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Hainbuch Jaw Module

If going from O.D. clamping to I.D. clamping from the same clamping device [turning and stationary] wasn't enough, in under two minutes you can swap in Hainbuch's new Jaw module to increase your clamping range to 190 mm. See the video here: *www.geartechnology.com/videos/Hainbuch-Jaw-Module-/*

Samp RASO 400 Shaving Machine

According to SAMP, the RASO 400 shaving machine is the most versatile shaving machine, thanks to its large, open "C" structure. It can shave gears in very different sizes, even big gears and long shafts. See the video here: *www.geartechnology.com/videos/Samputensili-RASO-400-Shaving-Machine/*

Gear Talk

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

In *The Essential Gear Book*, Schultz discusses what gear books and resources would be worthwhile for those just getting involved in gear manufacturing.

In *Language Barriers*, Schultz examines the challenges in teaching gears and gear manufacturing overseas and the difficulties communicating in a second language.

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Challenges Tempered by Optimism

Publisher & Editor-in-Chief
Michael Goldstein

For many of us, 2016 was a rough year—and the results of our annual State of the Gear Industry Survey show it. 40% of respondents indicated their companies had cut staff, while only 27% indicated an increase in employment. Clearly, there have been widespread cutbacks.

But it's not all bad news. The numbers for sales and production output were more evenly divided among the gainers and losers. Although 43% of respondents said sales were down, 38% said sales were up. Similarly, although 41% said production output decreased in 2016, 38% said it actually increased.

And when it comes to thinking about next year, the gear industry is somewhat more optimistic. The numbers give us the sense that things are leveling out, and that the worst may be behind us. For example, only 15% of respondents expect that their companies will be reducing employment levels in 2017, while 39% expect to increase. 59% expect both production output and sales to increase this year, versus only 14% who expect a decrease.

So, if production levels and sales are on the rise, then employment should follow, right? Well, not so fast. One of the key issues that continues to plague our industry—and all of manufacturing—is the difficulty in finding skilled labor. One of the most frightening results of this survey is the enormous number of people in our industry that are expected to retire in the next five years. 12% of respondents expect that more than 20% of their workforce will retire in the next five years. And there's a lot of concern over this issue. Almost half of respondents listed "Difficulty in Finding Skilled Labor" as one of their top-three challenges to their business.

None of this should come as a surprise to anyone. But it should be a wake-up call for those not paying close attention. Our industry clearly needs to encourage, educate and train the next generation of employees. The AGMA is certainly aware of this, and they're doing something about it. In his article on page 10, AGMA President Matt Croson mentions two new classes being offered. More importantly, he highlights education as one of the four key pillars of the association's strategy moving forward.

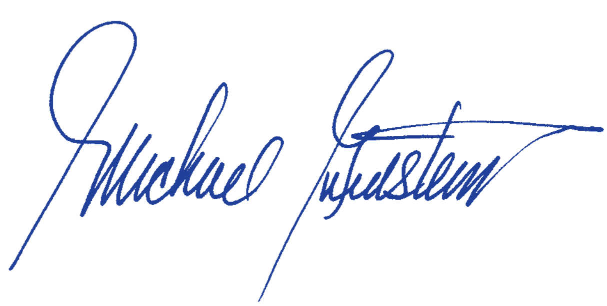
Another of AGMA's pillars is Emerging Technology. There's no doubt that the technology of manufacturing is changing, and the technology of gear manufacturing continues to evolve as well. Fortunately, it seems like the gear industry is up for the challenge. I found it quite interesting that nearly 11% of respondents expect their companies to purchase 3-D printing equipment in 2017. That's more than spline rolling, gear tooth honing or shaving machines.

Another surprise was that 50% of respondents expect their companies' capital spending to be $1 million or more. In addition, 93% indicated that their facilities and equipment were good or better, with only 7% indicating that their facilities and equipment are beginning to show their age.

Sure, our industry has its challenges. But it has promise, too. And that's why 83% of respondents tell us that they're optimistic about their companies' ability to compete over the next five years. The rest are undecided (10%) or pessimistic (only 7%).

The survey results begin on page 26. I hope you'll take the time to study them so you'll better understand how your own operation is doing relative to the rest of the industry. In addition, we've interviewed a number of key suppliers and industry veterans to provide additional insight, and you can see their comments in the article beginning on page 34.

I'd like to thank all of you who participated in the survey. We received nearly 300 responses from a wide variety of companies making gears of all types for many different industries. So, I'm confident in saying that the results are representative of the industry as a whole. Your enthusiastic participation is extremely valuable, not only to us, but to all who read these pages.



AGMA: Delivering Value in New and Measurable Ways

Matt Croson, President of AGMA

When I first met the leaders of the gearing industry in April 2016 at AGMA's 100th Anniversary Celebration, I did my best imitation of Joe Namath, who famously predicted a Super Bowl victory for his New York Jets: I guaranteed we would reach our 101st year!

We did, and we are kicking off a new century at AGMA with an exciting new Vision, Mission and four Strategic Imperatives.

Our new vision is: AGMA and its members drive power transmission innovation.

This bold vision positions our members at the center of innovation. Join AGMA and you are identifying your company with leadership and innovation. AGMA stands next to its members as a platform to discuss, share and communicate all the ways innovation can support customers… from our people (education), our products (emerging technology), our footprint (global) and our communications (industry voice).

While Namath did the predicting, he knew he couldn't do it alone. He needed a team, and that is how AGMA and its members will be positioned — as a collaborating partner that works in a coordinated manner to deliver innovation — the lifeblood of any company or organization.

The question remains: what will we do?

That answer partly lies in our new Mission Statement: "AGMA is the global network for technical standards, education and business information for manufacturers, suppliers and users of mechanical power transmission components."

One of the critical elements of this mission is worth noting. AGMA wants to deliver value to the complete supply chain — from the supplier side, the systems side, and even the downstream customers.

Every company lives and dies by the connection they have to the customer community. Our economic livelihood is tied to the symbiotic relationship we have established with the downstream customer community. AGMA leaders recognized this critical element and debated fiercely to include the entire supply chain, and all the pieces of the power transmission system.

> **AGMA's New Vision**
>
> "AGMA is the global network for technical standards, education and business information for manufacturers, suppliers and users of mechanical power transmission components."

This Mission Statement recognizes some of our historical value drivers, but the rest of the strategic plan asks AGMA to take on new, exciting roles as we explore how we can deliver on the vision.

The strategic plan focuses on four key elements that can directly help your company. Here are some of the new things we'll be doing:

Industry Voice — First of all, we're going to be proactive with downstream communication to ensure end users know that AGMA is a resource. We are going to key in on Gear Expo, the Drive Technology Show, and really make this event a downstream-focused, one-stop-shop for everything related to the power transmission industry. We will be more proactive with our communications efforts and invite the industry to come together as one, and make Gear Expo a center point for innovation.

Emerging Technology — Second, AGMA is going to keep the industry aware of disruptive technologies. We are starting with Industry 4.0, additive manufacturing, robotics and new alloys. Again, we want to be tied to innovation and support our members looking to adopt the latest in process steps or new technologies. AGMA will become a platform for dialogue, debate, even concern! We will not shy away from taking a good hard look at *any* emerging technology, even if it is a threat. Our goal is to prepare our members for a successful future, one tied to innovation and growth. Members will see this objective start to take form in early 2017, and we've already adjusted our website: check out *www.agma.org* and look under Resources for the significant research, news and informative links we have included.

Education — Third, we're kicking it up a notch on education. Over the next five years, AGMA will be committing significant resources towards education. We are taking a "help your own" approach to education, and making sure we are training our management, our engineering teams and our operators at the highest level possible. So many people *talk* about doing something, and we *are* doing something. We have two new classes on board for 2017, including Steels for Gear Application and Fundamentals of Gear Design & Analysis.

Global — Our final strategy is to support AGMA members looking to export or grow domestically, wherever they are. AGMA, even from its early days 100 years ago, has an international reach and international membership. Today, AGMA has members in more than 30 countries, and all AGMA members compete in a global marketplace. With our position as Secretary to ISO TC 60, AGMA works to create international consensus standards that are used globally. Our global strategy is also to expose more engineers and engineering students worldwide to AGMA's standards so that your future employees and customers are well-versed in AGMA's nomenclature and standards.

It's an exciting time to be an AGMA member.

I know that I promised we would get to the 101st anniversary, but clearly we are aiming much higher than that. We have a plan that can ensure our destiny as *innovators*. We have a plan that *builds* off our past, and challenges our leaders to stay fresh with disruptive technologies. We have a plan that focuses on our teams via strong, dynamic educational experiences. We have a plan to ensure the world knows our value.

> **AGMA's Mission Statement**
>
> AGMA and its members drive power transmission innovation.

I'll close with something most association leaders don't say: join AGMA, get involved, and I guarantee you will have fun. It's fun to build something, to be part of growth and work together with a group to address challenges that we all face.

As Broadway Joe once said, "When you have confidence, you can have a lot of fun. And when you have fun, you can do amazing things."

Join AGMA and let's go do some amazing things.

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agma

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Matt Croson became the president of the American Gear Manufacturers Association in 2016. Croson has more than two decades of leadership and communications experience in manufacturing trade associations. Prior to joining the AGMA, he was president and CEO of the Adhesive and Sealant Council.

Problem Solving for the Gear Industry

Aaron Isaacson, Managing Director, Gear Research Institute

If you've got a gear performance problem, the Gear Research Institute (GRI) is here to help you. Since inception in 1982, GRI has been a primarily industry sponsored, experimentation driven research facility. Whether establishing the fatigue life of gears or evaluating the impact of manufacturing processes on the performance of gears, GRI has pioneered methods and procedures for characterizing such properties that are accepted by the aerospace, vehicle and other industry sectors. This industry sponsorship and experimental tradition has continued and grown at the Applied Research Laboratory of Penn State since 1996, when GRI relocated to the campus of The Pennsylvania State University in State College, PA. We continue our relationship with the AGMA and the ASME, organizations which were instrumental in the creation of GRI, with a governing board of trustees whose members are nominated by these trade associations.

Most gear engineers like to say that their designs never fail. At GRI, we say the opposite. The challenging part is to design gears to fail by a specific mechanism, whether that means contact fatigue (pitting), bending fatigue (tooth breakage), scuffing, micropitting, wear, etc. Our mission is to accurately duplicate all gear failure mechanisms in a controlled manner, allowing factors affecting these mechanisms to be understood and characterized individually. Thorough characterization enables optimization of performance, cost or a balance of each. In order to accomplish this mission, we are very well equipped with testing hardware — from a series of universal test stands to conduct tooth bending fatigue tests to several roller on roller testers for rolling/sliding contact fatigue evaluation. Eight high- and low-speed power recirculating gear test machines perform fatigue tests on running gears. We are very well equipped to test at both the coupon and component levels. Further, we have an array of custom test stands, designed and built for specific sponsors to test their particular drive train components for durability and life.

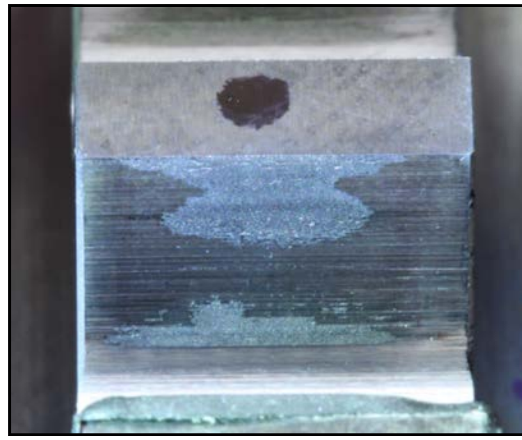

Figure 1 Test gear tooth with micropitting damage in both addendum and dedendum.

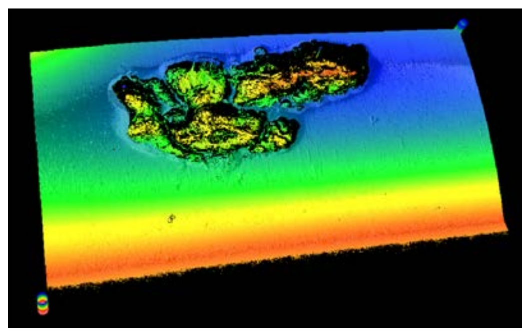

Figure 2 Optical interferometry characterization of pitted gear tooth flank.

Accompanying this experimental hardware is an attitude emphasizing attention to detail. Experimental data can be meaningless unless the test conditions are very carefully controlled. Invalid data is also very expensive, both in time and cost. A crew of skilled technicians, who have a combined work experience of almost a hundred years in gear testing, ensure that the experiments are conducted meticulously and flawlessly. While we do involve undergraduate and graduate students in our experimentation, they are always supported by one of our technicians until they are satisfied that the student has developed an aptitude to the relevant details. The process of gathering data is currently being automated to minimize the potential for random and observational error occurrence during data gathering and analysis.

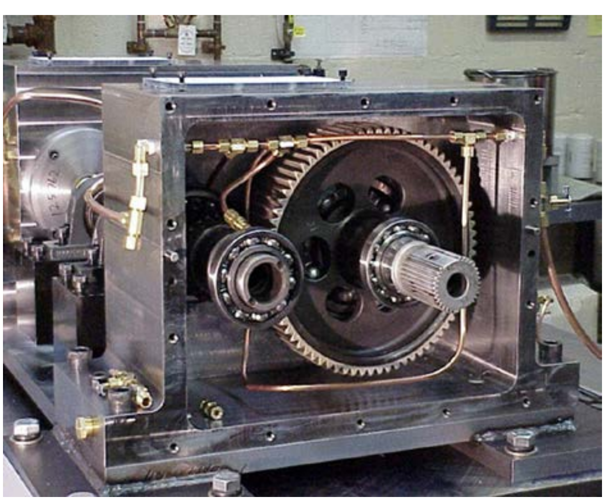

Figure 3 Custom designed power recirculating (four square) test rig for 7.5-inch center distance spur gears. Testing was conducted at various speeds, up to 6,500 rpm using a 100 HP drive motor resulting in circulation of approximately 1,600 HP in the test loop.

Further supporting this experimentation effort is a suite of rigorous analysis tools, some generic and some internally developed, to make physical sense of the collected data. A vast array of the latest materials characterization techniques, such as scanning electron microscopy, transmission electron microscopy, energy dispersive spectroscopy, Auger electron spectroscopy, X-ray photo-electron spectroscopy, X-Ray diffraction, optical interferometry, hardness testing (macro, micro and nano-indentation capabilities), etc. , that are unique to a large research institution like Penn State, add to GRI's ability to provide rational and meaningful results to our sponsor community. In a similar manner, experienced and nationally recognized academic faculty in a host of specialized

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Klingelnberg Closed Loop – Digital process control for cylindrical gears
Automatically corrects your machine - no typing needed!

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When using the Klingelnberg Closed Loop for cylindrical gears, the measuring results are stored in a universal XML file. This establishes clear and easy communication between the measuring machine and machine tool. Klingelnberg Closed Loop is an open system suitable for use with any machine tool and is already available for Klingelnberg/Höfler GearPro machine software.

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BEVEL GEAR TECHNOLOGY | MEASURING TECHNOLOGY | CYLINDRICAL GEAR TECHNOLOGY | DRIVE TECHNOLOGY disciplines are available for consultation and collaboration to address specific sponsor-related issues at Penn State, when they arise.

The combination of these resources has resulted in some exciting results in the recent past. We have completely characterized the gear related fatigue properties of AMS 6308, a steel that is being increasingly utilized in the aerospace sector of industry. We have compared this material to other more exotic, high hot hardness (temper resistant) steels such as Pyrowear 675, CSS-42L, Ferrium C64, etc. We have quantified the impact of processes achieving very high surface quality on gear fatigue life, to the point that these processes have now become the norm in many gear applications. Current and ongoing projects are related to characterizing methods to mitigate micropitting and the fatigue behavior of triple vacuum melt, ultra clean steels. Also of note is a continuing project characterizing the fatigue behavior of gears subjected to a billion load cycles. We are also heavily involved in establishing methods and procedures for evaluating the behavior of gears and lubricants in a "loss of lube" condition. These research activities are sponsored by industrial heavyweights like Boeing, Bell Helicopter, GE, Pratt & Whitney, Rolls Royce, Honeywell, John Deere, Sikorsky, and Carpenter Technology Corp. The majority of our test data is kept proprietary at the request of our sponsors. We also support small businesses in many government funded Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs, all geared toward making transmissions lighter, cheaper, more efficient and/or more durable.

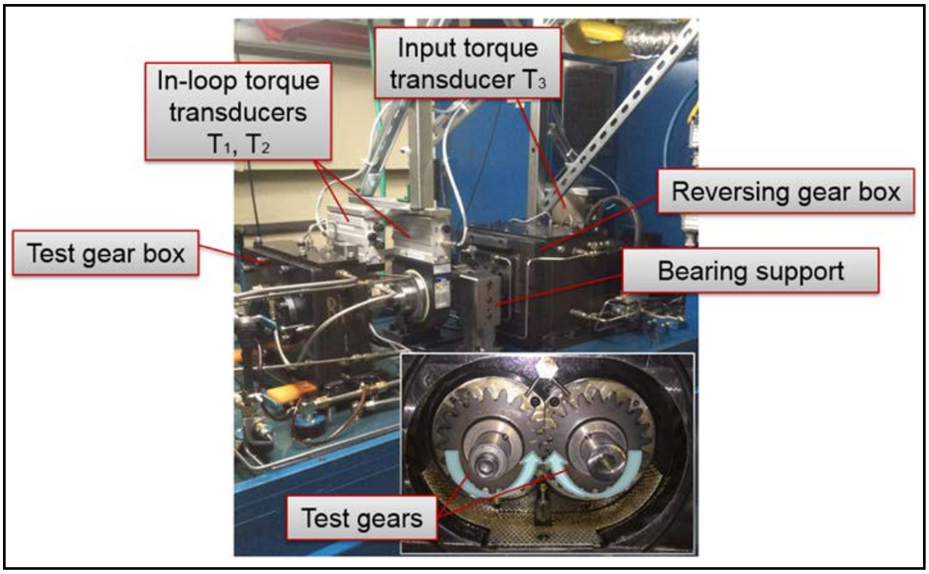

Figure 4 Gear tooth friction measurement test rig.

Due to our location at a major public university, there is a sense of remorse that GRI could be doing so much more in educating the future generation of engineers in gear technology. Through several industry grants, we've been able to give many undergraduate students some hands on, gear related training and experience. This provides an opportunity for students to broaden their engineering foundation in a skillset that is very desirable to companies desperate to maintain gear expertise within their organizations. However, the much larger goal of offering a gear technology curriculum to engineering students remains unfulfilled. This situation is frustrating in light of the fact that it is common knowledge that the nation's gear industry faces the challenge of an aging workforce and most graduating engineers in this country have very little or no exposure to gear technology. While institutional support towards this end has been recently forthcoming, resources to formulate and offer such courses have remained elusive. We intend to keep trying.

The Gear Research Institute has been in existence for 34 years, and geared systems will continue to be utilized in vehicle transmissions for the foreseeable future. We are confident that we have many more projects to formulate and execute for the benefit of this industry and their customers. If your organization has a gear or transmission related issue, GRI has the expertise and the desire to assist you with the problem. If you're interested in learning how you can support the education and training of the next generation of gear engineers — who could become your employees — please consider becoming a corporate or individual member of GRI. For more information about GRI, go to *www.gearresearch.org*.

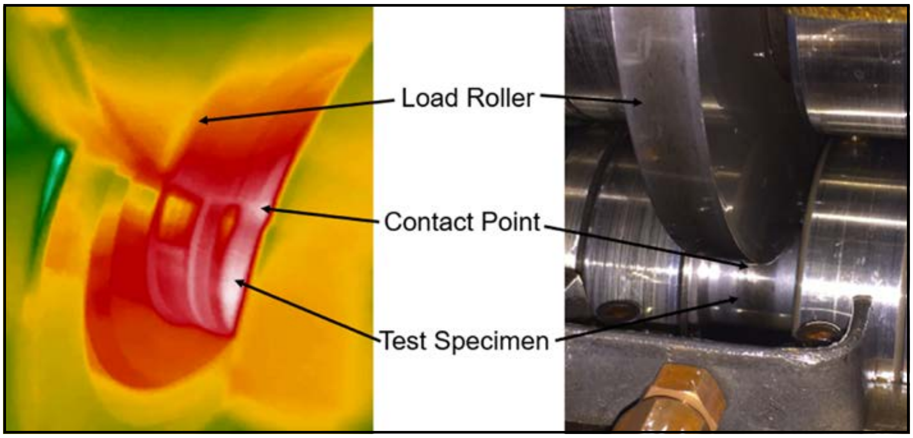

Figure 5 Infrared thermograpy and optical analog showing critical components of a rolling/sliding contact fatigue test during a loss of lube test. Contact temperature and traction force are monitored and recorded throughout the test and used in combination with accelerometer data for failure detection.

Aaron Isaacson is managing director of the Gear Research Institute and Head of the Drivetrain Technology Center at Penn State University's Applied Research Lab. Aaron received B.S. (1998) and M.S. (2009) degrees in mechanical engineering from Penn State and is currently pursuing his Ph.D. in materials science and engineering at Penn State.

Danobat

DEVELOPS CUSTOM GRINDERS FOR LARGE PART MACHINING

Danobat's customized gear grinding machines make it possible for Grupos Diferenciales to to turn, grind and measure large parts.

The Spanish machine tool manufacturer Danobat has been developing two highly versatile grinding machines for Grupos Diferenciales. These grinders will make it possible to turn, grind and measure large parts using a highly-efficient process.

Grupos Diferenciales, which specializes in producing high-tech gears for mechanical transmissions used in the automotive, maritime transport, railway and aeronautics industries, performs technologically-advanced tasks using difficult-to-machine materials with close tolerances.

There was a need to find a flexible, adaptable solution that could be highly customized, making it possible to finish the parts in a single set-up.

After evaluating different solutions existing in the market, Grupos Diferenciales decided to entrust Danobat with the development of two new pieces of equipment that allow the company to produce large parts compliant with stringent quality standards.

The main challenge consisted of producing optimum quality parts in a standardized manner.

The team of mechatronics engineers at Danobat designed and developed both horizontal and vertical grinders for Grupos Diferenciales. They are highly versatile and capable of turning, measuring and grinding parts of different sizes. The equipment has enhanced the tolerance and roughness of machined parts.

The VG-1000/700 vertical grinder is equipped with a multi-position head for hard turning and grinding of parts, as well as a measuring arm that makes it possible to verify whether the manufactured components meet the standards and provide optimal quality.

This grinding machine has a high stiffness, designed specifically for the stability and vibration elimination requirements in hard turning processes.

The measuring tool integrated in the machine is able to measure internal and external diameters, faces and cones with repeatability of less than 1 micron, thereby ensuring the dimensional geometry of the parts in less than 5 microns.

Danobat's experts designed this highly customized machine so that it could be adaptable to the already existing clamping tools. Therefore, the system has a main magnetic clamping system intended for manufacturing medium- to large-

The team of mechatronics engineers at Danobat designed and developed both horizontal and vertical grinders for Grupos Diferenciales.

sized diameters and a self-centering jaw chuck for batches of smaller parts.

One of the needs to be addressed by Grupos Diferenciales was the versatility and flexibility of the equipment. This is why Danobat included an automatic tool changer in the grinder that makes it possible to select the most appropriate tool for each type of part to be manufactured on each occasion.

To complete the tasks commissioned, Danobat also developed a horizontal grinder, the HG-72-2000-B12, capable of machining parts with a length of up to 2,000 mm, a diameter of 640 mm and a weight of 1.5 tonnes.

One of its main features is that it is equipped with a head that includes three grinding wheels, making it possible to machine external diameters, faces and threads. This head (which rotates around its vertical axis and reaches every point on the part) is powered by a 45 kW motor that reaches peripheral speeds of up to 45 m/s, with grinding wheels that have a maximum diameter of 610 mm.

Thanks to these features, the device is able to respond to all grinding needs, including parts with Ra 0.1, in a single set-up and with guaranteed geometric quality.

The inclusion of the Danobat MDM-300 multi-diameter measuring device, which runs in parallel with the machining process, is advantageous since it prevents subsequent measurements and enables single-stage grinding. This will ensure that the part meets all the requirements established in the design.

The Danobat MDM has a repeatability of ±1.5 microns, making it possible to measure a wide range of diameters. Once the grinding process has ended (but before removing the part), post-process verification may be performed.

Moreover, the machine includes a filtration unit, making it possible to filter up to 15 microns. This contributes significantly to the quality of the end product.

In order to meet the specific demands of Grupos Diferenciales, Danobat has closely cooperated with them with the aim of developing a solution that is fully adapted to the needs and requirements set out by the company. Likewise, Danobat is in constant contact with the company to give the proper advice and service needed to take care of this equipment.

For more information:

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Mitsubishi Heavy Industries

INTRODUCES SUPER GEAR SKIVING MACHINE

The opening of the JIMTOF machine tool show in Tokyo, Japan marked the debut of MHIMTC's new MSS300 super skiving gear machine. This new machine was developed to maximize the advantage of MHI's new three-tier skiving tool released in 2016.

The new MSS300 is designed specifically for the high-speed manufacturing of automotive internal ring gears. With a maximum outside diameter of 300 mm, the MSS300 brings flexible, high volume internal gear skiving to internal gear manufacturing.

In addition to internal gear cutting, the MSS300 is also capable of cutting parts with restrictive geometries, such as stacked pinion gears. Many applications that would have been shaped or manufactured in two parts previously can now be cut with the super skiving process.

The all-new machine features an ultra-rigid, powerful (33 kW) tool spindle capable of 6,000 rpm and ±30 degrees of helix angle. The direct drive work table offers 3,000 rpm with high torque and stable synchronization. The six-axis Fanuc 31i CNC controller utilizes graphic data entry screens for quick part setup.

For high speed operation, a ring loader is integrated into the machine design and is available as an option. The MSS300 is easily interfaced to robotic, gantry type, basket or conveyer automation.

Although the machine is designed to get the most productivity from MHI's newest super skiving tools, conventional pinion-type skiving tools are completely compatible and are utilized for certain applications. MHI's new super skiving tools typically produce three to five times more parts than conventional skiving tools.

Deliveries of the new MSS300 will begin in the second quarter of 2017. The MSS300, along with the innovative super skiving tools from MHI have established a new benchmark in productivity and process quality.

For more information:
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www.mitsubishigearcenter.com

Koepfer America

CNC GEAR HOBBING MACHINE OFFERS COMPACT FOOTPRINT

The Monnier + Zahner ("MZ") 500 D-drive gear hobbing machine offers CNC technology in a compact footprint for top-quality fine- and ultra-fine pitch gear manufacturing. Introduced by Koepfer America at IMTS 2016, the 500 D-drive is the latest in precision machine design from the Swiss company, MZ.

The machine features two identical direct-drive work spindles on the headstock and tailstock. This configuration allows driving the workpiece with less tailstock pressure, which results in minimized machine distortion and increased part quality and cutting performance. The double drive system also provides precise concentricity of the workholding and better drive performance for workpieces that are difficult to clamp.

With CNC hob shifting (up to 1.181" or 30 mm), a 12,000 rpm hob spindle, and capability for mounting bore- or shank-type hobs, a wide variety of components can be manufactured on the 500 D-drive. Furthermore, the machine offers options for Wahli automatic loading and unloading systems. Existing Wahli workholding can also be used. In the end, this is a high-production, high-quality, high-flexibility solution for cutting fine- and ultra-fine pitch gears.

The 500 D-drive is rated at 1.575" (40 mm) diameter at 40 DP (0.6 m_n) with a maximum workpiece length of 1.969" (50 mm) and maximum hobbing length of 1.181" (30 mm). This range ensures an optimal gear hobbing solution for instrumentation, medical products, robotics and more.

For more information:
Koepfer America, LLC
Phone: (847) 931-4121
koepferamerica.com

LMT Tools

CARBIDELINE-H HOB DESIGNED FOR LARGE LOT SIZES

The large family of carbide hobs from LMT Fette now has a name: CarbideLine. It comprises the CarbideLine-S solid carbide tools, the CarbideLine-H hybrid carbide tools and the multi-part gear cutting CarbideLine-I indexable carbide tools. All CarbideLine tools, just like the established PM-HSS and SpeedCore hobs, excel through maximum productivity in their specific fields of application.

CarbideLine-H tools are a new addition to the product range of LMT Tools and were presented to a trade audience for the first time at the AMB in Stuttgart. They cover the module range 5 to 12 and are designed for rough machining and finishing large lot sizes, where the tool costs of using solid carbide milling cutters are too high and the gear cutting quality is too low with indexable inserts.

CarbideLine-H tools are also highly suitable for machining high-strength materials up to 1,400 N/sq. mm and enable a gear quality up to quality grade AAA. Its preferred area of application is for gears for commercial vehicles, general mechanical engineering and energy technology. In one specific application it was possible to reduce the gearing costs per wheel by 20 percent with the CarbideLine-H compared with an indexable insert system.

CarbideLine-H tools can — like CarbideLine-S tools — be reconditioned up to 20 times at LMT service centers after they have exhausted their tool life and thus make a significant contribution towards reducing the life cycle cost.

For more information:
LMT USA Inc.
Phone: (847) 693-3270
www.lmt-tools.com

Röhm Products of America

EXTERNAL CLAMPING CHUCK PROVIDES GEAR SURFACE FACE GRINDING

Röhm Products of America now offers a powered external clamping chuck for gear surface face grinding. The KZF-S collet chuck is especially well suited for clamping gears/workpieces that have an external plane or gear teeth geometries accessible from the outside. Additionally, the chuck allows face and ID diameters to be turned or ground concentric to outer gear pitch diameters.

The compact KZF-S chuck provides high clamping forces, optimal workpiece stability and maximum axial accuracy achieved via axial draw-in of the workpiece against a rigid work

stop. The chuck maintains its centrifugal force for a smooth rotation of less than 0.01 mm.

KZF-S chucks have modular designs that feature case-hardened components for maximum versatility and low maintenance. The workholding system features a grommet for the integration of air or coolant and a sealed lubrication channel to eliminate chip penetration.

Available in three sizes, the KZF-S chucks accommodate diameters ranging from 30 mm to 180 mm. A simple bayonet connector enables users to quickly retrofit clamping sleeves to different diameters, and an intermediate adaptor with adjustment screws enables DIN55026 or optional A5-A8 mounting.

For more information:
Röhm Products of America
Phone: (770) 963-8440
www.rohm-products.com

GWJ Technology

ANNOUNCES UPDATED VERSION OF TBK 2014 SOFTWARE

GWJ Technology is pleased to announce the latest release of *TBK 2014,* the calculation software for gear manufacturing and mechanical engineering.

The new and updated version V31 comes with some interesting features. The calculation modules "Cylindrical Gears" and "Planetary Geartrains" allow the users to use the DIN 58405 standard for fine mechanics as well as ISO 1328 and ANSI/AGMA 2015 in addition to the DIN 3961 standard for gear allowances. Both modules now support not only DIN 3990 and ISO 6336, but also ANSI/AGMA 2101-D04 in order to determine the load capacity. Profile modifications, for example tip relief, are taken into consideration, in particular for scuffing. Furthermore, the cylindrical gear pair module allows users to define the number of tooth meshes. This can then be considered in the calculation of the load spectrum, too.

A new input option for the center distance was also added to the dimensioning function dialog. The calculation module for planetary geartrains also features a new dimensioning function. In addition, the number of teeth of the planets can be automatically determined or defined individually.

For more information:
GWJ Technology GmbH
Phone: +49 (0) 531-129 399 0
www.gwj.de

Liebherr

GEAR SHAPING MACHINE OFFERS SHORT SETUP TIMES AND FLEXIBILITY

Liebherr-Verzahntechnik GmbH has expanded its machine portfolio for small workpieces with the small-footprint (Platform 1) LS 180 F shaping machine equipped with an electronically operated, movable cutter head slide. The machine can shape smaller gears in different axial positions with only short set-up times. The machine is likely to be of interest for job shops, especially with aerospace work. The LS 180 F is also highly productive, capable of up to 1,500 double strokes per minute, processing workpieces up to 180 mm diameter, maximum module 5 mm.

Shaping continues to be the gear manufacturing process of choice for gears to be part of transmissions with minimum available space, for example, cluster gears with limited cutter overrun which can be machined in one clamping in the new Liebherr machine, avoiding additional set-ups.

Previously, only larger machines could accommodate such flexible applications; smaller shaping machines did not feature the necessary movable cutter head slide. The new LS 180 F now enables Liebherr to provide the right size of machine with a lot of features for small workpieces, too.

The new cutter head design also enables workpieces with both internal and external gear teeth to be machined in the same clamping operation. To accomplish this, the machine is equipped with a twin-track cam as standard. The LS 180 F continues to be available with a mechanical helical guide. The new version is also compatible with older versions, meaning that existing helical guides and removal cams can be used with the LS 180 F.

"One actual application is, for example, a component used to adjust aircraft landing flaps," says Dr. Andreas Mehr from the grinding and shaping technology development and application team at Liebherr-Verzahntechnik GmbH. "Every component features three gears that have to be positioned quite accurately to each other. That is why it is absolutely necessary to machine the entire gear tooth machining procedure in one clamping." But there are also potential customers for the LS 180 F in pump manufacturing as well as in the motorbike and tractor industry. "This machine is extremely versatile," Dr. Mehr emphasizes. "Given its high stroke rate of 1,500 double strokes per minute, this machine can produce small quantities very cost-effectively."

The LS 180 F enables Liebherr to combine the small footprint of the Platform 1 with applications that were previously only feasible using larger machines. The LS 180 (without vertical cutter head slide) will be redesigned and an LS 180 E (with electronic helical guide and movable cutter head slide) will be designed from scratch this year.

"Ultimately we will then be able to offer the same maximum flexibility in the smallest machine class as we have only been able to do with larger machines to date," says Dr. Hansjörg Geiser, head of gear cutting machinery development and design engineering at Liebherr-Verzahntechnik GmbH in Kempten (Germany), in summary.

For more information:
Liebherr Gear Technology, Inc.
Phone: (734) 429-7225
www.liebherr.com

Index

DEVELOPS NEW GENERATION OF G200 TURN-MILL CENTERS

Index has developed a new generation of its successful turn-mill center G200, a compact machine offering significantly higher performance — potentially up to 30 percent greater productivity — in the same footprint as the earlier generation. The redesign of the machine resulted in an increase of the maximum turning length to 660 mm, a higher performance milling spindle, and expanded live tool complement as well as the XPanel with i4.0 readiness. The result is a machine that is geared to the needs of the market, offering flexibility and high-speed machining of both bar stock and chuck parts complete in one setup.

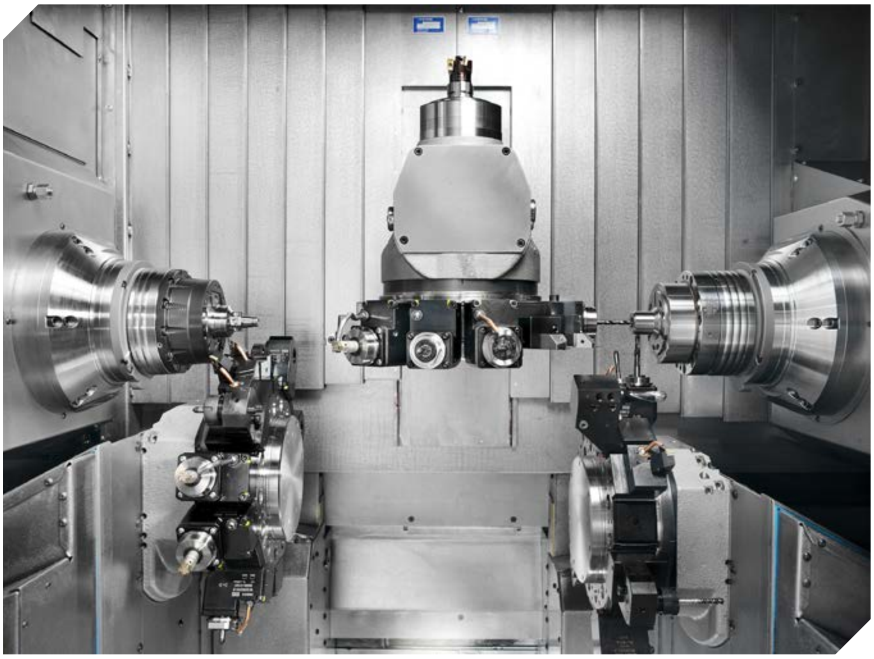
The machine bed is arranged vertically, making the machine stand higher, but extending in the work area, thus permitting second lower tool carrier to increase the productivity of the machine. Reducing cycle times by 30 percent compared to the first G200 generation is well within the bounds of possibility with appropriate workpieces, according to Index.

The fluid-cooled main and counter spindles are designed identically and feature a bar capacity of 65 mm (chuck diameter max. 165 mm). Their motorized spindles allow productive turning machining with a power of 31.5/32 kW (100%/40% duty cycle), a torque of 125/170 Nm and a maximum speed of 6,000 rpm.

The G200 has three tool carriers so tools can be assigned to almost any machining type on the main and counter spindles independently. This means great flexibility for the programmer in organizing the machining steps.

Due to the large work area, it is even possible to work with three turrets simultaneously on the main spindle or counter spindle, without them interfering with each other. One example: the lower right turret with an angular tool can machine the inside of a workpiece clamped in the main spindle, while the other lower turret and the upper tool carrier machine the outside. The same is also possible on the counter spindle. This increases the possibilities to use three cutting edges simultaneously, in some cases even four tools.

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




What's Up?
KX 260 DYNAMIC
Gear Center
A patented design with inverted spindle
• saves on investment
• saves on floor space
• saves on setup time
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ZULÄSSIG NUR FÜR GESCHLOSSENEN ARBEITSBEREICH
T1-300X160X145
MAX. 80 M/S
KAPP NILES
KX 260 DYNAMIC

2017 State of the Gear Industry

Reader Survey Results

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

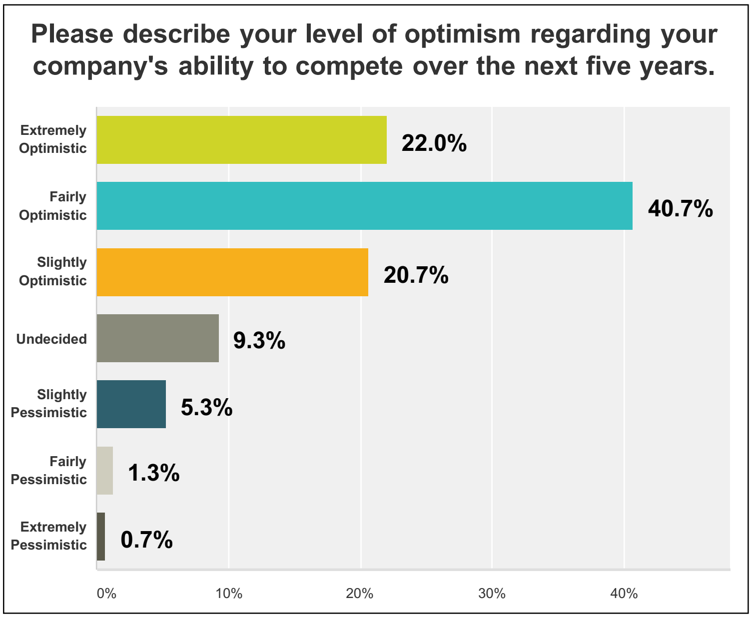
As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear manufacturing companies around the world.

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

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

Gear Industry Optimism

As usual, the gear industry is generally optimistic about its future. Over the past 10 years, our surveys have shown that about 88% of all respondents are optimistic about the future. This year is no different, with 83.4% showing some level of optimism. Of particular note this year is that among the optimistic, there was a shift toward "Extremely Optimistic" and "Fairly Optimistic". There are also fewer pessimists (7.3%) in 2017 than there were last year (12.5%).



Significant Business Challenges

More than ever, the theme of this year seems to be the difficulty in finding skilled labor. Here's a sampling of what respondents say are the most significant business, manufacturing and engineering challenges facing them today.

"Finding skilled labor."

"Increasing efficiencies."

"Limited factory footprint."

"Incorporating new technologies and products."

"Development of new technologies."

"Political uncertainty and being able to access a high level of skill."

"Marketing."

"Long procurement lead time."

"Cost competitiveness, technology obsolescence and improved flexibility."

"Rising cost of labor, materials and logistics."

"New production plant and new product line."

"Batch size fragmentation, increased number of products and therefore higher business complexity. Being able to develop new parts in a very short time (less than four months)."

"Keeping up with the work."

"Costs at low volumes."

"Staying competitive."

"Securing the quality of products, developing new parts."

"Finding skilled, multifunctional engineers."

"Doing more with less."

"Finding or developing skilled workers."

"Better throughput, better shop management."

"Skilled young engineering talent."

"Skilled labor. Gear experience is like no other."

"Automation."

"Transfer of product overseas due to currency fluctuation."

"Industry 4.0."

"Employee training, adding automation."

"Obtaining and keeping good engineers."

"Insane amount of quality requirements and audits.

Employment

Gear industry employment definitely took a turn for the worse in 2016, but the outlook for 2017 is more promising. 38% of respondents expect their companies to increase staff this year. Only 15% are expecting a decrease.

Finding competent employees."

"Talent."

"Shifting production around to different facilities and/or external suppliers."

"Budget constraints are very limiting to developing new designs/products."

"Lack of people."

"Increased foreign competition."

"Improve the engineering department to reduce the lead time of new gears."

"Increasing skilled workforce to meet customer demand."

"Skilled labor."

"Insurance expert working hard due to migration out of country."

"Keeping present equipment running smoothly."

"Manufacturing and product innovation."

"Finding engineering and trained/skilled labor."

"Productivity and new product development."

"Maintaining and training adequate labor."

"Finding and retaining good help. The quality of help is diminishing."

"Cost reductions."

"Employee training. Adding automation."

"Quality."

"Finding skilled labor."

"Short delivery time for highly customized products. Customer hesitates for months and then suddenly wants it in a short time."

"Increasing product range."

"Cut costs with increased productivity."

"Need to replace/modernize equipment."

"Cost reduction."

"Low tolerances."

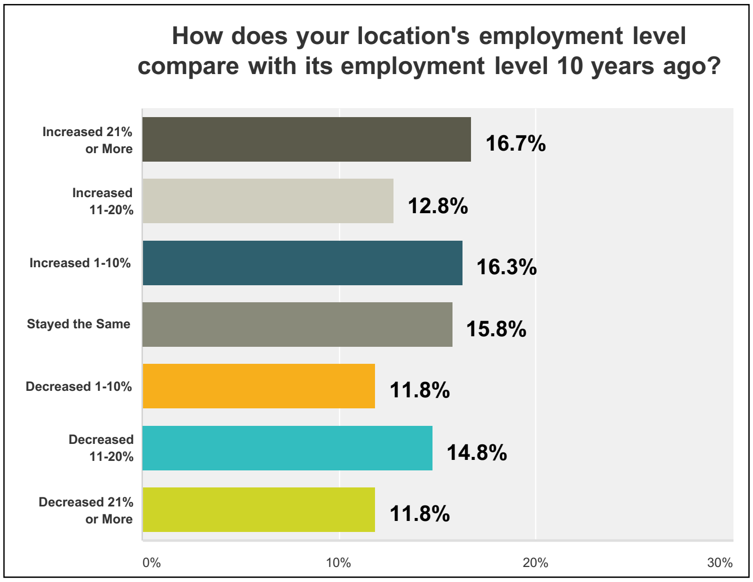
"Increasing efficiency."

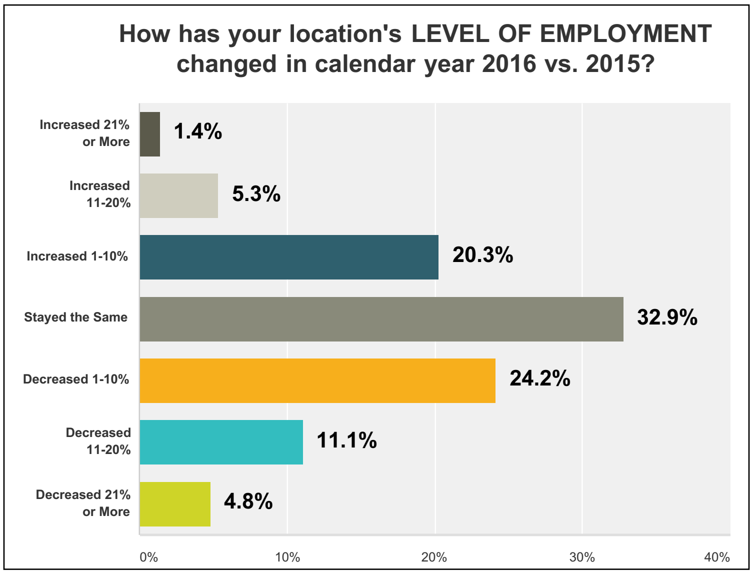
"Insane amount of quality requirements and audits. Finding competent employees."

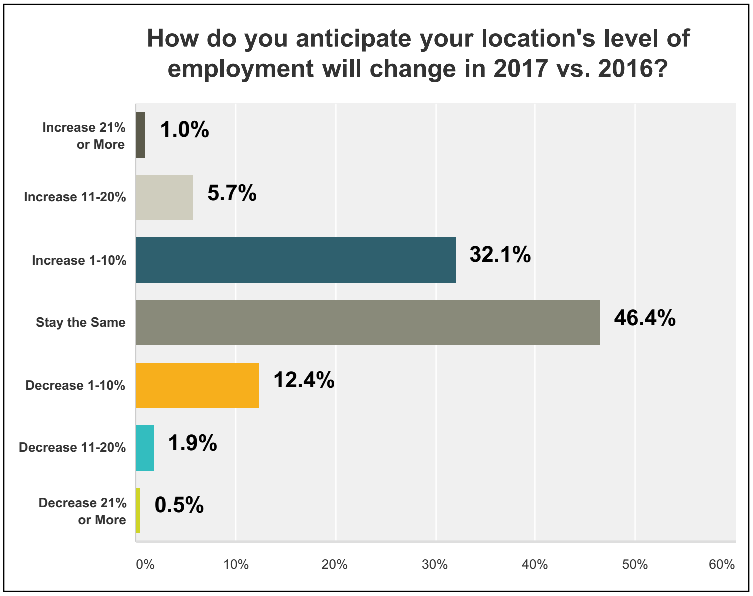
"Hiring a good mechanical technician."

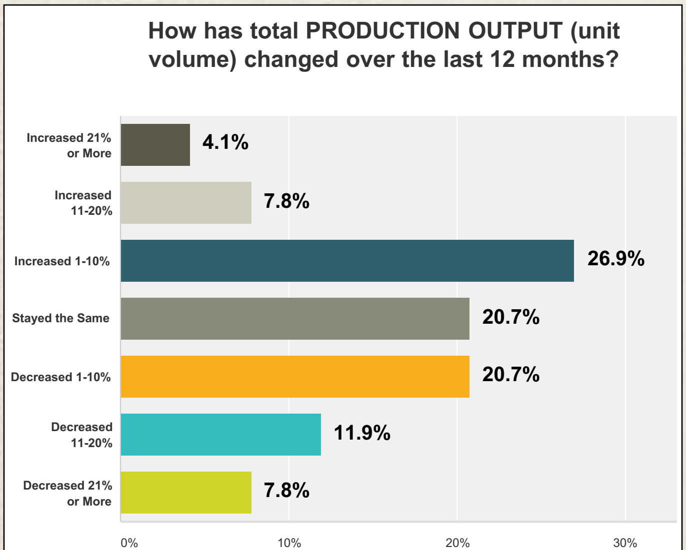
"Talent."

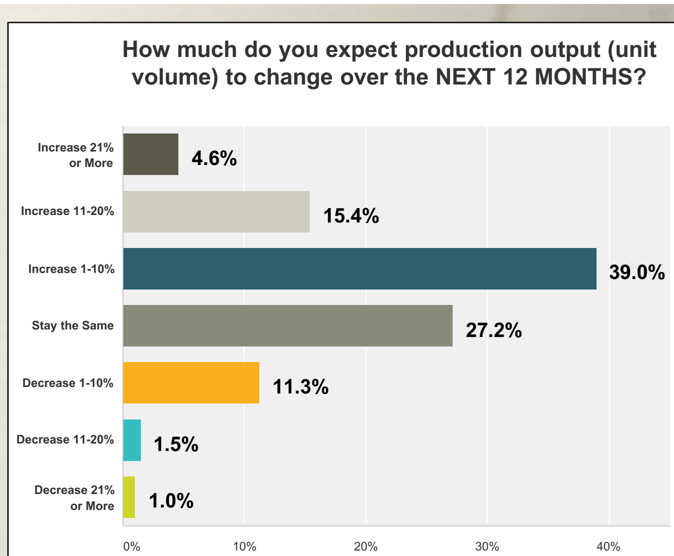
"Lack of capital to purchase new technology."

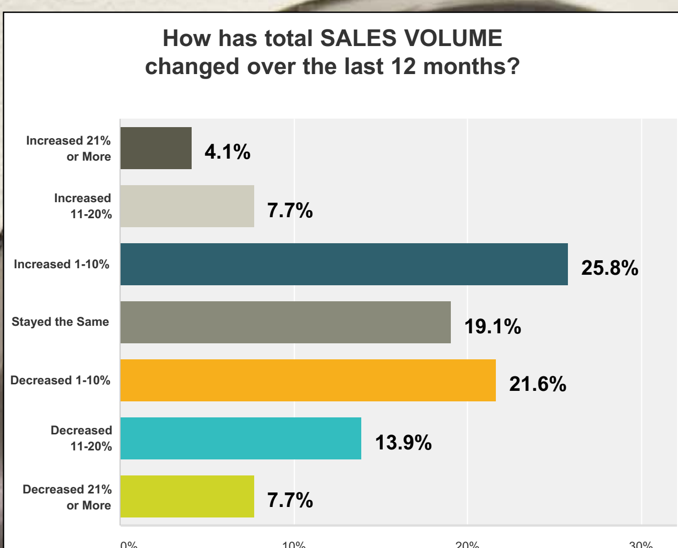


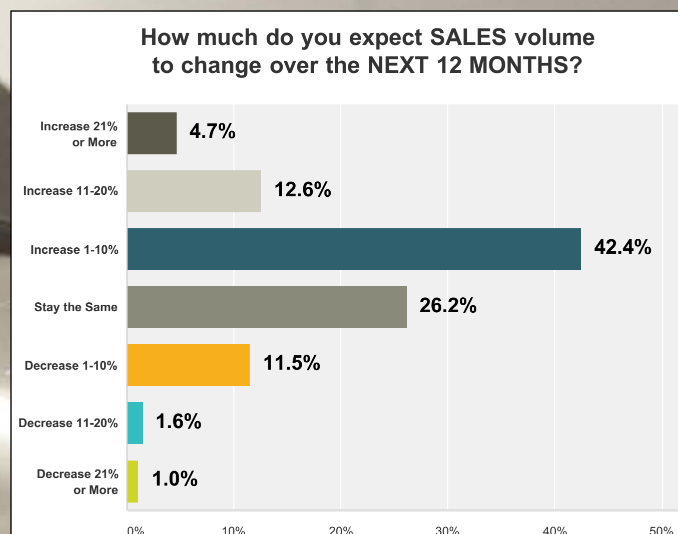


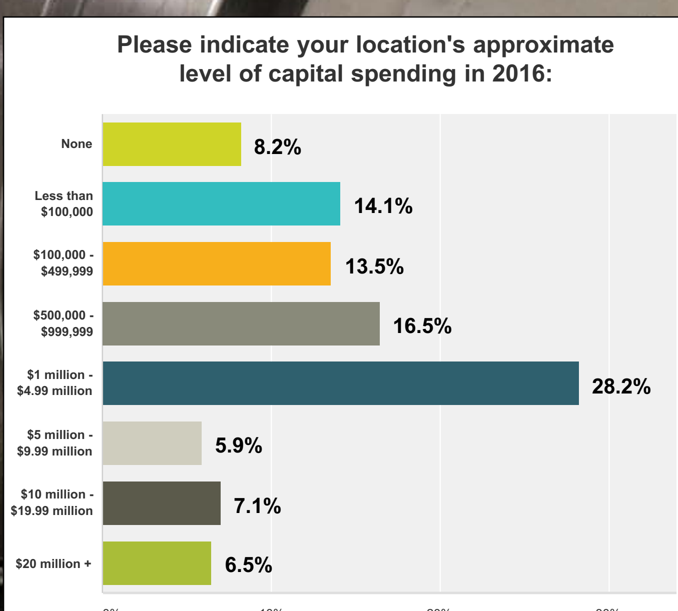


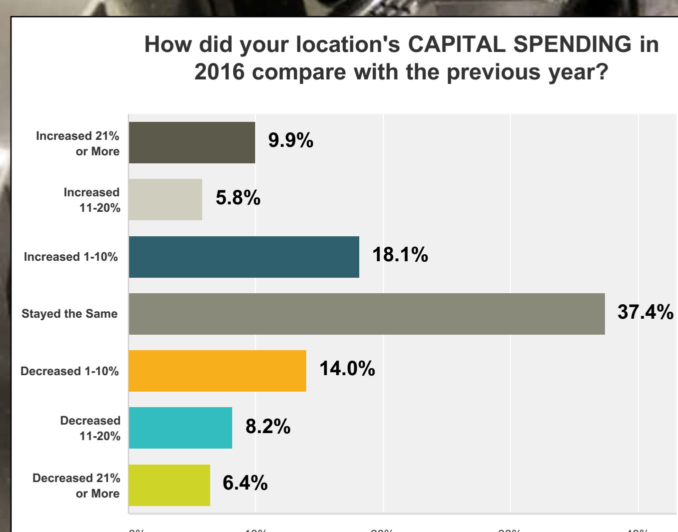

How has total PRODUCTION OUTPUT (unit volume) changed over the last 12 months?
Increased 21% or More 4.1%
Increased 11-20% 7.8%
Increased 1-10% 26.9%
Stayed the Same 20.7%
Decreased 1-10% 20.7%
Decreased 11-20% 11.9%
Decreased 21% or More 7.8%
0% 10% 20% 30%

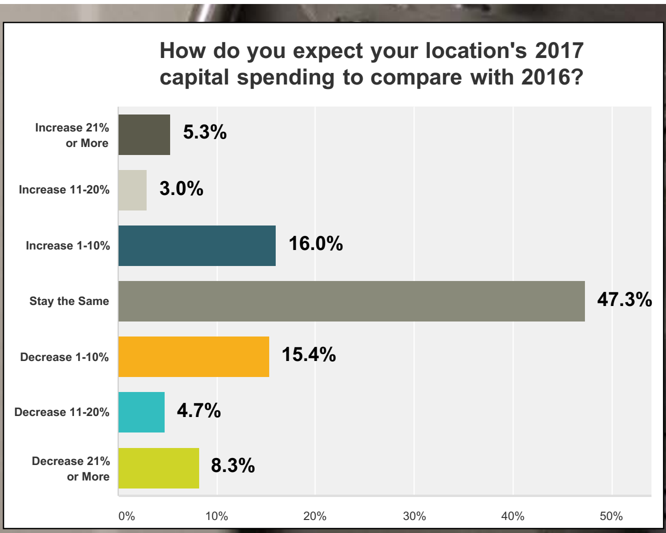

How much do you expect production output (unit volume) to change over the NEXT 12 MONTHS?
Increase 21% or More 4.6%
Increase 11-20% 15.4%
Increase 1-10% 39.0%
Stay the Same 27.2%
Decrease 1-10% 11.3%
Decrease 11-20% 1.5%
Decrease 21% or More 1.0%
0% 10% 20% 30% 40%


How has total SALES VOLUME changed over the last 12 months?
Increased 21% or More 4.1%
Increased 11-20% 7.7%
Increased 1-10% 25.8%
Stayed the Same 19.1%
Decreased 1-10% 21.6%
Decreased 11-20% 13.9%
Decreased 21% or More 7.7%
0% 10% 20% 30%


How much do you expect SALES volume to change over the NEXT 12 MONTHS?
Increase 21% or More 4.7%
Increase 11-20% 12.6%
Increase 1-10% 42.4%
Stay the Same 26.2%
Decrease 1-10% 11.5%
Decrease 11-20% 1.6%
Decrease 21% or More 1.0%
0% 10% 20% 30% 40% 50%

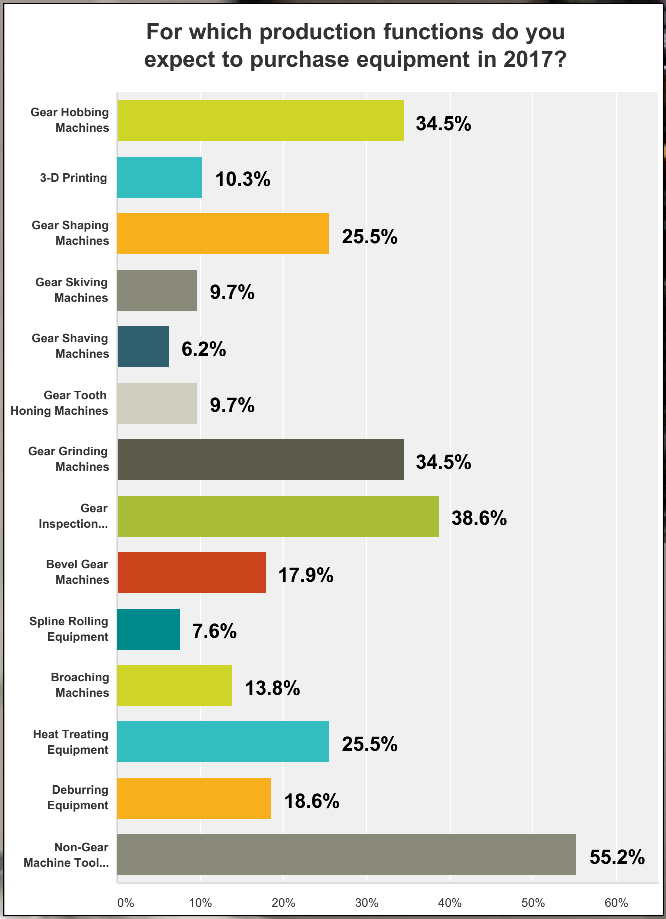

Please indicate your location's approximate level of capital spending in 2016:
None 8.2%
Less than $100,000 14.1%
$100,000 - $499,999 13.5%
$500,000 - $999,999 16.5%
$1 million - $4.99 million 28.2%
$5 million - $9.99 million 5.9%
$10 million - $19.99 million 7.1%
$20 million + 6.5%
0% 10% 20% 30%


How did your location's CAPITAL SPENDING in 2016 compare with the previous year?
Increased 21% or More 9.9%
Increased 11-20% 5.8%
Increased 1-10% 18.1%
Stayed the Same 37.4%
Decreased 1-10% 14.0%
Decreased 11-20% 8.2%
Decreased 21% or More 6.4%
0% 10% 20% 30% 40%



Capital Spending

The majority of respondents expect to see little change in capital spending versus last year, although more expect to cut back (28.4%) than expect to increase (24.3%).



More gear industry companies will be investing in 3-D printing in 2017 than will be investing in skiving machines, shaving machines, gear tooth honing machines and spline rolling equipment. Hobbing, shaping, grinding and inspection remain the most significant gear manufacturing technologies.

Capital Spending

78% of respondents work at locations that spent more than $100,000 on capital equipment in 2016.

48% work at locations that spent more than $1,000,000.

29% of respondents' companies spent less than last year.

34% of respondents' companies spent more

66% of respondents expect to spend the same as 2016 or more in 2017.

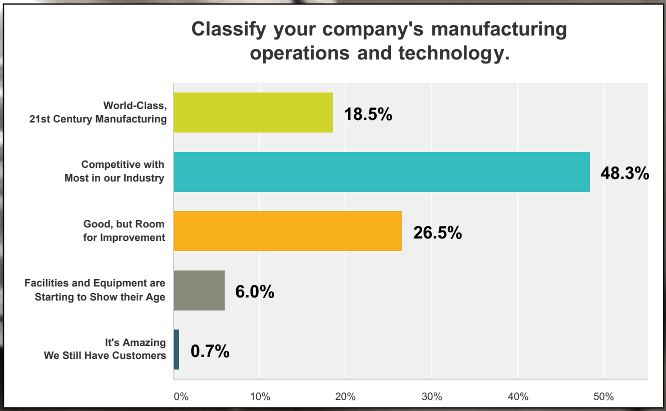
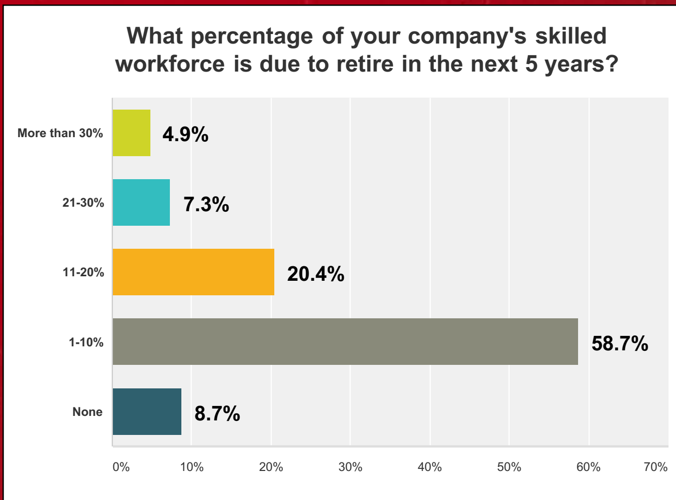
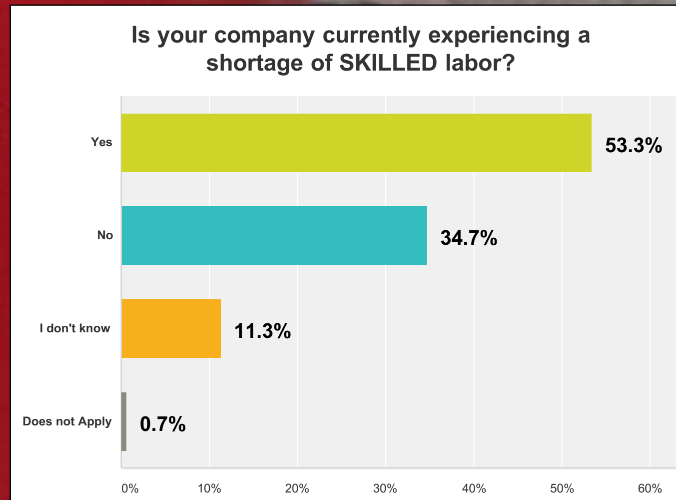
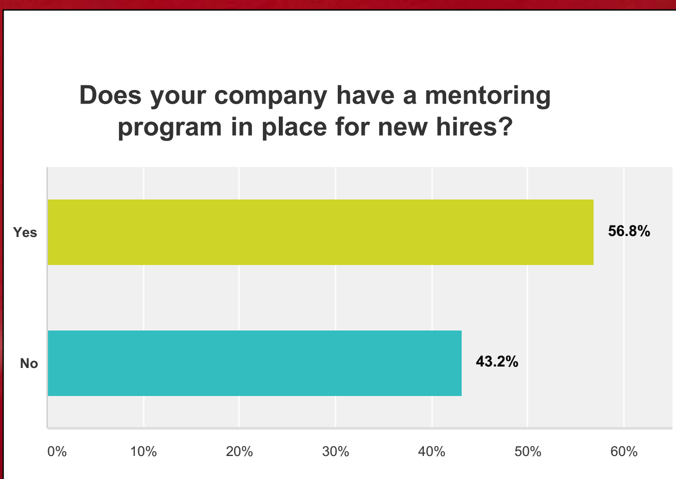


Photo by David Ropinski







Skilled Labor

53.3% of respondents indicated their companies' are experiencing a shortage of skilled labor. Although this number is smaller than last year (64%), it remains one of the hot topics in the gear industry and in manufacturing at large. It was one of the most frequently mentioned challenges cited by survey respondents.

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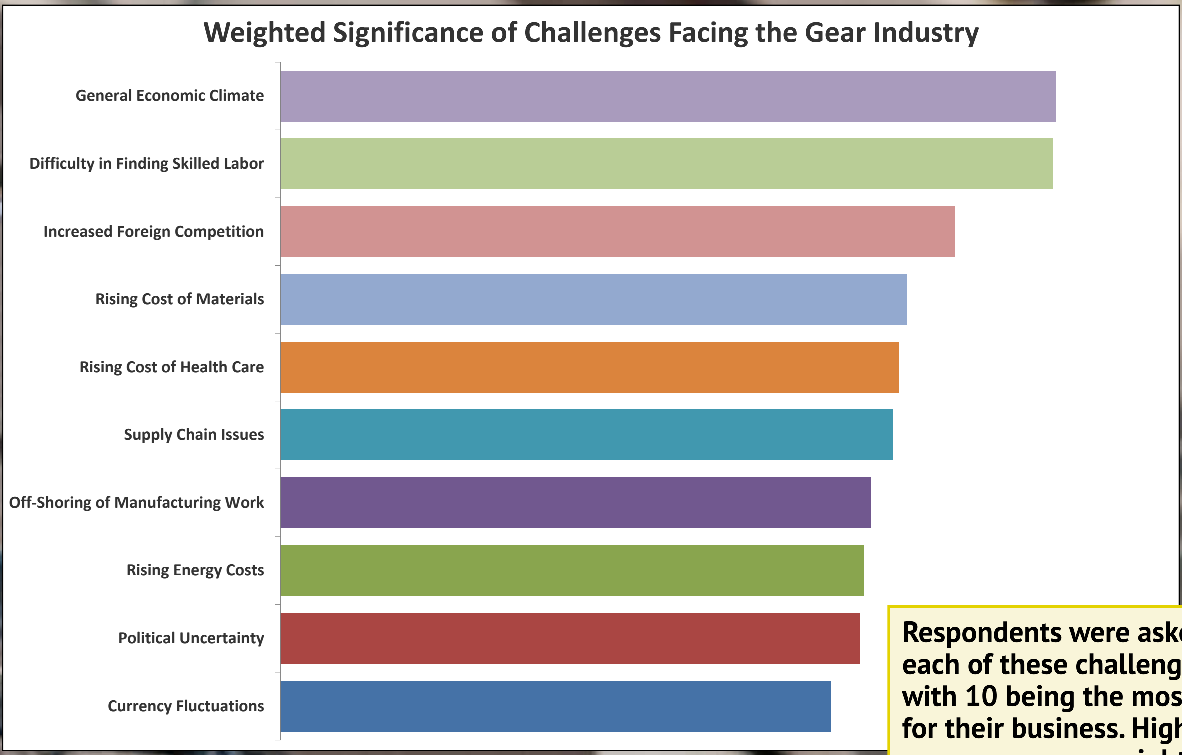


Respondents were asked to rank each of these challenges from 1-10, with 10 being the most challenging for their business. Higher-ranked responses were weighted accordingly to determine the challenges that are most significant overall to the greatest number of respondents.

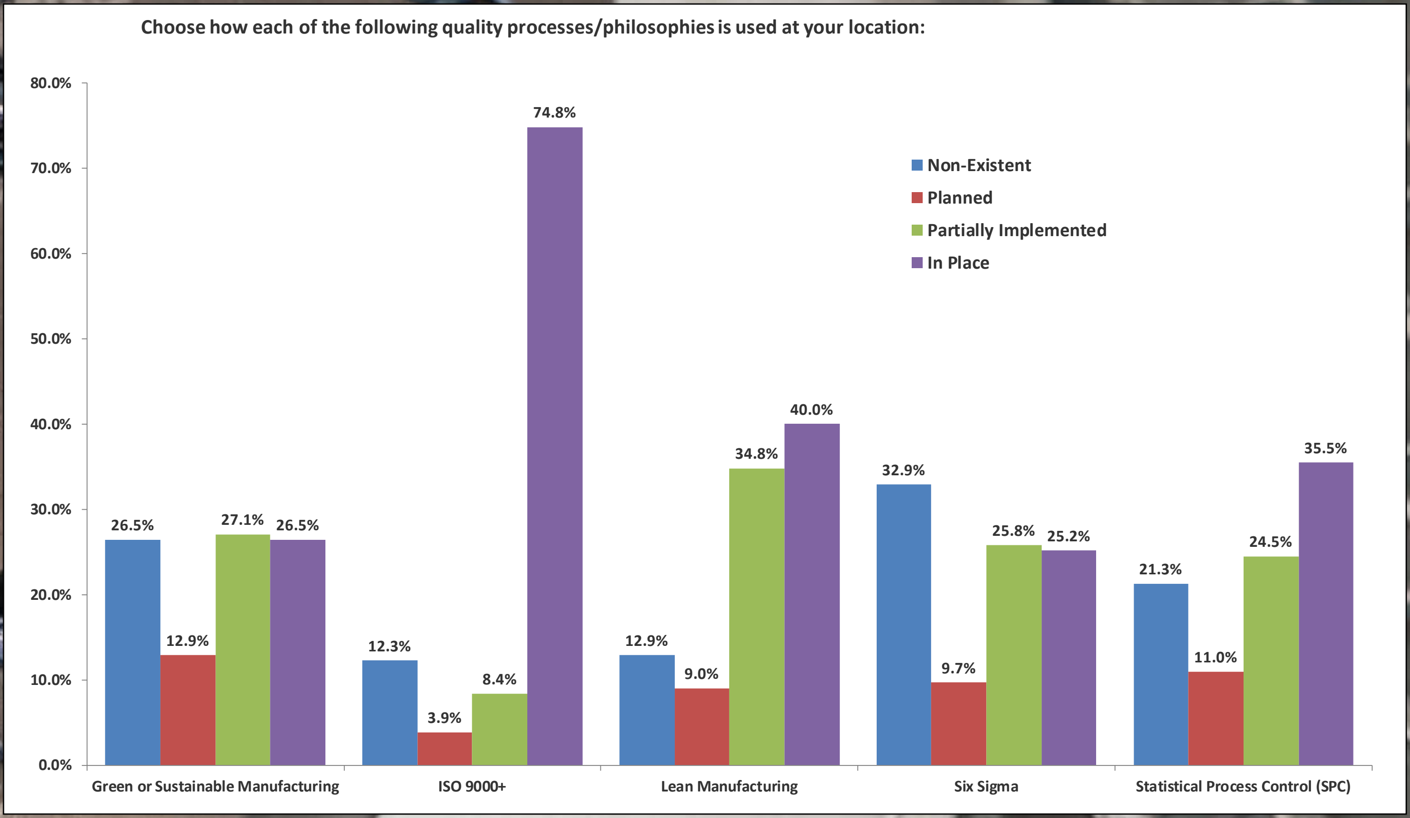
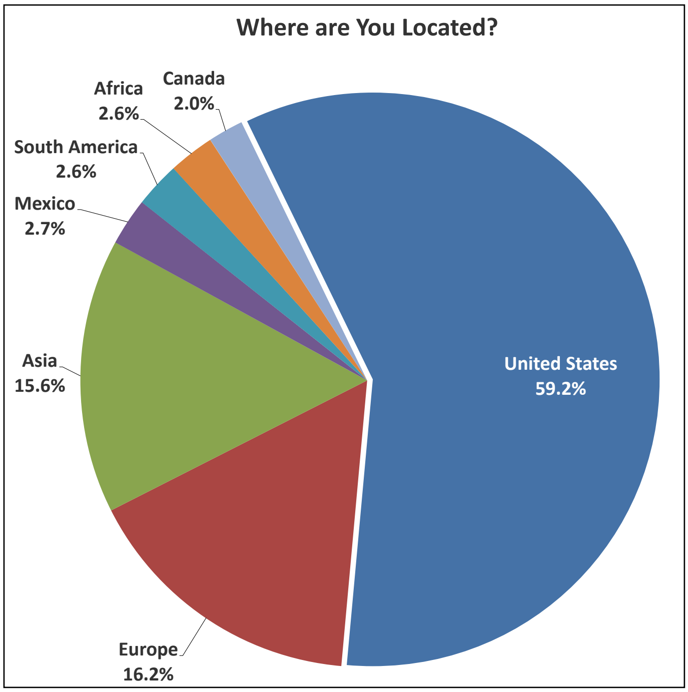
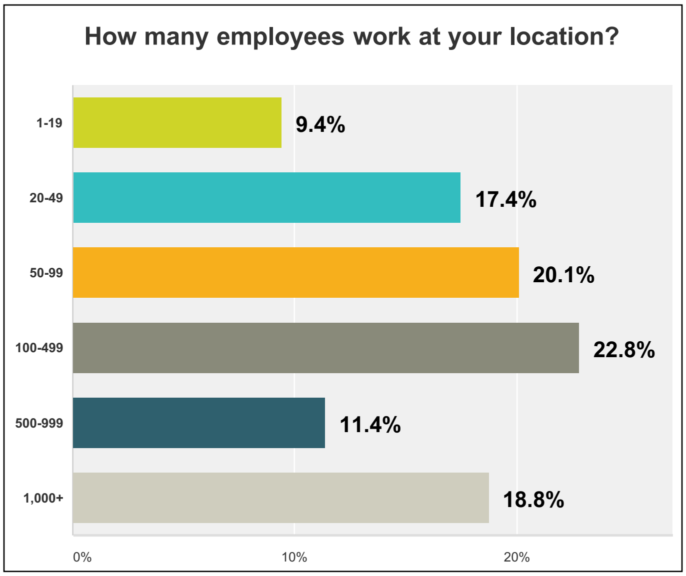
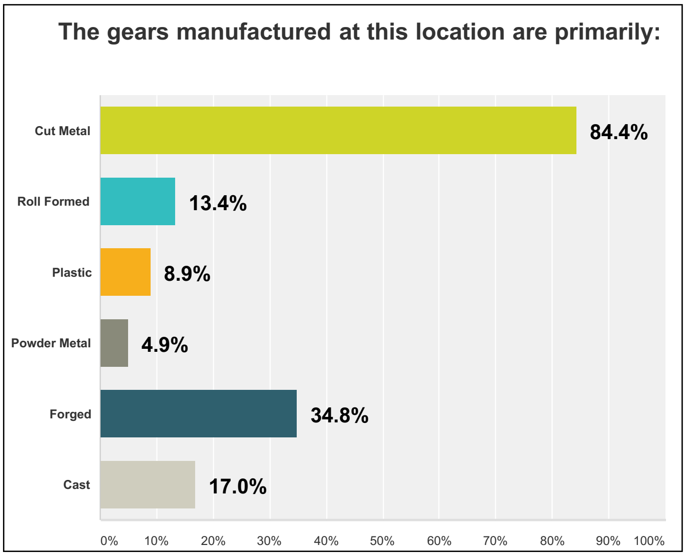
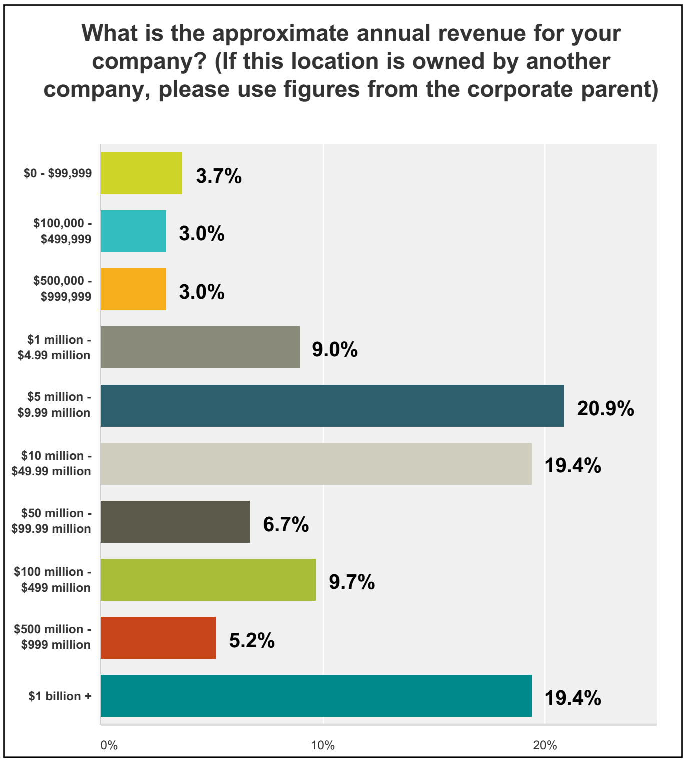


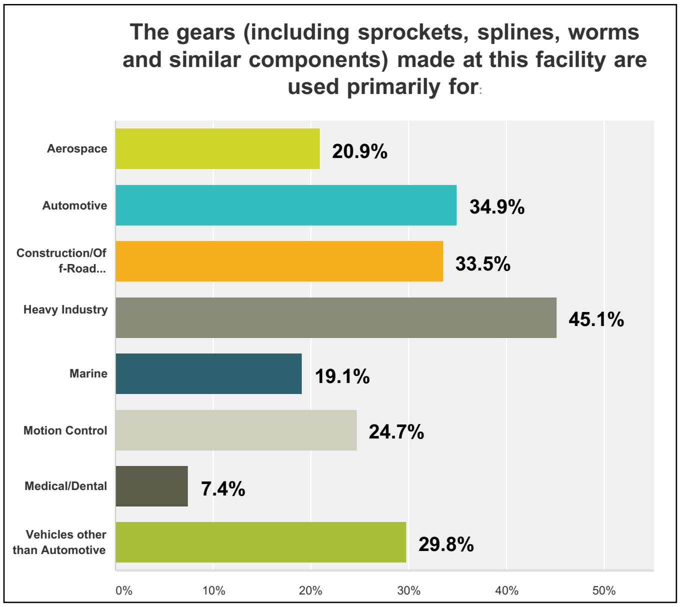
Photo by David Ropinski

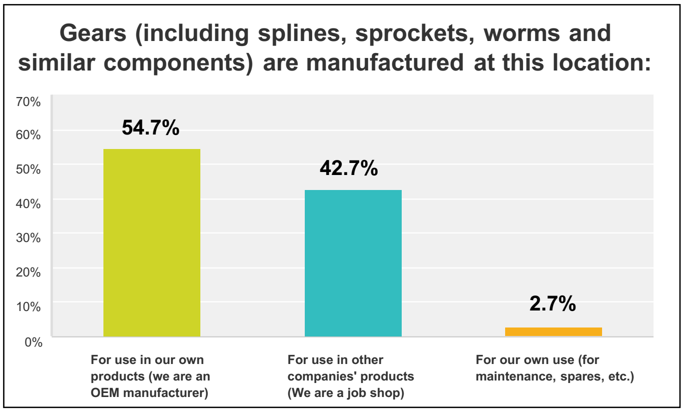

Where are You Located?
Canada 2.0%
Africa 2.6%
South America 2.6%
Mexico 2.7%
Asia 15.6%
United States 59.2%
Europe 16.2%


How many employees work at your location?
1-19 9.4%
20-49 17.4%
50-99 20.1%
100-499 22.8%
500-999 11.4%
1,000+ 18.8%
0%
10%
20%


The gears manufactured at this location are primarily:
Cut Metal 84.4%
Roll Formed 13.4%
Plastic 8.9%
Powder Metal 4.9%
Forged 34.8%
Cast 17.0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%


What is the approximate annual revenue for your company? (If this location is owned by another company, please use figures from the corporate parent)
$0 - $99,999 3.7%
$100,000 - $499,999 3.0%
$500,000 - $999,999 3.0%
$1 million - $4.99 million 9.0%
$5 million - $9.99 million 20.9%
$10 million - $49.99 million 19.4%
$50 million - $99.99 million 6.7%
$100 million - $499 million 9.7%
$500 million - $999 million 5.2%
$1 billion + 19.4%
0%
10%
20%


The gears (including sprockets, splines, worms and similar components) made at this facility are used primarily for:
Aerospace 20.9%
Automotive 34.9%
Construction/Off-Road... 33.5%
Heavy Industry 45.1%
Marine 19.1%
Motion Control 24.7%
Medical/Dental 7.4%
Vehicles other than Automotive 29.8%
0% 10% 20% 30% 40% 50%


Gears (including splines, sprockets, worms and similar components) are manufactured at this location:
70% 60% 50% 40% 30% 20% 10% 0%
54.7%
42.7%
2.7%
For use in our own products (we are an OEM manufacturer)
For use in other companies' products (We are a job shop)
For our own use (for maintenance, spares, etc.)

Slow and Steady

Gear Industry Focuses on Productivity, Quality and Innovation in 2017

Matthew Jaster, Senior Editor

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state of the gear industry
at www.geartechnology.com

The results of our Annual State of the Gear Industry Survey (See page 26) provided insight on 2016 as well as forecasts for 2017. We received feedback from nearly 300 gear manufacturing professionals for the online survey.

If you're a fan of political theater, congratulations 2016 was YOUR year. After a nasty, controversial election cycle, a new administration is taking over in Washington D.C. The presidential election came up as an answer to several survey questions including Reason for Change in Production in 2016, Reason for Expected Change in Production in 2017 and Reason for Expected Change in Employment in 2017. Some merely cited the elections in general, while others felt that an increase in production will come courtesy of one word: Trump.

Looking at production output, 2016 was strikingly similar to 2015. For many of our respondents, production output was either a little better (25 percent saw a production increase between 1–10%), a little worse (21 percent saw a production decrease between 1–10%) or it stayed the same according to 20 percent of those surveyed.

And this seems to mirror the overall state of gear manufacturing today. Many believe that 2017 will be better than 2016, but only by the slightest of margins. AGMA President Matt Croson said that the AGMA tracked 11 gear markets in 2016 and only one (aerospace) was up .7 percent.

"Six of the 11 are predicted to be up in 2017, so we're coming back," Croson said. "But clearly we're coming back from a starting point that was very low."

Many of our survey participants expect modest production increases this year and 47 percent of our survey respondents work in heavy industrial markets like oil and gas, mining and construction (areas that have been hit the hardest economically).

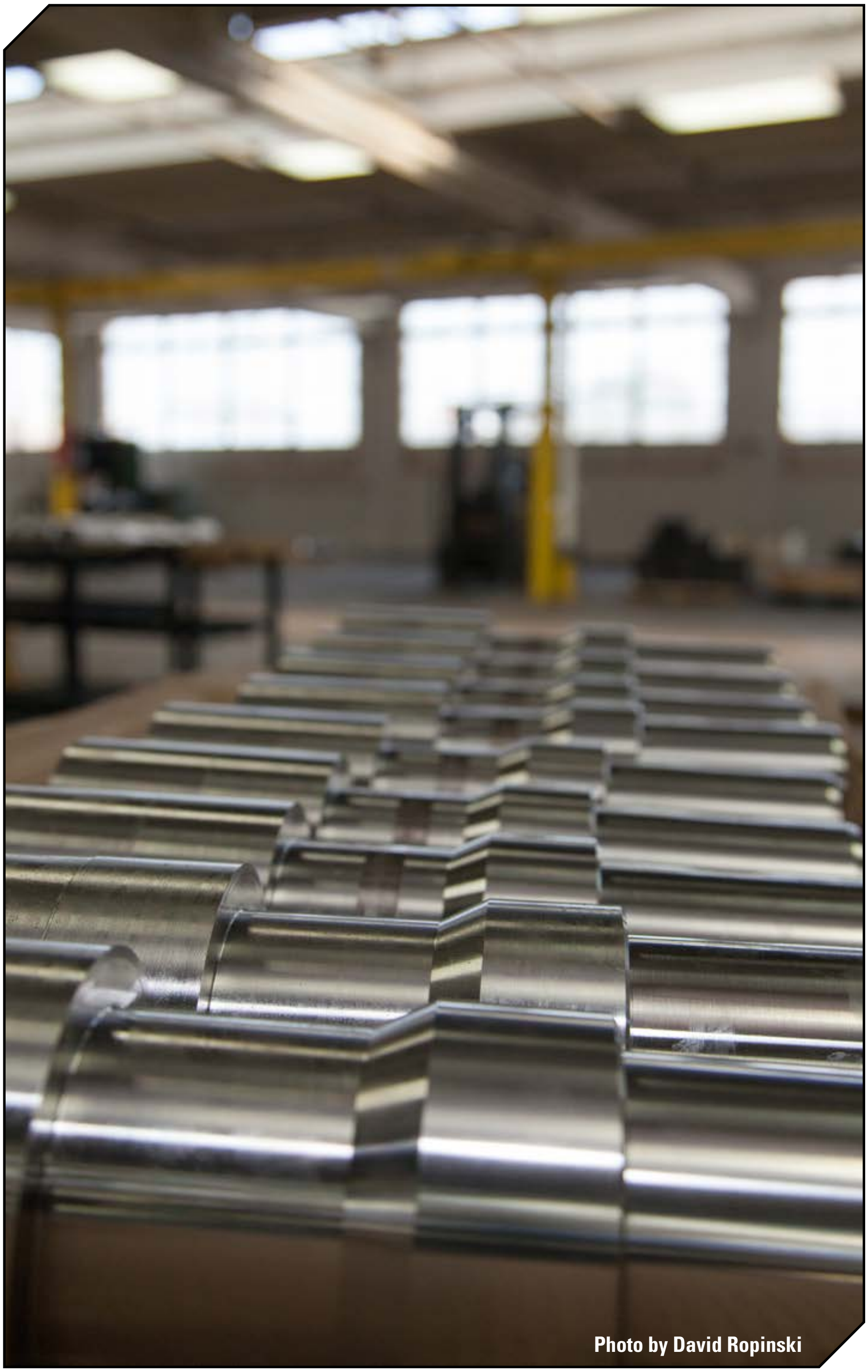


Photo by David Ropinski

The overall consensus regarding 2017 comes down to two keywords: innovation and productivity. As manufacturing production slowly increases here and abroad, gear manufacturers would be wise to stay on top of megatrends like the Industrial Internet of Things (IIoT), additive manufacturing, robotics and emerging alloys and new materials.

All of these trends could play a much larger role in our industry in the next 3-5 years. They're also emerging technologies that organizations like the AGMA will be monitoring for its members moving forward.

In addition to our reader's survey, *Gear Technology* caught up with representatives from Gleason, Liebherr, AGMA, Koepfer and EMAG to share their thoughts on the current state of gear manufacturing, plans for Gear Expo and modest expectations for 2017.

John J. Perrotti, Gleason Corp.

We are cautiously optimistic for 2017 even though overall demand for gear equipment has not seen growth in the past two years. We expect that pro-business policies in the United States may stimulate new demand which can help lift demand in other global markets. Also investments in infrastructure and energy policies both in the United States and abroad can help the recovery of many industries which have been depressed the past few years.

One of the key challenges will be the successful market launch of many of the new products and technologies we introduced in 2016. At IMTS, we displayed several of these new solutions including our new *GEMS* gear design software, our 260GX double spindle threaded wheel grinder, Genesis 400HCD hobbing machine with integrated chamfer cutting capability, 300PS power skiving machine for the hard finishing of internal gears, 300GMSL multi sensor inspection machine which opens a new era of gear measurement and the 500CB automated cutter build machine. These are all designed with potential to implement as part of a machine systems approach and deploy our Gleason 4.0 solutions to integrate into a digital manufacturing environment.

Trends within gearing are largely shaped by the end-markets that we serve. The electrification of vehicles, robotics, renewable energy to name a few megatrends that are driving different gear forms, power, efficiency and noise requirements all with the expectation of lower cost and consistent quality.

Trends within manufacturing are more integrated manufacturing systems and use of increased data to optimize production processes. Gleason is building our future strategies around these trends with fully automated, integrated machine systems complete with closed loop capabilities to create a highly efficient and precise gear-making capability.

When the industry meets at Gear Expo this year our solutions will provide the gear community the capabilities to remain competitive with the evolution of new power transmission requirements. We expect continued focus on gear design and the linkage to the manufacturing process, hard finishing of gears, elimination of idle times through automation and integration of secondary operations and digital manufacturing or what we refer to as Gleason 4.0. Gleason will have all of these solutions on display.

In order to be successful in the future we must innovate at an even faster rate. Education is the foundation for rebuilding and becoming once again the leader in the creation of manufacturing technology. Certainly government can assist by lowering the operating burden that companies face in the United States and helping to promote manufacturing as a desired career path. Also continuing to develop partnerships with basic research institutions (many which are sponsored through government funding) and the private sector will be increasingly important to continuously innovate. (*www.gleason.com*)

Scott Yoders, Vice President Sales, Liebherr Gear Technology

In the world of parallel-axis gear manufacturing, Liebherr is known for techniques such as dry-hobbing, twist-free grinding, and ChamferCut. Additionally, as Liebherr makes gears for our own equipment (Liebherr cranes, construction equipment, aerospace systems, diesel engines, etc.), our state-of-the-art solutions in hobbing, shaping, gear-grinding, skiving – and automation are practical and experience based. Together with our colleagues at Wenzel for gear inspection, we are a team of manufacturing engineering professionals that can indeed provide real world gear cutting experience, and turn-key solutions, to our customer base worldwide.

Some trends we see are at the extremes of gear design, ranging from nano-level technologies, up through heavy-duty gear applications. For example, as the topology of tooth flanks is concerned, we have made developments on the micro-geometry of tooth-flank modifications. Some industry trends illustrate the effect of deviations on flank-modified gear teeth, with the aid of topological measurements (from Wenzel WGT machines). These discrepancies have an impact on load carrying capacities and noise generation. To solve this problem, Liebherr has developed a deviation-free topological (DFT) generating- grinding technique. DFT allows our Liebherr customers to correct deviations, and even give options to the design engineer -- such as Generated End Relief (GER) and Noise Excitation Optimization (NEO).

At GearExpo, Liebherr will showcase an abundance of innovations, like how we are transforming gear-skiving into a reliable process and thus creating new gear machining possibilities. We will present a small gear shaping machine, which was specifically designed for high precision shaping of small pinions and multiple gear teeth, meeting the high standard of the aerospace industry. Additionally, Liebherr will highlight new LGG- grinding arms for internal gear teeth, as well as a basic-platform gear hobbing machine for job shops.

Additionally, we would like to introduce a new colleague, who has joined the management board of Liebherr-Verzahntechnik GmbH -- Dr. Hans Gronbach. Dr. Gronbach has been the chief development and design engineering officer since June 2016, and is responsible for championing innovation. His CV includes positions in both science and business; in-depth development experience and knowledge of machine tool markets. This makes him a perfect addition to our team. He will help guide Liebherr-Verzahntechnik GmbH into a successful future and enable the company to provide the best products for the markets of tomorrow. (*www.liebherr.com*)

David Harroun, Sales Manager, Koepfer America, LLC.

I am optimistic. We had positive reaction to our products during IMTS and we are seeing a lot of activity. Automotive is supposed to weaken slightly in the next years but it is still strong and there are new programs set to launch. Other markets that use our products such as aerospace and even medical are still strong.

One of our challenges remains recruiting talent. We are growing as a company and will be adding people in sales, application engineering, and technical service. We find these positions are difficult to fill.

We need to attract younger talented people to want to have a career in the gear industry. Many knowledgeable people in this industry are getting close to retirement age. The gear industry is a highly technical field and can't be taught in a short amount of time. If we can't attract younger people to be interested enough to enter *and stay* in the industry we will have many problems as the baby boomers retire.

Our normal customer is no longer looking for a machine to produce gears. They are looking for a process, specifically a very productive process. This means that you need to be able to provide equipment, processes, and systems in order to be prepared for this challenge. We take on this challenge by continuously developing the equipment with software, special cycles, and integration of additional processes to make the machines more productive.

Furthermore, Koepfer America, brings together several European companies to be a complete gear manufacturing system supplier of hobbing, shaping, chamfering/deburring, inspection, and gear tool sharpening equipment. Additionally, we supply hob/milling cutter, gear grinding wheel/honing wheel, and sharpening service.

Most of our customers are always looking for additional training. The gear industry is highly technical and is a little more difficult to learn, unless you have access to somebody with knowledge to help you along. We have reacted to this by providing an annual gear school training program which covers manufacturing and inspection of gears. Occasionally, we will hold these schools within the customer's facility to make it easier for them.

Regarding Gear Expo 2017: The talking points are always decreasing cost with a constant desire for increasing the quality level of the components. Grinding and honing have always been very expensive processes, however, the dressers and abrasives have taken great strides to bring this cost down significantly. Furthermore, since most grinding and honing operations are influenced by the pre-hobbing, it is also incredibly important to be able to hob parts with short cycle times while producing the best quality of part. (*koepferamerica.com*)

D. Kirk Stewart, Jr., Director of Sales, EMAG

EMAG is very optimistic about the gear industry going into 2017. Many regions and industries outside of the automotive business have been slow or declining in the last two years. However, consumption of machine tools is anticipated to increase for 2017.

EMAG's "Modular Standard" product line, which was launched in 2012, is now a mature and competitive platform which allows us to compete over a much more broad market. As such, to be successful in more regions, our sales coverage must provide local, pertinent knowledge to customers which are being exposed to the inverted spindle lathe solution for the first time.

2017 will be the year of increased productivity. All of our customers strive to gain more business and retain that which they already have. Yet at the same time, finding the skilled workforce to support this growth remains a challenge. EMAG is well positioned to support manufactures in this growth mode, given the self-loading principle of the VL and VT line of machines for chucker and shaft type parts, respectively. What this means is that with the same number of operators, more EMAG machines can be running, without any lost time for loading or unloading of components.

No doubt, maintaining the knowledge base of our engineers is a key to our success. As a wholly owned subsidiary of EMAG GmbH, we regularly 'trade' resources. Meaning that when we need help in North America, as an example, it is common for our colleagues to support us from Europe (or China, India, France, etc.), and vice versa. Having standard products around the world (rather than customized regional solutions – perhaps through third-party distributors) allows us to leverage the collective knowledge of our global organization, locally.

It is a recurring talking point that there is a generational gap between those with decades of invaluable experience to that of the younger generation of manufacturing engineers. As such, we find many customers looking for companies like EMAG which are able to provide value through providing more content. This content can come in the form of providing machine tools or systems which are doing more than one technology or machine in isolation. In the case of EMAG this may translate to a cell of machines which includes turning, hobbing, induction hardening, hard turning, welding, hard milling, and finish grinding with all the required automation thereof. EMAG is one of few companies which provide such a wide range of technologies focused on core components.

I expect that the dynamic nature of our business will be energized by the recent election of Donald Trump. In the last weeks, the election results have been met positively by small business owners and the customers they serve. As such, I expect that there will be much optimism at Gear Expo and increase buying at this time. (*www.emag.com*)

Matt Croson, President, AGMA

The theme of 2017 might be doing more with less. Our members will be very cautious this year regarding hiring and machine tool investments. They're going to want to believe in the upturn and they are going to be cautious managing their cash and investments. Many are hesitant to jump back in until they really start seeing some positive results. It's going to be a slow and steady climb.

I'm optimistic now and I was optimistic before the election. The optimist in me says that under the new administration areas hit hard like mining, oil & gas and construction will finally start moving in the right direction. This administration is already talking differently about energy. It will be interesting to see

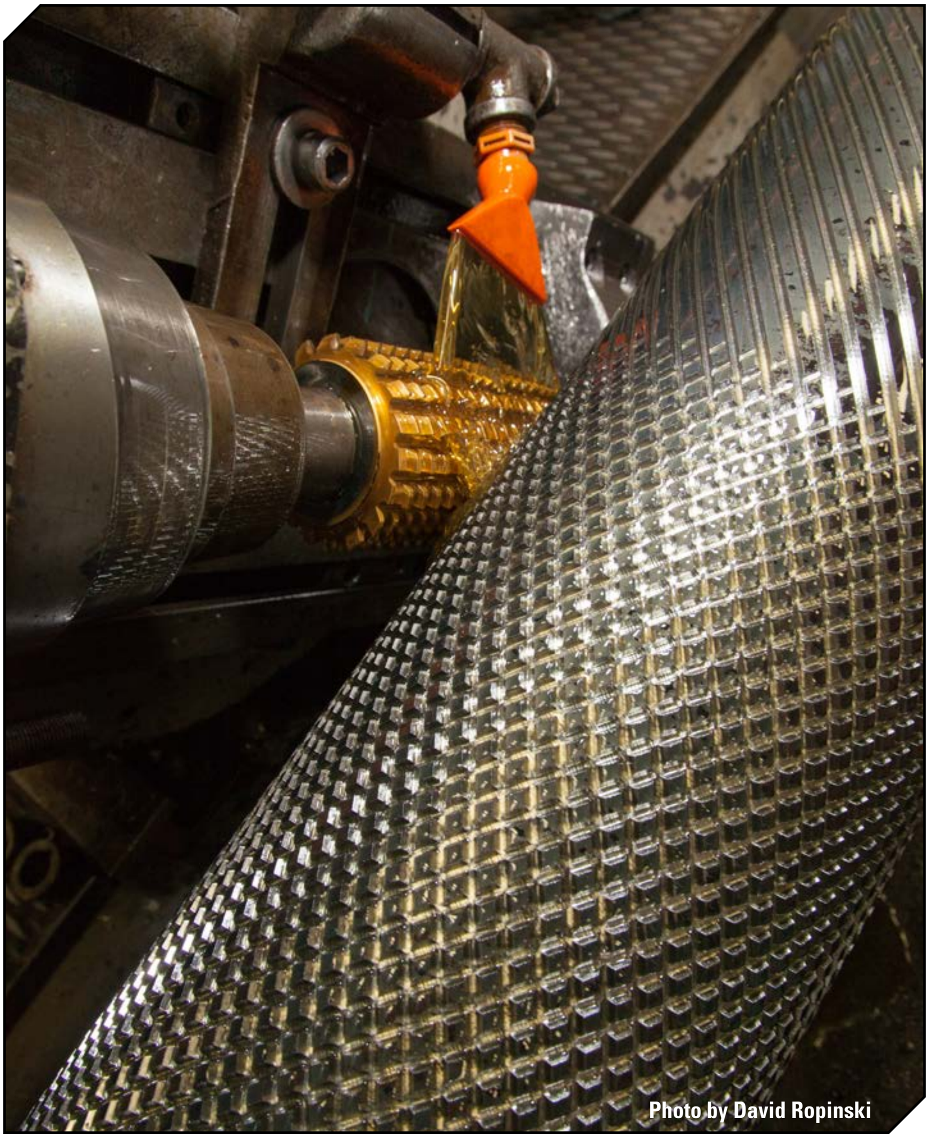


Photo by David Ropinski

how this plays out in the coming years.

We'll also see more mergers and buyouts in our industry in 2017. There are smaller companies (second and third generation owners) that might want out. They are taking the time to see what equipment they have, what products they're delivering and what their customer base looks like. I would expect to see maybe 10 to 15 companies involved in mergers and buyouts. It's not going to be a massive consolidation, but some are looking at other options.

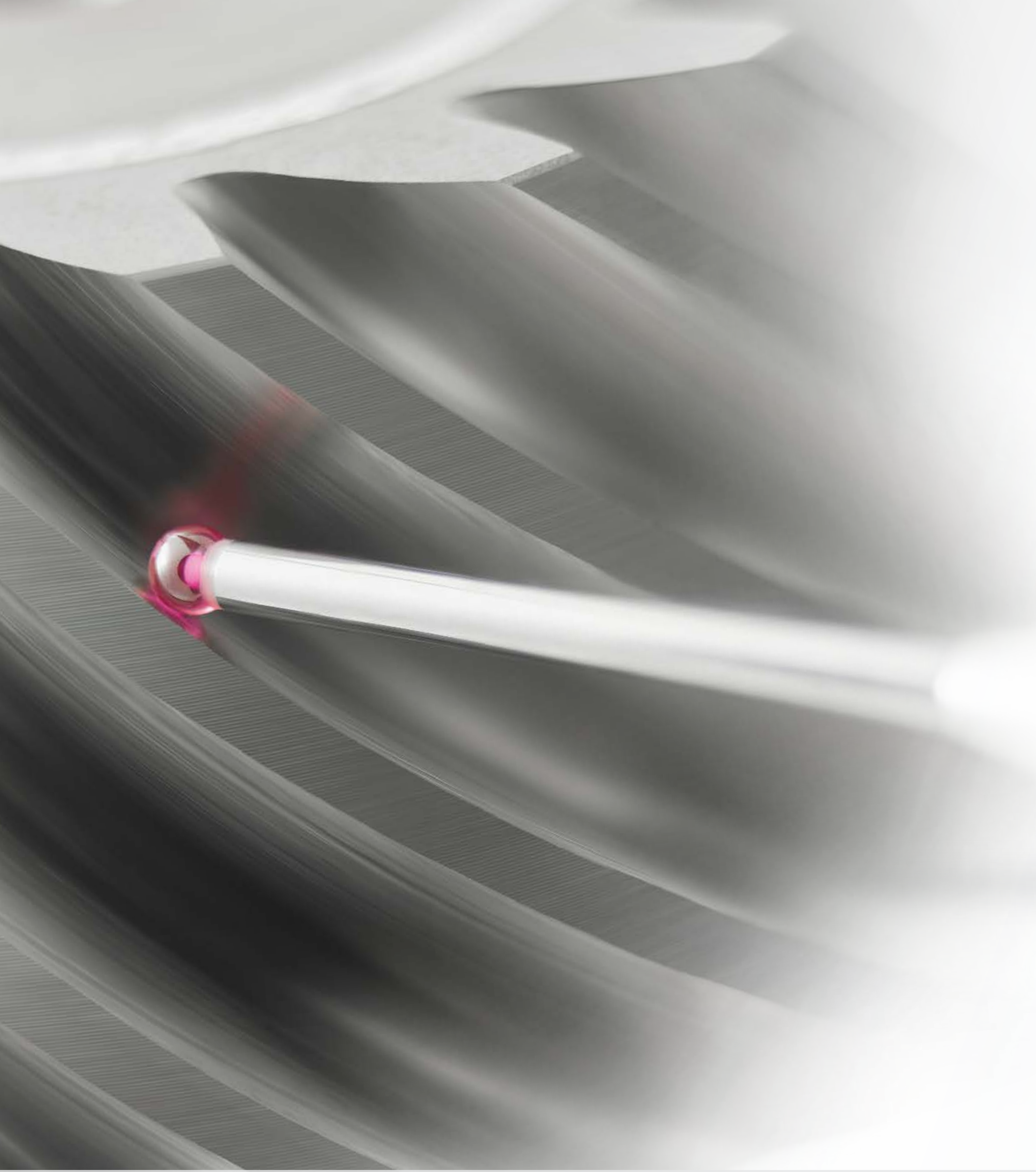
As far as emerging technologies and trends within the gear industry, the AGMA is tracking a few different areas that will be valuable to our members.

For example, we're paying close attention to additive manufacturing. It's a disruptive technology. ANSI has put together a group to look at standards development in that area. If you can make gears in a new and different way using additive, that is an interesting thing to look into. Companies like Boeing and GE are spending a ton of time examining the technology. They're looking beyond developing prototypes and determining if they can create full systems and products. It's one thing to make plastic gears this way, but if they can make gears that go into critical systems, people should really start paying closer attention to this.

Another area is the Internet of Things or Industry 4.0. We're going to have a special presentation on this at our Annual Meeting on the use of Industry 4.0 in the manufacturing sector. John Brandt, CEO of the Manufacturing Performance Institute (MPI) will deliver key findings followed by speakers from the industry and AGMA members that are successfully applying this technology today. We plan on discussing reasonable, pragmatic approaches to these systems. It could be as simple as putting a sensor at the end of your line to count the gears, but it could also be a plant where every gear, bearing and tool has a sensor of some sort that is helping companies with predictive maintenance and failure analysis.

Another trend we're keeping a close eye on is emerging alloys and new materials. We recently announced a new AGMA class in 2017 that will focus on new steels in gear applications. There are many new products and tools in the toolbox for today's engineers to leverage. Our members will need to stay on top of these changing technologies. We're seeing lighter and stronger products. Those involved in gear manufacturing are going to have to figure out what these new alloys and materials mean for their products moving forward.

Our focus now and in the future is to stand side-by-side with our members to drive power transmission innovation. This is our vision. It's exciting because it touches on the fact that our members will always be at the center point of innovation when it comes to gears. This is what they do. We have a communication role, a trade show role, with our members. Gear Expo is an example of how we can express innovation through our members. Additionally, our educational sessions, emerging technology research and online resources will benefit our members as well. (*www.agma.org*)

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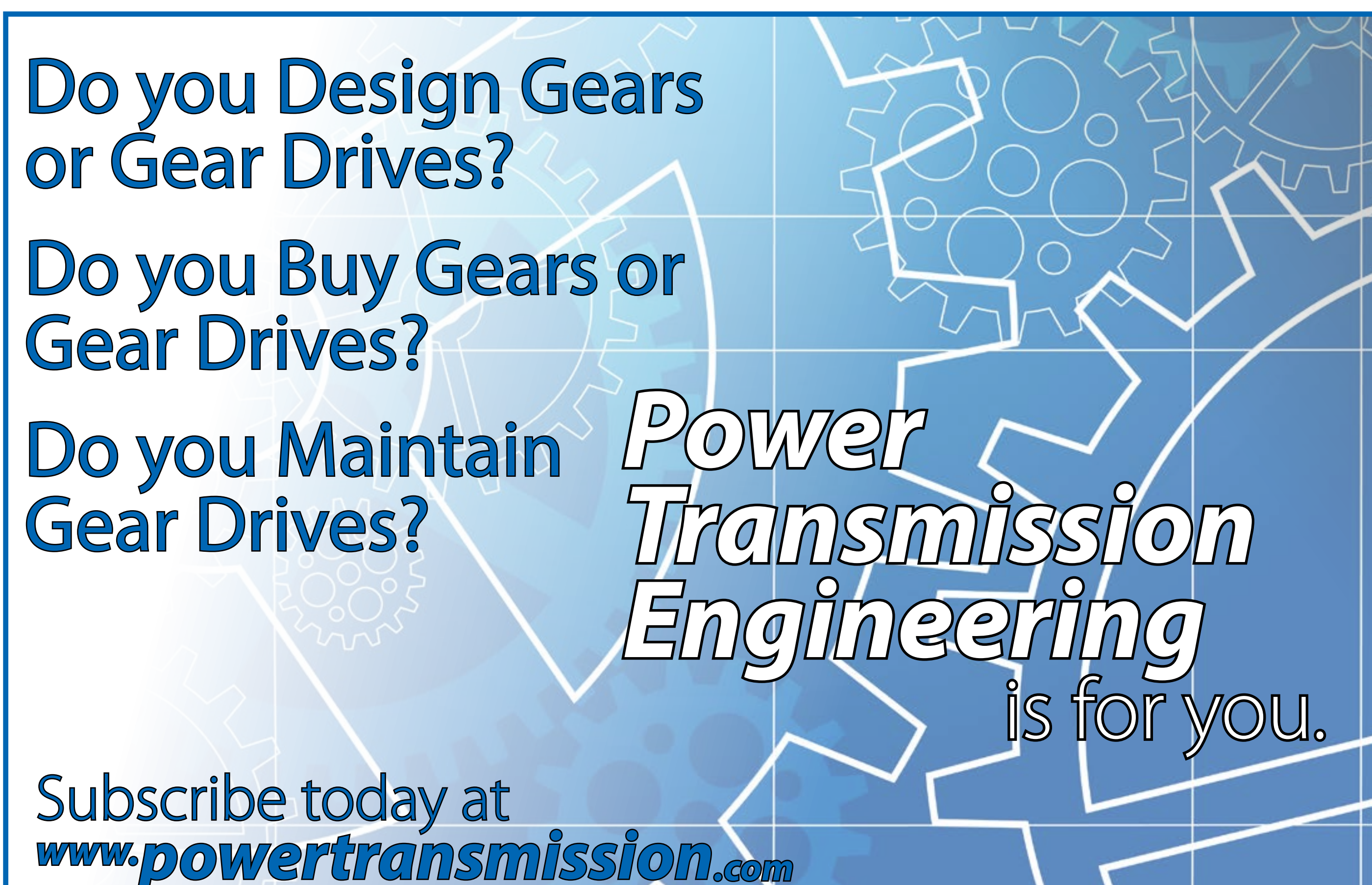
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Oil-Out Endurance Under the Lens

Oil-out durability in gears is becoming more important for the aerospace industry, prompting researchers to look for new, more powerful solutions.

Alex Cannella, News Editor

Oil-out conditions, or conditions in which an aircraft is operating without any oil in its gearbox or transmission, are devastating for an aircraft's hardware. Even the sturdiest gears usually can't last 30 minutes under such conditions before they catastrophically fail, and the whole system usually follows shortly after. That doesn't leave pilots with a whole lot of time to find a suitable location to land in the case of an oil-out emergency.

But an oil-out (or oil-off or loss-of-lubrication) incident is almost as rare as it is damaging, and so the topic falls in and out of the public eye every few years.

Currently, oil-out testing is back in vogue and research is ramping up to find ways to extend how long gears can last without oil. The military in particular is interested in extending oil-out time. In an article published this past fall, the Joint Aircraft Survivability Program (JASP) cited an increase in future aircraft's range and endurance as a primary factor in the military's increasing interest, as such improvements would lead to missions that would take military aircraft farther afield and require "corresponding improvement in loss-of-lubrication performance to enable long-distance exit from hostile areas." According to the article, NASA and the U.S. Army Research Laboratory have teamed up to study multiple potential solutions to the issue.

That alone should be enough for anyone working with the military to take notice and start looking into their own gears' oil-out performance, but it's also important to consider on the commercial side of aerospace, as well. Case in point: the 2009 crash of a Sikorsky S-92 helicopter that resulted in the deaths of the pilots along with 15 oil rig workers.

The folks over at Penn State University's Gear Research Institute (GRI) are doing their own testing for both military and commercial sponsors and are looking at different strategies to improve oil-out gear performance by targeting the root of the problem: heat.

The primary cause of failure in an oil-out incident is heat. Without any lubrication, the gears have more friction, which in turn produces more heat. The heat, in turn, has nowhere to go without any coolant to carry it away causing the gears to expand, which can result in a loss of backlash, and so on until the gears fail or seizure becomes imminent. For some gears, the whole process doesn't even take a full minute.

"There's a lot of interest in trying to understand the root cause of the failures," Aaron Isaacson, GRI's managing director, said. "And I think we understand certainly that heat generation is the problem, but fixing or even mitigating it is a challenge."

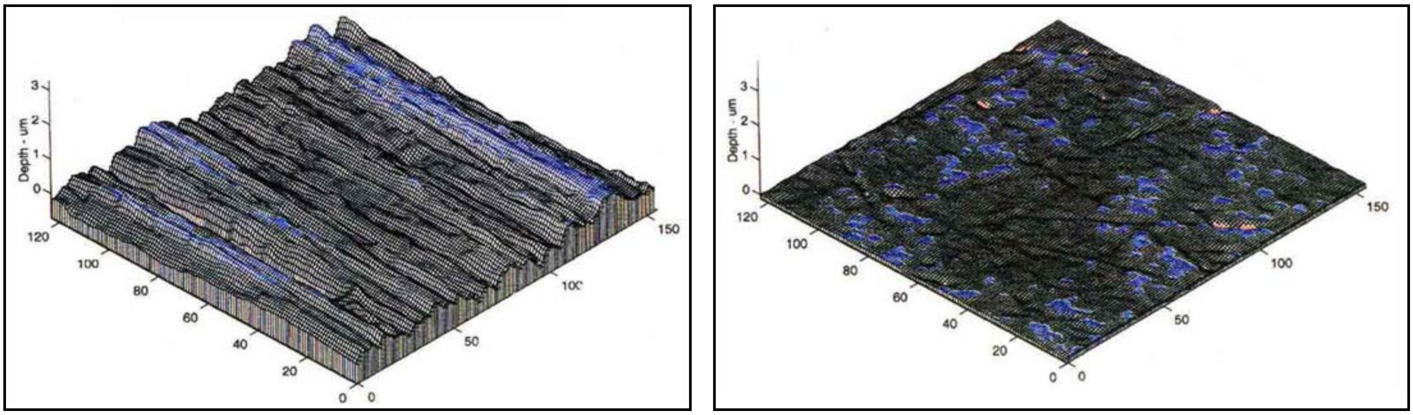
Much of the GRI's research is still in its formative stages, but in general, the institute has managed to narrow their options down to two broad approaches. One major focus is to slow the process of gear failure by reducing the friction, and thus the amount of heat, present in a gearbox without relying on lubrication.

Much of the study in this vein is looking at potential coatings, particularly the study of diamond-like carbon (DLC) coatings. DLC coatings initially popped up on GRI's radar when they were doing unrelated contact fatigue tests, but after seeing some coatings perform well there, the institute is interested in seeing if they can be applied to this new challenge.

"[Certain DLC coatings] appeared to work reasonably well, so the thought was, let's look at them in oil-out situations, as well," Isaacson said.

The other approach looks at improving a gear's oil-out durability by raising the thermal capability of the gear's material, increasing the amount of time the gear will remain operable in spite of rising friction and heat levels. Many of the steels the GRI is looking at here are newly developed alloys that temper at higher temperatures known as high hot hardness steels, which maintain their properties at temperatures well above most carburizing grades.

"We're going to accept the friction and the heat generation that occurs and real-



A machine surface finish (left) compared with an isotropic superfinish (right). Images courtesy of REM Surface Engineering.


BEFORE
AFTER

ize that we can't get rid of it," Isaacson said. "So we're going to try to deal with it and manage it in a different way by using a material that can take it, or at least take a little more of it."

Another interesting solution the GRI is looking at is a proprietary nanoparticulate oil. While Isaacson notes that the product still needs to be put to the test, the theory goes that even in an oil-out incident, the lost oil would leave a permanent film on the gear, improving lubrication in the system and extending gear durability.

"Even though the lubricant is no longer there in an oil-out situation, when it's operating, it's reacting and it's forming a tribological film on the surface of the teeth that will remain in the event of an oil-off situation," Isaacson said. "And that tribofilm will theoretically affect how the gears perform once the oil goes away."

It's also theorized that it may not be necessary to use the oil for more than a "break-in" period, lowering the cost of including oil-out protection for manufacturers.

Cost is certainly one of the GRI's chief concerns. Many potential products the GRI is studying either use expensive materials or require additional time for machining or heat treatment, something the GRI is acutely aware of.

"Cost is always a driver here," Isaacson said. "None of these are cheap solutions."

One potential solution that the GRI hasn't yet investigated is superfinishing. Ask REM Surface Engineering's Vice President, Justin Michaud, and he'll tell you that isotropic superfinishing isn't just a way to improve an aircraft's oil-out performance, but part of the future of aerospace gearing.

"REM's isotropic superfinishing process is a real technology that represents a fundamental improvement over pre-existing gear forming operations," Michaud said. "We aren't putting a coating on that might have adhesion problems or thickness irregularities. We aren't just knocking the tops off some of the peak asperities like honing and some of the more advanced super-grinding/polish-grinding machines. We are taking a distressed, periodically textured surface and polishing it to a particularly ideal state."

The list of ways REM's isotropic superfinishing process, which they've coined and trademarked as the ISF© Process, improves gear performance is extensive. Increased resistance to contact fatigue, bending fatigue and scuffing, elimination of micropitting, increased load carrying capacity/power density, reduced friction, elimination of the run-in/break-in step, increased lambda ratio, increased lubricant performance via reduced operating temperatures, reductions in structure born noise, reduced wear and improved coating adhesion are just some of the benefits REM attributes to their superfinishing technique.

That's quite a checklist of benefits that might make isotropic superfinishing sound like a cure-all that's just too good to be true, but Michaud's got the evidence to back his claims up. For example, an AGMA study found that spur gears treated with the ISF Process could run at a lubricant supply temperature 60 degrees Fahrenheit higher than ground spur gears before scuffing. In another study, isotropically superfinished gears survived 30 minutes at 400 ksi without lubrication, while ground gears failed within one minute.

The ISF Process's main benefit is that it reduces a gear's surface roughness to decrease friction between mating surfaces, but the technique's other major feature is the isotropic texture it creates, which improves contact fatigue resistance and lubricant adhesion. This improves gear durability in oil-out conditions by reducing friction and lengthening the time it takes for the gears to overheat and start breaking down.

The rest of the process's laundry list of other advantages stem from the combination of these two features. Both features, for example, improve a gear's lambda ratio, which in turn reduces how much oil is required to stay fully lubricated. With an improved lambda ratio, gears treated with the ISF Process can maintain full-film or mixed lubrication status in situations that would leave ground gears insufficiently lubricated. In an oil-out situation where there may still be residual trace of oil on the gears' mating surfaces, increasing the gear's lambda ratio is yet another theoretical way to improve a gear's durability.

For the cash-strapped gear manufacturer, it may be difficult to justify spending more than the bare minimum required to protect against oil-out conditions. It's understandable that manufacturers may not be in a rush to sink major costs into a feature that may never be used in a gear's life. But one of the ISF Process's selling points is that many of the features that improve gear durability in oil-out conditions also benefit gears during normal operation. The technique also requires no changes to a gear's design, just an additional manufacturing step, saving manufacturers some time and worry alongside money.

"Certainly, in normal operating conditions, you don't need to worry about a complete or nearly complete loss of lubrication," Michaud said. "But just as isotropic superfinishing will increase gear life during oil out conditions, in normal operation, an isotropically superfinished gear will have significant lifespan improvements over a ground gear."

Looking at it that way, the ISF Process's oil-out protection properties are almost more of a bonus than a central feature. Many of the same features that increase gear durability in oil-out conditions also contribute to reducing the risk of gears scuffing, another major concern for the aerospace industry. While modifying a gear's design to account for oil-out incidents may be more expensive than some would like, methods like REM's superfinishing process can help soften the financial cost with additional benefits.

According to Michaud, isotropic superfinishing shines most in "extreme" high-load, high-speed functions, such as with the rotorcraft gearboxes being studied by the U.S. Army Research Laboratory, as well as high-load, low-speed functions, but can be utilized across a broad spectrum of hardened gear applications. Michaud also noted that the ISF Process can also work as a solution to problems found late in the design or even manufacturing process.

"Isotropic superfinishing can absolutely be used as a quick fix to solve late stage design or in production issues," Michaud said. "If a gear design or system is experiencing failures or isn't operating to the levels of performance to which it was specified and surface finish is a factor, then applying the isotropic superfinishing is good path to consider."

REM has also invested a significant amount of time expanding the range of gears their superfinishing process supports. Some of the main alloys their process is compatible with include SAE 8620 and 9310, Pyrowear 53 and 675, Ferrium C61 and C64, M50/M50-Nil, CSS-42L, Nitralloys, AerMets and 440C. It's worth noting that some of those materials are the same alloys that the GRI is currently looking at in their own oil-out studies. The process has been used on gears as heavy as 10,000 pounds and gears with diametral pitches as high as 96, as well as multi-geared shafts, gear assemblies and gears with integral bearing races or seats.

Despite Michaud's belief in REM's ISF Process as a baseline innovation for the aerospace industry, growth has remained steady. Michaud attributes this to the nature of the industry, which he characterizes as understandably cautious when implementing new technology.

"It is one thing if your car breaks down, you're going to be inconvenienced and probably upset," Michaud said. "It is quite another thing if a helicopter transmission or turbo-fan gear fails, so you really can't take chances."

But between the ISF Process's numerous advantages, the multiple industry woes it provides a solution for and a growing pile of studies and papers verifying the process's benefits, REM is slowly winning the industry over. Whether the process will also become a commonly sought out solution for oil-out durability in gears remains to be seen, as REM certainly has a number of contenders to compete with. We're still far out from seeing a new de facto standard for oil-out durability in gears, with most current studies still in their planning stages, but going forward, it's going to be important to keep an eye on which processes perform best in those tests. The aerospace industry as a whole certainly will.

For more information:
Gear Research Institute
Phone: (814) 865-5832
www.gearresearch.org

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Business Development for the New Year

Joe Arvin

It's the New Year, and with it comes the opportunity to take a fresh look at your business objectives. Because business development is such a vital part of running a company, I'd like to present some guidelines I have found beneficial for securing new work and new customers.

Being Equipped for Competition

A critical part of winning new business is being properly equipped to compete, and more often than not, the winners are those with the most advanced machine tools. Manufacturing technology is evolving at a rapid pace and falling behind can have a severely negative impact on your ability to compete.

But you might be thinking, "Joe, I just don't have the millions of dollars needed for new machines." If that's the case, consider this. Be careful not to overlook the smaller details of your operation, such as the ever changing technology of cutting tools, quick change tooling, coolants, new processes, laser inspection, retrofitting existing equipment, and other similar augmentations. You can be surprised at how these improvements in aggregate can enhance your ability to compete.

> "Several years ago, my VP and I made it a point to visit one of our major customers at least three times per year. However, we started to see a significant decline in business. When we asked why, we learned that our competitor was visiting them every month."

Your Image

Image is critical to business development. Ask yourself this question: Does your company reflect the image of one that *you* would like to do business with?

Try this exercise. Clear your mind of problems. Then, drive up to your plant like a first time visitor; walk through your office and shop, taking a careful look at everything you see. With a clear mind, believe me, you will be surprised at what you see, and you will likely see things you'll want to change.

It's important to make sure your entire organization is a testimony to your commitment to excellence — not just your manufacturing capabilities. Also, be sure your company website and printed collateral material accurately present the image you want to convey. These will be vital tools when contact is made with prospective customers.

Only after fine-tuning your image will you be ready to take full advantage of your exposure efforts to the marketplace.

Goals and Planning for Market Exposure

Before I meet with a new manufacturing company, I will typically do some online research on them. Later, after the onsite tour, I often find myself saying, "I'm surprised you have this kind of capability." Being good at something and not broadcasting it to the market usually means missed opportunities.

As you develop your market exposure plan, it's important to first define your market proposition; what do you do and how does it set you apart from the competition? Remember that "offering quality" is not a market proposition that will set you apart from your competitors. Quality is a given. Instead, you must identify your specialty or niche, and this must be the cornerstone of your message.

> "Manufacturing technology is evolving at a rapid pace and falling behind can have a severely negative impact on your ability to compete."

Next, you will need a well thought out formal plan for how to spread this message; aimed at reaching both prospective and existing customers. Not having a strategic plan is like trying to steer a ship without a rudder.

The plan will first be driven by a *realistic* marketing budget. We'd all like to spend as little as possible on marketing, but your results will be directly proportionate to your investment. Then, with the budget identified, you will be able to carefully examine and evaluate the methods available for most effectively spreading your message. Today, there are many tools for communicating your message, including print ads, e-newsletters, direct mail, online video, online ads, and search engine optimization.

If you are saying, "Joe, I just don't have tens of thousands of dollars to spend on marketing," you're not alone. The impor-

Investing in new manufacturing technology is beneficial to securing new work and new customers.

Photo by David Ropinski

tant point here is to work with the budget you *do* have and spend it as wisely as possible, because doing a small, carefully funded campaign is certainly better than doing nothing.

Knocking on the Doors

Once you have communicated your message and your image to the market, you might get a few inquiries, but most marketing campaigns require the "sales" component to fully accomplish your goals. It's now time to get your outside sales team engaged and reaching out to people. To support their efforts, I would strongly recommend the use of a database driven contact management tool. Every single contact made by your sales team should be entered into this system. Operating with a stack of business cards and a folder full of notes is just not very efficient for the long run, and here's why. Building a contact database over time gives you a well groomed list of people for routine outreach, whether it's emails, phone calls, your e-newsletter, or direct mailings. Remember, that securing a good customer might require reaching out to them for months, if not years, and an efficient contact management system is the best way to facilitate this.

Several years ago, my VP and I made it a point to visit one of our major customers at least three times per year. However, we started to see a significant decline in business. When we asked why, we learned that our competitor was visiting them every month.

Conclusion

There are many aspects of business development that must be managed effectively. Having a competitive price and good quality doesn't necessarily mean you will get the order. Your image, market exposure, how you conduct your business, and establishing a solid relationship with your customer are essential. Ultimately, be the type of organization that you'd like to work with, and you will be rewarded with new customers and long term business relationships.

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

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Best Tooling for Hard Milling a Gear Tooth on 5-Axis Machining Center

QUESTION

What is the best tooling to use when hard milling a gear tooth on a 5-axis machining center? And what makes it the best? We have just bought a DMG Mori mono-block and are not getting the finishes at the cycle times we require.

Expert response provided by Julian Staudt, Saint-Gobain Sekurit.

Hard milling gears on a 5-axis machine is a very flexible technology regarding machinable gear types, as well as gear sizes; this flexibility is realized by use of universal tool geometries. The most flexible tool is a standard shaft mill. Disc mills can achieve higher cutting speeds and feed rates, but they are not usable for all types of gears; e.g. — not for most bevel gears. The more specialized a tool system is, the more productive it can be. Thus there is always a conflict between flexibility of the gearing technology and the achievable time-per-part.

Regardless of which tool systems best fit you and your gear portfolio, an optimized machining strategy is the main driver for the achievement of proper cycle times (Fig. 1). Tangential tool contact brings us more robust and faster processes, i.e. — quality gets better. High feed speed leads to big chip volumes, short cycle times, and often simultaneously to an improvement of cutting conditions; tool life and surface integrity improve. Nevertheless — 5-axis milling of gears does not typically match the capabilities afforded by today's specialized gearing technologies for hard finishing, relative to cycle time.

Julian Staudt worked for the past 12 years as research assistant (Gear Department) at the Chair of Manufacturing Technologies/Laboratory for Machine Tools (WZL) at RWTH Aachen University. Having completed in 2016 his doctorate studies, he currently works for Saint-Gobain Sekurit -- a supplier to the automotive industry.

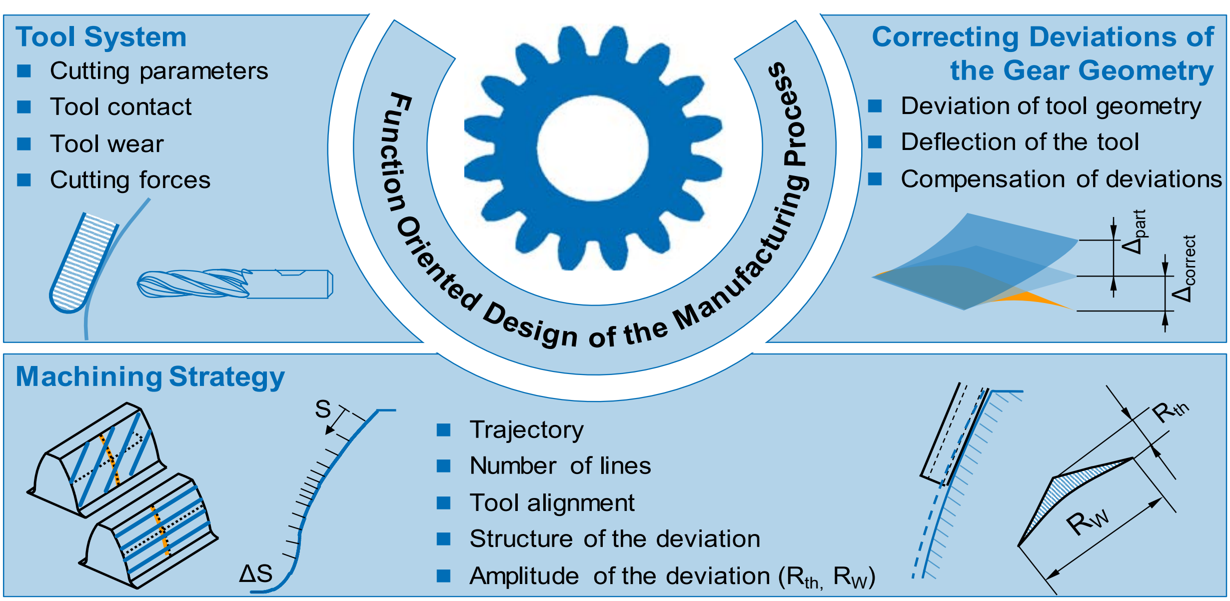

Figure 1 Function-oriented process design in 5-axis milling of gears.

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Development of High-Hardness-Cast Gears for High-Power Mining Applications

Fabrice Wavelet

Multiple possibilities are available to increase the transmissible power of girth gears. These solutions include: using a larger module, increasing of the gear diameter through the number of teeth, enlarging the face width, and increasing the hardness of the base material.

The first three parameters are mostly limited by cutting machine capability. Module, outside diameter, and face width (for a cast gear) can theoretically be increased to infinity, but not the cutting machine dimensions. There are also practical limits with respect to the installation of very large diameter/large face width gears.

The hardness is the sole parameter that is related to the base material.

Within the past decade, mining industry demand for gear-driven/high-powered grinding mills has pushed the installed power to levels previously thought to be unachievable or impractical. Girth gears are now being used to drive ball and SAG mills having total installed power in excess of 17,000 kW (23,000 hp).

The development of high-hardness materials suitable for these applications has resulted in the design and manufacturing of cast girth gears up to 350 HBW in steel and 340 HBW in ductile iron.

This paper intends to review the related impact in terms of design and manufacturing of such high- hardness gears and present a summary of results from a population of more than 170 gears manufactured from cast materials having hardness in excess of 300 HBW, including almost 20 gears manufactured from cast materials having hardness in excess of 340 HBW, with an approximately equal distribution between cast steel and ductile iron base materials.

Introduction

In the mining industry, users' demand for increased mill power and size has always been present. Continuous developments in the gearing industry have made this possible, to a certain extent: basically, a 36' mill diameter in terms of size and 17 MW in terms of power.

Beyond these values, and sometimes below as shown in Figure 1, is the domain of gearless drives.

This paper intends to review the latest developments made on increasing gear hardness, its impact on gear geometry, and finally the experience with gears above 300 HBW.

Parameters of Influence on Gearing Power

To date, three standards are available to determine transmissible power of a mechanical drive:

- AGMA 2001
- ISO 6336
- AGMA 6014

While the first two can be used on any type and size of gears, AGMA 6014 is the only standard dedicated to open gear applications, such as mills or kilns.

AGMA 6014-B15, the latest version from 2015, introduces two equations that allow the experienced gear engineer to design gear drives.

These equations are made to determine the transmissible power of a gearing based on its resistance to tooth bending and its resistance to surface pitting.

$$P_{atm} = \frac{\pi n_p d}{396{,}000} \, \frac{F}{K_{Vm} P_d} \, \frac{J S_{at} Y_N}{K_m K_{Bm}}$$

Equation 1 transmissible power (hp) based on tooth bending resistance (Ref. 3)

$$P_{acm} = \frac{\pi n_p F}{396{,}000} \, \frac{I}{K_{Vm} K_m} \left(\frac{d S_{ac} Z_N C_H}{C_P} \right)^2$$

Equation 2 transmissible power (hp) based on contact pressure resistance (Ref. 3)

In the above equations, parameters in blue are related to the

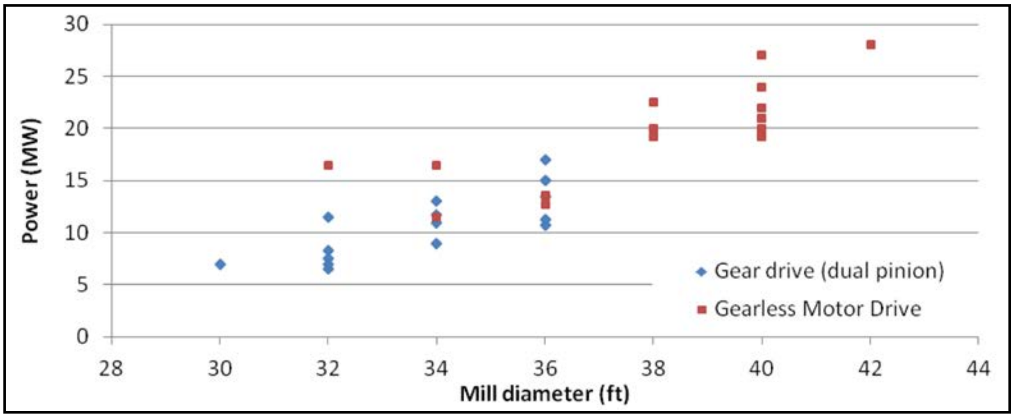


Figure 1 Drive type by mill size and power (Refs. 1–2).

tooth geometry and are notably related to the gear accuracy (i.e., AGMA 2000, withdrawn but still in use, Q10), the module/diametral pitch (i.e. the tooth size), and the gear face width (basically the length of teeth meshing with the pinion).

Parameters in red are a function of the material properties, but all reduced to the hardness.

The least value of these two calculations, themselves divided by a selected service factor, gives the transmissible power of the installation.

In other words, gear power relies on three major parameters for a given transmission error: module/diametral pitch, face width, and hardness.

The Choice of Hardness to Improve Gear Power

Through the past 10 years or so, major developments have been made by manufacturers to improve their manufacturing capacities with the target to increase mechanical drive capacity.

First was to increase the module size: from a common 25.4 module/1" DP (20 years ago), tooth size moved up to modules over 30, and now appears on a regular basis to be over 40. The largest module produced to date is 55 module/0.46" DP.

Consequence of module increase, apart from its important impact on power, is also the increase of outer rim thickness, and consequently the total weight of the gear.

AGMA 6014 recommends a minimum thickness of 4.5× module for the outer rim, not to derate K_{bm} factor in the bending resistance equation. Note that these 4.5× module are calculated based on a standard tooth height of 2.25× module, and 2.25× module below the tooth root to obtain K_{bm} equals unity.

For example, a module 42/0.605" DP, that has been used on nine gears between 2012 and 2016, implies a finished rim thickness of 190 mm, or 210+ mm thick un-machined. Even though this is not a problem for a cast gear, this thickness could be for fabrication. Therefore, larger module also means larger cutting tools, which may lead to use of a different process. The two main processes for tooth cutting are hobbing and single-index cutting. Hobbing tools are much larger than single-index tools at a given module size, implying both a significant difference in terms of cost, and that some machines cannot accept hobs with modules over a certain size.

A move to single-index cutting was needed and required for gears with large modules, i.e., 36 module /0.71" DP and above.

A single-index process is a problem when the tool has to be refurbished during the cut; it may generate high pitch error and/or helix angle errors when the tool is set back into operation.

Developments have been made with tool manufacturers to work with carbide inserts capable of cutting 100% of the teeth to the required quality, with no change in the course of final cut.

Then, the gear pitch accuracy is only a function of machine table rotation accuracy, which can be controlled by dedicated maintenance interventions.

On the other hand, in cast steel gears, a large tooth height (which is about 2.25× module) means deeper cuts into the rim, and this may lead to open micro-shrinkages at the surface (Fig. 2). These indications are well known; they are usually excavated and left as is.

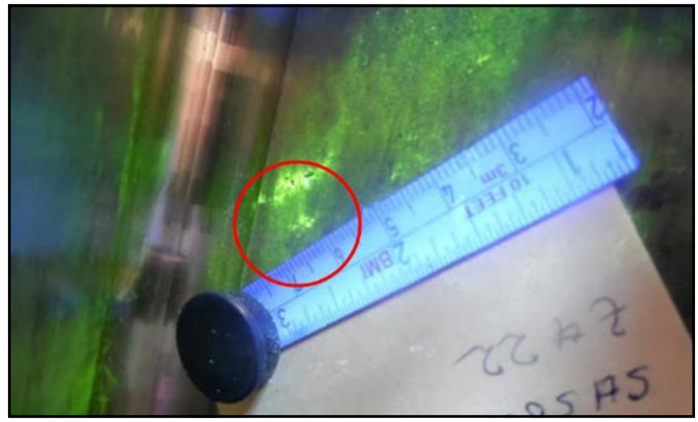


Figure 2 Micro-shrinkage into a cast steel girth gear.

Foundry experience is the key to minimize such indications. Over the past 2 years, 25% of large steel gears (with modules between 33.866 and 42 and hardness at 300+ HBW) have been produced with no indications in the teeth area.

The other 75% have an average 2.9 indications per segment. Modules are between 28 and 42. Considering ductile iron gears, none of the 260 gears produced for the mining industry over the past 12 years have shown this type of indication in the teeth area.

Although quality has improved, cast gears and porosities in the teeth area remain linked in people's minds.

The second parameter manufacturers have worked on is gear size: the more teeth, the larger power, but also larger is the diameter and the mill a gear can be assembled on.

As previously said, a 36' SAG mill was the limit a mill can be equipped with a mechanical drive, simply because the largest gear cutting machines were about 14 m/46' in diameter.

Four years ago, a new 16 m/52' gear cutting machine was commissioned in Germany that can allow the manufacturing of gears for mills up to 44' (which does not exist yet) with an AGMA 2000-Q10 quality.

In parallel with developments made on the module and on gear diameter, in order to continue to increase the potential power of gears, work was done on face width.

Building a gear blank with a 1 m face width is not difficult. Cutting such a face width to meet a lead error within AGMA Q10 tolerances, and assuring a good contact through meshing on site, are two challenging objectives with a very large face width.

As for large modules, wide faces can run into a limit as the lead deviation is critical for the power transmission: the larger the tooth, the more difficult the alignment.

In this case as well, single-index cutting seems more practical when talking about face width larger than 600–700 mm. With these new generation tools, profile and lead errors on face width of about 1 m are between 30 and 60 µm, with no undulations. The same dimension cut with a hob can give a lead error closer to the tolerance limit (80–100 µm). Hobbed profile error is about the same as with single-index cutting.

Even though the current limit of the face width is about 1,500 mm, this magnitude will make gear and pinion alignment very demanding, to say the least.

Keeping face width as narrow as possible should be the goal of the gear designer.

With physical limits reached on both the module and the face width, the last parameter manufacturers can act on is the hardness.

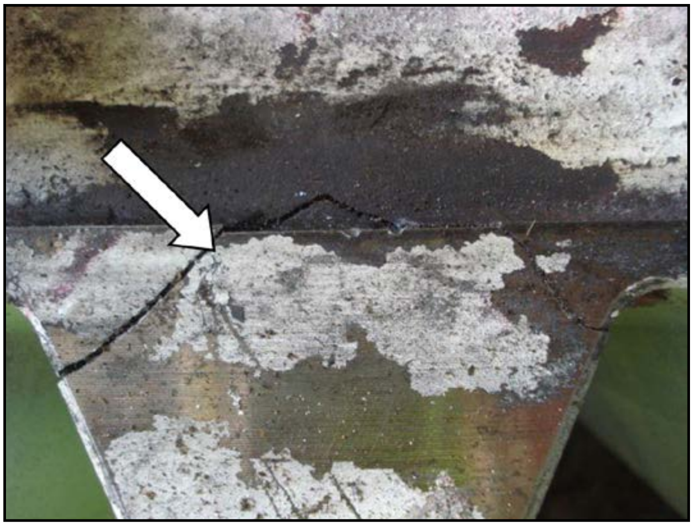


Figure 3 Tooth root crack due to misalignment.

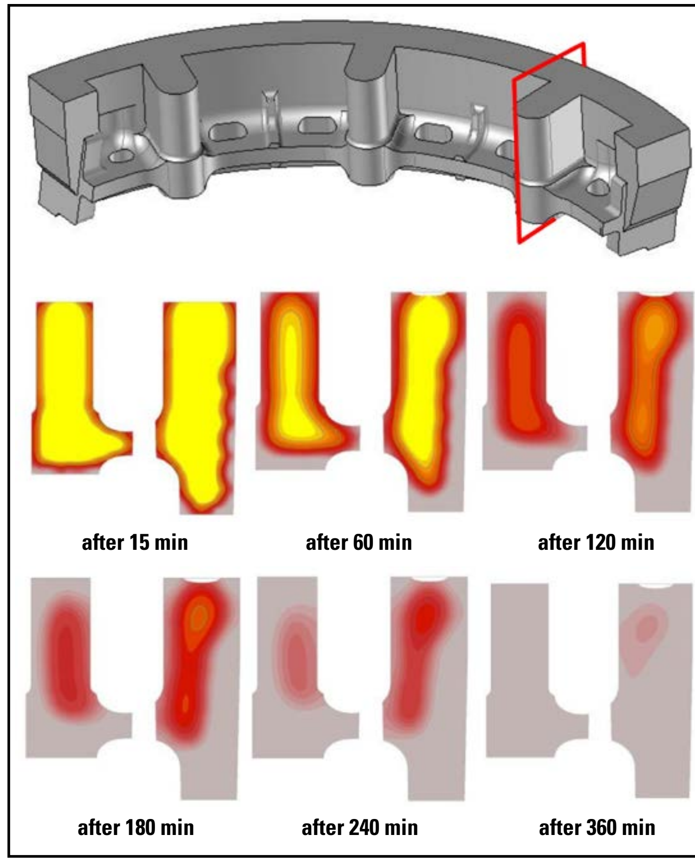


Figure 4 Example of solidification study on a steel gear segment.

Increasing hardness of the material, and its properties, is very interesting in that it is the only parameter that will reduce gear dimensions, and weight, for the same amount of power.

Less than 10 years ago the maximum designed hardness used was 320 HBW for steel gears and

290 HBW for ductile iron gears. This was simply due to the fact that mills were not needed for more power (based on average module and face width sizes) and also because these hardnesses have been proven over decades of duty.

Today, research makes possible production of cast gears with minimum guaranteed hardness of 350 HBW in steel and 340 HBW in ductile iron.

And tests are currently in process to produce 360 HBW gears — and beyond.

With the current range of possibilities being defined, what are the consequences of a hardness increase on the casting and machining process?

Obviously, reaching a higher range of hardness requires a different chemistry. Table 1 gives different examples for cast steels based on the required hardness.

With such chemical analysis, quench-ability (capacity of the material to maintain the hardness through the section thickness) improves, but the risk of defects increases as well.

To manage this risk, a lot of work and tests have been needed to redefine casting design, whether castings are made of steel or of ductile iron to reduce, if not avoid, internal discontinuities.

This covers, for example:

- ***Risers***: size, location, and the way they cool down was rethought using computerized solidification software to improve their effect on the time of solidification and to move the possible internal indications out of the casting itself, or at least in the non-critical areas (such as the teeth area).
- ***Pouring system***: distribution, position, and size of the ingates were analyzed. Their impact on the flow of liquid metal, as well as the perturbations they are generating, was discussed and led to modifications, i.e. pour at lower pressure, multiple ingates and reduced their sizes or movement of ingate position from the bottom to the side.

Autofeeding slope: in terms of casting thickness, there is always a difference between the bottom of the mold (drag side) and the top of it (riser side). This thickness difference between them is called the auto-feeding slope. Depending on the required quality and the chemistry, this slope can vary from 1° to 5°, and has a significant impact on weight.

Chills: the question of using chills, their number and distribution, was also modified in relation with module size and chemistry. Studies have been conducted in order to determine the correct size, form, and distribution of chills to obtain defect-free teeth.

Improving hardness has also impacted the manufacturing process and has required studies and modifications on the way.

To assure material soundness, some portions of the liquid metal are transferred into an AOD (argon/oxygen/decarburization) converter that allows limited "metal purification." That

Table 1 Examples of required and actual chemistry related to hardness

Material	Hardness	%C	%Si	%Cr	%Ni	%Mo
ASTM A148 Gr 130-115	(300 HBW)	requirements only on sulfur and phosphorus contents				
OF 40131 — A148 Gr 130	≥ 310 HBW	0.43	0.35	1.76	1.72	0.27
EN 10293 - G 35 CrNiMo 6-6	(290 HBW)	0.32–0.38	0.6 max	1.40–1.70	1.40–1.70	0.15–0.35
OF 49131 - G 35 CrNiMo 6-6	≥ 285 HBW	0.39	0.52	1.67	1.54	0.32
G 38 CrNiMo 6-6 *	(320 HBW)	0.34–0.45	0.6 max	1.3 min	1.3 min	0.15 min
OF 76668 — G 38 CrNiMo 6-6	≥ 320 HBW	0.41	0.34	1.74	1.71	0.38
G 40 CrNiMo 7-7 *	(340 HBW)	0.36–0.47	0.6 max	1.5 min	1.5 min	0.15 min
OF 41657 — G 40 CrNiMo 7-7	≥ 340 HBW	0.44	0.36	1.77	1.71	0.45

* Non-standard grades; specifically developed for heavy section and high hardness-cast gears

type of additional work allows minimizing nitrogen content to less than 20 ppm and improves impact resistance of the final material (even though it is a secondary property for gears in normal conditions of service).

Another side-note for manufacturing relates to upgrading, or process welding, of the blank. Higher hardness in conjunction with larger amounts of alloying elements implies specific welding procedures that requires being qualified and repeatable.

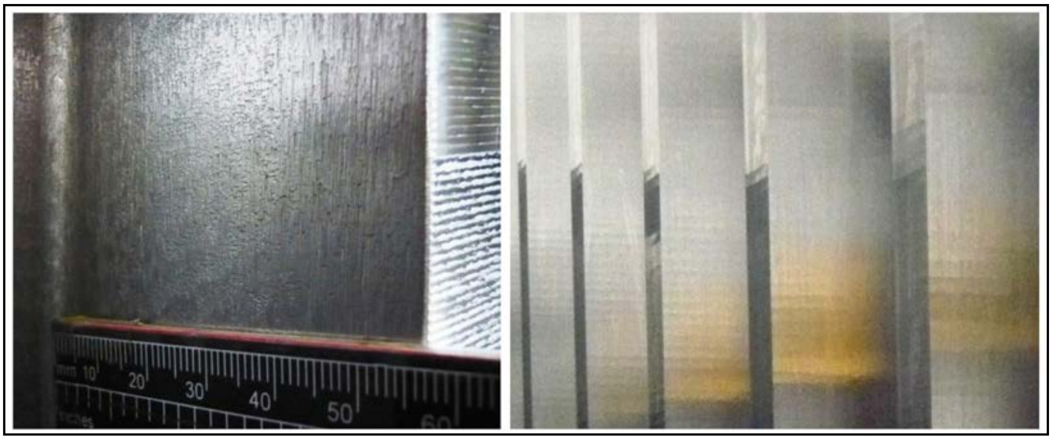


Figure 5 **(Left) Surface "scraping" on a tooth flank due to HSS tool wear on a 300 HBW gear: Ra 5 µm; (right) 320 HBW gear cut with carbide tools: Ra 0.6 µm.**

With an equivalent carbon for welding above 1, 320, HBW material is classified as "difficult to weld" by AWS.

Repair conditions will need to be the following:

- Pre-heating will be around 300° C (to pass over martensitic transformation starting point, Ms)
- Temperature during welding will be maximized to 450° C (to avoid embrittlement by chromium carbide precipitation)
- Post-weld heating must be maintained at 300+° C for 2+ hrs to allow diffusion of hydrogen and avoid martensite precipitation, then embrittlement
- Tempering of the integral casting to smooth heat-affected zone and avoid quenching products leading to brittle microstructures

That type of repair does not permit approximations and shall be done in a shop, both to control the heat-related deformations and the results obtained in terms of microstructure.

Another point to consider when manufacturing higher-hardness gears is the machining; the use of high- speed steel (HSS) tools becomes very limited. Most of the tools need to be made of either carbide or ceramic, which have a different behavior in relation to the gear material (in the way they cut, their productivity, and their operational parameters).

Figure 5 shows a recent case of the consequence of HSS tool wear during hob cutting. The surface finish was so rough that this gear needed a recut. Tooth thickness was reduced and finally fell below the required value. Verification of the bending resistance safety factor was needed to make sure this gear still met the requirements of the application.

As a comparison, Figure 5 also shows the results obtained by the use of carbide inserts on the cutting tool.

The conclusion is that, depending on gear size (outside diameter and face width) and hardness level, use of HSS tools above 280 HBW should be questioned.

On the inspection side, developing higher hardness grades makes no difference in terms of inspection techniques; ultrasonic and magnetic particle inspections can be used the same way as on any other material grades, with the same acceptance criteria.

Nevertheless, a study was performed on the impact of increased hardness over the ultrasonic velocity in ductile iron gears.

Ductile iron gears above 300 HBW have been recorded close to, or sometimes below, the standard limit of 5 450 m/s (Fig. 6), with no impact on the quality of graphite nodules.

This reduction in terms of velocity is mainly due to the microstructure, which is related to the hardness level.

The use of high-hardness gears (of or above 300 HBW) in a mill driving system also has some consequences on the pinion.

As per AGMA 6014, hardness difference between pinion and gear has a beneficial impact on gear rating (work hardening effect; C_H factor). For that reason, the gear industry usually considers a minimum difference of 40 HBW points in excess of the gear design hardness for pinion hardness.

Thus, a 300 HBW gear implies use of a pinion at 340 HBW minimum, which can be in the higher range of hardness for a through-hardened forging of this size. In such conditions, gear hardness maximum can be equal to pinion hardness minimum, and this can affect pinion wear and reduce its lifetime.

Selection of carburized and

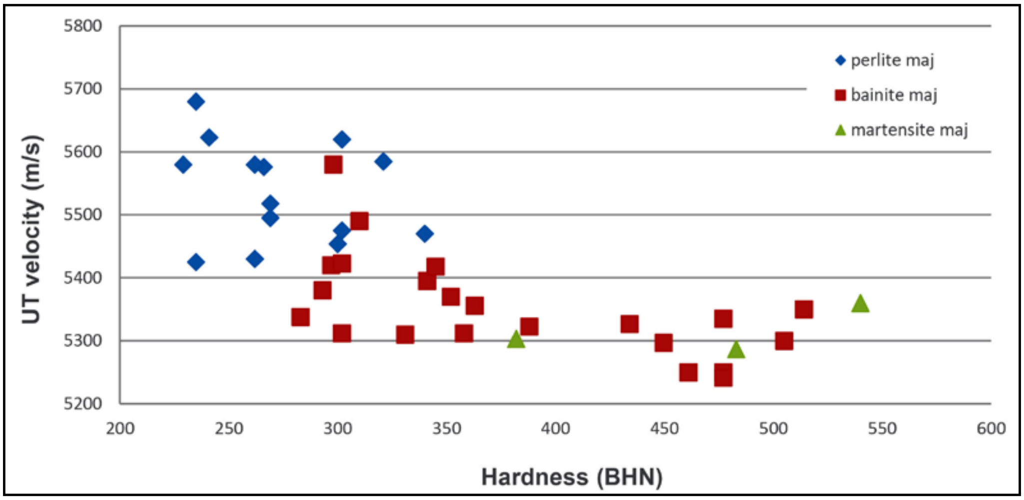


Figure 6 **UT velocity vs. hardness (and microstructure) on ductile iron gears.**

ground pinions with high-hardness gears is then recommended to improve both power rating and service life.

Gear Design Examples Based on Hardness Variations

The goal in this section is to study the impact that hardness variation can have on the gear design. For that purpose two ball mills have been considered; ball mills are the most-solicited machinery in a grinding circuit because its relatively small diameter causes more stress on the teeth.

- The first example considers an 18' ball mill driven by a 3,500 kW motor, single pinion drive. This type of mill is an average size, both in terms of dimensions and in terms of power.
- The second example is a hypothetical 26' ball mill driven by two pinions for a total power of 20 MW. This type of mill does not exist; the largest and most powerful ball mill to date is a 26' ball mill, dual drive, 17.5 MW.

Results are summarized in Tables 2 and 3 (with complete data in annex).

For a common size ball mill, Table 2 shows an interesting reduction on face width, whether the gear is made of steel or of ductile iron.

Consequently, weight is reduced, as is the final price. Moreover, alignment between gear and pinion with a reduced face width will be easier on site and more consistent across mill rotation.

Table 3 shows a different situation. While the reduction on the face width with a 20 HBW increase is small, it becomes significant with the combination of hardness and module increases.

Nevertheless, cost remains about the same, but the narrower face width allows easier alignment on site.

One can also note that, even though this 26' ball mill is purely a study, gear parameters used to reach a transmissible power of 20 MW have already been used and manufactured before:

- Module 45 is in the high range of module cut to date, but already few gears are in service with such a large value.
- A 900+ mm face width has been cut on many gears in service, obtaining successful alignment and contact.
- 340 HBW is also a value seen on a regular basis on gears in service for a significant time to date (Fig. 7), with good reliability.

Gears Above 300 HBW in Service

Figure 7 shows the number of gears manufactured for the mining industry by the company over the past 12 years.

The demand for gears beyond 300 HBW increases with time, whether they are made of steel or of ductile iron.

In terms of hardness, 2007 shows the first ever gear at 340 HBW. Then, a period of 5 years has been taken to validate such hardness. After 2012, 340 HBW became standard.

A new milestone will be reached this year (2016), with a minimum required hardness of 345 HBW for a steel gear.

In terms of service, of the over 130 gears produced to date with a hardness equal or above 300 HBW, only three have encountered failures:

- ***Tooth breakage***: a steel gear had a tooth break at the tooth root in service. The origin of the failure was an alignment problem, reducing contact to 30% over the face width. The power was then transmitted through a limited surface of the tooth, inducing a crack at the root. The damaged gear segment was replaced, and the gear was integrally re-cut and is back in operation with no more problems known to date.
- ***Pitting***: another steel gear encountered severe pitting on 100% of its teeth (cavities up to 2–3 mm deep). This was related to a lubrication problem. The gear was recut and stored as a spare.
- ***Outer rim through-crack***: a ductile iron gear developed a

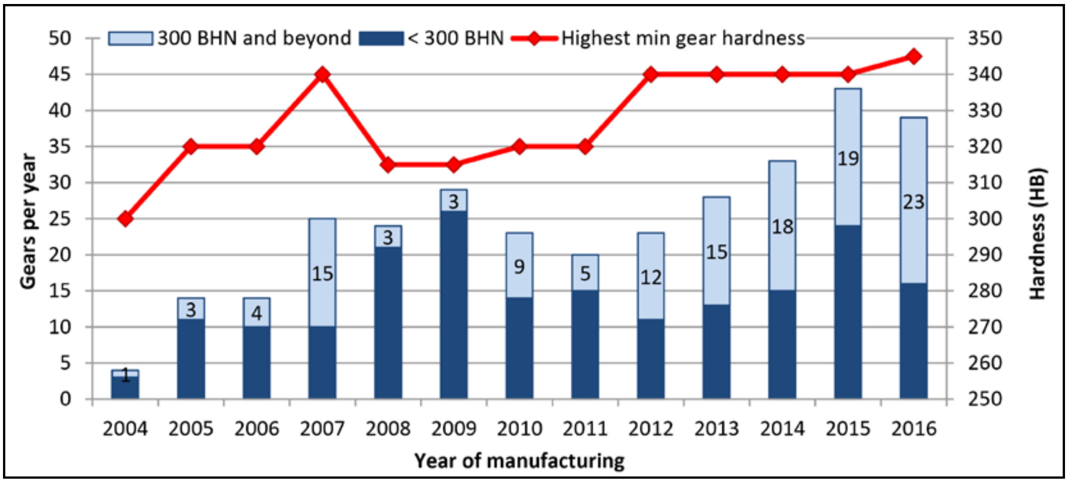


Figure 7 Gears below and beyond 300 HBW and highest minimum gear hardness, per year.

Table 2 Design variations for an 18' ball mill of 1×3 500 kW (single drive)

Design	« standard » 290 HBW, in steel	with 340 HBWHBW, in steel and a reduced face width	with 340 HBW, in ductile iron and a reduced face width
Module	25.4	25.4	25.4
Hardness	290 HBW	340 HBW	340 HBW
Face width	**750 mm**	**620 mm**	**710 mm**
Outside diameter	8011.6 mm	8036.1 mm	8018.1 mm
Transmissible power	3545 kW	3524 kW	3539 kW
Limiting factor	Bending	Bending	Bending
Weight	33 tons	29.2 tons	28.9 tons
Price index	100	92	84

Table 3 Design variations for a 26' ball mill of 2×10 000 kW (dual drive)

Desi gn	« standard » 320 HBW, in steel	with 340 HBW, in steel and a reduced face width	with 340 HBW, in steel with reduced face width and increased module
Module	42	42	45
Hardness	320 HBW	340 HBW	340 HBW
Face width	**1150 mm**	**1070 mm**	**990 mm**
Outside diameter	11058.6 mm	11071.7 mm	11167.2 mm
Transmissible power	10012 kW	10017 kW	10100 kW
Limiting factor	Bending	Bending	Bending
Weight	97.6 tons	92.5 tons	93 tons
Price index	100	98	91

crack through the entire thickness of the outer rim and over one-half of the face width. This was originated by a localized welding on the gear post-manufacture, to secure the mudguard, close to a threaded hole. The gear was replaced.

Conclusion

- The demand for more and more powerful mechanical drives grows every year. The main reasons, as seen from end users, are that they want to increase their output and productivity while working with a reliable system that is proven and that they can fix and maintain themselves.
- With limits reached on module and face width, increasing hardness above a standard level of 300 HBW became a target for many manufacturers.
- Pros and cons make the hardness choice arguable: it reduces global weight, allows narrower face width, and actual hardness is always higher than designed hardness, giving a "resistance" bonus, and it is an economical benefit most of the time. In the meantime, a high-hardness gear requires attention and cautions in terms of manufacture, as during the welding process for example, but this relies on the supplier, not the customer.
- The difficulty of increasing hardness to reach higher power is not solely a question of the minimum that can be reached (300, 320, 340 HBW) but more a combination of high magnitude with heavy section gears (150+ mm finish machined).
- The past 12 years have seen the development of high hardness gears, and it has proven to be a correct option, if not the right choice.
- Based on the number of gears made by the company above 300 HBW in service, compared with the number of failures encountered by this type of gear (knowing they are independent from the material), makes the hardness a reliable choice.
- Of course, proper lubrication, alignment, and survey of such a gear must be done as for any other gear in order to maintain its operation-ability through its lifetime.

References

1. Tozlu, F., M. Pasquier, F. Wavelet, F. Lessard and B. Mc Naughton. "QdX4 – a Mechanical Drivetrain Solution for High-Powered Grinding Mills," *SAG Conference* 2015, Paper 42.
2. Tozlu, F. and M. Fresko. "Auto-Genous and Semi-Auto-Genous Mills — 2015 Update," *SAG Conference* 2015, Poster P12.
3. AGMA, 2015. "Gear Power Rating for Cylindrical Shell and Trunnion Supported Equipment,"
4. ANSI/AGMA 6014-B15.
5. Uherek, F. "How to Spec a Mill Gear," AGMA Fall Technical Meeting 2013, Ref. 13FTM21.
6. Pasquier, M. and F. Wavelet. "Ductile Iron for Open Gearing — a Current Perspective," AGMA Fall Technical Meeting 2013, Ref. 13FTM23.
7. Ferry Capitain, 2011–2012. "Manufacturing Data Books," 41570 and 41602, Russian Copper."
8. Ferry Capitain, 2011–2012. "Manufacturing Data Books," 41657 and 416658, Constantia."

Fabrice Wavelet has been with Ferry Capitain (Groupe CIF, France) for the past 20 years. He first served as quality manager and for the last 12 years has been a project manager specializing in mining products. This work deals with all technical issues on the metallurgic side as well as on the mechanical side of the manufacturing of large and high-accuracy components for the mining industry. In 2010 he joined the AGMA Mill Gearing Committee and participated in the latest revision of the 6014 standard, which is dedicated to open gearing. Aside from these activities, Wavelet has also written technical papers — notably for AGMA — covering the manufacturing and inspection of large cast components for the heavy machinery industry.

Annex: Characteristics Used for the Gear Design of Two Different Mill Examples

Ball Mill 18'	1×3500 kW
Type	Ball Mill 18'
Mill rotation speed	13.9 rpm*
Inside diameter	5700 mm
Design standard	AG MA 6014-B15
Bending strength safety factor	Ksf = 2.5
Pitting resistance safety factor	Csf = 1.75
Lifetime	219 000 hrs
Mating pinion	I× pinion Z23 CH&G 56 HRc

Material	Cast steel	Cast steel	Ductile Iron
power (kW)	3545	3524	3539
hardness (HBW)	290	340	340
module	25.4	25.4	25.4
face width	750	620	710
pressure angle	25	25	25
helix angle	6.4	7.8	6.8
gear teeth number	312	312	312
outside diameter	8011.6	8036.1	8018.1
limiting parameter	bending	bending	bending

Ball Mill 26'	2×10000 kW
Type	Ball Mill 26'
Mill rotation speed	11.55 rpm*
Inside diameter	8300 mm
Design standard	AG MA 6014-B15
Bending strength safety factor	Ksf = 2.5
Pitting resistance safety factor	Csf = 1.75
Lifetime	219 000 hrs
Mating pinions	2× pinions Z21 CH&G 56 HRc

Material	Cast steel	Cast steel	Cast steel**
power (kW)	10012	10017	10100
hardness (HBW)	320	340	340
module	42	42	45
face width	1150	1070	990
pressure angle	25	25	25
helix angle	6.9	7.4	8.6
gear teeth number	260	260	244
outside diameter	11058.6	11071.7	11167.2
limiting parameter	bending	bending	bending

*** Based on 75% of the critical speed, and with critical speed (CS): $CS = \frac{43.305}{\text{inner diameter (m)}}$ (Ref. 4).**

**** With a pinion tooth number reduced to 19 to maintain pinion speed to 140–150 rpm.**

Repair of Large, Surface-Degraded Industrial Gears — a New Approach

Horacio Albertini, Carlo Gorla and Francesco Rosa

This paper presents a new approach to repair industrial gears by showing a case study where pressure angle modification is also considered, differently from the past repairing procedures that dealt only with the modification of the profile shift coefficient.

A computer program has been developed to automatically determine the repair alternatives under two goals: minimize the stock removal or maximize gear tooth strength.

It will also be shown that the refurbishment of industrial gears using these approaches can result in a 30–40% savings, compared to the cost of a new part, without reducing gear strength. This paper will also show that the whole repair procedure can be carried out in no more than two weeks, depending on the gear size.

Introduction

Heavy industry components are expensive for of two reasons: first, they are large and are manufactured in small batches, or even individually, and, second, their replacement is not easy. Usually (and for the same reasons), the machinery suppliers or the Original Equipment Manufacturer companies (OEMs) do not have spare parts available in enough time, thus the time spent from the order placement to delivery is long. Some of these companies may have ceased their activities, leaving their machinery users without any after-sales support. Despite this situation, the research in the field of overhauling and repairing used gears to bring them new life and longer durability is practically absent, while a great effort is spent to improve gear performances and production through new materials, heat treatments, manufacturing, and surface finishing processes.

Machine capabilities and tool manufacturing are among the reasons that strongly limited gear refurbishment and hindered the research in this field. For a long time, the repair of a gear was restricted to the modification of the profile shift coefficient, while the modification of the pressure angle was impracticable, due to the axis motion limitations of the conventional gear machinery and the cost of fabrication of the gear cutters. For example, the modification of the profile shift coefficient is a technique already applied some decades ago to repair a gearset, as can be seen in (Ref. 5). However, the possibility of changing the pressure angle from 20° to a fractioned angle was costly because of the machining tool's limitations. It was not worth to manufacture a gear cutter with a non-standard pressure angle to save a single damaged gear. The multi-axis CNC machine centers overcame this limitation by allowing modifications of both the pressure angle and the profile shift coefficient.

The following innovations are enabling new types of modification to be applied to gear refurbishment.

- Introduction of CNC machine centers with multi axis and CNC gear grinding machines
- Development of new cutting tool materials which are able to machine parts with a surface hardness of more than 60 HRC
- Advancements in reverse engineering
- Improvement of the central processor speed of computers

These modifications produce refurbishments with great accuracy, in a timely manner, and with cost savings.

From a sustainability point of view, the repair of gears reduces the waste of components, which could be in service condition, keeping them working up to their obsolescence. Moreover, a study of 200 gears, carried out by one of the authors during the last five years, shows that the repair cost of a gear part can correspond to an average value of 37% of the price of a new one. Sixty-three percent of the gears considered in this study were fabricated with quench and tempered materials, 32% were case-hardened, and 5% were normalized. It can therefore be concluded that the repairing of heavy components seems to be the more convenient way to fulfill the issues of maintenance deadlines and premature decommissions.

In a few words, there are two good reasons for determining if a repair job is desirable: time and cost.

Background

It is important to highlight that this paper is mainly focused on the repair of industrial gearboxes; hence, the procedures are focused on the common practice of this sector. The parameters (e.g., the minimum service factor of the analytical strength analysis) may need to be updated if the approach is applied in another sector; a "mild" damage in the steelmakers segment, in fact, can be considered "severe" in the wind power segment.

This research does not rely on the search of the root causes of the failures. Usually, a gear specialist had already done the failure analysis before the unit was sent to the repair shop. Moreover, the results of the failure analysis are not available to third parties, including the repair service suppliers. The duties of the companies that provide repair servicing of gearboxes are usually limited to equipment overhauling (knowing which parts will be replaced, repaired or reused), assembling, and testing.

Nevertheless, it is important for these companies to know the gear failure modes (Ref. 1) in order to determine if the gear design can be improved to avoid future premature failures. The repair service companies should also be skilled enough to know the manufacturing processes available, and their limits.

The proposed approach applies only to gears affected by mild damages. For example, gears that present cracking, fracture, bending fatigue, and severe plastic deformation cannot usually be repaired because of their heavily impaired geometry and mechanical properties. Gears affected by these types of failures can be easily identified and discarded by a simple visual inspection or other quick inspection methods, like a dye penetrant test (Fig. 1).

Gears that do not present severe failures may thus be repaired and put into service again. Wear, scuffing and Hertzian Fatigue are failure modes that the proposed method can potentially remove (Ref. 1).

Figure 1 Crack revealed by dye penetrant test.

Methodology

The first step consists of data gathering. If either the users or the manufacturers do not provide the gear data, the gears have to be accurately measured in order to determine all the necessary input data to run an analytical strength calculation. The analytical strength is then determined by inputting the gear geometry (Ref. 12), materials, and application parameters. Available gear software (Ref. 23) can be used to calculate gear set strength against pitting, bending fatigue, scuffing, and micropitting.

In any case, it would be better to know the original strength of the gear set to avoid the design of a weaker pair.

Once the actual geometry and strength of the gears are known, the second step can begin. This step consists in evaluating which gear geometry modifications are possible in order to decide either how to remove the damage or also to guarantee an adequate strength of the gear. A *Matlab* script has been developed to assist the designers in this phase; the script is based on the procedure described earlier.

The input of the script is the gear geometry data gathered from the reverse engineering (Ref. 26) or by the original drawings (if available). The program calculates the coordinates of the active profile of the pinion and the gear.

Tooth pointing must be avoided since the strength applied on the tip during the meshing can lead to a breakage. It is recommended that the tooth tip thickness shall not be less than 20% of the normal module (Ref. 25).

Then, the modification of the profile begins with the increasing of the pressure angle by an amount of 0.1° and the calculation of the new geometry is carried out.

The algorithm enters into a loop, increasing the profile shift coefficient of the pinion by an increment of 0.001 — and consequently decreasing the profile shift coefficient of the gear to keep the backlash — up to the point that the damage is completely removed from the tooth surface.

The new tooth profile with the changes of the pressure angle, profile shift coefficient and root fillet (if necessary) is verified against the "undercut" due to a possible interference (lack of material) of the original tooth on the tooth root of the new profile. The undercut above the active root diameter impairs the gear performance, leading to other issues like transmission errors and reduction of the strength against the bending fatigue.

The algorithm tests a new increment of the pressure angle, increasing it once more by an amount of 0.1° since either the root radius does not reach 0.2 times normal module (Ref. 25), or the new profile intersects the original profile on the active root diameter, or the pressure angle exceeds 25° — whichever occurs first.

This program provides two approaches: the first is aimed at minimizing the stock removal during the machining process, while the second maximizes the strength that a repaired gear could reach, taking into consideration the tooth actual geometry and the damage present.

Even if the procedure intends to save both pinion and gear (if the backlash between the pair is still in tolerance), in most of the circumstances the pinion, which is the less expensive among the pair elements, must be re-manufactured to obtain an adequate backlash. If the pressure angle is also changed, both members will need to be re-manufactured.

Apart from the macro tooth modification, the micro geometry modification can also be included to increase the gear strength. Tip and root profile modification, as well as flank modifications, are examples of modifications that may increase the resistance against failures like scuffing, pitting, and micropitting.

A second analytical strength calculation is then carried out using the modified parameters. These results are then compared with the strength of the original geometry. The result is accepted if the gear set safety factors are above the minimum required by the industrial application.

Finally, the modified gear set drawings are sent to the manufacturing department staff so that they can decide how to machine the parts.

Today this approach is usually convenient under the economical perspective, thanks to multi-axis CNC machine centers and the development of the new gear CAD/CAM software packages integrated in these machines.

According to (Ref. 8), the traditional gear machining methods, such as hobbing and shaping, pose geometric limitations on manufacturers' ability to produce gears in small and medium batches. The gears manufactured have the same geometric parameters of the tools, such as pressure angle, addendum, and dedendum height, and in some cases, the protuberance for a grinding process. Different parameters and sizes require different and expensive tools with long delivery time, especially for small batches or even individually. This is usually a time-consuming process.

In recent years new gear machining methods have been developed that allow the use of multi-axis CNC machines and standard tools like end-type or disk-type milling cutters. The tools are not affected by the limits described in the previous paragraph, and the milling using a multi-axis CNC machine is not only user-friendly but the final machining process is also in accordance to higher gear standard accuracies.

The tools are typically stocked-standards with simple shapes, enabling a reduction in the cost of consumable tooling per gear. The tooling used with these methods is solid carbide or inserted carbide tooling capable of hard cutting after heat treatment (up to 62 HRC). This type of tooling has predictable tool wear, which can be controlled. Hence, it is possible to get less part-to-part variation in the manufacturing process.

Procedure to remove damages from the gear tooth surface using the profile shift coefficient and the pressure angle. This section discusses in detail the technical aspect of the procedure, i.e. the rationale of the software code. For the sake of clarity, the procedure is described considering a single transverse section, even though the whole surface of a flank should be considered.

In order to better understand the procedure, it is worth noting that, in this paper, it has been assumed that the amount of material to be removed is not compatible with maintaining the original center distance together with an acceptable backlash, as instead could happen in the daily repair practice for less severe damages. Therefore, in order to keep the same center distance and an acceptable backlash, a new pinion has to be conceived, designed, and realized, so that it can mesh with the "new" mating gear that has been machined inside the "re-usable portion" of the "old" and damaged gear. Of course, the "new" pinion will be designed to correctly mesh with the gear, according to the basic laws of gearing (Ref. 25). In this paper in particular, it was decided to keep the normal module the same, so the pressure angle of the mating gear shall be modified to maintain the pitch base the same in both elements. Thus, unless the damage is not so deep that it enables the modification of both pinion and gear keeping the backlash in tolerance, one of the gears (usually the pinion, since it is the less expensive among the pair elements) must be manufactured.

Let us consider the section where the deepest superficial damage has been located. This damage can be treated as a profile deviation. The above introduced damages, i.e. large macropits and spalls, as well as profile deviations that are typically caused by wear or micropitting, can, in fact, be properly detected and measured by means of typical gear inspection procedures, since they have a typical surface extension of some millimeters and depths higher than some hundreds of micrometers. For initial pitting, in which the extension and the depth of the craters are smaller, the possible measurement problems can be overcome using non-contact measurement techniques, if available, or by estimating an upper limit for the depth of the craters. In this case, in fact, the depth of the craters is related to the region where the maximum stress level caused by the Hertzian pressure distribution occurs that can be evaluated by means of multiaxial fatigue criteria (Refs. 2–3). By definition these profile deviations are normal to tooth profiles in transverse plane. Nevertheless, deviation may be measured normal to tooth flank surfaces, and such measured values are to be converted before comparing them with limits of tolerances by dividing the values by $\cos\beta_b$ (Ref. 22).

The output of the inspection is the profile diagram, which includes the profile trace. Deviations of the curve (including the damage) from a straight line represent deviations of the profile from an involute curve (Ref. 22). For the purpose of gear tooth repair, it suffices to measure the "Total profile deviation" F_α (i.e. the maximum deviation) and the corresponding radius r_F on the tooth profile.

Let us assume that the maximum active tooth profile damage is equal to F_α and that it is located at radius r_F (Fig. 2). Point D is belonging to the original profile of the tooth and point F is located on the bottom of the damage. The segment DF is the vector N, the magnitude of which is F_α and the direction of which is the unit normal vector n to the tooth surface at point D.

On the basis of Livtin's equations (Ref. 24) (Fig. 3), the coordinates x_D and y_D of point D (i.e., point of the original profile at the diameter where the failure is measured) are given by Equations 1 and 2:

$$x_D = r_b \cdot \cos\left[\left(\frac{\tan\lambda_b}{p}\cdot\sqrt{r_F^2 - r_b^2}\right) - \eta\right] + \sqrt{r_F^2 - r_b^2}\cdot\sin\left[\left(\frac{\tan\lambda_b}{p}\cdot\sqrt{r_F^2 - r_b^2}\right) - \eta\right] \quad (1)$$

$$y_D = r_b \cdot \cos\left[\left(\frac{\tan\lambda_b}{p}\cdot\sqrt{r_F^2 - r_b^2}\right) - \eta\right] - \sqrt{r_F^2 - r_b^2}\cdot\cos\left[\left(\frac{\tan\lambda_b}{p}\cdot\sqrt{r_F^2 - r_b^2}\right) - \eta\right] \quad (2)$$

where:

$$\eta = \frac{s_{bn}}{d_b} \quad (3)$$

s_{bn} Base tooth thickness measured along the arc of the base cylinder of helical gears

d_b Base diameter

r_b Base radius

λ_b Lead angle on the base cylinder (which is the complementary angle of the helix angle at base cylinder)

p Screw parameter (Axial displacement in screw motion corresponding to rotational through the angle of one radian. The screw parameter is invariant with respect to the radius r of the cylinder that intersects the helicoid

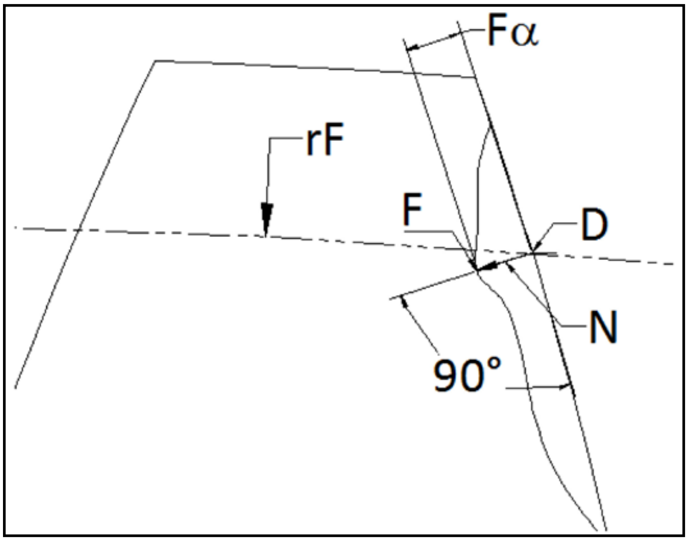


Figure 2 Normal vector of deepest failure.

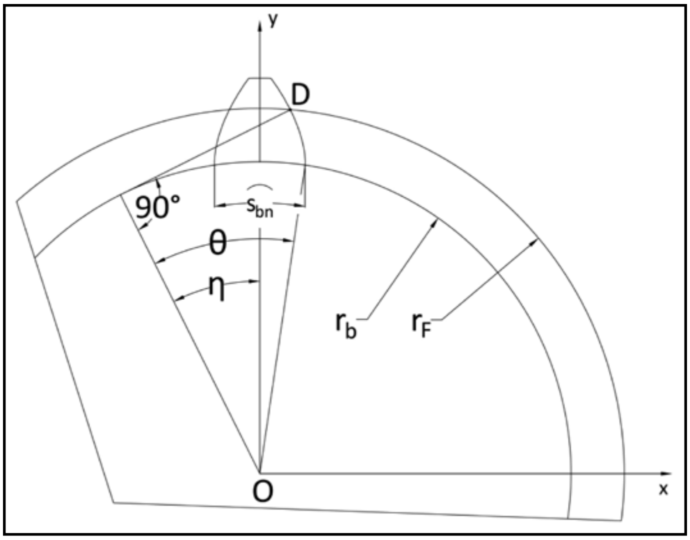


Figure 3 Gear profile generation (Ref. 22).

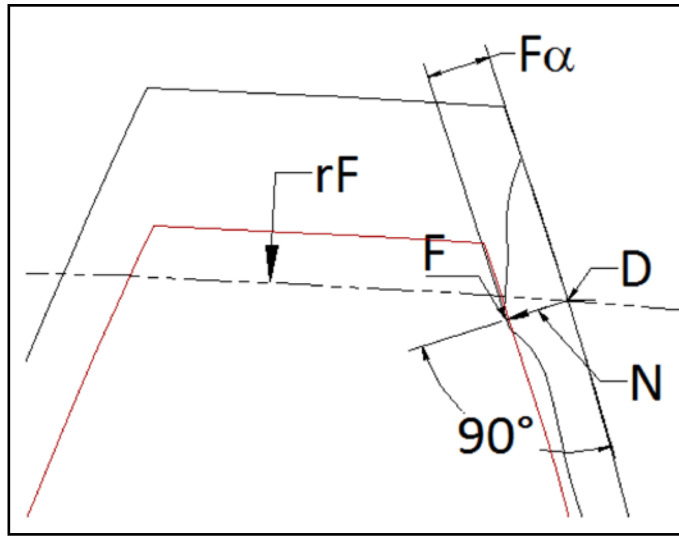


Figure 4 Modified profile, free from defects (red).

being considered, and is given by $p = r.tan\lambda$) (Ref. 24).

Flank normal transpose vector N at point D is given by Equation 4:

$$N = F_\alpha \cdot n = [\sin(\theta - \eta)\, F_\alpha - \cos(\theta - \eta) \cdot F_\alpha]^T \quad (4)$$

where:

$$\theta = \frac{\tan \lambda_b}{p} \cdot \sqrt{r_F^2 - r_b^2} \quad (5)$$

The coordinates x_F and y_F of point F (i.e. the "floor" of the defect) are therefore:

$$x_F = x_D - N_x \quad (6)$$
$$y_F = y_D - N_y \quad (7)$$

where:

N_x and N_y are the x and y components of vector N.

The aim of the repair procedure is to define a new gear tooth completely enclosed within the existing gear tooth (since it is only possible to remove material) and such that its external surface (free from defects) passes through point F. Figure 4 shows an example of the repaired tooth profile (in red).

This new tooth can be designed by reducing the profile shift coefficient and/or by changing the value of the pressure angle.

On the basis of the data of the original gear (gathered from reverse engineering or by the original drawings, if available) of the surface damage entity and on the actual loads, the developed script determines the pair of pressure angle and profile shift coefficient that remove the defect and maximizes tooth root strength.

However, several aspects are considered during these calculations.

The root radius fillet is usually changed, taking into account that the full fillet condition represents a limit.

Tooth pointing must also be avoided since a tip load application can result in a failure if the tip is completely hardened. It is recommended, in fact, that the tooth tip thickness shall not be less than 20% of the normal module. If the tip thickness condition is satisfied, the algorithm moves on the next check, which is the maximum radius fillet adopted on the tooth root diameter. If the radius fillet is less the maximum permitted, the original radius is kept; otherwise, the maximum fillet calculated is used.

The code plots two sets of graphics.

The first set of graphics consists in an overview of the area of the transversal section of the tooth (Fig. 8). The *y-axis* of these graphs shows the involute active profile in diameter units, and the *x-axis* shows the depth of the normal vector in respect of the involute curve (i.e. along unit normal vector direction $\boldsymbol{n} = \boldsymbol{N}/\|\boldsymbol{N}\|$). The shapes of the colored and the white area are the same for all the graphs of this output. The white area corresponds to the situations that, according to the developed method, are not possible to repair. This set is divided into two rows: the first row shows the parameters calculated to remove the damage with less stock removal as possible, and the second row shows the parameters that exploit the maximum strength the modified gear set can reach. The color represents the optimal value of the parameter, according to the color scale near each graph. More in detail, the first, second, and third columns represent the values of the pressure angle, the profile shift coefficient, and root fillet radius coefficient, respectively. The profile shift coefficient and the root fillet are consequences of the pressure angle adopted. The last graphic gives the reason why the code stops the loop — in other words, it shows that the new profile reaches the maximum pressure angle admissible (25°), or the minimum tooth tip thickness, or the new active profile will be undercut by the actual profile. The reader can see a vertical line, which marks the grinding limit for the production. Gears with damages beyond this limit must be firstly machined with a roughing process and then finished by grinding. There is also a horizontal line marked in these graphs. This line indicates the minimum diameter the gear can reach if the minimum profile shift coefficient is used (Fig. 8). It means that by turning the gear diameter, damages located above this line will be removed, regardless of the depth.

The second set of graphs (Fig. 12) takes into consideration only the measured damage and gives the original active profile of the gear-set, the damage depth, and the modified active profile calculated. Figure 12 also includes the values of the modified pressure angle, profile shift coefficient, and the tooth root fillet coefficient of both pinion and gear.

Figure 5 Refurbished gearbox.

Case Study — Quenched and Tempered Gearset

Figure 5 shows the case study gearbox. The user is a steelmaker, and this gearbox drives the wheel that moves the crane of either a 300/50 tons × 22 m hot metal charging crane or a 300/50 tons × 23.5 m teeming crane. This unit was first built in 1979, and some repairs have been carried out so far. The reason why the gearbox was removed from the crane is not known.

Table 1 summarizes the gear main data.

The gear geometry is calculated by gear calculation software (Ref. 23), and the profiles of the gear set are depicted in Figure 6. Gear set rating was calculated and the main results are summarized in Table 2. The minimum safety factors for these units are:

- Root safety: $S_{Fmin} \geq 1.5$
- Flank safety: $S_{Hmin} \geq 1.0$
- Safety against scuffing (integral temperature): $S_{int,min} \geq 2.0$
- Safety against scuffing (flash temperature): $S_{Bmin} \geq 2.0$
- Safety against micropitting: $S_{\lambda min} \geq 1.0$

It is worth noting that the safety against pitting is below the safety factor, which is supposed to be $S_{Hmin} \geq 1.0$. The pinion and the gear have safety factors equal to 0.77 and 0.80, respectively. This is evidence that the teeth may have their flanks damaged by pitting. Indeed, the inspection confirms the presence of pitting (Fig. 7).

The script developed is used, and the first information of the repair procedure is obtained. As Figure 8 shows, the repaired damage can be about 1.00 mm deep on the tooth tip and can linearly increase up to a depth of about 2.00 mm at the tooth root. The pressure angle can be increased up to 25° depending on the location and the depth of the damage. Deep damages located in an area near to the tooth root can be repaired using pressure angles from 15° to 20° (in blue). The modification of the profile shift coefficient is a consequence of the pressure angle calculated, and it can be seen that it varies from the original $x_2 = 0.4464$ to about $x_2 = -0.2$. The root radius fillet coefficient can be kept 0.3 mm as the original profile. The gear tip diameter can be reduced to a diameter below $d_{a2} < 645$ mm (the black horizontal line) if the minimum profile shift coefficient is used. In the second row, the graph shows the values for maximum strength, which means that the modified profile is the borderline from the colored area (maximum possible depth).

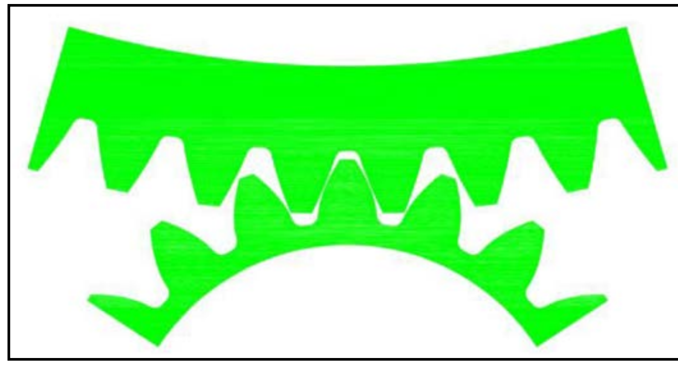


Figure 6 Profile of original pair.

Figure 7 Pitting detail.

Table 1 Gear set — main data

	Gear 1	Gear 2
Power (kW)	71.5	
Speed (1/min)	142.91	34.81
Torque (Nm)	2522.5	10355.4
Application factor	2	
Required service life	20000	
Center distance (mm)	400	
Center distance tolerance	ISO 286 Measure js7	
Normal module (mm)	8.0	
Pressure angle at normal section (°)	20.0000	
Helix angle at reference circle (°)	9.0375°	
Number of teeth	19	78
Face width (mm)	146.00	140.00
Profile shift coefficient	0.5000	0.4464
Material	34 CrNiMo 6	42CrMo 4
Surface hardness (HB)	300	260
Addendum coefficient	1.000	1.000
Dedendum coefficient	1.250	1.250
Root radius factor	0.300	0.300
Type of profile modification	None	None
Tip relief (μm)	8.50	9.20
Lubrication type	Oil bath lubrication	
Type of oil	Mobilgear 600 XP 320	
Oil temperature (°C)	70	

Table 2 Rating results of pair (9); (11); (13); (14); (15); (16); (17); (18); (19)

Contact ratio (Transverse/Overlap/Total)	1.4267/0.8750/2.3017	
	Gear 1	Gear 2
Actual tip circle $d_{a,e}$ (mm)	177.015	654.090
Root safety	2.09	1.84
Flank safety	0.77	0.80
Safety against scuffing (integral temperature)	4.03	
Safety against scuffing (flash temperature)	5.40	
Safety against micro-pitting	0.96	

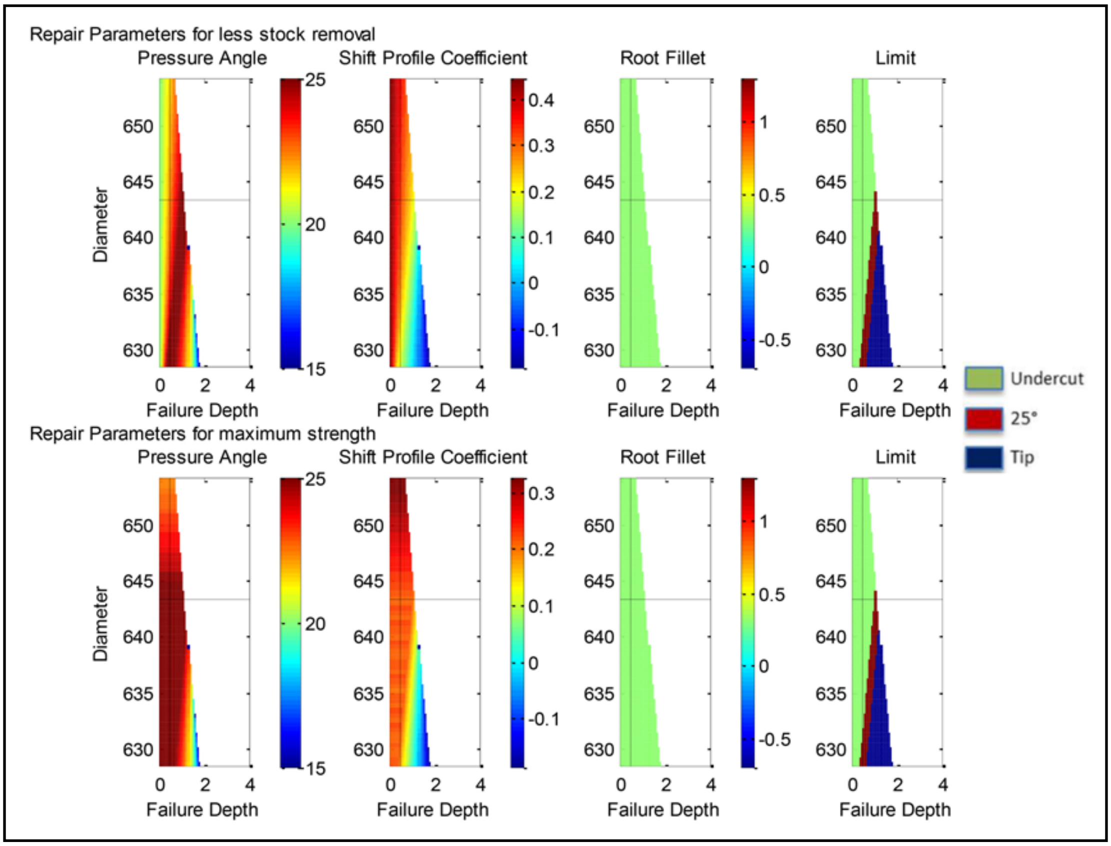


Figure 8 **Modification of damaged gear.**

The gear profile has also been inspected (Fig. 9a) (Ref. 22). The tooth of the gear profile surface that has the deepest pits is marked (Fig. 7); the profile chart is shown in Figure 9b. The depth and diameter location of the deepest pit are, respectively, F_α and $D1\_2$ of the left profile.

As can be seen, the pit is about 0.4 mm deep (the value in the chart is in microns) and it is located at diameter 634.710 mm. Despite the damage on the left flank, the right involute profile is in tolerance (DIN quality 9). The light blue arrow in Figure 10 shows the diameter of the deepest pit.

The coordinates of point D are calculated using Equations 1 and 2:

$$x_D = 317.277\,\text{mm} \quad (8)$$

$$y_D = -7.035\,\text{mm} \quad (9)$$

Applying Equation 4, the normal vector N is:

$$N = [0.122 \quad 0.342]^T \quad (10)$$

Thus the coordinates of the damage depth (Point F), using Equations 6 and 7 for x and y, respectively are:

$$x_F = 317.155\,\text{mm} \quad (11)$$

$$x_F = -6.693\,\text{mm} \quad (12)$$

The hypothesis for repair is to change the pressure angle to the maximum and the profile shift coefficient to the minimum in order to remove the damage and minimize the stock removal, avoiding tip pointing and undercut of the active profile of the repaired gear.

Figure 11 shows a detail of the gear profile and the location of the pitting.

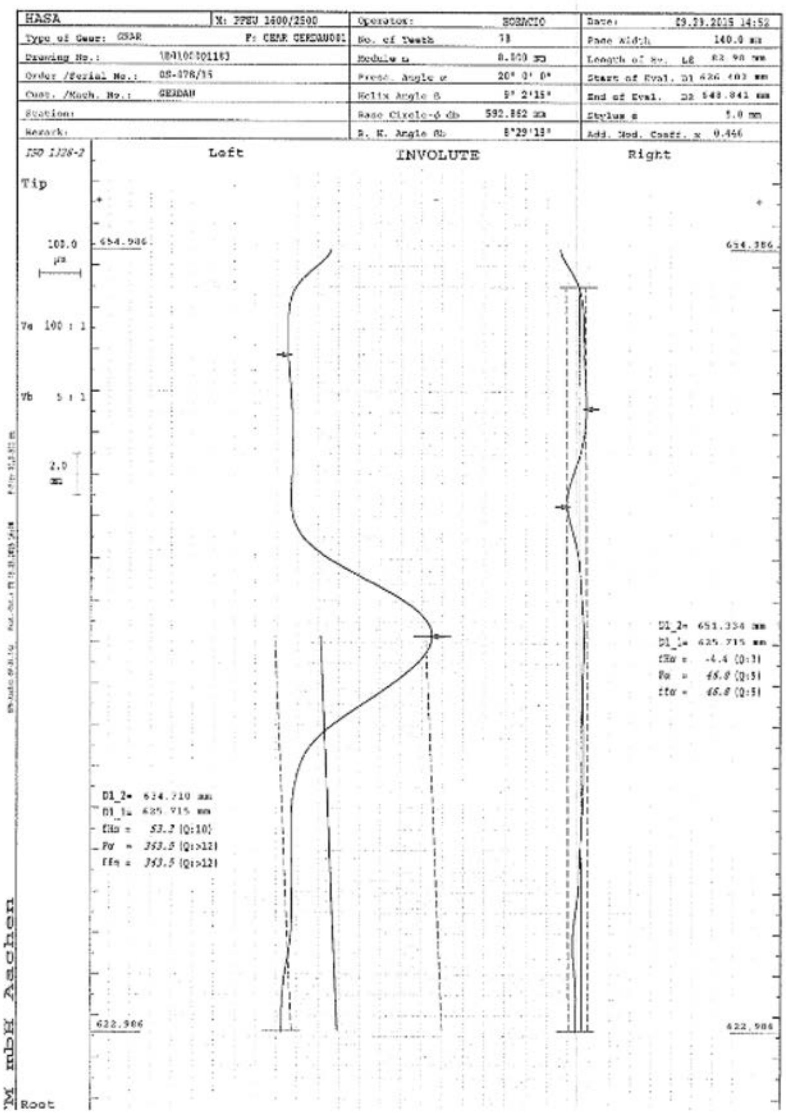
The second output of the script gives the profile of the original and modified teeth of the pinion and the gear, as well as the position and the depth of the damage. The second output also gives the nominal values of the parameters necessary to remove the damage considering the premises above. Normal pressure angle α_n, the profile shift coefficient x_2 and x_1, and the root fillet coefficient ρ are shown (Fig. 12).

Figure 13 shows a comparison between the new profile and the previous one. The red area represents the stock removal of the gear, and the yellow area is the complement of the profile of the new pinion that might be manufactured.

Table 3 summarizes the results of the calculations of the strength of the refurbished gear. Even if the software did not consider gear strength, since the decision was to minimize the stock removal, the root safety factors of the revised gear set are higher than the original gear pair. In particular, the safety against micropitting has been greatly improved. Even if pitting safety is still unsatisfactory, this result was accepted since the original gear pair has operated satisfactorily for about 30 years in similar conditions. It is worth noting that this gear has not been surface heat treated, hence its pitting resistance can still be increased by means of a flame or induction hardening treatment prior to finish grinding. Practically, these considerations demonstrate how the results of this approach can also supply useful hints to define a proper refurbishment procedure.

Using this procedure, the refurbishment of this case study may take about five days to be executed, considering in addition the machining process (turning, milling, and grinding). The machining and grinding processes were estimated and shall be evaluated since the production stages were not done. Figure 14 displays the Gantt chart from time elapsed up to the drawings' elaboration and the time estimated in the production to conclude process.

(A)



(B)

Figure 9 Damaged gear placed in gear-testing machine; a)—result of inspection; b)—pitting is about 0.4 mm deep and located in diameter of 634.710 mm.

Finally, an estimated cost to repair this gear is about 35% of the cost of a new one, apart from the cost to produce a new pinion.

Discussion and Future Works

The strength against micropitting greatly increased. However, this verification is of scarce relevance for industrial gears, while it is very important for wind power and turbo machinery gearboxes.

The pitting resistance is a critical factor for the quenched and tempered gears used in this study. This is due to the fact that these gears were through-hardened. The pitting resistance will increase greatly if their surfaces are nitride- or induction/flame-hardened. However, the increase in safety is noticed in comparison from the actual profile to the new profile. Consideration should be given to part distortion and original material selection if surface hardening processes are to be used.

The methodology tries to save at least one of the two mating gears (usually the more expensive one). This is the drawback of the methodology, unless the necessary intervention to repair is so superficial that the backlash between the pair is still in the tolerance, one of the gears of the pair (the pinion or the gear) might be sent to the scrap heap.

Delivery time is an important variable in repair procedures. As can be seen on the case study, the time spent (less than a week) in repairing is quite satisfactory if the meshing member does not need to be manufactured. However, even if a pinion is needed to be manufactured, the time spent can be less than the manufacturing of the whole gear set.

The cost is also relevant, and according to the author records, the cost of a gear repair is about 35% to 45% of the cost of a new part (not including the manufacturing of the mating gear, if necessary), depending on which material is used.

The effect of the profile and lead modifications were not evaluated in this research, so the software should take into consideration the micro-modifications, which improve the gear resistance to pitting, micropitting and scuffing.

In this work, the damages were inspected in a two-dimensional gear-testing machine. The damage can be topologically mapped in a three-dimensional machine, so the repair method can be further optimized.

In future works, to perform a better repair procedure an amount of stock removal must be considered and included in the script to improve the accuracy of the damage depth due to:

- The portion of the damage below the probe that is not reached, a consequence of its diameter

Table 3 Rating results of modified profile (9); (11); (13); (14); (15); (16); (17); (18); (19)		
Contact ratio (Transverse/Overlap/Total)	1.3312/0.8750/2.2062	
	Gear 1	Gear 2
Actual tip circle da,e (mm)	179.397	651.946
Root safety	2.13	1.90
Flank safety	0.79	0.81
Safety against scuffing (integral temperature)	4.08	
Safety against scuffing (flash temperature)	5.56	
Safety against micro-pitting	1.35	

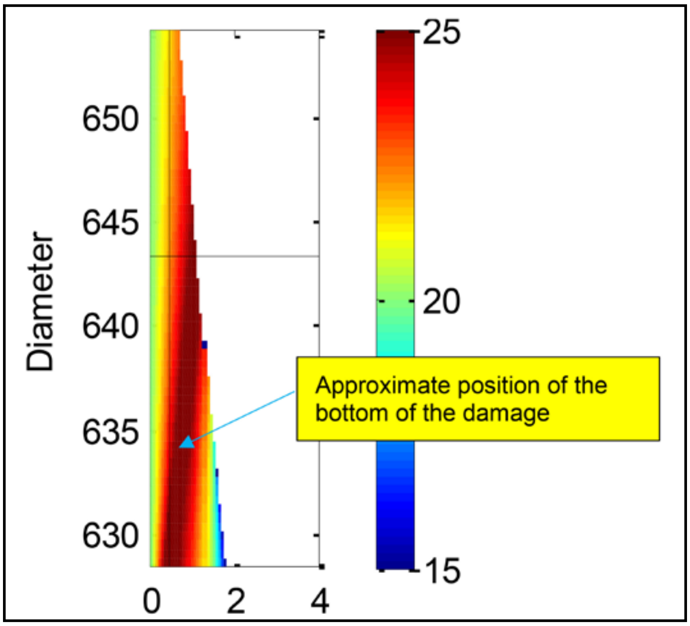


Figure 10 Position of bottom of damage inspected.

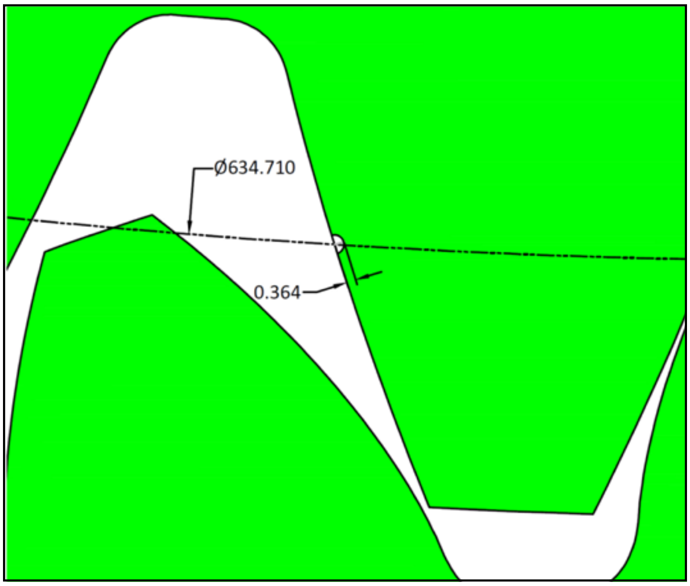


Figure 11 Detail of depth and position of pitting.

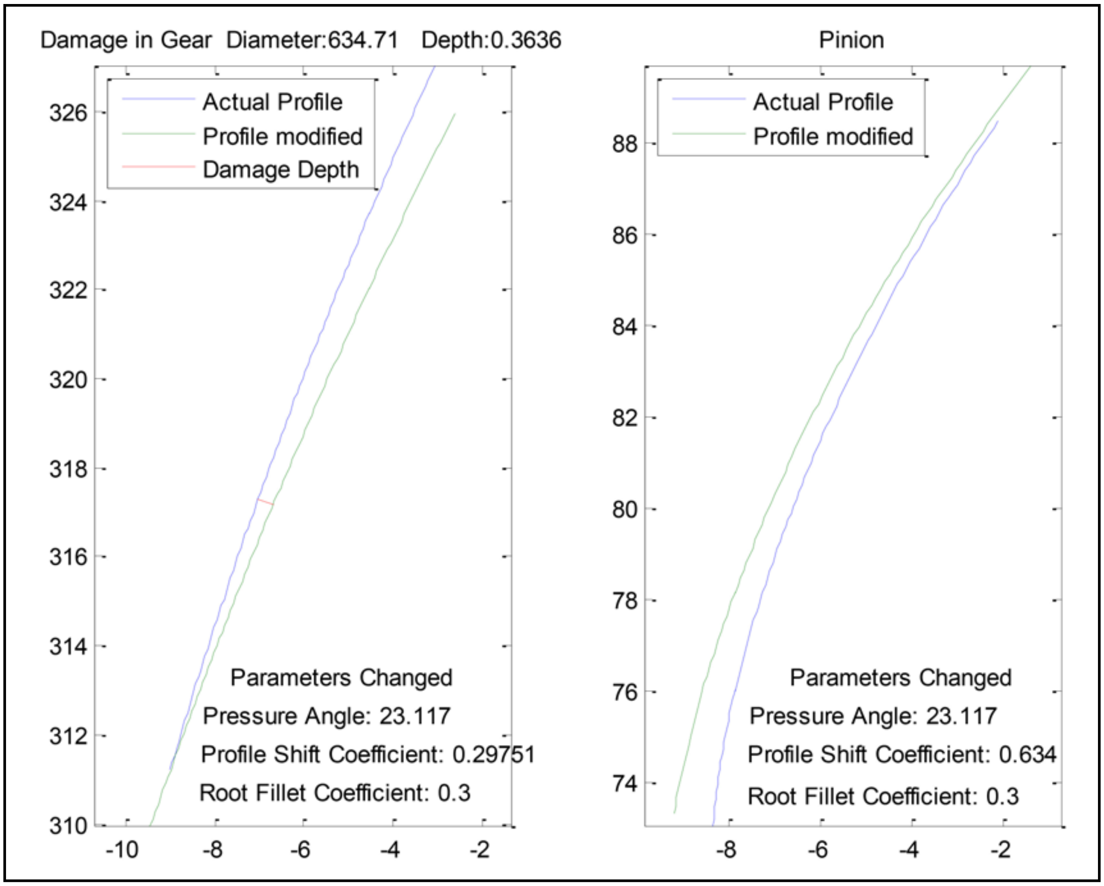


Figure 12 Modification chart.

- Small cracks typically associated with surface degradations

Gears can run in only one way; or they run loaded in one way and unloaded in the other way. Thus the flanks of the tooth can present different degrees of failure, and the gear flank wear is asymmetric. The approach can be optimized, taking into consideration the degree of damage from one flank to another, and less stock can be removed, or deeper failures can be removed, if an asymmetrical repair procedure is carried out. Moreover, the approach could even consider a refurbishment of the gears proposing an asymmetrical profile, i.e. — the right and left flanks having different tooth geometries.

The final product of the approach proposed in this article is a non-standard gear. It is important to evaluate the accuracy of the CAD/CAM software and the multi-axis CNC machinery in producing nonstandard gear sets.

Regarding surface-hardened gears, such as case-carburized and nitrided, the approach does not take into account that the hard layer of these gears could have been totally or partially removed during the machining process, due to uneven stock removal. For this reason, at the moment, the described procedure for gears is applicable to through-hardened gears, and additional investigations should be made on heat treatment processes in order to also apply it to surface-hardened gears. The potential for gear blank distortion must be carefully considered in light of dealing with a finished machine part that needs to keep its interface dimensions (e.g., bore and keyway) unchanged. This is a field for future research.

The machining process is an endless field to be explored. The cutting tools optimization focused in the repair of damaged gears is also a theme to be observed.

This approach could be applied not only in spur and helical gears but also in planetary gears, bevel gears, worm gears, asymmetrical gears, and other types of gears not mentioned.

Conclusion

The repair of mechanical components — especially gears — is a field with a lack of studies in the scientific community, but it is an active practice in the gear sector by the companies that provide maintenance servicing and by the after-sales of manufacturers. The cost of repair can be approximately 40% of the cost of a new gear.

This research has intended to provide a new approach to repair gears, creating criteria of acceptance between those gears

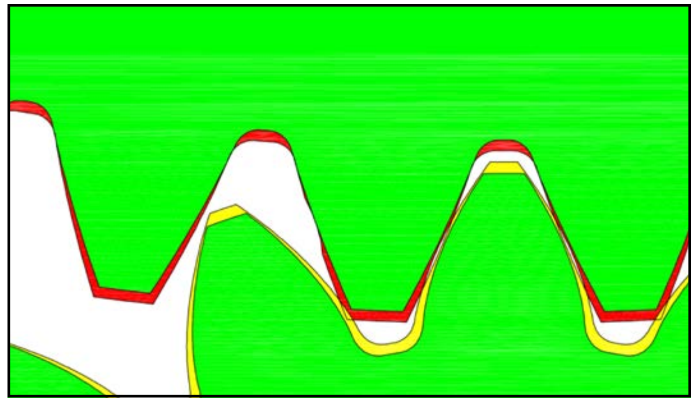


Figure 13 **Comparative chart of actual and modified pair — red area is stock removal and yellow area is amount increased.**

that cannot be useful anymore and those that can be reused. The first stage of the method eliminates gears that present deep damage to the tooth flanks, and the successive stages focus on superficial failure modes that can be removed by the modification of the gear tooth profile geometry.

The method shown is effective in repairing failures like wear, macro-pitting, micropitting, and scuffing. Among the superficial failures, the method has graphically shown how deep the damage could be, and it has shown that the repairable damage depth is dependent on its position on the tooth profile.

The software developed gives the user the two alternatives — if it is intended only to remove the damage with less stock removal during the machining/grinding process, or if it is also mandatory to have the gear tooth strength increased. For the last option the code exploits the maximum strength that the repaired gear can reach, without extrapolating the geometrical limits of tooth pointing, undercut, and pressure angles beyond 25°.

It is important to note that this methodology is effective because of the coming of the modern multi-axis CNC machinery with integrated CAD/CAM gear software and the improvement of cutting tools.

The methodology takes about one day to be executed from the visual inspection to the development of the new drawings, regardless of gear set size. Most of the time is spent in the machining shop, turning, milling, and grinding the parts. The time spent in production of the gears shall be more thoroughly studied in future works.

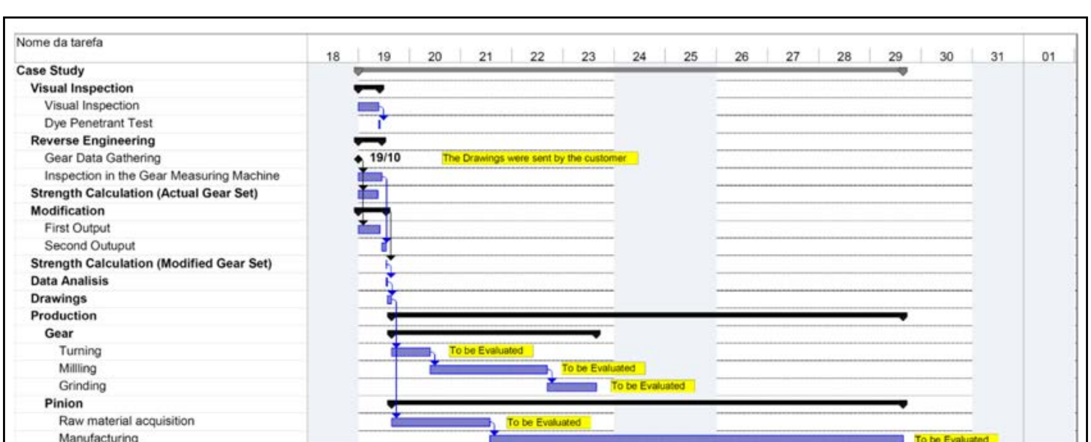


Figure 14 **Time spent to complete repair.**

References

1. AGMA, 2014. "Appearance of Gear Teeth – Terminology of Wear and Failure. First Edition," AGMA 1010-F14.
2. Conrado, E., S. Foletti, C. Gorla and I.V. Papadopoulos. 2011 "Use of Multiaxial Fatigue Criteria and Shakedown Theorems in Thermo-Elastic Rolling-Sliding Contact Problems," *Wear* 270, pp.344–354.
3. Conrado, E. and C. Gorla. 2011 "Contact fatigue limits of gears, railway wheels and rails determined by means of multiaxial fatigue criteria", *Procedia Engineering* 10, pp. 965–970.
4. Dudley, D. 1996, *Manuale Degli Ingranaggi*, Prima Ed., Tecniche Nuove, Milano, Italy.
5. Glew, T.C. 1980, "Failure Analysis and Repair Techniques for Turbomachinery Gears," *Proceedings of the Ninth Turbomachinery Symposium*, College Station, College Station, Texas, 1980, pp.11–23.
6. Gorla, C., F. Rosa, F. Concli and H. Albertini. 2012, "Bending and Contact Fatigue Strength of Innovative Gear Materials for Wind Turbine Gearboxes: Effect of Surface Coatings," ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE).
7. Gorla, C., F. Rosa, E. Conrado and H. Albertini. 2014, "Bending and Contact Fatigue Strength of Innovative Steels for Large Gears," *Procedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science.*
8. Hyatt, G. et al. 2014, "A Review of New Strategies for Gear Production," *6th CIRP Conference on High Performance Cutting*, University of Berkeley, Berkeley, California, Vol. 14, 2014, pp. 72–76.
9. ISO, 2014. "Calculation of Micropitting Load Capacity of Cylindrical Spur and Helical Gears – Part 1: Introduction and Basic Principles," ISO.TR 15144-1, 2nd Ed. – 2014.
10. ISO, 2014. "Calculation of Micropitting Load Capacity of Cylindrical Spur and Helical Gears – Part 2: Examples of Calculation for Micropitting," ISO. TR 15144-2, 1st Ed. – 2014.
11. ISO, 2008. "Calculation of Load Capacity of Spur and Helical Gears Part 1: Basic Principles, Introduction and General Influence Factors," ISO 6336-1, 2nd. Ed. – 2008.
12. ISO, 2007. "Gears - Cylindrical Involute Gears and Gear Pairs – Concepts and Geometry," ISO 21771, 1st Ed. – 2007.
13. ISO, 2006. "Calculation of Load Capacity of Spur and Helical Gears Part 2: Calculation of Surface Durability (Pitting)," ISO 6336-2, 2nd Ed. – 2006.
14. ISO, 2006. "Calculation of Load Capacity of Spur and Helical Gears Part 3: Calculation of Tooth Bending Strength," ISO 6336-3, 2nd Ed. – 2006.
15. ISO, 2006. "Calculation of Load Capacity of Spur and Helical Gears – Part 6: Calculation of Service Life Under Variable Load," ISO 6336-6, 1st Ed. – 2006.
16. ISO, 2003. "Calculation of Load Capacity of Spur and Helical Gears Part 5: Strength and Quality of Materials," ISO 6336-5, 2nd Ed. – 2003.
17. ISO, 2002. "Calculation of Load Capacity of Spur and Helical Gears – Application for Industrial Gears," ISO 9085, 1st Ed. – 2002.
18. ISO, 2000. "Calculation of Scuffing Load Capacity of Cylindrical, Bevel and Hypoid Gears – Part 1: Flash Temperature Method," ISO.TR 13989-1, 1st Ed. – 2000.
19. ISO, 2000. "Calculation of Scuffing Load Capacity of Cylindrical, Bevel and Hypoid Gears – Part 2: Integral Temperature Method," ISO.TR 13989-2, 1st Ed. – 2000.
20. ISO, 1998. "Vocabulary of Gear Terms – Part 1: Definitions Related to Geometry," ISO 1122-1, 2nd Ed. – 1998.
21. ISO, 1998. "International Gear Notation – Symbols for Geometrical Data," ISO 701, 2nd Ed. –1998.
22. ISO, 1992. "Cylindrical Gears Code of Inspection Practice Part 1: Inspection of Corresponding Flanks of Gear Teeth," ISO.TR 10064-1, 1^{st} ed. – 1992.
23. KISSsoft, 2013. "Shaft and Gears Advanced Training," *KISSsoft Trainining*, Bubikon, Switzerland, 2013.
24. Litvin, F.L. and A. Fuentes. 2004, *Gear Geometry and Applied Theory*, 2nd Ed., Cambridge University Press, New York, NY.
25. MAAG, 1985. *Maag Handbook*, Maag-Gear AG, Zurich, Switzerland.
26. Schultz, C.D. 2010, "Reverse Engineering," AGMA 10FTM09, *Fall Technical Meeting 2010*, American Gear Manufacturers Association, Milwaukee, WI.
27. Schultz, C.D. 1999, "Gearbox Field Performance from a Rebuilder's Perspective," AGMA 99FTM12, *Fall Technical Meeting 1999*, American Gear Manufacturers Association, Denver, Colorado.

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Carlo Gorla has since 1998 distinguished himself as professor of machine design in the department of mechanical engineering at Politecnico di Milano. His career has been devoted to the research of power transmission and gears—gears for aerospace application; gear failures; bending and contact fatigue; gear efficiency; gear noise; and transmission error. Gorla also serves as technical editor of the influential Organi di Trasmissione.

Francesco Rosa has worked in research and development in various roles for over four years, with people of different nationalities in small and big projects. He is currently a mechanical design engineer in the molded case circuit breakers group, principally covering topics related to cost saving. His technical competencies include 3-D and 2-D technical design, CAD/CAM machining, laser reverse-engineering, additive manufacturing and FEM simulations. Rosa is also skilled in product engineering and project management. Francesco Rosa attended both Politecnico di Milano (mechanical engineering degree) and Bologna University (doctorate). He is currently an assistant professor in the department of mechanical engineering at the Politecnico di Milano. His research interests include gear bending fatigue; methods and tools for geometric modeling of gears; numerical simulations of gear manufacturing processes; and gear meshing.

Horácio Albertini Neto, born in Belo Horizonte Brazil, holds a Ph.D. in mechanical engineering from the Polytechnic University of Milan. He started his professional career in 2002 as an industrial gearbox and power transmission design engineer at HASA Ltda. Since 2006, he has worked as an industrial manager in the same industry. In addition to his professional activity, he was a lecturer at Catholic University of Minas Gerais in 2013 and 2014, where he taught mechanical drawing and was invited to be a member of board of final projects in mechanical engineering. Furthermore, Horácio Albertini has a bachelor's in civil engineering and a master's degree in structure engineering from the Polytechnic University of Milan.

Emuge

INTRODUCES U.S. TOOL RECONDITIONING SERVICES

Emuge Corp. has introduced tool grinding and reconditioning services based out of the company's North American headquarters in West Boylston, MA. A clean, new state-of-the-art manufacturing facility at Emuge Corp. is now equipped with the latest technology high precision CNC grinding machines and inspection equipment, providing tool reconditioning for U.S. and Canadian customers for Emuge taps, drills and end mills, in addition to other brands of carbide drills and end mills.

"Reconditioning Emuge tools by Emuge makes sense," said Bob Hellinger, president of Emuge Corp. "Emuge has the knowledge and manufacturing expertise to refurbish an Emuge tool to its original condition and specification, providing maximum performance levels, predictable operation and longer life than any other method, all at a modest investment for the utmost value."

Emuge reconditioning services offer complete inspection and evaluation of all tools received. Reconditioning services include complete regrinding to the original geometry of Emuge taps, drills and end mills, as well as other brands of drills and end mills. Reconditioning services also include corner radius, Weldon flats and other modifications to standard end mills, and PVD coatings through a state-of-the-art coating system. All reground tools are delivered with a detailed report on services rendered. (*www.emuge.com*)

Seco/Vacuum Technologies

APPOINTS NEW VICE PRESIDENT OF SALES

Seco Vacuum Technologies, LLC is pleased to announce the appointment of **William (Bill) Warwick** to the position of vice president—sales. Warwick will be responsible for sales of capital equipment, spare parts, and aftermarket services throughout North America.

Warwick has extensive knowledge in vacuum technology, most recently holding the position of product manager at Schunk Carbon Technologies, LLC. He holds degrees in business management and environmental protection and has focused his career in sales, support and service of vacuum related products in the brazing, heat treating, and sintering industries.

Warwick joins a talented team of technical specialists selling and supporting both standard and custom vacuum furnaces for this new company of the Seco/Warwick Group. (*www.secovacusa.com*)

Bourn & Koch

ACQUIRES DIAMOND TECHNOLOGY INNOVATIONS

Bourn & Koch has acquired Diamond Technology Innovations (DTI), headquartered in Olympia, Washington, manufacturer of waterjet orifices, nozzles, and related products and services.

"The acquisition of Diamond Technology Innovations enhances Bourn & Koch's existing business in machine tool consumables and spare parts and provides an entrance into the waterjet market," explains Terry Derrico, president of Bourn & Koch. "Waterjet is one of the faster growing segments within the machine tool industry. We are excited to partner with the talented team at Diamond Technology Innovations and believe that both companies' employees, suppliers, and customers will benefit from this combination."

Ted Jernigan, president of Diamond Technology Innovations, commented, "We are pleased to have found a long-term home for the company and are excited about the opportunities that will result from this transaction." Jernigan will continue at Diamond Technology Innovations in his role as president and the company's day-to-day operations will not be impacted by the transaction.

Waterjet technology is capable of cutting a virtually limitless range of materials such as carbon fiber found in aerospace wing panels; glass and steel up to a foot thick; soft materials such as automotive headliners; tissue paper; and even food products such as chicken, cakes, and pickles. This is accomplished via an ultrahigh-pressure pump that generates a 94,000 psi stream of water which is then converted into velocity via a specially-engineered jewel orifice that produces a coherent jet stream to cut soft materials with pure water alone, or in combination with abrasive to cut hard materials. While the orifice is often times the most overlooked waterjet component; without it, the entire system would fail to function, making waterjet orifice design critical to waterjet cutting performance. (*www.bourn-koch.com*).

GMTA

PROMOTES KNOY TO VICE PRESIDENT

Walter Friedrich, president of GMTA (German Machine Tools of America) recently announced the promotion of **Scott Knoy** to vice president for the company. Knoy joined GMTA on July 1, 2005, back when the company was known as American Wera. Since then, Knoy has played a large role in the growth of the organization. Knoy was particularly instrumental in helping GMTA secure a "Global Purchase Agreement" with General Motors, according to Friedrich, who made the announcement from the company headquarters in Ann Arbor, Michigan.

"Scott has also played a key role in keeping the business running smoothly, especially during the last several years, as we've opened our facility in Mexico and I've been working in Mexico to support this effort," Friedrich observed. The GMTA Mexican facility in Queretaro is now fully functional, with plans for expansion already in the works.

As a sign of appreciation and a move for the future, Friedrich spoke with the GMTA board of directors at this year's IMTS and they agreed to offer Knoy the position of vice president at GMTA.

Speaking about the promotion, Friedrich said, "Between myself as the president and Scott as our vice president, we will continue to expand our market share, our products and technologies, plus our great customer relationships and service offerings."

Knoy comments, "I'm honored to accept the new responsibilities and to continue contributing to the growth of our company. Gears and the auto industry are in my blood, as my dad was in the business and I literally grew up around gear machines."

Knoy will continue to oversee the sales and marketing of the company, in addition to other administrative duties at the Ann Arbor headquarters. Knoy is also very active with AGMA, the gear association. He is a graduate of the University of Michigan and also holds an MBA. (*www.gmtamerica.com*)

Drake Manufacturing Services Co.

APPOINTS DIBBLE DIRECTOR OF SALES IN NORTH AMERICA

Drake Manufacturing Services Co., LLC has appointed **Bruce L. Dibble** as director of sales in North America.

Dibble is responsible for managing Drake's North American sales efforts and serving as advocate for its customers and prospective customers.

With many years of experience in the machine tool industry as former director of North American sales at Schmitt Industries, he understands the importance of solid customer relationships and collaboration for successful project execution.

Timothy Young, Drake CMO, states, "We are pleased to have Bruce on the Drake team to expand and support our precision thread grinding solutions in the steering systems, aerospace, cutting tool, speed reducer, ball screw and linear motion industries." (*www.drakemfg.com*)

Sandvik Coromant

BECOMES DMG MORI PREMIUM PARTNER

Cutting tool and tooling systems specialist Sandvik Coromant has signed an agreement to become a premium partner of leading machine tool manufacturer DMG MORI. The deal, which makes Sandvik Coromant the only tooling manufacturer to be named as a DMG MORI Premium Partner, will further strengthen the relationship between the companies on a global scale. Machine shops around the world will benefit from the combined knowledge and experience of the two market leaders.

As a DMG MORI Premium Partner, Sandvik Coromant will work with the machine tool builder on a wide-range of initiatives, including R&D and engineering, open house events, trade show appearances, technical seminars, website collaboration and the DMG MORI Journal. Specifically, the agreement will give users of DMG MORI machines access to the turning, parting and grooving, threading, milling, drilling, boring and reaming tools from Sandvik Coromant, as well as tooling systems and the company's extensive range of knowledge, industry solutions and services.

(Left to right) Dr. Masahiko Mori, Klas Forsström, Christian Thönes, Björn Roodzant, and Sean Holt.

"This agreement confirms our position as one of our industry's true premium and forward-looking companies," said Klas Forsström, global president of Sandvik Coromant. "As we join forces with a leading machine tool builder, for example, on turnkey projects, we take an active role in advancing technology for the industry." (*www.sandvik.coromant.com*)

Samputensili

APPOINTS GEAR TECHNOLOGY MANAGER

Samputensili recently announced the recent appointment of **Dr. Ing. Deniz Sari** to the newly created position of gear technology manager for Samputensili and its joint-venture Star SU. In his new role, Sari will analyze all best practices coming from Samputensili and Star SU manufacturing plants around the world combine them and optimize all production processes from design to shipping, not only from a technical, but also from an organizational point of view. In this sense, he will be responsible for supporting the international sales structure by developing solutions, systems and synergies across the company, and helping to establish seamless consumer experiences worldwide.

"As our organization continues to expand and evolve worldwide, talented professionals like Deniz help us grow and strengthen our position on the market," said Teodoro Ceglia, general manager of Samputensili Cutting Tools. "In particular, Deniz's extensive experience with production processes, technological solutions and industry experts will make our training programs stronger and more valuable for our customers who attend."

"Aachen University and the WZL represent state-of-the-art education and process development in gear manufacturing technology. We are very pleased to have Deniz Sari become part of our global gear technology team to help us develop gear manufacturing technology for the next generation," said David Goodfellow, president of Star SU LLC.

Born in Aachen, Germany, Sari holds a diploma degree and a doctoral degree in mechanical engineering from the RWTH Aachen University. After his study, he has worked first as a researcher, then as the leader of the Gear Manufacturing Group of the WZL of RWTH Aachen University.

"I am excited to join the company in a position where I can share my knowledge and skills," said Sari. "After working for the WZL of RWTH Aachen University, I look forward to putting my experience to work and implementing best-in-class systems across the company, including a strategic focus on the innovation of gear cutting tools, which will help customers grow their profits and efficiency." (*www.star-su.com*)

Best Carbide Cutting Tools

JOINS CERATIZIT GROUP

Best Carbide Cutting Tools, LLC has joined global carbide specialist, Ceratizit Group. Through this partnership, Best Carbide will have access to Ceratizit technologies and expertise that will help the company to improve its manufacturing process, technical capabilities and quality of tooling with the goal of ultimately adding greater value for customers.

For the first time in its 37-year history, Best Carbide becomes part of a global cutting tool organization. This will have a substantial benefit for Best Carbide's stability, growth, and advancement. The agreement is a win for both companies. Best Carbide Cutting Tools, LLC will continue to operate as it has in the past and honor all existing customer and vendor relationships moving forward, but now with full support from the Ceratizit Group. (*www.bestcarbide.com*)

DMDII

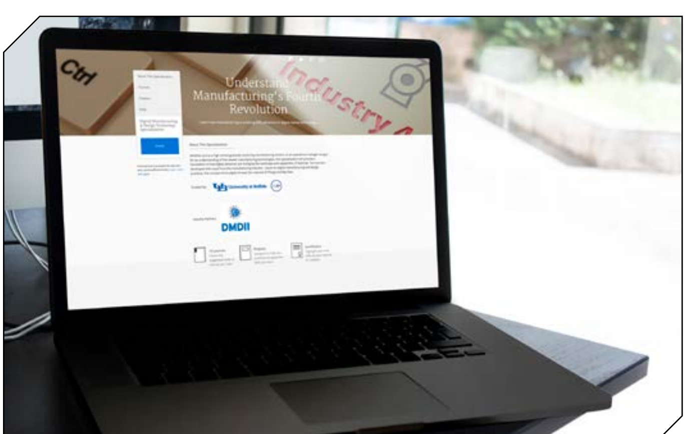
OPENS ONLINE DIGITAL MANUFACTURING COURSES

Enrollment has opened for the first three online courses of a 10-course "101" series focused on harnessing data to make American factories more efficient and competitive.

Developed in partnership with the University at Buffalo (UB) under coordination of The Center for Industrial Effectiveness (TCIE), Digital Manufacturing and Design Technology launches on Jan. 30. The massive open online course (MOOC) curriculum includes 40 hours of instruction, assessments, peer interactions and a final project.

Developed for both students and workers, the series will introduce a broad range of digital manufacturing and design technologies, and demonstrate how they can be used throughout a product's lifecycle.

TCIE designed the curriculum alongside industry partners, including Siemens PLM, SME, the Association for Manufacturing Technology, Moog Inc. and Buffalo Manufacturing Works. Its development was funded with a $380,000 award from the Chicago-based Digital Manufacturing



and Design Innovation Institute, a UI LABS collaboration. (UI stands for university and industry.)

"Workforce development is critical to maintaining American manufacturing competitiveness," said Caralynn Nowinski Collens, CEO of UI LABS. "It is also important that the collaborative knowledge DMDII gains through university, industry, startup and government collaboration reach as many people as possible."

The course modules will introduce digital manufacturing and design technologies, which use data to connect and improve each stage of the manufacturing process. For example, one module will explain how to upgrade legacy machines so they capture information about their production and performance. Another module on cyber-physical security will cover how to ensure these internet-connected devices are protected from hacking.

After completing the series, known as a "specialization," participants will earn a certificate in digital manufacturing and design.

"For decades universities and factories were worlds apart, but the speed of innovation is drawing them closer and closer," said Liesl Folks, dean of the UB School of Engineering and Applied Sciences. "Creating a first-of-its-kind, impactful curriculum on digital manufacturing is an important step in strengthening and retraining our manufacturing employment base."

The courses will be offered on Coursera, the world's largest platform for MOOCs. Individual course content, including videos and readings, can be accessed at no cost; the fee to enroll in the series, with access to all assignments and the opportunity to earn a specialization completion certificate, is $49 per month. (*www.coursera.org/specializations/digital-manufacturing-design-technology*)

Grind Master

ACQUIRES SPMS EUROPE

Grind Master recently announced the acquisition of SPMS Europe. SPMS is a French machine tool builder since 1974 with a strong technology focus in the European automotive industry. With 500+ global machine installations, the product range includes specialized superfinishing machines for automotive transmissions, deep fillet rolling for crankshafts, specialized grinding machines for cylinder head and cylinder blocks, centerless superfinishing machines and various deburring solutions. SPMS has been a supplier for Renault, Peugeot, CITROEN, Fiat, Ford, Jaguar and Volkswagon.

This alliance strengthens the position of both partners with an expanded range of global products and services. SPMS equipment complements Grind Master NANOFINISH range of microfinishing and superfinishing machines. Grind Master's strong presence in India and China also complements the strong European base for SPMS.

Grind Master now has solid operations in India, China and Europe with a strong collaboration in the United States. (*www.grindmaster.co.in*)

LMI Aerospace Inc.

FILLS TWO EXECUTIVE POSITIONS

LMI Aerospace Inc. has appointed Jay Inman as president of engineering services, a role he had been serving on an interim basis since September 2016. The company also has named Keith Schrader as vice president of operations, overseeing its aerostructures operations and supporting functions. Both positions are effective immediately and they will report to LMI Chief Executive Officer Dan Korte.

"Jay and Keith distinguished themselves as leaders in their respective organizations as we navigated through key executive vacancies in the second half of 2016," Korte said. "This time gave us the opportunity to take a closer look at our leadership structure as we continue to focus on developing talent from within and managing our business more efficiently. An added benefit of these organizational changes is cost savings, allowing us to balance how we run the business while making the necessary investments in our operations and infrastructure to be ready for anticipated production ramp-ups starting this year."

Schrader previously served as vice president and general manager of the Assembly & Machining Center of Excellence (COE), one of two aerostructures COEs that reported to a chief operating officer, all roles the company has eliminated. In his new role, Schrader will lead a consolidated operations organization comprising all of the company's assembly, machining, fabrication, composites and processing sites, as well as operational support functions including supply chain management; manufacturing engineering; quality and environment, health and safety.

With Inman's promotion, the company has eliminated the role he previously held as engineering services chief operating officer. (*www.lmiaerospace.com*)

February 15–16—AWEA Wind Power on Capitol Hill 2017 Wahington D.C. AWEA Wind Power on Capitol Hill is a rare opportunity for AWEA members and others who want to help advance wind energy to participate in advocacy training and then put that training to work to educate legislators and their staff on the wind industry's top policy initiatives at both the state and federal level. Over the course of two days attendees will participate in an advocacy boot camp where they'll learn the most effective techniques for conducting meetings on the Hill, and fostering long-lasting relationships with elected officials; put that training to work in face-to-face meetings with elected officials and their staff; understand how federal and state policies affect the future of U.S. wind development and network with colleagues in the industry and congressional staff at a reception on Capitol Hill. For more information, visit *www.awea.org*.

February 22–24—AGMA 2017 Gear Materials Clearwater Beach, Florida. Learn what is required for the design of an optimum gear set and the importance of the coordinated effort of the gear design engineer, the gear metallurgist, and the bearing system engineer. Investigate gear-related problems, failures and improved processing procedures. Gear design engineers, management involved with the design and manufacture of gearing type components; metallurgists and materials engineers; laboratory technicians; quality assurance technicians; furnace design engineers; and equipment suppliers should attend. The course is instructed by Ray Drago and Roy Cunningham. For more information, visit *www.agma.org*.

March 6–9—AeroDef Manufacturing 2017 Fort Worth, Texas. AeroDef 2017 showcases the industry's most advanced technologies across an innovative floor plan designed to facilitate interaction and business relationships between exhibitors and buyers looking for integrated solutions. Keynote speakers and panelists come from the highest level of government and business. They come to share their vision of the potential of technology, collaboration and public policy to transform manufacturing – concepts that attendees can actually experience on the exposition floor and in conference sessions. It's the one event that brings together high-concept, integrated solutions and real-world applications. Produced by the SME, in partnership with industry OEMs, the show's mission is to foster innovation across the extended enterprise to reduce costs, expedite production times and maintain manufacturing competitiveness in the global economy. For more information, visit *aerodefevent.com*.

March 7–9—An Introduction to Gear Process Engineering Naperville, Illinois. The first in a new training seminar series from Arvin Global Solutions, this course will give attendees an extensive background on gear processing. Presenters include Bruce Roberge, Ron Green, Matt Mondek, Chuck Schultz, Mike Steele, Al Swiglo and Kevin Walsh. These recognized experts will discuss specific aspects of gear machining as well as heat treatment and quality. The seminar fee is $1,925 and includes breakfast and lunch each day as well as a training manual containing a summary of seminar topics. For more information, visit *www.arvinglobalsolutions.com*.

March 7–12—TIMTOS 2017 Taipei City, Taiwan. TIMTOS is Asia's second largest and Taiwan's largest metal processing equipment trade show. This event will host a record of 1,103 exhibitors from 21 countries. Participants will use 5,434 booths to interact with 47,500 projected visitors from 90 nations. To mark the show's 26th cycle, TIMTOS is presenting several features, and a fresh focus on industry 4.0+ and smart manufacturing for seamless industrial upgrades. One show highlight is the Summit that takes place March 8th and March 9th in Conference Room 101 at the Taipei International Convention Center (TICC). It addresses the four topics of Smart Machines; Future Factories; the Automotive Manufacturing Revolution and the Aerospace Supply Chain. For more information, visit *www.timtos.com.tw/en_US/news/info.html?id=0B1908D16C18F485*.

March 21–23—AGMA 2017 Gearbox CSI Concordville, Pennsylvania. Gain a better understanding of various types of gears and bearings. Learn about the limitation and capabilities of rolling element bearings and the gears that they support. Grasp an understanding of how to properly apply the best gear-bearing combination to any gearbox from simple to complex. Gear design engineers; management involved with design, maintenance, customer service, and sales should attend. Instructors include Ray Drago and Joseph W. Lenski, Jr. For more information, visit *www.agma.org*.

March 22–25—The MFG Meeting 2017 Amelia Island, Florida. Hundreds of manufacturing leaders will gather to gain a deeper understanding of the forces transforming manufacturing—from the digital factory and cybersecurity to economic and global market trends. Featuring an array of entrepreneurs, technologists, business experts, and more, MFG speakers give insight for the future of manufacturing along with inspiration to lead your organization with courage, clarity, and wisdom. Keynote speakers include tech entrepreneur Josh Linkner, current player for the Philadelphia Eagles, Jon Dorenbos and Douglas K. Woods, president of AMT. Jointly produced by the Association for Manufacturing Technology (AMT) and the National Tooling and Manufacturing Association (NTMA), this event tackles the issues that affect the entire realm of manufacturing. For more information, visit *www.themfgmeeting.com*.

March 27–31—PCI Powder Coating 2017 Indianapolis, Indiana. The Powder Coating Institute (PCI) Powder Coating 2017 is the best place to be for learning, networking, and supporting the entire powder coating industry. The event will kick off with PCI's popular Powder Coating 101: Basic Essentials Hands-On Workshop, offered Monday and Tuesday, March 27 & 28. The workshop includes a comprehensive agenda that covers all the basics of powder coating operations and concludes with hands-on training demonstrations at an area powder coating manufacturer's facility. The Technical Conference will be held on Wednesday and Thursday, March 29 & 30, complete with general sessions each morning followed by concurrent technical sessions. The week will conclude with the PCI Custom Coater Forum on Thursday evening and Friday, March 30 & 31. For more information, visit *www.powdercoating.org*.

March 30–April 1—AGMA-ABMA Annual Meeting 2017 Rancho Mirage, California. The 2017 Annual Meeting marks the start of a new century for both AGMA and ABMA and the introduction of a more robust education program. Not only has the planning committee expanded the number of presentations, but they have also offered a tremendous amount of versatility, all thanks to the AGMA and ABMA members. Business presentations include Internet of Things, Economic Forecast, Aerospace Technologies, Disruptive Technologies, Hiring Practices, Post-Election Manufacturing Outlook, and a Guide to Selling Your Company. Additionally, "Endeavor to Succeed" will feature Captain Mark Kelly, Commander of the Space Shuttle Endeavour's Final Mission. For more information, visit *www.agma.org*.

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

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

____

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

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

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

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Swiss Watchmaking — with 3-D Printing

Jack McGuinn, Senior Editor

For centuries, Switzerland has been considered home to the greatest watchmakers in the world. Works of fine beauty and optimal precision have been the norm there seemingly forever.

But 3-D printing a Tourbillon knock-off? That actually works? *That's* news. The original Tourbillon was designed in 1795 by French-Swiss watchmaker Abraham-Louis Breguet. Highly prized by watch collectors, it is indeed a thing of beauty in its visual and mechanical execution.

Christoph Laimer, Zurich-based chief 3-D designer for *makeSEA.com* (an independent distribution registry for 3-D print designers) is the creator of this unique timepiece. It was manufactured/printed with a consumer market 3-D printer, the Ultimaker 2; the watch size is 98 mm (diameter) by 93 mm (length). Like, say, the Frankenstein monster, it is not a perfectly working replica—e.g., not very accurate, bulky, and only runs for about a half-hour. Yet it remains, as far as can be determined, the only existing, working watch that is 3-D-printed—including *every* gear. What's more, Laimer's creation took top prize at last year's Piemonte Share Festival. And for you at-home 3-D printers, you'll be thrilled to know that Laimer's source files for his 3-D model Tourbillon are available online free of charge (*Thingiverse.com*).

Following is a brief interview with Laimer—the creator of the first 3-D-printed mechanical watch.

When did your fascination with 3-D printing begin?

2013—on a business trip. After a hard day working as a software engineer in the factory, back at the hotel I was browsing the web for 3-D printing. When I saw the button "Buy Now" it happened that my index finger did an uncontrolled movement. Back home, the heavy box with the kit was already waiting for me. My first real project was a "normal" clock (go to *youtu.be/HgZBPYJ2Y-w*).

What compelled you to focus on 3-D full time?

I was working as a software engineer and manager for almost 20 years, and I still loved my job. Either I get retired at the same company, or I need to look for another company. Plan C was a break, and focus on hobby and family. So I constructed the Tourbillon. It wasn't my plan to make it a new profession.

At risk of appearing flip, how does one make a living at this? It seems more like a fun hobby than a commercial enterprise. Do you consult/do any industrial-type prototyping of, for example, gear or other components design?

It's still not sure, if my new profession has a future. I was lucky that I got a big work order from a U.S. company to create a whole set of 3-D-printable objects (*www.makeSEA.com*). I'm also lucky that my wife has a permanent part-time job, so the finances are not as critical. Certainly I'm using my time to get experienced in using CAD-tools, and extend my knowhow as a mechanical engineer. The required expertise for profiting from 3-D printing is much different than the traditional machining knowhow. So I'm hoping that my new knowhow extends my options for any new job.

A recent online article says "your belief that future watches will be highly customizable—not only engraving, ornaments or decoration, but very complex objects combining mechanics and electronics—has led (you) to explore and push the boundaries for 3-D printing." Can you expand on the "explore" and "push" parts?

Many published 3-D printing projects are decoration: vases, boxes, sculptures, etc. Just one, single mechanical block—and hence limited functionality. So far, 3-D printing was mainly used for visual prototyping. But that's not the limit of the 3-D printing technology. Today it is possible to 3-D-print complex mechanical objects in plastic or metal, and to use these objects as final product. My watch is a demonstration for this. Of course the 3-D printing technology is not useful for cheap, mass-production. Injection molding will always be much more efficient for producing thousands of identical items. (But) it is possible to design parametric mechanical models (that enable customization). To 3-D-print such a custom model is much cheaper than crafting it by hand. (*Primary source for this article: Jan. 12/16, "Introducing the World's First Fully Functional 3-D-Printed Watch: The Christoph Laimer Tourbillon," by Nicholas Manousos at HODINKEE.com.*)