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NOV/DEC 2015

STATE OF THE GEAR INDUSTRY

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ANNUAL BUYERS GUIDE

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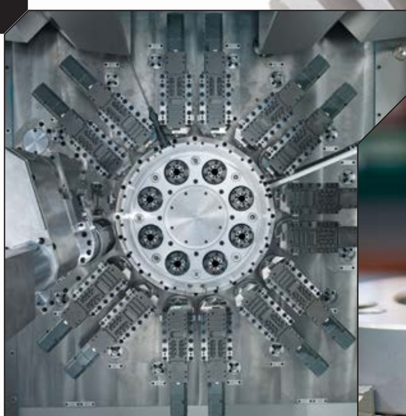

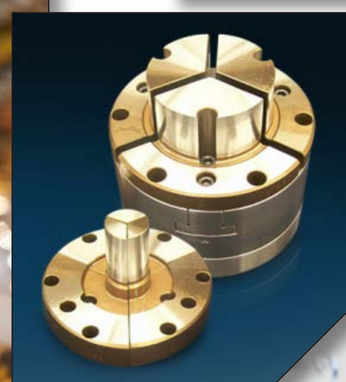

STATE OF THE GEAR INDUSTRY ISSUE

features

technical

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gear TECHNOLOGY

Vol. 32, No. 8

departments

THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

Ask the Expert Live

Gear Technology conducted four live sessions of "Ask the Expert" at Gear Expo 2015 in Detroit. Dozens of gear-related technical questions were asked and answered during the show. The sessions were centered around four topics:

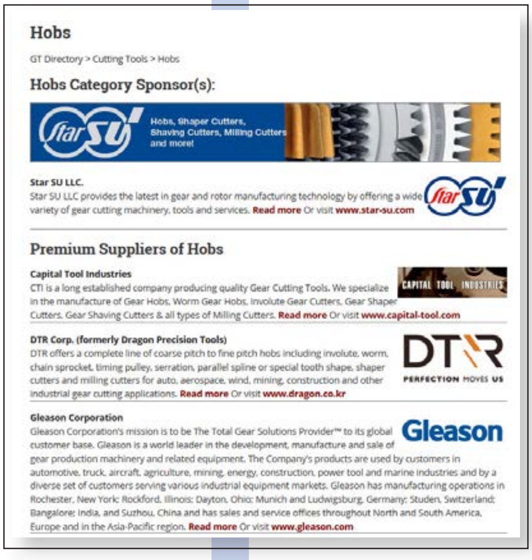
- Gear Grinding
- Cutting Tools
- Gear Design
- Ask Anything

Visit *www.geartechnology.com/videos* to watch the recorded sessions

Buyers Guide – There's Way More Online

This issue includes our printed Buyers Guide for the gear industry, but there's only so much room in the printed magazine. The online listings are broken down into hundreds of subcategories, and many of the companies in our industry have enhanced listings with complete company and product descriptions, along with photos. Visit our website to view the most comprehensive directory of gear industry suppliers available.

www.geartechnology.com/dir



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Gleason Corporation
Gleason Corporation's mission is to be The Total Gear Solutions Provider™ to its global customer base. Gleason is a world leader in the development, manufacture and sale of gear production machinery and related equipment. The Company's products are used by customers in automotive, truck, aircraft, agriculture, mining, energy, construction, power tool and marine industries and by a diverse set of customers serving various industrial equipment markets. Gleason has manufacturing operations in Rochester, New York; Rockford, Illinois; Dayton, Ohio; Munich and Ludwigsburg, Germany; Studen, Switzerland; Bangalore; India, and Suzhou, China and has sales and service offices throughout North and South America, Europe and in the Asia-Pacific region. **Read more** Or visit **www.gleason.com**

Looking for Gear Manufacturers?

Are you a gear or gear drive buyer? Listings of suppliers of gears, gear drives and many other types of mechanical power transmission components can be found online at *www.powertransmission.com*. Find comprehensive listings of gear manufacturers around the world.

If you *SELL* gears or gear drives (or other mechanical power transmission components), getting listed on powertransmission.com is fast, easy and free. Just visit *www.powertransmission.com/getlisted.php*

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(And a Little Mistletoe)...
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The Christmas Season reminds us to pause and give thanks for the many gifts we've received throughout the year. We're blessed with great customers and a skilled and dedicated family of employees – and the joy that comes from doing good work in the business we love.
We look forward to helping you achieve all your gear desires in 2016.

Meeting of the Minds

Publisher & Editor-in-Chief
Michael Goldstein

One of the great benefits of Gear Expo for us here at *Gear Technology* is the opportunity to meet face-to-face with many of the people who, in one way or another, contribute to our success throughout the year. After all, our success is dependent almost entirely on information and the people who provide it. These contributors include researchers at top technical universities, the heads of technology at major gear industry corporations, independent consultants with decades of gear industry experience, members and volunteers at leading industry organizations like the AGMA, our technical editors and others. These are the people who facilitate the continuing education of the gear industry. They are the knowledge providers who give you the tools you need to make better gears, more efficiently, and at higher profit. Very often, we are able to give you the advantage of their knowledge and experience through the articles in our magazine.

During Gear Expo, we were pleased to host a dinner for many of these contributors. The guest list was a veritable Who's Who of the intellectual gear industry. As one attendee commented, "Never in my 46 years of being in the gear industry have I been a part of a group as experienced and knowledgeable about the design and manufacture of gears—ever."

More importantly, the event provided a very informal, social environment for people from different (and sometimes competing) organizations to spend time with one another and share ideas. The attendees all knew *of* each other, but they didn't necessarily all know each other. But now they do, both prefessionally and personally. Gears were certainly discussed, but so were a wide variety of other topics, in multiple languages, all at the same time. Perhaps the greatest measure of this event's success was that throughout the dinner, every time I looked up, everyone was engaged in lively conversation.

For a short time, anyway, I felt like I was at the center of the gear universe.

Creating and maintaining contacts like these helps us continue to fulfill our role as "The Gear Industry's Information Source."

Another way we build on that role is by continuing to expand our information offerings to you, the gear community. At Gear Expo, we did so by presenting the first ever live and in-person sessions of "Ask the Expert." At our booth, we hosted four sessions, with three or four renowned experts in each session. The topics were "gear grinding," "cutting tools," "gear design" and "ask anything."

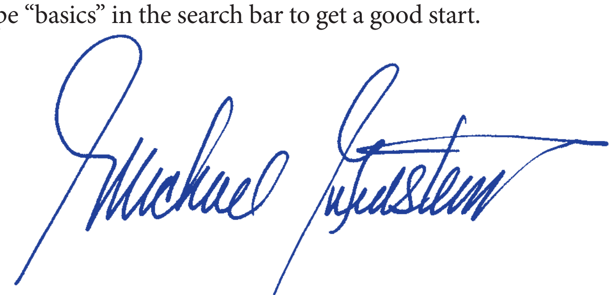
Some of the foremost authorities in the world were among our experts during the live sessions, and they attracted a crowd to our booth throughout the show. Even though I've been in the gear manufacturing industry for more than 50 years, I was delighted by the expertise of the presenters and the sophistication and depth of their responses. Many of our panelists are only available during a show like this on a very limited basis, often only to the largest of customers. To have them all together and be available to the industry at large was truly a first in our industry. Please see the article on page 92 for a rundown of the sessions, including the names and titles of the panelists, the questions asked and where to go online to view each of the video-recorded sessions.

The excitement we carried back home from Gear Expo was about more than just our own experiences at the show. Even outside our own activities, it was one of the best shows in recent memories. Foot traffic was good, and many exhibitors reported that the attendees came to the show with specific requirements, and orders were received. We heard similar reports out of EMO in September. So the anecdotal evidence, at least, points to a reasonably healthy gear industry for the immediate future.

The empirical evidence might be a little more mixed, as you'll see in our annual State of the Gear Industry survey results (page 26). As many of you are aware, there are major segments of the gear manufacturing community—namely mining and energy—that are less than robust, while others—like automobiles and aircraft—are rolling along like a precision ground gear. According to the survey results, the American gear industry seems to be in decent shape, with the overall level of optimism about the same as last year.

But there are pockets of trouble, to be sure. In particular, our respondents outside North America were decidedly more pessimistic this year, and many respondents continue to express concerns about the difficulty in finding skilled labor.

We'll continue to do our part by continuing to provide as much educational material as possible, in as many formats as we're able. How can you help assure this information keeps flowing to you and your associates? You can do your part by renewing your *free* subscription. Just visit *www.geartechnology.com* and click on "Subscribe" in the upper-left corner, and encourage all of the young and new people in your organization to do the same. Make sure they're aware that more than 31 years of gear-related education is available on our site for free, including our very popular "Back to Basics" series we ran in our first five years, explaining the mechanical interrelationships of tools and machines. Just type "basics" in the search bar to get a good start.



Buderus Schleiftechnik Dry Grinding Process

MORE ECONOMICAL DUE TO INTELLIGENT CONTROL OF HARD TURNING

Following the emergence of dry machining in the green manufacturing of high-precision metal components as the accepted technical standard to a major extent over the past few years, there are growing incentives to implement this method in grinding processes for hard finishing as well.

Cost savings and production operations more compatible with the environment are crucial arguments in favor of further development work in this segment. Yet is it possible to banish the risk of overheating during grinding and soiling caused by grinding dust in the machining chamber at all, and what can be done to combat the high level of tool wear? The technology experts at Buderus Schleiftechnik GmbH have developed a method that makes dry grinding even more economical due to the intelligent control of hard turning and grinding machining.

Machining metallic workpieces without cooling lubricant is already common practice in the field of green manufacturing. Complex filter systems, energy-intensive pump systems, the environmentally sound disposal of used coolants and the strain on operators' health in the direct machining environment are all negative factors that suddenly ceased to exist with this development. In the hard finishing segment, hard turning is the only process that can do without coolants to date. Until just recently, there had been no significant dry machining breakthroughs for grinding and other combined operations with demanding quality standards in the µm range. The risk of overheating during grinding, the clogging of grinding tools, greater heat dissipation and dust development that is difficult to get under control in the machinery compartment, as well as exploding tool costs, posed great challenges to the development departments of mechanical engineering companies.

In Asslar in central Hesse, engineers have been working on how to "dry out" hard finishing processes for quite some time. In several extensive series of tests on the synchronizer cones of toothed wheels in a passenger car gearbox, the engineers at Buderus Schleiftechnik have been able to take a step towards process maturity and keep tool costs within reasonable limits thanks to an intelligent combination of hard turning and conventional grinding.

To combat the high wear on the grinding tool, it makes sense to shorten the actual dry grinding process, which in turn keeps the thermal load for grinding wheel and workpiece at a low level. Accordingly, the objective is to use hard turning to reduce the grinding stock allowance beyond the usual level for wet machining in order to achieve the necessary surface quality and dimensional stability through final grinding. Leaving the grinding process out of the consideration altogether was never an option, since requirements of $Rz < 3$ µm and $Ra < 0.25$ µm cannot be achieved economically under series conditions through pure hard turning. The grinding machine used for the series of tests is a CNC335 from Buderus Schleiftechnik that has outstanding thermal, static and dynamic rigidity properties. A CBN-coated turning tool is used for the turning process. Dry grinding is done by a conventional sintered corundum grinding wheel made by Naxos- Diskus Schleifmittelwerke which, like Buderus Schleiftechnik, is a member of the DVS Group.

In order to solve the grinding dust problem, the dust is blown out of the grinding gap by a compressed air nozzle during machining. The air cools the machining spot at the same time. A dedicated extraction unit collects the dust directly where it is produced and thus avoids heavy soiling in the machinery compartment. Where dry grinding is

used, cooling lubricants are not required either. This is a cost factor that is often underestimated.

The various dry hard finishing processes introduced by different gearbox manufacturers up to now are convincing in many respects, but there is a certain amount of dissatisfaction among the users particularly on account of the high tool costs. For optimum matching of the hard turning and grinding processes to reduce tool costs, Buderus Schleiftechnik has developed an intelligent grinding stock allowance control which uses solid-borne sound sensors. The solid-borne sound sensor signal is transmitted without contact from the rotating grinding spindle to the measuring electronics. After turning, the residual machining allowance during grinding is measured by the solid-borne sound sensor. Technicians are walking a thin line when it comes to determining the optimum residual machining allowance, however. Whereas visible turning grooves must still be expected if the allowance is too small, an excessively large allowance will draw out the grinding process too much, increasing the risk of overheating during grinding and wear on the grinding tools.

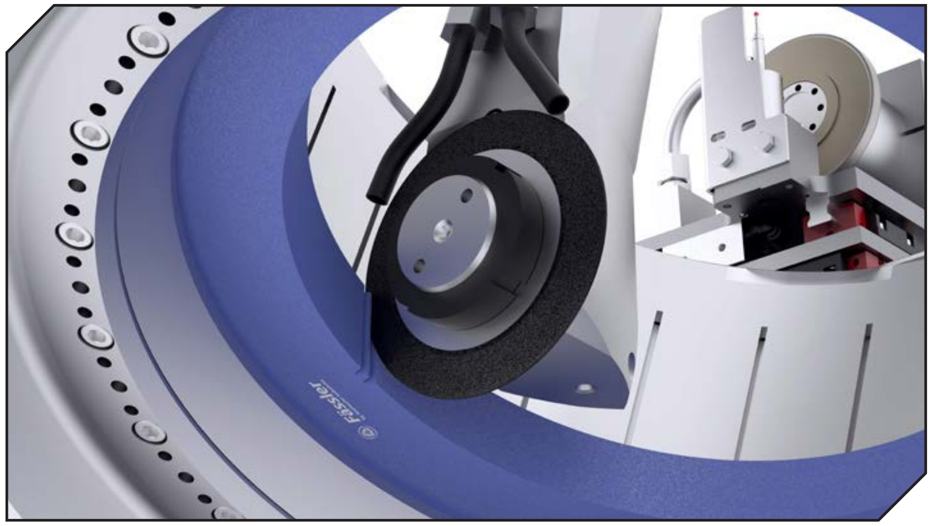
Accordingly, it is important to determine the optimum grinding stock allowance during systematic tests before starting production. The multiple integrated measuring procedures make the method process-reliable. The actual dimension is read out during the first cut and compared with target dimension ± tolerance. In the event of any deviation, the turning process is corrected accordingly for the very next workpiece. Correction limits and damping can be adjusted in addition. This guarantees process-reliable adherence to dimensions and surfaces.

The cone of control gears is often interrupted. This makes special demands on the process. For this reason, a somewhat higher residual machining allowance must be selected to achieve process stability. Burr on the interrupted edge can be prevented by changing the direction of rotation between hard turning and grinding.

After one series had been ground, Cm values of 3.1 were achieved for the cone diameter and Rz values between 2 and 3μm. The circularities were consistently less than 1.5 μm and thus lower than the usual 3 μm requirement. The structure of the unmachined and machined synchronizer cones were examined in order to investigate the heat input into the edge zone of the hardened workpiece. Longitudinal and lateral samples were taken from both the machined and the unmachined synchronizer cones and examined. All the points examined reveal a martensitic structure and a residual share of austenite in the carburized edge zone. It was thus proved that no edge zone damage is caused by overheating during the grinding process (Figures 5, 6).

The development at Buderus Schleiftechnik shows that dry machining can be offered as a cost-saving and more environmentally compatible alternative to conventional wet-machining processes.

For more information:
Phone: +49-69-24 00 08-77
www.dvs-gruppe.de



Fässler HGP-400 Honing System

DESIGNED FOR SMALL BATCH SIZES

At Gear Expo 2015, Fässler by Daetwyler Industries unveiled the new Fässler HGP-400 gear honing system, a gear honing machine that purports to be designed for "batch size one," bringing gear tooth honing to job shops and other smaller production run environments.

Previously, gear tooth honing required the use of an expensive diamond dressing gear to transfer the necessary geometry for a part onto the honing stone. This made the process economically feasible only for larger batch sizes. The HGP-400, however, uses a commercial, dressable grinding wheel to transfer the geometry to the honing stone.

According to company literature, the new technology reduces process development time from several weeks down to just a few days, as corrections can be carried out and transferred to the honing stone much more quickly than if a new diamond dressing gear were required for each iteration.

The HGP-400 is capable of honing workpieces with internal or external teeth, using either a single-flank or double-flank honing process. Also, the machine is capable of profile grinding, and it can accomplish both gear tooth grinding and honing in a single setup.

The machine can accommodate workpieces with modules from 0.5 – 6. It is capable of external honing workpieces from 20-270 mm diameter, and internal honing from 50-350 mm diameter. The profile grinding range includes workpieces from 20-320 mm for external grinding and 50-380 mm for internal grinding.

For more information:
Fässler by Daetwyler Industries
13420 Reese Blvd. West
Huntersville, NC 28078
info-usnc@daetwyler.com
daetwyler-usa.com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BCG-Minweight Software

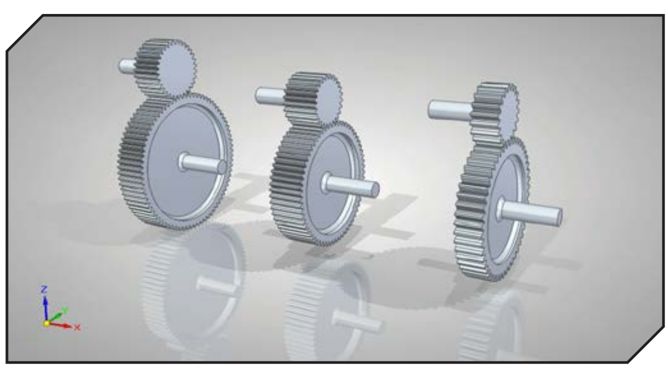
OPTIMIZES GEAR DESIGNS FOR SIZE AND WEIGHT

A new software tool specifies basic parameters for gear designs in order to optimize for size and weight. By providing inputs for design ratio, power and input RPM, along with contact and bending stress parameters, a set of design outputs can be generated that specify center distances, face widths, normal diametral pitches, pitch diameters and numbers of teeth.

Additional controlling factors used in the *BCG-MinWeight* optimization process include pitch-line velocity, face width to pitch diameter ratio, web thickness, housing weight, planetary carrier weight and others. Additional outputs include estimates for actual contact and bending stresses, pitch line velocities, load distribution factors, dynamic factors and AGMA quality levels.

The primary goal of *BCG-MinWeight* is to maximize the fidelity of initial designs so that size and weight estimates can be accurately defined before the center lines are established and the gear ratios are locked down. It's relatively easy to change design parameters such as pressure angles or face widths during the development process, but it's much more difficult to change reduction ratios and center distances after the preliminary design concept has been approved.

Another reason for using *BCG-MinWeight* is to establish optimal ratio splits for complex configurations that involve more than one mesh. Modules for two-stage and three-stage systems along with idler, planetary, star and reverted geartrain configurations have been developed. In complex gearbox systems, such as those in wind turbines, a sub-optimal split of the ratios in the gearbox can result in literally thousands of pounds of excess weight in the final design. Additionally, existing designs that are sub-optimal may benefit from the optimization process by re-specifying the diametral pitches and tooth counts in order to increase power capacity without adding weight.



For those companies who have developed gear materials and processes that result in improved properties and wish for them to be incorporated into new customer designs, *BCG-MinWeight* can be used to justify their use by quantifying reduced size and weight. In the accompanying illustration, three designs are shown, which utilize properties from AGMA Grades 1, 2, & 3 gear steels. All designs are specified to transmit 250 Hp through a single-stage reduction ratio of 2.5 with an input rotational speed of 2,000 rpm. For the three AGMA grades of steels using the carburization process, appropriate allowables for contact and bending stresses would be:

- Grade 1 – 180 ksi contact and 55 ksi bending.
- Grade 2 – 225 ksi contact and 65 ksi bending.
- Grade 3 – 275 ksi contact and 75 ksi bending.

The results of the optimization process reveal the following:

- Grade 1 – center distance = 6.813", estimated gear weights = 41.9 lbs.
- Grade 2 – center distance = 5.500", estimated gear weights = 29.5 lbs.
- Grade 3 – center distance = 5.583", estimated gear weights = 21.0 lbs.

The results indicate that the potential exists to reduce the overall weight of the specified design by 50 percent by using a Grade 3 material instead of a Grade 1 material.

For more information:
BC Gear & Engineering, Inc.
Phone: (517) 375-0238
bcgearengineering@gmail.com



NTX 1000

Index New CNC Multi-Spindle Lathe MS16 Plus

HAS A TOTAL OF 27 NC AXES

Designed to supplant cam-controlled multi-spindle lathes up to 22 mm bar diameter, the new Index MS16 Plus of the Index MultiLine series includes six CNC spindles for up to 22 mm diameter parts, accomplishing turning, drilling, milling, tapping, deep hole drilling or slotting in each of its six spindle positions. Workpieces are automatically indexed through the six positions, receiving two or more operations at each position. The result is high production of precision turned workpieces.

The 27 NC axes of the MS16 Plus include five NC grooving or boring slides, five NC cross-slides, one NC cutoff and/or back-boring slide, six work spindles and one NC synchronous spindle, drum indexing plus an additional five free NC axes of possible CNC-controlled auxiliary equipment are controlled by an Index C200-4D CNC.

The compact Index MS16 Plus provides the speed of a cam-controlled machine with the flexibility of CNC technology yet requires no more floor space than a cam-controlled multi-spindle machine. In addition, the MS16 Plus offers high ease of setup and more versatile machining options compared to cam-controlled machines.

Each of the six spindle positions can include a stable grooving or boring slide with one NC axis and a cross-slide with two NC axes (X- and Z-axes) that are arranged around each work spindle in a V-shape, allowing easy use of several tools simultaneously on each work spindle.

The NC-controlled synchronous spindle for gripping the workpiece and an NC cutoff and back-boring slide provide optimal conditions for efficient production of turned parts with simple to medium complexity and up to approximately 70 mm length.

The speed of each of the six spindles can be controlled separately. Spindle speeds can be varied during cutting for each spindle position and each cutting edge of the tool. Speed changes and positioning of the spindles are possible even during spindle drum indexing, avoiding secondary processing times. Additional advantages include maximum surface quality, short production times per piece, and extended tool life.

For rear end machining, the MS16 Plus is equipped with a synchronous spindle driven by a hollow-shaft motor allowing speeds up to 10,000 rpm and which can move 140 mm in Z at 30 m/min to engage several rear end machining tools on the NC cutoff slide with the X- and Z-axis in succession more quickly. To achieve the shortest cycle times possible, the synchronous spindle accelerates to a maximum of 10,000 rpm in less than 0.7 s.

For more information:
Phone: (317) 770-6300
www.indextraub.com

Riten Heavy Duty Spring-Loaded Live Center

AUTOMATICALLY COMPENSATES FOR THERMAL COMPENSATES

This center from Riten Industries is capable of adjusting the load on the workpiece. Utilizing Bellville washers, it automatically compensates for thermal expansion. Three color-coded rings illustrate the pounds of axial force that is being applied. This is beneficial when the tailstock on the lathe or grinder cannot display the required clamping pressure for accurate machining.

The center is offered in 3 to 6 Morse taper, in standard and tracer point. Maximum axial loads range from 1,150 to 5,600 lbs. RPM up to 4000, and weight of workpiece up to 7600 lbs. Accuracy guaranteed to ±.0001.

For more information:
Phone: (740) 335-5353
www.riten.com

Adcole Model 1310S Inline Camshaft Gage

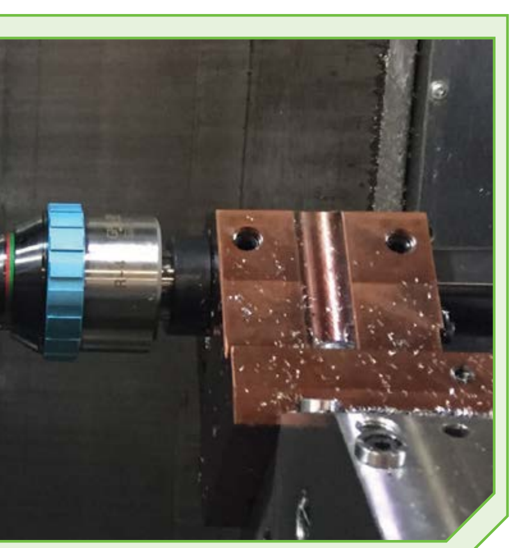
FEATURES SUB-MICRON ACCURACY

Adcole Corporation recently introduced a new high-speed, fully automated end-of-line camshaft measuring machine that features sub-micron accuracy and sub 25 second cycle times.

The Adcole Model 1310S Inline Camshaft Gage can measure up to 28 features including lobes, journals, chatter, and timing references with sub-micron accuracy and repeatability. Designed to be gantry or robot fed for 100 percent end-of-line inspection, this high-speed gage is fully automated to maintain the production machining process for up to 200 parts per hour in real-time.

Incorporating proprietary follower modules capable of 3,600 data points per revolution per follower, the Adcole Model 1310S Inline Camshaft Gage has an adjustable tailstock and headstock which engages all follower modules simultaneously. To assure high reliability, there are minimal moving mechanisms, and the menu-driven software provides instant data collection.

For more information:
Phone: (508) 485-9100
www.adcole.com



Heller 5-axis Machining Center

PROVIDES REDUCED SETUPS, HIGH PRECISION

The recently introduced CP 4000 series horizontal machining centers accomplish horizontal, vertical and tilted turning with A and B axes with high dynamics and chip removal rates. Designed for a wide range of applications, the five-axis mill/turning center CP 4000, equipped with PCU 63 swivel head unit and HSK-T 63 spindle taper, has a work area of 800/800/1,045 mm (X, Y, Z).

With 44 kW power, 242 Nm torque and up to 10,000 rpm spindle speed, the CP series achieves complex mill/turning operations, precise control of speed and acceleration and variable adjustment to achieve workpiece-specific precision and surface finish.

The CP 4000's machine concept is designed for turning operations, using a fifth axis provided by the tool. Vertical and horizontal turning operations of outer and inner contours can be accomplished with the C axis and optional A and B axes.

Common to all Heller machine tools, the CP 4000 enables productive cutting using economically efficient cutting parameters. High cutting performance is achieved due to the stiff swivel-head geometry, torsional stiffness and form fit provided by a spindle locking feature.

When the workpiece must be rotated against the tool, the rotary table with direct torque drive delivers the required power and speeds up to 1,000 rpm. To identify imbalances on the workpiece or the rotary table, Heller developed a machine function which uses internal drive signals to identify even the slightest imbalances on the workpiece, enabling precise centric clamping. A specially defined user interface supports the operator in correcting imbalances. For turning tools, Heller additionally offers a standard tool measurement system using tactile sensors. The CP 4000 is typically equipped with Siemens Sinumerik 840 Dsl control.

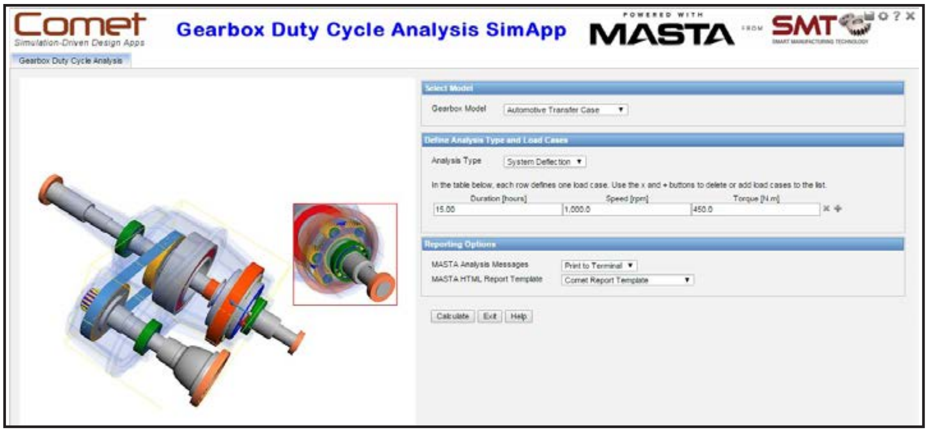
For more information:
Phone: (248) 288-5000
www.heller-us.com

Comet's New Cloud-Based Gearbox Durability SimApp

WILL PROVIDE MANY AUTOMATED PROCESSES

Comet Solutions, Inc. recently announced a program in support of gearbox design and manufacturing. The Comet Gearbox solution, consisting of a suite of solution-specific Gearbox SimApps, will provide automated processes integrating the broad spectrum of tools frequently used throughout gearbox development: CAD, FEA, multibody dynamics, gear/bearing simulation and CFD in order to predict and optimize performance in the areas of acoustics/vibration/dynamics, durability/reliability, efficiency and management of cost and weight.

"This program reaffirms our commitment to the drivetrain industry in general and gearbox design and manufacturing specifically," said Comet Vice President Steve Brown. "Earlier we announced a working partnership with renowned gearbox authority, Brian Wilson and his company, Advanced Drivetrain Engineering & Technology (ADET). Today we are pleased to announce a strategic partnership with SMT, a leader in the gear and bearing simulation industry. We will be featuring the Gearbox Durability SimApp at Gear Expo 2015 with others to follow. Over the coming months, Comet will deliver a complete suite of Gearbox SimApps along with related products and services."



For more information:
Phone: (513) 588-2773
www.cometsolutions.com

Developed in cooperation with ADET (Advanced Drivetrain Engineering and Technology) and utilizing SMT (Smart Manufacturing Technology) MASTA, Comet's new Gearbox Durability SimApp will provide gearbox OEM companies the means to perform basic durability evaluations of various gearbox system designs.

By loading a specific duty-cycle into the Gearbox Durability SimApp, they will be able to run an automated durability analysis of the entire gearbox system, including the effects of housing, shaft and bearing deflections. Often, during early design stages, gearbox OEMs do not always have specific details regarding how customers will use their products in the field. The non-engineering staff will have the ability to demonstrate durability performance to prospective customers by entering custom duty cycles representative of actual field usage, independent of their internal engineering staff. This new SimApp allows quick turn-around time regarding product capabilities, empowering gearbox OEMs in the market, while also providing feedback to the engineering team for refinement of future designs.

"We are anticipating some exciting new avenues for our CAE software to be delivered with our new strategic partner Comet Solutions," said SMT Technical Director Euan Woolley. "Pairing both our expertise by hosting durability simulation features in the Gearbox Durability SimApp will open up powerful MASTA functionality to a wider user base of engineers and ultimately drive smarter decision making within the industry. We look forward to the possibilities this partnership will bring."

2015 State of the Gear Industry

From the Economics to 4.0 — Industry Leaders Have Their Say

John Perrotti, CEO, Gleason Corporation

The global market for manufacturing, on balance, is fairly weak. Slowing growth in China and other emerging markets, weak sectors such as oil/gas, mining and agriculture create some headwinds in the market.

The general trend for quieter and stronger gears continues. Hence, hard finishing processes are in high demand. Power skiving, as a process technology, continues to grow in its use – not just with dedicated machines, but also on machining centers of various types. Nevertheless, the technology requires very stable machines, simulation tools, precise cutting tools and process knowhow to become successful.

Another trend that continues to gain momentum is the digital factory, as manufacturers explore how they can use data in a real-time environment to optimize their designs and manufacturing processes. Also, factory automation of all types continues to grow in popularity to reduce idle times and combine operations.

In 2015, Gleason Corporation celebrated an important milestone in its history: We have now been serving the gear manufacturing industry for 150 years. We have had the opportunity to celebrate this great achievement with our customers and employees at special events as well as major trade shows throughout the world.

We also took this opportunity to further invest in technology to extend our leadership in a highly competitive global marketplace. New products including our 200GX threaded wheel grinding machine, 300GMS-P shop hardened gear inspection machine, our 500CB automated cutter build machine and genesis 400H gear hobbing machine, along with significant process advances in power skiving, bevel gear grinding and lapping offer exciting potential for the future. As the "total gear solutions provider," we also expanded our line of cutting tools and workholding, our services business, including remanufacturing and re-control of machines, our plastic gears division, and automation solutions. All of these solutions ultimately fit into our Gleason 4.0 vision of the future where we link from design to the factory floor with closed-loop systems able to control and optimize gear production.

Bryan Barlow, Vice President Sales and Marketing, Delta Gear

What we're seeing is decisions being delayed by customers, and the demand for capacity – at least on the aerospace side – didn't come, at least not to the degree they forecasted back a few years ago with the new engine programs and the new aircraft programs. We're busy, but all this demand didn't come to everybody like the customers forecasted. We're in a price driven market because there's a lot of capacity, but it is available capacity. Our Delta Research division, which is a gear manufacturing facility, is the opposite. They're not in a price market – they're in a "give me the parts tomorrow" market. [Delta Research is] booming; things are great. There are a lot of new programs on the Delta Research side for us. Automotive seems to be on fire with all these new transmissions programs and new vehicle programs on the electric side.

The aerospace side, in my opinion, I think is soft. It's a little bit slow, and I think budgets are tight on the OEM side. You can see that their travel budgets are tight, so things are happening at a slower pace. For us, even though things are a little bit slower on the customer side, we're gaining market share because we're bringing on new OEM customers. We're either getting in on new programs or gaining market share. So for us, we're actually growing even though it's a little bit soft.

David Goodfellow, President, Star SU

I think that there have been some updates of products that have been out there for a year or two but have now manifested themselves into the reality of capable, production-ready processes.

One is scudding. Scudding, when tooled properly, is an extremely efficient process that often replaces traditional shaping and broaching and, in some cases, hobbing. Scudding is Profilator's registered, trademarked term. Some people call it hard skiving, which has been around a long, long time. It started actually in the '60s. But coming back to this process, with modern tool technology, we've been able to advance that Scudding process to become an extremely efficient, production-ready capability between the machine, the cutting tool and, of course, how you refurbish that tool after it's serviced. So that's one thing: You're seeing a trend now in eliminating broaching and shaping applications with extremely efficient machines.

The other breakthrough is that we've been working for about a year or two to be competitive in the gear grinding business. The old traditional hob and shave processes in automobile transmissions were hobbed and heat treated, and then they lived with whatever variations came after heat treat. But as of late, there's been a tendency to go to grinding after a heat treat to remove errors and distortion coming out of the heat treat process. So that grinding process is used for purposes like improving surface finish, which reduces noise and improves the efficiency of the transmission so it can take more power and torque, run more smoothly, and have better performance and longer life.

We introduced at the EMO Milan tool show a new grinder called SkyGrind – not because of the sky itself, but because it's skive hobbing to rough out the material, and then finishing grinding to remove the minimal amount of stock. The unique opportunity that we saw there was to do it without coolant. We thought if we could remove that from the process – it's pretty much the only process in the gear manufacturing process that isn't dry – it would be important to remove it and all the ancillary problems of coolant like smoke and drips. So we introduced this process and it's kind of unique.

Kerry Klein, Vice President Sales and Marketing, Arrow Gear

The biggest issue is that the economic portion of the business is not very strong right now. [Arrow Gear is] a mix of aerospace and industrial. Aerospace is doing OK, and industrial is pretty much down across the board. That's the toughest part: just trying to keep your head above water right now.

Arrow Gear is going through a little bit of a transition right now. It's been a family-owned company since it was born. It still is a family-owned company, but there's new management coming in and they're making some changes. We just completely redid our front offices – so we have a new look, a lot of new personnel in the company and we're really trying to bring the company forward with modern manufacturing, modern manufacturing tools and a new way of thinking. So that is all new stuff for the company.

We actually just purchased two new Mori Seiki NT machines; we purchased a new Gleason 600 cutting machine; we purchased some new inspection equipment. We actually have a lot of new equipment. We also have some new partnerships with European companies (Pritzwalk and Samputensili) – either they're selling our product overseas or we're selling their product here in North America. So there actually was a lot going on for us this year.

Bill Miller, Vice President Sales, Kapp Technologies

Basically, the automotive industry and the aerospace industry continued to boom. The mining and large commercial gearboxes and energy continued declining. Our product line is the most diverse in the industry and we produce gear grinding machines for every aspect of the market, so our reaction is simply to redeploy our resources as needed to apply to these growth areas. There haven't been any major shifts this year – it's just a continuation of the same trend.

We have two manufacturing facilities, and we utilize both of those now for the growth areas. We typically build smaller machines in Coburg and larger machines in Berlin. But those facilities have a dual purpose and we switch between the two; they're managed by the same production manager and planning people. So we have redundant capabilities. We're utilizing both of those facilities right now.

The other aspect of this is the continuing shift towards Mexico. We actually have more deliveries to Mexico than to the United States and Canada combined. During this period of recession for the large gear makers, we've taken this opportunity to develop a new basis for productivity and machine types, which is in the 1.2 meter range. We made an installation at True Gear & Spline in Cambridge, Ontario, and that was a very big success. We've also delivered our latest technology to the aerospace industry – and I hate to be cliché, but that's about all I can say about that.

Nicholas Bergmann, General Manager, Exsys Tool

What we're seeing now is we're trying to convert a lot of people from older technology that uses worm gears into hypoid gearsets. They're trying to make the equipment that it goes into more efficient – I think that has been a big buzzword in 2015, because everyone wants to go smaller and faster. Those are the other two buzzwords.

Some of the major companies we've dealt with are Mercedes and Bugatti – we're mostly automotive right now. We're trying to branch out and we have some robotics customers. I would say that within those sectors, those are the big things right now.

Honestly, our market share (in the gear industry) is very small right now. We're trying to gain market shares and really feel the market out in all of North America. We also sell live tooling and rotary gearboxes, and those things have taken off – but strictly speaking to gears, we haven't made significant progress yet. We really only started six years ago, so compared to some [other companies] who have been making gears for 100 years and have huge accounts and are well-established in the industry, a newcomer like us is really trying find our footing and have some of the big questions on what is new and trendy answered for us.

Hastings Wyman, CEO, Klingelnberg America

In my opinion, the defining trends of 2015 for the Gear Industry have been market based. Here I'm speaking primarily for what we see in North America. The potential everyone hoped for in 2014 for the U.S. auto industry has been fulfilled and then some, with all-time or near all-time SAAR levels. This obviously benefits anyone in the gear industry with any auto industry exposure. The industry switch to high multi-speed transmissions, with eight, nine, and 10 forward ratios, has meant a lot of big new programs, very high volumes and very short cycle times. It is typical now for automotive planet gears to be finish ground in less than 10 seconds, floor-to-floor. The auto industry, of course, places the highest demands on statistical quality, which means these super-fast cycle times are also happening at 1.67 Cpk, fully automated, three shifts, 24/7. And those gears need to be inspected on the shop-floor, in minutes, not in a gear lab, in hours. There was really impressive stuff happening in U.S. auto industry in 2015.

The heavy truck and aerospace industries are also doing quite well with very strong volumes, which is also very good for the gear industry. The new jet engines coming online in the next few years are very exciting. Decoupling the hot section from the cold section with a gearbox allows both parts of the turbine to run in more efficient regimes, for lower fuel consumption. On the downside in 2015, the big commodity boom is over. Everyone knows oil and gas are down, but so is coal, iron ore, copper, tin, nickel, you name it. So the big demand everyone saw for new big gear installations over the past 5 to 10 years has really taken a hit. The repair and maintenance market for these gears will weather a bit better, and in some cases may improve, so there are bright spots – but overall it definitely hurts the "big and heavy" end of the gear industry.

At Klingelnberg America, 2015 has been a big year. At the EMO show, Klingelnberg showed our Viper 500 parallel-axis gear grinder and our new C30 bevel gear cutting machine. At Gear Expo we unveiled our new G30 bevel gear grinder and P40 gear measuring machine. The Viper can form grind both external and internal gears with the day-in and day-out precision the Höfler brand is renowned for, and be configured for generating grinding, as well. But high technology doesn't add value unless you can make it work on the shop-floor, so Klingelnberg designed the C30 and G30 with a new common user interface around an industrial touch screen. We've had a terrific response from our customers on this development, because it answers a need they all face every day: training new employees, especially Millennials, many of whom don't have experience in machining or gear manufacturing. Our new machine interface is as intuitive for them as using their smartphone.

Outside of selling and delivering new machines, at Klingelnberg America we place a big focus on supporting our North American customers after the sale, through applications support, service, and parts and tooling. We're doing a lot of machine refurbishment work in Saline (MI), taking old lappers, cutting machines and grinders, doing complete mechanical overhauls, PPAP and putting them back into production. We added a lot of headcount in this area in 2015, and we will continue to in 2016.

For more information:

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

Delta Gear
Phone: (734) 525-8000
www.delta-gear.com

Star SU LLC
Phone: (847) 649-1450
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2015 State of the Gear Industry

Reader Survey Results

Gear Technology's **annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry.**

As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear manufacturing companies around the world.

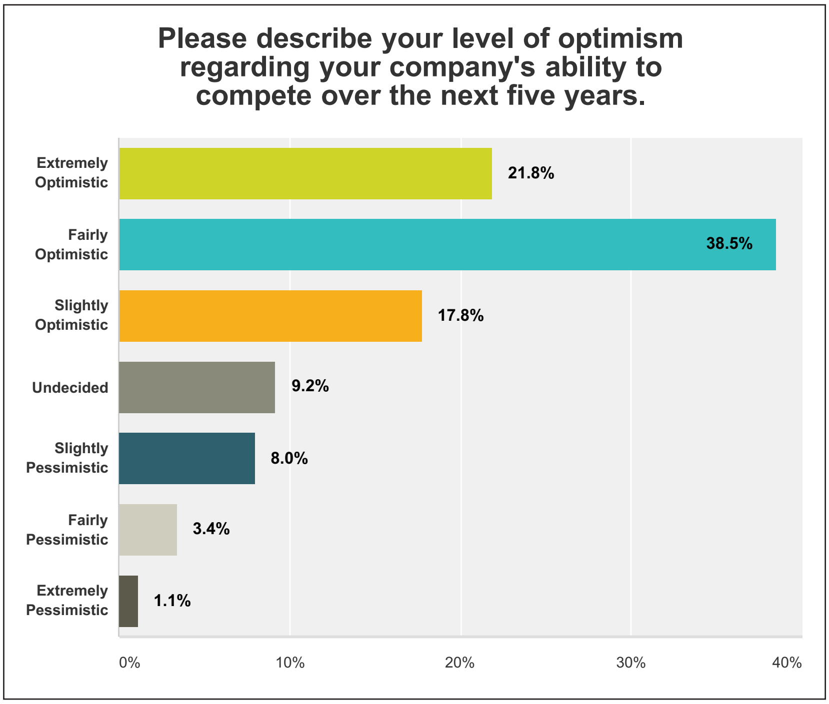
More than 300 individuals responded to the online survey, answering questions about their manufacturing operations and current challenges facing their businesses. All of the responses included in these results come from individuals who work at locations where gears, splines, sprockets, worms and similar products are manufactured. They work for gear manufacturing job shops, captive shops at OEMs and end user locations.

A full breakdown of respondent demographics can be found at the end of this article.

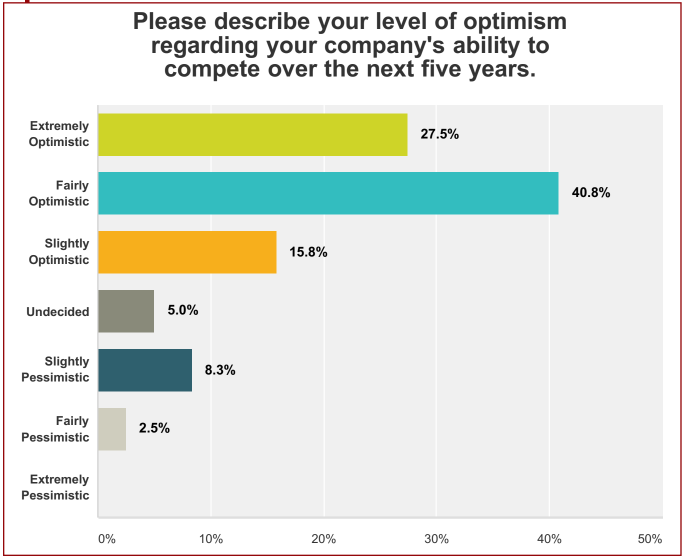
Gear Industry Optimism – A Tale of Two Gear Industries

The gear industry has been a generally optimistic bunch over the last 10 years, with an average of 88% of all respondents indicating some level of optimism about their companies' ability to compete. Both last year and this year, that optimism was lower than the 10-year average. In 2014, 85% of respondents indicated some level of optimism, and this year only 80% were optimistic. However, when you break the numbers down, you discover that most of the pessimism and undecidedness comes from outside North America. In fact the disparity in outlook between North American respondents and non-North American respondents has never been greater, according to our survey.

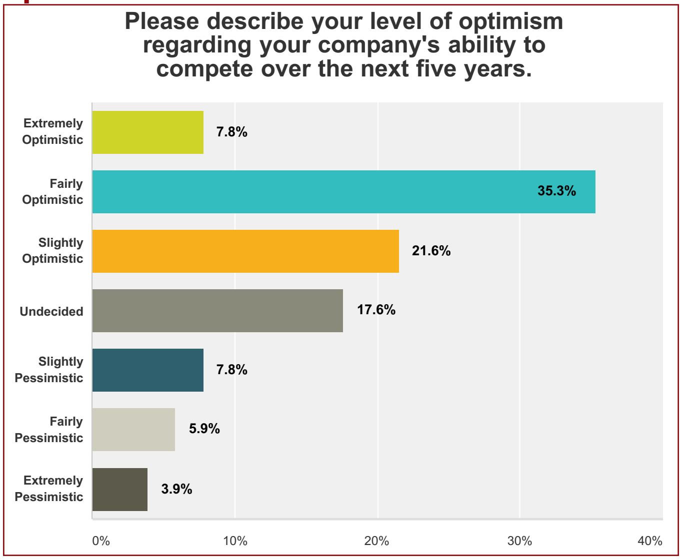
This year, 84% of North American respondents were optimistic about their companies' ability to compete. Outside North America, the number was only 65%.



Optimism in North America



Optimism Outside North America



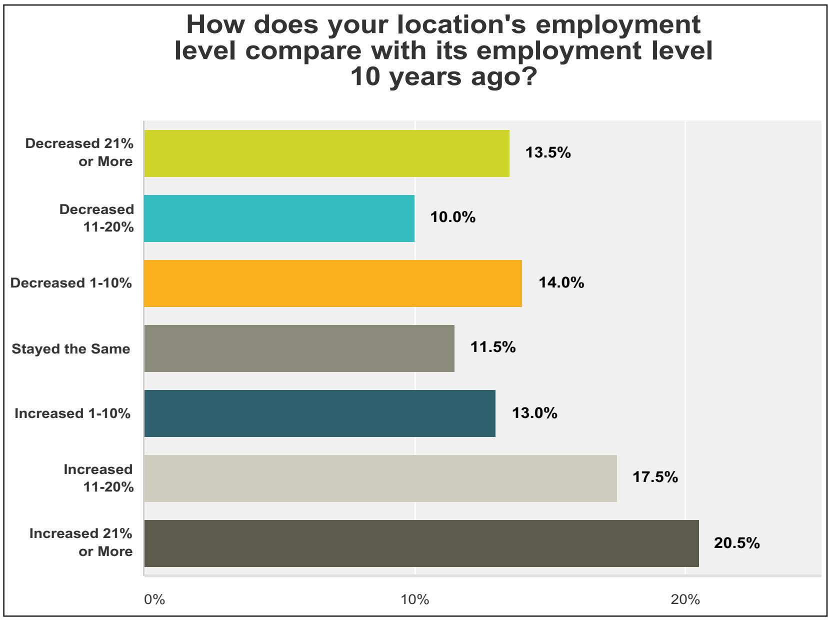
Employment

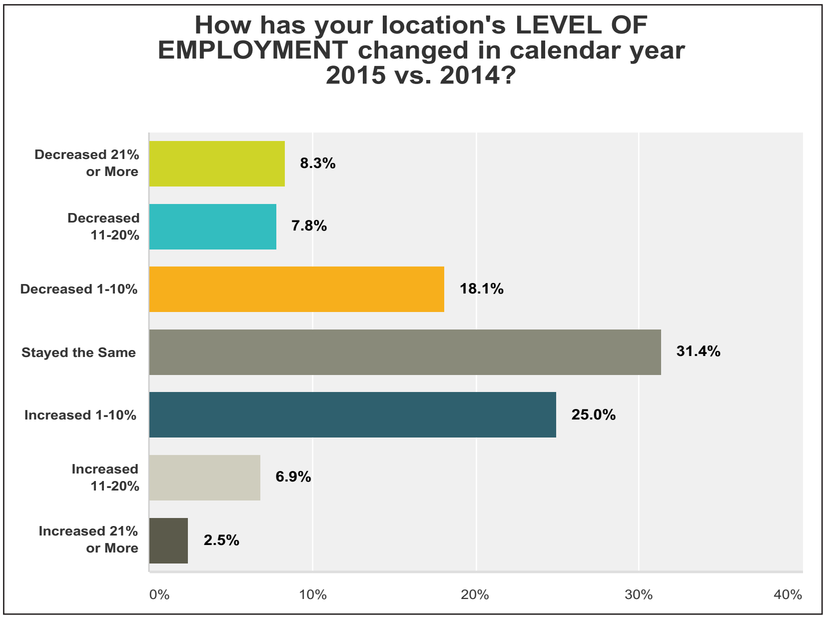
Gear industry implyment was slightly more volatile than it was in 2014, with a greater percentage of respondents indicating an increase (34.4%) as well as a greater percentage indicating a decrease (33.2%) in their company's level of employment. But the outlook for 2016 isn't quite as positive, with nearly 22% of respondents expecting a decrease in employment at their locations (that number was only 12% in 2014).

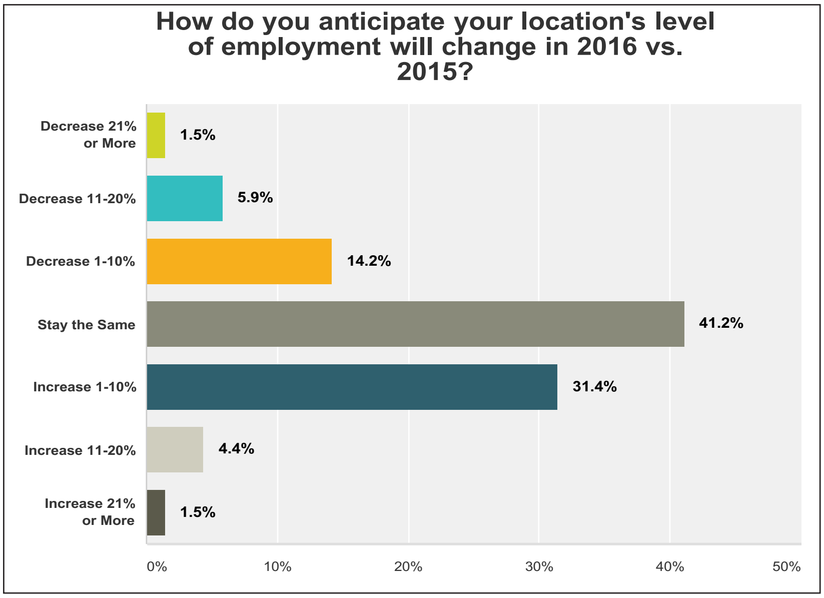
Significant Challenges

Perhaps more than in any previous survey, our respondents indicated that the difficulty in finding, training and keeping skilled labor remains at the top of their list of concerns.

"Finding and retaining key talent."
"Updating old machines and educating future gear engineers."
"The ability to introduce new suppliers and equipment to support increased demand."
"Adapting new gear cutting technology."
"Pass the break even point."
"Economy."
"Replacing experienced employees that are near retirement."
"Skilled resources."
"Finding skilled operators."
"Producing higher-cost, more complex gears."
"Employee skills."
"Finding new skilled employees."
"Sales increases."
"Cell implementation."
"Skilled labor."
"Finding qualified people."
"Lean manufacturing."
"Meet demand."
"Ability to staff for anticipated growth."
"Quality and repeatability."
"Skilled labor."
"Old engineering and manufacturing philosophies."
"Sharing knowledge of experienced workers with new staff."
"New product successsful launching process."
"Hold or increase productivity level."
"Finding technical professionals for both office and factory."
"Electing Federal Representatives that will focus on rebuilding our country's infrastructure."

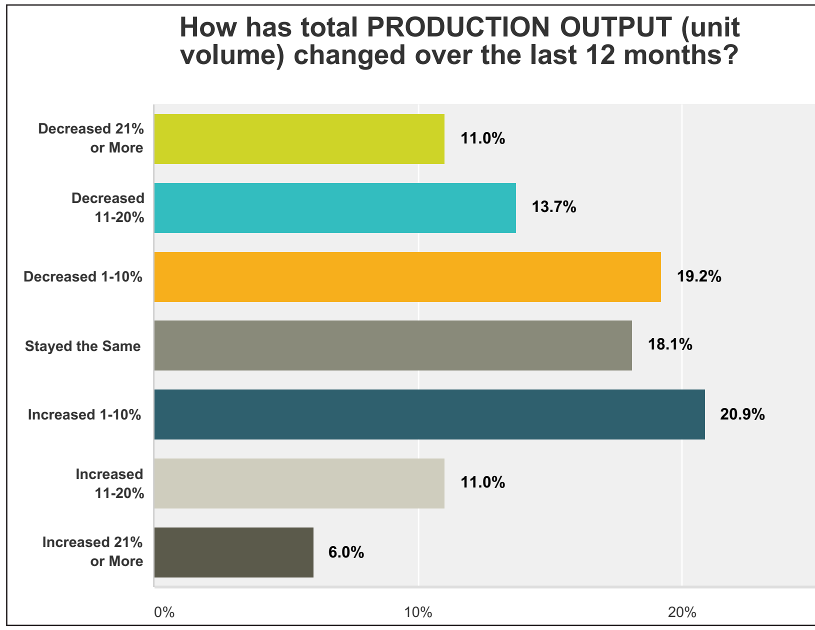


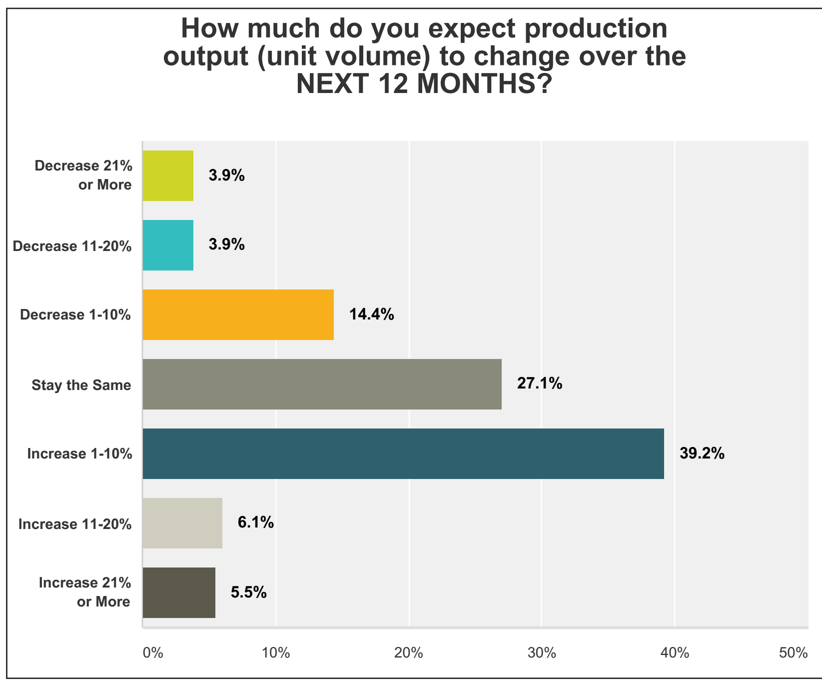




Significant Challenges

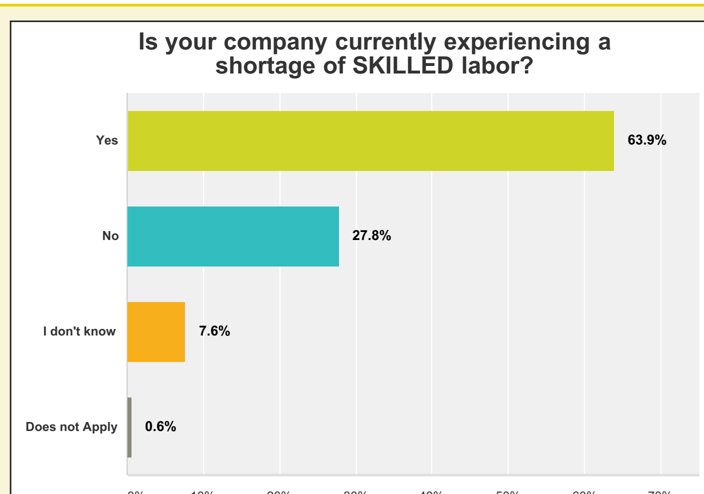
"Distortion at heat treating."
"Finding skilled labor to replace aging work force."
"Economy."
"Cost structure during slowdown."
"Increased competition, foreign and domestic."
"Research and development of new products."
"Right sizing for reduced volume."
"Bring out new product with lower R&D spending."
"Improving our efficiency and downsizing for lower sales expectations in 2016."
"Finding enough skilled people."
"Skilled labor shortage."
"Finding qualified personnel to fill vacancies."
"Maintaining a competitive workforce."
"How to squeeze higher quality out of older equipment."
"Adding qualified machinists."
"Upgrading our equipment."
"Implementing more automation."
"Finding (or training) skilled labor."

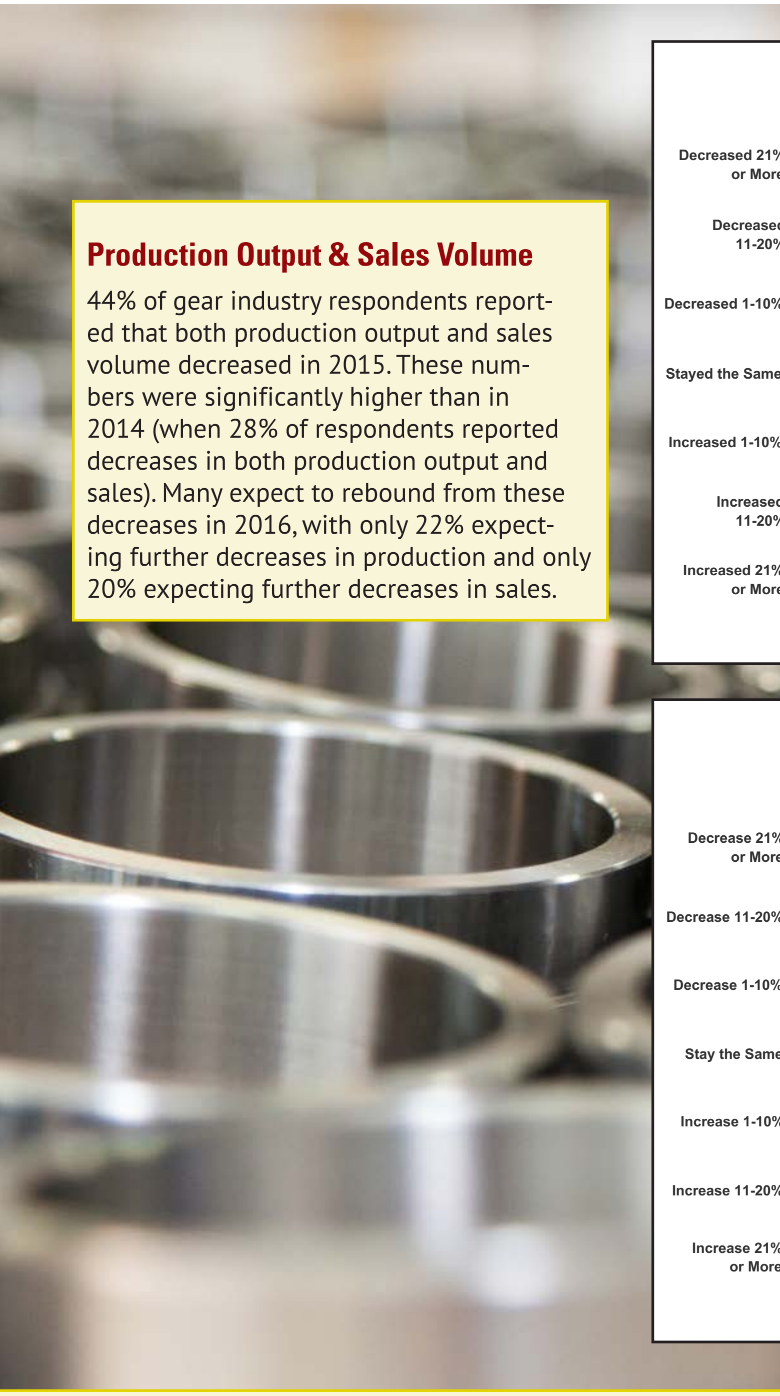




Skilled Labor

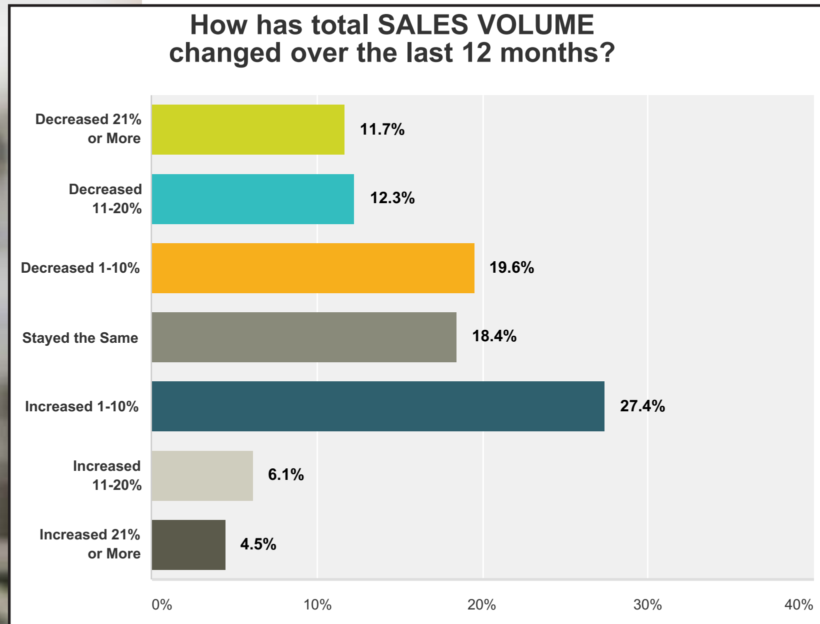
64% of respondents report that their companies are experiencing a shortage of skilled labor. This remains one of the hot topics in the gear industry and in manufacturing in general.

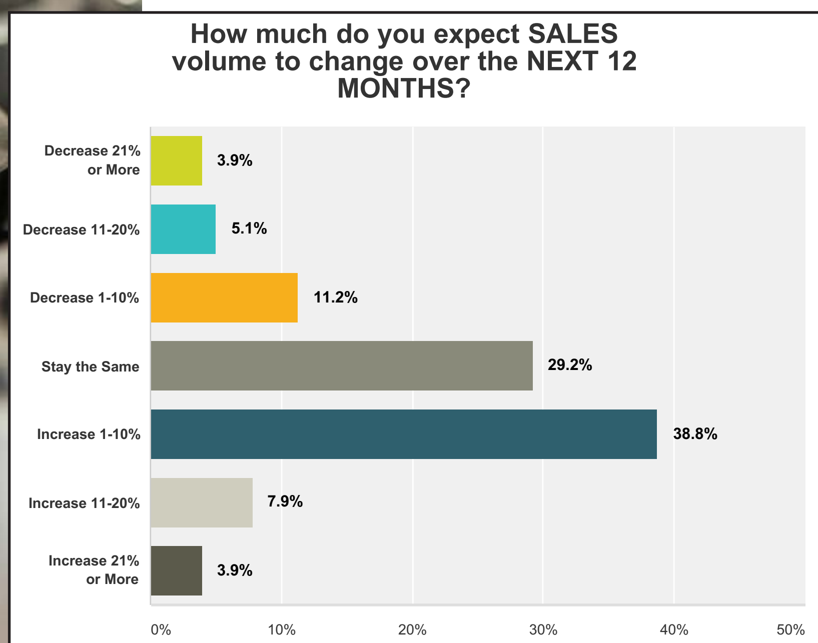


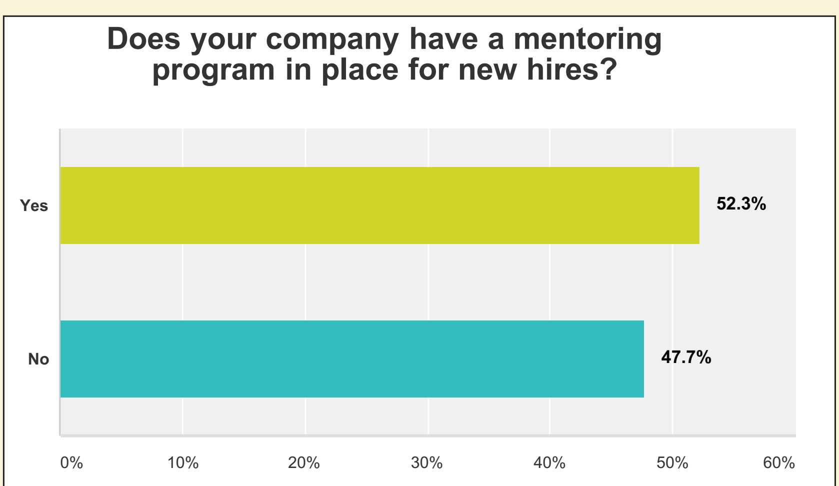


Production Output & Sales Volume

44% of gear industry respondents reported that both production output and sales volume decreased in 2015. These numbers were significantly higher than in 2014 (when 28% of respondents reported decreases in both production output and sales). Many expect to rebound from these decreases in 2016, with only 22% expecting further decreases in production and only 20% expecting further decreases in sales.







Capital Spending

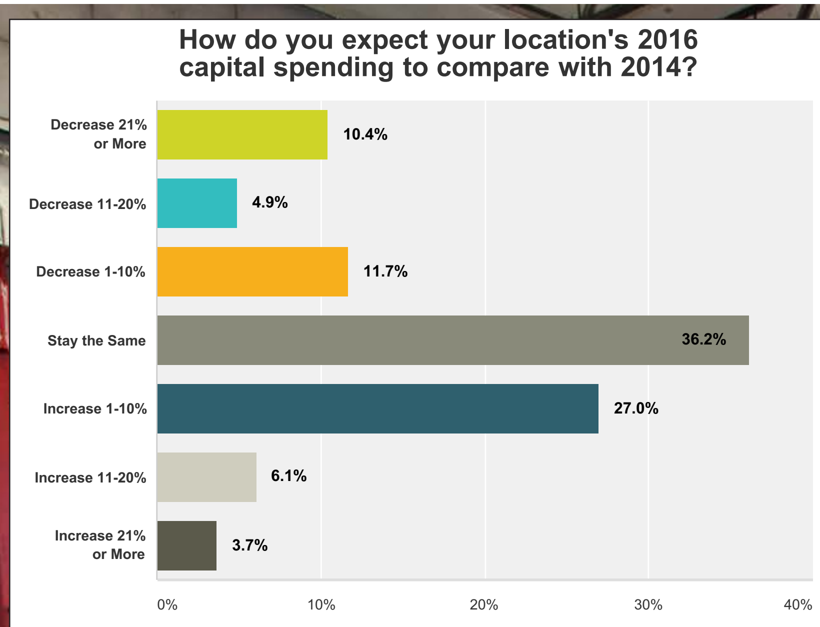
74% of respondents work at locations that spent more than $100,000 on capital equipment in 2015.

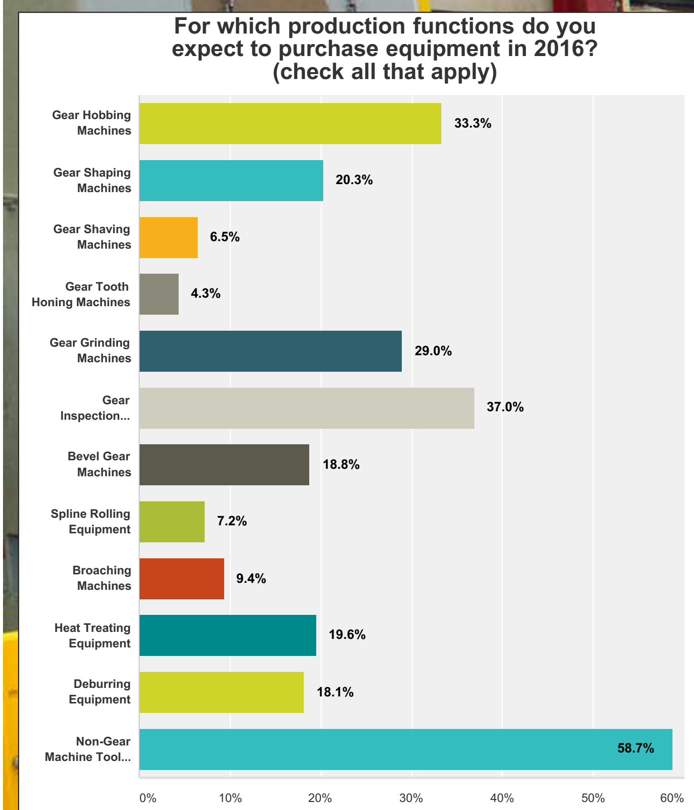
46% work at locations that spent more than $1,000,000.

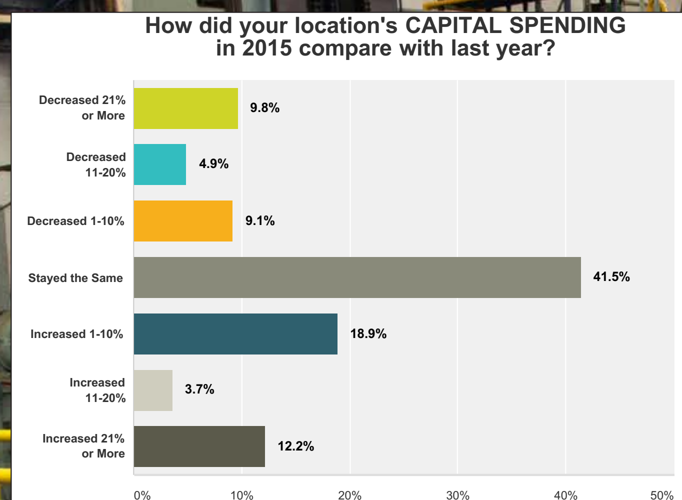
24% of respondents' companies spent less than last year.

35% of respondents' companies spent more.

67% of respondents expect to spend the same as 2015 or more in 2016







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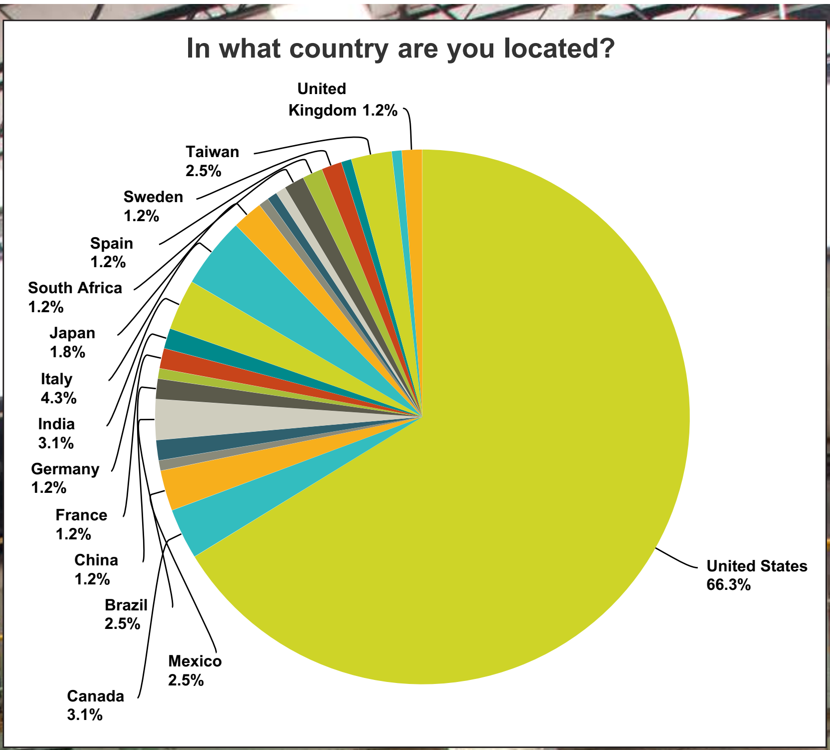
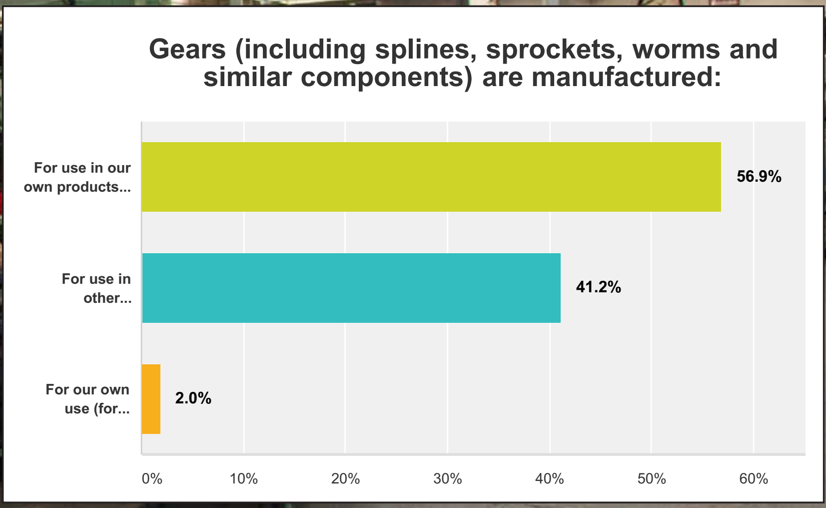
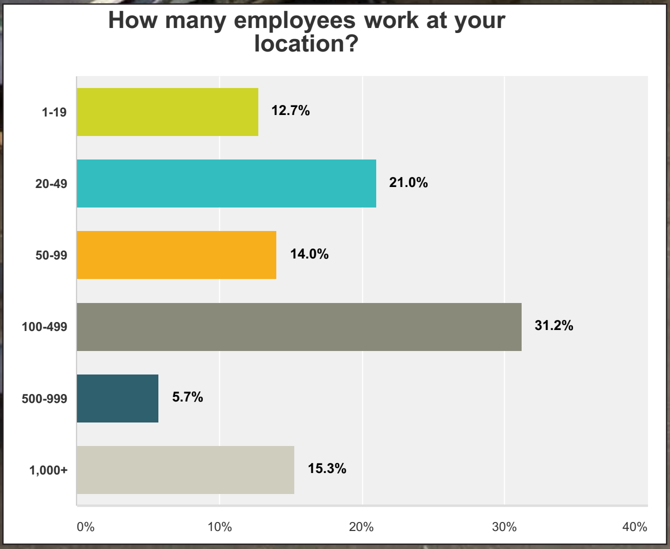
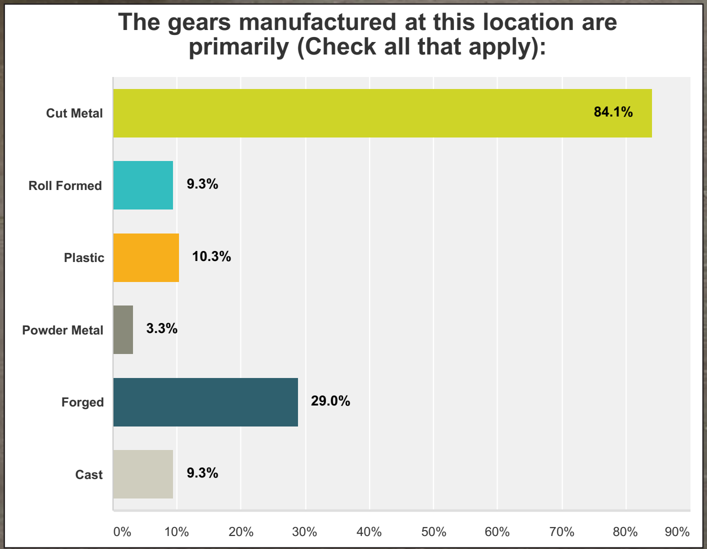
Demographics

The 2015 State of the Gear Industry survey received responses from a wide cross-section of the gear industry. The breakdown of respondents is shown here and on the next page.









Demographics

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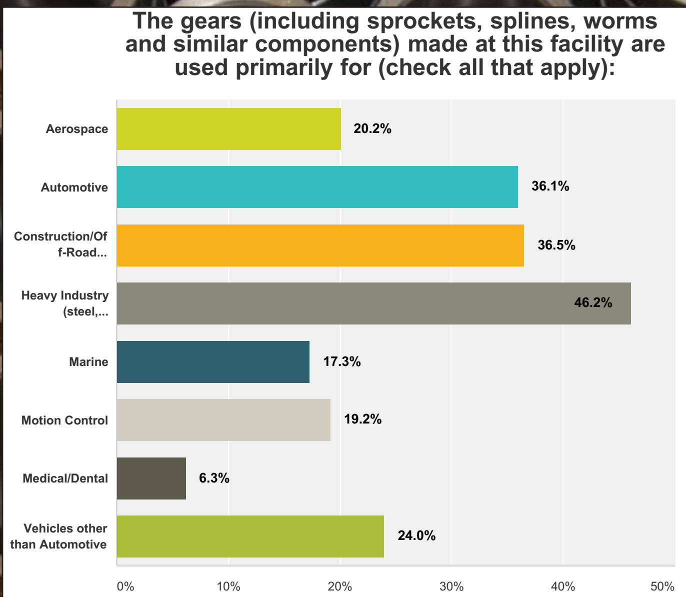

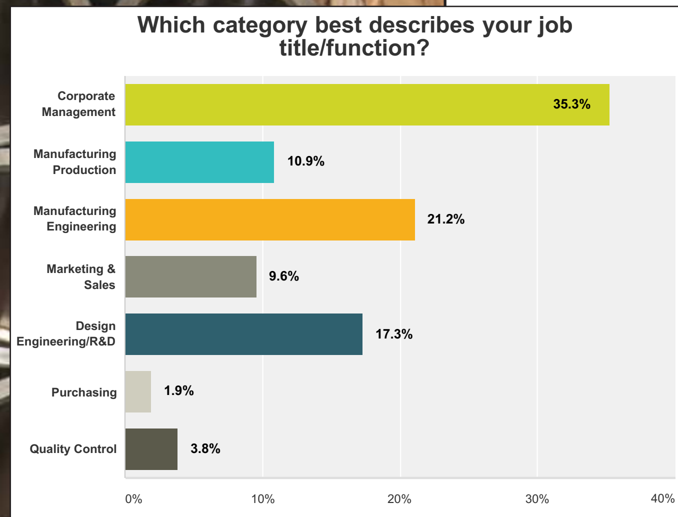

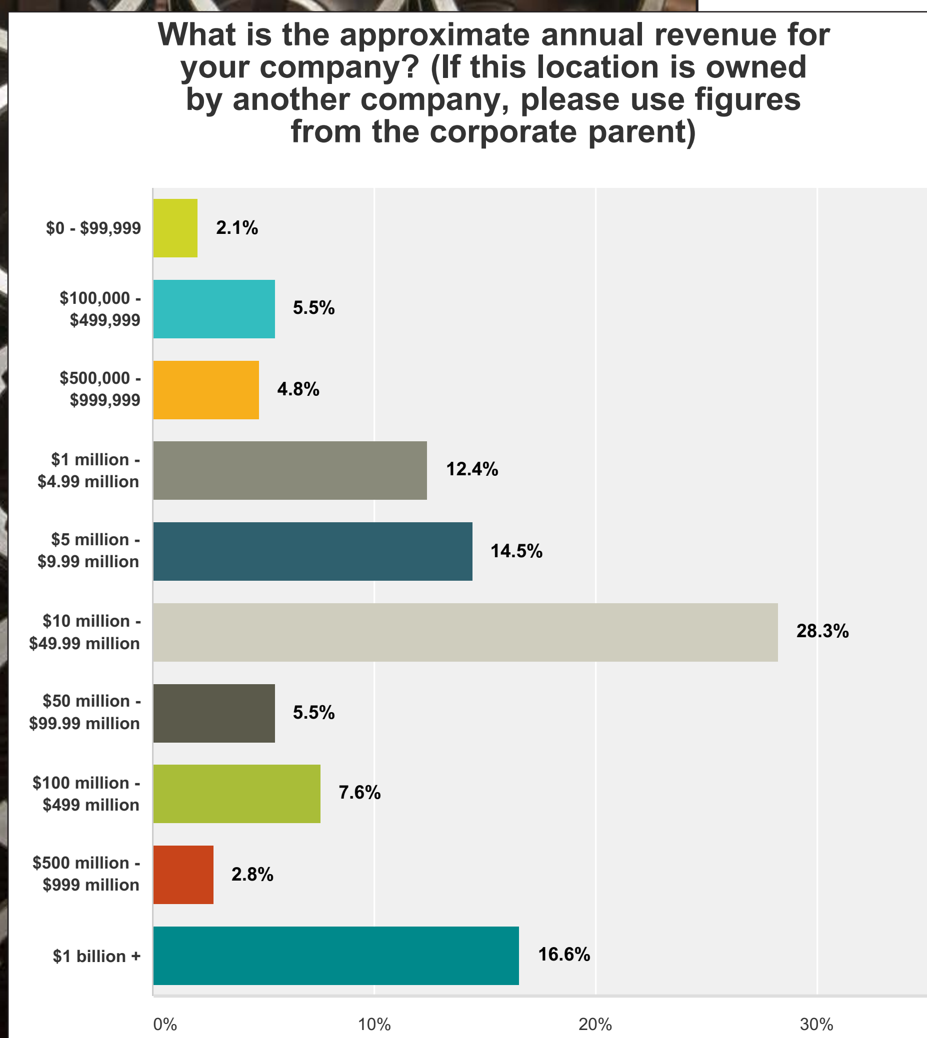


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About This Directory

The 2015 *Gear Technology* Buyers Guide was compiled to provide you with a handy resource containing the contact information for significant suppliers of machinery, tooling, supplies and services used in gear manufacturing.

Bold Listings throughout the Buyers Guide indicate that a company has an advertisement in this issue of *Gear Technology*.

But Wait! Where are the Gear Manufacturers Listed?

If you are looking for suppliers of gears, splines, sprockets, gear drives or other power transmission components, see our listing of this issue's power transmission component advertisers on page 68. In addition, you will find our comprehensive directory in the December 2015 issue of Power Transmission Engineering as well as in our online directory at *www.powertransmission.com.*

Handy Online Resources

The Gear Industry Buyers Guide – The listings printed here are just the basics. For a more comprehensive directory of products and services, please visit our website, where you'll find each of the categories here broken down into sub-categories: *www.geartechnology.com/dir/*

The Power Transmission Engineering Buyers Guide – The most comprehensive online directory of suppliers of gears, bearings, motors, clutches, couplings, gear drives and other mechanical power transmission components, broken down into sub-category by type of product manufactured: *www.powertransmission.com/directory/*

How to Get Listed in the Buyers Guide

Although every effort has been made to ensure that this Buyers Guide is as comprehensive, complete and accurate as possible, some companies may have been inadvertently omitted. If you'd like to add your company to the directory, we welcome you. Please visit www.geartechnology.com/getlisted.php to fill out a short form with your company information and Buyers Guide categories. These listings will appear online at *www.geartechnology.com,* and those listed online will automatically appear in next year's printed Buyers Guide

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www.carbidetool.com

Carborundum Universal Ltd.
www.cumiabrasives.com

Ceramtec North America
www.ceramtec.us

Cold Forming Technology
www.coldformingtechnology.com

Colonial Tool Group
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Comco Inc.
www.comcoinc.com

Continental Diamond Tool Corporation
www.cdtusa.net

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DTR Corp. (formerly Dragon Precision Tools)
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alex@dragon.co.kr
www.dragon.co.kr
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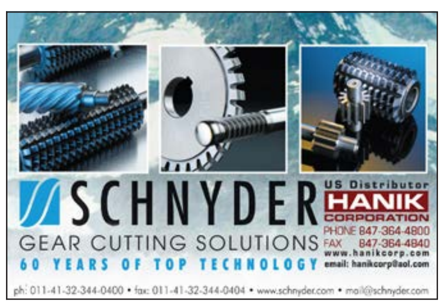

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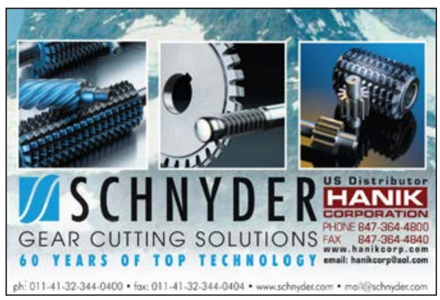

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Boltex Manufacturing
www.boltex.com

Brooker Bros. Forging Co.
www.brookerbrosforgings.com

C.E. Sweeney & Associates
www.castingsandforgings.com

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Celanese
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Concast Metal Products
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www.dsm.com/highperformancegears

DuPont
plastics.dupont.com

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www.hanrotools.com

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Fax: +(49) 7123-18384
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Hartech
www.hartech.com.tw

Havlik International Machinery Inc.
www.havlikinternational.com

Heller Machine Tools
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IMEXSU Group
www.imexsu.com

IMT Group India
www.imtgrindinggroup.com

ITW Heartland
www.itwheartland.com

Index Corporation
www.indextraub.com

Index-Werke GmbH & Co. KG Hahn & Tessky
www.index-traub.com/gearing

International Tool Machines (ITM)
www.itmfl.com

Involute Gear & Machine Company
46449 CONTINENTAL DRIVE
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Fax: (586) 329-3965
rodney.soenen@involutegearmachine.com
www.involutegearmachine.com

J. Schneeberger Corp.
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James Engineering
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JRM International, Inc
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cdmcmachine.com

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Chrystec Machine Tools Pvt. Ltd.
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Diametal AG
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www.dixitechcnc.com

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Seco/Warwick Europe S.A.
www.secowarwickeurope.com.pl

Sedlock Companies
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Setco India Service Center
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Saazor
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ELK GROVE VILLAGE, IL 60007
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Development of Usable Bevel Gearset with Length and Profile Crowning

Hermann J. Stadtfeld

Bevel Gear Technology

Chapter 2, Continued

In the previous sections, the development of conjugate bevel gearsets via hand calculations was demonstrated. The goal of this exercise was to encourage the reader to gain a basic understanding of the theory of bevel gears. This knowledge will help gear engineers to better judge bevel gear design and their manufacturing methods.

In order to make the basis of this learning experience even more realistic, this chapter will convert a conjugate bevel gearset into a gearset that is suitable in a real-world application. Length and profile crowning will be applied to the conjugate flank surfaces. Just as in the previous chapter, all computations are demonstrated as manual hand calculations. This also shows that bevel gear theory is not as complicated as commonly assumed.

— Hermann J. Stadtfeld

The conjugate bevel gearsets covered in previous sections ("Gear Mathematics for Bevel & Hypoid Gears", August 2015 *Gear Technology*, and "Development of a Face Hobbed Spiral Bevel Gearset," September/October 2015 *Gear Technology*) will not provide usable flank contact because of tolerances and load-affected deformations of the gearbox housing, the bearings and shafts, and the gear body and teeth. In addition to edge contact and load concentration, large motion transmission errors can occur that will repeat from tooth mesh to tooth mesh and cause significant operating noise. In order to design gear pairs with high load carrying capacity and low noise emission, flank crowning is required to limit the tooth contact area within the boundaries of the teeth. The art of selecting the optimal crowning is based upon satisfying two basically opposite requirements: A) the load-free or low-load operation should provide the maximal possible contact area; and B) tooth contact must not reach the boundaries of the teeth in case of high-load operation.

In low-load operation, noise emission due to tooth mesh impact is dominating. A large contact pattern and small motion transmission error keep the tooth mesh impact low and subsequently the noise at a low level. The contact pattern movement and contact zone enlargement under load require sufficient length and profile crowning in order to prevent edge contact. The most common crowning corrections used today consist of second order functions in profile and length direction. Although second order functions can only achieve a compromise between crowning requirements A and B, they are still well suited for gear pairs which are lapped after heat treatment. The reason for this is the non-linear modification due to lap removal.

In contrast to that, non-linear crowning can be applied to bevel gear pairs that are ground after heat treatment. Non-linear crowning is known under the name UMC corrections. UMC corrections can fulfill crowning requirements A and B without the usual compromises.

As an introduction to the usage of crowning and its effect on tooth contact and motion transmission error, the face hobbed Formate bevel gearset developed in the previous section will be used as a basis for a crowning development. The result is a good example of a typical bevel gearset with length and profile crowning, as is often used in the industry.

Basic gear data:

Method	continuous indexing with Gleason face hobbing	
Tooth depth along face width		parallel
Shaft angle	Σ	$= 90°$
Offset	$a = TTX$	$= 0\,mm$
Number of pinion teeth	z_1	$= 13$
Number of ring gear teeth	z_2	$= 35$
Outer ring gear pitch diameter	D_{02}	$= 190\,mm$
Face width	$b_1 = b_2$	$= 30\,mm$
Mean spiral angle	$\beta_1 = \beta_2$	$= 30°$
Pinion hand of spiral	$HOSP_1$	= left-hand
Nominal cutter radius	R_w	$= 88\,mm$
Number of cutter starts	Z_w	$= 17$
Pressure angle	$\alpha_C = \alpha_D$	$= 20°$
Profile shift factor	$x = x_1 = -x_2$	$= 0$
Tooth depth factor	f_{Depth}	$= 1$
Top-root-clearance factor	f_{CL}	$= 0.2$
Profile side shift factor	$x_S = x_{S1} = -x_{S2}$	$= 0$
Pinion addendum	h_{K1}	$= (f_{Depth} + x) * m_n = 1.0 m_n$
Pinion dedendum	h_{F1}	$= (f_{Depth} + f_{CL} - x) * m_n = 1.2 m_n$
Ring gear addendum	h_{K2}	$= (f_{Depth} - x) * m_n = 1.0 m_n$
Ring gear dedendum	h_{F2}	$= (f_{Depth} + f_{CL} + x) * m_n = 1.2 m_n$

Wanted are the blade profile parameters and basic machine settings for the gear design with length and profile crowning.

Table 1 Numerical ring gear blank specifications

Ring Gear - Blank Data			
Variable	**Explanation**	**Value**	**Dimension**
z_2	number of ring gear teeth	35	-
$RINR_2$	inner cone distance (along root line)	69.56	mm
$RAUR_2$	outer cone distance (along root line)	99.56	mm
$GATR_2 = \gamma_2$	pitch angle	69.62	°
$GAKR_2$	face angle	69.62	°
$GAFR_2$	root angle	69.62	°
$ZTKR_2$	pitch apex to crossing point	0.00	mm
$ZKKR_2$	face apex to crossing point	–4.27	mm
$ZFKR_2$	root apex to crossing point	5.12	mm
$DOMR_2 = m_{f2}$	face module	4.63	mm
HGER	whole depth of teeth	8.80	mm

Table 2 Numerical pinion blank specifications

Pinion - Blank Data			
Variable	Explanation	Value	Dimension
z_1	number of teeth pinion	13	-
$RINR_1$	inner cone distance (along root line)	58.42	mm
$RAUR_1$	outer cone distance (along root line)	88.42	mm
$GATR_1 = \gamma_1$	pitch angle	20.38	°
$GAKR_1$	face angle	20.38	°
$GAFR_1$	root angle	20.38	°
$ZTKR_1$	pitch apex to crossing point	0.00	mm
$ZKKR_1$	face apex to crossing point	–11.49	mm
$ZFKR_1$	root apex to crossing point	13.78	mm
$DOMR_1 = mf_1$	face module	4.63	mm
HGER	whole depth of teeth	8.80	mm

Calculation of Blank Data

The blank data of pinion and ring gear will not change from the previous section. The required blank data — the basis for the calculations in this section — are repeated here in Tables 1 and 2.

The Creation of Length Crowning

The length curvature of a circular tooth flank is not consistent with the inverse of the cutter head radius, but is the curvature of the cone section at the reference point perpendicular to the blade pressure angle. Figure 1 shows this principle with cylinder K_1 which smooths onto the blade enveloping cone at the reference point.

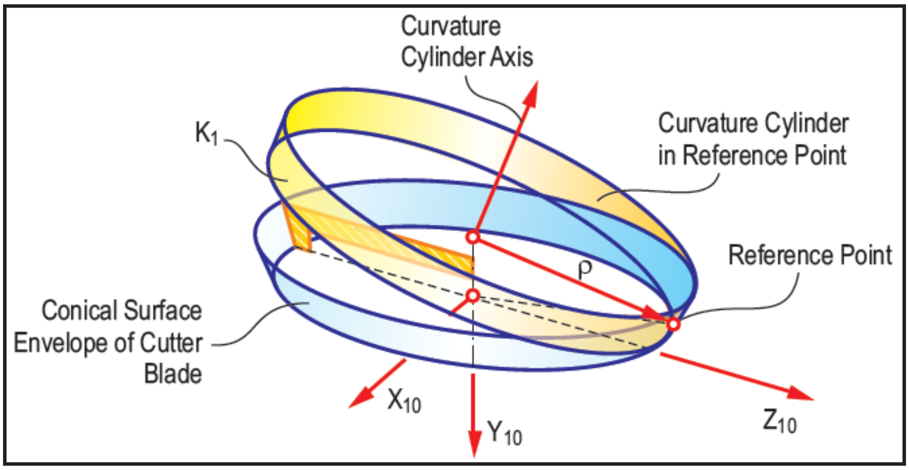


Figure 1 Blade enveloping cone and cone curvature ρ.

The tooth length curvature in Figure 1 is 1/ρ. A change in length crowning can now be realized if the axis of the cutter head is rotated (tilted) around the reference point while the cutting edge remains in the same spatial position (Fig. 2). The rotation is conducted around an axis lying in the X_4–Z_4–plane and is perpendicular to the vector R_{WOB}; i.e., R_{WIB}.

In the current example, a length crowning by tilting the ring gear cutter head should be created. First, the outside blade and the concave flank cut with it are observed (Fig. 2). If a length crowning of $\psi = 50$ µm (from center to heel and from center to toe) is desired, then the required curvature change is calculated as follows:

The function of the crowning parabola is: $\psi = d\xi^2$ (1)

The second derivative of the crowning parabola is the curvature change: $\psi'' = 2d$ (2)

With half the face width projected with the spiral angle $\beta = 30°$ onto the flank line tangent direction:

$$\xi = 15\,mm / cos\beta = 17.32\,mm \quad (3)$$

and

$$\psi_{Zehe} = \psi_{Ferse} = 0.05\,mm \quad (4)$$

substituted in Equation 1 and solving for coefficient d delivers:

$$d = \psi / \xi^2 = 0.000167\ [1/mm] \quad (5)$$

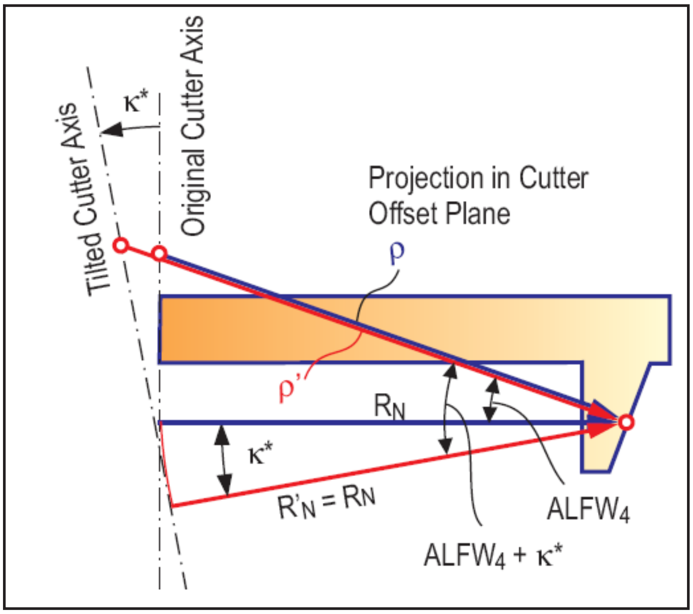


Figure 2 Cutter head tilt for generating a length crowning.

Whereas the required curvature change is:

$$\Delta K = \psi'' = 0.000333 \ [1/mm] \tag{6}$$

For the creation of a positive length crowning, the curvature radius ρ of the concave flank has to increase, as shown in Figure 2. The following calculation can be derived:

From Figure 2, with $ALFW_4$ from the previous section ("Development of a Face Hobbed Spiral Bevel Gearset," September/October 2015, Eq. 4) and R_N from the previous section ("Development of a Face Hobbed Spiral Bevel Gearset," September/October 2015, Eq. 6):

$$\rho = R_N / cos\ (ALFW_{4\text{-}conjugate}) = 81.17\ /\ cos 20° = 86.38\ \text{mm} \tag{7}$$

Curvature changes are added with the correct sign to the inverted curvature radii:

$$1/\rho' = 1/\rho - \Delta K \rightarrow \rho' = \rho/(1 - \Delta K * \rho) = 88.93\ \text{mm} \tag{8}$$

Figure 2 also yields the relationship for ρ' ($R_N = R_N' = const$):

$$\rho' = R_N'\ /\ cos\ (ALFW_{4\text{-}conjugate} + \Delta\alpha) \tag{9}$$

Equation 9 can now be solved for Δα:

$$\rightarrow \Delta\alpha = arccos\ (R_N'/\rho') - ALFW_{4\text{-}conjugate} = 4.11° \tag{10}$$

The value Δα is used in order to rotate the cutter head, and with it the cutter head axis as well as the vector *RW*, around a line which lies in the X_4–Z_4–plane that is perpendicular to the vector R_{WOB}, i.e. — R_{WIB} (*see "Development of a Face Hobbed Spiral Bevel Gearset," September/October 2015, Fig. 1*). The corresponding calculations are covered in the following section.

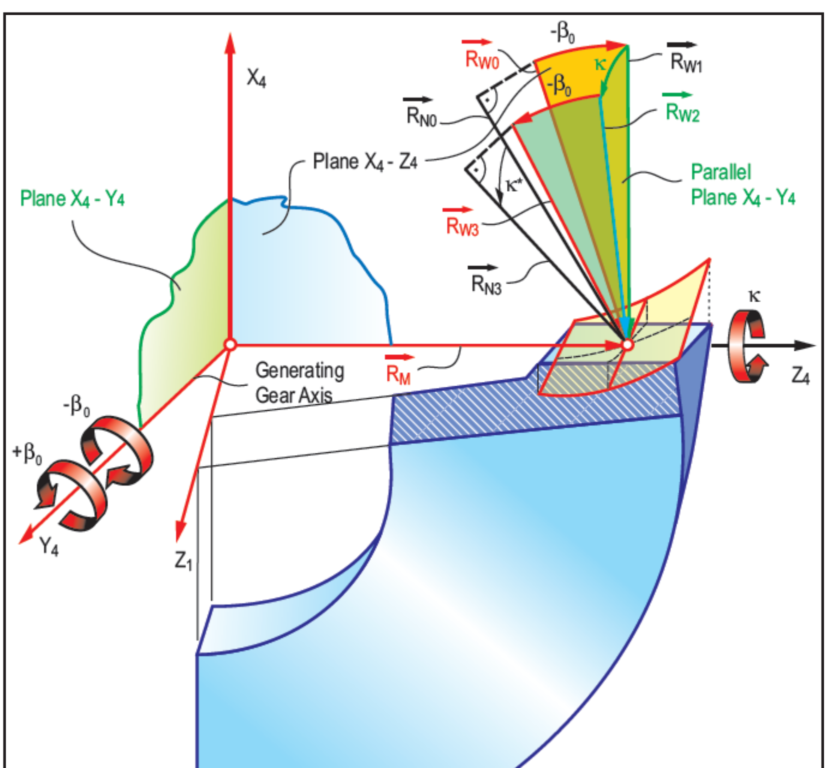


Figure 3 Rotations of normal vectors for a length crowning tilt.

Calculation of Basic Settings for the Cutting Machine

The machine settings that realize a cutter head tilt can be derived with the help of Figure 3. Vector R_{W0} lies in the generating gear plane. The first rotation around the Y_4–axis about an angle $-\beta_0$ results in vector R_{W1}. The second rotation is the real correction rotation around the Z_4–axis about an angle Δα, which results in R_{W2}. The third rotation is a back rotation into the final position (R_{W3}) about the angle $+\beta_0$ and around the Y_4–axis. β_0 is the angle of the R_W–vector in face hobbing; it is also called the "static spiral angle":

$$\beta_o = \beta - \delta_W = 7.27° \tag{11}$$

The final position differs from the starting position by a rotation Δα around the tangent of the flank line.

The rotational matrix of the negative static spiral angle $-\beta_0$ around the *Y*-axis is:

$$(-TBET) = \begin{Bmatrix} cos(-\beta_0) & 0 & sin(-\beta_0) \\ 0 & 1 & 0 \\ -sin(-\beta_0) & 0 & cos(-\beta_0) \end{Bmatrix} = \begin{Bmatrix} .9919 & 0 & -.1265 \\ 0 & 1 & 0 \\ .1265 & 0 & .9919 \end{Bmatrix} \tag{12}$$

The rotational matrix of the tilt angle Δα is:

$$(TALF) = \begin{Bmatrix} \cos\Delta\alpha & sin\Delta\alpha & 0 \\ -sin\Delta\alpha & cos\Delta\alpha & 0 \\ 0 & 0 & 1 \end{Bmatrix} = \begin{Bmatrix} .9974 & -.0717 & 0 \\ .0717 & .9974 & 0 \\ 0 & 0 & 1 \end{Bmatrix} \tag{13}$$

The rotational matrix of the positive static spiral angle $+\beta_0$ about the *Y*-axis is:

$$(+TBET) = \begin{Bmatrix} cos\beta_0 & 0 & sin\beta_0 \\ 0 & 1 & 0 \\ -sin\beta_0 & 0 & cos\beta_0 \end{Bmatrix} = \begin{Bmatrix} .9919 & 0 & -.1265 \\ 0 & 1 & 0 \\ .1265 & 0 & .9919 \end{Bmatrix} \tag{14}$$

The total rotation according to Figure 2 therefore yields:

$$(ROT) = (+TBET) \times (TALF) \times (-TBET) \tag{15}$$

$$(ROT) = \begin{Bmatrix} .9975 & -.0711 & .0003 \\ .0711 & .9974 & -.0091 \\ .0003 & .0091 & .9999 \end{Bmatrix} \tag{16}$$

Since the operations above are rotations versus transformations, the matrix subject to rotation is oriented at the right side of Equation 16 and is multiplied from right to left with the matrixes that include the rotations. Any number of additional rotations is possible by adding rotational matrices at the left side of the equation next to (+*TBET*).

In order to calculate the new machine settings, it is necessary to establish an actualized E_X–vector. It is evident from Figure 2 that the vector R_M remains unchanged.

$$\vec{R}_M = \{0., 0., 86.34\}$$

$$\vec{R}_{W0} = \{-87.29, 0., 11.14\}$$

The new vector R_{W3} results from the multiplication of vector R_{W0} from (*text, section 2.4*) with the rotational matrix (*ROT*):

(17)

$$\vec{R}_{W3} = (\vec{ROT}) \times \vec{R}_{W0} =$$

$$\left\{ \begin{matrix} .9975 & -.0711 & .0003 \\ .0711 & .9974 & -.0091 \\ .0003 & .0091 & .9999 \end{matrix} \right\} \times \{-87.29,\ 0.,\ 11.11\}$$

(18)

$$\vec{R}_{W3} = \{-87.07,\ -6.31,\ 11.11\}$$

This yields: $\vec{E}_X = \vec{R}_M - \vec{R}_W = \{87.07,\ 6.31,\ 75.23\}$

With the E_X–vector, the following machine settings can be calculated:

(19)

Center roll position: $\boldsymbol{W450_{3,4}} = arctan\ (E_{XX} / E_{XZ}) = 49.17°$

(20)

Radial distance: $\boldsymbol{TZMM_{3,4}} = \sqrt{E_{XX}^2 + E_{XZ}^2} = 115.07\ \text{mm}$

(21)

Sliding base: $\boldsymbol{TYMM_{3,4}} = E_{XY} = 6.31\ \text{mm}$

The cutter head axis Y_8 of the ring gear setup for the simple bevel gearing case in (*text section 2.4*) is collinear to the generating gear axis Y_4. Also, the axes X_8 and Z_8 have the same directions as the axes X_4 and Z_4 of the generating gear system. The orientation matrix of the cutter head coordinate system X_8–Y_8–Z_8 (cutter tilt matrix) expressed in the generating gear system is therefore a unit matrix.

(22)

$$(TKAP) = \left\{ \begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix} \right\}$$

The new cutter tilt matrix that accommodates length crowning is calculated by multiplication of the cutter tilt matrix (*TKAP*) with the rotational matrix (*ROT*), which includes all the necessary rotations. Since this operation is also a rotation, not a transformation, the matrix to be rotated is placed at the right end of the equation and is multiplied from right to left with the matrix that includes the rotations:

(23)

$$(TKAP_{Tilt}) = (ROT) \times (TKAP)$$

(24)

$$(ROT) = \left\{ \begin{matrix} .9975 & -.0711 & .0003 \\ .0711 & .9974 & -.0091 \\ .0003 & .0091 & .9999 \end{matrix} \right\}$$

The mean column vector of the cutter head coordinate system matrix includes the three dimensional information of the cutter tilt. Cutter tilt and tilt orientation are calculated as follows:

(25)

$$\boldsymbol{WXMM_{3,4}} = arccos\{TKAP(2,2)\} = 4.13°$$

(26)

$$\boldsymbol{WYMM_{3,4}} = -W450_{3,4} + arctan\{TKAP(1,2)\ /\ TKAP(3,2)\} = 131.88°$$

All other machine settings remain the same. This yields the machine settings in Table 3:

Table 3 Geometrical and kinematical machine settings

Machine Basic Settings			
Variable	**Explanation**	**Value**	**Dimension**
$WXMM_{1,2}$	cutter head tilt pinion	20.38	°
$WXMM_{3,4}$	cutter head tilt ring gear	4.13	°
$WYMM_{1,2}$	swivel angle pinion	51.07	°
$WYMM_{3,4}$	swivel angle ring gear	131.88	°
$W450_{1,2}$	center roll position pinion	–51.07	°
$W450_{3,4}$	center roll position ring gear	49.17	°
$TYMM_{1,2}$	sliding base position pinion	–26.19	mm
$TYMM_{3,4}$	sliding base position ring gear	6.31	mm
$TZMM_{1,2}$	radial distance pinion	112.20	mm
TZMM34	radial distance ring gear	115.07	mm
$AWIM_{1,2}$	machine root angle pinion	–90.00	°
$AWIM_{3,4}$	machine root angle ring gear	–159.62	°
$TX2M_{1,2}$	pinion offset in the machine	0.00	mm
$TX2M_{3,4}$	ring gear offset in the machine	0.00	mm
$TZ2M_{1,2}$	machine center to crossing point pinion	0.00	mm
$TZ2M_{3,4}$	machine center to crossing point gear	0.00	mm
$UTEI_{1,2}$	indexing ratio of pinion cutting	0.764706	-
$UTEI_{3,4}$	indexing ratio of ring gear cutting	2.058824	-
$UDIF_{1,2}$	ratio of roll for pinion cutting	0.371428	-
$UDIF_{3,4}$	ratio of roll for ring gear cutting	1.000000	-

Calculation of the Cutter Head Geometry

The blade geometry of the ring gear cutter head will change as a result of the modified blade angles with constant remaining radius R_W. The amount the blade protudes beyond the generating plane remains identical to the values from the previous section ("Development of a Face Hobbed Spiral Bevel Gearset," September/October 2015, Fig. 2). This is, in case of length crowning tilt, only a compromise. In order to optimize the root fillet and avoid a step between the track of the inside blade and the outside blade, a blade stepping can be calculated. However, it is not a subject which will be covered in this example calculation.

$$\boldsymbol{S890_3} = h_{F2} = 4.80\ \text{mm}$$
$$\boldsymbol{S890_4} = h_{F2} = 4.80\ \text{mm}$$

The lead value of the cutter head tilt is the value about which the vector R_W must be rotated. This lead value has already been calculated as $\Delta\alpha$ in the previous section. The entire angle $\Delta\alpha$ is not applicable to the blade cutting edge because the cutter head normal radius vector R_N is oriented under the blade offset angle δ_W to the cutter head radius vector R_W. Vector R_N is bound to vector R_W (Fig. 3) and follows all three rotations conducted by R_W. This can be realized rather easily by the multiplication of R_N with the rotational matrix (*ROT*):

(27)

$$\vec{R}_{N0} = \{-70.295,\ 0.,\ 40.585\}$$
$$\vec{R}_{N3} = (ROT) \times \vec{R}_{N0} = \{-70.10,\ -5.37,\ 40.56\}$$

The angle between the vector R_{N0} (before the rotation) and R_{N3} (after the rotation) is derived from the scalar product between the two vectors. This angle κ* corresponds to the blade correction angle; there is only a slight difference between $\Delta\alpha$, i.e. κ:

(28)

$$\vec{R}_{N0} \bullet \vec{R}_{N3} = \{-70.295, 0., 40.585\}\ \{-70.104, -5.365, 40.561\}$$
$$\vec{R}_{N0} \bullet \vec{R}_{N3} = 6574.128$$

(29)

$$|RN0| = |RN3| = RN = 81.17$$
$$\kappa^* = arccos\{(\vec{R}_{N3} \bullet \vec{R}_{N0}) / R_N^{\ 2}\} = 3.794°$$

In order to cut the correct pressure angles on the ring gear flank surfaces, new blade angles need to be calculated:

$$ALFW_4 = ALFW_{4\text{-}conjugate} + \kappa^* = 23.794° \quad (30)$$

The cutting process is considered a completing method because outside blades and inside blades are connected to the same cutter head. This means both flanks of one slot are machined at the same time. Subsequently, the length crowning by cutter head tilt can only be produced on both flanks (convex and concave) at the same time. An increase of the outside blade angle by cutter head tilt requires an equally large reduction of the inside blade angle in order to keep the gear pressure angles constant. This also leads to both flank sides having nearly identical length crowning values.

$$ALFW_3 = ALFW_{3\text{-}conjugate} - \kappa^* = 16.206° \quad (31)$$

With: $SPLF = 0$, and $R_N = 81.17$ mm, the normal blade point radii, recalculated with (*see text*) Equations 2.65 and 2.66 are:

$$RCOW_3 = R_N - SPLF/4 + h_{F2} * tanALFW_3 = 82.57\,\text{mm}$$
$$RCOW_4 = R_N + SPLF/4 - h_{F2} * tanALFW_4 = 79.05\,\text{mm}$$

The new cutter head and blade geometry data are recorded in Table 3.

Simulation of the Gear Cutting Process and Tooth Contact Analysis of the Example with Length Crowning

Input of the modified blade data and machine settings into the basic machine dataset for the flank generation and roll simulation program yield the analysis results in Figure 4. Already the introduction of pure length crowning leads to fundamentally different analysis results. The Ease-Off topography shows a circular material removal along the face width. The ordinate values at heel and toe of the coast side (equal to the concave ring gear flank) correspond at mid profile exactly to the 50µm which the calculation was based on. The Ease-Off topographies of coast and drive side show clear twistings. This is typical for face hobbed bevel gear sets and shows that the cutter head tilt causes differences in the epicycloids between top and root of the tooth. In the event of undesirable flank twist, which will cause a slight increase of the contact pattern bias direction, a split of the length crowning into a pinion component and a gear component can prevent a twisted Ease-Off. The split of the length crowning into pinion and gear cutting creates distortions of the epicycloids, which between pinion and gear will cancel each other out.

The motion error characteristic in Figure 4 shows very small amplitude values because the path of contact direction is mainly oriented in the profile direction. The contact patterns in the lower portion of Figure 4 are limited in face width direction, as expected. The mean points (stars in the graphics) are located at the top limitation of the active common flank area on the coast side, and at the root limitation on the drive side. The reason for this is the missing profile crowning, which causes an indifferent mean point position in profile that is influenced merely by Ease-Off changes in the single µm range. The introduction of profile crowning as demonstrated in the next section will resolve this problem.

The Creation of Profile Crowning

Ease-Off perpendicular to the tooth length direction is called profile crowning. This crowning is oriented perpendicular to the pitch line, i.e.—to the root line (depending on the process). Profile crowning is mostly achieved with blade modifications. Instead of a straight cutting edge, a curved profile is applied which is tangential to the blade pressure angle at the reference point. As an example, the development with length crowning is used. Since the initial blade profile is a straight line, the cutting edge parameters for a chosen profile crowning of $\psi = 10\,\mu$m can be calculated with the following sequence of Equations 32–41:

With half of the profile depth projected about the pressure angle of $\alpha = 20°$:

$$\xi = 4\,\text{mm} / cos\alpha = 4.25\,\text{mm} \quad (32)$$

and

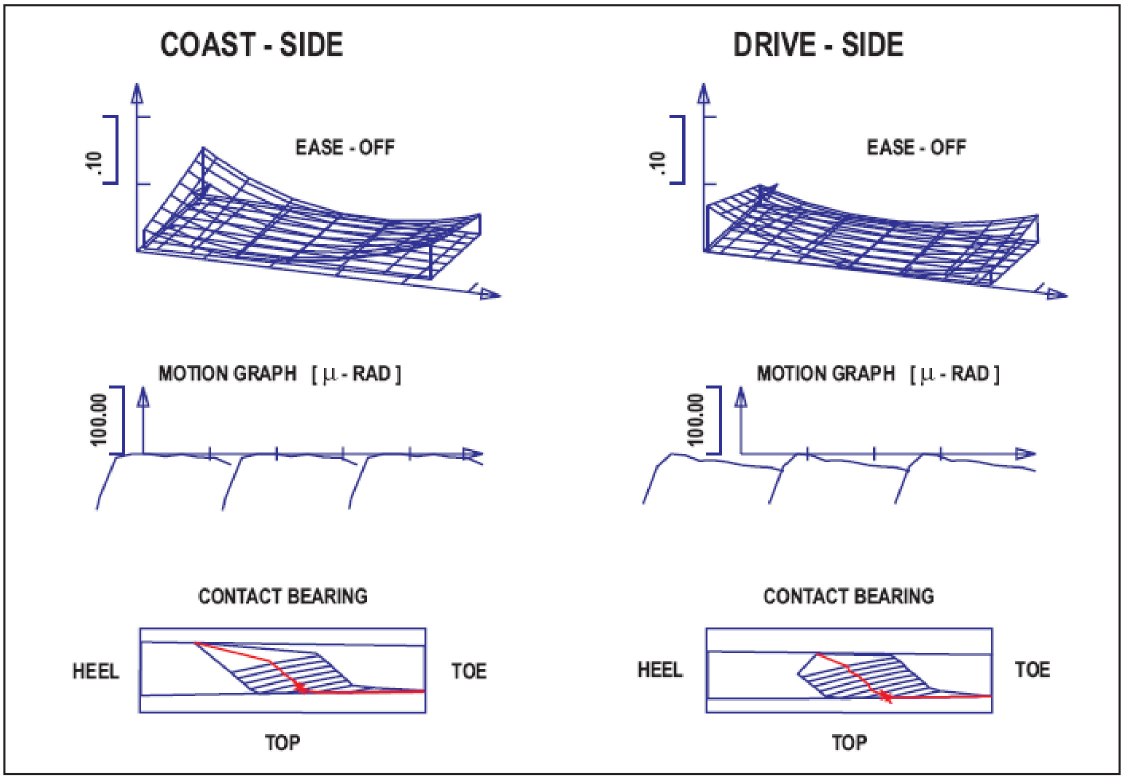


Figure 4 Graphical results of roll simulation of a pair with length crowning.

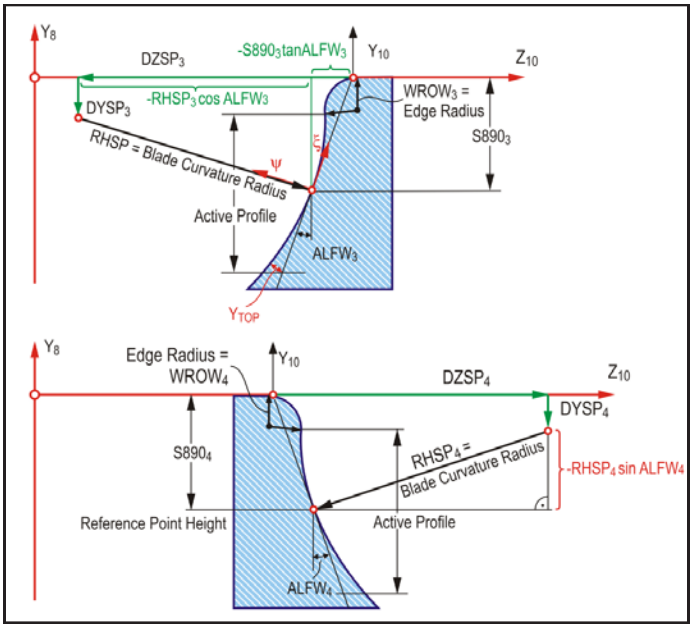


Figure 5 Blade profiles with circular correction.

Table 4 Cutter head and blade specifications			
Cutter Head and Blade Data			
Variable	Explanation	Value	Dimension
$S890_{1,2}$	reference point to blade tip pinion	4.80	mm
$S890_{3,4}$	reference point to blade tip gear	4.80	mm
$WAME_1$	blade phase angle pinion convex	10.59	°
$WAME_2$	blade phase angle pinion concave	0.00	°
$WAME_3$	blade phase angle ring gear convex	–10.59	°
$WAME_4$	blade phase angle ring gear concave	0.00	°
$XSME_{1,2}$	blade offset in pinion cutter head	34.00	mm
$XSME_{3,4}$	blade offset in ring gear cutter head	–34.00	mm
$RCOW_1$	cutter point radius pinion inside blade	82.92	mm
$RCOW_2$	cutter point radius pinion outside blade	79.42	mm
$RCOW_3$	cutter point radius ring gear inside blade	82.57	mm
$RCOW_4$	cutter point radius ring gear outside blade	79.05	mm
$ALFW_1$	blade angle pinion inside blade	20.00	°
$ALFW_2$	blade angle pinion outside blade	20.00	°
$ALFW_3$	blade angle ring gear inside blade	16.21	°
$ALFW_4$	blade angle ring gear outside blade	23.79	°

$$\psi_{Top} = \psi_{Root} = 0.01\,\text{mm} \tag{33}$$

substituted into Equation 1 and solved for coefficient *d* results in:

$$d = \psi/\xi^2 = 0.000554 \tag{34}$$

Which gives the required curvature change with $y'' = 2d$:

$$\rho = 1\,/\,\psi'' = 903.13\,\text{mm} \tag{35}$$

The curvature radius ρ must be applied to the blade profiles of inside and outside blades, as shown in Figure 5, in order to create positive profile crowning. The blade curvature radius *RHSP* equals ρ. All bold-printed variables are required for a complete definition of the curved blade profile:

$$\boldsymbol{RHSP_3} = \rho = 903.13\,\text{mm} \tag{36}$$

$$\boldsymbol{DYSP_3} = S890_3 - RHSP_3 sin\,(ALFW_3) = -242.47\,\text{mm} \tag{37}$$

$$\mathbf{DZSP_3} = -RHSP_3 cos\,(ALFW_3) - S890_3 tan\,(ALFW_3) = -869.99\,\text{mm} \tag{38}$$

$$\boldsymbol{RHSP_4} = \rho = 903.13\,\text{mm} \tag{39}$$

$$\boldsymbol{DYSP_4} = S890_4 - RHSP_4 sin\,(ALFW_4) = -364.12\,\text{mm} \tag{40}$$

$$\boldsymbol{DZSP_4} = RHSP_4 cos\,(ALFW_4) + S890_4 tan\,(ALFW_4) = 826.49\,\text{mm} \tag{41}$$

This leads to cutter head and blade geometry according to the data in Table 4. Only the ring gear blade data, with reference to the definition of the curved cutting edges, are added to the values in Table 3.

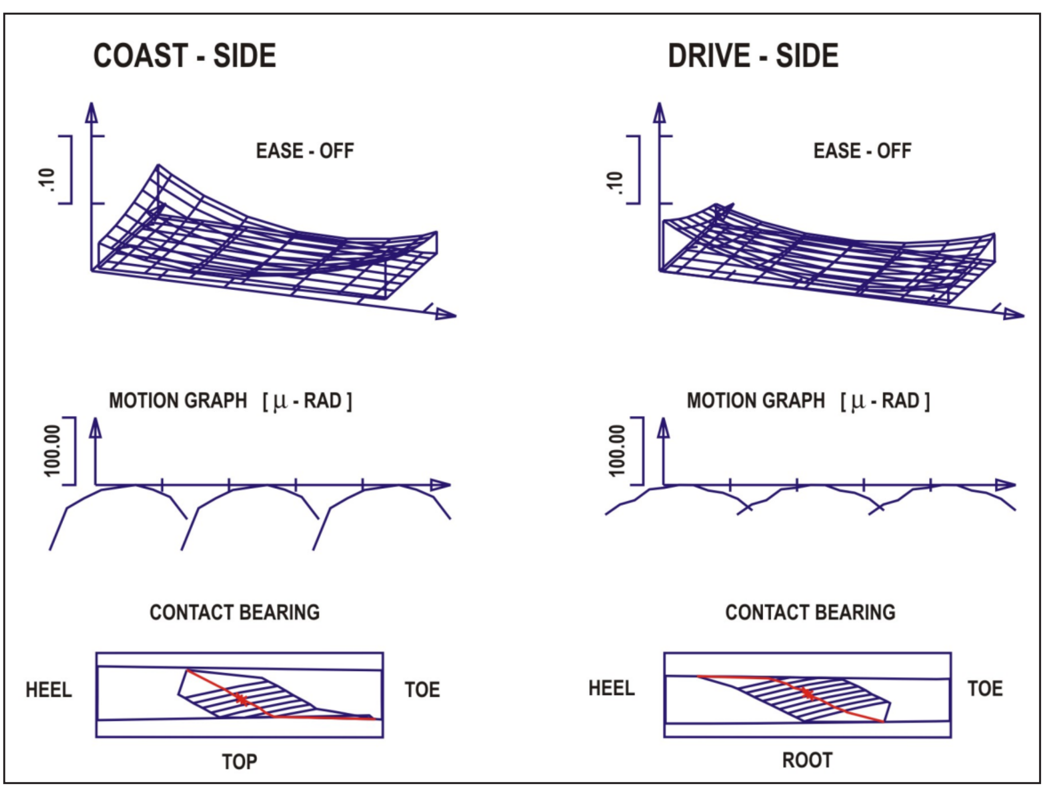


Figure 6 Graphical results of roll simulation (TCA) of a pair with length and profile crowning.

Simulation of the Gear Cutting Process and Tooth Contact Analysis of the Example with Length and Profile Crowning

After inputing the blank data from Tables 1 and 2, the modified machine settings from Table 2 and the blade data from Table 4 for creating length and profile crowning into the basic machine dataset of the flank generation and roll simulation program, the analysis results in Figure 6 are acquired.

The Ease-Off topographies for coast and drive side in Figure 6 now have a circular curve in length as well as in profile direction. This Ease-Off makes the gear design insensitive to manufacturing tolerances and load affected deformations. The motion transmission error in the middle of the figure shows a parabola-shape graph for each of the three preceding pairs of teeth.

The tooth contact pattern in the lower part of Figure 6 shows a bias in characteristic — typical for bevel gear pairs manufactured in the face hobbing process. The mean points (stars at the contact center) are now centered at the middle of the profile. The results of this section not only show a usable, but a well-designed, typical bevel gearset as it is developed for hard finishing by lapping. Small deficiencies in the amount of active profile can be eliminated with a profile shift.

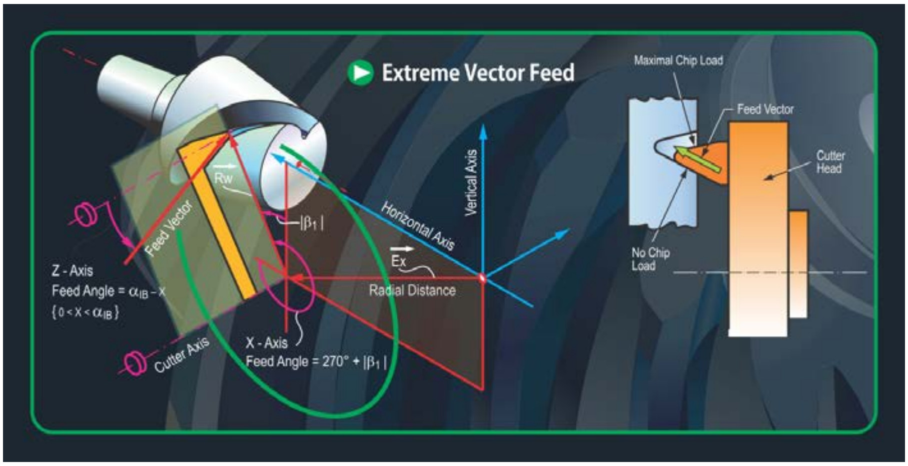


Figure 7 Extreme vector feed of a tilted cutter.

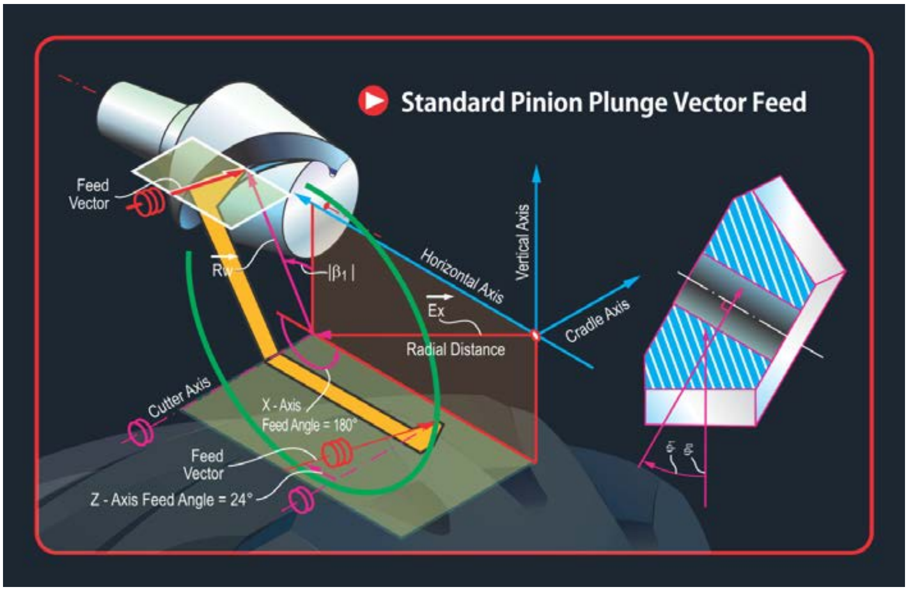
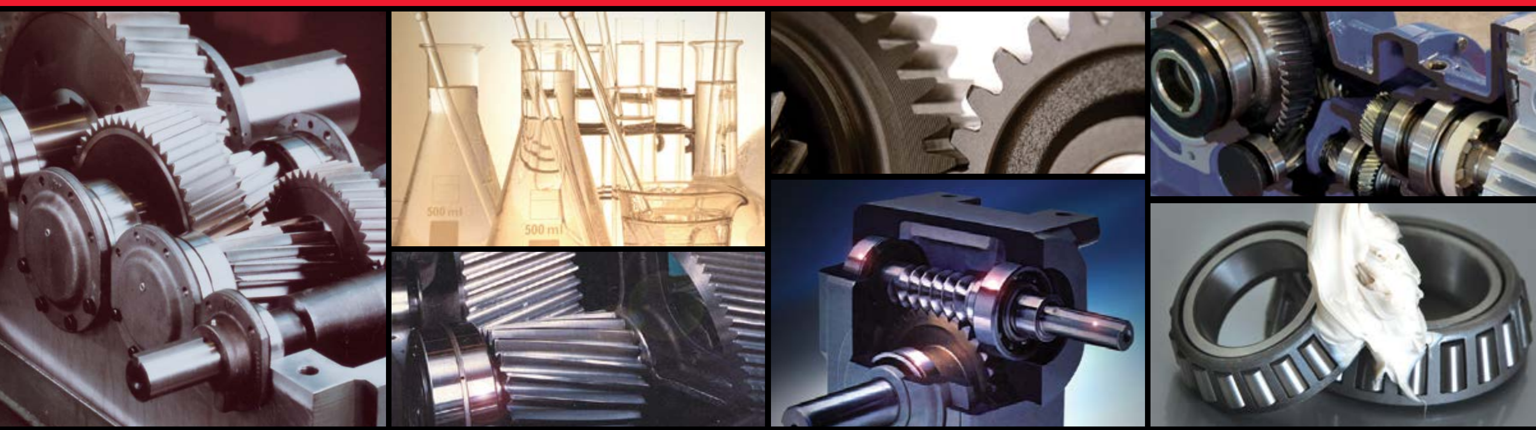


Figure 8 Pinion vector feed of a tilted cutter 180 – 24."

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



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Knowing When Enough Is Enough
Predicting Impending Bending Failure in a Test Environment

Suren B. Rao and Aaron Isaacson

Introduction

Detection of impending gear tooth failure is of interest to every entity that utilizes geared transmissions. However, it is of particular significance at the Gear Research Institute (GRI), where sponsored efforts are conducted to establish gear material endurance limits, utilizing gear fatigue tests. Consequently, knowing when a gear is about to fail in each and every test, in a consistent manner, is essential for producing reliable and useful data for the gear industry. To accomplish this end, researchers at GRI and the Drivetrain Technology Center (DTC) at ARL/Penn State have developed a metric called the Average Log Ratio (ALR), described further in the following article. This ALR accurately predicts impending bending failure and is being further developed to predict contact fatigue failures.

The Mission

In all the fatigue testing — the institute's forte — that is conducted at GRI, knowing when a certain, consistent level of failure has occurred is vital. In determining this experimentally, we compare one life-to-failure set of test specimens against the life-to-failure of another set of test specimens in order to compare the durability of one versus the other. A consistent failure criterion is essential in this effort. More discussion and the theoretical basis of this topic are presented here.

The traditional mode of detecting failure in most gear and gear material testing has been to monitor the time domain vibration levels with an accelerometer mounted near the test mesh (Fig. 1). The failure criterion is typically an increase in RMS or peak vibration above a set threshold. This has been found to be very arbitrary, as the level of vibration is dependent on several factors such as the speed, load, tooth geometry, the dynamic response of the test rig system — even background noise.

In recent years, with the wider availability of hardware/software packages that are capable of Fast Fourier Transform (FFT) analysis, GRI has begun to monitor the acceleration levels at specific fundamental frequencies and their harmonics — with significantly improved results. Figure 2 shows a typical frequency spectrum (FFT) for a vibration signal from the 4-square gear test rig in Figure 1. In this spectrum, the fundamental tooth mesh frequency on the torque reversing gear pair is the large peak at about 1,700 Hz. The peaks associated with the fundamental rotational frequency and its harmonics are on the left side of the large tooth mesh peak. The peaks to the right of the tooth mesh peak are further rotational harmonics; harmonics of the tooth mesh frequencies in the test box, harmonics of the tooth mesh frequencies in the torque reversing gear box and their accompanying side-bands. By monitoring energy levels at the specific, relevant frequencies, much more consistent and repeatable results are being obtained, whether it is a running gear bending fatigue test or a surface durability test. While we are still fine-tuning this methodology for surface durability failures, we are confident that we are detecting the initiation of bending fatigue failure of running gear teeth in an extremely consistent and accurate manner — and long before any other technique known can detect this failure.

The basis for monitoring the vibration level at certain fundamental frequencies and its harmonics is that the transmission error vibration excitation from meshing gear pairs contains information pertinent to the health of the gears. Further, in the case of bending fatigue, plastic tooth deformation constitutes the dominant source of gear health changes prior to failure (Ref. 1). This plastic deformation of the teeth leads to deviations of the loaded tooth working surface from a perfect equally spaced position. If the meshing gears are operating at a constant speed and load, the deviations of the loaded tooth-working-surface manifest themselves in the transmission error of the meshing gear pair and in the generated vibration spectra.

In the research at ARL/Penn State, a metric defined as the Average-Log-Ratio (ALR) to quantify the health of the gear has been developed (Ref. 2). The ALR

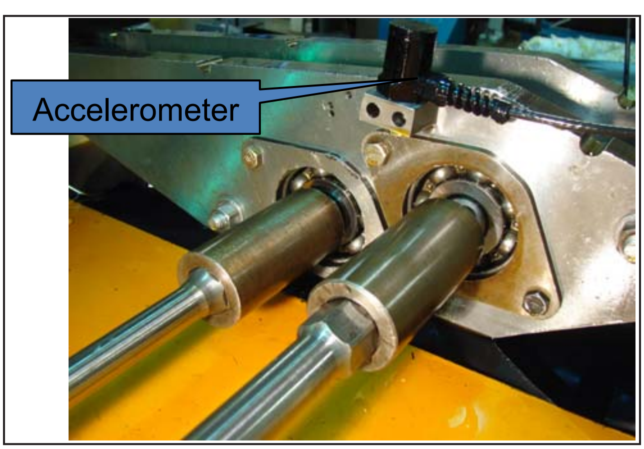

Figure 1 Mounted acceleromator.

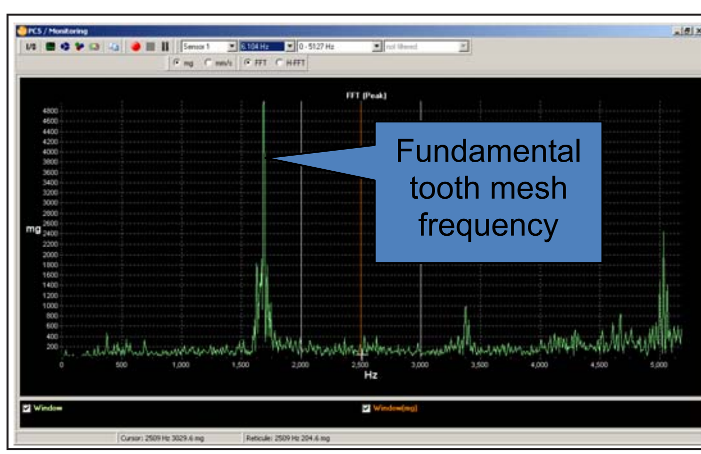

Figure 2 Acceleration spectra.

is defined by the equation below and a value of the ALR significantly larger than zero and increasing in running time is an indication of damage on one or more teeth of the gear.

$$ALR \triangleq \underset{over\ n}{average} \left| \log_e \frac{|\alpha_y(n)|_a}{|\alpha_y(n)|_b} \right| \quad (1)$$

The transducer-response Fourier series coefficients $\alpha_y(n)$ are related to the transmission-error Fourier series coefficients and complex-frequency-response function; more details on Equation 1 are provided in Reference 2; this metric was evaluated for a pair of running spiral bevel gears. Figure 3 shows the progression of the value of the ALR metric for the meshing gears. Increases in the ALR indicate the onset of damage; i.e.—plastic deformation or an increase in transmission error.

In this figure, the value of the ALR, computed with statistical averaging, remained almost constant for approximately 2 hours and 30 minutes running time, but then began to increase monotonically after about 4 hours of operation, when the gear pair loading was reduced. After further running, the ALR metric again increases, as damage to the gear tooth progresses. This methodology could be an effective approach to gear health monitoring in gearboxes as the diagnostics and prognostics of mechanical machinery become an essential requirement of such systems.

Acknowledgement. *The referenced research at ARL/PSU was done by Dr. William Mark.*

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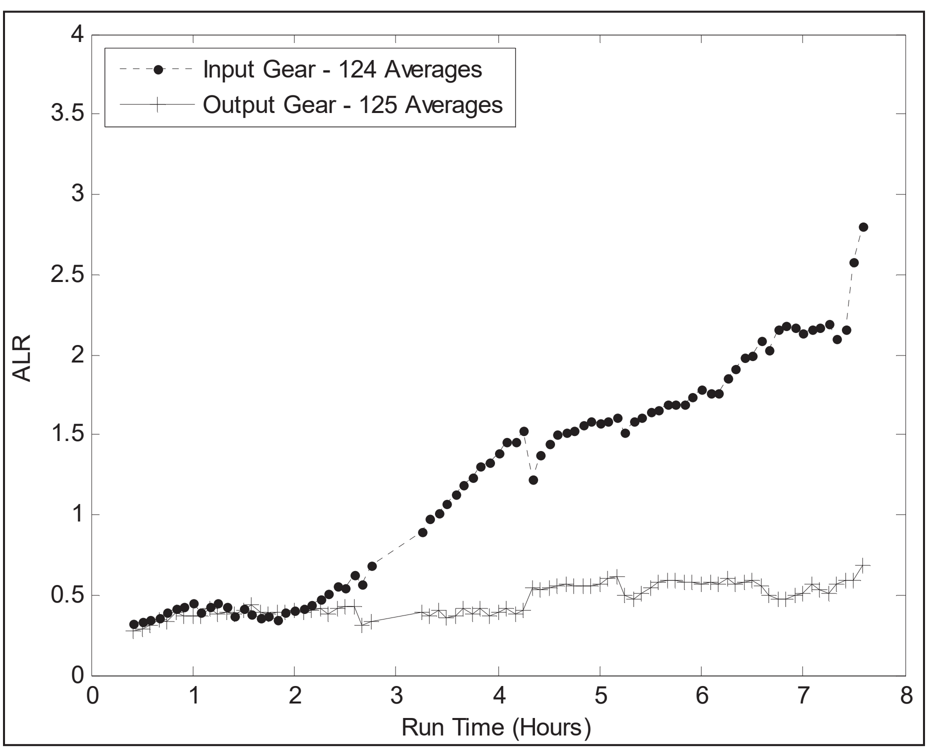
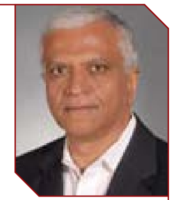


Figure 3 Progression of the value of the ALR metric for the meshing gears.



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Process Model for Honing Larger Gears

Fritz Klocke, Markus Brumm and Marco Kampka

Hard finishing technology, e.g.—honing—is used to manufacture high-performance gears. Gear honing is primarily used to hard finish small- and medium-sized automotive gears. And yet trials have shown that gears with a module larger than $m_n = 4$ mm can also be honed efficiently, but problems often occur due to unstable process design. In this paper a model to improve the process design is described.

Introduction

Hard finishing technology is used to remove deviations from hardening, to machine tooth flank modifications and to meet quality requirements. The case hardening process is necessary to enable the gear to transmit high torque with smaller gears in high-power applications. In industrial applications, profile gear grinding, generating gear grinding and gear honing are most commonly used as hard finishing processes for gears. Each of these high-performance processes is using geometrically undefined cutting edges. Gear honing is primarily used to hard finish small- and medium-sized automotive gears with a module m_n less than 4 mm. One advantage is high economic efficiency as well as great surface quality. Trials have shown that gears with a module larger than $m_n = 4$ mm can also be honed efficiently. Problems occurred primarily in the reliability of the process—which leads to the conclusion that there is no problem, in principle, but rather a lack of knowledge of the honing process for large gears. Process parameters and tool specifications must be adjusted to derive the desired quality sought in honing larger gears.

To reduce time and effort, intensive trials with an empirical/physical process model were conducted. After discussing the theoretical process analysis, this paper focuses on practical process analysis based on force and vibration measurements.

Challenge

Initial attempts to scale up the process parameters from small to large gears have shown that this is not possible for all components. These results suggest that there is a lack of suitable process parameters and design data for honing large-module gears. This is due to the kinematics of the gear honing process, where a large number of variables impart added complexity to the process. Additionally, small transmission ratios and high overlaps occur between the workpiece and honing tool for large gears (Fig. 1).

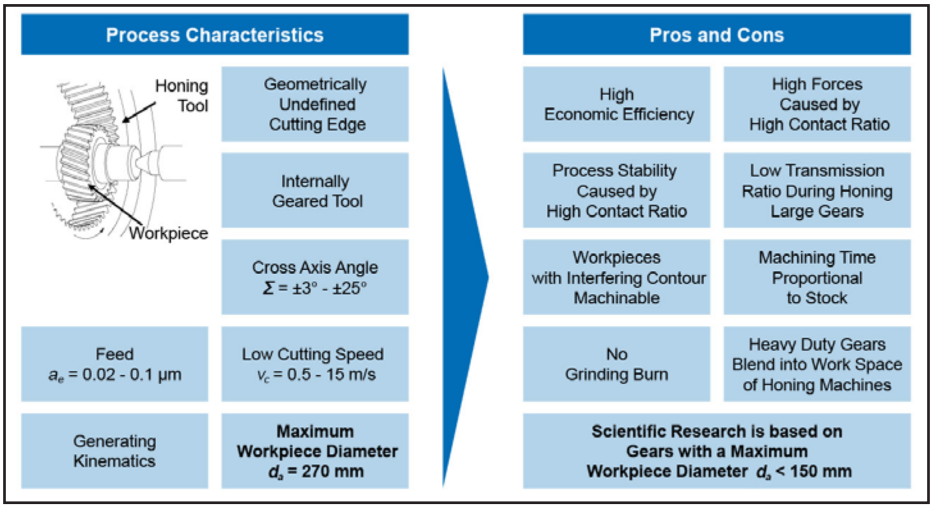

Figure 1 Process characteristics of gear honing.

High overlaps lead to large spindle moments, which are necessary to cut a high amount of material as large contact zones occur. Secondly, the gear ratio between honing tool and workpiece becomes smaller due to the limited space, thus the machined volume for each tooth of the honing tool increases and the lifetime of the honing tool decreases, respectively, as the dressing cycles shorten.

Another process characteristic is that an internally toothed tool with geometrically undefined cutting edges meshes under a cross-axis angle with an externally toothed workpiece. Compared to other grinding processes, these cutting speeds are very low and barely reach up to $v_c = 15$ m/s so that thermal structural damage can be avoided on the workpiece. Another advantage is that workpieces with interfering contours can be machined and that honing machines are already available in the industrial environment of large-module gears. A disadvantage of the honing process is the very low infeed—and thus the processing time—increases in proportion to the allowance.

In addition to process-related limits, the maximum size of the workpieces to be processed is limited to a tip diameter of 270 mm by the current honing machine generation, as the machines can hold honing with a maximum outside diameter of 400 mm. Given that honing is mainly found in the automotive industry, most of its scientific study is based on gears with a tip diameter of less than 150 mm.

Research Objective and Approach

Due to the existing challenges, a research project to optimize the honing process for large gears was initiated (Fig. 2).

The objective of this research project is to increase efficiency and process safety during honing of large-module gears. The objective of this report is to build an empirically physical process model. The model is intended to increase the efficiency and process reliability for honing and to contribute to an improved

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understanding of the process. The procedure for this is explained throughout the report. First of all, specific values for different honing process designs are generated on the basis of evaluated process designs chosen for practical experiments to allow direct linking of the results. To increase the amount of information gathered in the practical investigations, the test machine was equipped with additional measurement devices that make it possible to detect both the process resulting forces and the vibrations of various machine components.

For this purpose, the test workpiece and the honing tool designs are presented for different cross-axis angles in (*Workpiece and Honing Tool Designs*) before the results of the analytical calculation for the presented workpiece honing ring combinations are explained. The test machine and the measuring chain are then shown before the results of the force measurements are discussed in (*Empirical Process Analysis* section).

Workpiece and Honing Tool Designs

The workpiece used for the investigations presented in this paper is a transport transmission gear. The number of teeth is $z = 47$, with a module of $m_n = 4.55$ mm and a normal pressure angle of $\alpha_n = 21°$. The helix angle is $\beta = 18°$. The gear has a width of $b = 46.92$ mm and a tip diameter of $d_a = 231.75$ mm.

For the analytical calculations and honing trials, four different honing tool designs are used (Fig. 3); four different cross-axis angles were chosen. The complex relationships during honing require that additional geometric variables must be changed by adjusting the cross-axis angle Σ. This is due to the relationship that the sum of the helix angle of the tool and workpiece forms the cross-axis angle Σ. At a constant helix angle β of the workpiece, a change in the cross-axis angle Σ is followed by a change of the helix angle of the honing tool β. Therefore, the number of teeth z needs to be adjusted — resulting in a tip and root diameter change. This in turn must be compensated for by an adjustment of the center distance a. The corresponding honing tool designs can be found in Figure 3. In addition to the reference tool for this workpiece with a cross-axis angle of $\Sigma = -8°$, three other cross-axes were selected with pairwise different signs of the cross-axis angle at $\Sigma = -8°$ and $\Sigma = +8°$. This leads to the same cutting speed at the same rotational speed for this pairing.

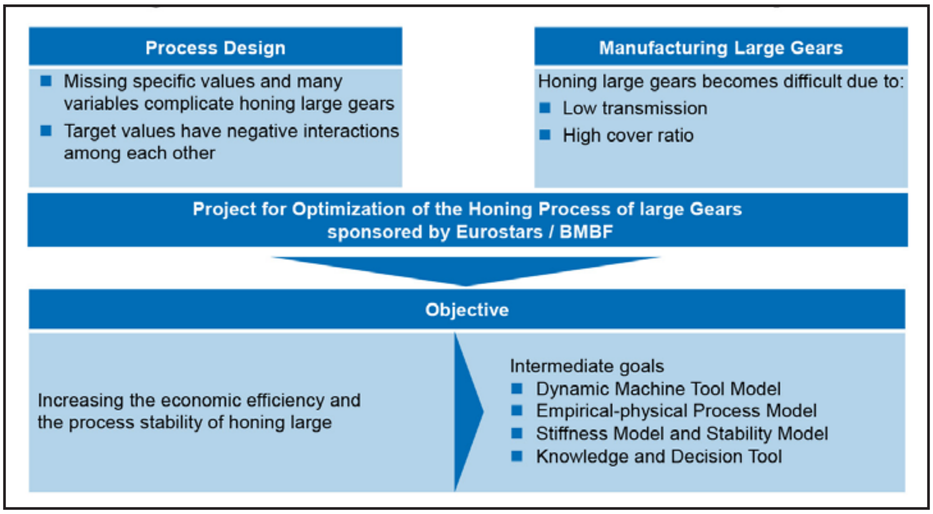

Figure 2 Research objective.

	HR1	HR2	HR3	HR4
Σ [°]	-15	-8	-3	+8
β_{HR} [°]	2.599	9.818	14.961	26.24
z_{HR} [-]	75	75	73	67
$d_{a,HR}$ [mm]	330.994	335.791	332.498	327.35
$d_{f,HR}$ [mm]	354	358.4	355.5	350.4
a [mm]	-60.779	-62.884	-61.2937	-58,380

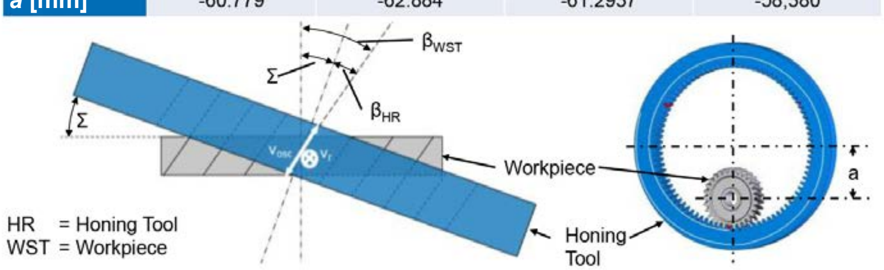

Figure 3 Honing tool designs.

Analytical Modelling of the Gear Honing Process

The cutting speed v_c is mainly responsible for machining the stock. The cutting speed is made up of the three components — lateral gliding speed v_{gH}, longitudinal sliding speed v_{gL} and oscillation speed v_{osc}. The oscillation speed is by a factor of 10^{-3} less than the other two components, and can therefore be ignored, so that the cutting speed may be described by the scalar addition of the lateral gliding speed v_{gH} and the longitudinal sliding speed v_{gL}. The lateral gliding speed v_{gH} can be calculated out of the radii of curvature and the angular velocities of the meshing parts, while the longitudinal sliding speed v_{gL} depends on the circumferential speed, helix angle and cross-axis angle. From cutting speed v_c and feed speed v_{rad}, the cutting performance is derived. The cutting performance can be used as a measure for process efficiency, which is the relevant value for honing process optimization.

For noise optimization, the cutting angle is the decisive factor, according to Köllner. An optimum noise behavior occurs when the machining marks are orthogonal to the lines of contact between wheel and pinion, with the cutting angle matching the angle of the machining marks (Ref. 1). Schweikert, however, determines that the cutting angle has no influence on the noise characteristics of gears and that it is sufficient that either pinion or wheel is honed (Ref. 2). The path of the line of contact depends mainly on the helix angle of the gear. The contact line length and orientation are two other evaluation criteria. The contact line length can be used as a measure of the contact area between tool and workpiece. Due to the constant contact force, a larger contact area leads to lower surface pressure. Thus, cutting material is more difficult because the necessary force for chip formation remains constant on the workpiece, but the processing power is distributed over a larger area. Consequently, cutting performance decreases with an increase of contact line length.

To a particular extent, this problem affects honing of large gears because an increase in size is usually associated with an increase of gear width. This is followed in turn by longer contact lines and an increase of material volume, which leads to a reduction of cutting performance — which is critical for the economic efficiency of the process.

Due to the independence of the contact line orientation from cutting angle and machining marks, the orientation of the contact lines has no direct influence on the process result, but does so indirectly via the process dynamics on the surface finish. Nevertheless, the orientation can be used as an indicator for process behavior. If machining marks occur, which are oriented parallel to the axis, the whole contact line length comes into contact very quickly. The expected effect is similar to a premature tooth contact and can lead to unsatisfactory process results. If the contact lines are more steeply oriented, the contact comes gradually and thus exerts no negative effect on the process (Ref. 1). The disadvantage of these kinematics is that the contact line length changes continuously during honing. This leads to different machining forces and torques that can negatively affect the process itself. Therefore, an optimization of the contact line orientation must be made in order to achieve an optimum result.

In addition to the previously conducted analysis of the contact line length for a tooth flank, the contact line length must be examined at the same time on both flanks of each engaged tooth. To describe the change in contact line length, a suitable value was found in the difference of total contact line length between both flank sides. First, the summation of contact length of all engaged teeth is

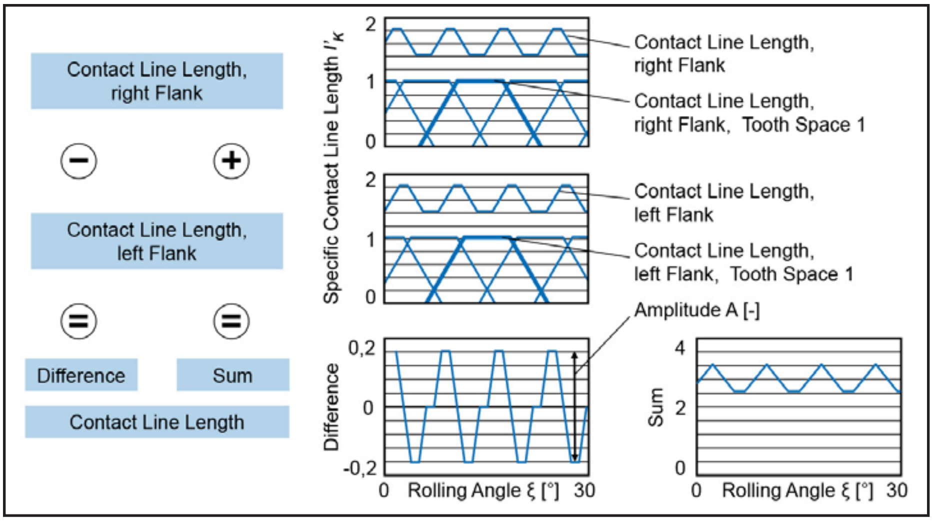

Figure 4 Difference and sum of the length of line of contact.

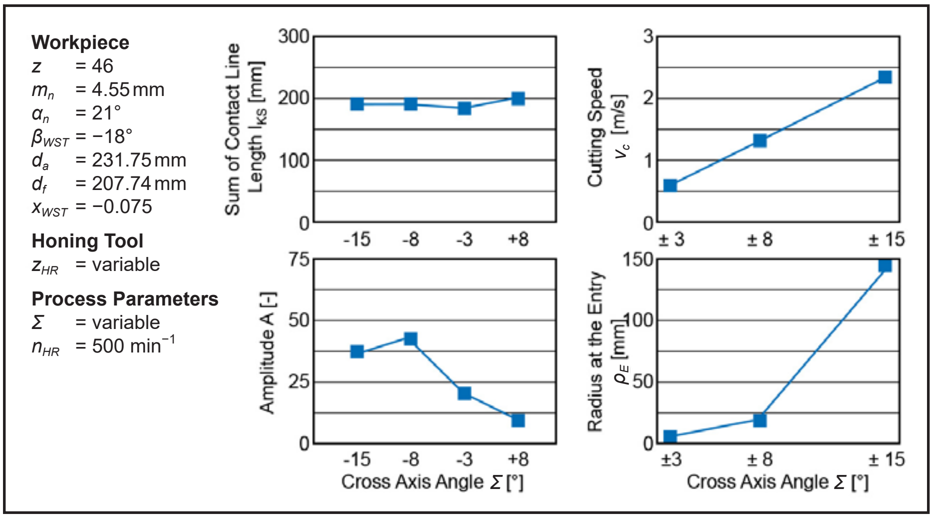

Figure 5 Influence of the cross-axis angle on the characteristic values.

separately formed for the left and right flanks to get the total contact line length. Subsequently, the total contact line length of the left and the right flank (Fig. 4) are subtracted from each other. At the considered helical gear, there is an angle on the contact lines, and thus, as already explained, a change in contact line length over the tooth profile. This continuous change in the contact conditions between left and right flank results in a change of torque. An exact machining of the desired topology is therefore not possible.

To describe this effect, the difference in total contact line length will be used. The total contact line lengths of the left and right flank can be regarded as phase-shifted oscillations — with the same frequency and amplitude. The difference in contact line length is shown in Figure 4; each difference of the total contact line length from the zero point changes torque during honing (Ref. 1).

In the following, the influence of the cross-axis angle on the process at a constant rotational speed of $n = 500$ min^{-1} and a constant feed of $f = 0.06$ μm is investigated. The simulated total contact line length l_{KS} as the sum of contact line lengths of left and right flank of the workpiece is influenced by the cross-axis angle (Fig. 5).

Within the group of negative cross-axis angles no systematic change in the total contact line length was identified. The value at $\Sigma = -15°$ and $\Sigma = -8°$ is $l_{KS} = 188$ mm, and decreases to $l_{KS} = 182$ mm for $\Sigma = -3°$. In contrast to this group the values for the total contact line length are increasing for positive cross-axis angles. The total contact line length increases to $l_{KS} = 199$ mm at $\Sigma = +8°$. Due to the higher total contact line length for cross-axis angle with a positive sign, it is assumed that the cutting forces will be increased for these process parameters.

A positive effect of using positive cross-axis angle is indicated by the amplitude *A*. The amplitude *A* is defined in this report as the unit less value of the difference between minimum and maximum of total contact line difference between left and right flank. From the amplitude $A = 25$ at $\Sigma = -15°$, the amplitude increases to the significant maximum $A = 42$ at $\Sigma = -8°$ before decreasing to $A = 22$ at $\Sigma = -3°$. In the area of positive cross-axis angle, the level is considerably lower, and the values of the amplitude reach a minimum of $A = 10$ at $\Sigma = +8°$. Low amplitude ensures a stable process without much disturbance in torque (Ref. 1). The results shown therefore point out that a positive cross-axis angle can be a possible solution if there are any vibration problems machining this component. At large cross-axis angles, the radius at the entry of the abrasive grain into the workpiece gets bigger and can result in a shallow immersing of the abrasive grains into the workpiece. This ensures that a high theoretical chip length l_s is generated. The chip length will be significantly reduced because the minimum cutting thickness is achieved rather late by the flat path, and a lot of energy will be flowing into plastic deformation of the workpiece material. Therefore the cutting process at a cross-axis angle of $\Sigma = \pm 15°$ is energetically classified as unfavorable. However, the flat grain path can have a positive effect on the wear behavior of the honing tool, since the collision energies are small and lead to longer tool life (Ref. 3). Large, effective direction angles are energetically advantageous because they allow good stock removal. This is achieved because the abrasive grains will penetrate the workpiece material more steeply via a decrease in radius of curvature. The stresses on the grain as it enters the workpiece will increase so that a decrease of honing tool lifetime is possible (Ref. 4).

Experimental Set-Up

The machine used for the trials in this paper is a modified gear honing machine (HMX-400) from Fässler. In addition to the standard integrated force measurement in *x*-direction to hone gears by force-controlled feed, a variety of other sensors was integrated into the machine (Fig. 6).

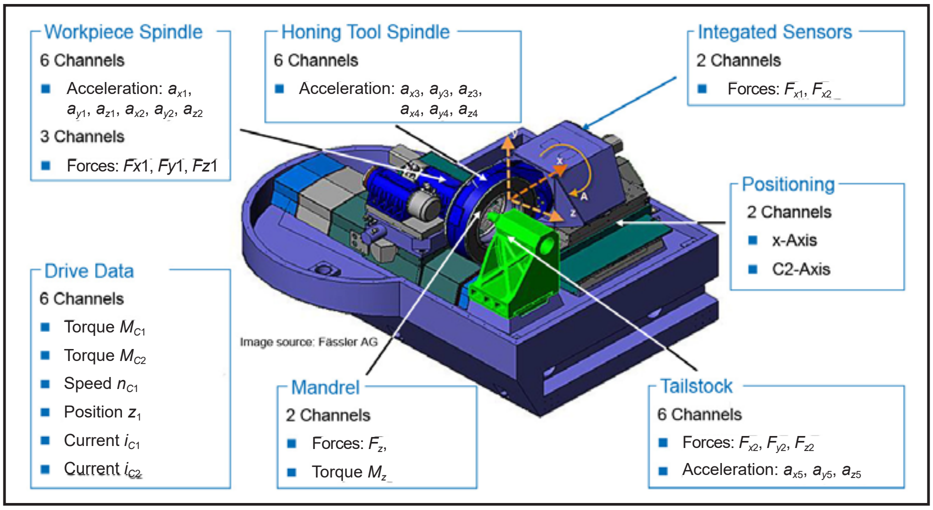

Figure 6 Trial set-up.

The workpiece side force is measured via pre-loaded sensors from Kistler. These were placed in the flux-of-force of the workpiece spindle and in the flux-of-force of the centering point. Accordingly, this arrangement allows receiving the forces in the three directions of a stationary coordinate system, corresponding to the coordinate system of the machine. Another sensor for measuring the force in *z*-direction is located in the mandrel and transfers the data without contact via a telemetry unit. The internal drive data is used to detect the torque of the spindle, the rotational speed of the tool spindles and the complementary current. In addition, the positions of *z1* and *x*-axis are recorded in parallel. The measurements with the calibrated force sensors are presented in (*Empirical Process Analysis* section).

Since gear honing is a highly dynamic process, various influences can lead to vibrational excitation of the machine. To measure those vibrations, three-axis acceleration sensors were built into the spindles and centering point. In each case, two sensors were used in the spindle and the centering point, which, by their arrangement, allows us to draw conclusions about any torques. Based on this data it should be possible to describe the process extensively and to couple process forces and vibrations with a machine model. By integrating such a massive measurement system, especially in the power flow in case of the force sensors, the rigidity of the machine is reduced. Therefore, the results need to be particularly scrutinized in the range of the excitation behavior of the machine and cannot be transferred directly to the serial machine.

The sensor output voltages are converted by charge amplifiers to a range from $U = \pm 10\,V$, which can be received by the measuring card. As a measuring card serves a modular system from National Instruments that allows synchronized recording of 32 channels with a resolution of 16 bit, the scanning of the sensors is carried out with a frequency of 15 kHz and thus with a significantly higher frequency than the tooth meshing frequency of the presented process. Furthermore, to avoid aliasing and to reduce the data rate to a level that's easy to handle, the measurement datasets are hardware-based, pre-filtered, clocked down to a frequency of about 5 kHz and transmitted in real time to an external disk.

The trace of a clocked-down 5 kHz signal is plotted over time (Fig. 7, top). The yet very high frequency continues complicating the interpretation of the force signals, so the signal must be further processed. For this purpose, the signals are reduced in *Matlab* to a frequency of 25 Hz and subsequently formed by the moving average of 100 readings. The resulting trace is shown (Fig. 7, bottom). In addition to the consideration of the mean values, the dynamics of the measured amplitudes and frequencies must be addressed.

To reduce the amount of data, the datasets were divided manually due to a lack of an automated cutting recognition so that only main machining time is considered and the non-contact time and spark out are not incorporated within the results. These areas were determined individually for each experimental point, as the process execution with a constant feed rate lead to varying processing times because of the fluctuating distortion due to the heat treatment and soft machining of the components.

Empirical Process Analysis

To simplify the interpretation of the results — and to eliminate as many variables as possible — only the measurement results of two tool designs with a cross-axis angle of $\Sigma = -8°$ and $\Sigma = +8°$ will be compared in the following. The analytical evaluation of these designs showed a significant difference between the amplitude parameters and therefore should be favorable to analyze the influence of the amplitude parameter on the process. The process parameters used in the trials were derived from a constant cutting speed of $v_c = 3$ m/s at the pitch diameter of the workpiece. The resulting rotational speeds of the honing tool were $n = 1{,}783$ min^{-1} for a cross-axis angle of $\Sigma = +8°$ and $n = 1{,}872^{-1}$ for a cross-axis angle of $\Sigma = -8°$. The feed rate was $f = 0.09\,\mu$m for both processes. As an example, the resulting radial forces in x direction are shown (Fig. 8). The force readings follow a characteristic curve. First, a progressive increase in force is applied by establishing contact and slowly machining first feed marks and generating cut deviations from the preprocessing. This is followed by an approximately linear increase in force. This shows that during machining, no stable process is reached, where a constant force would be assumed. The force curves for both cross-axis angles are similar.

The maximum force for a cross-axis angle of $\Sigma = -8°$ is $-1{,}800$ N and therefor a little bit higher as for a cross-axis angle of $\Sigma = +8°$ with a maximum radial force of $-1{,}650$ N. But the approximately five percent lower rotational speed at a cross-axis angle of $\Sigma = +8°$ is followed by less machined material. Considering the linear increase in force, the maximum force would be higher for the same material removed. The difference between the maximum forces would decrease to an insignificant amount and can therefore be ignored.

An influence of the specific value of the total contact length, which was at

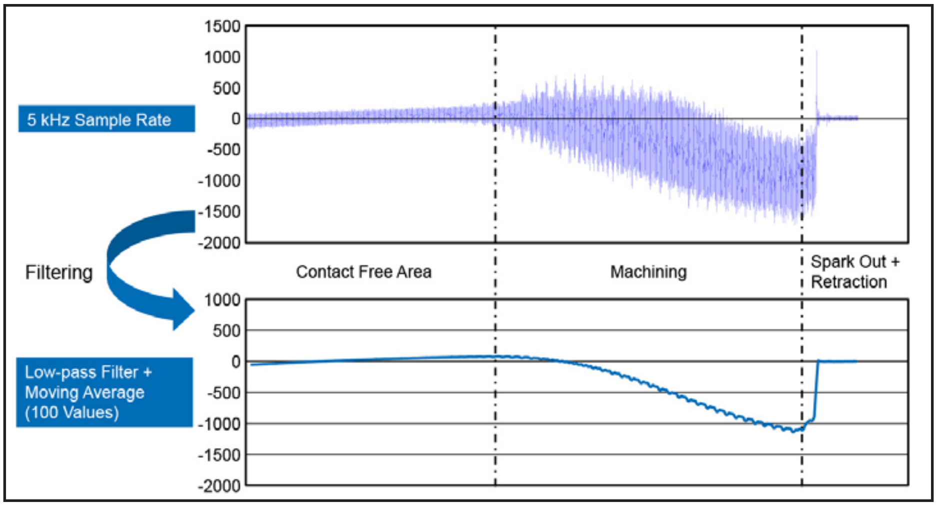

Figure 7 Signal processing.

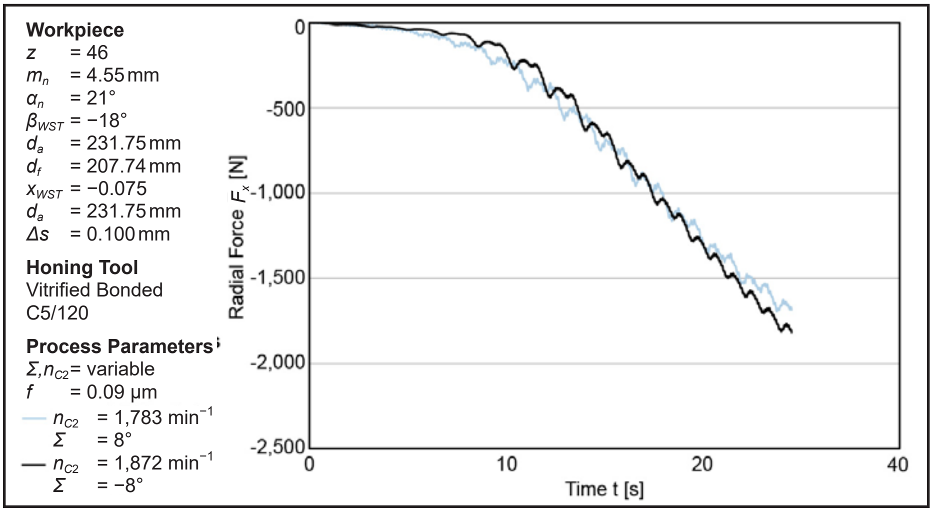

Figure 8 Influence of the cross-axis angle on the radial force one-half.

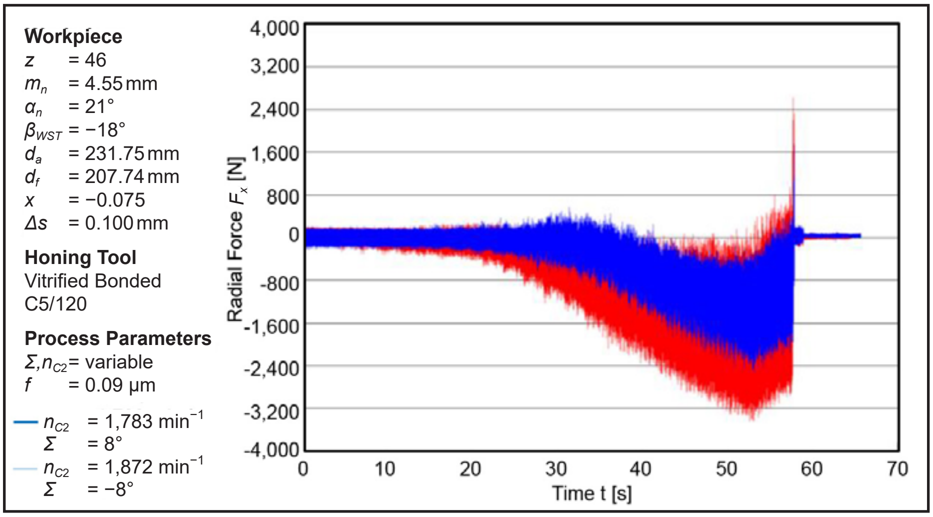

Figure 9 Influence of the cross-axis angle on the radial force 2/2.

$l_{KS} = 188$ mm for $\Sigma = -8°$ and $l_{KS} = 199$ mm for $\Sigma = +8°$, on the maximum force was not found. The difference between the analyzed tool designs in case of total contact length seems too small to be found in the measurements. But comparing the quality of the honed gears machined by using the whole variety of tools mentioned before to the average or maximum forces shows no correlation. Therefore, the vibration during gear honing will be in focus in the following. Figure 9 shows the force reading during honing with less filtering than before.

Comparing the force amplitudes near the end of the process, a force amplitude of 2,000 N can be found for a cross-axis angle of $\Sigma = +8°$ and a force amplitude of 3,200 N for a cross-axis angle of $\Sigma = -8°$. Therefore, the influence of the contact line length difference shown in (*Analytical Modelling of the Gear Honing Process*) is confirmed. The amplitude value of $A = 42$ at $\Sigma = -8°$ is significantly higher than the amplitude of $A = 10$ at $\Sigma = +8°$. Since there is a factor of more than four between the amplitude values and only a factor of 1.5 between the force readings, it is shown that there is no linear correlation and only a qualitative prediction is possible. The difference in force amplitude leads to a bad workpiece geometry for a cross-axis angle of $\Sigma = -8°$ whereas a good workpiece geometry for a cross-axis angle of $\Sigma = +8°$ was achieved. Changing the cross-axis angle to $\Sigma = +8°$ made it possible to machine the part 50% faster with a good workpiece geometry compared to the reference process design with a cross-axis angle of $\Sigma = -8°$.

Summary and Outlook

Gear honing is an established hard finishing process for small gears. Although modern gear honing machines are capable of honing gears with a tip diameter up to $d_a = 270$ mm, gear honing could not become accepted in the industry for hard finishing gears with a tip diameter between $da = 150$ and $d_a = 270$ mm. There are positive examples of parts that size that are honed successfully, but the process often missed the needed stability to generate the demanded quality reliably. To date, the scientific investigations of honing large gears are insufficient.

It was the research objective of this paper to develop an approach for an empirical-physical process model. The analyses of the process forces in connection with the process parameters and the analytical calculated characteristic values were shown. In an ideal process, force and torque would seek a stationary state — which was not reached in the trials. The cross-axis angle variation during the trials has shown — in comparison with the characteristic values of the analytical calculation — that the characteristic values are partially meaningful. On the one hand, for the total contact line length, no correlation was found regarding the maximum forces during honing. But it was also shown that there is no direct correlation between the maximum force and gear quality. Therefore, this specific value is not useful. On the other hand, the amplitude parameter *A*, as the difference between the contact line length between the right and the left flank, can be used to give a quantitative predication of the force amplitudes in the process that can be directly related to gear quality. A huge increase of productivity is possible by changing the cross-axis angle and therefore reducing the force amplitudes during honing.

This analysis has shown great potential for the presented workpiece. Additional gear designs must be analyzed and compared to the prediction values to validate the approach.

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Markus Brumm, a RWTH graduate with a degree in mechanical engineering, began his career in 2005 as a research assistant in gear investigation at the Laboratory for Machine Tools and Production Engineering (WZL) of the RWTH Aachen. He subsequently became that group's team leader in 2010. In November 2014, he joined Klingelnberg GmbH as manager of the company's Technology Center.

Prof. Dr.-Ing. Dr.-Ing. E.h. h.c. Dr. h.c. Fritz Klocke studied manufacturing engineering at the TU Berlin, was a research fellow there at the Institute for Machine Tools and manufacturing Technology until 1981, and then as head engineer until 1984, receiving his engineering doctorate in 1982. Klocke worked in industry from 1984 until 1994 at Ernst Winter & Sohn in Hamburg. On January 1, 1995 he was called to the RWTH Aachen as Professor of Manufacturing Engineering Technology and has since then been Chair of Manufacturing Technology, co-director of the WZL Laboratory for Machine Tools & Production Engineering at the RWTH Aachen and head of the Fraunhofer Institute for Production Technology IPT in Aachen. Klocke was awarded the Otto-Kienzle Memorial Coin in 1985 by the Manufacturing Engineering University Group. The title,"Dr.-Ing. E.H," was bestowed upon Klocke by the University of Hannover in 2006 for his outstanding achievements in science, his efforts in the industrial implementation of a broad range of manufacturing techniques, and for his commitment to numerous scientific committees. The title "Dr. h. c." was awarded him in 2009 by the University of Thessaloniki and in 2010 by Keio University in Tokyo for his achievements in production science, his engagement in international cooperation, and his benefits as a teacher and supervising tutor of student engineers.

Dipl.-Ing. Marco Kampka is a scientific research assistant at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Chair of Manufacturing Technology. After one year of military service (2004), Kampka earned from 2005-2012 his degrees in mechanical engineering at Aachen, with a focus on production engineering, in particular the hard finishing of gears, gear honing and surface properties.

Ask the Expert Goes LIVE!

POPULAR GEAR TECHNOLOGY AND PTE FEATURE A BIG HIT AT GEAR EXPO

During Gear Expo 2015, *Gear Technology* and *Power Transmission Engineering* magazines hosted four live sessions of "Ask the Expert." Based on the magazine column of the same name, the sessions featured world-renowned experts in gear design, manufacturing and theory. The experts took questions from the audience and provided their technical expertise to the gear industry professionals in attendance. Each session covered a specific area of gear technology and lasted from 45 minutes to an hour.

Gear Grinding

The Gear Grinding session featured Harald Gehlen, Head of Application Engineering for Reishauer; Enrico Landi, Machine Tools Product Center Director for Samputensili; Dr.-Ing. Andreas Mehr, Technology Development Manager for Grinding and Shaping at Liebherr; and Dr. Hermann J. Stadtfeld, VP Bevel Gear Technology and R&D at Gleason. Here are just a few of the grinding questions included in the session:

- What grinding parameters affect the risk of grind temper?
- Can accuracy of inspection be trusted if it's done on the grinding machine, or does it need to be inspected on an independent CMM?
- What are the advantages of CBN grinding over dressable ceramic?
- How do you decide how much stock to remove per pass?
- What is flank twist or bias in ground helical gears, and can it be eliminated?
- Those who were not in attendance can visit www.geartechnology.com/videos to watch the video-recorded sessions.

Cutting Tools

- The Cutting Tools session featured Dr.-Ing. Nicklas Bylund, Manager of the Engineering Competence Center at Sandvik Coromant; John O'Neil, Engineering Manager for Gear Cutting Tools at Star SU; and Dr. Hermann J. Stadtfeld, VP Bevel Gear Technology and R&D at Gleason. The cutting tools related questions included these and many others:
- When are short lead hobs needed, and how do you select them?
- Do hobs and shaper cutters need to be re-coated after every use?
- How does hob or cutter material affect feed and speed selection?
- When is climb hobbing advisable?

Gear Design

The Gear Design session included Octave Labath, independent consultant and *Gear Technology* technical editor; Dr. Hartmuth Müller, Chief Technical Officer at Klingelnberg; Prof. Dr.-Ing. Karsten Stahl, Head of the Gear Research Center (FZG) at the Technical University of Munich; and Frank Uherek, Principal Engineer for Gear Engineering Software Development at Rexnord. The gear design questions included:

- Is it true that ISO 6336 rates gears with higher load capacity than AGMA 2001?
- How do you select profile shift for the pinion for spur gears?
- What are the advantages of asymmetric gears?
- If a hobbed pinion has undercut, can I make it on a five-axis machine and eliminate the undercut and optimize the root fillet?

Ask Anything

The last session covered the widest variety of topics, as we invited our audience to "ask anything." The experts on hand included Octave Labath, independent consultant and *Gear Technology* technical editor; Dr. Hartmuth Müller, Chief Technical Officer at Klingelnberg; Chuck Schultz, independent consultant and *Gear Technology* technical editor and resident blogger; and Prof. Dr.-Ing. Karsten Stahl, Head of the Gear Research Center (FZG) at the Technical University of Munich. Questions included:

- What is the optimum case hardness for carburized gears?
- How do sintered, composite gears compare to case carburized gears?
- Between a straight bevel gear, a spiral bevel gear and a hypoid gear, which one can transmit more load, and which one is quieter?
- Is there a reference and an example calculation for "short pitch hobbing"?

In addition to all of the above, there were many more questions asked and answered. If you are interested in hearing the presentations and learning the answers to these questions, please visit *www.geartechnology.com/videos*, and choose the appropriate session.

Meeting of the Minds

AT GEAR TECHNOLOGY CONTRIBUTORS' DINNER

On October 20, the editors and staff of *Gear Technology* and *Power Transmission Engineering* were pleased to host a dinner for many of our technical editors, authors, regular contributors and others who share our vision and passion for advancing the collective knowledge of the gear industry. In attendance were (from left to right): Randy Stott, Associate Publisher & Managing Editor, Gear Technology; Dipl.-Ing. Michael Hein, research at FZG; Dr.-Ing. Thomas Tobie, department leader, FZG; Dr. Michel Octrue, mechanical power transmission researcher from CETIM; Chuck Schultz, Principal, Beyta Gear Service, and technical editor/resident blogger, Gear Technology; Dr. Ulrich Kissling, President, KissSoft; Frank Uherek (back row), Principal Gear Engineer at Rexnord and technical editor, Gear Technology; Octave Labath, independent consultant and technical editor, Gear Technology; Prof. Dr.-Ing. Karsten Stahl, Head of the Gear Research Institute (FZG) at the Technical University of Munich; Yefim Kotlyar, Technical Specialist, Navistar; John Lange, instructor, Gleason Gear School; Enrico Landi, Machine Tools Product Center Director, Samputensili; John O'Neil, Engineering Manager for Gear Cutting Tools, Star-SU; Thomas "Buzz" Maiuri, Chairman, AGMA Technical Division Executive Committee; Prof. (emeritus) Dr.-Ing. Bernd-Robert Höhn, FZG; Michael Goldstein, Publisher & Editor-in-Chief, Gear Technology; Dr. Hartmuth Müller, Chief Technical Officer, Klingelnberg; Dr. Hermann Stadtfeld, VP Bevel Gear Technology & R&D, Gleason; Alex Kapelevich, Principal, AK Gears; Dean Burrows, President, President of Gear Motions and Chairman of the Board of AGMA; Carlo Gorla, Professor at Politecnico di Milano and Technical Director at *Organi di Trasmissione*; Jack McGuinn, Senior Editor, Gear Technology; Erik Schmidt, Assistant Editor, Gear Technology; Norm Parker, Bearings Technical expert at General Motors and resident blogger for Power Transmission Engineering; Bob Smith, Principal, R.E. Smith & Co. and technical editor, Gear Technology; Dave Friedman, Associate Publisher and Sales Manager, Gear Technology; Amir Aboutaleb, VP of the Technical Division, AGMA. Photo by Dave Ropinski, Art Director, Gear Technology.

Timken Expands Service Center in Washington

TO DELIVER MORE REPAIR CAPABILITIES

The Timken Company recently opened a 70,000-square-foot, motor and gearbox repair facility adjacent to its existing service center in Pasco, WA. Built to enhance service to Timken Power Systems' (TPS) customer base throughout the Pacific Northwest, the $7 million investment gives the facility additional capabilities to repair large electric motors, wind turbine generators and industrial gearboxes under one roof.

"We continue to grow our Timken Power Systems offering of services, working to provide customers in demanding industries with full drive train repairs — including gearboxes, motors, generators and large-diameter bearing repair," said Carl Rapp, vice president of the Timken Power Systems business. "This investment extends our U.S. regional service center network capabilities and positions us to more completely support our industrial customers in the Pacific Northwest to help them optimize their equipment lifecycle performance."

Leveraging the legacy regional strength of the H&N Electric services brand, TPS' Pasco service center houses some of the broadest repair capabilities in the region, able to serve customers in the wind energy, power generation, oil and gas, mining, pulp and paper and agricultural sectors. Its efficient layout optimizes space and features large-capacity cranes, lathes, ovens, VPI tanks and boring mills. With this equipment, TPS is capable of repairing electric motors up to 5,000 horsepower and wind turbine generators to meet developmental demands of 5 MW and larger. Additionally, the facility performs complex industrial gearbox repairs to the standards of Philadelphia Gear, the gear brand that stands at the center of the Timken Power Systems portfolio.

The well-equipped facility features: fifty-ton crane lift capacity with 35 feet clearance under hook; twenty work station jib cranes; large-capacity vacuum pressurized impregnation (VPI) system with a 10-foot diameter and 24-inch shaft well, capable of processing a rotor/shaft length up to 14 feet; large-capacity burn and bake capability; enhanced machining capability provided by a 70-inch swing lathe, 60-inch horizontal boring mill, surface grinder and a 72-inch radial drill press; large-capacity dynamic balance capability on isolated and thickened slab; magnetic particle inspection; large-capacity 5,000 horsepower motor and gearbox test center capability; and dedicated production bays for large and small/medium sized motor repair cells.

"Our team has been eager to expand deeper into the Northwest market. We've been a leader in the wind market sector for some time and we recognize the larger industrial opportunity here," said Nathaniel Glessner, Timken manager of the Pasco facility. "It's exciting to now be able to develop that potential and offer existing customers larger motor/generator repair capacity as well as introduce new capabilities to a broader market."

Don Jordan

AWARDED THE HIGH HONOR OF ASM FELLOW

Solar Atmospheres' Corporate Metallurgist, Don Jordan, was recently awarded the high honor of ASM Fellow (FASM) at the ASM Awards Dinner held Oct. 6, 2015 during the MS&T15 Conference in Columbus, OH.

According to ASM, "The honor of Fellow represents recognition of distinguished contributions in the field of materials science and engineering, and develops a broadly based forum for technical and professional leaders to serve as advisors to the Society."

Don's citation read: "For sustained technical excellence in a career that includes development of wear and corrosion resistant materials for Navy submarines and outstanding leadership in the development and implementation of novel vacuum heat treatment technology for surface treatment of metals."

"Obviously I am honored, yet I am privileged to work with the Solar R&D Team; they make me look good," Jordan said.

Jordan is a 27-year member of ASM International and has served in every executive position of the Philadelphia Liberty Bell Chapter, including 2002-03 Chairperson. As evidence of Jordan's service and commitment to the ASM Philadelphia Chapter, he has received: two President's Awards (2004 & 2007); Adolph Schaeffer Special Achievement Award (2005); Philadelphia Chapter Distinguished Service Award (2008); Delaware Valley Materials Person of the Year Award (2010); Albert Sauveur Lecture Award (2013); and Meritorious Service Award (2014). Jordan also is a member of: NACE, SAE & the Aerospace Metals Engineering Committee (AMEC), and APMI.

Christian Dalton

HIRED AS EXPANITE'S NORTH AMERICAN SALES MANAGER

Since the opening of the 6500 ft^2 production-, laboratory- and test center in Hillerød, Denmark, in 2013, Expanite has been experiencing growth in the European markets.

During 2015, the company has seen a number of new customers in the USA and Canada, and it has therefore been natural to establish a subsidiary—Expanite Inc.—and at the same time open a new treatment center in Ohio.

Expanite can now offer its North American customers the same superior gaseous surface hardening treatment options as in Europe. Customers can choose to have their material processed in our facilities in Ohio on a day-to-day basis or opt for a fully automatic solution installed directly in their production line thereby eliminating the cost, logistics and risks involved in shipping the parts for hardening.

Expanite is also expanding its presence in North America by welcoming **Christian Dalton** as new North American sales manager. Christian Dalton has a Ph.D. in Material Science and Engineering from Case Western Reserve University. With the addition of Christian Dalton, the opening of Expanite Inc and the new treatment center, the company is ready for the continued expansion of the Expanite's processes as the leading techniques for hardening of stainless steel.

Romax and Comet Solutions

ENTER INTO PARTNERSHIP TO AID USERS OF ROMAXDESIGNER

Romax Technology Ltd. and Comet Solutions, Inc. recently announced a partnership between the two companies. Specifically, the agreement will provide users of RomaxDesigner software with the ability to create automated simulation processes that integrate CAD, FEA, Romax and others.

RomaxDesigner enables users to quickly and accurately perform detailed analyses of critical performance attributes, including durability, efficiency and dynamics, including advanced features such as manufacturing variation and planetary sideband analysis.

Comet provides simulation automation and standardization processes by integrating the variety of tools used by gearbox/transmission product engineers, including CAD, finite element meshers, RomaxDesigner, structural analysis tools, fatigue life tools, packaging/tolerancing tools, and other detailed gear design tools. By integrating data and tools within a single automation environment that includes optimization capabilities, Comet enhances the system analysis aspects of RomaxDesigner, providing product engineers with a capability to explore the interactions between flexible structural components, such as housings and planetary carriers, and the resulting gear, bearing and overall system performance.

"Romax is widely recognized as a leading global provider of integrated software and services for gearbox, bearings and driveline systems," said Dan Meyer, Comet Solutions president and CEO. "Comet further extends the capabilities of RomaxDesigner creating an integrated and automated design and analysis environment. This allows users to invoke a variety of software tools for faster design evaluation. While we are naturally excited by this partnership, the true beneficiaries are the world's gearbox and drivetrain communities who will see sustained improvements in, design integrity, and time to market."

DMG MORI USA

LAUNCHES CUSTOMER-CENTRIC SALES AND SERVICE MODEL

DMG MORI recently launched a direct-to-customer sales and service model in the United States. The company will double its existing local service and sales centers to 27 locations across the country in close proximity to customers. This expansion will enable DMG MORI USA's sales and service teams to more efficiently and effectively serve more than 13,000 customers and nearly 100,000 machine tool users across industries including aerospace, automotive and medical industries.

The new model will connect DMG MORI USA employees closely to customers and will speed up critical processes, such as managing local service support and sharing new product improvements based on the feedback of U.S. customers. It also maximizes the company's ability to quickly reach and service machines, and take immediate action on customer feedback. This direct sales and service model is part of an effort by DMG MORI to closely partner with customers.

"DMG MORI USA will partner on a very localized basis with our customers to improve value and outcomes, and ensure they're fully connected to the innovative power we can offer through our global size and scale," said Dr. Thorsten Schmidt, who will lead DMG MORI USA as chief executive officer. "This transition also opens great opportunities for DMG MORI employees who will now have the freedom to work directly with customers, co-create advancements and deliver insight-driven solutions."

The move to more localized service accompanies several internal DMG MORI USA leadership changes. DMG MORI's Global Executive Board selected Schmidt to lead DMG MORI USA, calling upon Schmidt's more than 13 years of leadership experience within the company to run the U.S. market.

Schmidt will be supported by a management team of leaders currently working at DMG MORI USA. Current President and CEO Mark Mohr will support the new sales and service organization as president of the DMG MORI Manufacturing plant in Davis, CA, utilizing his knowledge of customer needs in future product developments.

November 30-December 3—DMC 2015 and DMSMS 2015 Phoenix Convention Center, Phoenix, AZ. The DMC is the nation's largest annual forum for enhancing and leveraging the efforts of scientists, engineers, managers, technology leaders and policy makers across the defense manufacturing industrial base. This event brings together leaders from government, industry and academia to exchange perspectives and information about critical Department of Defense (DOD) industrial base policies, sector analyses and manufacturing technology programs for the production and sustainment of affordable defense systems. This is the premier national forum for presenting and discussing initiatives aimed at addressing enhanced defense and related national manufacturing capabilities and requirements. Since its inception in 1969 as the Manufacturing Technology Advisory Group (MTAG) Conference, DMC has provided the defense community with a forum for presenting the latest innovative manufacturing technology developments. Average attendance is well over 1,000, divided between government and industry participants, with a small complement from academia. DMC 2015 continues a long-standing tradition of presenting the requisite policy, strategic investment planning, program management, risk mitigation and workforce education and training efforts necessary for efficient technology adoption and resilient, force shaping impact in a period of shrinking defense budgets. The DMSMS Conference is the nation's largest annual forum for enhancing and leveraging the efforts of scientists, engineers, managers, technology leaders, and policymakers across the defense manufacturing industrial base. This event brings together leaders from government, industry, and academia to exchange perspectives and information about critical DoD industrial base policies, sector analyses, and manufacturing technology programs for the production and sustainment of affordable defense systems. This is the premier national forum for presenting and discussing initiatives aimed at addressing enhanced defense and related national manufacturing capabilities and requirements. The DMSMS Conference focuses on mitigating risks resulting from obsolescence due to the loss of manufacturing sources or material shortages. Over 200 exhibits will showcase government and industry manufacturing initiatives and qualified suppliers for semiconductors, electronic and mechanical parts, life-cycle management, parts management, and obsolescence management. Both shows will happen at the same time and place. While each show will have its own agenda, there will be some crossover between the two (such as combined luncheons) and it is possible to attend both for the price of one. For more information, visit *http://dmcmeeting.com*.

December 7-10—Gleason Cutting Tools Gear School 2015 Rockford, Illinois. This comprehensive 3 and1/2 day program is a blend of shoptime and classroom study. A coordinated series of lectures is presented by engineering, production, inspection and sales staff members averaging 27 years' experience. It's an ideal course for those individuals who are seeking to understand the fundamentals of involute gear geometry, nomenclature, manufacturing and inspection. Training groups are kept small so that individual concerns may be fully addressed. Students are welcome to bring sample gear prints and inspection charts for discussion and interpretation. The fee is $895 per person (group rates available) which includes handbook and all materials, one group dinner and all lunches. Hotel room is not included. The curriculum includes fundamentals, high speed steels and coatings, cutting the gear, gear inspection, a plant tour as well as individual instruction and specific problems. For more information, visit *www.gleason.com*.

December 7-10—14th International CTI Symposium Estrel Hotel, Berlin. The automotive industry is about to change drastically due to energy and CO2 discussion, interconnection and automation. This results in new requirements on drive trains and transmissions with regard to efficiency, comfort, dynamics and safety, which in turn lead to a large variety of competing drive and transmission concepts and to a previously unknown wave of innovations for components and assemblies. It does not only apply to the new electrified drive trains, but also to conventional drive trains and transmissions, which will remain the pillars of drive technology for the time being. At this year's Symposium, the hybrid transmission concepts of companies such as Toyota will be combined as "Dedicated Hybrid Transmission" (DHT) for the first time and discussed in front of an expert audience. The DHT concepts enable the vehicle to be driven in serial and/or parallel hybrid mode, purely electric, and optionally in combustion engine drive mode. For more information, visit *www.transmission-symposium.com/en*.

December 10-12—PRI Trade Show 2015 Indiana Convention Center, Indianapolis, IN. Racing industry professionals from across the US, and 70 countries, will gather in Indianapolis this December for the Performance Racing Industry Trade Show (PRI 2015). It will pack the Indiana Convention Center with exhibits of new racing products, motorsports engineering solutions, machining equipment and more. Approximately 1200 racing companies will exhibit in PRI 2015, which takes place Dec. 10-12. The show provides racing retailers, race engine builders, professional race teams, WDs, motorsports engineers and more the opportunity to preview virtually all the new racing technology becoming available for the next racing season. Racing entrepreneurs can meet face to face with suppliers, make purchase decisions, and have the new products in stock for the start of racing in 2016. For more information, visit *www.performanceracing.com/tradeshow*.

January 4-8—SciTech 2016 Machester Grand Hyatt, San Diego, CA. The AIAA Science and Technology Forum and Exposition (AIAA SciTech 2016) is the largest event for aerospace research, development, and technology. The expo will draw more than 3,000 participants and feature more than 2,000 technical presentations, including the best papers from students around the world. Bringing together 12 individual technical events at a single location, this forum is the place to engage with colleagues within your discipline and to interact with experts in other disciplines. For more information, visit *www.aiaa-scitech.org*.

January 21-26—2016—IMTEX Forming Bangalore International Exhibition Center, Bangalore, India. IMTEX Forming is an event for the Indian Metal Forming Industry. It is South and South-East Asia's apex exhibition showcasing the very latest trends in metal forming machine tools as well as technological refinements from India and other global players. The event attracts visitors from a wide spectrum of manufacturing and ancillary industries starting with key decision and policy makers as well as industry captains who are keen to source latest technologies and manufacturing solutions for their production lines. IMTEX Forming has become a one-stop forum where customers can experience "live" display of the products enabling them in the decision making process to enhance their manufacturing capabilities. IMTEX Forming 2016 is a greatly expanded fair and includes all forming technologies. The show focuses on sheet metal, but also covers plastics, ceramics, composites and exotic materials. For more information, visit *www.imtex.in/imtex2016*.

gear TECHNOLOGY

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

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

____

5 → My company's principal product or service is:______________________

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

- ☐ My company MAKES gears (20)
- ☐ My company BUYS gears (22)
- ☐ I DESIGN gears (23)
- ☐ I am a SUPPLIER to the GEAR INDUSTRY (please specify product or service) (24)

____

Is there a colleague within your company that might benefit from having their own copy of ***Gear Technology*** magazine?

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ad index

Mekanizmalar!

Mekanizmalar. Ever heard of it? No, it's not a lost password from *1,001 Arabian Nights*. In fact it is a website — since 2004 — that employs the universally loved art of animation *(Adobe Flash)* to clearly explain the basic and not-so-basic workings of mechanisms — including geared, pneumatic, hydraulic and electronic components.

The man behind Mekanizmalar is **Dr. Seyhan Ersoy**. He journeyed from his native Turkey to the U.S. in 1979 to complete his Ph.D. studies, and then returned home to begin a career as an associate professor. He came back to the states in 1989, working for United Technologies Research Center as a researcher in collaboration with Lehigh University. He later held programmer positions — until 2009 — at AT&T, IBM, Cadmus and USA Tech. Regarding gears, Ersoy puts it this way: "From1985 – 1989, I worked in a company as a consultant in which I learned a great deal about pneumatic, hydraulic and, to some degree of experience — gears. I read a lot about gears, but I do not consider myself an expert. I consider myself a dedicated learner." Now 66, Ersoy says he is "doing what I always wanted to do — work on something that I like."

And we thought you'd like to know more about this interesting gentleman — especially after you've had a chance to visit his website (*Mekanizmalar.com*).

ADDENDUM (ADD) *What compelled you to begin Mekanizmalar.com? — e.g., are you an engineer expressing himself through animation, or an animator expressing himself through engineering?*

SEYHAN ERSOY (SE) I am a mechanical engineer who made his living by doing programming. Therefore I consider myself as a programmer with a strong passion about mechanical engineering. This puts me in a special position. Having engineering knowledge and programming skills are a good combination for mechanical animators.

(ADD) *Is your intent to educate?*

(SE) The short answer to this question is yes. If I elaborate, I could say my intent was to educate young engineering students by exposing complexity of a mechanism with animations. They say "a picture is worth a thousand words;" but with current technology we can comfortably say that "a picture is worth a thousand words — but animations are priceless."

(ADD) *How is the traffic level on the site? Keeping you busy? I understand you have a day job?*

(SE) I have a part-time day job. I teach at Lehigh University as adjunct professor; I teach *Mat Lab* and *Arduino* programming to engineering students. Traffic level is changing through the time of year. During the summer when the schools are on vacation, traffic goes down, but gradually it rises slowly.

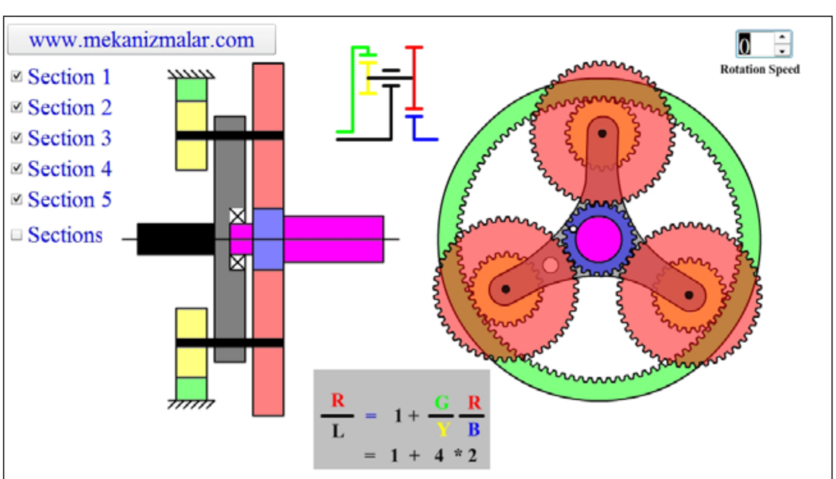
My site keeps me very busy and I enjoy doing it. They say "Find a job you like doing and never work again." But from time to time I do some stuff that no one out there can do; it gives me a lot of satisfaction.

(ADD) *Do any technical training schools (or high schools, jr. high — lower?), companies, etc. use your tutorials for training purposes?*

(SE) I know schools are using my tutorial through *YouTube*. (Power transmission giant) Danfoss purchased the rights to use (my) hydraulic pumps videos for internal training. One publisher purchased my T-head engine animation rights to use in a thermodynamic book they were going to publish. A utility company wanted me to do two animations for them; one was a pumped storage system and the other one a Francis turbine animation.

(ADD) *Could there be plans for something like that in either a commercial or NFP scenario?*

(SE) We live in America, and in America there is no such a thing as a free lunch. Having said that, let me elaborate on your question. I would love to do this kind job commercially and make money out of it. But it requires finding the right connections (and) with the right resources. Since I have limited connections, I find it like chasing a pipe dream. I believe the future is in the animations and the right team with the right content can be a great competitor to *www.howstuffworks.com*. NFP is not seems attractive to me; however as far as money is concerned, I am in the red. If I flip burgers at McDonald's for the amount of time I put to my animations, I would be in a much better situation than I am in now. Making money doing something you hate, or doing something you like with less money — I chose the latter.



If "A picture is worth a thousand words," what is the value of moving pictures? This animated planetary gearset tutorial is just one example to be found at the *Mekanizmalar* website (courtesy Mekanizmalar/Ersoy).