

Universal Hobs

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

QUESTION

I make all the double helical gears that go into a gearbox. Four different gears in all that go into this unit. If the gear module for the bull gear and the intermediate gear are the same (these are the two individual gears that mate), and the gear module for the high-speed pinion and high-speed gears are the same (these are the other two individual gears that mate in the gear box as well), is it then possible to just use two hobs in this setup to make all four gears, since they mate together with each other? We are currently using a different gear hob for each gear.

Editor's Note: While this question was asked and answered in the 2016 Sept/Oct issue of *Gear Technology*, what follows is a more detailed response to the question.

Expert Response: Provided by Dr. Hermann J. Stadtfeld:

The short answer to the reader's question is YES!

However, the reader who asked the question—and many other readers—might like to get some more information as to why and how?

Double helical gears consist of a left hand and a right hand helical gear with opposite helix angles that are grouped together on one shaft. The two-toothed sides of double helical gears commonly have the same module (or diametral pitch) and the same helix angle, where the sign of the helix angle is opposite between the two sides (Fig. 1). The manufacturing problem of double helicals is the width of the space between the two-toothed section. This space has to provide sufficient over travel clearance for a hob cutter. If the groove is too small the two helicals can be manufactured separately and then assembled back-to-back on a shaft. If separate manufacturing is not an option, then a shaping process can be employed that will accommodate very small, over travel grooves between the toothed sections. Shaping is slow and the cutters used are non-standard tools that are expensive compared to standard hobs.

Figure 1 Double helical gear.

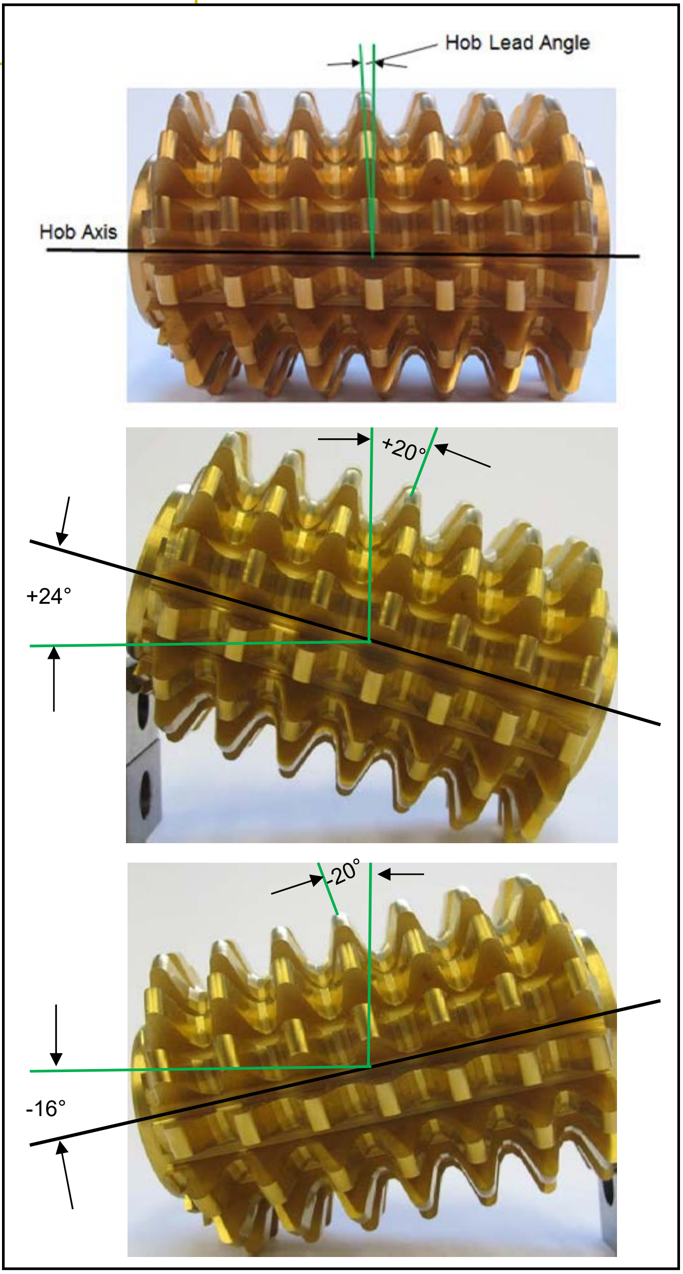

Figure 2 Module 4.75mm single start right hand protuberance hob with tip relief.

This leads to the advantages and the universal application of hob cutters. Standard hobs are available for a preferred range of modules (metric hobs) and diametral pitches (English system hobs). Standard hobs are also available with protuberance for root relief and with a tip relief section. Figure 2 (top) shows a module 4.75 hob with protuberance and tip relief. A hob with a certain module represents a section of a generating rack (Fig. 3). While the hob rotates with rotation *F*, the generating rack is shifted in direction *G*. The shift *G* requires a rotation *C* of the work gear. If the hob has one start, then one rotation of the hob requires the work to rotate by one pitch. The generating rack principle in Figure 3 makes clear that the hob could also be positioned in front of the rack (where the work is), and the work gear could in turn be positioned where the hob is located (Fig. 3). This principle explains the answer to the reader's question but there are some details to be considered. The hob teeth wind around the hob body like threads with a lead angle. If a spur gear is manufactured the hob axis will have to be swiveled out of its initial, horizontal position by the thread lead angle.

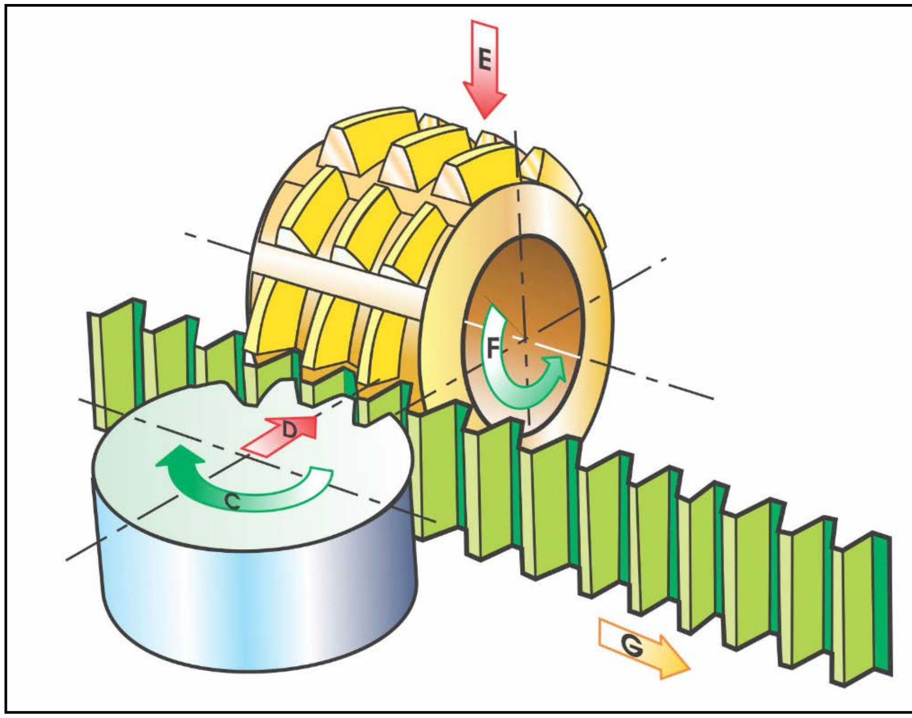

Figure 3 Hob and generating rack principle.

The double helical gear in Figure 1 has a helix angle of +20° on its bottom part and +20° on its top part. The hob in Figure 3 has right hand threads with a lead angle of 4°. In order to cut the top gear, the hob has to swivel 20° + 4° = +24° in clockwise direction, as shown in Figure 2 (center), if it is positioned in front of the gear in Figure 1. When the same hob cuts the bottom part the required swivel angle is –20° + 4° = 16°, as shown in the lower graphic in Figure 2.

The right hand top gear in Figure 1 meshes with a left hand mate and vice versa for the top gear. This fact already indicates that the same right hand hob cannot only cut the two members of the double helical we see in Figure 1, but also the two members of the mating double helical.

In order for helical and other gears to mesh correctly, the same module and pressure angle are required, which are both given when using the same hob. If the two mating gear pairs use the same root fillet radius and also have the same root and tip relief, then it is possible to use the same hob for both mating gears, which amounts in case of double helicals to four gears being cut with one hob. In our example the hob swivel angle will always have to change between bottom and top gear between –16° and +24°. Hobbing experts point out that the cutting conditions are better and that the influence of the surface scallops to the involute profile is lower if the hob is swiveled in the direction of the lead angle rather than against it. The influence of the hob lead angle to the cutting conditions is more significant in case of multiple start hobs, and can be neglected in case of single start hobs. If multiple start hobs are used it is recommended to use a left hand hob to cut a right hand part, and vice versa.

Using the same hob for pinion and gear is also possible if the two meshing members require different amounts of profile shift. The profile shift will not change the pitch diameters of the cut gears, but will alter the outside and root diameter. Profile shift is simply accomplished by turning the gear blanks with the correct outside diameter required for the particular profile shift and then, depending on the sign of the profile shift, advancing or retracting the hob versus the work in direction *D* (Fig. 2) in the hobbing machine.

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Dr. Hermann J. Stadtfeld is vice president—bevel gear technology/R&D—The Gleason Corp., and valued contributor to Gear Technology magazine.

Performance of Gears Manufactured by 5-Axis Milling

Julian Staudt, Cristoph Löpenhaus and Fritz Klocke

Free form milling of gears becomes more and more important as a flexible machining process for gears. Reasons for that are high degrees of freedom as the usage of universal tool geometry and machine tools is possible. This allows flexible machining of various gear types and sizes with one manufacturing system. This paper deals with manufacturing, quality and performance of gears made by free form milling. The focus is set on specific process properties of the parts. The potential of free form milling is investigated in cutting tests of a common standard gear. The component properties are analyzed and flank load-carrying capacity of the gears is derived by running trials on back-to-back test benches. Hereby the characteristics of gears made by free form milling and capability in comparison with conventionally manufactured gears will be shown.

Motivation, Objective and Approach

Due to several advantages in matters of flexibility and degrees of freedom in gear and process design, 5-axis milling has established itself as an accepted manufacturing technology for the gear making industry (Refs. 1; 2; 11; 12; 3; and 26). Beyond the pure academic application in fundamental research, there are three main areas of application in the industry for this technology, i.e. — prototyping, single part production, and repair/spare parts; application areas for this technology are summarized (Fig. 1).

Because of the high flexibility, small batch sizes and various other gear types can be economically realized. Combining soft and hard machining on one single machine tool creates advantages over conventional process chains — even for manufacturing of very big gears and single part production. Furthermore, short delivery periods are one of the major aspects in the production of spare parts. Due to the usage of a universal machine tool and universal milling tools, delivery times for special hobbing tools can be eliminated and the duration of the production cycle for spare parts is reduced massively.

Five-axis gear milling finally provides the opportunity for additional degrees of freedom in gear and part design, in comparison to conventional gear making technologies. Now, the microgeometry of tooth flank and tooth root can be optimized freely. In addition, the minimal run-out of the tool and the accessibility to the cutting area can be used for constructional improvements to the entire gearbox and its arrangement of the gears.

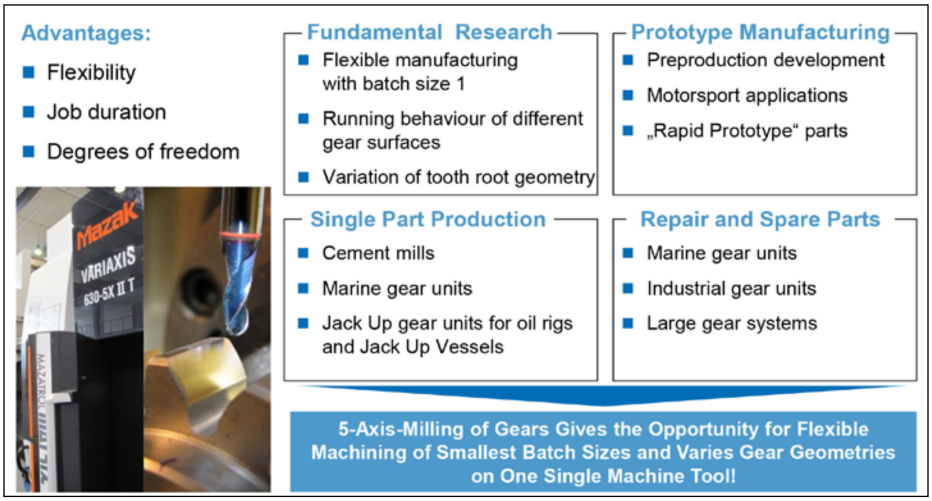

Figure 1 Area of application for free-form milling of gears.

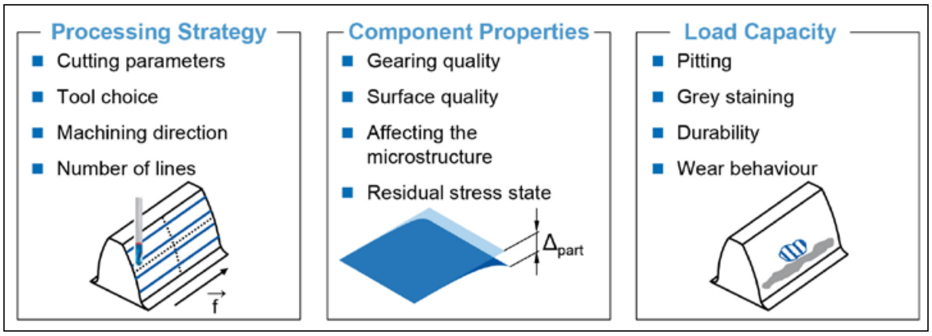

Figure 2 Objective and approach.

With use of standard milling tools, the application area of gear types and sizes is virtually unrestricted. With this process all conventional gear types and tooth geometries can be realized. Furthermore, the technology is flexible concerning new gear types.

Note that as the technology is not as yet available (Refs. 12; 24; 22; 34; 11; 35), there is no scientific analysis available concerning the potential of this process regarding gear quality. In order to utilize the full potential of this technology the performance of the parts — in comparison with conventionally ground gears — must be analyzed.

This paper deals with the potential of 5-axis milling for gears, based upon years-long comprehensive and scientific work on the free form milling of gears. (Refs. 15–18; 19; 30–31). The objective of this paper and the approach concerning the related investigations are shown in Figure 2.

The process terminology and process characteristics — as machining strategy and process specific surface structure — are explained. The potential of gear manufacture with free form milling is investigated in cutting tests of a common standard gear type C; therefore the gear geometry and the surface were analyzed. Gear quality is compared to requirements of conventionally machined gears.

Process Definition — Terminology of Free Form Milling of Gears

According to DIN standard, manufacturing of gears on universal machine tools is located in the area of NC form milling (Ref. 4). The manufacturing process regarding machine tool and control unit is comparable to manufacture of molds and dies (due to similar materials, hardness and accuracies) and to the manufacture of impellers and turbo machinery components (due to similar geometries). Beyond this general definition of free form milling, process specific parameters for the manufacturing of gears have to be characterized. The process description includes the definition of process parameters, the tool selection and the generation of input data (Fig. 3).

A portion from the full description of the process characteristics of the free form milling of gears contains: *Tool selection, generation of input data* and, particularly, *machining strategy*; these three aspects will be discussed in the following. Characteristics beyond that are defined by terminology of gear manufacturing and NC free form milling and will be adapted.

Selection of milling tools. The selection of milling tools is divided into soft machining and hard machining. Because of different requirements rough and fine cutting steps are met with different tools. For the machining of tooth root, a tool change can be necessary, too; standard milling tools are characterized by the parameters shown (Fig. 3, left).

For stability reasons a large as possible tool diameter is chosen; tool length is chosen as short as possible. Tool size, as well as blade radius, is restricted by the gear geometry.

Different types of milling tools are sorted into groups by their blade geometry. Possible tool geometries are full radius, torus and shaft cutter. Depending on the type of tool, there is a point or line contact between tool and gear flank. The

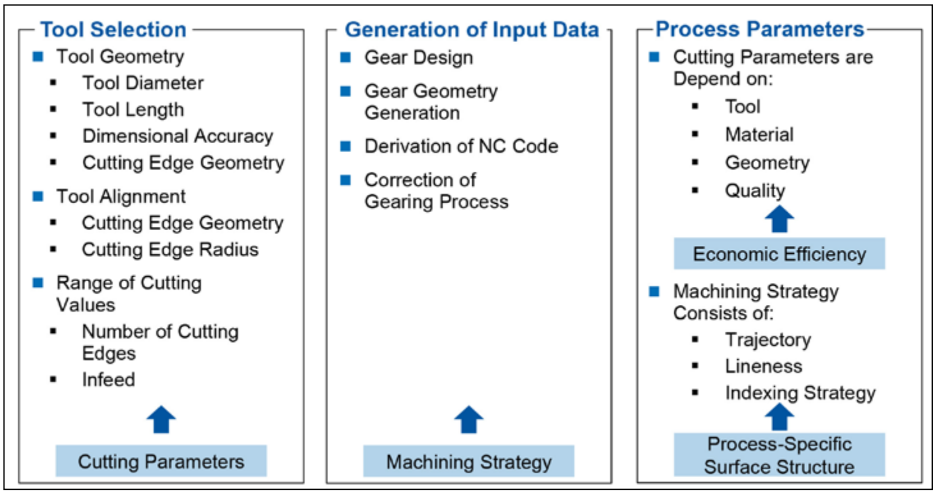

Figure 3 Process characterization.

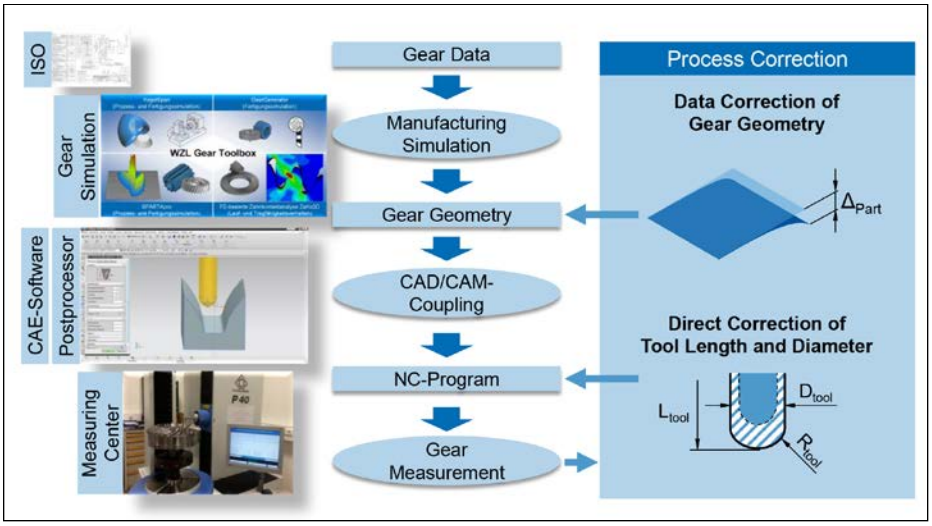

Figure 4 CAx process chain.

chosen machining strategy is essential for these contact conditions and for restrictions of tool selection.

Generation of machine input data. In contrast to manufacturing of gears on conventional gear manufacturing machines, free form gear milling requires a defined geometry in the form of coordinates. Figure 4 shows the CAx process chain necessary for the generation of the NC code.

After gear design, the gear data is sent to the CAx process chain. In the first step the gear data is transferred into the gear geometry. The creation of gear geometry can be done analytically or by a manufacturing simulation, and includes a defined geometry of flanks and tooth root. In the next step the gear geometry is converted into NC code.

Deviation of geometry resulting from the manufacturing process can be offset by closed loop between manufacturing, gear measurement and generation of NC code. Depending on the correction method, different steps of the CAx process chain are necessary for the compensation (Fig. 4, right).

Machining strategy. The machining strategy includes three major aspects of the definition of the manufacturing process, i.e. — the *lineness, trajectory* and *cutting strategy*; Figure 5 provides an overview of the machining strategy.

The trajectory defines the path of the tool in machining relative to the tooth flank. The lineness is the term for the quantity of required tool paths for the machining of one tooth flank and for the space between the lines. The indexing procedure describes the systematics of machining all gaps successively. This includes manufacturing order and movement of all axes during indexing between two teeth. All three components of machining strategy will be defined and described in the following.

Trajectory. The definition of the trajectory is based on technological requirements for the running behavior of the gears. Furthermore, the trajectory has a significant influence on processing effort and process kinematics. Different trajectories are shown on the left hand side of Figure 5. The trajectory can be defined in direction of tooth width, profile direction or diagonal on tooth flank. Furthermore, common structures can be imitated (gear honing or gear finish hobbing) and new structures can be realized. From the manufacturing point of view, there are no technological restrictions. In terms of economical process design, the complexity of trajectories must be taken into account because complex trajectories require additional axes and movements of the tool.

Lineness. Lineness in part defines the number of tool paths that significantly influence machining time. Also, lineness defines the schema how tool paths are located on the tooth flank; there are three possibilities that can be seen in the middle of Figure 5.

First, tool feed can be equidistant for each tool path. That leads to a changing structure all over the tooth flank. The second possibility is to define tool feed depending on gear geometry in order to keep the space between two paths on the gear flank constant. Surface structures at tip and tooth root are the same. The last shown possibility is an independent definition of line spaces in tool feed and tooth profile direction. Here the structure can be defined freely and the flank surface can be realized based upon stress deviation for the whole flank. Thus the effort for process configuration is, in this case, very intense.

The space between tooth paths defines the kinematic surface roughness (Ref. 13). The kinematic surface roughness can be described geometrically so that the surface requirements can be accounted for during configuration of the milling process.

Cutting strategy. The cutting strategy is divided into two categories — *indexing* and *cut distribution*. The centering of the gap for hard machining can be realized by measuring equipment on the machine tool. The indexing strategy can be steady or unsteady. During steady indexing the proximate gap is located next to the current one. The advantages are short movements of tool and part during machining, as shorter machining times can be realized. Errors in part rotation and thermic influences are accumulated during machining so that the pitch deviation between first and last tooth is high. During unsteady indexing the gaps are machined/evenly distributed all over the gear. Errors are not accumulated in this case; the peak of pitch deviation can be avoided. Machining time will be higher than with steady indexing because more movements are necessary.

The distribution of cuts depends on the hard finishing allowance; single- or multi-cut strategies can be realized in order to finish the gear after heat treatment. The single-cut strategy leads to short manufacturing times and high chip volumes. Multi-cutting includes pre-finishing steps so that hardening distortions are equalized before the final cut is applied. In this case the chip volumes can become very small and the thermal influence on the part increases.

Scope of the Investigation and Experimental Setup

Using the given process definition for the free form milling of gears, fatigue tests were begun. The gear quality, further part properties, and the running behavior of the gears made by free form milling are analyzed; Figure 6 provides an overview of the experimental setup.

The used gear type is a standard test gear type C (Refs. 8; 21; 34). For analysis of the manufacturing technology and running behavior, only the pinion ($z_1 = 16$) was made by free form milling. The wheel ($z_2 = 24$) was conventionally profile ground.

Four different machining setups were chosen; (top, right) Figure 6 shows all used process parameters. The test gears were manufactured in single-cut strat-

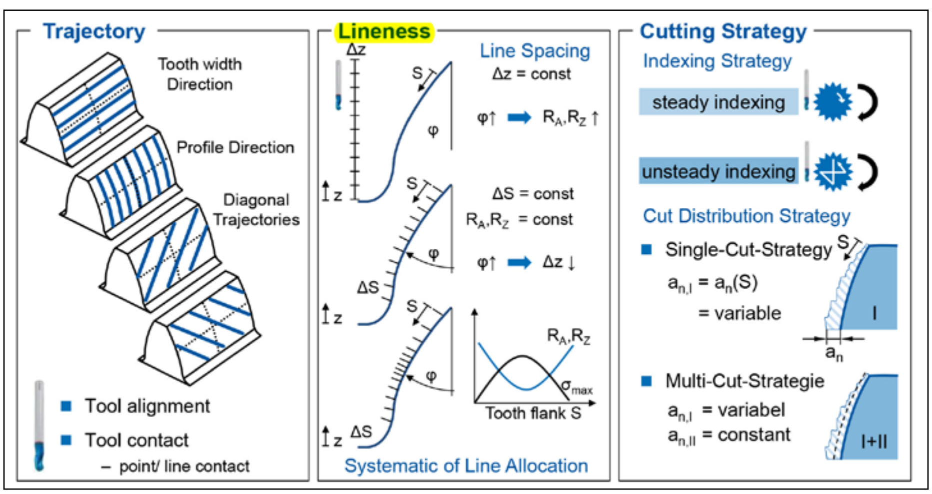

Figure 5 Definition of manufacturing strategy for free-form milling of gears.

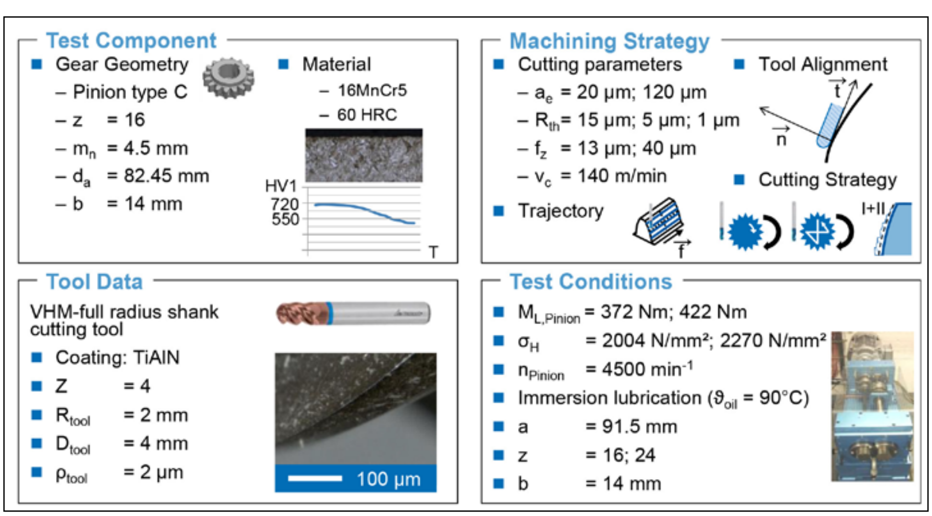

Figure 6 Scope of investigations.

egy ($a_e = 20$µm) and multi-cut strategy ($a_e = 120$µm). Furthermore, the theoretic process-specific surface deviation was varied from $R_{th} = 1$µm up to $R_{th} = 15$µm.

Defined test conditions are related to FVA No. 0/5 and shown (Fig. 6, bottom right) and (Ref. 9). Flank load carrying capacity for all variants was derived. In addition, conventionally ground gears were tested and a reference S/N-curve derived.

Integrity of Gears Machined by Free Form Milling

The first analysis aims for a comprehensive analysis of all gear properties. Therefore the gear quality, the process-specific surface structure, and the characteristics of the surface near (near surface) material structure are analyzed.

Gear quality. The gear quality of all four variants is shown (Fig. 7). The first three variants were made by a multi-cut strategy. The process-specific surface structure was varied by the lineness. The fourth part was realized by the same lineness as the third one, but hard finishing was done in a single-cut. The last of the shown parts is the reference gear, which is profile-ground.

All gears match the requirements of IT 5 concerning pitch and quality in lead direction. The quality in profile direction is pre-defined by the chosen lineness. Because of that the first part — with $R_{th} = 15$µm — has a profile quality of IT 8, which is directly related to the lineness and the resulting profile form deviation $f_{f\alpha} = 15$µm. All in all, it is clearly visible that all variants have a sufficiently geometrical gear quality. The chosen manufacturing strategy affects the resulting gear geometry; thus the resulting gear quality becomes predictable and can be specified during manufacturing process design.

Process-specific surface structure. The gear quality measurements show a profile form deviation that is directly related to the chosen lineness; therefore the focus of the surface analysis initially is on the process-specific surface structure. The tactile 3-D measurement of the variant $R_{th} = 15$µm is shown (Fig. 8). The surface-specific surface structure is divided into the amount of the deviation R_{th} and the spacing of the structure *RW* (Refs. 15–16; 19). Both parameters are driven by the tool alignment, tool geometry, and the

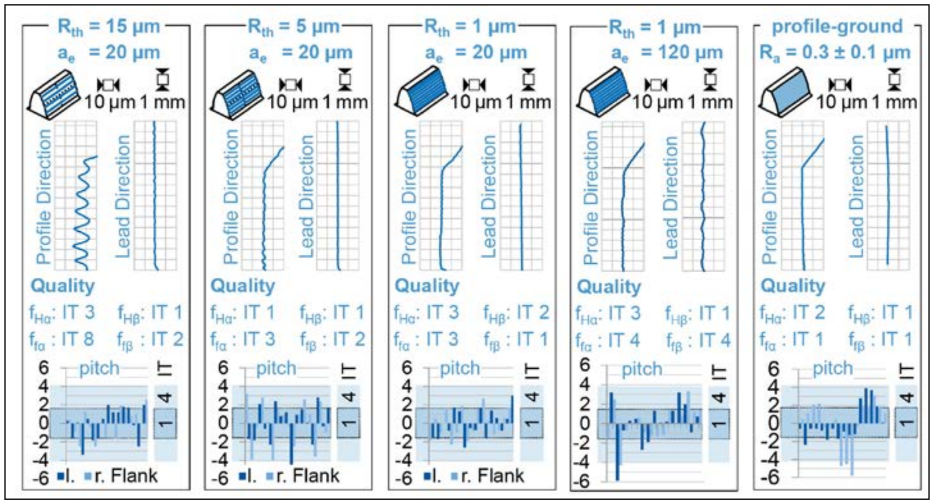

Figure 7 Gear quality.

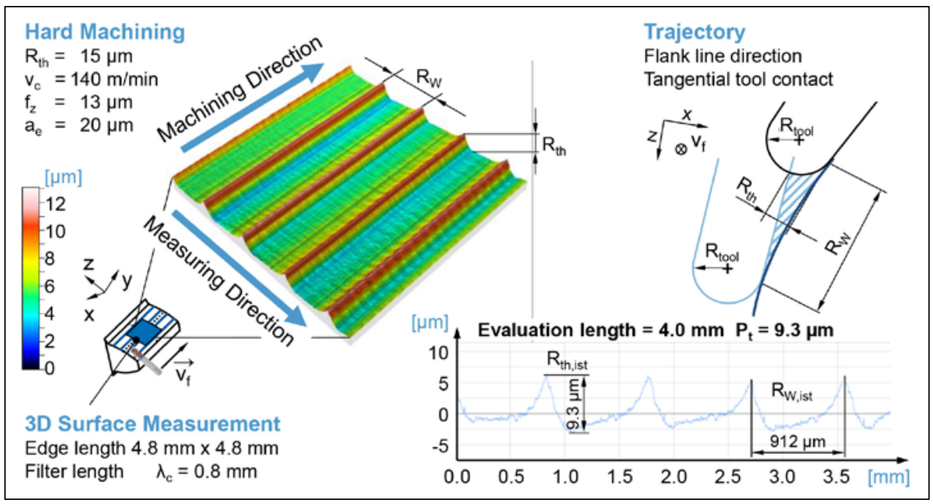

Figure 8 Process-specific surface structure.

chosen machining strategy (e.g., trajectory and lineness).

The resulting surface structure meets the existing definition (Refs. 15–16; 29). The actual value of the deviation $R_{th,ist} = 9.3$µm is smaller than $R_{th} = 15$µm because the number of trajectories must be an integer and the deviation $R_{th} = 15$µm may not be exceeded. In the shown case the difference between $R_{th,ist}$ and R_{th} can be high because the number of trajectories, $N = 10$, is small.

The microscopic geometry of the surface structure complies with the theoretical penetration between tool and part (Fig. 8). The change of the lineness must affect this structure directly. The results of the variation of the lineneness are shown (Fig. 9).

By increasing the number of lines, the deviation is reduced. The variant with $R_{th} = 1$µm finally leads to a good surface quality that is equal to the reference. The variant with $R_{th} = 5$µm sticks in the middle and compromises between high surface deviations (like the variant with $R_{th} = 15$µm) and high machining times (like the variant with $R_{th} = 1$µm). The change of the cut distribution from multi-cut strategy ($a_{e\ II} = 20$µm) to single-cut strategy ($a_e = 120$µm) leads to an increasing surface roughness. The difference is explained by the increase of chip volume and resulting increase of the cutting force that affects dynamic tool deflection and leads to a wavy surface structure in the machining direction.

Characteristics of surface-near area. The flank load capacity of gears is highly affected by the conditions of the surface-near area of the parts (Ref. 24); therefore negative effects of hard machining on the material structure must be avoided. Thus micrographs, residual stresses and the full width at half-maximum (FWHM) must be analyzed.

Material structure. There was no grinding burn or negatively affected

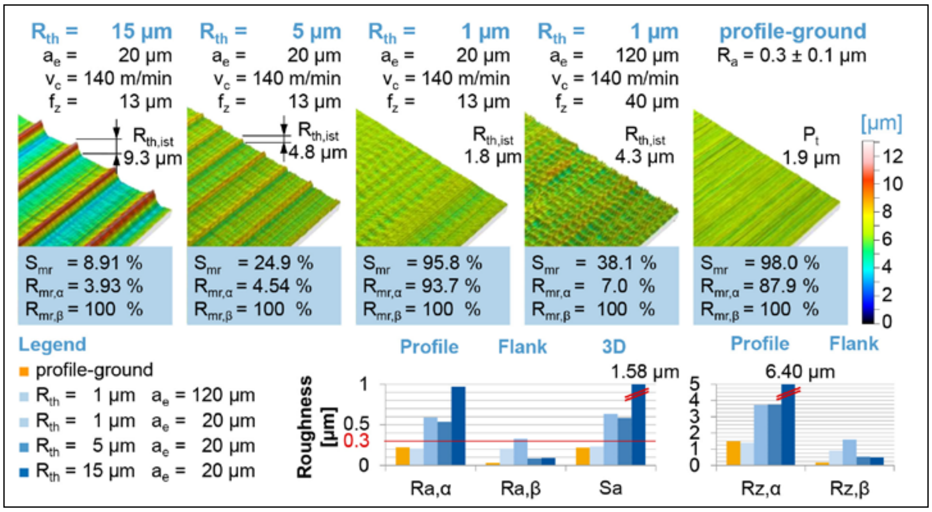

Figure 9 Surface quality.

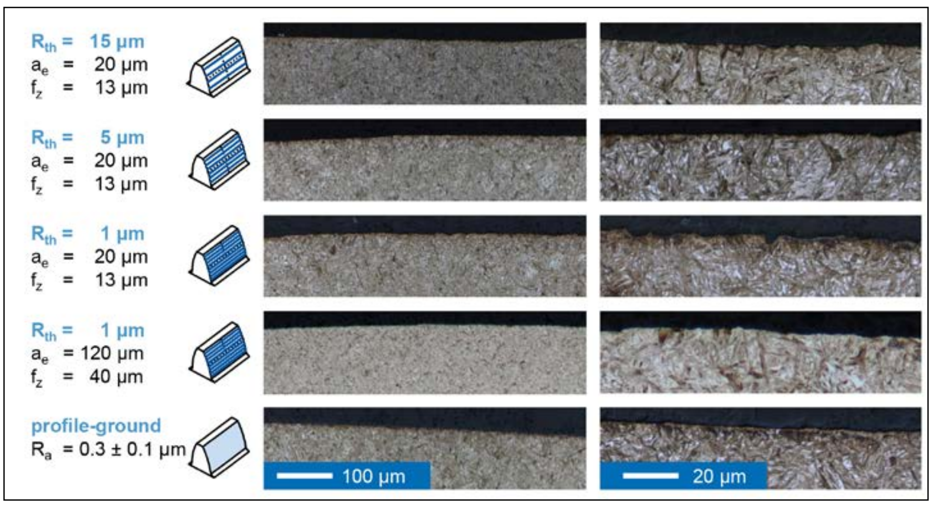

Figure 10 Material structure.

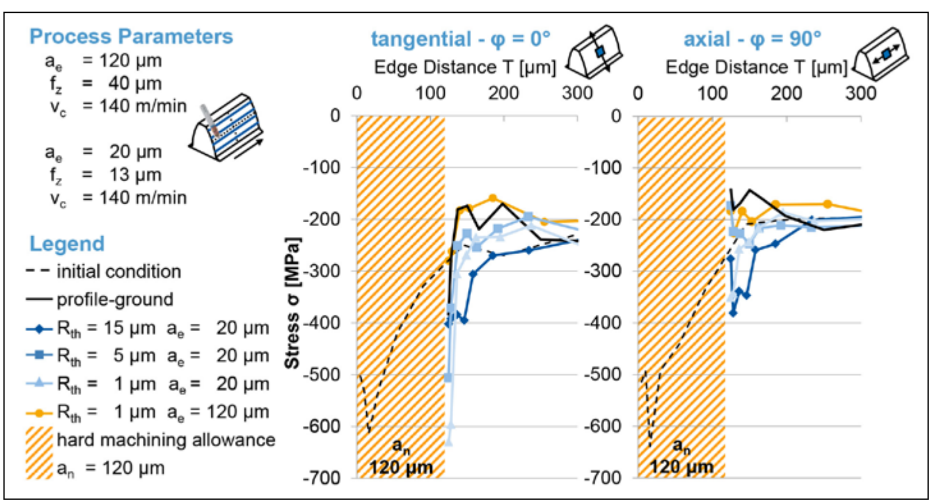

Figure 11 Depth profile of residual stresses.

material structure detected by nital etching of the hard machined parts. In order to prove even small influences, additional metallographic investigations were conducted; micrographs of all variants are shown (Fig. 10).

The material structure of both variants with R_{th} = 15µm and 5µm has no visible influence on the microstructure due to the hard machining. In contrast, the variant with R_{th} = 1µm and a_e = 20µm (with multi-cut strategy) shows a slight annealing of the material at the outer surface, which correlates with the reduction of the chipping volume and much higher machining time. In this way the amount of thermal energy led into the part is increased. The variant with R_{th} = 1µm and a_e = 120µm (with single-cut strategy) also has no negatively influenced surface near area. This indicates that only the combination of higher machining time and small chip volumes lead to an exceeding of the critical level of thermal capacity of the material.

The profile grinding has a relatively small influence on the material structure of the reference part. The microstructure of the reference part is equal to material structures due to profile grinding known from literature (Refs. 7 and 27); thus no defect is detectable at the reference parts.

Depth profile of residual stresses. By measurement of the depth profile of residual stresses a closer look at the properties of the surface near area is possible. Influences of the 5-axis milling process and the chosen machining parameters on the properties can be quantified this way. Therefore the initial condition after heat treatment and the profile ground reference were analyzed as well. Figure 11 displays an overview of all measured depth profiles; the residual stresses of all parts were measured in tangential (profile) direction and in axial (lead) direction.

The direction of tool feed is in lead direction and equal for all machined parts. Hard machining parameters seem to have a relatively small influence on the depth profile in axial direction. Beneath an edge distance of T = 30µm, all residual stress profiles are equal.

In tangential (profile) direction there are bigger effects on the residual stresses at the gear surface. The variant with minimal chip volume (R_{th} = 1µm, a_e = 20µm, f_z = 13µm) leads to $\sigma_{tangential}$ = −630 MPa directly at the surface. High chip volume (R_{th} = 1µm, a_e = 120µm, f_z = 40µm) is barely affecting the residual stresses.

Mechanical loads lead to an increase of compressive residual stresses, whereas thermal load reduces compressive residual stresses (Ref. 31). Because of this, grinding burn is usually detected by a local reduction of compressive residual stresses (Refs. 7; 27; 35; 26).

The small influence of microstructure (Fig. 10) was not detectable by analysis of the depth profile of the residual stress measurements (Fig. 11); even nital etching did not reveal any affected surface near area. This is why micro-residual stress also must be taken into account.

FWHM of residual stress measurement. Influences of the hard machining process on micro-residual stresses and homogeneity of material structure can be detected by analysis of the full width at half maximum (FWHM). Literature shows a correlation between reduction of part durability and a drop of FWHM by 10% (Refs. 1 and 32).

The depth profiles of FWHM of all 5-axis-milled variants are shown (Fig. 12). In addition, the profile ground reference is shown as a solid black line. The FWHM of the two variants with the smallest chip volumes (R_{th} = 1µm and 5µm, a_e = 20µm) are affected by the machining process at a depth down to T = 10µm. This is the same area where the annealing of the surface near area was detected in the micrographs (Fig. 10).

The variants with higher chip volumes are not affected in case of FWHM by the machining process. This can be confirmed by the analysis of the micrographs, which also show no negatively influenced material structure. This correlation between the reduction of FWHM and the resulting part durability must be confirmed by conducting flank load capacity tests.

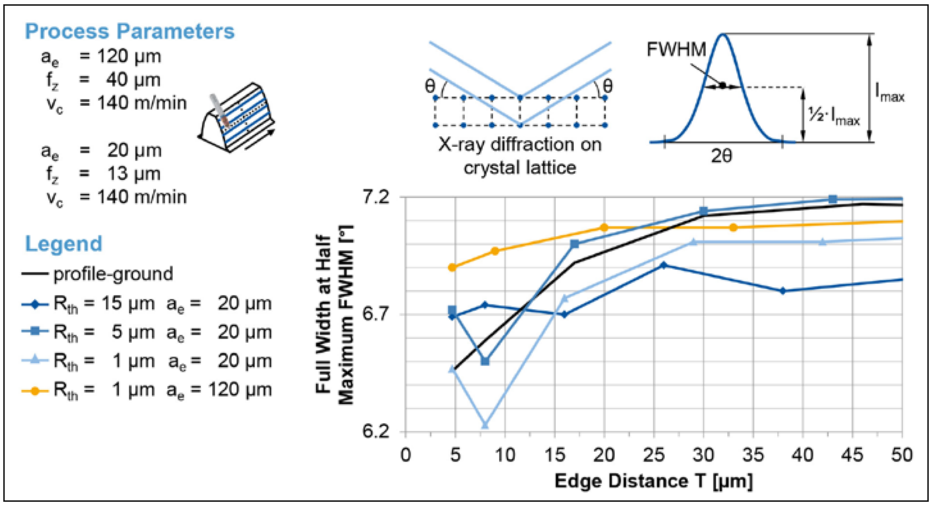

Figure 12 FWHM of residual stress measurement.

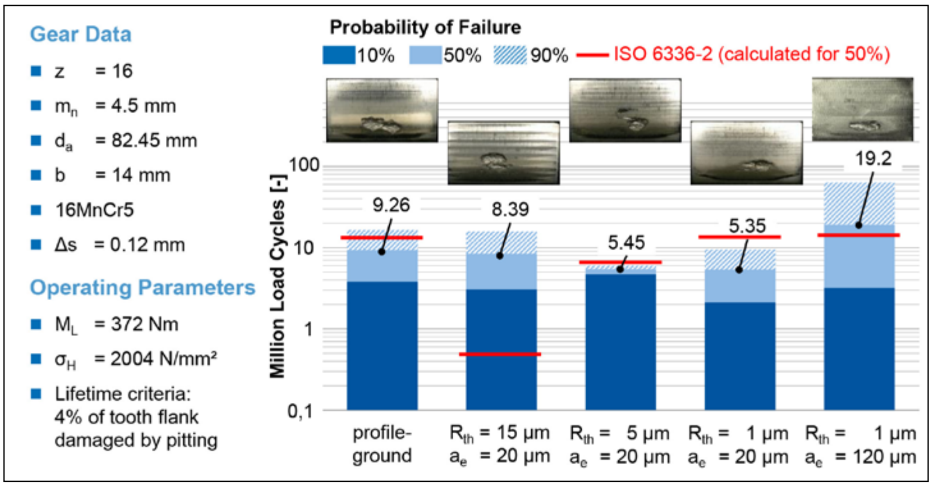

Figure 13 Tooth flank load capacity dependent upon processing strategy.

Flank Load Carrying Capacity of Gears Made by Free Form Milling

To prove the usability of 5-axis milling as a technology for industrial applications, the applicability of the ISO 6336 standard must be verified (Ref. 10). Concerning this, the effects of the process-specific characteristics of gears made by 5-axis-milling on the performance of the gears was validated in tests according to FVA Nr. 0/5 (Ref. 9). Therefore pinions of the standard test gear type C were used as the test part. The gear was conventionally profile ground. The tests were carried out on back-to-back test rigs according to DIN ISO 14635 (Ref. 5). Additionally, a Woehler curve for 50% probability of failure was derived from the profile ground gears as a reference for all tests. Based upon this reference, flank load carrying capacity can be calculated according to ISO 6336-2 for 50% probability of failure.

The tests were proceeded at M_L = 372 Nm load. Figure 13 shows the resulting performance of all variants for 10%, 50% and 90% probability of failure as a bar chart. According to ISO 6336-2, cycles-to-failure were calculated theoretically, based on the results of the Woehler curve, for the specific flank deviations $f_{fα}$ caused by the process-specific surface structure of the specific variants.

It can be observed that the first 5-axis-milled variant (R_{th} = 15µm, a_e = 20µm) seems to massively exceed the expectation. In contrast, the third variant — machined with R_{th} = 1µm and a_e = 20µm — misses the expectation. The second variant (R_{th} = 5µm, a_e = 20µm) meets the calculated value, whereas the last variant actually exceeds the durability of the profile ground reference.

The differences in the durability of the gears cannot be based upon differences of surface structure; this means that a closer look at wear behavior of the parts is required. Therefore the occurrence of micropittings after 20 hours of testing and number of pitting defects on one single gear during the complete test were analyzed; results are shown (Fig. 14).

High process-specific surface deviations lead to bigger areas of micropitting. Thus, the variant R_{th} = 15µm shows a 50% area of micropitting on the flanks. At the variants R_{th} = 5µm and R_{th} = 1µm (both multi-cut-strategy), a nearly equal amount of micropitting occurs. This cannot be explained

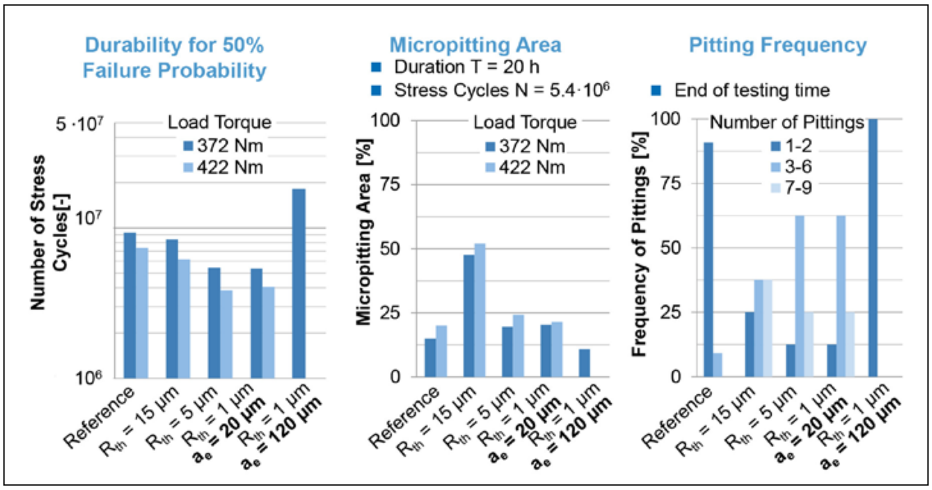

Figure 14 Wear behavior dependent upon processing strategy.

by the surface alone, as the surface quality of both variants is different. The variant $R_{th}=1\mu m$ and $a_e=120\mu m$ (single-cut strategy) has the best result concerning the micropitting area. As in the case of load cycles, micropitting behavior is even better than the reference.

In addition, pitting frequency at the end of each test run was analyzed. The distribution of the number of pittings for each variant is shown (Fig. 14, right). The reference usually has no more than one or two pittings on each gear. This failure characteristic is well known from literature for case hardened gears (Refs. 10; 24). All variants with higher process-specific surface structures (R_{th} 15µm and 5µm) have a much higher number of pittings. The variant $R_{th}=1\mu m$ and $a_e=20\mu m$ with the big area of micropitting, and the annealing of the material structure, leads to a high number of pittings as well.

In summary, failure behavior of gears made by free form milling depends directly on the chosen manufacturing parameters. The higher the chip volume, the better the gears performed in case of micropitting and pitting behavior (Fig. 14). As known from literature, good surface quality results in better running behavior. Too high process-specific surface structures affect micropitting and, finally, cause damage by pitting. The variant $R_{th}=1\mu m$ and $a_e=120\mu m$ (single-cut strategy) has the best result and shows the same behavior of failure as state-of-the-art gears. Hereby, the expectation of an ideal process strategy for free form milling of gears is verified (Ref. 30).

Summary and Outlook

The capabilities of five-axis milling of gears are becoming increasingly important, as this process is a flexible manufacturing technology for the machining of small batch sizes and single parts. And since there was no comprehensive knowledge available regarding the resulting function of 5-axis-milled parts (Refs. 21; 28), the aim of this paper was to describe the influence of 5-axis milling on the properties of the part and the resulting function of the gears in application.

The influence of the manufacturing strategy and chosen parameters on part integrity is important in predicting load-carrying capacity, and is decisive for industry application of 5-axis milling. Based on standard test gears, machining and running tests were carried out. From that R&D fundamental knowledge of the general process design for 5-axis milling of gears was derived (Ref. 30).

The machining strategy for free form milling of gears was defined based on existing definitions (Refs. 15; 18; 29). The process-specific surface structure was predicted, and from here on can be addressed during manufacturing process design. The surface near properties of the microstructure were influenced by the chosen manufacturing parameters. Number of trajectories, cutting strategy and tool feed can lead to unfavorable small cutting volumes; therefore an impairment of the function by tempering occurs. This impairment is small in comparison to grinding burn in conventional gear profile grinding, and so it is not possible to detect this effect by nital etching. The analysis of FWHM (full width at half-maximum) of the measurement of residual stresses was derived as an appropriate value for the quantification of the thermal impairment. The reduction of FWHM at depth $T=10\mu m$ led to a negative effect on the function of the gears.

The performance of gears made by free form milling was proven and documented by this investigation. The tests showed a significant influence of the process-specific surface structure on the lifetime of the gears and the resulting wear behavior during application. It was shown that gears made by free form milling will provide the same performance as conventional, profile-ground gears — part integrity being equal. Large process-specific deviations lead to unconventional wear behavior that is not describable by existing criteria (damage of 4% of the flank by pitting, for example).

If the machining strategy leads to a gear and surface quality that is comparable to conventionally machined gears, free form-milled gears will have the same performance. Unfavorable choice of machining parameters leads to an impairment of the surface near microstructure and so to a lack of performance. In this way the positive effects of a good surface or gear quality can be reversed (Ref. 30).

Further investigation is needed in order to establish the transferability of outcomes of this research from standard test gears to actual application scenarios in industry. Especially, additional challenges concerning tool wear and realization of complex geometries — such as bevel gears — must be faced in order to utilize 5-axis milling as a process for hard machining of gears for industrial applications.

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Dr.-Ing. Dipl.-Wirt.Ing. Julian Staudt in 2016 completed his doctoral thesis in production engineering — “Function-Oriented Machining of Gears by Free-Form Milling.” Since 2012, Staudt was a research assistant at the chair of Manufacturing Technologies at Laboratory for Machine Tools (WZL) at RWTH Aachen University. While continuing his studies, Staudt (2007–2012) was a student worker at Laboratory of Machine Tools (WZL), concentrating on surface densification of P/M gears; condition monitoring of gears; and tool wear in bevel and hypoid gear cutting processes. While in the midst of his studies, Staudt served (2004–2005) performed military service in the German Air Force. He currently works for Saint-Gobain Sekurit — a supplier to the automotive industry.

Dr.-Ing. Dipl.-Wirt.-Ing. Christoph Löpenhaus is a 2010 industrial engineering graduate of RWTH Aachen; he received his Ph.D. (local strength and friction models for gears) in 2015. Upon graduation he worked as a research assistant in the gear testing group of the Laboratory for Machine Tools (WZL) of RWTH Aachen and in 2011 was named the group’s team leader. Lopenhaus has since 2014 worked as chief engineer of the department for gear technology at WZL.

Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Dr. h.c. Fritz Klocke began his distinguished career (1970–1973) as an apprenticed toolmaker while at the same time pursuing his production engineering studies at Lemgo/Lippe Polytechnic, and later (1973–1976) at Technical University Berlin. He then (1977–1981) went on to serve as Assistant at the Institute for Machine Tools and Production Engineering, Technical University Berlin. Starting in 1981, Klocke achieved or received the following academic credentials and awards: Chief Engineer; (1982)Doctorate in engineering; (1984–1994)employed at Ernst Winter & Sohn GmbH & Co., Norderstedt; (1984) Head of Process Monitoring; (1985) Technical Director, Mechanical Engineering Department; (1985) Awarded Otto Kienzle Medal by the Universities Production Engineering Group; (1995) Director of the Chair of Manufacturing Technology at the Institute for Machine Tools and Production Engineering (WZL) of the RWTH Aachen, and director of the Fraunhofer Institute for Production Technology, Aachen; (2001–2002) Dean of the Faculty for Mechanical Engineering; (2006) Honorary Ph.D. by the University of Hannover; (2007–2008) President of the International Academy for Production Engineering (CIRP); (2009) Honorary Ph.D. by the University of Thessaloniki; (2010) Honorary Ph.D. by the Keio University; Award of Fraunhofer Medal; (2012) Fellow of the Society of Manufacturing Engineers (SME); (2014) Eli Whitney Productivity Award (SME); and (2014) Fellow of RWTH Aachen University.

Analysis and Optimization of Contact Ratio of Asymmetric Gears

Alexander L. Kapelevich and Yuriy V. Shekhtman

Introduction

The contact ratio of spur gears is a critical parameter that affects gear drive performance. The influence of this parameter on the gear drive load capacity, efficiency, and noise and vibration is well known. There are studies (Refs. 1–3) dedicated to the analytical and experimental comparison of gears with low and high contact ratios. The dynamics and efficiency of high-contact-ratio asymmetric tooth gears were described in (Refs. 4–5).

These publications explore contact ratio using a very similar evaluation approach. The gears are designed traditionally, based on a preselected basic (or generating) rack. This makes the contact ratio dependent on the number of teeth of mating gears, basic rack addendum, and X-shifts. A contact ratio is considered nominal, as it is designed without influence of deflections under the operating load. Comparable gear sets with different contact ratios are identical in numbers of teeth, tooth size, and modules.

Such comparisons might have some theoretical value, but for practical gear design, equalizing some performance parameters in comparable gears is more important. For example, high-contact ratio gears provide load sharing between two or three pairs of teeth, increasing the load capacity. However, when they are compared with high-pressure angle and low-contact ratio gears (assuming identical numbers of teeth and tooth sizes), the mesh efficiency of high-contact ratio gears is significantly lower, because of their long tooth addendums and low pressure angle. Now a gear designer faces a dilemma: what is more important, high load capacity or high gear efficiency? Comparing gear sets with identical numbers of teeth and tooth size shows that it is impossible to simultaneously maximize both of these performance factors.

This article presents an analysis of asymmetric tooth gears considering the effective contact ratio that is also affected by bending and contact tooth deflections. The goal is to find an optimal solution for high performance gear drives, which would combine high load capacity and efficiency, as well as low transmission error (which affects gear noise and vibration).

Effective Contact Ratio and Transmission Error

The (trademarked) Direct Gear Design method (Ref. 6) defines the nominal contact ratio for external gears as:

$$\varepsilon_\alpha = \frac{z_1}{2\pi}(\tan\alpha_{a1} + u\tan\alpha_{a2} - (1+u)\tan\alpha_w) \qquad (1)$$

where:

a_w = Operating pressure angle
α_{a1} and α_{a2} = Outer diameter profile angles
$u = z_2/z_1$ = Gear ratio
z_1 and z_2 = Number of teeth of mating pinion and gear

Effective contact ratio can be defined as the ratio of the tooth engagement angle to the angular pitch. The tooth engagement angle is a gear rotation angle from the start of the tooth engagement with the mating gear tooth to the end of the engagement. The effective contact ratio is:

$$\varepsilon_\alpha = \frac{\varphi_1}{360/z_1} = \frac{\varphi_2}{360/z_2} \qquad (2)$$

where:

φ_1 and φ_2 = Pinion and gear engagement angles
$360/z_1$ and $360/z_2$ = Pinion and gear angular pitches

Transmission error is (Ref. 7) —

$$TE = r_{b2}(\theta_2 - u\theta_1) \qquad (3)$$

where:

θ_1 and θ_2 = Driving pinion and driven gear rotation angles
r_{b2} = Driven gear base radius

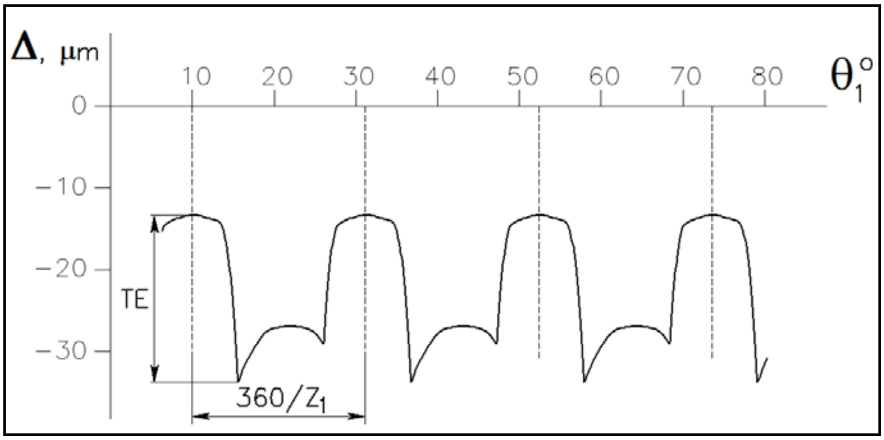

Figure 1 Transmission error chart; Δ – distance in microns between actual tooth contact point and ideal contact point.

A typical spur gear transmission error chart is shown (Fig. 1).

The effective contact ratio and transmission error are influenced by manufacturing tolerances and operating conditions, including deflections under load, temperature, etc. of the gears and other gearbox components. In this article, only bending and contact tooth deflections are considered for the definition of the effective contact ratio and transmission error. Each angular position of the driven gear relative to the driving gear is iteratively defined by equalizing the sum of the tooth contact load moments of each gear to its applied torque. The related

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tooth contact loads are also iteratively defined to conform to tooth bending and contact deflections, where the tooth bending deflection in each contact point is determined based on the FEA-calculated flexibility and the tooth contact deflection is calculated by the Hertz equation.

Comparable Gear Analysis

Comparable gear set macro geometry is defined by the Direct Gear Design method (Ref. 6); it allows for having the drive flank nominal contact ratio as one of the gear design input parameters. The mating gears have optimized root fillets. The specific sliding velocities are equalized to maximize gear mesh efficiency, which for external spur gears is equal to (Ref. 7):

$$E = 100 \times \left(1 - \frac{f}{2\cos\alpha_w} \times \frac{H_s^2 + H_t^2}{H_s + H_t}\right)\% \tag{4}$$

where:

f = Average friction coefficient

H_s = Specific sliding velocity at start of approach action

$$H_s = (1+u) \times \cos\alpha_w \times (\tan\alpha_{a2} - \tan\alpha_w) \tag{5}$$

H_t = Specific sliding velocity at end of recess action

$$H_t = (1+u) \times \cos\alpha_w \times (\tan\alpha_{a1} - \tan\alpha_w)/u \tag{6}$$

Maximum gear mesh efficiency is achieved when the specific sliding velocities $H_s = H_t$ are equalized. Then maximum mesh efficiency for external spur gears can be defined from Equations 4–6 (considering also Eq. 1) as:

$$E = 100 \times \left(1 - \frac{f\pi\,(1+u)}{2u} \times \frac{\varepsilon_\alpha}{z_1}\right)\% \tag{7}$$

All comparable gear sets are assumed to have identical maximized mesh efficiency E, average friction coefficient f, and gear ratio u. Then, according to Equation 7, the nominal contact ratio is inversely proportional to the pinion's number of teeth, as in:

$$\frac{\varepsilon_\alpha}{z_1} = \left(1 - \frac{\mathrm{E}}{100}\right)\frac{2u}{f\pi\,(1+u)} = const. \tag{8}$$

The criterion 8 is used to analyze parameters of external spur gear sets with asymmetric teeth. Comparable asymmetric tooth gear sets have different numbers of teeth and identical center distance a_w, gear ratio u, coast flank pressure angle α_{wc}, minimal pinion and gear tooth tip thicknesses th_{a1} and th_{a2} that are required to avoid the harden through tooth tips for the carburized harden gears, average friction coefficient f and gear mesh efficiency E, pinion and gear material properties, and equalized specific sliding velocities H_s and H_t. The face widths b_1 and b_2 are defined to approximately equalize the pinion and gear tooth bending stresses considering the optimized root fillets.

If the center distance is identical for all gear sets, the operating modules are inversely proportional to the number of pinion teeth and defined as:

$$m = \frac{2a_w}{z_1(1+u)} \tag{9}$$

The operating pitch diameter tooth thickness ratio:

$$TTR = S_{w1}/p_w = S_{w1}/(S_{w1} + S_{w2}), \tag{10}$$

where:

S_{w1} and S_{w2} = Pinion and gear tooth thicknesses at the operating pitch diameters

p_w = Operating circular pitch

The operating pitch diameter tooth thickness ratio value is TTR selected to provide equalized specific sliding velocities H_s and H_t and identical pinion and gear tooth tip thicknesses th_{a1} and th_{a2}.

The maximized drive flank pressure angle α_{wd} is defined to achieve minimal contact stress. It must also provide the nominal drive contact ratio $\varepsilon_{\alpha d}$ defined by Equation 1, the preselected values of the coast flank pressure angle α_{wc}, and pinion and gear tooth tip thicknesses th_{a1} and th_{a2}.

The asymmetry factor is:

$$K = \cos\alpha_{wc}/\cos\alpha_{wd} \tag{11}$$

The bearing load is:

$$F = 2000T_1/d_{bd1}, \tag{12}$$

where:

T_1 = Pinion operating torque in Nm

d_{bd1} = Pinion drive flank base diameter in mm

Load sharing factor is:

$$L = F_{cmax}/F, \tag{13}$$

where:

F_{cmax} = Maximum contact load in the single tooth set contact

Table 1 Gear parameters for several gear sets defined to satisfy pre-selected comparison conditions

Gear set comparison conditions	Center distance – 150 mm; Gear ratio – 2:1; Coast Pressure Angle – 15°; Pinion and Gear face widths – 35 mm and 30 mm; Tooth tip thickness – 0.30·module; Average friction coefficient – 0.05; Gear mesh efficiency – 99%; Pinion and Gear material properties: Modulus of elasticity – 207,000 MPa, Poisson ratio – 0.3; Pinion Torque – 1500 Nm; All gears have optimized tooth root fillets.														
Numbers of teeth – Pinion	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Numbers of teeth – Gear	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
Module, mm	7.143	6.667	6.25	5.882	5.556	5.263	5.000	4.762	4.545	4.348	4.167	4.000	3.846	3.704	3.571
Tooth Thickness Ratio	1.075	1.083	1.092	1.101	1.110	1.114	1.123	1.132	1.137	1.146	1.155	1.160	1.165	1.174	1.179
Drive Pressure Angle, °	42.0	39.1	36.6	34.5	32.7	31.1	29.7	28.3	27.0	25.8	24.8	23.9	23.0	22.3	21.5
Asymmetry Factor	1.300	1.245	1.203	1.172	1.148	1.128	1.112	1.097	1.084	1.073	1.064	1.057	1.049	1.044	1.038
Nominal Drive Contact Ratio	1.11	1.19	1.27	1.35	1.43	1.51	1.59	1.67	1.75	1.83	1.91	1.99	2.07	2.15	2.23
Effective Drive Contact Ratio	1.24	1.33	1.42	1.51	1.60	1.69	1.78	1.86	1.96	2.04	2.13	2.22	2.31	2.40	2.49
Specific Sliding Velocities	0.279	0.292	0.301	0.309	0.316	0.321	0.322	0.330	0.334	0.338	0.340	0.343	0.345	0.347	0.349
Bearing Load, N	40368	38601	37417	36448	35647	35037	34890	34072	33673	33320	33045	32839	32616	32422	32247
Load Sharing Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.743	0.692	0.674	0.644	0.630	0.620
Contact Ratio Type	Low					Medium				Transitional			High		
Selected Gear Sets	-	**1**	-	-	-	**2**	-	-	-	**3**	-	-	-	**4**	-

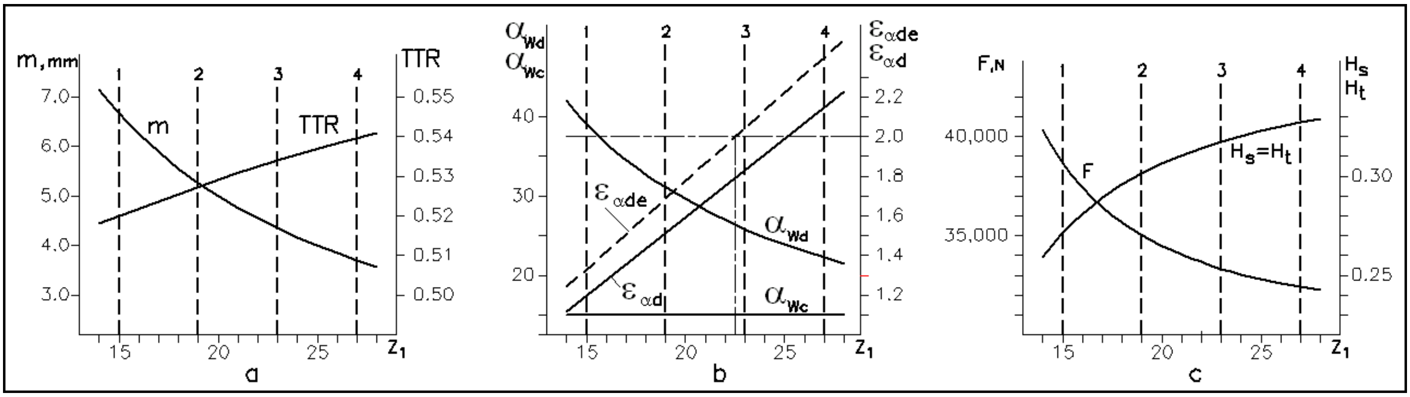

Figure 2 Main gear parameter charts; a)—module and tooth thickness ratio; b)—drive and coast flank pressure angles, and nominal and effective drive contact ratios; c)—bearing load and specific sliding velocities.

If the drive flank effective contact ratio $\varepsilon_{\alpha de} < 2.0$, the load sharing factor $L = 1.0$. Similar to the effective contact ratio and transmission error, the load sharing factor is defined accounting only for the bending and contact tooth deflections.

- Table 1 presents gear parameters for several gear sets that are defined to satisfy pre-selected comparison conditions. The highlighted parameters for four gear sets are selected to define the transmission error under variable operating loads and to find a gear set with the optimal contact ratio.
- Gear set 1 has a 15-tooth pinion and 30-tooth gear with a low contact ratio ($\varepsilon_{\alpha d} = 1.19$ and $\varepsilon_{\alpha de} = 1.33$.
- Gear set 2 has a 19-tooth pinion and 38-tooth gear with a medium contact ratio ($\varepsilon_{\alpha d} = 1.51$ and $\varepsilon_{\alpha de} = 1.69$).
- Gear set 3 has a 23-tooth pinion and 46-tooth gear with a transitional contact ratio ($\varepsilon_{\alpha d} = 1.83$ and $\varepsilon_{\alpha de} = 2.04$). It is called transitional because it has a nominal contact ratio < 2.0 and an effective contact ratio under the given operating load > 2.0. Such gear sets under low load have one or two mating tooth pairs in contact. When the load is increased to its operating level and tooth deflections are increased, the gears are engaged in two or three mating tooth pairs in contact. These results in tooth load sharing and a single-tooth load reduction.
- Gear set 4 has a 27-tooth pinion and 54-tooth gear with a high contact ratio ($\varepsilon_{\alpha d} = 2.15$ and $\varepsilon_{\alpha de} = 2.40$).

The main gear parameters vs. pinion number of teeth charts are shown (Fig. 2).

The Figure 2 charts indicate that with increasing numbers of pinion teeth, the tooth thickness ratio TTR also increases slightly, the drive flank pressure angle α_{wd} lowers, but the nominal and effective contact ratios $\varepsilon_{\alpha d}$ and $\varepsilon_{\alpha de}$ grow. As a result of

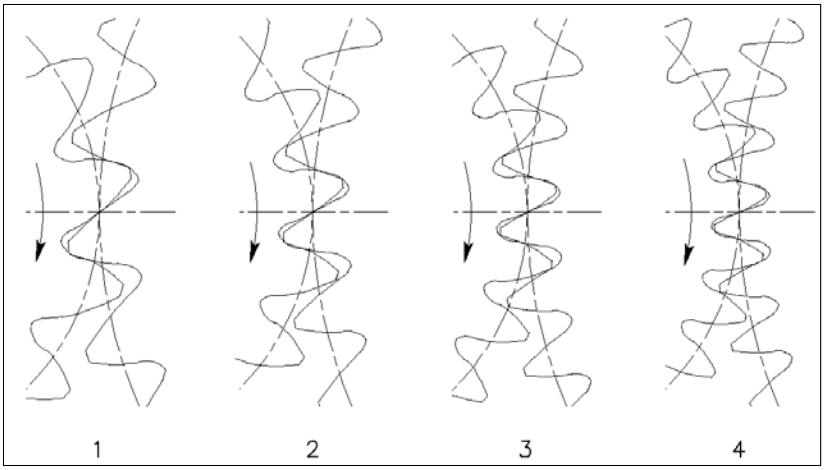

Figure 3 Selected gear sets.

Table 2 Results of selected gear set analysis under different driving torques

Gear set 1 – low contact ratio: $\varepsilon_{ad} = 1.194$, $z_1 = 15$, $z_2 = 30$, $m = 6.667$ mm, $\alpha_{wd} = 39.0°$, $\alpha_{wc} = 15.0°$								
Pinion Torque, Nm	250	500	750	1000	1250	1500	1750	2000
Contact Stress, MPa	714	921	1115	1288	1433	1570	1695	1812
Pinion Bending Stress, MPa	53.7	108	161	215	269	322	376	430
Gear Bending Stress, MPa	52.9	106	159	212	264	317	370	423
Effective Drive Contact Ratio	1.25	1.28	1.29	1.31	1.32	1.33	1.34	1.35
Transmission Error, mm	3.1	6.1	8.8	11.3	13.7	16.1	18.4	20.8
Load Sharing Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Gear set 2 – medium contact ratio: $\varepsilon_{ad} = 1.512$, $z_1 = 19$, $z_2 = 38$, $m = 5.263$ mm, $\alpha_{wd} = 31.1°$, $\alpha_{wc} = 15.0°$								
Pinion Torque, Nm	250	500	750	1000	1250	1500	1750	2000
Contact Stress, MPa	717	930	1132	1311	1464	1601	1726	1845
Pinion Bending Stress, MPa	65.0	130	195	260	325	390	455	520
Gear Bending Stress, MPa	66.9	134	201	267	334	401	468	535
Effective Drive Contact Ratio	1.59	1.63	1.65	1.67	1.68	1.69	1.72	1.74
Transmission Error, mm	2.9	5.5	8.2	10.6	12.9	15.1	17.2	19.3
Load Sharing Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Gear set 3 – transitional contact ratio: $\varepsilon_{ad} = 1.831$, $z_1 = 23$, $z_2 = 46$, $m = 4.348$ mm, $\alpha_{wd} = 25.8°$, $\alpha_{wc} = 15.0°$								
Pinion Torque, Nm	250	500	750	1000	1250	1500	1750	2000
Contact Stress, MPa	740	962	1143	1260	1348	1436	1528	1622
Pinion Bending Stress, MPa	76.8	153	216	258	301	353	412	470
Gear Bending Stress, MPa	81.4	162	228	271	314	359	408	458
Effective Drive Contact Ratio	1.95	1.99	2.01	2.02	2.03	2.04	2.06	2.08
Transmission Error, mm	2.6	5.0	7.3	6.8	6.2	5.8	5.9	6.3
Load Sharing Factor	1.0	1.0	0.944	0.848	0.783	0.748	0.731	0.722
Gear set 4 – high contact ratio: $\varepsilon_{ad} = 2.149$, $z_1 = 27$, $z_2 = 54$, $m = 3.704$ mm, $\alpha_{wd} = 22.3°$, $\alpha_{wc} = 15.0°$								
Pinion Torque, Nm	250	500	750	1000	1250	1500	1750	2000
Contact Stress, MPa	661	820	974	1121	1253	1366	1470	1572
Pinion Bending Stress, MPa	70.0	140	210	280	350	420	490	560
Gear Bending Stress, MPa	65.2	130	196	261	326	392	457	522
Effective Drive Contact Ratio	2.25	2.3	2.33	2.36	2.38	2.40	2.42	2.44
Transmission Error, mm	1.5	2.9	4.2	5.5	6.7	7.8	8.9	9.9
Load Sharing Factor	0.655	0.648	0.643	0.639	0.636	0.634	0.632	0.630

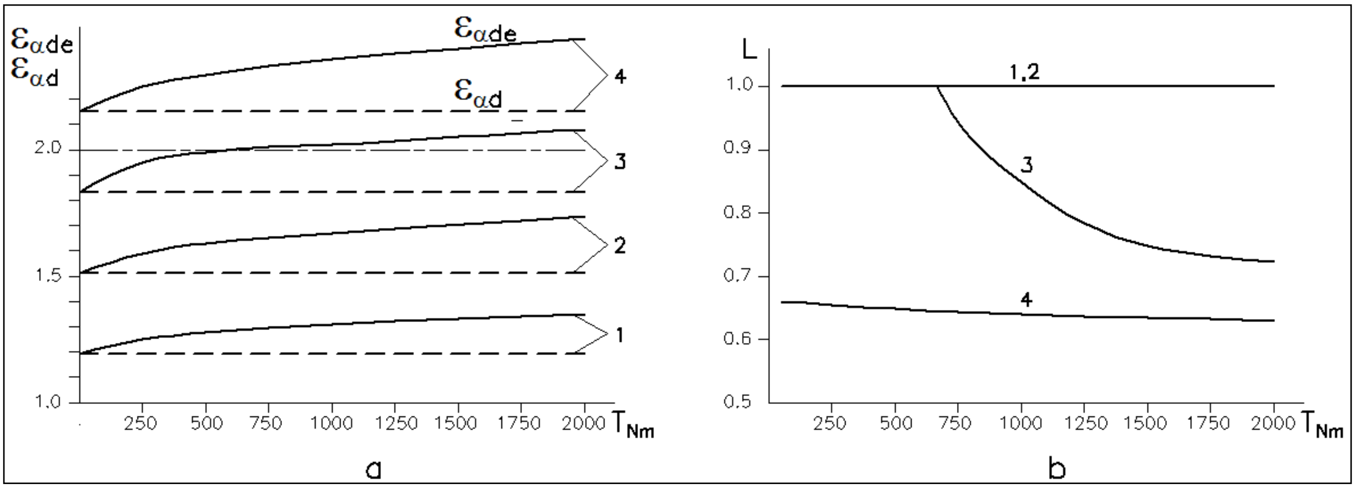

Figure 4 a) nominal and effective contact ratios; b) load sharing factor.

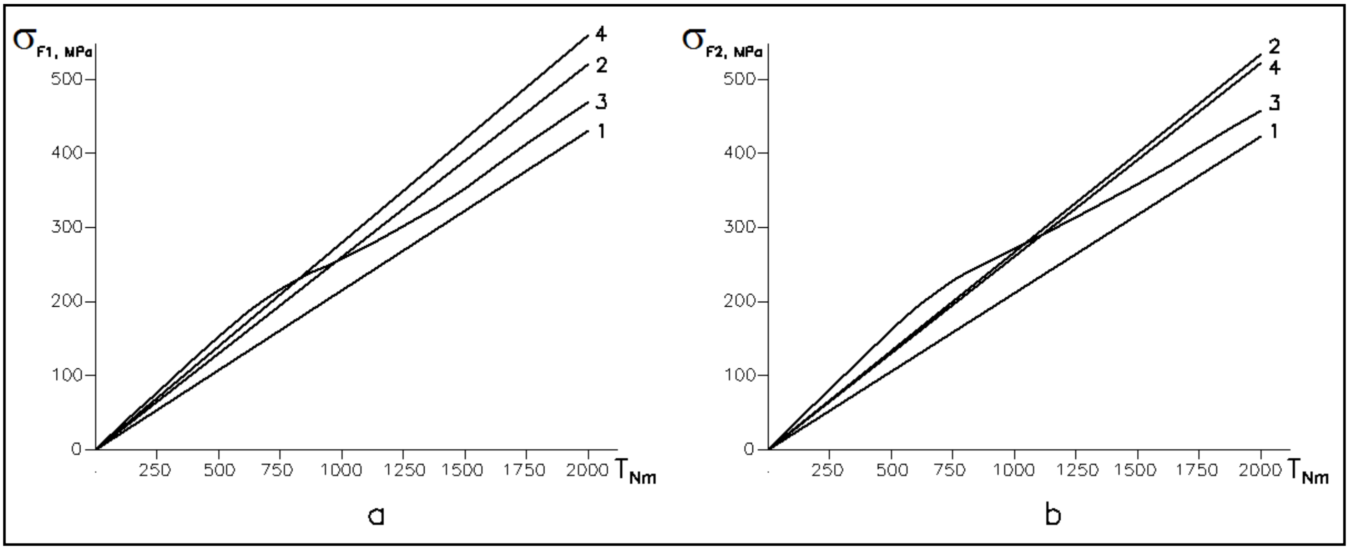

Figure 5 Pinion a) and gear b) bending stress charts.

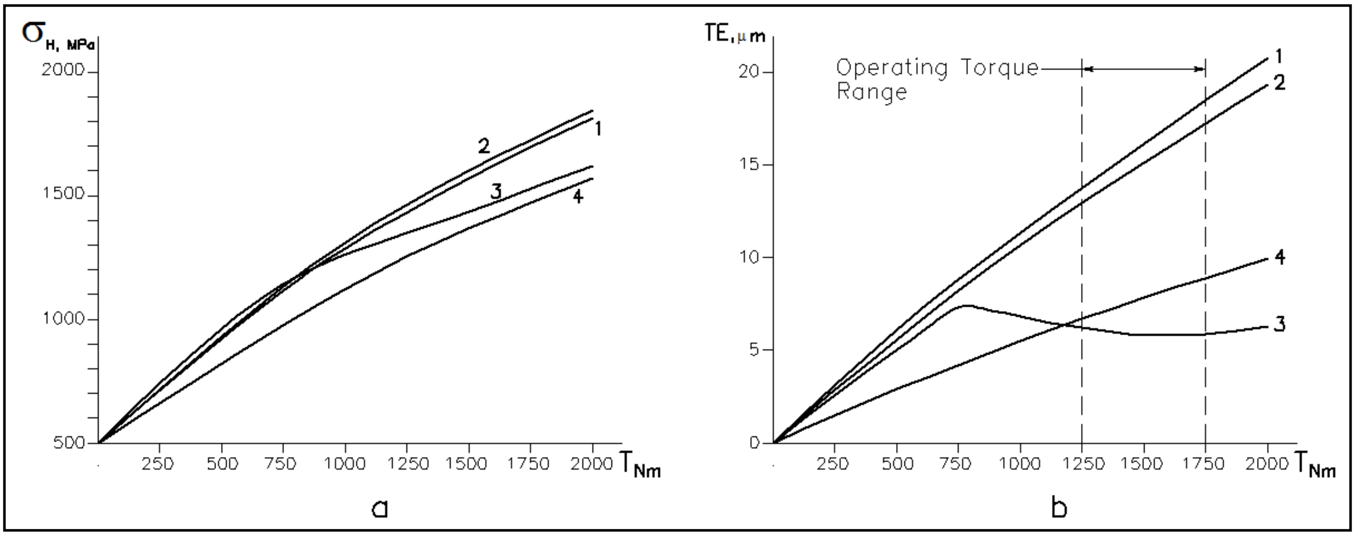

Figure 6 a) contact stress; b) transmission error.

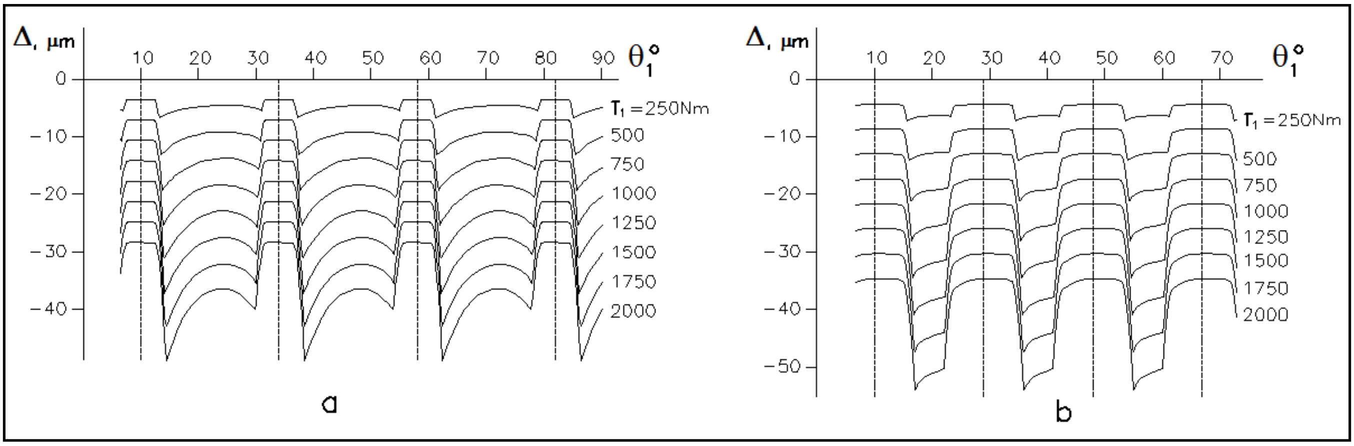

Figure 7 **Transmission error charts: a) gear set 1; b) gear set 2.**

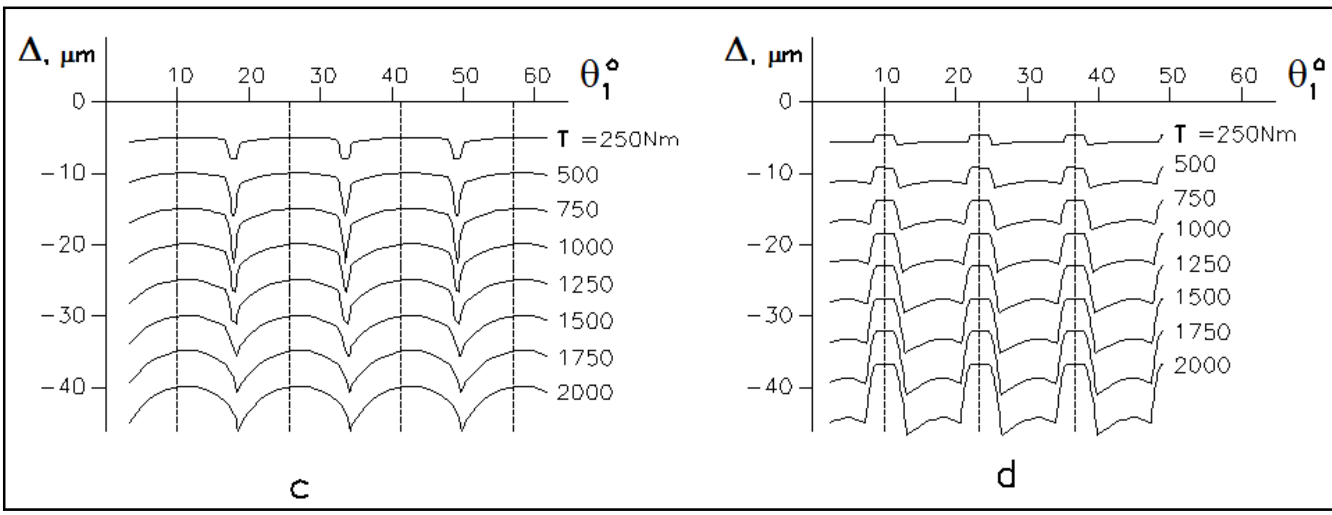

Figure 8 **Transmission error charts: a) gear set 3; b) gear set 4.**

the drive flank pressure angle reduction, the bearing load *F* is noticeably reduced, but the equalized specific sliding velocities H_s and H_t are increased because of the increased contact ratios.

Figure 3 shows the selected gear set meshes at the same scale; arrows indicate the driving pinion torque direction.

Results of the selected gear sets analysis under different driving torques are shown in the Table 2.

Main gear parameters vs. pinion operating torque for gear sets 1–4 are shown in Figs. 4–6.

Figures 7 and 8 present the transmission error charts of gear sets 1–4 at different driving torques.

The charts in Figure 6b clearly indicate that with increasing operating torque, the transmission error of gear sets 1, 2, and 4 increases as well. In gear set 3 the transmission also increases until the effective contact ratio exceeds 2.0 and the gear engagement is converted from 1–2 mating tooth pair contact to the 2–3 mating tooth pair contact. Then the transmission error of gear set 3 decreases slightly, stays flat, and then gradually increases. Within the operating torque range, gear set 3's transmission error is the lowest in comparison to the other gear sets.

Summary

The article presents an analysis of nominal and effective contact ratios of several sets of spur asymmetric tooth gears with equal maximized gear mesh efficiencies but different numbers of teeth. This analysis has defined the main gear performance parameters, including tooth bending and contact stresses and transmission errors under variable operating load, accounting for bending and contact stress deflection. It demonstrated that transitional contact ratio gears appeared to be an optimal solution within the operating load range, providing minimal transmission error, bending stress that is lower than that of gear sets with medium and high contact ratio gears, and contact stress that is lower than that of gear sets with low and medium contact ratio gears. These transitional contact ratio gears with relatively constant transmission error within operating load range are potentially good for tooth flank microgeometry optimization for additional transmission error reduction. This analysis confirms the article (Ref. 3) conclusion that gears with integer values for the contact ratio are inherently quiet, when the effective contact ratio is considered instead the nominal contact ratio.

The presented contact ratio analysis and optimization method is equally applicable and can be very beneficial for directly designed symmetric tooth gears.

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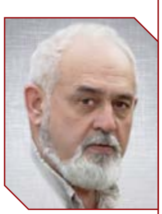
Dr. Alexander L. Kapelevich operates the consulting firm AKGears, LLC. He is the developer of the trademarked Direct Gear Design methodology and software. His areas of expertise are gear transmission architecture; planetary systems; gear tooth profile optimization; gears with asymmetric teeth; and gear drive performance maximization. Dr. Kapelevich is the author of Direct Gear Design and many technical articles, a good many of which have appeared in *Gear Technology*. He can be reached at *ak@akgears.com*.



Dr. Yuriy V. Shekhtman is an expert in mathematical modeling and stress analysis, and a software developer for AKGears, LLC. Drawing upon over 40 years' experience, he has created a number of computer programs based on FEA and other numerical methods. He is also the author of many technical publications. Dr. Shekhtman can be reached at *y.shekhtman@gmail.com*.

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Siemens Industry Inc.

PARTNERS WITH TECHNICAL SCHOOLS FOR L.E.A.P. INITIATIVE

Siemens recently announced the launch of a new workforce development program for secondary and technical schools across America called L.E.A.P. — the Lifelong Educational Advantage Program. Made available through Siemens Cooperates with Education, the effort is designed to give high school and technical school graduates a basic-to-advanced machine tool knowledge that will benefit them in their future careers as CNC (Computer Numerical Control) machinists.

Educational program

L.E.A.P. starts with Sinutrain, a PC-based, control-identical training system. This software turns any PC screen into an exact representation of the Sinumerik Operate graphical user interface. The numeric kernel (NC) that drives Sinutrain also powers the Sinumerik 828D and 840D sl controls. Comprehensive knowledge doesn't require investing in a machine, as all courses can be taught on a PC.

Through L.E.A.P., Siemens offers students and educators: PC-based training system using Sinutrain, same HMI, setup and simulation screens as actual machine controls, full basic-through-advanced CNC learning, modular content customized to curriculum, free instruction training, support and certification, hardware simulators and machine tool partners.

As part of the program, Siemens provides training courses in two machine tool disciplines: milling and turning. Each of the courses is divided into levels with pre-requisites. Each course level receives a complete curriculum, which includes both classroom and hands-on training models to increase student engagement and understanding. Upon successful completion of each level, students receive Siemens L.E.A.P. Certifications documenting the advanced skill sets needed in today's highly technical manufacturing careers.

"Currently, STEM (Science, Technology, Engineering and Math) jobs are growing at 1.7 times the rate of non-STEM jobs. Employers need graduates who are more than basic machine operators for basic parts cutting. Siemens CNC instruction best supports this career path from basic to advanced knowledge," explains Brian Hamilton, CNC education manager, Siemens Industry, Inc.

Additionally, Siemens offers the instructional content and support that technical schools require. In partnership with machine tool builders such as EMCO, Romi, Index, Knuth and others, Siemens addresses the need for skilled manufacturing labor by preparing students for a career in the job shop or production department environments.

Comprehensive understanding and higher performance

The Sinumerik CNC platform features a universal interface for rapid progression across control packages. One interface teaches students both basic and advanced CNC skills. As students learn the program and how to operate the Sinumerik 828D job shop control, they become equally comfortable in using the higher-level Sinumerik 840D sl CNC.

The Sinumerik CNC empowers more high-end machining applications than any other control technology platform in the world. Included among the CNC capabilities are universal HMI, true conversational language for operation, shopfloor programming and visual verification of the cutting cycle. All these features can be simulated on the PC seat provided with L.E.A.P.

Getting started is easy

Once an educational institution is enrolled in the Siemens Cooperates with Education (SCE) program, a site assessment will determine which L.E.A.P. program best fits participating school needs. Assistance with the installation of the Sinutrain software package, as well as scheduling for instructor training and certification, are available.

(www.industry.usa.siemens.com/topics/us/en/cnc4you/Pages/certification-program.aspx?sp_source=usdf100019)

Machine Tool Builders

HANDLES SALES AND MARKETING ASPECTS OF DIABLO FURNACES LLC

Diablo Furnaces LLC is a new start-up company manufacturing, retrofitting, upgrading, servicing and supplying parts for atmosphere heat treating equipment. Operating under the name Diablo LLC, the infrastructure has been in place for 1½ years working with Machine Tool Builders (aka MTB). Separately launching its own company, Diablo LLC has a plethora of thermal processing knowledge as many employees have worked within the industry for commercial heat treaters and OEMs.

Diablo Furnaces LLC supplies the following products and services: Tubes, elements, fans, chain guides, pushers, roller hearths, retools, catalyst, recontrol of old equipment, conversions: electrical to gas, upgrading burner systems, repair kits, water and air cooled fans, IQF – Internal Quench Furnaces, box furnaces, tempers, washers and power transfer carts.

As its sales representative, Machine Tool Builders will be handling the sales and marketing aspects of Diablo. Machine Tool Builders was chosen as the official sales representative for Diablo equipment because of its reputation for excellence. MTB currently handles representation for: Hera, a hobbing equipment manufactured in Korea by Yunil Machine; Burri BZ generative gear grinders and PM-550T profile machine for threaded and non-threaded wheels manufactured in Germany by Burri GmbH; D+P (Donner+Pfister AG) gear checking and measurement systems with the flexibility of mobility. Systems are manufactured in Switzerland by Donner+Pfister AG (aka DPAG). MTB also rebuilds, recontrols, services and repairs gear cutting and grinding equipment. (*www.machinetoolbuilders.com*)

ANCA

NAMES NEW U.S. AND CANADIAN SALES MANAGER

ANCA Machine Tools (AMT) has named **Keith Grillot** sales manager for its U.S. and Canadian markets, according to Russell Riddiford, ANCA president. Grillot has previously held key positions with ANCA.

"We have a solid core group of highly competent associates and dealers and we will continue to work hard to exceed the expectations of our customers with the highest quality machine tools and professional competence in applications engineering and service," Grillot said.

Recently, ANCA announced it is expanding its plant here by 50 percent to accommodate a greater inventory and spare parts warehouse capacity and a dedicated customer focus and training center. It will also double its machine demonstration area. (*www.anca.com*)

Gleason

ACQUIRES KISSSOFT AG

Gleason Corporation has announced that it has acquired KISSsoft AG, located in Bubikon, Switzerland. KISSsoft is a leader in the development of design software for gears and power transmission systems, serving customers globally across a wide spectrum of industries.

Gleason Total Gear Solutions — KISSsoft Calculation Programs for Machine Design

Dr. Ulrich Kissling, the founder and chief executive officer of KISSsoft, comments: "We are excited about our future partnership with Gleason. Given Gleason's mission as a Total Gear Solutions Provider, its strength in bevel gear design and its position as a world leader in gear manufacturing and metrology solutions, the potential opportunities to provide our customers with new solutions is compelling. In addition, Gleason's global reach and long-time customer relationships will open up new doors for our products."

John J. Perrotti, president and chief executive officer of Gleason Corporation, adds: "KISSsoft joining Gleason will deliver significant synergies and provide our customers greater value by linking design and manufacturing expertise, having the potential to to radically improve the efficiency of designs and the manufacturing solutions optimum for those designs. The KISSsoft team has developed a strong base of loyal customers that we look forward to serving together with KISSsoft."

The KISSsoft management team and entire staff will remain intact with an ever-greater focus on serving its customers. They are looking forward to further collaboration with customers, partners and friends. (*www.gleason.com*) (*www.kisssoft.ch*)

Klingelnberg and Starrag

ANNOUNCE COOPERATION FOR DEVELOPMENT OF GEAR MACHINING PRODUCTS

Klingelnberg and Starrag have announced that they are going to cooperate on the development of powerful products for complete machining and a joint purchasing policy.

The first innovative project that Klingelnberg and Starrag are going to implement together is the introduction of a five-axis machine for complete toothed gear machining, with which several process steps can be carried out on one machine. In this way, different manufactured parts will be able to be produced directly from bar stock in the future, which represents significant added value for the customer. The new product will be marketed under the Klingelnberg name and will be presented to the general public for the first time at this year's EMO trade fair in Hanover, which is taking place Sept. 18–23, 2017.

"We are the perfect match in terms of technological know-how and also with regard to market segments — Starrag has intensive coverage of the aerospace area, among other things, and we have a strong presence in the automotive industry, for example," says Jan Klingelnberg, CEO of the Klingelnberg Group. Whereas Starrag has the entire technology spectrum for cutting, turning, drilling and grinding of metal workpieces in its portfolio, Klingelnberg is the gearing technology specialist. This does not just include the development and production of machinery for bevel gear and cylindrical gear machining, but also the range of precision measuring centers for measuring all kinds of rotation-symmetrical components. An automatic connection can be realized between the Klingelnberg measuring technology and the production machines using the closed loop assistant system, which no other competitor on the market has. The gearing specialist's software provides a continuous digital process, which guarantees that there will be a reliable and precise production procedure from construction to workpiece.

The cooperation is going to start with joint development of the machinery. Other cooperation projects are also in the pipeline. "We have deliberately sought out the Klingelnberg Group as our partner because we have a very similar company philosophy and culture," explains Walter Börsch, CEO of the Starrag Group. (*www.klingelnberg.com*) (*www.starrag.com*)

PTG CEO Dr. Tony Bannan

APPOINTED OFFICER OF THE ORDER OF THE BRITISH EMPIRE

Dr. Tony Bannan, 52, chief executive officer of Rochdale-based Precision Technologies Group (PTG), received the OBE from HRH The Prince of Wales at an investiture at Buckingham Palace on Friday, Jan. 27, 2017.

Dr. Bannan was appointed an Officer of the Order of the

British Empire in the Queen's 90th Birthday Honors List 2016, in recognition of his services to the UK economy, international trade and inward investment.

After joining PTG company Holroyd Precision as technical director in 1999, Dr. Bannan became managing director of PTG's machine tools divisions (Holroyd Precision, Binns & Berry and Crawford Swift) in 2007. He was appointed as group chief operating officer in September 2008, and then PTG's group chief executive officer in June 2010.

Referring to his appointment, Dr. Bannan said that he was: "Very proud and humbled to be recognized with such a great honor," and that "Credit for the accolade must be given to my family, for the many years of patience and support as I've travelled the world on behalf of the business — and to the many colleagues, past and present, that I've been lucky enough to work with.

"Without the commitment, skills and imagination of the people who have worked in and led PTG — and before that, Holroyd — what has been built and exists today might never have been," he continued. "I am lucky to have benefited from a strong legacy, and I remind myself and those around me of this fact very often. It is very important to recognize our duty to successive generations."

As a further example of PTG's achievements, in 2015 Holroyd Precision was presented with the Queen's Award for Enterprise, the UK's highest accolade for business success. Holroyd received the award for International Trade, having achieved year-on-year growth in exports. This was the fourth occasion that Holroyd won the Queen's Award. (*www.ptgltd.com*)

April 19–21—AGMA Fundamentals of Gear Design and Analysis Indianapolis, Indiana. This course provides a fundamental understanding of gear geometry, types of arrangements, design principles, the basic gear system design process, and gear measurement and inspection techniques. It is designed for powertrain engineers, engineering directors and managers, component suppliers, vehicle platform powertrain development specialists, and those involved in the design and application of geared systems and assemblies. The course will be facilitated by William "Mark" McVea, Ph.D., PE. Dr. McVea is president and principal engineer of KBE+, Inc. where he and his team design and develop complete powertrains for automotive and off-highway vehicles. For more information, visit *www.agma.org*.

April 25–27—Reliable Plant 2017 Columbus, Ohio. This three-day event offers attendees learning sessions and case studies on the latest industrial lubrication and oil analysis technologies. The comprehensive conference schedule covers every facet of the machinery lubrication industry and includes workshops on topics such as employee performance, lubrication fundamentals, condition-based maintenance and maintenance planning. The 150,000 square foot exhibit hall, receptions and educational sessions facilitate networking opportunities as well as the implementation of new ideas attendees can bring back to their manufacturing facilities. Reliable Plant is focused on both entry level and management positions within the lubrication industry including engineers, plant managers, maintenance professionals, safety personnel, planners, quality managers and more. For more information, visit *conference.reliableplant.com*.

April 30–May 3—CIM 2017 Montreal, Quebec. Founded in 1898, the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) is the leading technical society of professionals in the Canadian Minerals, Metals, Materials and Energy Industries. The CIM Expo features nearly 450 companies showcasing the latest in mining equipment, tools, technology, services and products. The event includes plenary sessions intended to bring focus and start dialogue around the conference theme of "New State of MINE." Leaders from all aspects of mining and some from unexpected tangential sectors are brought together in these thought-provoking discussions. For more information, visit *convention.cim.org*.

May 1–4—Offshore Technology Conference 2017 Houston, Texas. The Offshore Technology Conference (OTC) is where energy professionals meet to exchange ideas and opinions to advance scientific and technical knowledge for offshore resources and environmental matters. OTC is the largest event in the world for the oil and gas industry featuring more than 2,300 exhibitors, and attendees representing 100 countries. Founded in 1969, OTC's flagship conference is held annually in Houston. The event provides excellent opportunities for global sharing of technology, expertise, products, and best practices. OTC brings together industry leaders, investors, buyers, and entrepreneurs to develop markets and business partnerships. Technical highlights include updates on world-class projects, offshore renewable energy, the digital revolution, safety and risk management and more. For more information, visit *www.2017.otcnet.org*.

May 2–4—AGMA 2017 Gearbox System Design Clearwater Beach, Florida. Learn the supporting elements of a gearbox that allows gears and bearings to do their jobs most efficiently. Gain a deeper understanding about seals, lubrication, lubricants, housings, breathers, and other details that are involved in the designing of gearbox systems. Gear design engineers; management involved with the design and manufacture of gearing type components; metallurgists and materials engineers; laboratory technicians; quality assurance technicians; furnace design engineers; and equipment suppliers should attend. Instructors include Raymond Drago and Steve Cymbala. For more information, visit *www.agma.org*.

May 2–4—Discover More with Mazak Schaumburg, Illinois. In addition to real-world part cutting demonstrations of the industry's most innovative machine tools—including Mazak's HCN-5000/50 Horizontal Machining Center, Quick Turn 250MSY and Quick Turn Primos 100 Turning Centers—the company will conduct seminars and training sessions centered around its Mazatrol Smooth CNC technology. Furthermore, attendees will discover how easy it is to securely enter the world of IIoT with the Mazak SmartBox. This scalable, end-to-end solution connects manufacturing equipment, including machines, software and other devices, to a factory's network and allows the free flow of information to management systems via MTConnect. For more information, visit *mazakusa.com/moremidwest*.

May 16–18—Eastec 2017 West Springfield, Massachusetts. With more than 500 exhibitors, complimentary conference sessions, industry keynotes and much more, EASTEC is an event dedicated to keeping northeast manufacturers competitive. It's where manufacturing ideas, processes and products that make an impact in the northeast region, are highlighted through exhibits, education and networking events. The event offers a unique chance to connect with resources that can solve your company's most pressing problems, improve productivity and increase profits. This year's show includes in-depth workshops that explore several management topics as well as information on additive manufacturing. The Smart Manufacturing Hub examines IIoT, 3-D printing, and the latest automation technologies. For more information, visit *www.easteconline.com*.

May 23–25—Fundamentals of Parallel Axis Gear Manufacturing Pheasant Run Resort, St. Charles, Illinois. Koepfer America's Gear School is designed for entry-level gear manufacturing personnel. Attendees include manufacturing management, industrial engineers, supervisors, set-up personnel, operators and quality control. The seminar is an intensive three-day program with a limited class size of 30, providing an optimum learning environment. The seminar fee includes a workbook, miscellaneous materials and demonstration of current gear manufacturing equipment. Transportation to and from the demonstrations and plant tours will be provided. Seminar Fee: $975 per person, includes meals. Price of hotel room is not included in seminar fee. For more information, visit *koepferamerica.com/education*.

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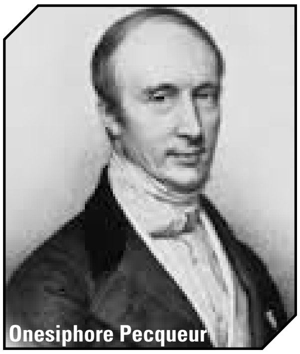
Jack McGuinn, Senior Editor


Onesiphore Pecqueur

Your automobile's differential is easily one of its most important components. This becomes crystal-clear to anyone that has ever had to pony up to replace one. The differential, that mathy-driven, mechanically complex system that keeps axles and pinions running smoothly was invented by — a watchmaker — for a watch.

The watchmaker was Onésiphore Pecqueur — former farm boy, apprentice, and master watchmaker. Now, almost 75 years after his death, Pecqueur is the inspiration for a new timepiece under development — or "concept watch" — available from the semi-eponymous Pecqueur Conceptuals, a nichey-techy, boutique design shop. As posited on their website (*pecqueurconceptuals.com*):

"Through the differential, a watchmaker contributed significantly to the development of the automobile. The invention of the differential in the 19th century was the first technological bridge between watchmaking and automobiles. Today, the link between these two worlds of sophisticated mechanics continues. Pecqueur can take the credit for being at the origin of this crossover."


A 21st century version of Onesiphore Pecqueur's differential. Photo courtesy Pecqueur Conceptuals.

The watch is to be designed — fittingly — by the Peugeot Design Lab in France and made by Swiss-based Noosphaire under the Pecqueur Conceptuals label.

It was 1827 that Pecqueur, as a watchmaker, filed a patent for what would prove to be a key element in the development of the automobile. Realizing that wheels on an axle do not rotate in unison, he invented a mechanical differential based on watchmaking. This key element enabled the adjustment of the rotational ratio of two wheels on the same axle when turning. So the case can be made that Pecqueur was indeed the first automotive engineer.

Pecqueur was a mechanical — and mathematical — genius. Indeed, it was during his apprenticeship in Paris that he realized neither his master or fellow watchmakers made sufficient use of mathematics, which he believed was essential to improving mechanical movements and, in particular, smooth-functioning of gears.

Patent in hand, in 1828 Pecqueur devised the "next big thing" — the differential. Unfortunately, Pecqueur was seemingly the only one aware of its significance. It wasn't until some 50 years later that his technique would be practically realized by Amédée Bollée — then one of the world's leading automobile engineers — at Le Mans. According to the Pecqueur Conceptuals website "Pecqueur's differential in the 19th century was the first technological bridge between watchmaking and automobiles."

Prior to the differential, Pecqueur in 1820 presented his 'regulatory pendulum' for adjusting watches. He did this by equipping a deregulated timepiece with a pendulum gear so as to form a mechanical equation. The watch thereby acquired the normal motion of the regulatory pendulum and showed the correct time. The Academy of Sciences celebrated the quality of his work and presented him the gold medal during France's 1823 National Exhibition of Industry. On this occasion, the watchmaker Abraham Louis Breguet, whose inventions and fame led France to become the benchmark of European watchmaking, publicly congratulated Onésiphore Pecqueur.

In addition to the differential, Onésiphore Pecqueur's genius led him to develop a new arithmetic applicable to mechanics and thus find new ways to add or subtract movements while maintaining equality. He thus invented the regulatory processes of mechanical equation.

Absent any training or mentoring, Pecqueur was left to base his ideas using a wooden family clock that more or less accurately marked the hours and minutes. He began to imagine and build new mechanisms that would enable his clock to not only indicate the hours, but also the days of the week, month, lunar phases and zodiac signs. With this first creation, watchmaking became his life and his passion never left him. And so Pecqueur left Pas-de-Calais to study and perfect his art in Paris with a renowned master watchmaker.

A year later, Pecqueur was appointed workshop foreman at the prestigious Conservatoire des Arts et Métiers in Paris. His imagination and creativity took off in this hotbed of creativity. Not a semester went by without him revealing something new: a rotary steam engine — ancestor of the rotary engine; a plan for an atmospheric railway; an artesian water pump; a mechanism for making fishing nets in a single operation; a water circulation cooling system; a dynamometer; and a sugar beet refining processor — which he industrialized in his own factory.

Pecqueur was a prolific inventor and a visionary whose theories quickly led to practical applications. By focusing on mechanical movements, Pecqueur was in step with the vanguard of the first half of the 19th century that marked the beginning of the railway and the use of the steam engines. Pecqueur died in Paris in 1852. He was 60 years old. (Sources: *Encylopaedia Brittanica [brittanica.com]*; *Pecqueur conceptuals.com*; *Wikipedia.com*.)

First-Time Heat Treater Streamlines Production, Reducing Lead Times by Nearly 85%

Customer Story

A manufacturer of Aerospace-grade fasteners wanted to streamline their production process and shorten lead times while still keeping costs low. They realized that to meet their objectives they needed to bring heat treatment in-house.

While the decision to bring heat treatment in-house made sense, this would be their first vacuum furnace. Ipsen's TITAN® product line appealed to them as it was built on the principle that everyone can be heat treater, whether you are new to the industry or an expert. As such, all TITAN furnaces are carefully designed and crafted with the end user in mind.

"We used to send our products to a local heat treater before bringing them back in-house to finish the production process ... In the end, this strategy just wasn't working for us. It created long lead times and a convoluted in-house workflow that simply wasn't sustainable."

However, they not only needed a heat-treating system that could run their required processes, but also a company that had the resources to support them throughout the process. This included assistance with on-site installation, expert training and timely field support. In the end ...

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