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MAR/APR 2013

Heat Treat 2013

Automotive Getting Sincerely Plastic

My Gears Are Bigger than Your Gears

THE OSU GearLab: Still Making a Joyful Noise

TECHNICAL

INDUCTION HEAT INNOVATION UPDATE

HEAT TREAT AUDIT? NO SWEAT!

DUAL-CLUTCH GEARBOX SHAFT — OPTIMALLY PROCESSED

ASK THE EXPERT:
WORKHOLDING MULTI-TASK MACHINING: LARGE SKEW BEVEL PINION

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THE JOURNAL OF GEAR MANUFACTURING


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Vol. 30, No. 2 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007. Canadian Agreement No. 40038760.

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Vol. 30, No. 2

departments

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THE GEAR INDUSTRY'S INFORMATION SOURCE

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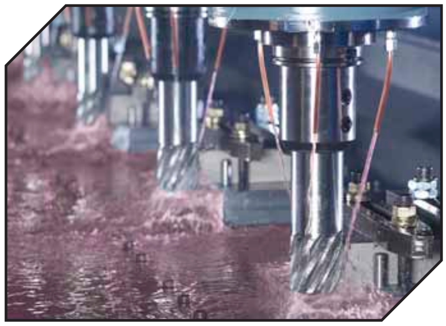
Lubrication Innovations



New products and technologies from Dayton Progress, Oelheld, Techno-Sommer, Klüber Lubrication and Cimcool demonstrate the latest lubrication innovations including high-performance greases, grinding fluids, dispensing systems, coatings and advanced industrial fluids in the February *Gear Technology* E-Newsletter:

www.geartechnology.com/newsletter/0213/lube0213.htm

Gear Technology Archive

The complete set of Gear Technology back issues is now online. Every issue from 1984 through today is available for free to subscribers. This trove of knowledge includes all of the technical articles, feature articles and back-to-basics articles we've ever published.

To browse the archive visit: *www.geartechnology.com/issues*

Join the Gear Technology Group at: *www.linkedin.com/groups/Gear-Technology-Magazine-3893880.*

LinkedIn:

In response to Senior Editor Jack McGuinn's article on NDT Testing for Big Gears in the January/February issue of *Gear Technology*, Tom Shumka, president of Global Inspections-NDT, Inc. discusses a new method for NDT on large gears. "ASTM E2905 uses Electromagnetics for this NDT method. It is fast and efficient and all data can be electronically archived for future trending." To contact Shumka on this subject e-mail at *tom@global-ndt.ca*.

The Star PTG-6L Tool Grinder was also featured on Gear Technology's LinkedIn Group Page. Engineered to manufacture complex cutting tools the new Star PTG-6L tool and cutter grinder is a five axis, CNC controlled cutter grinder for manufacturing, sharpening and reconditioning a wide variety of cutting tools *(http://info.star-su.com/ptg-6l)*

Klingelnberg Spiral Bevel Tooth Form Generation

A video currently on our website from Hauer Helicopter shows single point cutting of a spiral bevel crown gear on a three-axis CNC milling machine. *www.youtube.com/watch?v=bKnHOyDWeh0.*

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

Turn Off the Noise

Publisher & Editor-in-Chief
Michael Goldstein

Trying to figure out what's going on in this crazy economy of ours seems a bit like reading tea leaves—one part pseudoscience and three parts wild conjecture. Of course some pundits are telling us that *this* bull market has legs, while others insist that we're due for a major correction. Some pump us up with positive news, while others remind us about scary stuff like the budget deficit, the European financial crisis and unemployment.

In March I spoke at the Gear Forum in Parma, Italy. It was a prestigious event, featuring a number of high-profile gear industry speakers, including Prof. Dr.-Ing. Karsten Stahl, Head of Institute at the FZG Gear Research Centre at the Technical University of Munich (Germany); Dr. Ulrich Kissling, founder of KISSsoft AG (Switzerland); Dr. Michel Octrue, power transmission expert at CETIM—the Centre Technique des Industries (France); Andrea Piazza, transmission & hybrid design manager at Fiat Powertrain Technologies (France); and Charlie Fischer, VP of the Technical Division at AGMA. The event was moderated by Prof. Carlo Gorla of Politecnico di Milano, who is also Technical Director of *Organi di Trasmissione*. My presentation was about the state of the gear industry. In preparation, I spent a lot of time poring over statistics from industry associations, government agencies and even our own "State of the Gear Industry" survey, which appeared in our November/December 2012 issue. Even though there was a lot of encouraging news to be found in those reports, I found that the statistics and information were either outdated or too far removed from gear manufacturing.

Sure, it's nice to know that machine tool sales last year were better than they've been in more than a decade, but I wanted to know what's going on *now* and what's going to be happening over the *next* six months. So I asked my readers and advertisers.

The gear machine tool and cutting tool suppliers all said business is very strong. Right now, they are scrambling to meet the needs of a resurgent American automobile industry. Machinery manufacturers are installing equipment for the 8-speed transmissions that are becoming a larger part of auto makers' lineups. At the same time, they're already quoting on machinery for the *next* generation of transmissions—the 9- and 10-speeds under development. Every gear machine supplier agreed that the automotive business will remain strong for some time.

I also talked with several gear manufacturers. One, a Midwest gear manufacturing job shop, serves a wide variety of industries, including aerospace, off-highway, specialty automotive, power tools, appliances, power transmission and material handling equipment. That manufacturer believes 2013 will be down compared to 2012, which was very strong compared to 2011. So they're having a very good year, just not quite as good as last year, which was outstanding.

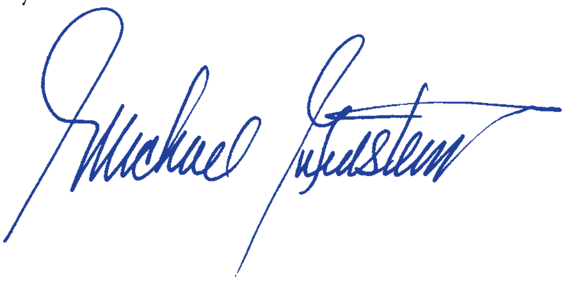
Another gear manufacturer I spoke with specializes in gears for mining, energy and heavy industry. Although all of those markets are either down or stagnant, he still felt positive about his business moving forward. In his case, over the past couple of years, business had been strong enough that a significant amount of work was farmed out overseas. But now that things have slowed down, much of the previously outsourced work is being brought back home. Also, the energy industry seems to be in an unusual place. For example, the fracking industry has put a hold on gearbox orders for compressors—not because the demand has dissipated, but because the industry needs to wait for pipelines to be built. Those orders should come back strongly in 2014, this manufacturer says.

Finally, I spoke with a gear manufacturer who specializes in aerospace gearing. According to him, business remains very strong despite Defense Department cuts and the European crisis. So many programs are already in place that they'll be busy filling those orders for several years.

A theme that kept coming up in my conversations was the fact that U.S. manufacturers and the American economy are well positioned with regards to the supply of energy. Our natural gas costs 25 percent of what it costs outside North America, and our oil costs 80 percent of world prices. Lower energy costs reduce overall manufacturing costs, especially for the chemical and heat treat industries. Within 5-7 years, many expect North America to be a net exporter of energy, with perhaps the largest reserves of energy in the world.

After speaking with all of these suppliers, I feel a lot better. I know that some of the core businesses that support gear manufacturing—automotive and aerospace—are going strong. Other industries that play a big role, such as energy, off-highway and farm equipment, will likely come back stronger in the second half of 2013 and the first half of 2014.

So turn off your televisions and your radios. Shut down your browsers, your apps and your streaming news feeds. Do whatever it takes to quell the barrage of headlines and opinions that compete for your attention. Once you've eliminated the noise, listen to your customers. That's what I did.



DFM Crucial for Gear Industry Success

John P. Walter and Georges Assimilalo, Precipart Corporation

All photos courtesy of Precipart.

"Design for manufacturability" (DFM) is a well-established practice, essential to realizing the successful transformation of concepts into mass-produced gears and motion control devices. And yet, all too often issues that could have been avoided are identified very late in the process that impact production costs and schedules. This suggests that key DFM principles are often underutilized in practice and are not applied consistently—or to the degree necessary—to avoid these negative results.

By considering in detail three DFM-based best practices, we can offer insight for improving the conditions for success as manufacturing partners work together towards a common goal. Engaging key stakeholders in an organized team from the very start of a project, conducting a thorough feasibility study, and implementing the proper quality assurance tools will help ensure that the final product is reliable, manufacturable and acceptable to the original equipment manufacturer (OEM) andend user.

Integrated Product Development Teams

For DFM to be successful, it is vital to create a truly integrated multi-disciplinary design and product development team from the beginning. This team should include representatives from key departments that will be involved—from design through production—including engineering; product management; manufacturing; quality; sales and marketing; supply chain; and others appropriate to a given project.

In addition, it makes sense to include representatives from outside your business, such as key suppliers and other design and manufacturing specialists who may be needed on a specific project. Good collaboration here can help ensure that an elegant gear or motion control design is practical to manufacture and meets the cost targets and performance goals set by the end user. An integrated team also reduces the risk of a "silo" approach where one element may be overemphasized while other design considerations are overlooked.

All critical customer requirements must be clearly established during initial team meetings, as total project lifecycle costs and speed to product launch are often defined early in the process. A good multi-disciplinary team looks at details such as materials selection, degree of manufacturing difficulty, supply chain issues and market/industry-based requirements such as regulatory stipulations.

Consulting early on with key suppliers can help in avoiding costly rework later. For example, Precipart recently reviewed the design of a tight tolerance gear assembly for a medical imaging device, and we identified a potential performance flaw early in the design phase. As a result we recommended bench assembly and light run-in to create the contact pattern on a helical gear to reduce

A DFM approach can produce significant benefits even from the smallest details; for example, where a change to a gear tolerance by .002" can significantly improve the performance of a device.

backlash by approximately .002", which would significantly improve the durability, performance and lifecycle of the device.

The dynamics and open communication of a multi-disciplinary team are crucial to ensuring successful DFM processes. A senior staff engineer from a medical device manufacturer recently told us, "The level and degree of DFM teams vary, but from the design phase perspective, suppliers who are critical to the project's success should be included in the discussions, and the sooner the better. We receive great input from our suppliers in their fields of expertise, and having a good partnership with them ensures the launch is successful."

Feasibility Study

A comprehensive feasibility study is part of an effective DFM process and it should examine key specifications and potential design issues that may occur throughout the life of the gear or motion control device; it should also offer recommendations to address any performance issues in various environments and conditions.

Application-specific requirements are fully evaluated in the feasibility study. For example, some aerospace applications may focus on torque and speed, while others focus on accuracy. A gearbox which controls the positioning feedback system of an aircraft's landing gear must utilize anti-backlash gears to avoid inaccuracies in the system. Envelope size and weight may be other key considerations for aerospace applications, due to space and weight constraints on the aircraft. These critical design and application requirements must be captured up front as inputs for the integrated product development team.

A thorough feasibility study will also help identify concerns about production tooling – i.e., whether existing tooling is sufficient or if custom tooling is needed. It can also assess the tolerance of materials for post-fabrication treatments such as deburring.

Poorly finished parts are frequently a cause of order rejection and production delays. The feasibility study can help identify areas of dimensional inaccuracies and rough surfaces that can lead to noise, excessive wear and backlash between the pair of gears in mesh, which can result in inefficient power transmission. After reviewing these factors, the DFM team can implement design or manufacturing alternatives that prevent these problems from occurring.

A comprehensive assessment will utilize computer-aided modeling and analysis techniques to determine load values and directions, life expectancy, heat treatment specifications and tolerance areas such as stack-ups, backlash and hysteresis. Collaborating with partners that have both high-precision manufacturing capabilities and design services to conduct feasibility studies throughout product development lends itself to a more successful product launch.

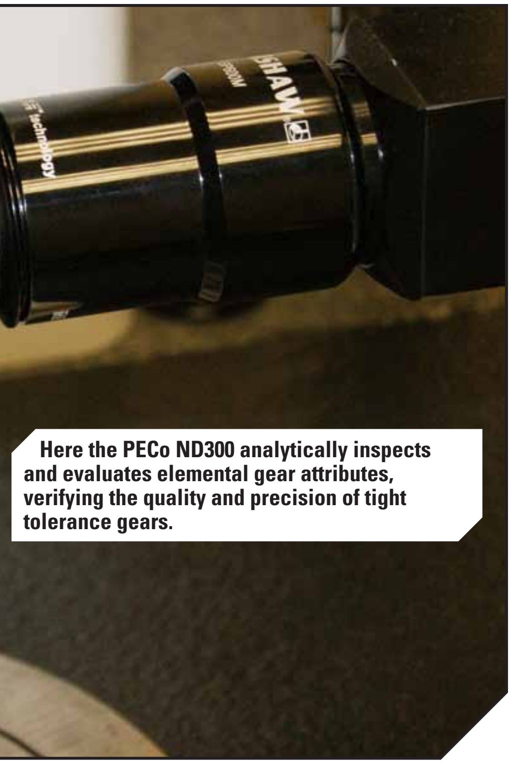
All critical customer requirements must be clearly established during initial team meetings, as total project life cycle costs and speed to market are often dictated during early design stages.

Building in Quality to Support DFM

Quality initiatives such as risk management and Six Sigma can help reduce variation and remove waste from the manufacturing process. An effective DFM process takes these types of quality initiatives into account up front to help build quality into the design and mitigate risk in the production of new gears or motion control devices.

Risk management utilizes several techniques to identify all the critical-factor project elements. The "design of experiment" (DOE) is one example. As a methodology for systematically applying statistics to experimentation, it is used to identify the source of variation in processes such as manufacturing. DOE is critical in evaluating or validating a component or procedure and helps ensure that a product functions as intended, without costly testing and revision while in production. Despite its high value, DOE methodology is often overlooked in the rush to get a project moving.

Another key risk management process is the "failure mode and effect analysis" (FMEA). It is difficult to have a success-



Here the PECo ND300 analytically inspects and evaluates elemental gear attributes, verifying the quality and precision of tight tolerance gears.

ful DFM process if FMEA is skipped or minimized; as part of the planning phase, it helps guide the team in troubleshooting and in working through worst-case scenario factors during the design process.

Whenever possible, providing component suppliers and partners with an overall FMEA system is extremely useful; it serves to identify the most important product features and design tolerances in order to determine how to control them and document the process, including all changes. The FMEA system provides the direct inputs for the supplier's "design failure mode and effect analysis" (DFMEA).

Having a culture of continuous improvement that utilizes lean manufacturing and Six Sigma techniques, such as kaizen, ties in well to designing for manufacturability. These initiatives require "on-the-floor" presence by designers, engineers and other team members who, after participating in discussions on quality and observing production processes, incorporate their lessons learned into the product design. One kaizen team at Precipart helped triple throughput by changing a component finishing process to minimize the time spent in prepping parts for assembly.

Conclusions

Successful delivery of gears and motion control devices requires more than a sophisticated design. Design for manufacturability ensures that innovative technology delivers true economic value while guiding the development process, as well as the teams responsible for achieving success, so that the new gear or motion control device can be produced cost-effectively, brought to market with minimal delays, and perform reliably.

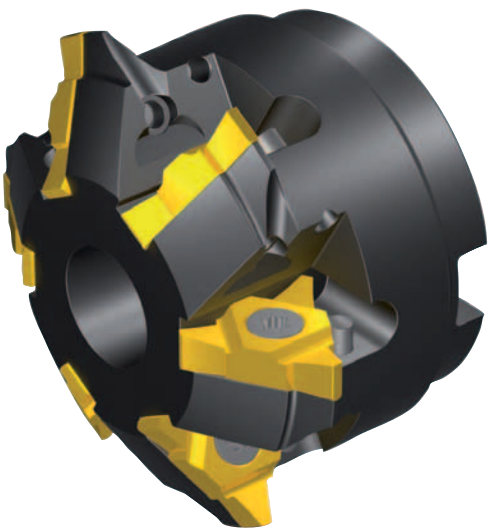
John P. Walter is president and chief executive officer at Precipart, where he has worked for 25 years.

Georges Assimilalo is vice president of engineering and chief operating officer at Precipart, where he has worked for 18 years managing the engineering and design teams.

Vargus USA

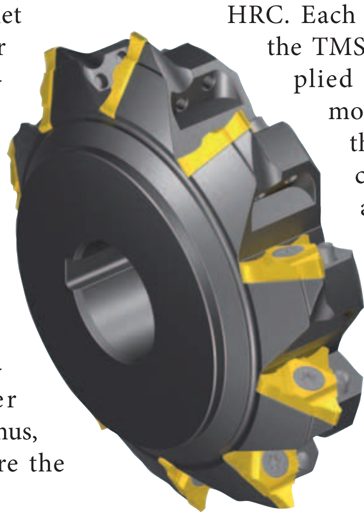
OFFERS ALTERNATIVE TO CONVENTIONAL HOBBING

A well-known gear manufacturer in the United States had an application they were currently using conventional hobbing methods on. They had three main objectives which were cost, productivity, and quality of the part. What the customer required from Vargus USA was a faster more reliable tool to manufacture their splines. “The previous method was slow and cumbersome,” says Mike Trimble Vardex product manager. “The new process is faster and more cost effective.



TMSD gear milling tools solved all of the customers’ needs for the application. First, the price was five percent cheaper than the cost of the current hobbing methods. Secondly, the productivity of the TMSD was almost 75 percent faster than the current tooling. Third, the reliability met all class requirements for the spline. “The customer was very happy and all the requirements of the test satisfied. Subsequent orders have been placed,” says Joe Magee, gear milling product manager.

The main improvements the customer received as an added bonus, but did not expect were the tool life and part finish both were considerably better than the current method. “The finish was better than a 64 Ra (roughness average), competition was 125 at best, 250 on average,” Magee says.



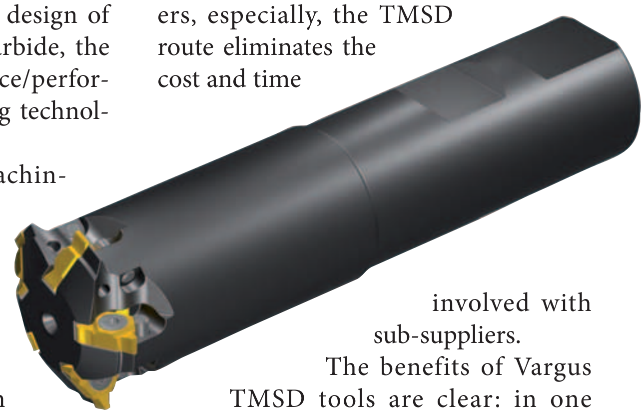
As for the overall project summation the customer was able to move the parts from a secondary operation on a hobbing machine to the part they were now completing on their machining center; reducing handling, extra set up and utilization time on the extra operations.

The Vardex Gear Mill is suitable for medium and large batch size spline and gear manufacturing and is faster, simpler, easier to use and much more economical than existing HSS/HSS PM cutters. With its state-of-the-art design of PVD coated fine substrate carbide, the Gear Mill offers absolute price/performance advantage over existing technology.

TMSD is suited to the machining of both straight and helical teeth gears, and gear modules from 1 mm to 6 mm. All materials can be accommodated, from very soft to hardened steels of 60 HRC. Each insert profile in the TMSD portfolio is supplied with the appropriate module shape of one, two or three cutting corners (special forms can be supplied), and the ability to achieve a full profile in accordance with Class 7 DIN 3962. Importantly, because the tooling focuses on carbide inserts located in ‘standard’ tool bodies for end, shell and disk milling on three-axis CNC milling machines (the cutting edge is subject to relatively low loads), TMSD is affordable for companies of every size across all industry sectors.

This is in stark contrast to the usual need for ultra-expensive hobbing machines and tooling (which also needs recoating after regrinding) with their inherent lengthy set-up times. Likewise, traditional milling disks are often only suitable for rough machining on softer materials.

TMSD, therefore, alleviates the cost and potential quality problems for many companies where relatively small batches do not justify the expense of a dedicated machine – and for manufacturers, especially, the TMSD route eliminates the cost and time involved with sub-suppliers.

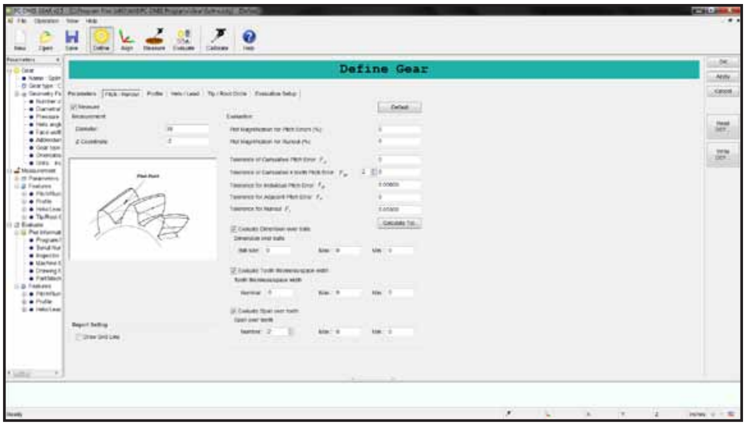


The benefits of Vargus TMSD tools are clear: in one case, involving a 40.5 mm diameter 42CrMoS4V gear with 52 teeth, a TMSD milling operation took just five seconds to produce each slot. TMSD also produced similar savings in one spline milling application, reducing gear rack production from 10.7 min to only 3.3 min. Similar benefits have also been achieved with plastic gears.

For more information:
Vargus USA
Phone: (800) 828-8765
www.vardexusa.com

Hexagon Metrology

RELEASES PC-DMIS GEAR 2.5



Hexagon Metrology announces the release of *PC-DMIS Gear 2.5*, a software module designed for basic and advanced gear measurement applications. The new version simplifies measurement routines by using a parameter-driven graphic interface to speed inspections of helical gears, spur gears, bevel gears and pinions. *PC-DMIS Gear 2.5* software is compatible with standard CMMs, eliminating the need to invest in separate gear measurement equipment.

The software also runs on vision CMMs for inspection applications of small spur gears. *PC-DMIS* is an integrated metrology system used for developing inspection routines, measuring parts, managing data, evaluating and reporting results. Expert and non-expert operators can quickly build gear inspection routines by first completing a rules-driven form, then choosing the desired inspection report(s) from a set of pre-defined, standard formats. The software then automatically generates the program and inspection reports. Users can also create measurement alignment and probe qualification routines to completely automate the inspection process. *Gear* supports a wide range of international standards, including AGMA 2000-A88, DIN 3962, JIS B 1702 and ISO 1328.

Ken Woodbine, president of Hexagon Metrology's software division, said that *Gear* is a very cost-effective inspection method as compared to expensive, dedicated gear measurement equipment. The software interface has been enhanced and simplified, and even entry-level operators can run inspection routines accurately. Utilizing forms, wizards and pre-defined routines, users can calibrate probes, define datum, and measure and evaluate gears in record time.

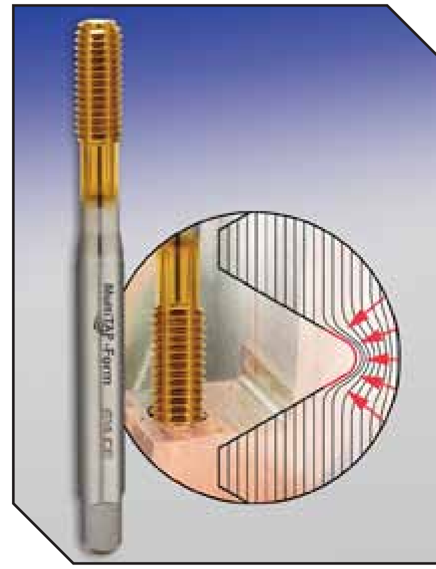
For more information:
Hexagon Metrology
Phone: (800) 274-9433
info@hexagonmetrology.us
www.hexagonmetrology.us

Emuge

INTRODUCES GENERAL PURPOSE FORMING TAP

Emuge Corp. has announced the introduction of MultiTAP-Form, a high-performance forming tap designed to deliver a wide range of materials including carbon steel, steel alloys, stainless steel, aluminum, copper, brass, and bronze. MultiTAP-Form is uniquely designed to produce threads within both 2B and 3B classes of fit, eliminating the guesswork of calculating H-limits.

"MultiTAP-Form will significantly improve thread quality and boost output while reducing production costs," said Peter Matysiak, president of Emuge Corp. "One high-performance MultiTAP-Form will handle most common materials and applications. MultiTAP-Form also eliminates the need to stock numerous types of taps that are suitable for forming applications," added Matysiak.



The forming of threads offers many advantages over conventional thread cutting. A formed thread is one where the material has been displaced instead of cut, which provides suitable thread surface quality and increased static and dynamic strength of the thread. Additional benefits include eliminating the risk of poor threads due to axial miscutting and the ability to increase tapping speeds.

"Our MultiTAP line is the result of collective years of Emuge's extensive tapping expertise, application research and a challenge the company issued to its engineers to design a multi-purpose tap. Emuge design engineers responded by choosing a select base material along with special geometry and surface treatment that would work in as many common materials and applications as possible," stated Matysiak.

All MultiTAP-Form Taps are made with Emuge's trademark long shanks, which are DIN length, designed for extra reach. Tap sizes include a range for UNC or UNF threads, from #4-40 to 3/8-24 inch sizes, to metric sizes from M4×0.7 to M10×1.5.

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

Mahr Federal

INTRODUCES LATEST PORTABLE AIR GAGE

Mahr Federal has introduced the next generation of its Micro-Dimensionair line of portable air gages. The new Micro-Dimensionair II incorporates the enhanced Micro-Maxum II Digital Indicator and an interchangeable handle to provide accurate, convenient readouts at the measurement site. The digital dial on the new Micro-Dimensionair II rotates through 270 degrees for easy viewing, and the IP-5-rated gage provides the exceptional accuracy and repeatability Mahr Federal users have come to expect. Air gaging has increased in popularity in recent years as part tolerances have gotten tighter. It is fast and accurate, readily used in production environments, and the gages even help clean parts by blowing dirt away.

The Micro-Dimensionair II incorporates all the benefits of the enhanced Micro-Maxum II line including: dynamic max, min, TIR; two-point-difference measurement; multiplier factor for ratio measurements; indicator serial number identification; resolution to 20 µin; selectable, continuous output; and longer battery life. All standard features are retained, such as inch/metric measurement in digital or analog display; bi- and unilateral tolerances with presets; multiple data output formats; auto-zeroing; and normal/reverse settings for ID/OD.

The new Micro-Dimensionair II also offers the versatility of use in the single master mode for fixed range resolution, or the gage can be used in a two-master mode allowing the magnification to be set by the masters. The interchangeable handle on the new Mahr Federal Micro-Dimensionair can be configured as a pistol grip or normal end-mount for easy application of the plug to the part. For large, heavy plugs the handle can also be mounted between the tooling and the display to provide a well-balanced, ergonomic measuring system. The gage can also be bench-mounted or even mounted directly on the machine tool for added convenience.

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

Sandvik Coromant

RELEASES COROCHUCK 930

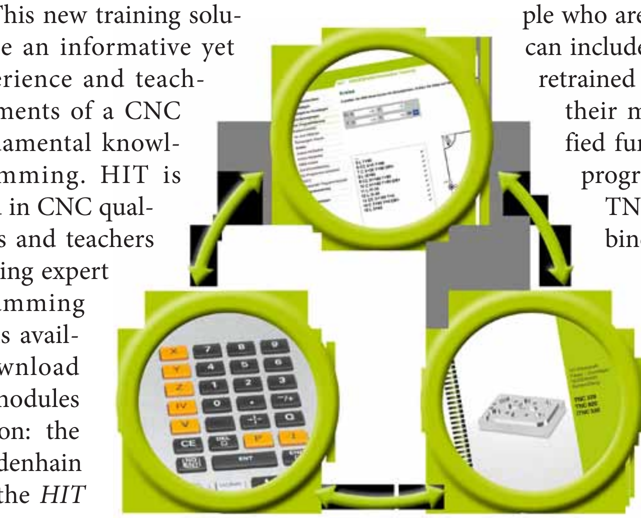
CoroChuck 930 is a high-precision hydraulic chuck from Sandvik Coromant for milling and drilling operations. The secret behind the high-precision and pull-out security is in the optimized design of the brazed membrane that allows for maximum, secure clamping with two supports on each side (fulcrums). This design ensures suitable torque transmission to improve the performance of solid carbide end mills, drills and reaming tools. This performance is repeated over multiple clamping cycles to retain high-quality component surfaces and extend tool life. Additionally, the CoroChuck 930 is designed with damping features that minimize vibrations during the machining process. Based on a hydraulic tool clamping system, the CoroChuck 930 can be quickly tightened or released with a dedicated torque wrench, thus improving efficiency through quick and easy set-ups and changes. No external equipment is required to clamp or unclamp the system. The chuck holds tolerances within microns to improve tool precision, surface finish and productivity. The precision run-out can be measured at <4 µm (157 µ inch) at 2.5 × DC. CoroChuck 930 is suitable for all types of machine tools that either have a rotating spindle or workpiece; lathes, multi-task machines, machining centers and driven tools in turning centers and vertical turning lathes. Available in pencil, slender and heavy duty design, CoroChuck 930 is balanced according to DIN 69888.

For more information:
Sandvik Coromant
Phone: (800) SANDVIK
us.coromant@sandvik.com
www.sandvik.coromant.com

Heidenhain

RELEASES CNC TRAINING TOOLS

Heidenhain Corporation has released a unique online interactive training tool for CNC instruction called *Heidenhain Interactive Training (HIT)*. This new training solution was designed to create an informative yet entertaining learning experience and teaches the most important elements of a CNC machine and imparts fundamental knowledge about CNC programming. HIT is intended for those interested in CNC qualification, as well as students and teachers who are interested in obtaining expert materials on CNC programming and machine operation. It is available as an economical download in many languages. Three modules make up this learning solution: the *HIT* software, an online Heidenhain programming station, and the *HIT* workbook, providing a relevant learning solution for qualified basic and advanced CNC training. It also proves useful for people who are unfamiliar with CNC fundamentals. This can include vocational schools, as well as those being retrained or master craftsmen who want to improve their machinist's kills. *HIT*'s software for qualified fundamental and advanced training explains programming with Heidenhain controls, called TNCs (Touch Numeric Controls). *HIT* combines theoretical training with practical exercises and therefore simplifies the beginning steps of programming. Both a free demo version and single and multiple licenses are available for download.



For more information:
Heidenhain Corporation
Phone: (847) 490-1191
info@heidenhain.com
www.heidenhain.de/elearning

Hardinge

RELEASES COLLET ADAPTATION CHUCKS

Hardinge HCAC Collet Adaptation Chucks will adapt most spindles to accept C-series pull back collets, J-series pull back collets, stationary B-series collets, style-S master collets, step chucks and closers and dead-length collets. It is possible to increase your machining capabilities by substituting a collet chuck over a jaw chuck for part diameters up to 6 inch, depending on spindle size. The benefits of using collet chucks in place of jaw chucks include: lighter weight; no hoist required to mount on spindle; faster job setup time; faster acceleration and deceleration due to less weight and smaller diameter; higher spindle speeds for reduced cycle times; optimum gripping with higher precision capability and more. Another style of Hardinge collet adapter is their quick-change FlexC Vulcanized Collet System that provides collet changeover in seconds using a manual compression wrench. The FlexC collet system has a guaranteed accuracy within .0004" (.010 mm) TIR for both collet system styles A (pull-back stationary stop) and D (pull-back thru-hole) and .0008" (.020 mm) TIR for style DL (push-to-close dead-length).The collet head has a generous gripping range to allow variation in bar stock without having to change the collet. Because there is no collet body, the collet segments will remain parallel to the stock, even when there are variations in the bar stock. This parallel clamping minimizes stock "push-back" that can create inconsistent part lengths. The spindle mount will fit on A2-5, A2-6, A2-8 and some flat back spindles (main and sub).

For more information:
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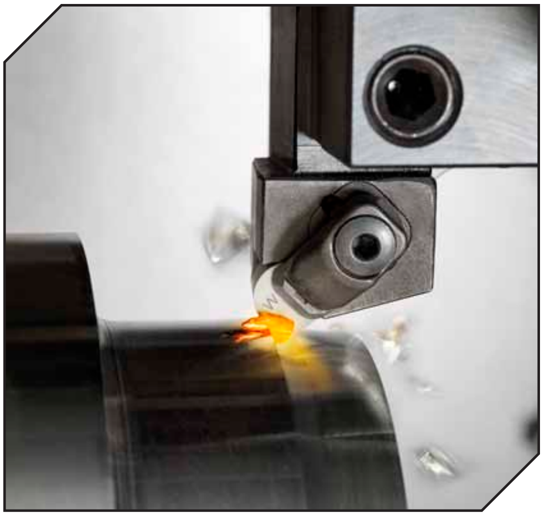
Walter USA

INTRODUCES CERAMIC GRADES



Walter USA, LLC has introduced WIS10 and WWS20, two new ceramic grades that deliver suitable results, particularly when turning high-temp super alloys. Turning Inconel, Waspaloy, Stellite and other heat-resistant super alloys can be very tough on the carbide tools typically used to machine them. That's because of the high cutting temperatures they generate, along with greater tool stresses and increased tool wear. Ceramic inserts have very high hardness, heat resistance and wear resistance, and can stand up more effectively to the demanding conditions encountered in machining super alloys. Walter's two new complementary grades, silicon nitride-based WIS10 (Sialon ceramic) and WWS20 with silicon carbide whiskers (whisker ceramic), stand up to these applications with increased tool life and process reliability. They are designed to deliver cutting speeds five to ten times higher than carbide in many super-alloy roughing and semi-finishing operations. With its self-reinforced structure of silicon nitride ceramic and enhanced chemical stability, WIS10 offers excellent notch wear resistance and excels at turning all types of heat-resistant super alloys. The application area for WIS10 ranges from light roughing to semi-finishing operations. The new WWS20, for its part, delivers superior fracture resistance thanks to its silicon carbide "whisker fibers," which add the toughness needed to handle interrupted cuts. This makes it suitable for turning forged or cast out-of-round workpieces with uneven surfaces or heavy interruptions, and for high feed rates used when removing large amounts of material. In addition, WWS20 excels at turning hardened steel. Walter supplies WIS10 and WWS20 indexable, ceramic turning inserts in the negative basic shapes C, D, R and S, and positive basic shape inserts in RC and RP format; all are available with different cutting edge designs. For turning there are also tool-holders available with carbide shoe and clamping system. This gives the user the best possible tool-holder system for turning, capable of cutting speeds up to 1350 sfm.

For more information:
Walter USA, LLC.
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us@walter-tools.com
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Mazak

SET TO EXHIBIT AT PRECISION MACHINING TECHNOLOGY SHOW 2013

Mazak will spotlight two small-footprint machines that are big on providing precision, productivity and profitability to shops across all industry segments in Booth 349 at the Precision Machining Technology Show (PMTS) 2013 in Columbus, Ohio (April 16-18). Throughout the show, PMTS attendees will experience real-world cutting demonstrations on the highly efficient Hyper Quadrex 150MSY Multi-Tasking Turning Center and high-value Vertical Center Universal 400-5X 5-Axis Vertical Machining Center. Mazak personnel will also be available to provide attendees with technical advice on how to improve throughput and shorten lead times using these machines.

The Hyper Quadrex 150MSY and Vertical Center Universal 400-5X both feature Mazak's new Matrix 2 CNC control that uses advanced technology to provide extremely fast processing speed, excellent cornering, suitable part surface finishes and reduced cycle times. Furthermore, the CNC control brings unbeatable accuracy and increased productivity to highly complex applications requiring multi-tasking operations; full, simultaneous five-axis machining; and the incorporation of automation.

Because it easily pairs with bar feeder systems and workpiece unloaders, as well as gantry robot loaders, the Hyper Quadrex 150MSY enables shops to achieve long periods of unmanned operation over breaks, nights and weekends. Such automation places the machine in automation Levels 1 and 2 of the 3-4-5 solution. The Vertical Center Universal 400-5X accommodates articulated robots, placing it in automation Level 4 of the 3-4-5 solution. Articulated robots are a highly advanced alternative to traditional production and enable shops to fully automate the machine's load and unload operations.

For more information:
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JOB SHOP LEAN

Ed's Note: This is the second article in an eight-part "reality" series on implementing Continuous Improvement at Hoerbiger Corporation. Throughout 2013, Dr. Shahrukh Irani will report on his progress applying the job shop lean strategies he developed during his time at The Ohio State University. These lean methods focus on high-mix, low-volume, small-to-medium enterprises and can easily be applied to most gear manufacturing operations.

Dr. Shahrukh Irani, Director IE Research, at Hoerbiger Corporation of America

Figure 1 Items Removed after a 5S Sorting Event.

Lean Team Building

The organizational hierarchy of the lean enterprise is comprised of executives, managers, engineers, supervisors and employees. Yet, when it comes to continuous improvement (CI) events, the literature on lean indicates an over-emphasis on the shop floor. These kaizens typically involve the plant manager, supervisors and employees who work in the department where the kaizen was done. It's as if engineers and managers are not contributing their share of the effort to improve the bottom line!

Conventional wisdom says to let all CI work be considered and implemented only by the employees themselves. Otherwise, improvements will not be accepted or solutions will be implemented in half-hearted fashion at best. Should we avoid solving those "sticky" problems that have not been solved for years just because shop floor employees may not be able to solve them? Or should we expand our choice of who we put on these problem-solving teams so that experience blends with computer skills and analytical abilities?

Guidelines for Forming Problem-Solving Teams

In this section, I will describe the strategies that have guided the composition (team size, skills and experience of each member, extent of cross-functionality, etc.) of the continuous improvement teams that I have successfully utilized in the course of my job at Hoerbiger Corporation of America:

Plan the composition of the team to suit the scope and complexity of the problem.

Prioritize the problems based on impact on the bottom line and not who will be available to work on the team.

Insist that the project *must* improve key performance indicators (KPI) such as safety, quality, delivery, waste elimination, etc. in the area where the team will work.

Leverage external resources; in particular, student interns from a reputed industrial engineering department or on-staff industrial engineers (or manufacturing engineers).

Utilize computer-aided analytics if the problem merits it, such as the Six Sigma statistical analysis software, *Minitab*.

I will discuss the above guidelines in the context of a series of inter-linked CI projects that we are doing in the shipping department.

Shipping: Where our Continuous Improvement Efforts Began

The shipping department is the closest to the customer, and its main objective is to maximize shipped orders every month.

It was decided to assess how much of the current floor space in the shipping department was "dead" and therefore could easily be reclaimed. First we did a walkthrough of the entire department with the shipping team and pointed out examples of areas that were VA (value-added), NNVA (necessary-but-not-value-added) and NVA (wasted). It was the NVA areas that we focused on because they were occupied by junk. Naturally, the very first continuous improvement project was a simple housekeeping task that lasted about two hours. We handed everybody a few red stickers and asked them to go around the department and affix their stickers to items that they were confident nobody had any use for.

It turns out that our shipping department is essentially a job shop. It stands to reason because (1) Each of the five cells in our machine shop is a high-mix low-volume job shop and (2) both focused factories in molding – cold compression molding and hot compression molding – are high-mix low-volume flow shops. The shipping department handles a mix of workflows since we serve global customers whose typical shipments involve a variety of parts. Different kits have different packaging requirements (carton size vs. wooden crate, labeling specific to the customer and country of destination, etc.). The routings that were processed in the shipping department were due to the following product mix:

- Packing Rings
- Piston and Rider Rings
- QRC Packing Rings
- Bushings and Cases
- GE Kits

The department was advised to separate the product, person and information flows for each of these routings. The spreadsheet containing the *Production Flow Analysis and Simplification Toolkit (PFAST)* Input File was then sent to Pranav Joshi, a graduate student in the Department of Integrated Systems Engineering at The Ohio State University. The *PFAST* software was made available by The Ohio State University for this project. We used the *PFAST* Analysis Report to generate five new alternative layouts for the shipping department. These layouts were designed based on guidelines such as a separate cell for each customer, a central shared "IT Hub" and other desired features.

Presently, Clement Peng, from the IE department at Texas A&M University, plans to visit HCA-TX every Friday and completely immerse himself in the day-to-day operations of the shipping department. His goal is to develop a detailed blueprint for the final layout, including a budget and implementation timeline.

Now that I am in industry, a real-world classroom where the true relevance and need for IE is widely evident, I am able to teach Peng how lean radically changes the standard approach to facility design that is taught in any contemporary IE textbook for facilities planning. Why? Because the footprint of each and every workstation, table, aisle, rack, container, etc. in the layout is potentially bloated with waste.

Toyota either pioneered or raised the importance of concepts such as right-sizing, mobile machines, reconfigurable layouts, visual WIP management, combined operations, jidoka (automation with a human touch), parallel operations, and more. For example, Robert Lu (an employee in the shipping department) carefully places all the parts that are going to be shrink-wrapped on a GE skinboard (cardboard backing) on the packaging table. Next, he carefully picks up the GE skinboard, slowly turns around and places the kit on the table of the shrink-wrap machine. Should not the two tabletops that he works on be a single sliding table that slides into and out of the shrink-wrap machine? At least that idea made us all pause and think for a moment during one of our weekly team meetings.

Inventory Control Techniques

While the Sort phase of a full-fledged 5S program usually yields results, the real benefits to be gained from doing 5S are when the "hidden evils" such as ergonomic risks, inventory costs, inefficient flows of people and material are banished. Since inventory costs are visual and measurable, Team Shipping decided to take a systems approach to control the purchasing costs for the carton inventory. These cartons and wooden crates are used to ship our products all over the world, often to other Hoerbiger plants.

That there appears to be excessive inventory of several SKUs (stock keeping units) of carton inventory is obvious. So we collected data on purchases of the different SKUs made from June 20, 2012, to November 7, 2012. This time series display of the data did not yield any insights. Instead, when we plotted the same data using the classical Pareto rule of 80-20, some valuable insights were gained.

Here is where looking at color printouts of *Excel* graphs doesn't necessarily match the reality of the shipping department. It was pointed out to us that the high inventory of the GE Whiteboards was an unavoidable business situation because (1) we shipped that item

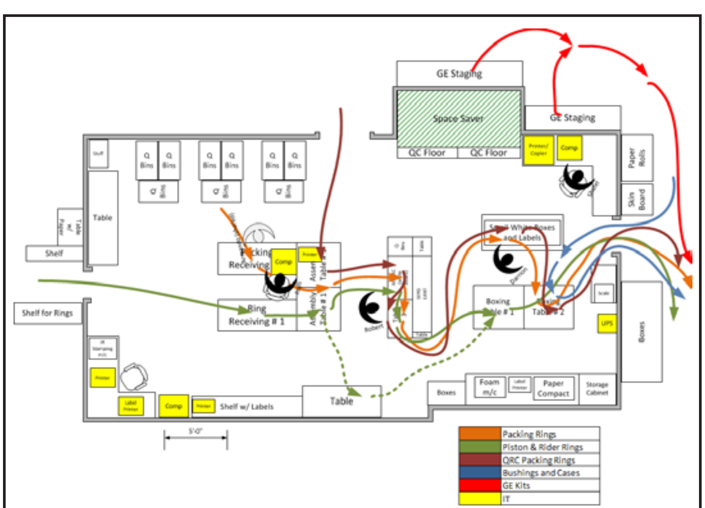


Figure 2a Current layout of the shipping department.

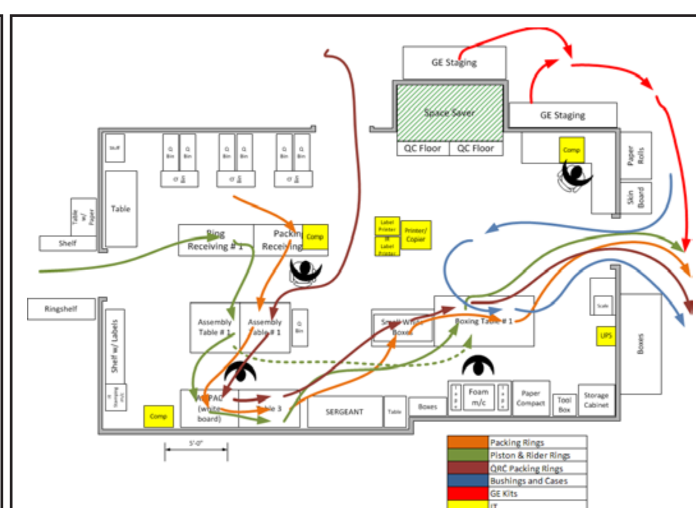


Figure 2b New layout being designed for the shipping department.

to sister divisions and (2) the supplier was committed to shipping a full pallet instead of split loads. So what appeared to be NVA (non-value-added) was actually N&VA (necessary and value-added). One of the important decisions taken after supervisor Charlotte Pett met with our materials manager, Anthony Herrell, was to plan purchase quantities (Average Demand + Safety Buffer) for a week-by-week planning horizon.

Here is how we are integrating lean and IE to develop a comprehensive system for inventory control. Figure 3a and Figure 3b show the "bicycle rack" that was fabricated and installed by a team of employees (Francisco Salazar, Juan Nunez and Armando Gomez) on a Saturday. The key reasons for this design are: (1) to exploit the natural shape and size of how these items are delivered to us (2) to compact all of this inventory into a smaller volume, which freed up the topmost racks where the wooden crates are stored and (3) it is easy to eyeball each slot to know how much on-hand inventory we have for that particular SKU.

Another idea that is being pursued is to utilize a moving average or exponential smoothing forecasting algorithm that uses the past few weeks' consumption for any SKU and forecasts a ballpark requirement for next week. This forecast is adjusted by Pett who has intimate knowledge of any hiccups in the shipment schedule for next week.

Darrion Lincoln, a shipping employee, is helping to collect the weekly usage and receipts data for each SKU and Shalini Gonnabathula, our industrial engineer, is maintaining the forecasting model written in *Excel*. While there is no immediate confirmation that this reliance on analytics is good/bad, at least we are trying to integrate gut feel, experience, practical logistical costs and statistical data analysis.

The data collection will also help us to sort the SKUs by volume into "Runners" (high weekly usage) and "Strangers" (low weekly usage). This, in turn, will help us to implement a 1-bin kanban system for the latter category of SKUs; i.e. the entire inventory for that SKU will be stored in the outside rack. Whereas, a 2-bin kanban system will be used for the Runners; i.e. the inventory for each of those SKUs will be split between a mobile carton stand (2-3 days usage) kept right next to the table on which Lincoln packs cartons and the outside rack (rest of the inventory). Pett is following up with this supplier (*http://www.stackbin.com/categories/carton-racks/*) recommended to her by Herrell.

In addition to the above features of our inventory control system, we received valuable assistance from one of

Figure 3a **Bicycle rack for compact storage of cartons.**

Figure 3b **Detailed view of bicycle rack.**

our suppliers—Grainger. Inmer "Ivan" Guzman is one of their onsite reps, regularly replenishing inventories of shop supplies, office supplies, etc. One day I observed him using his iPhone to swipe bar codes for items stored in the cabinets in our lunch room. That was my first introduction to a VMI (vendor managed inventory) system that starts as a bar code swipe and ends as an order quantity uploaded to their ERP system.

As we discussed our lean projects, he walked me over to one of his pet projects—an e-kanban system to manage supplies in our first aid cabinets on the shop floor. The numbers placed on the containers connect to the bar code for that item on the sheet stuck inside the glass door of the cabinet. If all goes well, that same system is what we will use to automate the weekly replenishment of the carton inventory held in the shipping department. Once that system is debugged we can implement the same data-driven computerized inventory control for: QRC packing boxes, GE skinboards, wooden cartons, bushings supermarket, powders and bar stock.

Material/Size	Consumption during Oct. 9 - Nov. 6	Inventory on 11/6/2012	Footprint [square inches]	Volume [cubic inches]
18X18X4	37	38	324	1296
16X16X4	99	58	256	1024
12X12X6	49	124	144	864
10X10X8	38	105	100	800
14X14X4	-28	68	196	784
12X12X4	7	88	144	576
8X8X8	44	69	64	512
10X10X5	128	27	100	500
9X9X6	75	93	81	486
8X6X6	116	93	48	288
6X6X6	56	172	36	216
18X18X10	121	1	324	3240
14X14X14	17	37	196	2744
16X16X10 1/2	73	93	256	2688
20X20X6	24	18	400	2400
14X14X10	127	71	196	1960

Figure 4 Grouping cartons with similar packing volume.

The Strategic Value of University/Industry Partnership

The downside of having quickly "plucked all the low-hanging fruit" so soon during our lean journey in the shipping department is that complex problems now need to be tackled.

- Figure 4 presents the potential for reducing the number of different cartons that we buy. If we could standardize on the sizes that we use, and reduce this number, that ought to reduce our purchasing and inventory carrying costs. For example, the carton sizes 8×6×6 and 6×6×6 differ by a cubic volume of only 72 cu. in. We studied the data on the usage of these two sizes during the period October 9–November 6. If we decided to buy only the 8×6×6 size in the future, that would result in us shipping a total volume of (2×6×6×56) cubic inches of air that would have to be filled up with crumpled paper or foam padding. How does that cost trade off against being able to buy 35 more cartons of the 8×6×6 carton size? This appears to be a technical problem that could be offered to an IE graduate student doing their MS thesis. Or, we could be pragmatic and listen to Pett who has already eliminated 4 SKU's as of the writing of this column.
- Figure 5 shows that the current state of how the on-hand inventory of the many different packing rings that we make and sell to our customers is stored in floor-mounted bins (Q-bins) and the space saver (vertical lift module). What do

you think of the packing efficiency of the current storage scheme? Further, metallic rings must be stored in the Q-Bins while the lighter non-metallic rings are stored in the space saver. This project is included in Pranav Joshi's portfolio. He will be working with warehouse and inventory supervisor Andrew Reynolds to pursue the following goals: (1) reduce the on-hand inventory levels and (2) reduce the average pick time to collect the different part numbers that constitute a shipment, which is typically comprised of many part numbers.

- There is a rack on the other side of the shipping department where orders pending shipment are staged. One category of orders is those that are waiting for one or more line items to complete production. If the shipping department is assessed on just one KPI – total $ shipped per month – then all these orders on that rack should be seen as an easy opportunity to improve the KPI. Simply by engaging the staff in a 5 Whys discussion, we have identified half a dozen reasons why such incomplete shipments result. This is a Six Sigma project that we hope will interest Clement Peng to continue working with us while he is studying at Texas A&M University. Or, we have green belts on staff at our Pompano Beach location who could partner with Shalini on this future project.

How IE Research could Really Benefit All U.S. Manufacturers

Like any small for-profit manufacturer, HCA-TX is not geared to solve any complex operational problem as if it were a three-year research project funded by the National Science Foundation. The shipping department, like any other cell or department, is a high-pressure work environment that is time-constrained and resource-constrained, but luckily, not patience-constrained. Team Shipping pursues just one daily goal—receive the "stuff" coming in from one door and get it out the other door onto a truck that same day. If operational problems arise, they are solved using common sense, firefighting, thumb rules, resignation, brute force, overtime, teamwork, negotiations with customers and suppliers, sometimes even prayer. The nearest that we have by way of computer-aided optimization is spreadsheet-based solvers. And Team Shipping has done well to date.

Despite the above operational constraints, I think that there is merit in HCA-TX establishing a university-industry partnership with a couple of IE departments in the state. Once I read *Lean Thinking*, in 1999, I was convinced that lean is the correct industrial engineering that we never taught to our students in any IE department. In a perfect world, a group of practice-oriented IE faculty would first work in industry to get sufficient work experience.

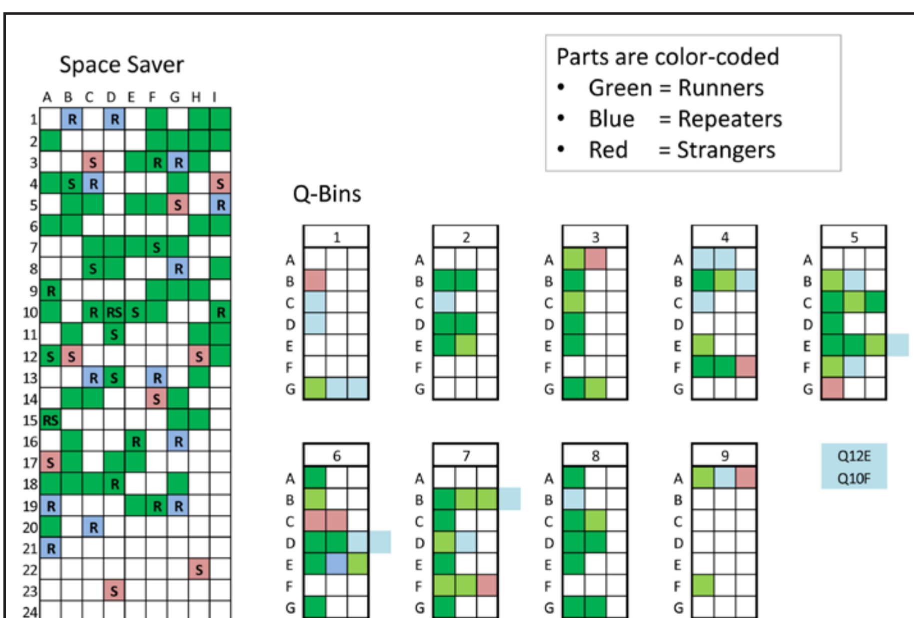


Figure 5 Current storage of packing rings in the Q-rings and space saver.

Then they would seek federal funding to establish a national industry-university research center in partnership with the NIST network of Manufacturing Extension Partnerships (MEP). And what would they do? Produce a slew of much-needed heuristic optimization software tools that would allow industrial engineers in the field to modernize and extend lean beyond its pencil-and-paper problem-solving tools.

Dr. Shahrukh Irani is the director of industrial engineering (IE) research at Hoerbiger Corporation of America (www.hoerbiger.com). In his current job he has two responsibilities: (1) To undertake continuous improvement projects in partnership with employees as well as provide them OJT training relevant to those projects and (2) To facilitate the implementation of job shop lean in HCA's U.S. plants. Previously, he was an Associate Professor in the Department of Integrated Systems Engineering at The Ohio State University (OSU). There his research focused on the development of new IE methods to adapt and scale lean for use by high-mix, low-volume SME's (small and medium enterprises). His research group created PFAST (production flow analysis and simplification toolkit), which is a software program for material flow analysis and facility layout to implement Job Shop Lean. At OSU, he received the Outstanding Faculty Award for excellence in teaching from the graduating classes of 2002, 2003, 2004, 2005, 2006 and 2009. In 2002, he received the Charles E. Mac Quigg Student Award for Outstanding Teaching from the College Of Engineering. He is a member of IIE.

How's Your Shipping Department?

Matthew Jaster, Associate Editor

This month's **Job Shop Lean** column addresses key steps to maximize the shipping department. This area is often overlooked, given the day-to-day priorities of a typical gear manufacturing operation. By focusing on lean principles and team building, a few tweaks to shipping can maximize productivity, improve lead times and increase revenue. Best of all, it's not rocket science! A few minor improvements could result in significant savings and could be the difference in gaining or losing an important contract in the future.

Quality/Inspection

"Many companies take for granted the fact that the shipping department is the last quality check before the product goes out the door," says Bipin Doshi, president, Schafer Gear Works, Inc. "It's essential for the shipping team and the production team to be on the same page. If the department takes a proactive approach and is very conscious of everything that is happening, they can make sure they don't ship product with any problems."

Communication between departments is crucial as well as a holistic approach to lean manufacturing that involves everyone from the ground up.

"Our greatest challenge is to improve quality and delivery time while also reducing costs," Doshi adds. "Continuous improvement (CI) initiatives have helped open communication lines between departments, so the shipping personnel, for example, know what's going in and out on a weekly and monthly basis. It's nice to have an extra set of eyes before your product goes out the door. We consider our shipping department sort of like the last line of defense before our product reaches the customer."

Maximizing Space

"We essentially grew out of the building we were in previously," says Tony Werschky, sales/partner at Delta Research Corporation. "We moved into a new building and created a flexible gear cell that includes part cleaning, deburring, packaging and shipping. This essentially has streamlined our production process and helped us with our throughput."

Whiteboards for communication improvements keep personnel up to date on everything coming in and going out of the department. Because the company specializes in both aerospace/defense and automotive applications, documenting the entire inspection process is critical for success. "Maintaining our whiteboards and keeping the entire team aware of what projects have been completed and what projects need to still be addressed helps to accomplish our goals."

Delta also incorporates "floating personnel" throughout the shop floor. These multi-tasking employees may operate a machine one day and be pulled the next day to assist in the shipping department. "This is dictated by the amount of work in a certain area, it's nice to have the flexibility to move them around depending on our priorities," Werschky says.

Additional space in the building has also led to converting tables to work centers for the deburring crews. "This gave us room to create areas with better lighting and usable work surfaces," he adds, "which has also led to efficiency gains."

While Delta's lean manufacturing enhancements were assisted with a move to a larger building, other companies may just need to rework or reimagine their work areas in order to increase efficiency.

Carton Count

"Maintaining the proper amount of shipping material, for example, used to be a real problem," Werschky says. "If you're packaging a special order and it's out of the ordinary, it may require a certain box size you typically don't carry. It's time consuming to chase around looking for the best material to ship the product. We try to carry the right amount of materials for our current requirements. This prevents us from not having enough shipping containers and also prevents us from carrying too much."

Committing to Lean

Schafer Gear Works and Delta Research Corporation boast rather efficient shipping departments and lean manufacturing has most certainly played a key role. In 2009, both companies appeared in a lean manufacturing article ("Steadfast and Streamlined," ***Gear Technology***, August 2009) that discussed the benefits of lean during the economic downturn. These companies have paid close attention to the lasting benefits of continuous improvements across the shop floor. These improvements continue to pay off today.

Heat Treat 2013

Gear Market Offers Opportunities for Ingenuity and Innovation

Matthew Jaster, Senior Editor

Growth in the heat treating sector depends on many factors including product development, technology advancements, customer demand and a little luck. Successful organizations will have the right products available during strong market periods while investing in new technologies when the market slows down. Global expansion is essential as companies in the United States and Europe look to China and India for growth opportunities. In this issue, *Gear Technology* looks at various heat treat companies involved in the gear market today and the new developments leading up to the **27th ASM Heat Treating Society Conference and Exposition** that's co-located with **Gear Expo 2013** (September 17-19, Indiana Convention Center, Indianapolis). Engineers involved in this market segment see an emphasis on training, software, service/support and collaboration with their customers to remain relevant in heat treating moving forward.

Austempering with Applied Process

The Applied Process family of companies specializes in the austempering heat treatment process of steels and irons. "Austempered Ductile Iron, ADI, constitutes the majority of our work, and the remainder of our heat treating work is split between austempered steel, carbo-austempered steel, austempered gray iron, carbidic austempered ductile iron, and marquenched steel," says Justin Lefevre, regional sales engineer at Applied Process.

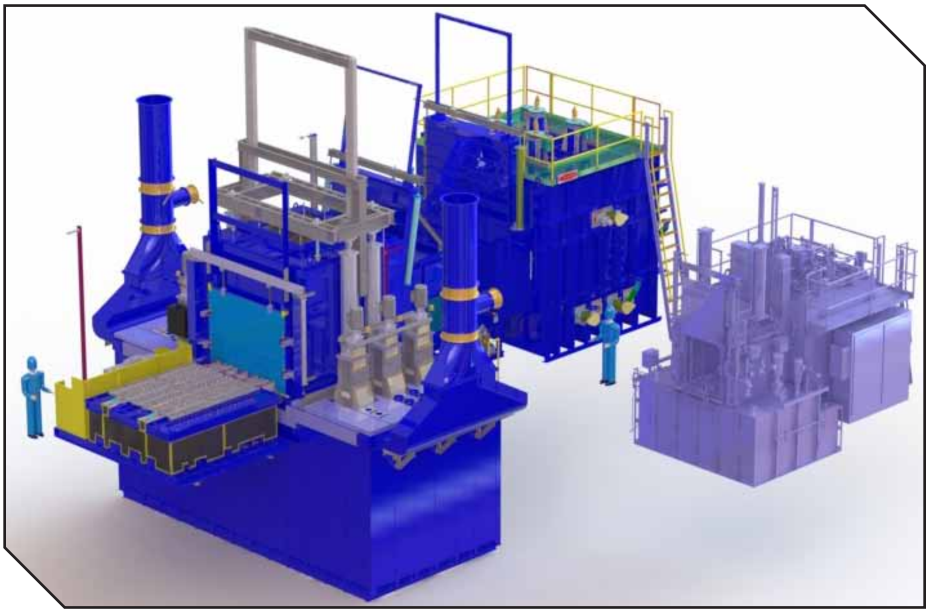
ADI offers gear manufacturers an opportunity to gain the manufacturing ease of ductile iron with properties comparable to some of the common steel gear heat treatments at a low product cost. "Austempered and carbo-austempered steel provide high performance solutions for applications where tooth breakage is an issue and redesign is no longer an option. The low levels of distortion attributed to austempering can help eliminate secondary machining processes, press quenches, and distortion issues," Lefevre says.

According to Lefevre, several of the most significant advances in heat treating today have been in the refinement of induction hardening methods and practices, shortening of the carburizing cycles, vacuum carburizing and quenching, and ion/plasma nitriding. The advances in these areas have led to lower cost and higher performing products with less waste/scrap.

"As the demand for lighter, more efficient power transmission systems grows, the optimization of gear material selection, processing and design will be critical. Tools to optimize gear and gearbox design will be critical in this process and could come in the form of software that optimizes gear design, new materials or advances in heat treatments," Lefevre adds.

"Quality heat treatment requires a capable system that is in control. Software, for example, plays a key role in the control of our austempering cycle development as well as the monitoring and reporting of our furnaces' settings and operating conditions. As technology and refinements of heat treating systems improve, so will the ability to integrate these system, where appropriate, in the manufacturing process. Certain types of heat treating processes lend [themselves] to integration in line with machining; i.e. induction hardening," Lefevre says.

Applied Process collaborates closely with manufacturers on many design projects, and often the most successful austempered parts arise from early engagement between the design engineers and Applied Process. "Growing the pie for austempering is our mission, and generating value through strategic



Applied Process and AFC-Holcroft joined together to produce a Monster Parts Universal Batch Quench-Austemper (UBQA) furnace (courtesy of Applied Process).

partnerships is a key part of this process. We engage in evaluation of the existing material, manufacturing methods, and application stresses of parts with designers. In doing so, often the optimum choice of material and manufacturing method is apparent, which sometimes leads to austempering business," Lefevre says.

Applied Process launched AP Monster Parts Division in 2012 in Oshkosh, Wisconsin with what is believed to be the largest universal batch quench austempering furnace in the world and added two furnaces in the Livonia, Michigan plant. In January 2013, the company hosted AP University for the first time to give customers an opportunity to learn about ductile iron design, foundry practices and austempering in general. "It was so successful that we have already planned another AP University for May of 2013. This, of course, is in addition to the 25-50 onsite presentations that we do for multiple customers every year."

As for overall business, it softened during the last quarter of 2012 but Lefevre expects 2013-2014 to show improvement especially in the larger gears for their new furnace. "We already have several projects underway that involve conversions to austempered ductile iron gears in the heavy industrial market; we cannot say much more than that about the projects. Our efforts in the near future in relation to gears are to focus on conversion opportunities in agriculture, mill gears, and automotive applications," Lefevre says.

Factors that will determine the future success of Applied Process include governmental policies and regulations that impede the growth of the economy, the company's ability to get austempering, specifically ADI (austempered ductile iron), as an accepted heat treatment/material in the gear-making/using community and the ability to produce property data that end users of gears require in order to specify austempering/ADI as a suitable material.

"Natural gas and raw mineral prices impact our cost model; however continuous improvements to our equipment help to mitigate these effects. The long term outlook for natural gas, electricity, and alloy costs are all positive for the heat treating industry. In other words, lower or stable prices will lead to stable prices for our customers," Lefevre adds.

For more information:
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smetz@appliedprocess.com
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Aerospace Advantages with Solar

Low-pressure vacuum carburizing (LPVC) and vacuum gas nitriding (VGN) are the two main areas in which Solar serves the gear market. "The advantages include clean, bright parts with limited to no distortion," says Tim Steber, regional sales manager. The company also boasts an R&D department with metallurgist, scientists and engineers on staff for consultation and oversight of work.

Solar's Souderton plant recently received a Nadcap accreditation in carburizing, allowing it to better serve the aerospace market. This accreditation joins Solar's other Nadcap approvals for heat treating, brazing and fluorescent penetrant inspection. Additionally, earlier this year the company became an approved supplier for General Electric Aviation (GEA), UTC Aerospace Systems (UTAS) and Moog Corporation.

Solar Atmospheres is comprised of more than 40 vacuum furnaces backed by NADCAP Accreditations and certified by ISO 9001/AS9100 (courtesy of Solar).

Don Jordan, vice president of R&D/corporate metallurgist, says that growth in the aerospace market has been significant for Solar, particularly with new high alloy grades developed specifically for LPVC including Ferrium C61 and C64, Pyrowear 675 and CSS-42L. "Our company collaborates with all prime rotorcraft (helicopter) aerospace companies and their suppliers," Jordan says.

Jordan believes that the most significant products and technologies in the future will be continued developments and advancements in LPVC and high-pressure gas quenching in vacuum heat treat processing of traditionally oil quenched alloys (e.g. 4140). Laser induction hardening will also play a significant role in multi-functional machining operations.

Trevor Jones, principal engineer at Solar says that software has an increased role in heat treating today. "Process modeling of LPVC parameters (time, temp, hydrocarbon) and the resultant hardness profiles. Process modeling of quench rates and distortion profiles as well," Jones says.

While business is good, hiring skilled workers and the rising costs of raw materials and energy remains a significant challenge. "Vacuum heat treating is not a well-known industry/science in the manufacturing world. Skilled workers have always been difficult to find and retain in our industry and remains true today," Jones says. "Raw material pricing of fixturing, electrical rates and process inert gas prices significantly affects the bottom line."

In order for future success the company will continue to develop surface treatments of materials, add furnace capacity and obtain qualified personnel.

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Stack Focuses on Quality and Process Requirements

Stack Metallurgical Services began with a couple of atmosphere furnaces and has evolved into a versatile provider of heat treating services. "Vacuum carburizing provides improved case depth uniformity over the tooth profile," says Nels Plough, president and general manager at Stack Metallurgical Services, Inc. "Root to flank ratios is as much as 90 percent versus 65 percent for conventional gas carburizing. Intergranular oxidation is also eliminated in vacuum carburizing. Fixture and furnace designs offer reduced distortion by providing uniform heat removal from the part."

Much like other heat treat companies, software is becoming a key element to industry requirements. "Computerized control of every aspect of the furnace is critical. Precise, repeatable processing is vital to give our customers the high quality parts their industry requires. In addition, a charting program records all of the important parameters of a run for verification. While the physics of heat treating haven't changed, our ability to precisely and repetitively control the process has been greatly enhanced by software advances," Plough says.

Stack has key customers in the gear industry, according to Plough. "When we work in close contact with them, our ability to meet their specifications is greatly improved. The more each of us know about the requirements and limitations of the products, the more improvements can be made."

Both energy costs and labor are two significant challenges at Stack. "As the economy continues to improve, the energy resources will become more expensive and have a large effect on profitability. Energy costs must be controlled. Renewable energy initiatives are going to drive these costs higher," Plough adds.

Despite these challenges, business continues to grow. "The strength of this business is dependent on the overall economy, but also on our ability to grow and adapt to the increasing quality & processing requirements," Plough says.

For more information:
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Brad Foote Gearing: In-House Heat Treat

Brad Foote Gearing boasts one of the largest captive heat treatment facilities in North America with a state-of-the-art facility that covers 50,000 square feet and features a computer control room to monitor heat levels, carbon potential and the cycle time of each heat treat load.

"We have added nine pit furnaces with the largest being 88" by 150" deep," says Richard Baker, plant manager at Brad Foote Gear Works. "Along with the furnaces we also added a 35,000 gal oil quench tank, 2-10 ton overhead cranes, a control center with all new SSI furnace controllers for each individual furnace and individual monitors. All of the nine furnaces were completely rebuilt and new recuperating burners were installed in each."

Brad Foote began primarily as an in-house heat treating facility but expanded to commercial work because of the company's well-known capabilities and capacity. "We helped a competitor on a very large part that they couldn't handle in their plant. Because of our quick turnaround, pricing, in-house testing lab and quality, they sent us more work," Baker says.

Commercial work has really taken off, according to Baker, in the last part of 2012 and so far in 2013. "It has been steadily growing because of our capacity we can offer competitive pricing and delivery which has helped us for repeat business and helped out customers by getting them their parts back quickly— depending on the case depth sometimes back within a week or less."

The company specializes in AGMA Grade 3 carburizing of large and small gearing, thru-hardening, normalizing and stress relieving. While Baker won't divulge any secrets to the company's success in this market, he does have an idea why many captive heat treaters fail when they attempt to get commercial work. "The trick is to stay within your capabilities and not over-promise anything. We know gearing and have been carburizing gearing for many years. Our workforce experience averages more than 20 years of heat treat experience."

Brad Foote's captive heat treat facility in Pittsburgh, Pennsylvania is one of the largest in North America (courtesy of Brad Foote Gear Works).

For more information:
Brad Foote Gear Works
Phone: (708) 298-1100
www.bradfoote.com

ALD-Holcroft: In-Line and In-Synch

ALD offers furnace systems for low pressure carburizing (LPC) with high pressure gas quenching (HPGQ) or oil quench. The company offers LPC heat treat services for those gear manufacturers that do not want to heat treat in-house. The biggest advantages of ALD's products and services include, "distortion control, excellent carburizing homogeneity even for components with complex shapes, avoiding intergranular oxidation (IGO) and surface oxidation, shorter cycle times compared to atmospheric carburizing, integrating heat treatment into the production line, no conditioning necessary, clean surfaces of parts after heat treatment and it's an environmentally friendly process that utilizes a small consumption of resources (no disposal of oil, salt bath residues or detergent residues).

Dr. Volker Heuer, ALD-Vacuum Technologies GmbH, believes that better distortion control and the integration of heat treatment into the manufacturing line are two of the most significant developments in heat treating. Additionally, the role of software has increased. "All new processes are developed with help of simulation software," Heuer says. "Process monitoring software is integrated into modern furnaces (quick alerts if quality is in danger) and software will have a key role if fully synchronized manufacturing lines are established (collection of all quality data on one computer)."

The company's introduction of its SynchroTherm is evidence that ALD-Holcroft believes that the in-line, in-synch approach will have significant market appeal. "Our unique approach to high volume processing has become the mainstay in the automotive gear market. The extremely high up-time of our systems in conjunction with an outstanding service network has ultimately been a winning combination," Heuer adds.

The company is having great success in Europe, Mexico, Russia and South Korea and continuing to focus on China, India, Southeast Asia and the United States for the future.

ALD has found its fair share of challenges when it comes to energy pricing and raw materials. "Prices of raw materials have a direct effect on our equipment pricing. Further, our customer base has

All new processes are developed with the help of simulation software according to Dr. Volker Heuer (courtesy of ALD-Vacuum Technologies).

reluctance to improve alloying factors (because of cost) in materials in order to take advantage of higher temperature processing. The math proves the process is worth the extra cost, but quite often legacy parts and processes dictate," Heuer adds.

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Ipsen: Improving the Customer Experience

Ipsen is known in the industry for its wide range of equipment, advanced technology and strong service and support in Asia, North America and Europe. The company's atmosphere equipment includes pusher, batch and rotary hearth furnaces while its vacuum technology includes single chamber with AvaC + high pressure gas quench to 15 bar, 2 chamber furnace oil quench.

Ipsen's mission is to be a dependable, long-term partner, recognized for the quality of its products and reliability of its commitments. "This means collaborating with our customers to find out what they need and want out of their thermal processing equipment, allowing us to provide the best equipment, which in turn allows them to be successful," says Geoffrey Somary, president and CEO of Ipsen USA.

Aftermarket Support and Service is one of the most important aspects of Ipsen's business. "When you buy heat treat equipment from Ipsen you buy equipment backed by 65-year experience, and we don't stop at delivering new equipment. We are here to help you maintain and care for your equipment in order to help you minimize downtown and keep your equipment running for years to come. Our Engineered Components group helps your equipment stay up-to-date with retrofits and upgrades. We have some furnaces out there that have been running for 60+ years, so it's important to keep these furnaces working for our customers, including new hot zones, upgraded controls, adding capabilities and much more," Somary says.

Today, the company is focusing on improving the customer experience. "With our Titan line of furnaces, we already offer what we call 'The Titan Experience.' This prepares our customers for the arrival of their new furnace as well as guidance and advice throughout the life of the furnace, helping our customers maintain their furnaces better and minimizing downtown. Our goal is to extend that same process and thinking to our full line of furnaces," Somary says.

Machine tools rapidly handle single-piece flow, whereas traditional heat treatment has always been done in batches. This disconnect in the production flow will be driven toward unity over the coming years.

"The challenge, of course, with heat treating is the long cycle times, so the real innovation will come from both process and electro-mechanical improvements. While some solutions exist to heat treat single trays of parts in-line, the process speed has not been sufficiently improved. Ipsen has been working on this very topic in its research and development center for the past two years and we are approaching a unique solution that we expect to bring to market over the next years," Somary adds.

As a worldwide heat treater, Ipsen has seen the various markets fluctuate through the years. "After a period of flatness in Asia, we have seen a decent recovery in the past 3-6 months that looks to be holding and increasing in momentum. The Americas have been going very strong for several years now, driven by low energy costs, aerospace industry growth and a nicely rebounding automotive sector. Europe has been steady with more fluctuation than the other regions, but trending strong over the first half of 2013. We are focusing as a company, not so much on regions and industries, but, instead, on working tirelessly to provide the exact product that fits our customers' needs at a competitive price. This approach wins in all markets," Somary says.

While many in heat treating are challenged to find skilled help, Ipsen has taken a proactive role in recent years. "We know that if we simply stand still and do things the way we've always done them, we will get run over. So in 2012, we decided to start the Ipsen Corporate Academy. This offering helps us to find, attract, train and retain the best talent available. In this three-month program, new recruits participate in a rotational training program that helps them take the knowledge they've learned in school/previous jobs and turn it into experience – what we call books to business. It is our hope that this will allow them to build a strong foundation for success. The Ipsen Corporate Academy benefits not only the new hires, but also the company as a whole. We make better use of everyone's time and resources through this streamlined approach, making this a smart investment. We reinforce our corporate culture by creating an inclusive, welcoming climate all while creating a more cohesive, productive and collaborative team of employees," Somary says.

The future health of the organization will bring growth, challenge and opportunity, according to Somary. "We are committed to what we call *evolutionary* innovation, as well as *revolutionary* innovation. The idea is that we must contribute to the success of our customers in order to achieve success as a company by bridging the gap between our customers' dreams and the technology available to make those dreams reality. This is the concept behind our, 'You dream it, we build it,' philosophy. Our mission also reinforces this idea – Be a dependable, long-term partner, recognized for the quality of our products and reliability of our commitments."

For more information:
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Talking Truth to Power: Plastic Gears Taking Back Seat to No One

Automotive industry embraces proven yet evolving technology

Jack McGuinn, Senior Editor

The $50 billion dollar 2008 bailout of the U.S. auto industry— initiated by President George W. Bush and completed by the Obama administration had— and continues to have—its detractors. Those in the business of supplying U.S. automakers with engineered-plastic gears and other critical car components are not among them.

Indeed, the U.S. automotive industry has been in rebound mode since 2010, according to the Society of the Plastics Industry (SPI) (*plasticsindustry.org*). And since 2011, according to Stout, Risius and Ross (SSR) (*srr.com*), an industrial-focused financial adviser and consultancy, "North American automotive production totaled 15.4 million units in 2012—up from 13.1 million units in 2011—and is expected to increase further to approximately 15.9 million units in 2013." Not all of that is in plastics, of course, but the industry's cut of the pie becomes increasingly significant with each new year. Backing that up in a recent radio broadcast, available online at the SPI site, is Bryan Osborne, vice presidentof sales and marketing for injection molder/manufacturer Venture Plastics, Inc. (Newton Falls, OH), stating that "About 50 percent of a car is plastics today," and that demand for more fuel-efficient vehicles is behind the increase.

"Under-the-hood" automotive gears from Kleiss Gears (all photos courtesy Kleiss Gears).

"That includes under the engine, manifolds, fuel rails, (etc.)."

And that claim is certainly supported by the fact that the automotive industry is the second-largest user—after packaging—of U.S. plastic products.

And finally, these 2011 post-recession numbers from the SPI business blog, *In the Hopper*, under the headline, "U.S. Automakers' Upbeat 2011 Is Sweet Music for Plastics Industry":

"2012 looks to be a good year for U.S. automakers, domestic and foreign brands, as well as for their creative partner suppliers in the plastics industry. For what they have each been through in the last few rough years, both automakers and plastics suppliers have more than earned some good times."

More (inclusive) "plastifacts" from SPI:

- The plastics industry is the third largest manufacturing industry in the United States
- The U.S. plastics industry employs more than 885 thousand
- The U.S. plastics industry creates more than $380 billion in annual shipments
- When suppliers to the plastics industry are considered, there are 1.4 million workers and total shipments grow to $465 billion
- There are more than 16,200 plastics facilities in the United States
- The U.S. plastics industry had a $16.3 billion trade surplus in 2011
- The plastics industry has a presence in every state
- From 1980 to 2011, U.S. plastics industry shipments have grown at a 0.1 percent annual rate

But enough numbers crunching; let's talk to some of the folks and companies behind the numbers— the engineered materials suppliers and the component manufacturers.

Rod Kleiss is the president of Kleiss Gears (*kleissgears.com*) in Grantsburg, WI. This story having an automotive focus, we cut right to the metal vs. plastic under-the-hood chase. (And let's face it: it's all about metal vs. plastic, is it not?) Plastic has already made great inroads regarding engine gears and parts for consumer-type vehicles; but we asked Kleiss just how far along are things in qualifying various gears and power components for industrial-size engines? (To be clear, industrial in this context means off-highway, heavy equipment.) The answer lies in both materials engineering and sophisticated design.

"(Partnering) with Victrex (a leading materials supplier to the engineered resins/plastics industry), we have been molding and testing plastic gears in engines for a few years now with some very good success. We have found some unique design approaches that work quite well in replacing their metal counterparts. This includes varying the pressure angle to fit the specific requirements and applying a minor helix to the gears just to limit the potential for tooth slap.

"We have just begun our first production order for a molded gear replacement of a ground gear in road building equipment. We are not at liberty right now to reveal the customer or application but I hope to get permission within the next few weeks."

And for John Winzeler (*winzelergear.com*), owner/operator of Chicago-based Winzeler Gear, and playing it a bit closer to the vest, "With all gearing applications, appropriate testing and development are critical. Today many small engines have molded plastic cam gears. Of course there are limits to temperature and load capacity."

By all accounts polymer is here to stay, but in what types of automotive applications? Where can plastic be counted upon to match or prevail in performance? In quite a few places, according to Kleiss. But he's willing to share (with metal).

"Plastic is better for vibrating loads, such as counterbalance shaft rotation or vibrating equipment applications," says Kleiss. "Also, in applications where normal loads are not excessive but occasional, short-term spikes must be anticipated. In general I think that plastic will find its place at the front end of transmissions where higher speeds and lower torques are occurring. They will reduce rotating mass and the corresponding noise and leave the high loads to the steel gears."

One claim of plastic gearing is beyond dispute — less noise and vibration.

And why is that?

"Sound levels are a function of speed and accuracy for all types of gearing," Winzeler explains. "Plastic materials generally are softer than metals and absorb energy better."

As Kleiss puts it, it's kind of a mystery. "One of the basic reasons is that they (plastic gears) just don't carry sound as well, and their natural frequency is much lower. I think you can hear the effect of that directly in (sound testing). (It may be that) under a vibrating load, the plastic teeth bend a little and this load-sharing may tend to dampen the physical oscillation of the gears, while the hard metal gears translate every small motion into rotation. That is just a speculation or theory though."

Among the most critical plastic components now — and for some time, in fact — being used in vehicles are plastic bearings. For the best source of updated information on that score we went to two major, international materials suppliers with diverse portfolios — DSM, headquartered in The Netherlands (*dsm.com*) and Ticona Engineering Polymers, a Celanese company based in Dallas, Texas *(celanese.com/ticona/ticona.aspx)*.

"Plastic bearings (bearing cages) are more mature (accepted) in the automotive market than gears and actuators," points out Pascal Feijts, DSM applications development manager/global research and technology. "For plastic gears the new trends in downsizing and turbocharging drive the need for more electrical actuators with geartrains. Also, metal replacement for in-engine gears to improve NVH or improve emission and fuel levels is more and more upcoming."

Ticona's David Sheridan, senior design engineer, agrees that "Yes, engineering thermoplastics are proven sliding materials in precision engineering applications such as thrust bearings, sleeve bearings and bushings. Although they don't have the high-load-bearing capacity of metal, plastic bearings offer lower cost; lower weight; ability to run 'dry'; inherent low friction and noise; maintenance-free operation; chemical resistance and broad design flexibility."

He also touts one of his company's patented products — Hostaform C 9021 AW — for its "low-wear, friction, and squeak system," as a "material of choice for high-quality molded engineering parts subject to high stress, including gears, bearings and other sliding elements used in precision engineering."

And what about gearboxes? It's a given that their engineering complexity is matched only by their need for robustly made components to operate in miserable conditions.

"It all comes down to loads on the gears (torque rating) in combination with the durability requirements to see how far plastics can go," Feijts allows. "Reinforced plastics are more likely (specified and used) here due to high strengths needed, but they suffer on wear rate compared to unreinforced plastics."

For his — and Ticona's — part, and on behalf of reinforced fiber products that Feijts alluded to, Sheridan points to "An innovative transmission from Hi-Lex America Inc. (that) reliably and quietly opens and closes automotive lift gates thanks to high-precision shafts and gears injection-molded with Celcon POM and Celstran long-fiber-reinforced thermoplastics (LFRT). The two-stage reduction transmission uses precision steel ball bearings mounted on plastic shafts and 2.5-inch-diameter plastic gears to achieve the desired reduction between the electric motor and a flexible torsional cable. The first-stage gear and shaft and second-stage output plastic gear are injection molded from Celcon POM M90 and Celcon GC25T, respectively. The second-stage output shaft is injection molded from Celstran PA 66-GF50-02. The

"About 50 percent of a car is plastics today; that includes under the engine, manifolds, fuel rails, (etc.)."

Bryan Osborne, *VP of sales & marketing, Venture Plastics, Inc. (Source: SPI).*

Hi-Lex transmission with plastic gears reduces cost, weight and especially, noise."

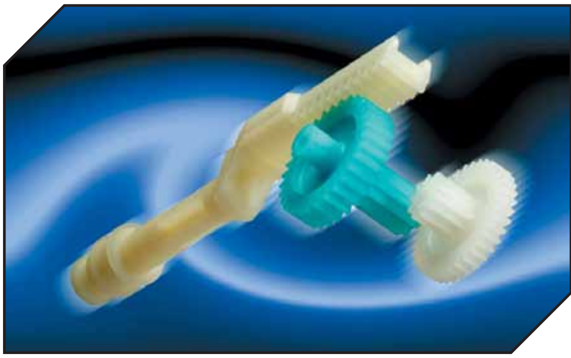
Yet regarding worm gears, common in gearbox designs, work remains to be done for the plastics industry.

"I understand that well-lubricated steel worm drives can be really efficient, much greater than 95 percent. We are not there with plastics," Kleiss admits. "One rule-of-thumb is to estimate efficiency as .95 for a reduction ratio of 3.5:1; therefore, a 40:1 worm drive might be expected to achieve 85 percent efficiency in the gear mesh. You really have to look at the sliding friction of the teeth on each other in a plastic worm to get a good idea of efficiency."

On the other hand, Winzeler believes that "Plastic worms may provide lower friction — thus higher efficiency — due to the lubricity of the plastic material compared to metals. We recommend all applications be, at a minimum, initially lubricated with grease."

Staying with our components suppliers, we queried Kleiss on microgears, a nascent-yet-promising technology with great promise for plastic.

"Micro gears (> 200 DP) are still an infant science in my book," Kleiss concedes. "In larger gears, grinding accuracy can produce more exact geometry than molding, but as the gears keep getting smaller, that advantage begins to disappear. But along with that disappearing advantage comes more difficulty in inspecting the gear itself. For instance, we are using .2 mm probes now, but are still unable to reach totally into the root of a small microgear. Vision inspection is problematic because it requires a sharp edge, which molded plastics do not have. X-ray scanning or CT tomography looks to be the most promising, but its accuracy is still not truly precise enough. The very best way to measure them right now is by testing the finished product in an instrumented transmission. We've done this; it works."



And when it "works," does that mean polymer microgears will be more "features-laden," than their steel counterparts, as has been reported in some quarters?

"Because we can add features easily to a molded gear that would be virtually impossible to add to a cut steel gear — yes," says Kleiss. "Even a simple compound gear becomes a task for the gear hobber, but it is simply adding another cavity for the molded-gear manufacturer. We can put a spur gear onto the end of a worm with no problem and add features on to that spur, if desired. That would be quite difficult for the metal gear manufacturer."

> "The state-of-the-art has advanced to where plastic gears are now in drives of up to three-quarters horsepower; future applications may take them higher."
> David Sheridan, *Ticona*

Current uses and applications-in-waiting for plastic microgears include, says Kleiss, "small medical pumps with throw-away gears that could never be considered as a cost-effective option in steel," adding that "All the new microgear applications will be served better by plastics. The challenge will be to actually build the little transmissions. Molding the gears might be the easiest part of the project."

All photos courtesy Winzeler

Jumping back to the materials end of things, one wonders is the glass half-full or half-empty regarding the heights to which plastic gears and related components (bearings, actuators, etc.) might ascend in the automotive arena.

"Depending on the system or application, I have seen durability requirements for motor management actuators going up to 30, 40 million load cycles, with quite challenging torque ratings," says DSM's Feijts. "Other in-engine applications are fit-and-forget, so durability levels can go up to 1, 1.3 billion load cycles! We at DSM are continuously looking into possible ways to improve our materials. Both strength and durability (which can be differently defined depending on which application we are talking about) are important subjects that we are looking at both on the polymer matrix and/or reinforcement/filling side."

For Ticona's Sheridan, it is a matter of "The higher the performance requirements for a drive, the more complicated the up-front design effort is required to make plastic gears work. The state-of-the-art has advanced to where plastic gears are now in drives of up to three-quarters horsepower; future applications may take them higher. Horsepower limits for plastic gears vary with the polymer, depending upon the mechanical properties that change with temperature. Temperature control, therefore, is critical for plastic gear load capacity. Lubricants — both internal and external — that reduce frictional heating or dissipate heat will increase plastic gear load capacity. Furthermore, long-glass-fiber-reinforced plastics will allow for larger tooth and wall thicknesses of a larger-size plastic gear that will withstand higher loading."

To some analogous degree, plastic gearing is as reliant on the art of injection molding and its continued research and development as is its more mature metal counterparts — forging and casting. Is there a tilting point?

"Injection-molded plastic gears have come a long way," says Sheridan. "Historically, they were limited to very low-power transmissions such as clocks, printers and lawn sprinklers. Today's stronger, more consistent engineering polymers, and better control of the molding process, now make it possible to produce larger, more precise gears that are compatible with higher horsepower."

In addition, "Gear analysis software can now optimize plastic gear designs based on temperature, moisture pick-up and other environmental factors. The unrealized potential of plastic gearing is becoming more apparent to the industry. Testing of plastic gears specifically to characterize gear resins in different service environments has begun. The new data will allow design engineers to more accurately predict gear performance. Better predictions mean faster, shorter design cycles, since the development phase may be approached with greater confidence."

Perhaps; DSM's Feijts believes plastic continues to suffer "second-cousin" status vs. metal in the perception of some. And it has nothing to do with process.

"No, current limitations are more depending on the market's perception of using plastic gears instead of metal ones. The market is opening up due to more stringent national and international emission and fuel consumption legislation, so for the time being the injection molding technologies available (which are also evolving continuously) are sufficient enough."

Proper lubrication and lube maintenance can be as critical to the working order of a plastic-fashioned gearset as with metal. Difference being, however, and it's a big one, there are *reams* more literature on metal gear and bearing/lubrication issues than exists for plastic. For the relative "new kid" on the block, it can be more trial-and-error as the application opportunities — and their challenges — continue to multiply.

"We work very closely with oil and grease manufacturers, but are also working on improving the dry lubricants (types and composition) that we use for our engineering plastics," says Feijts. "New, emerging applications also introduce new insights in lubrication requirements, so this needs constant develop-

ment and research into the fundamentals of wear and friction between plastic — with itself — or other materials."

The way Sheridan explains it, it's even trickier — details, details, details. And — less is more.

"A fundamental misconception in plastic gear design is that — whatever the resin — 'It's just plastic.' The choice of a gear resin demands careful study. Inexpensive, commodity resins generally lack the fatigue life, temperature resistance, lubricant resistance and dimensional stability required for quality plastic gears in all but the most primitive applications. However, many of today's engineering resins provide the necessary performance for working gear trains. They also have the consistent melt viscosity, additive concentrations and other qualities essential to consistent, accurate molding.

"Generally, it is easier to mold high-quality gears with resin containing minimal additives than with highly filled blends. The specifier should call for only as much glass or mineral filler or lubricant additives as are actually needed. If external lubrication is required, the drive designer, resin supplier and lubricant supplier should work together to select an appropriate lubrication system."

A discussion of plastic and automotive cannot ignore the — perhaps not yet of elephant stature, so let's go with creature — in the room: the powder metal (PM) industry. How does its performance match up with plastic? A fair question, or an apples-and-oranges thing? Judging from the following replies, sounds like PM and plastics have a peaceful coexistence, with limited overlap. Think of PM as the plastic family's brawny-not-brainy counterpart.

"Powder metal serves an important function as a low-cost, high-strength mate to plastics at the input or output end," says Kleiss, (but) "PM gears are limited in their architecture. Helix angles must remain low and it is much more difficult to add features to the parts. They also have rougher surfaces. In general, we are finding that if we can't use plastic, we will go to a cut metal gear for better function."

Adds Winzeler, "Powder metal gears can withstand higher loads and temperatures, (but) plastic gears will be lighter, quieter, and may withstand more impact. Plastic gears can be configured with more complex configurations."

And what of plastic-based gear and other standards — international or otherwise? The lack of an internationally blessed set of commercial, industry/application standards continues to frustrate and challenge most every aspect of the plastics industry.

As for the material suppliers appearing here, "Apart (from the fact) that this is mainly driven by gear manufacturers, DSM as a material supplier is also involved in developing national or international standards, (whether with) AGMA or VDI/DIN," says Feijts.

"Ticona is an active member of the (AGMA) Plastics Gearing Committee," Sheridan adds. "We work with members to evaluate materials, designs, rating, manufacturing, inspection and the application of molded or cut plastic gears. This committee is responsible for drafting plastic gearing industry documents and guidelines."

Meanwhile, have a heart for Mr. Kleiss.

"I despair of any chance for meaningful standards in the plastics industry. I spent years attending Plastic Gearing Committee meetings at AGMA to no real effect. I finally just left to preserve my sanity. It is nice sometimes to stop beating your head against a wall."

Ouch!

As one considers the issues just touched upon here, one last question beckons. Just how will all this shake out? "This" being the whole dynamic of metal replacement and the continuing advance of highly engineered materials with seemingly no ceiling in sight. Will the eventual and ever-shifting playing field always have a place for metal? Will we see companies buying up one another, whether it being metal-based vs. plastic or the opposite?

> "I despair of any chance for meaningful standards in the plastics industry."
> Rod Kleiss, *Kleiss Gears*

"What I see is that metal companies are forced by OEMs or Tier1s to investigate the possibilities for plastic gears, but most of them will unlikely acquire a plastic gear manufacturer," Feijts conjectures. "Most of the bigger plastic gear manufacturers do have metal gear production in place already (to a certain level). As they are (now) more and more system suppliers, they try to keep the 'gearing' business in-house."

As for Kleiss, if we read him correctly, both industries (within one larger industry, keep in mind) should be able to co-exist peacefully — and in one piece.

"I don't know who should acquire who in this crazy world," he laments. "I do know that we are working with more traditional gear houses now than ever before. Customers want a source for their transmissions. They don't want to be the controller of a process that they really don't understand.

"I do not think that metal and plastic are competitors. The two materials and their manufacture each solve unique problems in the generation of rotary motion. I know that my engineers find it very easy to talk with traditional gear engineers. We are all working on the same problems. I would love to have gear cutting as available to us as molded gears. I'd love to go to a potential client with both types of gears on the table. I think it would open us up to a whole new level of work."

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MY GEAR is Bigger than YOUR GEAR

Industry Battles it Out for World's Largest Gear Title

Matthew Jaster, Senior Editor

In 2009, scientists at the Institute of Materials Research and Engineering, Singapore, developed a working molecular-sized gear that could be fully controlled, rotating both clockwise and counter-clockwise. This was made possible by "nudging" the gear with the probe of a scanning, tunneling microscope. According to the Guinness Book of World Records, it is the smallest working gear in the world.

In an attempt to locate the LARGEST gear in the Guinness Book of World Records, this author fell incredibly short. There's no mention of, for example, some of Rexnord/Falk's mining girth gears or the single-helical SAG mill girth gear from David Brown (England) delivered in 2008 for a mining operation in Armenia. (A gear that weighed more than 65,000 kilograms [143,300,30 lbs] boasted 362 teeth, 0.75 DP, 863.6 mm face width, 12.4 m OD and a 10.5 m diameter bore). At that time, David Brown had claimed the size record.

Not to take anything away from the engineers and scientists in Singapore, but looking at a molecular gear through a microscope isn't nearly as impressive as seeing a GIGANTIC piece of metal getting the job done in a copper mine or a sugar mill. It's true what they say about engineering and manufacturing: Size does matter.

So why can't an interested engineering geek find any information today on the world's LARGEST gear and why hasn't anyone talked to Guinness about it?

Opening a HUGE Can of Worms

The world's largest gear is kind of a sore spot for some manufacturing organizations. It can become a rather contentious subject particularly if you get engineers from competing firms discussing the topic. "This was brought up at a recent SME meeting," says William Rhody, marketing manager, mill products at Rexnord. "Some companies will downplay the capabilities of their competitors or assume that they have the biggest or the best equipment without doing the research. There's a lot of misinformation out there so it's nice to set the record straight."

Hofmann Engineering recently shipped a gear boasting an outside diameter of 13.2 meters and weighing 73.5 tonnes.

From a manufacturing standpoint, Rhody believes a debate about the world's largest gear would have to include both the physical size as well as the power. "I can see how several companies could make a case depending on the way you look at it."

In our research, companies in the discussion for world's largest gear would include Rexnord/Falk (United States), P. van der Wegen Gears (The Netherlands), Hofmann Engineering (Australia), CMD/Ferry Capitain (France), FL Smidth (Denmark) and NKMZ (Ukraine). (*Ed.'s Note: These were the companies that responded to inquiries on the subject. If we're missing a company that should be in the discussion, please contact us at* publisher@geartechnology.com*).*

Rhody's assertion that various companies debate and discuss their manufacturing capabilities and flex their BIG GEAR muscles is absolutely true. There have been arguments in the past, press releases sent out claiming world records and even trade organizations and magazines attempting to crown a king. Unfortunately, proving what company has manufactured the largest gear on the planet may be as superfluous as finding out what restaurant serves the world's BEST cup of coffee.

Can ***Gear Technology*** make the impossible possible?

Before we start debating who should or should not be in the discussion, let's take a moment to acknowledge the impressive engineering knowhow that goes into producing some of the world's largest gears. From our standpoint, it seems as though every couple of years a gear comes along that supports the notion that engineering is truly an inspired art.

"The precision to which large gears are manufactured under controlled conditions is quite extraordinary," says Rhody. "It's something a lot of people don't appreciate until they see one up close and personal."

"It's not easy money," adds Holger Fritz, product manager, mill gearing, at Hofmann Engineering. "If you don't have a temperature-controlled environment, for example, a gear of 10,000 mm grows 1.15 mm with every 10 degrees Celsius depending on the material. This is significant when you are trying to achieve micron accuracy. With big gear cutting, you need a lot of experience and you always have to keep in touch with new technologies to improve quality levels, cutting times, etc."

Marthe Prunier Ferry, president of Ferry Capitain agrees. "It's a challenge to control the temperature precisely in order to have a good distortion, have a rigid clamping so that there is no vibration and have enough tonnage capacity on the table of the cutting machine.

There is also the matter of the base materials used for high-power gearing.

"With increasing power requirements in mining applications, for example, it is important that materials technology keeps pace with machining technology," adds Ferry (Ferry Capitain can produce cast steel and ductile iron gear materials having a minimum hardness of 340 BHN, whereas the state-of-the-art only 15 years ago was 280 BHN).

The largest gears in operation are utilized in areas like mining, steel, sugar

Ferry Capitain's recently commissioned VBCM16 is capable of turning and cutting gears up to 16 meters in diameter with 1,200 mm face width and 350 tons on the table.

mills and construction applications. "Mining is the biggest market for our operation, but we have manufactured a lot of big gears for the cement and fertilizing industries as well," says Fritz. "We've also made slew gears for satellite dishes."

Many of these gears are large enough to comfortably sit an entire manufacturing staff (*See photo on page 47*).

The Big Gear Contenders

Hofmann Engineering shipped a forged steel mill gear recently boasting an outside diameter of **13.2** meters and weighing 73.5 tonnes. It will transmit 17,000 kW when driven by two 9-tonne pinions. The gear is being utilized in an undisclosed copper mine in China.

"This gear is just 1 mm bigger than the gear that we manufactured five years ago for BHP Billiton (an Australian mining and petroleum company)," says Fritz. "We are also quoting on different designs at the moment with dual pinion mills up to 22,000 kW and dual girth gear mills up to 34,000 kW. We currently have an order for a mine in North America for a ball mill gear with a with a 9,000 kW single pinion drive."

While Fritz doesn't know what gear sizes the competition is supplying to the mining market, he does note that Hofmann boasts one of the biggest gear cutters in the world. "Our biggest machine is a 15,000 mm machine, followed by 14,000 mm, followed by an 11,000 mm. These machines are all hobbing/form cutting machines, but we also have three MAAG machines."

But can Hofmann actually claim the title of world's largest gear? Not so fast, according to the competition.

Rexnord/Falk boasts a **13.5** meter OD SAG mill gear set at the Los Bronces Copper Mine. "We also have two Detour Lake SAG mill gear sets, at **13.4** meters," Rhody says. "Additionally, there are five others with diameters between **13** and **13.2** meters. In terms of mill power, two of these have a total mill power of 24,138 hp. There are three other ball mill gear sets, with diameters less than 13.1 that have a mill power of 23,132 hp."

Hans van der Wee, of P. van der Wegen Gears b.v., says the company once delivered a **14** meter gear. "At the moment we have several very big gears on order (to be delivered at the end of this year and the beginning of next year) with an external diameter of a little below 14 meters. These gears are all for the minerals industry."

In fact, P. van der Wegen is currently working on different methods for the manufacture and production of large gears. "At the moment our maximum diameter capability is 16.5 meters," says van der Wee. "We are currently expanding our capacity and capabilities so that we will be able to produce gears (using the generating method and not, as many others do, the single-indexing method) up to a maximum diameter of 30 meters, though we have not yet encountered these size gears."

Ferry Capitain has already produced a **13.6** meter diameter girth gear, according to Ferry, and the company is currently producing a **16** meter diameter girth gear.

While Ursula Mian, head of marketing and communication at FLSmidth MAAG Gear states that the company is limited to about **11.2** meters, she confirms that P. van der Wegen Gears, Ferry Capitain and NKMZ are in the discussion. "We know that van der Wegen can today produce up to **14** meters and they are investing soon in a new machining center to produce even larger gears. Novokramatorsky Mashinostritelny Zavod (NKMZ) in Kramatorsk, Ukraine produces up to **15** meters on a new multi-machining center and Ferry Capitain can surely produce **14** meters."

So, Ferry Capitain at **16** meters takes the crown, right?

Not quite.

What Makes a Gear a Gear?

The world's biggest gear saga played out once in back issues of this very magazine when one Peter Mayo, of Toronto, N.S.W., Australia discussed a 92 meter diameter "red mud" tailings thickener in Western Australia. The question was raised whether or not a thickener rack or dragline rack should be even considered gears in the first place or should the name be reserved for gears that rotate ("The Bridges of Cook County and Other Sagas" *Gear Technology* September/October 1996).

In the very next issue, in an article entitled, "Gears on Film" (*Gear Technology* November/December 1996), the late Eliot K. Buckingham, an authority on the gear industry, stated, "To my mind, a single gear is a piece of metal with projections on it. A gear is designed to be operated with another gear or gears. You do not design a single gear …"

In the article, Buckingham approached the biggest gear question the same way. "The largest gear in the world

William Rhody, marketing manager, mill products at Rexnord, believes both physical size and power need to be included in the World's Biggest Gear debate.

is a cog railroad, since the rail is a rack, which is a segment of a gear of infinite diameter."

Perhaps this argument would best be resolved by getting all the companies together in a room with a potential BIG GEAR customer and let the chips fall where they may (pun intended). For all intents and purposes, it's difficult to argue which gear is the biggest or most powerful because it's essentially going to come down to satisfying a customer's request. If a gear customer has a need for a 35 meter gear, these companies will find a way to manufacture one. It's what they do.

"As the technology improves, companies will be capable of making larger and larger gears and it's going to be impressive to see the results," Rhody adds. "It's fun to imagine how big they might actually get."

In the meantime, talking about it only leads to anger and/or resentment. Someone that sees a press release claiming "World's Largest" immediately scoffs because the record won't stand for very long. In fact, the average *Photoshop* aficionado could "create" the world's largest gear with a few mouse clicks and some minor photo manipulation. Until Guinness sends a representative down to verify one of these mining gears with a notepad and a serious tape measure, all bets are off.

The Great Cop Out

No one will be named manufacturer of the "World's Biggest Gear" in this article. Instead, it's better to just stand back and admire the handy work of these massive components. If you're hell bent on naming a champion, we suggest a bit of restraint. By the time you've crowned the manufacturer of the world's largest gear, we're confident that some other company will be shipping a bigger one.

Good for the big gear business, ultimately bad for the bragging rights.

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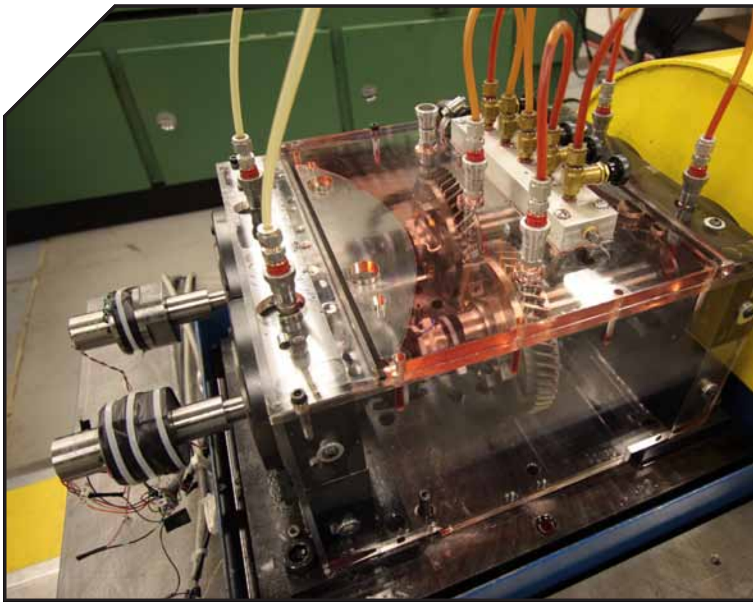
The Gear and Power Transmission Research Laboratory: Where Innovation Thrives

Jack McGuinn, Senior Editor



When, in 1980, OSU professor Donald R. Houser created the Gear and Power Transmission Research Laboratory — then known as the Gear Dynamics and Gear and Power Transmission Laboratory (GearLab) — he did so with the seed money provided by just three companies. Thirty-three years out, the lab has continued to grow, impress and—most importantly—succeed; it now boasts a roster of some 50 sponsoring companies and government agencies.

In 2003 GearLab merged with a research group headed up by Professor Ahmet Kahraman (see interview to follow), who was then at the University of Toledo's Center for Gear Research. The partnering led to a dramatic expansion of GearLab capabilities and facilities, in turn leading to explorations into the farther reaches of gear and power transmission research. Kahraman in 2006 assumed directorship of the center, as Houser retired from active teaching.

All along, the GearLab has been on a mission, a mission dedicated to aiding its participating (sponsoring) industries and government agencies by "enhancing gear and power transmission technology through fundamental and applied research and transfer research results; providing graduate and undergraduate students with applied educational and research opportunities in gear- and power transmission-related disciplines; and keeping sponsors updated on the latest gear and transmission technologies."

The referenced "sponsors" are members of the GearLab Consortium. The group includes some of the biggest and most influential companies and agencies in the country. Among Consortium membership benefits:

- Access to research findings with good leverage of investment
- Licenses to state-of-the-art computer software for gear design and analysis
- Access to experimental databases of GearLab
- Access to past GearLab research in the form of papers, reports and theses
- Limited consulting services, free of charge
- And what is required of would-be Consortium members?
- $12,000 per year for companies with more than 250 employees; one-time initiation fee of $4,000 for new members
- $4,000 per year for companies with fewer than 250 employees; one-time initiation fee of $1,000 for new members

It is a perfect "win-win" for both the lab and the companies and government agencies that support it—true American capitalism at work. On one hand, interested — and paying — parties are served by some of the best engineering minds and most sophisticated testing equipment in the world, as GearLab personnel are charged with researching, say, a potentially major application or material breakthrough, etc. On the other, we, as a nation — along with the gear and its ancillary industries (and their stockholders) — benefit greatly from the work being done there. And one more invaluable benefit: engineers — aspiring or veteran — are able to work their wonders confident in the knowledge that they are set up for success—not failure. Example: since its inception, research dollars at GearLab at have exceeded $15 million.

A sampling of previous and ongoing Consortium-funded projects include:

- An experimental and theoretical investigation of modulation sidebands of planetary gear trains
- A model to predict overall transmission error of a planetary gear set
- Development of a load distribution model for spiral bevel and hypoid gears
- Development of a straight bevel gear load distribution model
- A model to predict overall transmission error of a planetary gear set

Some Consortium member companies: Gleason Corp.; Honeywell; Hyundai; Hyundai Heavy Industries; ITAMCO; John Deere; Rexnord; Meritor; Kawasaki Machine Industry; Pratt & Whitney; Moog; and Reishauer.

And government agencies/cabinet departments: Department of Energy (DOE), the Army Research Laboratory, and the National Renewable Energy Laboratory (NREL).

Perhaps most important of all is the fact that, according to the Gear and Power Transmission Research Laboratory's Website (*gearlab.org*), over 150 Masters and Ph.D. students have been supported and mentored by the GearLab, most of whom are now helping to fill those critical positions at gear and power transmission companies that often go unfilled when vacated by their retiring predecessors. And the GearLab is where two influential industrial short courses on gear noise — now considered industry-standard chapter-and-verse — were developed and offered to the industry by Drs. Houser and Rajendra Singh

—"educating more than 1,350 engineers from over 320 companies on the subject matter."

The GearLab's state-of-the-art facilities in the Scott Laboratory (since the 2006 renovation) include the Gleason Gear and Power Transmission Laboratory, bequeathed by the Gleason Family Foundation. The facility consists of six high-bay rooms and 4,000 square feet of laboratory space with built-in facilities such as isolated test beds and two computational research laboratories that house the research team. The test facilities are arranged in three laboratories, dedicated to experimental investigation of different aspects of gearing.

There is the ***Gear Dynamics Research Laboratory,*** which houses a number of state-of-the-art test set-ups and machines to investigate the behavior of gear pairs and gear systems under dynamic operating conditions. It includes the Gear Dynamics test machine designed to measure transmission error, vibrations and root strains of spur and helical gears with or without shaft misalignments. Both encoder- and accelerometer-based transmission error measurement systems are incorporated with this test machine. Another valuable test set-up is a planetary test gear machine to measure planet load sharing, efficiency and dynamic behavior of planetary gear sets under loaded conditions. Other test set-ups in this lab include a low-speed load dynamometer currently being used for planetary gear set and hypoid transmission error measurements, as well as a full-scale transmission dynamometer suitable for loaded dynamic tests of gearboxes, transmissions and spin tests of axles.

The Gear Efficiency and Fatigue Research Laboratory also features a number of test machines, designed specifically to evaluate the efficiency and durability aspects of gears, gear materials and lubricants: Two twin-disk test machines for contact fatigue, scoring and traction measurements; an efficiency test machine with helical gear efficiency fixtures that is

Home to some of the most sophisticated gear testing and monitoring equipment on the planet, the OSU Gear and Power Transmission Research Laboratory boasts a gear dynamics test machine designed to measure transmission error, vibrations and root strains of spur and helical gears—with or without shaft misalignments. Also on the premises are three standard FZG gear durability test machines (next page) for performing pitting, tooth bending fatigue and scoring tests.

The Consortium, comprised of sponsoring companies and government agencies, is what keeps the lights on at the Gear and Power Transmission Research Laboratory. Consortium members' need for invaluable research and development—and their willingness and ability to pay for it—are the drivers for the valuable work done there by lab personnel (all photos courtesy Gear and Power Transmission Research Laboratory).

designed to evaluate loaded and unloaded power losses of gear pairs under high-speed (up to 10,000 rpm) and high-load conditions (up to 700 Nm); three standard FZG gear durability test machines for performing pitting, tooth bending fatigue and scoring tests; and an MTS load frame fixture to perform single-tooth bending fatigue tests.

The third facility, the ***Gear Metrology Research Laboratory,*** supports the experiments occurring in the other two laboratories by providing systems for the measurement of surface roughness and tooth profiles, and imaging the test surfaces. A Gleason-Goulder single-flank, unloaded transmission error tester, a Gleason M&M gear CMM, a Taylor Hobson Tally-Surf surface roughness profiler and miscellaneous digital microscopes and data collection and analysis instrumentation are also available in this lab.

Add to all this a priceless cache of research-specific technical papers produced in-house over the years and typically presented at VDI- and ASME-sponsored conferences.

Bottom line — after the money has been spent, the checks have been cashed and the work completed—virtually every project the Gear and Power Transmission Research Laboratory takes on is done so with the following goals firmly in its sights:

- Increase power density
- Improve quality
- Reduce noise and vibration
- Improve efficiency and lubrication
- Reduce cost of power transmission and gear systems

It is, after all, what gear systems designers strive for every day. And what is accomplished at the Gear and Power Transmission Research Laboratory — the GearLab — on a daily basis.

(*For more on the Gear and Power Transmission Research Laboratory, please see accompanying Q&A with lab director* Ahmet Kahraman.)

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A *Gear Technology* Interview with Ahmet Kahraman, Director, Gear and Power Transmission Research Laboratory

Jack McGuinn, Senior Editor

***Gear Technology* (GT). Can you tell us about the projects sponsored at the GearLab?**

Dr. Ahmet Kahraman (AK). Projects sponsored by the OSU Gear Research Consortium cover a wide spectrum of gear topics, including gear design optimization; gear contact mechanics; gear system dynamics; gear tribology and lubrication; gear system efficiency; contact and bending fatigue; surface wear; and scuffing. At any given time, we will have 7–10 (masters and doctorate) students supported by the Consortium to perform such research projects. Research findings are presented to the Consortium members and implemented in our software packages that are licensed to the members.

GT. What are "individually sponsored projects," and how do they work?

AK. These are the projects funded by a single company, while on some occasions more than one company might partner up to fund a project. The sponsoring company may or may not be a member of the Gear Research Consortium. (The) sponsoring company funds the entire project exclusively. The results of these projects are kept confidential (i.e., they are not shared with the Consortium membership). A research contract agreement is signed between the company and the University to address all legal issues including non-disclosure, licensing as well as publications.

GT. Is your work split evenly between government and industry, or something else?

AK. We work with government entities such as the (Department of Energy, National Renewable Energy Laboratory and the Army Research Laboratory) on the Federal side, while more than 80 percent of our current funding is industrial in nature.

GT. In reviewing the GearLab site, it appears that a majority of your research is automotive-related. Accurate? If so, why the emphasis?

AK. About half of our research expenditures are automotive-related, while the rest is aerospace- and off-highway-related. Of 67 current consortium member companies, about 25 are automotive (OEM and 1st Tier suppliers), 10 are aerospace, 20 are off-highway and industrial gearbox companies, and the rest are from manufacturing, oil, consulting, software and recreational vehicle industries. As such, while we are involved with the automotive industry heavily, we cannot say our research is limited to automotive needs only. Our sponsor base is rather diverse, covering various industries.

GT. Assuming the GearLab is international in scope, are U.S. national security considerations ever a factor in working with a foreign entity?

AK. Yes, GearLab has an international focus and reach. Of 67 current members of the consortium, about one-third are non-U.S. companies from countries such as S. Korea, Japan, Germany, Italy, France, U.K., China, Turkey, Sweden, Canada and Mexico. Yet we are trained and set-up to perform research with ITAR (International Traffic in Arms Regulations) or export controls restrictions as well. We currently have several projects of this type and we have systems in place to fully comply with such requirements.

GT. What would you consider the GearLab's greatest achievement to date?

AK. While we are proud of the positive impact of our research on the gear and power transmission industries, and our contributions to the state-of-the-art in gearing, our greatest achievement within the last 30 years has to be our educational impact on the industry. We graduate about 10 students with (masters and doctorates) in gearing-related topics each year who are hired exclusively by power transmission companies. We have more than 175 GearLab alumni working in industry on gears and power transmissions; you can trace a many practicing gear engineers to GearLab. In addition, we also provide gear-related, industrial short courses. More than 1,500 engineers (have taken) our industrial courses over the years. As such, GearLab's greatest achievement has to be that it was able to educate gear technologists needed by the industry.

GT. Why aren't there more "GearLabs" in the U.S.?

AK. This might have many answers to it. The misguided perception that gears are a "mature" technology with limited research and science potential is perhaps one reason. U.S. universities will not hire new professors to work on gears, as this is not as high on their lists as other emerging areas, such as nano or bioengineering. Meanwhile powertrain industries have been dealing with real, tough and perennial issues that require immediate attention. (Another) reason might be that U.S. powertrain companies are not that enthusiastic about university research — perhaps due to their past experiences. There is still a perception that academic research is not applicable to practical problems. I would like to think that our projects in GearLab are examples to make a case that academic research can be done to investigate a science issue while at the same time solving a particular real-life problem of industry.

GT. What can be done to enlist more bright young people in mechanical and power transmission components engineering?

AK. Our strategy has been involving undergraduate students in gear research as early as possible. We engage sophomores and juniors actively and hire them as undergraduate research assistants early on. Once they become a part of GearLab and witness what we are all about, they typically stay with us through their graduate education.

Dr. Ahmet Kahraman is a Howard D. Winbigler professor of mechanical and aerospace engineering at The Ohio State University, and director of the Gleason Gear and Power Transmission Research Laboratory. He also directs the Pratt & Whitney Center of Excellence in Gearbox Technology. Kahraman was past chairman of the ASME Power Transmission and Gearing (PTG) Committee and the 2007 and 2009 ASME PTG Conferences. A former associate editor of the ASME Journal of Mechanical Design, he serves on the editorial boards of Journal of Sound and Vibration, Journal of Multi-Body Dynamics, and Mechanics-Based Design of Structures and Machines. Kahraman is an ASME fellow and member of STLE. He received his Ph.D. degree in mechanical engineering from Ohio State in 1990. His areas of research focus include gear system design and analysis; gear and transmission dynamics; gear lubrication and efficiency; gear and fatigue life prediction; and test methodologies.

Workholding Options

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

QUESTION

We manufacture some gears that require an axial face as a datum, as well as locating on the bore for centering. Other gears use only the bore for both axial and radial locating. What type of workholding is appropriate for each type of part? Is there workholding that will work for both types?

Response from Hank Kohl, president, Hainbuch America Corporation

For the parts with a bore that is the radial datum and an axial face, a "pull-down"-type mandrel is most effective. As the part is centered on the bore, the collet pulls the parts down against an end-stop for the axial reference. These can be with or without a draw bolt, thus allowing a blind-hole application.

Pull-down mandrel (illustrations courtesy Hainbuch).

When parts that have only a bore for datum, a "dead-length" mandrel is appropriate. These expand only on the bore and do not pull against the face. This prevents a non-datum-surface from affecting the alignment of the part during clamping.

For the flexibility to use both types, a quick-change system—consisting of a flange and actuating unit—will enable a fast changeover from "pull-down" to "dead-length." These are generally off-the-shelf, standard components.

Dead-length mandrel.

Hank Kohl

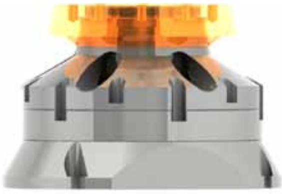
Second response from Chris Brown, business manager for Forkardt, an ITW Workholding Company.

For gripping on only an ID bore, a collet or expanding mandrel are usually the preferred method; this is when there are no other datums to locate from. Typically, the manufacturing process will use centers for putting the gear on a common centerline, and the collet/mandrel is used for securing the gear while under rotation and against any torque applied during the process. This is very common in gear hobbing. Where centers are not used, accuracy will be dependent on a collet fixture, as centerline will be established by the accuracy of the fixture, as opposed to the accuracy of the centers.

When centering on the ID is required—along with an axial face as a locating datum—a pull-down chuck is recommended. This most likely would be a collet chuck that pulls the gear down against a positive stop or locating face. These are typically not something that the buyer can purchase off the shelf, but more likely requires some design work that can be accomplished—in some instances—rather easily. But for more complex or demanding applications, contacting a workholding company is advised. Designs of this type can accommodate diameters as small as .5" (12 microns) and up to 40" (1 meter) or larger. Regarding larger instances, if a collet is not used, some form of either manual or power chucks are used. The key will be to pull the gear back against a qualified surface in order to hold any GD&T requirements.

Collets would be most commonly used, however, due to the need to locate on an axial datum; a special fixture would be needed to accommodate both examples. It can be accomplished relatively easily by eliminating the locating detail on the fixture.

Chris Brown



PRECISION POWER PARTNERSHIPS

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Producing Large-Sized, Skew Bevel Gear Pinion Using Multi-Axis Control and Multi-Tasking Machine Tool

I. Tsuji, K. Kawasaki and H. Gunbara

This paper proposes a method for the manufacture of a replacement pinion for an existing, large-sized skew bevel gear using multi-axis control and multitasking machine tool.

Introduction

Bevel gears are used to transmit power and motion between the intersecting axes of two shafts, most often mounted on shafts 90° apart. They may have straight, Zerol, spiral or skew teeth (Refs. 1–4), and are common in gear transmissions (Ref. 5).

The transmission of straight bevel gears is regarded as a particular case of skew bevel gears (Ref. 6) in that their contact ratio is larger than that of straight bevel gears and skew bevel gears have oblique teeth.

Skew bevel gears are typically used in power generation plants and are quite large. In recent years these mostly aging plants have been undergoing extensive retrofitting and so it has often become necessary to replace the skew bevel gears used in them. In some cases, where only the pinion member is changed, it then becomes necessary to manufacture a new pinion that performs well with the existing gear member.

It is now possible to machine these gears' complicated tooth surface due to the development of multi-axis control and multitasking machine tools (Refs. 7–8). Therefore, high-precision machining of large-sized, skew bevel gears has become commonplace.

Proposed here is a method for manufacturing new pinion mates for large-sized, skew bevel gears using multi-axis control and multitasking machine tools. This manufacturing method has the dual advantages of arbitrary modification of the tooth surface and of machining the part without the tooth surface (Ref. 9).

To begin, understand that the tooth surface forms of skew bevel gears are modeled mathematically. Next, the real tooth surfaces of the gear member are measured using a coordinate measuring machine (CMM), and the deviations between the real and theoretical tooth surface forms are formalized using the measured coordinates. It is now possible to analyze the tooth contact pattern and transmission errors of the skew bevel gears while addressing the deviations of the real and theoretical tooth surface forms by expressing the deviations as polynomial equations.

The components of the deviations of tooth surface forms corresponding to the distortions of heat treatment and lapping, etc., are used because the motion concept can be implemented on the multitasking machine.

Further, deviations of the tooth surface forms of the gear member can be reflected in the analysis of the tooth contact pattern and transmission errors, and the tooth surface form of the pinion member that has good performance mating with the existing gear member is determined. Finally, the pinion member is manufactured by a swarf cutting that is machined using the side of the end mill of a multi-axis control and multitasking machine tool. Afterward, the real tooth surfaces of the manufactured pinion member are measured using a CMM and the tooth surface form errors are detected. Although the tooth surface form errors were especially large on the coast-side, they are in fact minimal on the drive-side. In addition, the tooth contact pattern of the manufactured pinion member and the provided original gear member were compared with the results from tooth contact analysis (TCA), and there was good agreement.

Tooth Surfaces of Skew Bevel Gears

As mentioned, the tooth surface forms of skew bevel gears are modeled mathematically. In general, the geometry of the skew bevel gears is achieved by considering the complementary crown gear as the theoretical generating tool. Therefore, the tooth surface form of the complementary crown gear is considered first.

The number of teeth of the complementary crown gear is represented by:

$$z_c = \frac{z_p}{\sin \lambda_{p0}} = \frac{z_g}{\sin \lambda_{g0}} \tag{1}$$

where:

z_c is number of teeth of complementary crown gear
z_p is number of teeth of the pinion
z_g is number of teeth of the gear
λ_{p0} is pitch cone angles of the pinion
λ_{g0} is pitch cone angles of the gear

Figure 1 shows the tooth surface form of the complementary crown gear assuming to be straight bevel gears with depth-wise tooth taper. O-xyz is the coordinate system fixed to the crown gear and the *z* axis is the crown gear axis of rotation. Point P is a reference point at which tooth surfaces mesh with each other and is defined in the center of the tooth surface. The circular arcs with large radii of curvatures are defined both in xz and xy planes; the xz and xy planes correspond to the sections of the tooth profile and tooth trace of the tooth surface, respectively.

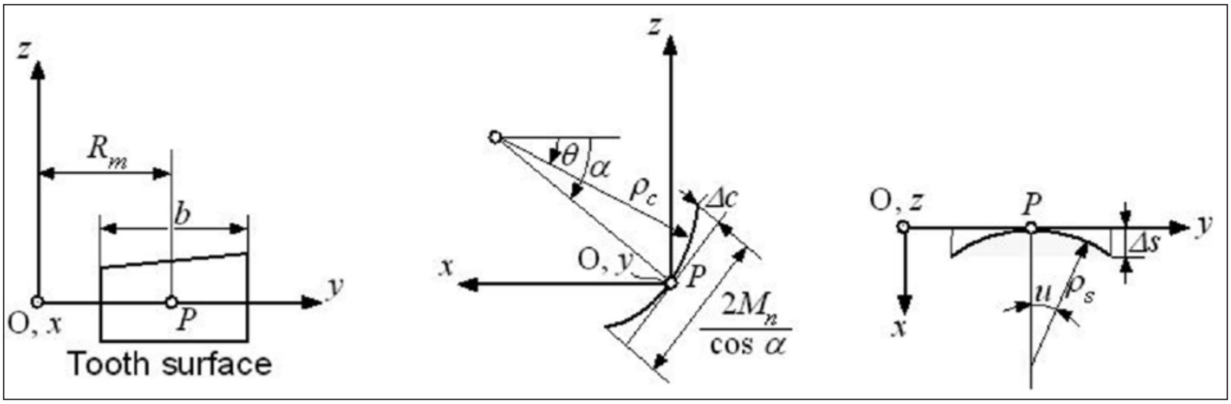


Figure 1 Tooth surface form of complementary crown gear.

This curved surface is defined as the tooth surface of the complementary crown gear. The following equations demonstrate the relations between ρ_c, Δc and M_n in xz, and between ρ_s, Δs and b in xy planes, respectively (Ref. 10).

Since skew bevel gears have teeth that are straight and oblique, the skew bevel gear has in fact a skew angle (Fig. 2). Thus the complementary crown gear also has the skew angle, defined as β. The tooth surface of the complementary crown gear is expressed in O-xyz using ρ_c and ρ_s:

$$\rho_c = \frac{\Delta c^2 + \left(\frac{M_n}{\cos\alpha}\right)^2}{2\Delta c} \qquad \rho_s = \frac{\Delta s^2 + \frac{b^2}{4}}{2\Delta s} \tag{2}$$

where:

ρ_c = radius of the curvature of the circular arcs in the xy plane, and has influence on Δc
Δc = amount of tooth profile modification
M_n = normal module
α = pressure angle
ρ_s = radius of curvature of the circular arcs in the xy plane, and influence on Δs
Δs = amount of tooth profile crowning
b = facewidth

$$X(u,\theta) = \begin{bmatrix} -\rho_c(\cos\theta - \cos\alpha) - \rho s(1-\cos u) + \rho_s \sin u \tan\beta \\ \rho_s \sin u + R_m \\ \rho_c(\sin\alpha - \sin\theta) \end{bmatrix} \tag{3}$$

where:

X = position vector of tooth surface of complementary crown gear in O-xyz
u = parameter which represents curved lines
θ = parameter which represents curved lines
R_m = mean cone distance

The unit-normal X is expressed by N.

The equation of the tooth surface of the complementary crown gear = X. The complementary crown gear is rotated about the z axis by angle ψ and generates the tooth surface of the skew- bevel gear. This rotation angle — ψ — of the crown gear, is the generating angle. When the generating angle is ψ, X and N are rewritten as $X\psi$ and $N\psi$ in O-$x_sy_sz_s$, assuming that the coordinate system O-xyz is rotated about the z axis by ψ in the coordinate system O-$x_sy_sz_s$ and is fixed in space. When ψ is zero, O-$x_sy_sz_s$ coincides with O-xyz.

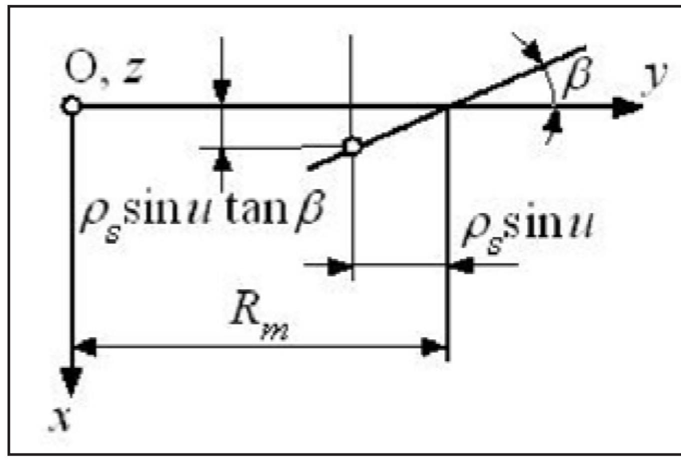


Figure 2 Skew angle of complementary crown gear.

Assuming the relative velocity W ($X\psi$) between the crown gear and the generated gear at the moment when generating angle is ψ, the equation of meshing between the two gears is as follows (Refs. 11–12):

$$N_\psi(u,\theta;\psi)\,W(u,\theta;\psi) = 0 \tag{4}$$

where:

$N\psi$ = the unit-normal vector of $X\psi$ in O-$x_sy_sz_s$
$X\psi$ = position vector of tooth surface of complementary crown gear in O-$x_sy_sz_s$
ψ = parameter representing rotation angle of complementary crown gear about the z axis

From Equation 4 we have $\theta = \theta(u,\psi)$. Substituting $\theta(u,\psi)$ into $X\psi$ and $N\psi$, any point on the tooth surface of the crown gear and its unit-normal are defined by a combination of (u,ψ), respectively. When the tooth surface of the complementary crown gear in O-$x_sy_sz_s$ is transformed into the coordinate system fixed to the generated gear, the tooth surface of the skew-bevel gear is expressed. The tooth surfaces of the pinion and gear are expressed as x_p and x_g, respectively. Moreover, the unit-normals of x_p and x_g are expressed as n_p and n_g, respectively. Henceforth, the subscripts "p" and "g" indicate that each is related to the pinion and gear.

Measurement of Gear Member

Manufacturing errors occur in bevel gear cutting, sometimes because whether the mathematical model, as mentioned earlier, fits the real tooth surface of the existing gear member or not, is not obvious. Therefore the tooth surfaces of the gear member are measured using a CMM and the deviations between the real and theoretical tooth surface forms are formalized.

Coordinate measurement of real tooth surface. The theoretical tooth surfaces of the gear member are expressed as $x_g\,(u_g, \psi_g)$, as mentioned. A grid of n lines and m columns is defined and a point—or reference point—is specified on the tooth surfaces of both the drive- and coast-sides; the reference point is usually plotted in the center of the grid. The position vectors $x_g\,(x, y, z)$—namely, u, θ and ψ—are determined for the solution of simultaneous equations by considering one point on the grid of the tooth surface; the unit-normal (n_x, n_y, n_z) of the corresponding surface point is also determined since u, θ and ψ are determined (Ref. 13).

For measurement, the gear member is set up arbitrarily on a CMM whose coordinate system is defined as $O_m\text{-}x_m y_m z_m$. We can make origin O_m and axis z_m coincide with the origin and the axis of the gear member, respectively. The whole grid of surface points, together with the theoretical tooth surfaces, is rotated about the z_m axis so that y_m is equal to zero at the reference point. Therefore, the position vector of the point and its unit-normal are transformed into the coordinate system $O_m\text{-}x_m y_m z_m$ and are represented by:

$$x^{(i)} = \left(x^{(i)}, y^{(i)}, z^{(i)}\right)^T \quad (i = 1, 2, \ldots, 2nm)$$
$$n^{(i)} = \left(n_x^{(i)}, n_y^{(i)}, n_z^{(i)}\right)^T \tag{5}$$

where:
$x^{(i)}$ is the position vector of the *i-th* point of tooth surface in $O_m\text{-}x_m y_m z_m$
$n^{(i)}$ is the unit-normal vector of $x^{(i)}$

The real tooth surface of the gear member was measured using a CMM (Sigma M and M3000 developed by Gleason Works). When the real tooth surface is measured according to the provided grid, the *i-th*-measured tooth surface coordinates are obtained and numerically expressed as the position vector (Refs. 13–14):

$$x_m^{(i)} = \left(x_m^{(i)}, y_m^{(i)}, z_m^{(i)}\right)^T \quad (i = 1, 2, \ldots, 2nm) \tag{6}$$

where:
$X_m^{(i)}$ is the position vector of the *i-th*-measured tooth surface coordinates in $O_m\text{-}x_m y_m z_m$

When the deviation δ between the measured coordinates and nominal data of the theoretical tooth surfaces for each point on the grid is defined towards the direction of the normal of the theoretical tooth surface, *i-th* δ can be determined by:

$$\delta^{(i)} = \left(x_m^{(i)} - x^{(i)}\right) n^{(i)} \quad (i = 1, 2, \ldots, 2nm) \tag{7}$$

where:

the deviation between measured coordinates and nominal data of tooth surface is $\delta^{(i)}$ for each point on the grid towards the direction of the normal of tooth surface; δ is equal to zero at the reference point.

The fundamental components of the deviations of tooth surface forms corresponding with the distortions of heat treatment and lapping, etc., are used because the motion concept may be implemented on a multitasking machine.

Formalization of deviations of tooth surface form. Based on the method mentioned earlier, the deviation δ for each point on the grid is calculated when the points on the tooth surface are measured (Ref. 15). However, it is difficult to ideally fit δ to the theoretical tooth surface because δ varies at each point on the grid. We therefore define (X, Y) whose X and Y are toward the directions of the tooth profile and tooth trace, respectively, and form the following polynomial expression:

$$\delta = \delta_{11} + \delta_{12} + \delta_{21} + \delta_{22} + \delta_{31} + \delta_{32} + \delta_{41} \tag{8}$$

where:
δ_{11} = parameter-defining deviation
δ_{12} = parameter-defining deviation
δ_{21} = parameter-defining deviation
δ_{22} = parameter-defining deviation
δ_{31} = parameter-defining deviation
δ_{32} = parameter-defining deviation
δ_{41} = parameter-defining deviation

Figure 3 shows the procedure formalizing the relation between the fundamental components of polynomial expression and the deviation of tooth surface form. First, the tooth trace deviation δ_{11} and tooth profile deviation δ_{12} are expressed as the following first-order equations of X and Y, using fundamental components a_{11} and a_{12}, respectively (Fig. 3a):

$$\delta_{11} = a_{11}\,X$$
$$a_{11} = \frac{\delta_{11}}{0.5\,H}$$
$$\delta_{12} = a_{12}\,Y$$
$$a_{12} = \frac{\delta_{11}}{0.5\,T} \tag{9}$$

where:
a_{11} = fundamental component of polynomial expression
H = range of the evaluation of the tooth surface in X directions
a_{12} = fundamental component of polynomial expression
T = range of the evaluation of the tooth surface in Y directions

The tooth trace deviation δ_{21} and tooth profile deviation δ_{22} are expressed as the following second-order equations of both X and Y, using fundamental components a_{21} and a_{22}, respectively (Fig. 3b):

$$\delta_{21} = a_{21}\,X^2$$
$$a_{21} = \frac{\delta_{21}}{(0.5\,H)^2} = \frac{4\,\delta_{21}}{H^2}$$
$$\delta_{22} = a_{21}\,Y^2$$
$$a_{22} = \frac{\delta_{22}}{(0.5\,T)^2} = \frac{4\,\delta_{22}}{T^2} \tag{10}$$

where:
a_{21} = fundamental component of polynomial expression
a_{22} = fundamental component of polynomial expression

Further, the deviations δ_{31} and δ_{32} in the directions of the bias-in and bias-out are expressed as the following second-order equations of both X and Y, using fundamental components a_{31} and a_{32}, respectively (Fig. 3c):

$$\xi_1 = \tan^{-1}\left(\frac{T}{H}\right),\; L_0 = \frac{H}{\cos \xi_1} \tag{11}$$

$$\delta_{31} = a_{31}\,(X \cos \xi_1 - Y \sin \xi_1)^2$$

$$a_{31} = \frac{\delta_{31}}{(0.5\,L_0)^2} = \frac{4\,\delta_{31}}{H_0^2}$$

$$\delta_{32} = a_{32}\,(X \cos \xi_1 - Y \sin \xi_1)^2$$

$$a_{32} = \frac{\delta_{32}}{(0.5\,L_0)^2} = \frac{4\,\delta_{31}}{L_0^2}$$

where:

a_{31} = fundamental component of polynomial expression
a_{32} = fundamental component of polynomial expression

The tooth trace deviation δ_{41} is expressed as the following third-order equations of *X* and *Y*, using fundamental components b_1, b_2 and b_3, respectively (Fig. 3d):

$$\delta_{41} = b_3X^3 + b_2X^2 + b_1X \tag{12}$$

Thus b_1, b_2 and b_3 are determined from the following conditions: δ is equal to zero when $X = -0.5H$ and $X = 0.5H$. In addition, δ is equal to δ_{41} when $X = 0.25H$. Reflecting the polynomial expression δ to the theoretical tooth surface, the position vector is represented by:

$$x_a = x + \delta\, n \tag{13}$$

Thus x_a describes the theoretical tooth surface with consideration of the tooth surface form deviations. The tooth contact patterns and transmission errors with the tooth surface form deviations are analyzed using x_a. The position vector of the *i-th* point of the theoretical tooth surface is expressed as $x_a^{(i)}$.

Formalization of Measured Results

The real tooth surfaces of the gear member to be used were measured on a CMM and the deviations between the real and theoretical tooth surface forms were formalized. Table 1 shows the dimensions of the skew bevel gears. The pitch circle diameter of the gear member is 1,702.13 mm — very large. Five points in the direction of the tooth profile and nine points in the direction of the tooth trace for the grid were used. Figure 4 shows the formalized results of the measured coordinates. Figure 4a shows the measured results using a CMM compared to the theoretical tooth surface. Figure 4b shows the formalized results using Equations 9, 10 and 11 in Equation 8. Figure 4c shows the formalized results using Equation 12, in addition to Equations 9, 10 and 11 in Equation 8. The maximum values of the magnitude of deviations are 0.793 mm, 0.128 mm and 0.066 mm in Figure 4a, b and c, respectively. The overall deviations gradually decrease as a whole from Figure 4a and 4c. As the deviations are formalized with a large number of equations, the deviations decrease and fit the measured coordinates well to the theoretical tooth surface. Therefore, once formalization of the deviations was validated the fundamental components of the deviations of the tooth surface forms corresponded to the distortions of heat treatment and lapping, etc.

Tooth Contact Analysis (TCA)

Concept of tooth contact analysis. The tooth surface form of the pinion member that has good performance mating with the existing gear member mentioned earlier is considered based on tooth contact analysis. In this case, the tooth surface form of the

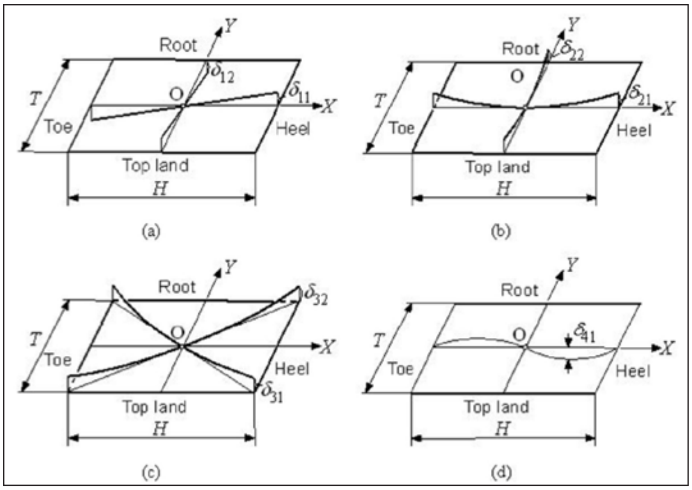


Figure 3 Procedure formalizing relation between fundamental components of polynomial expression and deviation of tooth surface form.

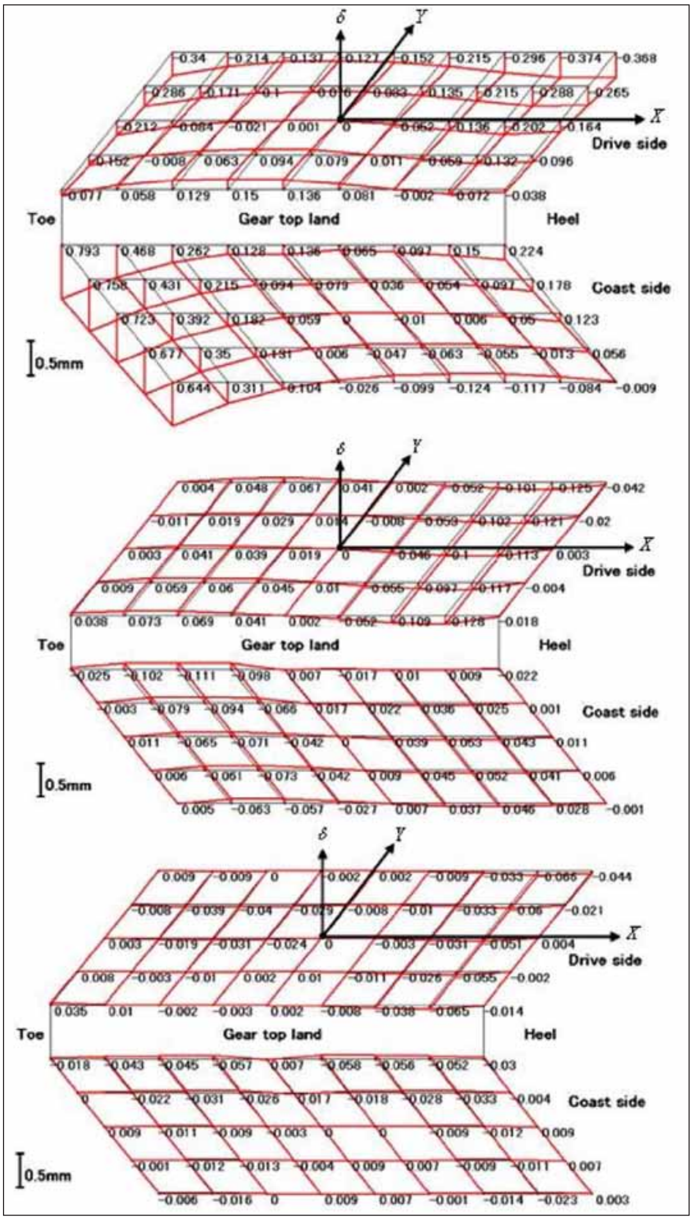


Figure 4 Formalized results based on measured coordinates.

pinion member is modeled using Equation 1and the appropriate amount of profile modification and crowning is calculated.

The pinion and gear members are assembled in a coordinate system O_h-$x_hy_hz_h$ (Fig. 5) in order to analyze the tooth contact pattern and transmission errors of the pinion member and existing gear member. Suppose that φ_p and φ_g are the rotation angles of the pinion and gear, respectively. The position vectors of the pinion and gear tooth surfaces must coincide and the direction of two unit-normals at this position must be also agree in order to contact the two surfaces. Therefore, the following equations yield:

$$B(\varphi_p)\, x_p(u_p, \psi_p) = C(\varphi_g)\, x_g(u_g, \psi_g)$$
$$B(\varphi_p)\, n_p(u_p, \psi_p) = C(\varphi_g)\, n_g(u_g, \psi_g) \tag{14}$$

where:

B and *C* are the coordinate transformation matrices for the rotation about the y_h and z_h axes, respectively

φ_p is the rotation angle of pinion about *yh* axis in O_h-$x_hy_hz_h$

φ_g is the rotation angle of gear about *zh* axis in O_h-$x_hy_hz_h$

$$B(\varphi_p) = \begin{bmatrix} \cos\varphi_p & 0 & \sin\varphi_p \\ 0 & 1 & 0 \\ -\sin\varphi_p & 0 & \cos\varphi_p \end{bmatrix} \tag{15}$$
$$C(\varphi_g) = \begin{bmatrix} \cos\varphi_g & -\sin\varphi_g & 0 \\ \sin\varphi_g & \cos\varphi_g & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Table 1 Dimensions of skew bevel gears			
		Pinion	Gear
Number of teeth	z_p, z_g	18	116
Pitch circle diameter		264.1346 mm	1702.1302 mm
Pitch cone angle	λ_{p0}, λ_{g0}	8.8167 deg	81.1833 deg
Normal module	M_n	10.6764	
Mean cone distance	R_m	759.65 mm	
Pressure angle	α	14.5 deg	
Skew angle	β	15 deg	
Face width	*b*	203.2 mm	
Shaft angle		90 deg	
Backlash		0.4064 - 0.5588 mm	

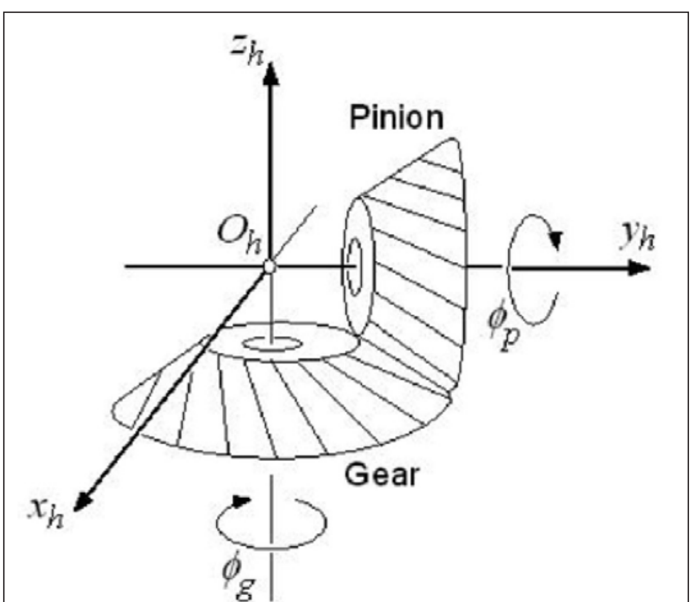


Figure 5 Meshing of pinion and gear.

Since $|n_p| = |n_g| = 1$, Equation14 represents a system of five scalar, non-linear equations with five unknowns — u_p, ψ_p, u_g, ψ_g and φ_g — considering angle φ_p as the input parameter. The continuous solution of the system of the non-linear equations permits the determination of the path of contact considering that φ_p changes every moment. A method of successive approximation is utilized in order to obtain a numerical solution of Equation 14. In this case it is convenient to use a cylindrical coordinate system.

The paths of contact on the pinion and gear tooth surfaces are represented by x_p (u_p, ψ_p) and x_g (u_g, ψ_g), respectively.

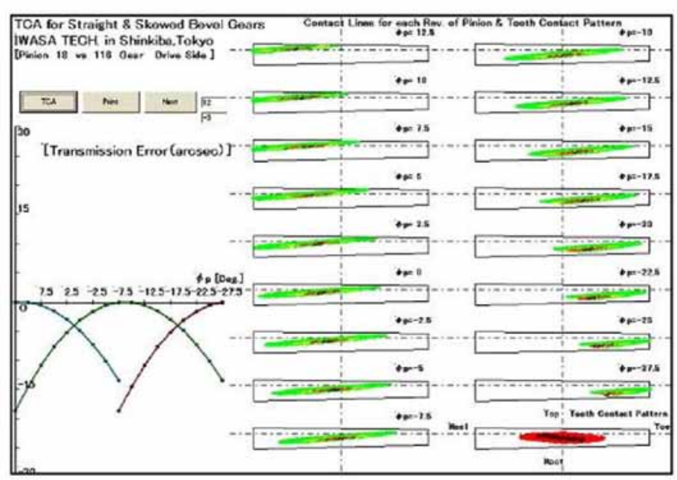
When the pinion is rotated by the angle φ_p the gear should be rotated by the angle $z_p/z_g\varphi_p$, assuming that pinion and gear are conjugate. Realistically, however, this is not the case, and transmission errors occur. The function of transmission errors is defined as:

$$\Delta\varphi_g(\varphi_p) = \varphi_g(\varphi_p) - \frac{z_p}{z_g}\varphi_p \tag{16}$$

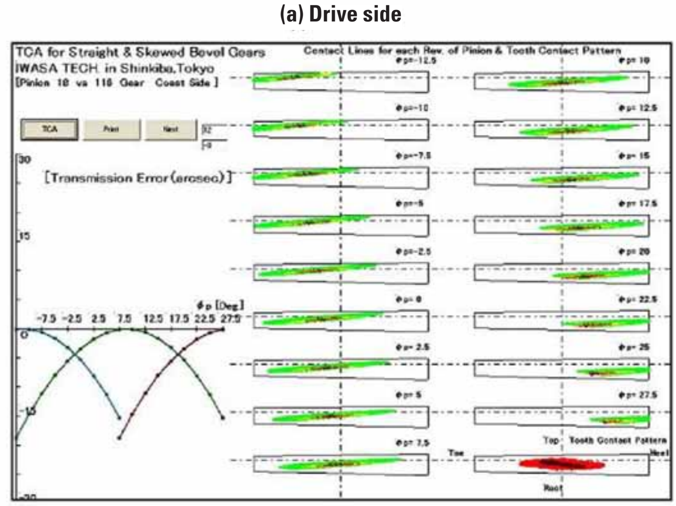
where:

$\Delta\varphi_g$ = function of transmission error

Results of TCA. The tooth contact pattern and transmission errors of the pinion member model (Eq. 1) and existing gear



(a) Drive side



(b) Coast side

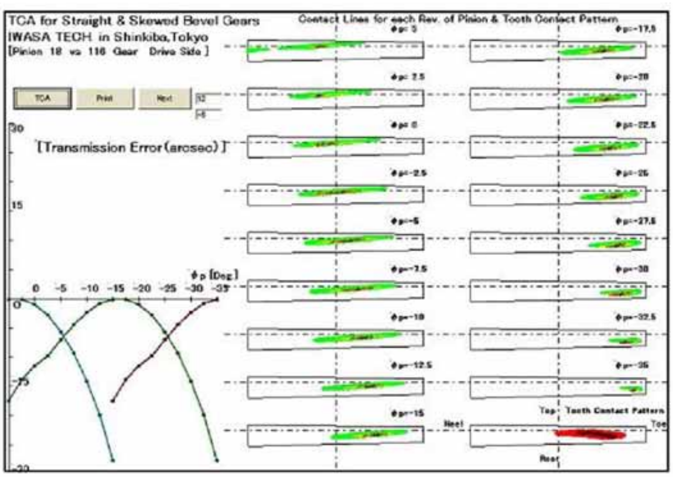
Figure 6 Analyzed results of tooth contact pattern and transmission errors without accounting for tooth surface form deviations.

member whose tooth surface is calculated under unloaded condition were analyzed based on the method used earlier.

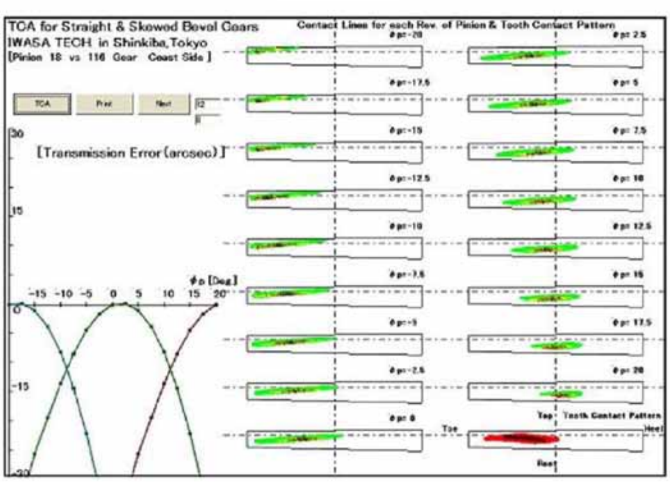
Figure 6 shows the analyzed results of tooth contact pattern and transmission errors, without taking into account the tooth surface form deviations described earlier. Figure 6a is the result of drive-side, and Figure 6b is that of the coast-side. The amounts of tooth profile modification and crowning of pinion member are $\Delta c = 0.05$ mm and $\Delta s = 0.05$ mm — on both drive- and coast- sides — respectively. These values have influence on the tooth contact pattern and transmission errors, as mentioned. The right side from the center (Fig. 6) shows the analyzed contour line on the gear tooth surface at every instant when the rotation angle φ_p of the pinion changes from 12.5° to -27.5° on the drive-side, and from -12.5° to 27.5° on the coast-side. The lowest figure of the right side shows the total tooth contact pattern considering contact ratio. The region whose clearance between the pinion and gear tooth surfaces is less than 30 mm is displayed. The tooth contact patterns are obtained around the centers on the tooth surfaces of both drive- and coast-sides.

The left side (Fig. 6) shows the analyzed transmission errors. The shape of transmission errors is parabolic; the parabolic transmission errors occur due to the influence of both profile modification and crowning. In this case the rotation is transmitted smoothly. Therefore it is important to have the intersection before and after meshing. The maximum value of the transmission errors is about five arcsec of both drive- and coast-sides. These transmission errors can be adjusted by changing Δc and Δs.

Figures 6 and 7 show the analyzed results of tooth contact pattern and transmission errors with respect to the tooth surface form deviations. The amount of tooth profile modification and crowning of pinion member are $\Delta c = 0.1$ mm and $\Delta s = -0.4$ mm on the drive-side, and $\Delta c = 0.2$ mm and $\Delta s = 0.79$ mm on the coast-side. In addition, -0.4° in α and 0.05° in β on the drive-side and -0.25° in α, 0.03 degrees in β are changed. The tooth contact pattern deviates slightly from the center on the tooth surface of both drive- and coast-sides. These contact patterns seem to be acceptable in practical use. In addition, the transmission errors become large on the coast side. These transmission errors also seem to be acceptable in practical use.



(a) Drive side



(b) Coast side

Figure 7 Analyzed results of tooth contact pattern and transmission errors with respect to tooth surface form deviations.

Manufacture of Pinion Member

The pinion member was manufactured using a 5-axis control machine (DMG Co., Ltd. DMU210P) based on the results of TCA. In this case the reference and hole surfaces, in addition to the tooth surfaces, can be machined and a tool approach provided from optimal direction using multi-axis control since the structure of the 2-axis of the inclination and rotation in addition to translational 3-axis are added; therefore, a thicker tool can be used. This should reduce the machining time and produce a smoother tooth surface. The radius end mills made of cemented carbide for a hard cutting tool were used in the machining of tooth surface. The number of edges is six and the diameter of end mill is 10 mm. Ball end mills were used in the machining of the tooth bottom. The number of the edges is six and the diameters of end mills are 10 mm and 5 mm, respectively, in the machining of the tooth bottom. The pinion material used was 18CrNiMo06. The tool pass was 1 mm for the large-sized pinion member. First, the pinion work was rough-cut and heat treated.

Afterward, the pinion member was semi-finished with the machining allowance of 0.3 mm after heat treatment. Finally, the pinion was finished with the machining allowance of 0.05 mm by swarf cutting. Machining with high accuracy and efficiency utilizing the advantages of a multi-axis control and multitasking machine tool in swarf cutting can be expected. Table 2 shows the conditions for semi-finishing and finishing of the pinion tooth surfaces. Figure 8 shows the situation of swarf cutting of the pinion member. The machining time of one side in rough-cutting is about 50 minutes; semi-finishing and finishing take about 170 minutes; the machining was finished without problems, such as defects of the end-mill.

Tooth Surface Form Error and Tooth Contact Pattern

The manufactured pinion tooth surfaces were measured using a CMM and compared with nominal data determined from the theoretical pinion tooth surface mating with the theoretical gear tooth surface—and without taking into account tooth surface form deviations. Figure 9 shows the measured result of the pinion member. Since tooth surface form deviations were not respected in the theoretical gear tooth surface, the tooth surface form errors are relatively large. In particular, the tooth surface form errors are large on the coast-side. The large-sized

Table 2 Conditions of pinion machining					
Processes	Diameter of end mill, mm	Revolution of main spindle, rpm	Feed, mm/min	Depth of cut, mm	Time/one side, min
Semi-finishing	10.0	1400	1100	0.2	120
Finishing	10.0	1600	1100	0.05	420

Figure 8 Swarf cutting of the pinion member.

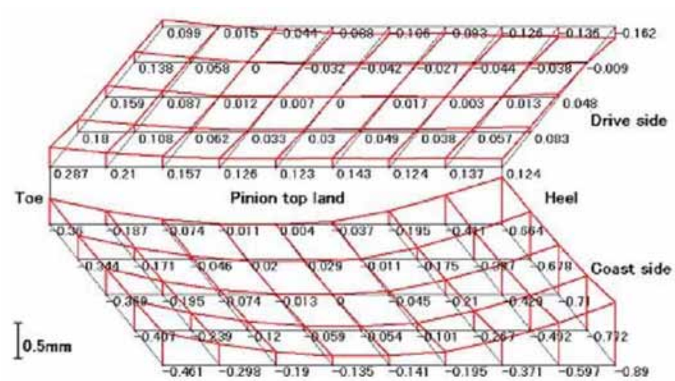
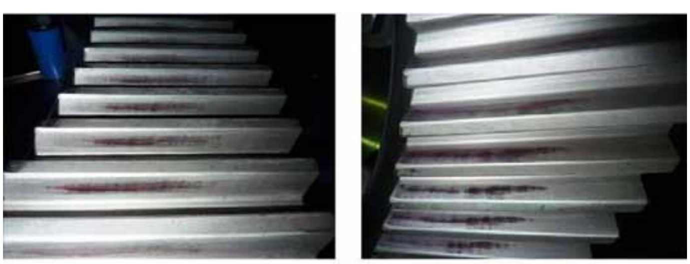


Figure 9 Measured result of the pinion member.



(a) Drive side (b) Coast side

Figure 10 Experimental tooth contact patterns.

skew bevel gears were set on a gear meshing tester and the experimental tooth contact patterns were investigated. Figure 10 shows the result of the experimental tooth contact patterns on the gear tooth surface of the drive- and coast-sides, respectively. Although the experimental tooth contact pattern deviates from the center of the tooth surface slightly on both drive- and coast-sides, it is almost the same as that in Figure 7, with respect to the tooth surface deviations. From these results the validity of the manufacturing method of the pinion member using a multi-tasking machine was confirmed.

Conclusions

In this paper a manufacturing method of the pinion member of large-sized skew bevel gears using multi-axis control and multitasking machine tool respecting the existing gear member was proposed. The main conclusions obtained in this study are summarized as follows:

- The tooth surface forms of skew bevel gears were modeled mathematically.
- The deviations between the real and theoretical tooth surface forms were formalized using the measured coordinates of the real tooth surfaces of the gear member.
- The tooth surface form of the pinion member that has good performance mating with the existing gear member was determined using the results of tooth contact analysis.
- The pinion member was manufactured by swarf cutting using a multi-axis control and multitasking machine tool.
- The real tooth surfaces of the manufactured pinion member were measured using a CMM and the tooth surface form errors were detected.
- The experimental tooth contact patterns of the existing gear member and manufactured pinion member were compared with those of tooth contact analysis. As a result, there was good agreement.

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Recent Inventions and Innovations in Induction Hardening of Gears and Gear–Like Components

Dr. Valery Rudnev

This paper examines the expanding capabilities of induction hardening of gears through methods like spin hardening or tooth-by-tooth techniques.

Introduction

This presentation provides a review of basic principles and applications devoted to induction hardening of small-, medium- and large-size gears using tooth-by-tooth techniques and encircling method.

Depending upon the gear size, required hardness pattern and tooth geometry, gears are induction hardened by encircling the whole gear with a coil (so-called "spin hardening of gears"), or for larger gears, heating them "tooth-by-tooth" (Refs. 1–6).

Tooth-by-Tooth Hardening

The tooth-by-tooth method comprises two alternative techniques: "tip-by-tip" or "gap-by-gap" hardening (Refs. 1–4).

The tip-by-tip method can apply a single-shot heating mode or scanning mode, while gap-by-gap techniques exclusively apply the scanning mode. Inductor scanning rates are typically within 6 mm/sec to 9 mm/sec. Both tip-by-tip and gap-by-gap techniques are typically not very suitable for small- and fine-pitch gears (modules smaller than 6) (Refs. 1–2).

When using tip-by-tip hardening, an inductor encircles a body of a single tooth. This technique is not often used, because the hardening patterns typically do not provide the required fatigue and impact strength. Gap-by-gap hardening is a much more popular technique compared to the tip-by-tip method. This is the reason why the term tooth-by-tooth hardening is often associated with the gap-by-gap hardening method. Gap-by-gap hardening requires the inductor to be symmetrically located between two flanks of adjacent teeth. Inductor geometry depends upon the shape of the teeth and the required hardness pattern. Special locators (probes) or electronic tracing systems are often used to ensure proper inductor positioning in the tooth space.

Two scanning techniques used include one where the inductor is stationary and the gear is moveable, and the other where the gear is stationary and the inductor is moveable. The latter technique is more popular when hardening large-size gears. Inductors can be designed to heat only the root and/or flank of the tooth, leaving the tip and tooth core soft, tough and ductile (Fig. 1). Though this is one of the oldest hardening techniques,

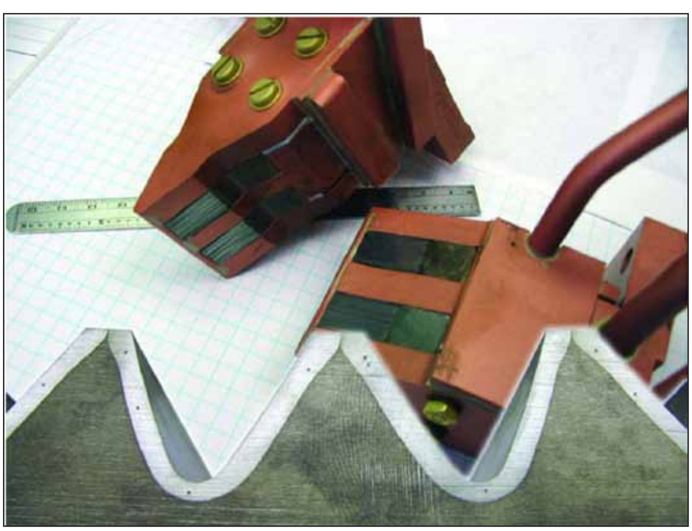

Figure 1 For tooth-by-tooth hardening, inductors can be designed to selectively harden specific areas of gear teeth where metallurgical changes are required (Ref. 2).

Figure 2 Induction gear hardening machine for large bearing ring with teeth located on exterior (courtesy Inductoheat).

recent innovations continue improving the quality of gears heat treated using this method.

Thermal expansion of metal during the heating should be taken into consideration when determining and maintaining the proper inductor-to-tooth air gap. After gear loading and initial inductor positioning, the process runs automatically based on an application recipe. Figure 2 shows examples of a tooth-by-tooth induction hardening machine.

When developing tooth-by-tooth gear hardening processes, particular attention should be paid to electromagnetic end/edge effects and the ability to provide the required pattern in the gear end areas. Upon scanning a gear tooth, the temperature is distributed within gear roots and flanks quite uniformly. At the same time, since the eddy current makes a return path through the flank and, particularly through the tooth tip, proper care should be taken to prevent overheating the tooth tip regions, in particular at the beginning and at the end of the scan hardening. Improved system design helps to maintain required hardness uniformity.

Specifics of gear geometry demand a particular process control algorithm. In the past, the process control recipe was limited to an available variation of power and scan rate vs. inductor position. Recent innovations now enable inverters to independently control both power and frequency during scanning operation, which optimizes electromagnetic and thermal conditions at initial, intermittent and final stages of scanning. As an example, Figure 3 shows Inductoheat's Statipower IFPt (Independent Frequency and Power control) inverter. The ability to independently change during scanning the frequency and power of an induction system represents the long-held dream of commercial induction heat treaters, since such types of set-up would provide the greatest process flexibility. Statipower IFPt is an IGBT-type power supply specifically designed for hardening and tempering applications, allowing independently adjustable frequency via CNC program in a 5-40 kHz frequency range and power in the range of 10-360 kW. This concept substantially expands heat treat equipment capabilities for processing parts by programming power and/or frequency changes on the fly, maximizing heating efficiency and temperature uniformity while heating complex geometry components.

Figure 3 **Inductoheat's Statipower IFP is an IGBT-type power supply specifically designed for induction hardening and tempering applications; it provides independently adjustable frequency via CNC programming in a 5–40 kHz frequency range and power in the range of 10–360 kW.**

Encircling Hardening Techniques

Gear spin-hardening (encircling inductors). Spin-hardening is the most popular approach for induction hardening gears with fine- and medium-size teeth. Gears are rotated during heating to ensure an even distribution of energy. Single-turn or multi-turn inductors that encircle the whole gear can be used (Refs. 1; 3–6). When applying encircling coils, it is possible to obtain substantially different hardness patterns by varying process parameters.

As a rule, when it is necessary to harden only the tooth tips, a higher frequency and high power density should be applied; to harden the tooth roots, use a lower frequency. A high power density in combination with the relatively short heat time generally results in a shallow pattern, while a low power density and extended heat time produces a deep pattern with wide transition zones.

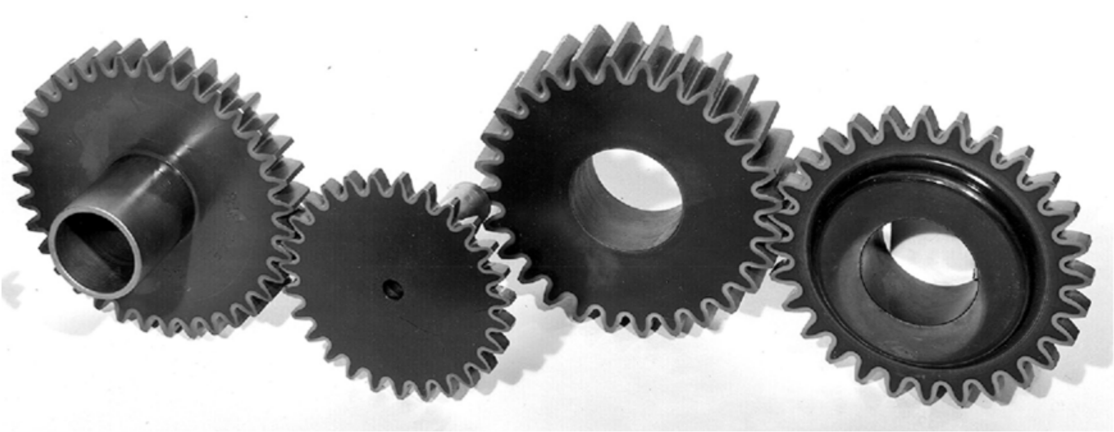

Figure 4 **Contour-hardened gears (courtesy Inductoheat).**

Quite often, to prevent problems such as pitting, spalling, tooth fatigue and endurance and impact limitations, it is required to harden the contour of the gear, or to have gear-contour hardening (Fig. 4). This often also maximizes beneficial compressive stresses within the case depth and dramatically minimizes distortion of as-hardened gears keeping it under 80-100 microns (0.003"– 0.004").

Many times, obtaining a true contour-hardened pattern can be a difficult task due to the difference in current density (heat source) distribution and heat transfer conditions within a gear tooth.

Simultaneous dual-frequency gear hardening. Some induction practitioners have heard about simultaneous dual-frequency gear hardening, which utilizes two appreciably different frequencies working on the same coil at the same time (Ref. 6). Low-frequency helps to austenitize the roots of the teeth and high frequency helps austenitize the tooth flanks and tips.

However, it is not advantageous to have two different frequencies working simultaneously all the time. Many times, depending upon the gear geometry, it is preferable to apply lower frequency at the beginning of heating cycle; after achieving a desirable root heating, the higher frequency can complement the initially applied lower frequency, thus completing a job in tandem.

Figure 5 shows a single-coil dual-frequency system that comprises medium-frequency (10 kHz) and high-frequency (120 to 400 kHz) modules working simultaneously— or in any sequence desirable to optimize properties of the heat treated gears (Ref. 6); total power exceeds 1,200 kW. As expected, smaller gears will require less power.

Inductoheat's simultaneous dual-frequency induction gear-hardening system (Fig. 5) also has some "auto-match" items to simplify tuning. It is rugged and can be used for high-volume, single-shot hardening of several powertrain components, dramatically minimizing distortion of heat treated parts and providing a superior hardness pattern with favorable distribution of residual stresses.

Novel development in induction gear-hardening—TSH steels. There was a belief that not all gears and pinions were well-suited for induction hardening. Hypoid and bevel gears, spiral bevel automotive pinions and noncircular gears used to be rarely induction-hardened and typically carburized. This situation has been changed. As an example, Figures 6a and 6b show an example of inductively case-hardened components (Refs. 7–8).

Figure 5 Inductoheat's simultaneous dual-frequency inverter for gear contour hardening (courtesy Inductoheat).

TSH steels are low-hardenability (LH) low-alloy steels characterized by limited hardenability and a reduced tendency for grain growth during heating into the hardening temperature range. They can be substituted for more expensive standard steels typically used for conventional induction hardening or carburizing grades. TSH steels have significantly less alloying elements such as manganese, molybdenum, chromium and nickel, making them less expensive than the majority of conventional low alloy steels. Their chemical composition is somewhere between micro-alloy steels and plain carbon steels, providing fine-grain martensite with extremely high compressive stresses at the tooth surface.

With TSH technology, components are usually through-heated at relatively low temperatures sufficient for austenitization or partial heated (depth of heating needs to be 2-3 times deeper than required harden depth) and then are rapidly quenched. The hardened depth is mainly controlled by the steel's chemical composition. Even though components made from TSH steels are often heated through, their limited hardenability allows obtaining crisp hardness case depth with well-controlled hardness pattern having minimum case hardness deviations even when hardening complex-shaped parts (Figs. 7–8).

In the past, it was practically impossible to induction harden components shown in Figs. 6–9. Now it is possible to

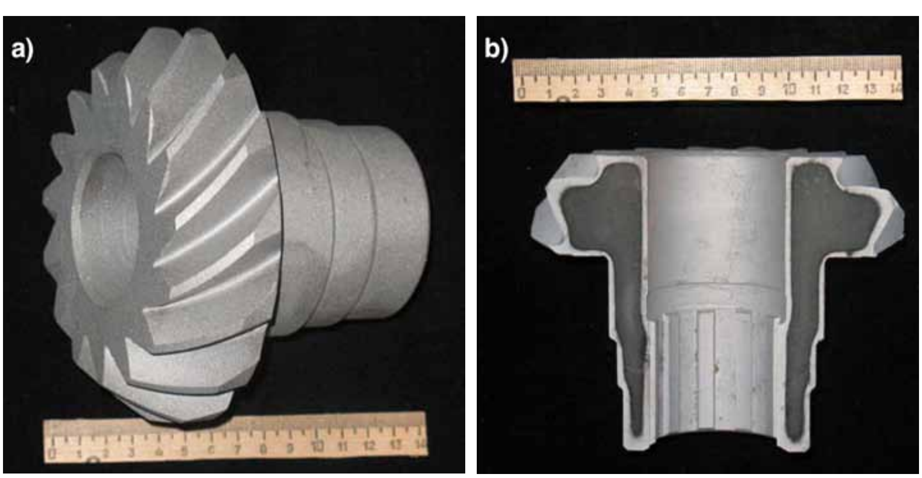

Figure 6 TSH (through-heating for surface hardening) steel's uninterrupted induction-hardened pattern is obtained on a spiral bevel gear (courtesy ERS Engineering Corp.).

get those impressive, uninterrupted hardness patterns by using a simple operation: through heating those parts using low frequency inverters and water quenching. Notice that the spiral bevel pinion (Fig. 6) was induction-hardened on OD, ID and teeth region using a single operation having continuous hardness pattern. The carrier pin (Fig. 9) was induction hardened on the outside surface (1.25" diameter) and two inside diameters (longitudinal and transversal) using a single operation that also produced an uninterrupted case hardness pattern. The inside diameter of the longitudinal hole was 0.5"; the inside diameter of the transverse hole was 0.25" (Fig. 7).

Figure 7 Section of induction-hardened transmission gear (courtesy ERS Engineering Corp.).

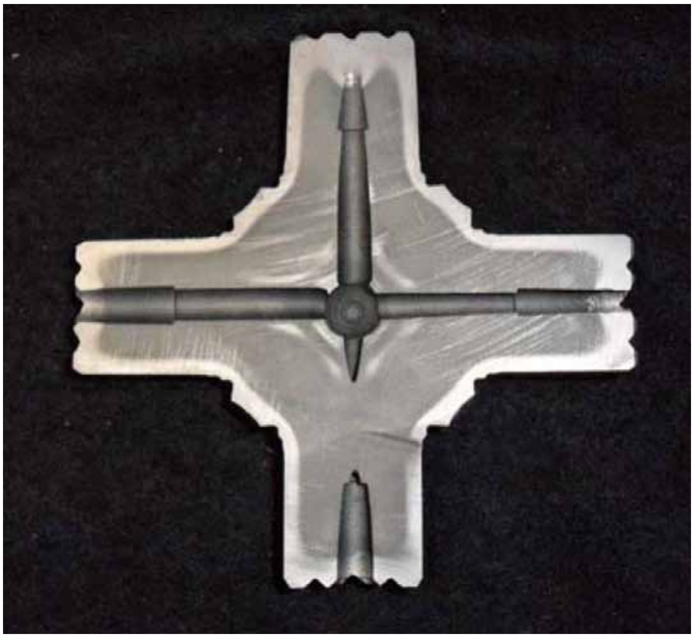

Figure 8 Induction-hardened automotive journal cross section (courtesy ERS Engineering Corp.).

Figure 9 Carrier pin: simultaneous OD- and ID-hardening (courtesy ERS Engineering Corp.).

Conclusions

Induction heat treating being an environmentally friendly, green and lean technology is an increasingly popular choice for induction-hardening of gears and gear-like components.

Recently developed inverters and process know-how further expand its capabilities.

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How to Conduct a Heat Treat Audit

Daniel H. Herring

This article first appeared in *Industrial Heating* magazine

Audits of the heat treating department are a vital part of any good quality program—either as part of a self-assessment or ISO program for a captive shop or—of equal importance—as part of an evaluation of the capabilities of a commercial heat treat supplier. In either case, the audit process needs to be formal in nature and follow specific guidelines.

The audit process should be designed to ask basic questions, such as:

- Who is performing the heat treatment and are they competent?
- What procedures are being used to carry out the heat-treating operation?
- Are they adequate to assure proper quality?
- Where is the work being done?
- Is the shop performing the work capable of performing the required task(s)?
- When was the last assessment?
- Was it representative of current practice?
- Why is an assessment required at this time? i.e.—did a quality issue or problem trigger the event? If so, will the audit questions help resolve it?
- How will the audit be performed; are the right personnel in place to reach meaningful conclusions?

What Constitutes a "Good" Audit?

Most audits that "fail" do so because they do not reveal the true nature of what is happening within the heat treatment operation. Care must be taken to look at both the quality aspects (forms, instructions, compliance) and the performance aspects (process control, work handling, etc.). Too often, audits focus their attention on the former and give a cursory look at the latter. This disconnect is the reason many organizations are confused as to why their departments or suppliers fail to achieve continuous improvement.

To be useful, heat treat audits need to ask tough and realistic questions—not just be forms in which the auditor fills in the blanks. The true story is revealed only in the details. It is critical that audits "drill down" to the level that the work is being done; meaning, a good heat treat audit spends less time in the office than on the shop floor. Finally, auditors must reward well-run operations and not hesitate to give them top scores when deserved. Here's a look at some of the critical information necessary for conducting a meaningful, comprehensive audit.

General (company/department profile)

A. Date, supplier's name and plant location
B. Key contact information, including corporate contacts (if appropriate), plant manager, quality manager, metallurgist and—first-, second- and third-shift supervisors
C. Financial viability

Capabilities (general requirements)

A. List all part numbers, cross-indexing them to their corresponding engineering drawings, specifications (including all testing requirements) and special needs (e.g., distortion concerns, handling concerns, dimensional tolerances, etc.).
B. List the types of materials that the heat treater is qualified to run.
C. List the heat treat processes capable of being run; be sure to tie each heat treat process with the specific equipment involved by part number.
D. List each heat treat cycle, including the type of quench; be sure to identify all relevant process and equipment variables.

Instructions (for auditors)

A. Clearly define what will be required in the heat treat audit and communicate this information to the intended parties well in advance of the physical audit so that the necessary information can be gathered ahead of time.
B. Create a consistent and fair rating guideline (see below) and adhere to the categories and questions selected.
C. Be sure that both parties agree to corrective actions and completion dates, and that responsibilities are clearly delineated.
D. Follow up personally within the specified time frame.

Sample Rating Guidelines (for audit questions)

A. If a required activity is not being performed (rating = 0)
B. If there is only rudimentary activity (rating = 1); or if the activity is being performed and documented but has minor deficiencies (rating = 2)
C. If the activity is inadequate for the task required (rating = 3); or if the activity is properly documented but not properly performed (rating = 4)
D. If the activity is being adequately performed and is documented (rating = 5); and if, in addition, includes evidence that the activity achieves the task(s) required (rating = 6)
E. If the activity is well-documented and is adequately performed (rating = 7); and if, in addition, continuous improvement is evident (rating = 8)
F. If the activity is well-documented and beyond expectations (rating = 9); and if continuous improvement is overwhelming (rating = 10)

Continuous Improvement Program (areas to review)

A. Good-Better-Best practices related to heat treatment and testing
B. Process parameter variability is being controlled
C. Equipment variability is being controlled
D. Laboratory best practices are being used
E. Scrap-Reject-Rework plans and procedures being used
F. Documented planned preventive maintenance

Audit FAQs

A. Are heat treat part handling, processing and storage adequate to preserve product integrity and quality?

B. Are adequate controls employed to ensure that the processing and inspection status of the product are known throughout the heat treating operation? Are process/product monitoring and controls functions (and responsibilities) clearly defined?
C. Is both the responsibility for and practice of heat treat process (recipe) development, testing methods and quality planning clearly defined?
D. Does the heat treater have available—and use—a procedure for reviewing part design and specifications in relation to method of loading, as well as heat treat process parameter and equipment selection?
E. Are process verification and/or capability studies conducted on all new part numbers?
F. Are control plans and process (FMEAs) used as a basis for establishing quality programs for heat treat processes?
G. What procedures are in place, and how does the heat treater react to customer concerns (internal or external indicators)?
H. Are controls in place and being used on the shop floor to effectively monitor the process?
I. If necessary, are statistical process control (SPC) methods utilized for key product parameters?
J. Are written procedures/work instructions defining heat treat and quality functions available and in use on the shop floor (i.e., is the quality manual a living document)?
K. Are adequate, in-process monitoring and inspections/tests performed, and are there adequate records?
L. If on-site, does the testing or metallurgical laboratory have the tools, procedures and expertise to accurately determine part quality? If off-site, is the testing laboratory properly accredited?
M. If part testing and/or PPAPs are performed, are records available with supporting documentation for the relevant heat treated products?
N. Are documented and verifiable heat treating reject, reprocessing and/or scrap records available?
O. Is there an effective preventive maintenance program in place for both the heat treating and process monitoring equipment?
P. Does the heat treater have an effective system for ensuring the quality from his suppliers and service providers (instrumentation calibrations, quench oil checks, etc.)?
Q. Is plant cleanliness, housekeeping, environmental and working conditions conducive to a safe, efficient operation in which continuous improvement can take place?

Non-Conformance (document, in detail)

- Major and minor non-conformances
- Pertinent general and specific observations

Corrective Action (for each supplier location)

A. Issue statement
B. Corrective action(s) required
C. Responsibility
D. Implementation date
E. Root cause found
F. Follow-up plan (actions and dates)

A Look at CQI–9

A new automotive industry action group (AIAG) heat treat audit guideline—CQI–9, Special Process: Heat Treat System Assessment—was released in March 2006. It is intended to help standardize the heat treat audit process. The HTSA supports the automotive process approach as described in ISO/TS 16949:2002.

Within each audit area, the major sections covered are: (1) process and test equipment requirements; (2) pyrometry; (3) process monitoring frequencies; (4) in-process/final test frequencies; and (5) quenchant and solution test frequencies.

Summing Up

Heat treat audits are so important that, in this writer's opinion, they need to be conducted by trained and certified heat treat personnel—not just auditors skilled in the procedures involved. Both captive and commercial heat treatment organizations should demand that this aspect of their business be given the attention and respect it deserves. A standardized audit guideline with fixed frequency-of-compliance is long overdue. With ever-increasing product performance demands from customers, only continuous improvement will assure the heat treatment industry of continued growth and prosperity.

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Optimization of a Process Chain for Gear Shaft Manufacturing

Fritz Klocke, Markus Brumm, Bastian Nau and Arne Stuckenberg

The research presented here is part on an ongoing (six years to date) project of the Cluster of Excellence (CoE). CoE is a faculty-wide group of researchers from RWTH Aachen University in Aachen (North Rhine-Westphalia). This presentation is a result of the group's examination of "integrative production technology for high-wage countries," in which a shaft for a dual-clutch gearbox is developed.

Introduction, Goal and Approach

Industrial production in high-wage countries like Germany remains at risk. Nevertheless, there exist examples of thriving manufacturing companies who are dominating their competitors by utilizing advanced cost-, time- and materials-saving systems to enhance their production capabilities and profit margins. The RWTH Aachen University Cluster of Excellence program (CoE) is contributing to exploring and realizing fundamental developments in the theory of production science—in both its organizational and technical aspects (Ref. 1).

To succeed in this endeavor, top-down research of entire enterprises is required—beginning with management, proceeding on to the process chains, and ending at single-process technology efforts. To validate the need for this work, newly gained, "real" knowledge is used to make "real" parts. Indeed, in this paper the manufacture of a modern, dual-clutch gearbox gear shaft is investigated; the main intent being to assess existing and new process chain and manufacturing technologies.

Today's complex production systems produce components and products of high complexity, requiring sophisticated yet cost-efficient process and supply chains. The production system of the mentioned gear shaft was documented—beginning with analysis of the turned green body. This documentation includes: manufacturing technologies; completed actions; input and output conditions; and process parameters at every step of the operation. The example observed was compared to existing practices and the state-of-the-art manufacturing of gear shafts. To gain additional value the methods and results of the CoE were adapted to the optimization of the gear shaft. In practice, the CoE is divided into several parts; for this study individualized, virtual and hybrid production systems of the CoE are validated.

- "Individualized" production is the ability of production systems to be flexible for either small or large batch sizes.
- "Virtual" production means using smart software solutions to shorten, for example, construction and design processes.
- "Hybrid"production presents opportunities for employing different manufacturing technologies simultaneously. The optimization is achieved with both technological and economic realities in mind. This includes consulting with the customer, examining market research data and drawing upon the collective knowledge and expertise of groups like the CoE.

After assessing the in-place process chain with the customer, alternative chains are developed. The proposed new process chain is analyzed concerning its potential for flexible and economic production of small-batch sizes. This is crucial in this particular scenario because, to be profitable, a production line for gear shafts must be able to produce many types of shafts over a year's time—even if it is a high-volume product.

The results are then assessed using factors and protocols that are valid and practical for a company and its entire operation. These general factors are: process reliability; manufacturing costs; floor-to-floor time; required staff; investment costs; flexibility; and logistic effort. These factors help define a company's new process chain and processes. As well,

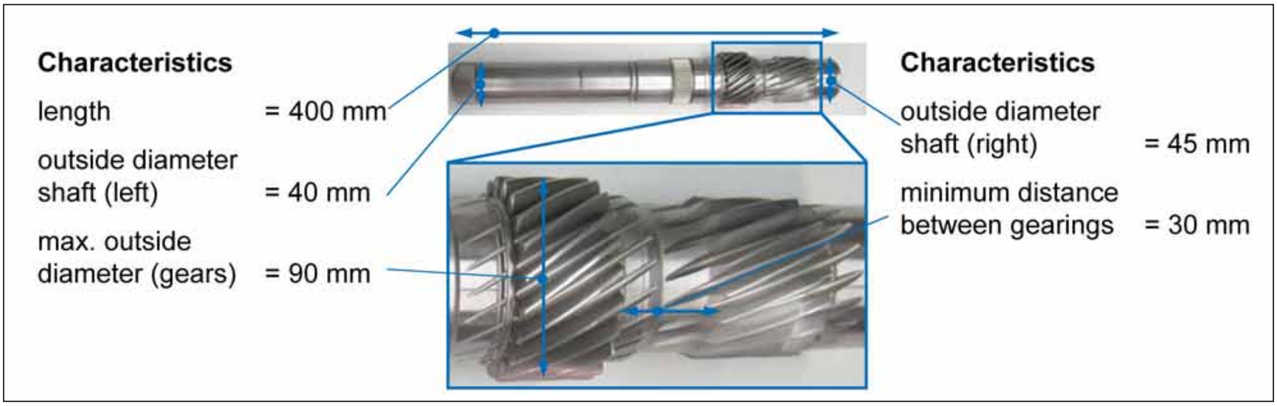


Figure 1 Example of dual-clutch gear shaft.

Y ↓ X →	Process reliability	Manufacturing costs	Floor to floor rime	Staff requirements	Investment costs	Flexibility	Logistic effort	Sum	Weighting
Process reliability	-	2	2	2	2	2	2	12	5
Manufacturing costs	0	-	1	2	2	2	2	9	4
Floor to floor time	0	1	-	1	2	2	2	8	4
Staff requirements	0	0	1	-	1	2	1	5	2
Investment costs	0	0	0	1	-	2	2	5	2
Flexibility	0	0	0	0	0	-	2	2	1
Logistic effort	0	0	0	1	0	0	-	1	1

	Process reliability	Manufacturing costs	Floor to floor rime	Staff requirements	Investment costs	Flexibility	Logistic effort	Result
Weighting	5	4	4	2	2	1	1	
Hobbing	5	5	5	4	5	3	5	91
Shaping	5	3	3	4	4	5	5	75
Skiving	2	3	4	4	3	4	5	61
Broaching	4	5	5	4	4	1	5	82
Rolling	1	5	5	5	5	5	5	75

Standings	
1	Hobbing
2	Broaching
3	Shaping
3	Rolling
5	Skiving

Figure 2 Process chain result.

these factors are impacted—for good or bad—by weighting factors; the weighting factors are generated by a method-paired comparison. (*Authors' Note: the general structure in the investigation addressed by this article is in two parts: i.e.—1) An investigation on gearing; and 2) Secondary machine elements—bearings, sealing surface. Validation of the "gained knowledge" is the end-product: a high-art, dual-clutch gearbox shaft*—Fig. 1*)*.

The main challenges presented by this particular gear shaft are its close proximity between gear sets and the diverse bearings locations. In addition, the shaft is of a tube design—specified for lightweight needs and realization of the dual-clutch concept. Through this tube a second shaft—with a connection to the second clutch—is inserted. Length is about 400 mm; maximum outside diameter for the gears in the case about 90 mm; the maximum outside diameter for the gears of the shown example part is less. The outside diameter of the shaft is increasing from 40 mm on one side to 45 mm on the other; minimum distance between the gearings is about 30 mm.

Analysis of the Gear Manufacturing

An example for the assessment of manufacturing technology can be seen in Figure 2. Each realistic and possible manufacturing technology for the green-machining of gears is assessed against the main factor. The result is multiplied by the weighting factors and assessed—leading to the given order. The ranking of broaching is superfluous here because the second power gear with smaller tip diameter cannot be broached. This approach is also used for the other manufacturing steps.

The analysis method above shows that hobbing is best for green-machining, while the conclusion drawn for hard-finishing of the gears is that honing works best. Generating gear grinding is not an option because both gears on the shaft are too close together, i.e.—insufficient space for the recess of the grinding worm. In this instance a new or alternative manufacturing process for power gears does not yet exist, due, perhaps, to the relatively long gaps between technological "breakthroughs" specific to a mature industry such as gear manufacturing. Indeed, gear manufacturing innovation requires significant investment; e.g.—machine tools. The latest innovation in machining gears may be the ability to hone manufacturing parts with a near-grinding quality via "power honing."

Upon complete evaluation of the in-place process chain, one more optimization potential can be found in the single manufacturing process. This can be achieved by using virtual production methods such as manufacturing simulation. Therefore for the design of gear hobbing processes a manufacturing simulation is developed. Its necessity and the benefit of simulation software are acknowledged, especially for complex machining operations with a high number of variants for the tool and process design. After the calculations the results are compared with momentary process design for both gears. However, no software exists at this time capable of providing universal simulation of the entire production process due to missing interfaces and inconsistent data formats. It is a gap that must be closed in the future.

The approach for process optimization of gear hobbing begins with starting parameters—just like the process parameters and limitations of the actual process design. Potential limitations may be machine tool parameters such as maximum-revolutions-per-minute for the tool or workpiece spindle, or gear design restrictions like maximum-feed-mark deviations. Yet despite these default values and given restrictions, the software calculates every possible tool design capable of achieving these requirements.

The design of the gear shaft shows two power gears arranged close together, directly on the shaft; one gear is an interfering element for the manufacture of the other. The tool design is started with the general geometric boundary conditions for the tool. The results are no restrictions concerning the tool outside diameter for Gear No. 2 and a maximum tool outside diameter for Gear No. 1. A geometric calculation leads to a maximum outside diameter for Gear No. 1 of 45 mm. The outside diameter for Gear No. 2 can be chosen freely. The calculation is started with momentary process design (Fig. 2—red signs).

For example, Gear No. 1:

It has a hob outside diameter of $d_a = 45$ mm; number of threads $z_0 = 1$; and number of gashes $n_i = 9$. In the chart the limits for variation are shown. The number of threads were varied from one to three; the hob diameter from 40 to 45 for Gear No. 1, and from 60 to 100 mm for Gear No. 2. The number of gashes is varied from 7 to 19, and 11 to 21.

The result revealed by the simulation is that the single-threaded variant is always the most productive. The reason—especially for Gear No. 1—is the lower helix angle for the thread at a lower number of threads. A higher helix angle results in a longer way of entry for the tool. Also, the larger the outside diameter process, the more productive the process. The larger, outside diameter of the single tooth is thicker and therefore more reconditioning cycles can be realized. In general, with the investment for one tool, more workpieces can be produced. As mentioned, the tool outside diameter for Gear No. 1 is limited by Gear No. 2. The maximum-outside-diameter is also limited by the machine tool, as both gears have to be produced in one step, on one machine tool.

The number of gashes should be as high as possible from the technological side. A higher number of gashes leads to lower-generated cut deviations. From the productivity aspect a certain number of reconditioning cycles becomes possible, so the single teeth should not be too thin. Especially for Gear No. 1, this tool design—with number of gashes at $n_i = 11$—is quite a low number when compared with Gear No. 2, with its number of gashes almost doubled at $n_i = 21$. The remaining teeth will be quite thin, with the small outside diameter of $d_{a0} = 45$ mm.

The simulation for Gear No. 1 leads to a tool design similar to the real-time process, so the use and functionality of the actual process design could be proven. In general, the simulation enables a very fast design of the tool by avoiding long-lasting iteration cycles. In contrast to only experience-based tool design, the calculation has a robust basis.

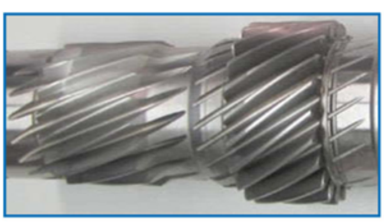
Analysis of Secondary Machine Elements

Within analysis of secondary machine elements the bearing seats of the gear shaft were investigated. Alternative manufacturing technologies for the finish process of the bearing seats were also evaluated. The technologies had to meet a number of requirements and conditions, including:

- Material: case-hardened steel 20MnCrS5
- Surface hardness: HRA 81-83
- Surface roughness: $Rz = 2$ µm
- Concentricity: 0.02 mm
- Circularity: 0.004 mm
- Parallelism: 0.06 mm
- Retain fitting tolerance
- Retain accuracy grade of cylindrical shaft
- Right angularity tolerance of contact surfaces
- Free of damage and pores
- Economic manufacturing

During rough analysis, five manufacturing technologies were identified that are able to manufacture the bearing seats with the necessary requirements (Fig. 4).

Because the project's focus was on innovative manufacturing technologies *and* conventional processes (grinding, hard-turning), a hybrid manufacturing process known as "ultrasonic-assisted-



Gear 1		Gear 2	
z =	17	z =	29
α =	21.5°	α =	18.5°
m_n =	2.37 mm	m_n =	2.5 mm
β =	19.9°	β =	27.9°
d_a =	50.7 mm	d_a =	90.96 mm
d_f =	37 mm	d_f =	74.6 mm

	Gear 1	Gear 2
threads	1, **2**, 3	1, **2**, 3
hob diameter	40, **45**	60..**80**..100
gashes	7..**9**..19	11..**19**..21

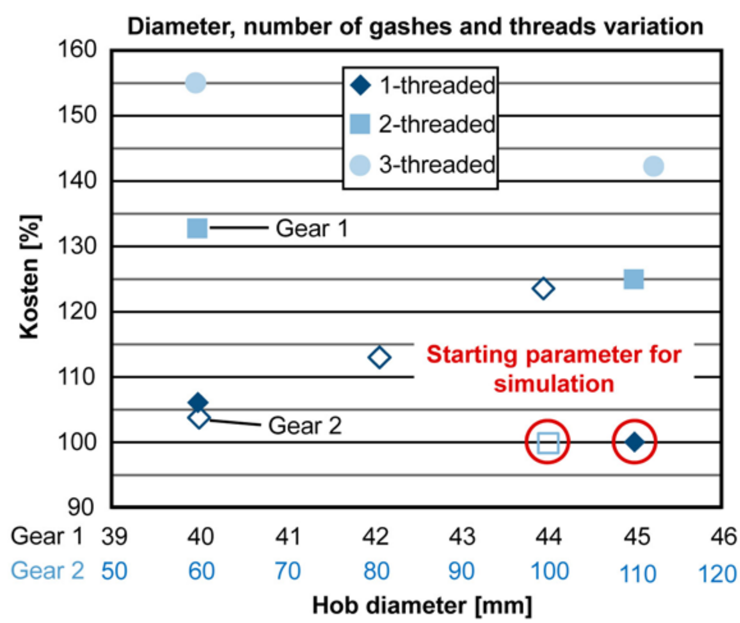


Figure 3 Calculation result.

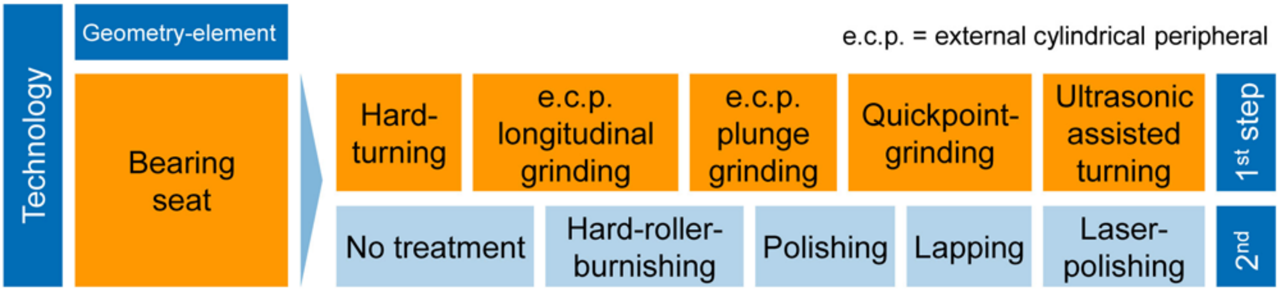


Figure 4 **Alternative manufacturing technologies for bearing seats.**

	Process reliability	Manufacturing costs	Floor to floor time	Staff requirements	Investment costs	Flexibility	Logistic effort	Result
Weighting	5	4	4	2	2	1	1	
Hard-turning	4	5	4	5	5	5	5	86
E.c.p. longitudinal grinding	4	4	3	3	3	4	5	69
E.c.p. plunge grinding	5	4	5	5	3	3	5	81
Quickpoint-grinding	3	4	5	4	3	4	5	74
Ultrasonic aided turning	3	3	3	4	3	4	5	62

	Process reliability	Manufacturing costs	Floor to floor time	Staff requirements	Investment costs	Flexibility	Logistic effort	Result
Weighting	5	4	4	2	2	1	1	
Hard-roller-burnishing	5	5	5	5	5	4	5	94
Polishing	4	4	2	4	3	3	3	64
Lapping	4	4	3	4	3	3	3	68
Laser-polishing	4	3	2	3	1	5	4	57

E.c.p. = external cylindrical peripheral

Figure 5 **Results of rough analysis.**

	Requirement	Hard-turning	E.c.p. longitudinal grinding	E.c.p. plunge grinding	Quickpoint-grinding	Ultrasonic assissted turning
Rz [µm]	2	< 1	≈1	≈1	≈1	< 0,1

E.c.p. = external cylindrical peripheral

Figure 6 **Results of surface roughness tests.**

turning" was considered. In addition, a second process step was considered for manufacture of the surface properties should the first process step prove incapable of meeting all requirements. For this step, hard-roller burnishing—a process not yet common to this field—was employed. Within rough analysis the manufacturing technologies were assessed considering the impact factors shown in Figure 2. This assessment was conducted by experts from the industry and research institute. The results show that hard-turning and plunge-grinding are the preferred manufacturing processes. As a possible second step, hard-roller burnishing should be used (Fig. 5).

To assess the surface quality that can be achieved with the manufacturing technologies discussed here, a Fourier analysis was performed, enabling assessment of the possible surface roughness of the bearing seats. The advantages and disadvantages of these alternative manufacturing technologies are listed below; results of the surface roughness tests are shown in Figure 6.

- Hard-turning without ultrasonic support
  - Low ripple
- Grinding-procedure
  - Higher amplitudes during lower wave numbers
  - Ripple is influenced by self-excited (regeneration effect) and separately excited (imbalances, SLS-radial deviation) oscillations
- Quickpoint grinding
  - Higher amplitudes than e.c.p. longitudinal grinding are machine-based
  - Higher machine stiffness
  - Lower oscillations than e.c.p. longitudinal grinding
- Ultrasonic-assissted turning
  - Low fundamental oscillation
  - Very good concentricity

Via rough analysis of manufacturing technologies, two manufacturing chains were chosen for a detailed observation.

1. ***Plunge-grinding followed by hard-roller burnishing***: This alternative was chosen because plunge-grinding is a common process that can achieve good results; roller burnishing is an innovative process that can manufacture the required surface properties. Also, these technologies can be combined well.
2. ***Ultrasonic-assisted turning***: To date, this manufacturing technology is rarely used in this field. The surface properties can be achieved without a second step, so it was investigated to determine whether significant time savings can be obtained and if this technology can operate cost-effectively.

Within the detailed observation time, costs and the quality of the manufacturing technologies were analyzed by experts that in fact provide these processes. It can therefore be said that in both cases, only one machine tool is needed, as the roller-burnishing tool can be integrated into the grinding machine. There is a lot to be said for both plunge- grinding and roller-burnishing, but their set-up and process-parameter optimization must be done individually. Another advantage of roller-burnishing is the low tool wear and savings in cooling lubricant. The actual process of finishing with abrasive blocks can be substituted. But the main advantage of ultrasonic-assisted turning is that the second finishing step is eliminated. This translates to lower machine investment as the cost for an ultrasonic unit for machine integration is low. But this is a limited experience with this technology and it will require much more effort in process-parameter optimization to lower the process time and attain high production output. It is also unknown at this time which workpiece materials can be manufactured using ultrasonic-assisted turning. Silicon and carbides prevent the use of diamond tools typically required for this process because of their risk of fracture. It is yet to be determined whether a surface roughness far beyond the required properties is needed and justifies the effort in establishing this innovative technology.

Conclusion

- In partnering with the Cluster of Excellence, "Integrative Production Technology for High-Wage Countries" methods were developed to anticipate future requirements of tomorrow's markets. Beyond the theoretical research technology conducted, examples were chosen that in fact demonstrated the acquired knowledge. This article examined and presented the results of the technology used in producing the prototype gear shaft.
- In general, it was possible to create alternative manufacturing chains to manufacture a gear shaft in a more effective and efficient way than is typically done. By using these new manufacturing chains it is possible to manufacture more individual products and reduce planning efforts via simulation methods and the integration of other planning alternatives over defined interfaces. However, a general planning approach was not implemented or tested at this time.
- Within the investigation, a general look at the process chain—as well as a more detailed technological look at a single process—was taken. The investigations were done on an actual gear shaft
- In summation, the traditional process chain was approved as good. Likewise, the same process design of single-technology-hobbing was approved. The advantages demonstrated by the new methods are the faster and more economical ways to generate a process chain and single-process designs.
- For the next testing phase, evaluation of three manufacturing chains—including logistics and factory planning—would be useful. In this way the exact time and cost potential of a specific manufacturing chain could be determined and an integrated planning approach implemented.

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Dr.-Ing Bastian Nau was a research associate and doctoral candidate under Prof. Klocke in production engineering at the technology planning group at RWTH Aachen University. His principal research activities are technology planning and investigations on process chain design; he was awarded his doctorate in 2012.

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Hagen Hans Hofmann

(1940-2013)

Mr. Hagen Hans Hofmann was born on January 30, 1940 in Berlin, Germany. Since his father was an opera singer with the Badisches State Theater in Karlsruhe, the family moved to Ettlingen in 1948. After college he successfully completed studies in Radio and Television Technology with Radio Becker in Ittersbach. The next three years Hofmann spent in Brazil where he set up a technical support center for Radio Becker. Upon his return to Germany he joined Höfler Maschinen-und Messgeraetebau GmbH in Ettlingen on February 1, 1965 as constructive design engineer for measuring equipment. Shortly thereafter he switched from design engineering to international sales. In 1978 the company split into Dr.-Ing. Höfler Messgeraetebau GmbH and into BHS Höfler Maschinenbau GmbH. The measuring division was newly set up and managed by Dr. Höfler, while the Maschinenbau division was sold to BHS and moved their operations to Ettlingen-Oberweier. Hofmann was nominated the marketing and sales director for BHS, a position he held until December 31, 1989. During this time he founded Höfler's first overseas subsidiary in New Jersey, USA in 1984. On January 1, 1990 BHS Höfler Maschinenbau was sold from BHS to Suedweststahl AG, at which time Hagen Hofmann was nominated president of the company. He held this position until March 2006 when he retired after many successful years in the gear industry. After a short illness Hofmann passed away on February 1, 2013. All members of the former Höfler Maschinenbau GmbH as well Höfler America Corp. will always remember him for his visionary and charismatic leadership.

LMC Workholding

COMPLETES $2 MILLION EXPANSION

LMC Workholding recently completed a $2 million expansion at its Logansport, Indiana facility with several new machines, all green lighting, office renovations and other plant improvements. The new machines include an expandable six-pallet horizontal machining center, several vertical machining centers, lathes and grinders. With these new machines, LMC plans not only to improve its existing capabilities, but also to meet growing demand for products and services including larger products and specialty products. Jay Duerr, LMC Workholding president, said, "We have been upgrading machine capabilities, buying new ones to increase capacity, and remodeling parts of the plant and all of our offices. Our goal is to have the best facility in the workholding business to serve the ever changing needs of our growing customer base and the machine tool industry in general. As they continue to drive us into providing more product and services as their business evolves, we must keep pace. We are proud of what we've been able to accomplish in our 97-year history and look forward to getting our customers and prospects here to see everything for themselves." For more information, visit *www.lmcworkholding.com*.

Klüber Lubrication

APPOINTS KRAEMER AS CEO

Klüber Lubrication, a worldwide manufacturer of specialty lubricants, announces the appointment of **Ralf Kraemer** as chief executive officer. Kraemer assumes the role of CEO from Dieter A. Becker, who returns to Klüber's global headquarters in Munich, Germany, after leading the North American operations for nearly three years. Born in Germany, Kraemer brings more than 15 years of sales, marketing and management experience in the metal cutting, woodworking, industrial equipment and power transmission industries to his new role at Klüber. "We're excited for the opportunity to have Ralf lead Klüber Lubrication North America," said Becker. "Klüber places particular importance on its industry-leading customer service and in-depth technical and application support. We are committed to providing excellent support to our thousands of customers throughout North America, and Ralf's skills, experience and dedication to a customer service-oriented focus make him the perfect fit to execute this promise." Prior to joining Klüber, Kraemer managed operations at a Swiss technology company in the Chicago area and established and developed the North American manufacturing facility and business operations for a German machine tool accessories company near Raleigh, N.C. For the past nine years, he was responsible for the North American operations of a German machine tool company in Pittsburgh, PA. Kraemer holds a degree in industrial engineering and management from the Karlsruhe Institute of Technology and an MBA from the Isenberg School of Management from the University of Massachusetts Amherst.

Somaschini

ANNOUNCES BUYOUT OF SOUTH BEND GEAR

Somaschini S.p.A., headquartered in Trescore Balneario (Bergamo) Italy, announces the purchase on Nov. 30th from Schafer Gear Works Inc. all of its minority membership interests of South Bend Gear LLC. With this purchase Somaschini becomes the sole owner of South Bend Gear LLC. The production unit in South Bend will act in tight cooperation with the parent company under the new name of Somaschini North America LLC and led by their new chief executive officer, Dr. Andrea Scanavini, who was previously working as coordinator for the previous JV on behalf of the Italian shareholder. Gianfranco Somaschini, CEO of Somaschini Italy, is appointed as president of the North American company. "This decision represents a new milestone in the long history of our company" said Dr. Scanavini "and it fits in the strategy of deeper penetration in the North American market in the particular sector of medium- and high-volume ground cylindrical gears with diameters between 50 and 400 mm as we are currently manufacturing at the parent company in Italy." Somaschini S.p.A. was established in 1922 in Milan and transferred to Trescore Balneario (Bergamo) Italy, east of Milan in 1943. Somaschini is a diverse supplier of gears that are sold to a variety of markets in Europe including automotive, passenger and heavy-duty trucks,

motorcycle, marine, textile machines, machine tools, robotics, railway and renewable energy. In 2007, Somaschini established Somaschini Automotive S.r.l. in a satellite facility located in Entratico (Bergamo), Italy to bring all high-volume automotive production into a dedicated plant. Today, the Somaschini Group has 250 employees and sales of 50 million Euro.

CALL FOR PAPERS!

Are you sitting on an idea for a technical paper but wondering where to present it? Do you have one already written, sitting on your desk, gathering machine dust?

How about *Gear Technology*? We are always looking for gearing- and power transmission component-relevant technical papers for publication in the magazine and in its digital version. Having your work appear in *Gear Technology* guarantees you an audience of the most experienced and discriminating industry players. You say your work has not been peer-reviewed? Not a problem, as we are lucky—and thankful—to have on-hand some of the most experienced and brilliant minds in the industry—our technical editors. So if your work "passes muster" and is published, you'll know you were reviewed by the best—and most demanding.

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For publication guidelines and more information, please contact Jack McGuinn at *jmcguinn@geartechnology.com*.

Dwight Smith

INCREASES ROLE AT KAPP AND NILES

Kapp Technologies is pleased to announce that **Dwight Smith** has been named sales manager for Kapp and Niles products and services for the Great Lakes and New England states, plus Iowa and New Jersey. His role also includes product management for the R&P Metrology line of large gear measuring equipment which Kapp Technologies distributes in North America. Smith has over twenty five years of experience in the gear industry. He first worked in the field of metrology in the eighties as vice president of Precision Measuring Corp. before joining Cole Manufacturing, Inc. in 1989. Cole Manufacturing represented complementary gear-related equipment manufacturers, including Kapp and Niles machines. He has developed and presented the in-depth Gear Basics training internationally, and chairs an AGMA committee. He will continue to teach the AGMA Basic School. "Smith practices his philosophy of service, support, and sales, in that order. He is a relentless advocate for our customers," said Bill Miller, vice president of sales for Kapp Technologies. "He has tremendous experience and he's made many contributions to this industry for over 25 years. We are excited to have Dwight on our team."

"I have always known that the Kapp and Niles people are of the highest caliber," said Smith, "and their products lead the industry in both technology and support. It is great to be fully engaged with such a great team."

Star SU

APPOINTS SIMIONI AND CELLA

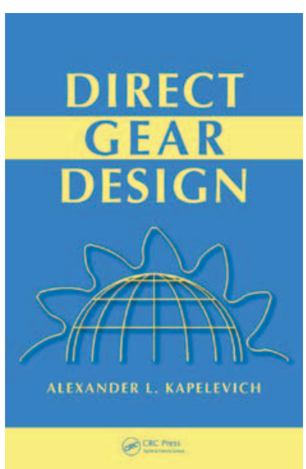
Alex Simioni has been appointed sales manager at Star SU for the South America market. "In his new position, Simioni will be responsible for developing a new sales network for machines and tools in South America, while helping to establish brand recognition for the Star SU organization internationally," said David Goodfellow, president of Star SU, LLC. Simioni, 39, brings fifteen years of sales experience with Star round tools and machines. In his last position, he served as director of sales for Startec IC Ltd., a representation and licensee of Star Cutter Company in Brazil. He holds a master's degree in business administration (FGV), a bachelor of business administration degree (Unimep), and a mechanical engineering degree (EEP). He is fluent in English, Spanish and Portuguese.

Chris Cella has been appointed application engineer at Star SU, LLC. In his new role, Cella will provide additional depth to the application engineering department, with a focus on continually improving customer technical support and tool design services. Cella brings two decades of experience in the fields of round tools, gundrills and gundrilling to his new position. He has spent the last decade providing tool reconditioning services, continuous improvement programs and troubleshooting support in the aerospace, automotive, heavy truck, hydraulic, power generation and transportation industries. He holds a bachelor's degree in mechanical engineering from the University of Illinois at Chicago.

Direct Gear Design

DEBUTS IN MARCH

Direct Gear Design (Hardcover; 328 pp.; CRC Press) by Dr. Alex Kapelevich, is now available for online purchase—at both CRC Press ($129.95) and Amazon ($117.58). *Direct Gear Design* presents Kapelevich's copyrighted, alternative "direct gear design" approach and compares it to traditional methods. It covers all theoretical and practical matters of advanced gear geometry and outlines various optimization techniques for custom gear drive performance maximization. It explains asymmetric gear design and its benefits for various applications and provides real-world examples of direct gear design implementation. *Direct Gear Design* includes information on macrogeometry of gear, tolerancing and tolerance analysis, gear measurement, gear fabrication technologies and tooling and much more. Kapelevich is a consultant at AKGears, LLC and a regular contributor to *Gear Technology*. To order, visit *www.crcpress.com/product/isbn/9781439876183*; or *www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Daps&field-keywords=kapelevich*.



Applied Process

HOSTS FIRST AP UNIVERSITY

More than 30 designers and engineers went "back to college" to learn how austempered ductile iron (ADI) could work in their manufacturing operations. The first ever AP University, hosted by Applied Process, Inc., was held in January at Eastern Michigan University on the Livonia Campus and Joyworks Studio in Ann Arbor, Michigan. The program was so successful that plans are in the works for another session.

The three-day event was created to educate those who design engineered components on how to best utilize the opportunities provided by ductile iron and ADI. Curriculum covered a range of topics and was taught by industry professionals. Classes covered the casting process, castability studies, casting issues and resolutions, successful weldment to casting conversions, an introduction to ADI, Austempering 101, ADI applications in gearing and applications of casting conversions. Attendees toured the Applied Process plant and visited Joyworks, a metalworking studio focused on research and education owned by John R. Keough, chairman of Applied Process.

"The event was much more than expected," explained Tim Covert, senior material engineer at Ford Motor Company. "We deal with ADI, but I was new to casting design. I was impressed, not only by the process, but by the knowledge and professionalism shown by the Applied Process staff."

Austempering is an isothermal heat treatment that produces a structure that is stronger than those created by conventional heat treatments. Austempered ductile iron (ADI) is a specialty heat-treated material that creates a lighter, stronger, quieter and more wear resistant part.

Bill Maenle, engineer and product design at Unverferth Mfg., has dealt with ADI in the past. "Moving from welding to casting has allowed us more flexibility, which means we can best cater to the needs of specific soil conditions. In my experience, ADI provides a better product with more reliability."

Many attendees who were new to ductile iron, more specifically ADI, left AP University with a knowledge base that will allow them to convert and improve current and future projects. "I am a chemist by degree and knew little about heat treatments and metals three days ago," admitted Michael Schmidt, business manager at Pennsy. "As we move into metals I am confident we will find applications for ADI."

April 8–12—Hannover Messe 2013. Hannover Fairgrounds, Hannover, Germany. The world's leading trade show for industrial technology returns in 2013 with a full lineup of trade shows under the banner "Integrated Industry." The 11 co-located shows include Industrial Automation; Motion, Drive and Automation; Energy; Wind; MobiliTec; Digital Factory; ComVac; Industrial Supply; Surface Technology; IndustrialGreen Tec and Research and Technology. Russia is the official partner country in 2013. Discover new perspectives on energy, automation and industrial supply and engineering topics as well as a broad range of events and displays affecting the global industrial market today. Other Hannover highlights include Metropolitan Solutions, TectoYou, Job and Career Market and Energy Efficiency in Industrial Processes. For more information, visit *www.hannovermesse.de*.

April 9–10—AmCon Design and Contract Manufacturing Expo 2013. Seattle, Washington. AmCon is a contract manufacturing expo for all job shops and contract manufacturers that provides custom metal, plastic, rubber or electronic parts and related manufacturing services to OEMs. Attendees include top level purchasing, engineering and production managers who are directly involved in buying custom contract manufacturing services. Representatives from companies of all sizes attend from a range of industries, often with blueprints in hand. The AmCon shows occur regionally throughout the year. Past attendees include ABB, General Electric, Honeywell, Johnson Controls, Parker Hannifin, Rockwell Automation, Saint-Gobain, Siemens and more. For more information, visit *www.amconshows.com*.

April 15–18—Gear Design and Theory. Gleason Cutting Tools Gear School, Loves Park, Illinois. This comprehensive three-and-a-half-day program is a blend of shop time and classroom study. A coordinated series of lectures is presented by engineering, production, inspection and sales staff members. It is recommended for those seeking to understand the fundamentals of gear geometry, nomenclature, manufacturing and inspection. Training groups are kept small so that individual concerns may be fully addressed. Shop tours and demonstrations are conducted to visually enhance the understanding of classroom discussions. The fee of $895 includes handbook and all materials, one group dinner and all lunches. For more information, visit *www.gleason.com*.

April 24—Intensive Water Quenching Workshop. IQ Technologies Inc. hosts an all-day workshop to provide attendees with an overview of IntensiQuench (IQ) processes, examine the data from actual part studies, and give attendees a forum to discuss the application of intensive quenching to enhance the performance properties of their heat treated products. The workshop will help answer questions such as: How can my heat-treated products benefit from intensive water quenching and save costs? How does the IQ process provide both enhanced strength and better ductility at the same time? How does intensive quenching equipment differ from traditional water, oil, salt or gas quenching systems? Manufacturing engineers, experienced heat treat metallurgists, steel product design engineers should attend this workshop. For more information, visit *www.intensivequench.com*.

April 25–27—AGMA/ABMA Annual Meeting. Park Hyatt Aviara, Carlsbad, California. Featured presenters include Jay Timmons (National Association of Manufacturers), Jim Meil (Eaton Corporation) and Dan Campion (Solar Turbines). Former MLB pitcher Jim Abbott will also give a presentation on overcoming adversity. There's also a scheduled visit to the United States Marine Corps Air Station in Miramar and a night of entertainment celebrating the iconic music of the 1960s. The event includes general sessions, presentations, receptions and the AGMA/ABMA Golf Tournament taking place at the Park Hyatt Aviara Golf Course. For more information, visit *www.agma.org*.

April 29–May 2—Gear Dynamics and Gear Noise Short Course. Gear Dynamics and Gear Noise Research Laboratory. The Ohio State University, Columbus, Ohio. For more than 33 years, this course has been offered as a tool to engineers and technicians involved in the analysis, manufacture, design, specification or utilization of simple and complex gear systems. Industries that find this course helpful include the automotive, transportation, wind-energy, process machinery, aircraft, appliance, general manufacturing and all gear manufacturers. The course material is covered in such a way that the fundamentals of gearing, gear dynamics, noise analysis and measurements are covered. This makes the course appropriate to the gear designer with little knowledge of noise analysis, as well as to the noise specialist with little prior knowledge of gears. Course attendees are asked to present a brief synopsis of problems they have encountered or of a procedure they have used for gear noise analysis and reduction. Possible approaches to solve each problem are discussed. For more information, visit *www.gearlab.org*.

May 7–May 9—Gear Manufacturing and Inspection. Crowne Plaza O'Hare, Rosemont, Illinois. In this seminar, Gear Manufacturing and Inspection: Methods, Practices, Application and Interpretation for the Design Engineer, attendees will gain a broad understanding of the methods used to manufacture and inspect gears—and much more. First, attendees will learn about methods behind a variety of gears, including external and internal spur, single and double helical gears, as well as bevel and worm gears. A description of each basic manufacturing and inspection method is provided. Both the methodology and underlying theory are explained. The "features" associated with each manufacturing method are discussed with regard to their impact upon and their ability to refine, guide and optimize the design process. Similarly, attendees will walk through interpretations of the results of all inspections. Instructor Ray Drago, chief engineer-gear technologist, Drive Systems Technology, Inc., will provide gear engineers with a good foundation in both manufacturing and inspection processes and procedures. For registration information, visit *www.agma.org*.

May 22–May 23—AGMA Marketing and Forecasting Conference 2013. Crowne Plaza, Chicago O'Hare Hotel and Conference Center, Rosemont, Illinois. What's going on in the gear market? What is happening in the end user market that will affect next year? How can you better prepare your company for the ups and downs of the current economic climate? The Marketing and Forecasting Conference will present a comprehensive report on the U.S. Economic Conditions, Industry Conditions for Gears, Gear Market Bookings and Gear Market Shipments. This will be broken down into a series of end user markets including total gears, industrial machinery gears, construction machinery gears, farm machinery gears, power transmission equipment, mining, ship and offshore, railroad and aerospace gears. IHS Global Insight has developed news reports that will forecast these various markets. This AGMA member-only event includes a reception and dinner for networking opportunities. For more information, visit *www.agma.org*.

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

- ☐ My company MAKES gears (20)
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How Gear Hobbing Works

Hobbing is one of the most fundamental processes in gear manufacturing. Its productivity and versatility make hobbing the gear manufacturing method of choice for a majority of spur and helical gears.

One of the most important concepts to understand about gear hobbing is that it is a generating process. The term *generating* refers to the fact that the shape of the gear tooth that results is *not* the conjugate form of the cutting tool. Rather, the shape of the tooth is generated by the combined motions of workpiece and cutting tool. During hobbing, both the hob and the workpiece rotate in a continual, timed relationship.

For a spur gear being cut with a single-start hob, the workpiece will advance one tooth for each revolution of the cutter. When hobbing a 20-tooth gear, the hob will rotate 20 times, while the workpiece will rotate once. The profile is formed by the equally spaced cutting edges around the hob, each taking successive cuts on the workpiece, with the workpiece in a slightly different position for each cut. Several cutting edges of the tool will be cutting at the same time. Figure 1a demonstrates the path of the cutting tool (in red) relative to the workpiece (in blue). As can be seen from the figure, the relative motions of the cutting tool and workpiece are what allow a straight-sided tool—the hob—to generate an involute curve.

During this rotation, the hob is typically fed axially with all the teeth being gradually formed as the tool traverses the work face (Fig. 1b).

The hob itself is basically a worm with gashes cut across it to produce the cutting edges (Fig. 2a). Each cutting tooth is also relieved radially to provide chip clearance behind the cutting edge (Fig. 2b). This also allows the hob face to be sharpened and still maintain the original tooth shape. In its simplest form, the hob tooth takes on the shape of a straight-sided rack tooth (Fig. 2c). The final profile of the tooth is created by a number of flats blending together. The number of flats corresponds to the number of cutting gashes which pass the workpiece tooth during a single rotation. Thus, the greater the number of gashes in the hob, the greater the number of flats along the profile, which improves the "smoothness" of the tooth profile.

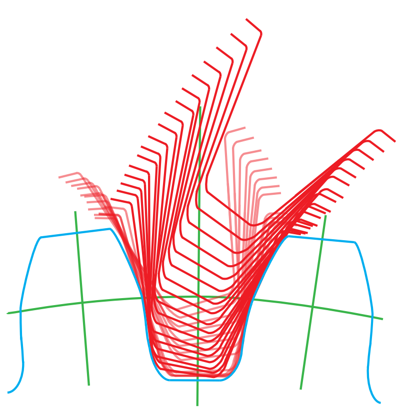

Figure 1a Hobbing is a generating process. The relative motions of the cutting tool and workpiece allow a tool with straight-sided cutting edges—the hob—to generate an involute curve.

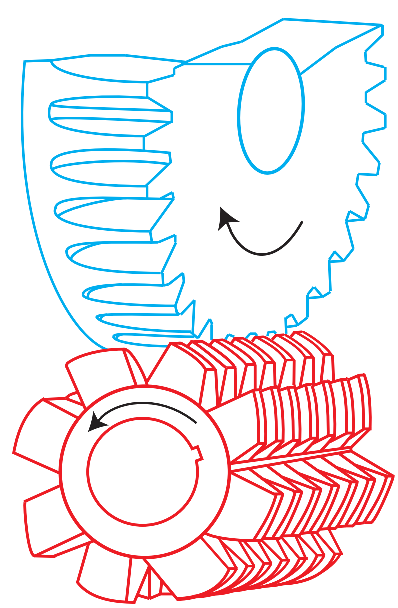

Figure 1b Hob and workpiece each rotate during the hobbing process. For a spur gear being cut with a single-start hob, the workpiece will advance one tooth for each revolution of the cutter.

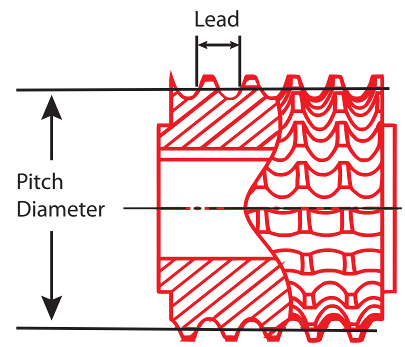

Figure 2a The hob is basically a worm with gashes cut across it to produce the cutting edges.

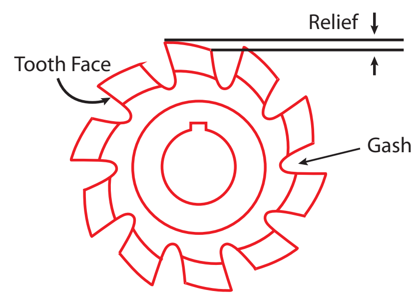

Figure 2b This side view of a hob shows how each cutting tooth is relieved radially to provide chip clearance behind the cutting edge.

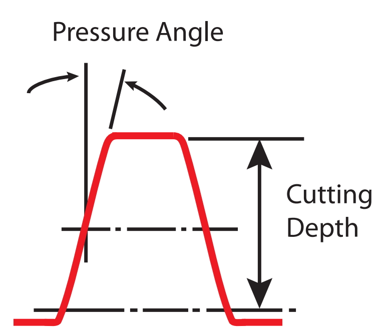

Figure 2c In its simplest form, the hob tooth takes on the shape of a straight-sided rack tooth.

Where Can I Learn More?

The material in this Back-to-Basics Brief was adapted primarily from "The Gear Hobbing Process," by Dennis Gimpert, which appeared in the January/February 1994 issue of ***Gear Technology***. The original article goes into much greater detail about cutter modifications, hobbing machine mechanics, different hob feed approaches, multi-start hobs and hob thread-spacing errors.

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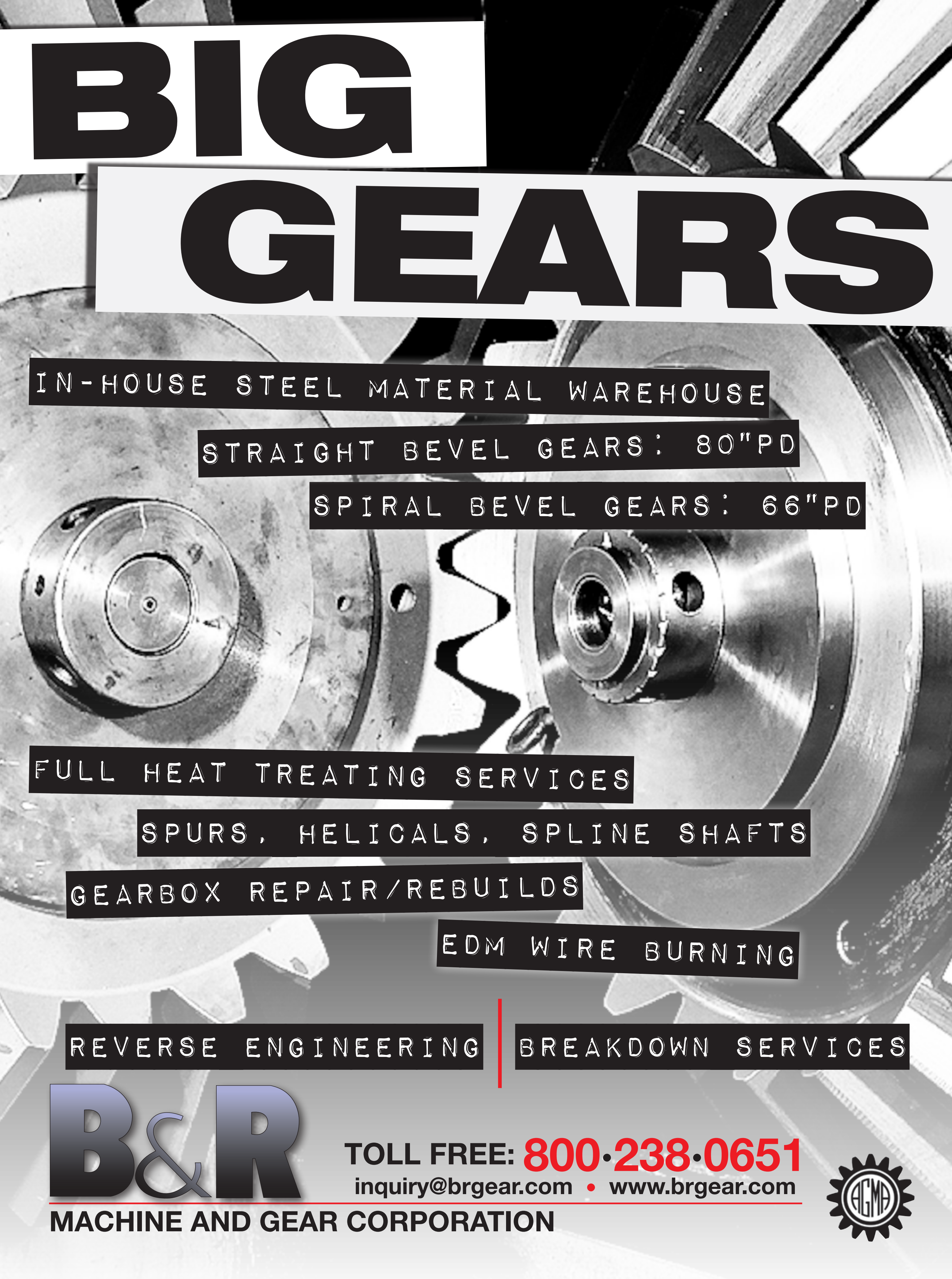
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