gear TECHNOLOGY®

NOV/DEC 2013

STATE OF THE GEAR INDUSTRY

SURVEY REVEALS CURRENT TRENDS AND FUTURE EXPECTATIONS

2013 BUYERS GUIDE

Gear Manufacturing Machines, Tooling and Services

LOOKING BEYOND THE NUMBERS

A NEW DAY FOR U.S. RAIL?

FLEXIBLE AND LEAN: EDUCATIONAL RESOURCES

TECHNICAL

ASK THE EXPERT: High-Temp Gears

DESIGN AND OPTIMIZATION OF PLANETARY GEARS

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THE JOURNAL OF GEAR MANUFACTURING

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PTG-1

GS 400

Affordable hob sharpening and in-house tool maintenance

Star's PTG-1 sharpens both straight and spiral gash hob designs up to 8" OD x 10" OAL. Additionally, it sharpens disk, shank and helical type shaper cutters and a wide range of round tools, making it a versatile tool room machine.

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our machines are making history

Gears for the Curisoity Rover were ground using the KAPP VUS 55P.

August 2006
NASA begins development on Mars Science Laboratory Rover(MSL)-later renamed Curiosity.

December 2008 *(date for illustrative purposes only)*
Critical gears are required for MSL's 6 wheels. An American manufacturer is chosen to produce these. KAPP VUS 55P is chosen to grind them.

November, 2011
Curiosity launches into space from Cape Canaveral Air Force Station, Florida.

August 6, 2012
Curiosity lands successfully on Mars.

September 2012 - July, 2013
Curiosity collects first samples of material ever drilled from rocks on Mars. Analysis shows evidence of conditions favorable for life in Mars' early history.

Gears good enough for NASA.

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gear TECHNOLOGY

Vol. 30, No. 8

departments

Intelligence in Production.

Gear manufacturing technology innovations from Liebherr.

During development of our innovations, we place particular emphasis on choosing an optimal solution for the respective application. The result: Process stability and an outstanding quality of manufactured components – with the highest level of economy possible.

Generating grinding machine LGG 180/LGG 280
- A single-table solution for gear grinding of workpieces up to Ø 180 mm, or up to Ø 280 mm, and workpiece lengths up to 500 mm
- Extremely fast load/unload times of 4 seconds, chip-to-chip, with a single-table
- New Palletizing Cell LPC 3400

Gear hobbing machine LCH 180 two
- Multi-cut strategy with roll/press deburr-chamfering
- Primary hobbing time is done in parallel to the load/unload, and roll/press deburr-chamfering, between two cuts – on two work-tables

Gear hobbing machine LC 180 Chamfer Cut
- High chamfer quality with one-cut hobbing strategy
- Primary hobbing time is done in parallel to chamfering in a second machining position

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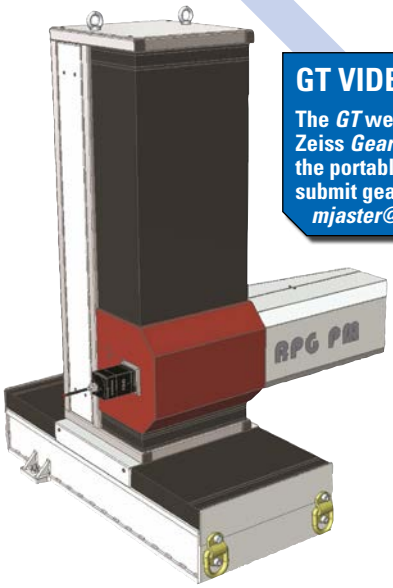

GT VIDEOS

The *GT* website currently features the latest innovations from Zeiss *Gear Pro* software as well as a video from Kapp/Niles on the portable gear inspection system from R&P Metrology. Please submit gear industry videos to Senior Editor Matthew Jaster at *mjaster@geartechnology.com*.

GT Events

The 3rd International Power Transmission Expo (IPTEX) is dedicated to the gear and power transmission industries. India is rapidly turning into a global manufacturing hub, thanks to the country's manufacturing and engineering capabilities, vast pool of skilled expertise and its size. IPTEX 2014 takes place February 27 – March 1 at the Bombay Exhibition Center, Mumbai, India. See both websites (*www.geartechnology.com* and *www.powertransmission.com*) for additional information.

2014 Editorial Calendar

Our 2014 media kit is currently available online at: *www.geartechnology.com/mediakit.pdf*. Upcoming focus and feature topics include:

January/February: Big Gears and Powder Metal

March/April: Heat Treating and Gear Grinding and Finishing

May: Cutting Tools and Automation/ Productivity

Submit article ideas to Managing Editor Randy Stott at *wrs@geartechnology.com*.

Ask the Expert

Do you have a question about gear design, manufacturing, heat treating, inspection or assembly? Submit your questions to Senior Editor Jack McGuinn at *jmcguinn@geartechnology.com*.

LinkedIn

Join the *Gear Technology* discussion group that keeps members up-to-date on global gear data, personnel changes, job postings and more from companies like IHS Global, Moog, Gleason, MHI and others.

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BPA WORLDWIDE

We Hope You Get Everything On Your Wish List…Merry Christmas From Forest City Gear

We've been pretty good at Forest City Gear this year. The Holiday Season finally gives us a chance to pause and give thanks for the many gifts we've received throughout the year. Great customers…a skilled and dedicated family of employees…the continued joy that comes from doing good work in the industry we love…and much more. We look forward to working with you to fulfill your wish list in 2014.

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Measured Optimism

Publisher & Editor-in-Chief
Michael Goldstein

Gear manufacturers are generally an optimistic bunch. At least, that's what we've found in our annual "State of the Gear Industry" survey. This year's results — based on the responses of hundreds of gear manufacturers — appear on pages 26–34.

Despite some significant challenges facing manufacturers today, the majority of gear manufacturers expect next year to be as good as or better than 2013. For example, 89% of respondents expect equal or higher sales in 2014. Not surprisingly, then, 90% of respondents expect both production and employment to be at or above 2013 levels.

But finding the right people to fill those needed jobs seems to be one of the toughest challenges facing gear manufacturers. It ranked second (just barely) behind "General Economic Climate" as the most significant challenges facing gear manufacturers today, and among the written responses, the difficulty of finding skilled labor was a consistent theme.

Fully 63% of respondents indicated that they are currently experiencing a shortage of skilled labor at their locations. "(It's) hard to find young people with interest and solid high school training like it used to be back in the day," said one industry veteran. Another indicated he could hire 30 additional employees right now, if only he could find them. "The manufacturing technology now available has surpassed the level of available skilled help," said another.

In some ways, this may be even more difficult for gear manufacturers than in other manufacturing industries, due to the complexities of the processes involved. One respondent indicated he had no trouble finding operators to run turning or milling machines, but qualified gear manufacturing operators are much more difficult to come by. Another said that the changing technology of gear manufacturing itself has further complicated matters, with gears and splines being manufactured on mill-turn machines and lathes rather than dedicated gear machinery.

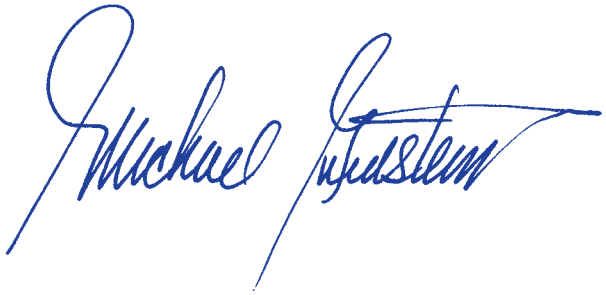
But I repeat what was said at the start: the gear industry is an optimistic bunch. About 89% of respondents indicated some level of optimism regarding their companies' ability to compete over the next five years. No matter what challenges face them today, the overwhelming majority feel that there's a future for them in the gear industry. More than any other measure in our results, I'd say that's a positive sign.

There's a lot more information in the survey results, so please take a few minutes and peruse them. It's a great opportunity to see where your gear manufacturing operation fits in among the rest of the industry. But the state of the gear industry is evidenced by more than just numbers. We're constantly talking to people in the industry to get a feel for trends and expectations. As a companion piece to the survey, Senior Editor Jack McGuinn interviewed a number of people in the industry to provide flavor and insight that go beyond the raw numbers. His article begins on page 22.

In addition to the results presented in this issue, we asked a number of questions about how you use *Gear Technology* and what types of articles and subjects you'd like to read more of. As in the past, we're gratified to know that we seem to be on the right track. According to the results, the overwhelming majority of you read every issue, and 70% of you spend at least 20 minutes with each issue, while 30% spend more than 40 minutes with each issue. Most of you are making use of our website, with 76% regularly accessing our free online archive, which contains 30 years of articles.

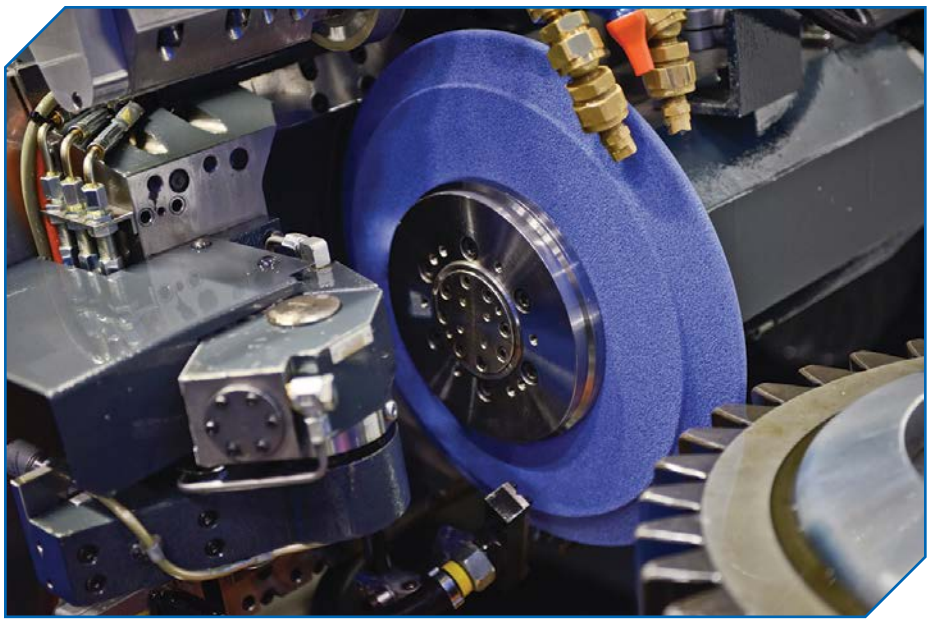
I'd like to thank everyone who took part in the survey. Your participation is extremely valuable — not only to us — but to the industry as a whole. We appreciate all of the additional feedback you provided, including suggestions for next year. You can be assured that we're taking all your suggestions to heart and will use your comments to help plan our future issues.

Best of luck to all in the gear industry for a prosperous 2014.



3M

OFFERS CUBITRON II CONVENTIONAL WHEELS FOR GEAR GRINDING



3M Abrasive Systems is introducing 3M Cubitron II conventional wheels for gear grinding, giving engineers new tools to take the manufacturing processes to the next level of productivity. These gear grinding wheels are the result of incorporating both 3M's precision shaped grain and state-of-the-art bonding systems, which enable a new dimension of gear grinding performance—helping achieve consistent, high quality finishes and tight geometry tolerances, part after part, while increasing the efficiency and productivity of manufacturing operations.

In 2009, 3M launched the first Cubitron II brand coated abrasive product incorporating 3M precision shaped grain technology. "Customers found tremendous improvement in processing speeds and product life, making it one of our most successful product launches ever," said Dan Cunningham, director sales and marketing, 3M Abrasive Systems. Since that time 3M has begun to extend their precision shaped grain technology into their bonded abrasive products, providing similar benefits. "We're very proud to introduce these new bonded products to our Cubitron II family."

Last year's introduction of the Cubitron II bonded abrasives containing 3M precision shaped grain represented a major transformation of the grinding process. Now, the launch of Cubitron II bonded abrasives for gear grinding is giving engineers a broad range of benefits in gear grinding, including increased throughput, less wheel dressing, a dramatically lower risk of burning, extended wheel life and consistent grinding performance.

This level of performance is made possible by combining the benefits of state-of-the-art bonding systems with the precision shaped grain technology pioneered by 3M. While conventional ceramic abrasive grains tend to "plow" through metal, resulting in a slower cut and shorter wheel life, the precision shaped grains of Cubitron II continuously fracture as they wear, forming sharp points and edges that slice through metal, wear evenly and provide superlong life and consistency under normal grinding pressure. "By traditional standards, grinding generally refers to machining with undefined cutting edges, while turning and milling utilize defined cutting edges," says Walter Graf, global segment leader, 3M Abrasives Division. "The grain in 3M Cubitron II abrasives turns this definition on its head!"

For the first time, a grinding wheel can claim to be made up of "geometrically defined cutting edges," as each and every grain is exactly the same engineered shape. By looking at the resulting "flowing" chips from these new grinding products, it might be more appropriate to talk about the process as "micromilling" rather than grinding. These free-flowing chips no longer clog up the grinding wheel and, therefore, the grinding wheel remains free-cutting without loss of cutting ability. In repeated tests, this has shown to drastically reduce the risk of burning and to give consistent and predictable results.

"The tests aren't perfectly created scenarios, either – we're talking about long-term trials under production conditions that have shown grinding times being cut, in most cases, by at least 50 percent in comparison to grinding wheels made of standard ceramic abrasives," continued Graf. "You can see why we're so excited!"

The initial family of Cubitron II gear grinding wheels includes products available in single rib, threaded and spiral bevel configurations.

For more information:
3M
Phone: (888) 364-3577
www.3M.com

Liebherr
INTRODUCES LGG 180

Liebherr's new LGG 180 machine for profile and generating grinding combines short grinding times with consistent high large-scale production quality, thanks to a one-table design. The advantage to the one-table solution is higher quality throughout the entire production. Every machined part is manufactured under the same conditions for the highest reproducibility, said Dr.-Ing. Andreas Mehr, grinding and shaping technology development and consultancy at Liebherr-Verzahntechnik GmbH. "A key argument in favor of the one-table solution is the statistical capability and reliability in continuously producing controlled µ-range finish quality," Mehr emphasizes.

The new grinding head allows for rotation speeds up to 10,000 rpm and has spindle power of 35 kW. Given this performance data, the head enables high cutting speeds and high feed rates. The new grinding machine can exploit the considerable potential of the innovative abrasive Cubitron II. The machine will enable undulations to be applied specifically to gear wheel flanks for noise optimization purposes for the first time. The ability to produce sub-µ range waviness cost-effectively gives designers a whole new range of optimization options.

Production advantages

The LGG machine delivers fast processing combined with the set-up advantages of a one-table solution. In addition, the machines for both 180 mm and 280 mm gears have the same compact external dimensions, facilitating installation within production lines. "Vehicle manufacturers can thus develop a complete production line, in which all gearing components for a passenger vehicle transmission can be ground: planetary and sun gears, bore-type gears, as well as drive and pinion shafts with lengths up to 500 mm. In order to minimize any thermal impacts, the machine bed is of a thermally stable material. The core of the machine is the newly developed grinding head. Conventional solutions have been chosen here in several areas in order to be prepared for yet higher quality requirements.

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

Gleason Corp.

PRESENTS LATEST MACHINE TOOL TECHNOLOGIES

Complete Power Skiving Solutions

Gleason Corporation has announced their complete set of Power Skiving solutions, providing an economical process ideally suited for the production of internal gears, and for all gears with interfering contours and features. By combining unique machine, cutting tool, and Power Skiving process expertise, Gleason offers users significant performance improvements, particularly in operations where shaping, forming, pressing and broaching are typically used. As compared to shaping, for example, Gleason Power Skiving Solutions can deliver productivity rates as much as eight times higher.The Gleason Power Skiving process

additionally delivers quality levels that are superior to other soft machining processes, with the potential to be used as a 'green' finishing operation.

Built on proven Gleason machine platforms with models available for work pieces as large as 700 mm in diameter, Gleason Power Skiving machines utilize extremely rigid guideways and specially designed spindles with oversized diameters and more rigid bearings. Easily integrated into production lines, a large selection of peripheral equipment provides users with the ideal solution for any production volume and lot size.

Gleason provides the cutting tools and the Power Skiving process, helping to deliver significantly better part quality and surface finishes than shaping. Profile modifications as well as a tooth tip chamfer can be built into the cutter while lead modifications are realized by additional movements of the machine axes. The cutting cycles can be modified for aggressive roughing and fine finishing maximizing both productivity and quality. Profile, lead and tooth thickness can be corrected according to the results shown on the inspection charts.

Comprehensive Power Skiving Technology Software enables users to easily simulate the entire cutting process and plan the most effective process strategy. Users can analyze the influence of different cutting tool geometries and process parameters. The Technology Software allows you to decide if a given part can be safely and economically power skived or whether it would be better shaped, making Power Skiving as simple and familiar as shaping.

Gleason 1500GMS

Gleason Corporation's 1500GMS Analytical Gear Inspection System has been updated to deliver improved inspection speeds and offer many new features to meet the widest range of inspection tasks for gears and non-gears as large as 1,500 mm in diameter.

Among the many new design options now available on the new 1500GMS is its ability to include surface finish measurement as part of the normal gear inspection process.Typically, this inspection procedure is performed offline with other dedicated, expensive equipment requiring time-consuming setups which also require additional periodic calibrations and preventative maintenance schedules. Instead, the 1500GMS saves precious time by inspecting multiple traces on any number of gear teeth using a motorized rotary probe system adapted to the existing SP80H 3-D scanning head. A wide range of surface finish inspection parameters are possible, with programming for the operation incorporated right into the 1500GMS' popular

GAMA suite of applications' software.

The new 1500GMS can also perform increasingly important Barkhausen noise testing to detect grind burn as just another routine step taken during the course of normal gear inspection. The 1500GMS uses proven Stresstech Rollscan 300 Analyzer technology integrated into the platform to save the time and setups usually required to perform Barkhausen off-line on other equipment, and eliminate the additional requirement of Nital Etching.

The new 1500GMS now supports non-gear metrology as well, through use of the Gleason-Capps prismatic measurement software platform, making it ideal for the inspection of any rotationally symmetrical workpiece that requires high accuracy inspection of features common to all types of gears. These include characteristics like bolthole patterns, tapered bores and their relationship to the gear faces, diameters, lengths, etc. This option is available in three levels of sophistication, from simple self-taught routines to full CAD based programming from full 3-D models. This new capability greatly enhances the overall capability of the machine and allows the inherent accuracy of an ana-

lytical gear inspection machine to carry over into coordinate metrology applications.

These enhancements are available on all nine standard models of analytical gear inspection systems from Gleason Metrology Systems.

Phoenix 280G

The new Phoenix 280G bevel gear grinding machine establishes a new benchmark for bevel gear grinding for gears up to 280 mm in diameter with a design that's reliable, highly productive and easy to operate and maintain. There are no rails, wires or pipes in the work chamber to collect swarf, keeping the chamber clean for low preventive maintenance. In addition, the machine offers rapid set-up and all major set-up items can be completed without tools, including the grinding wheel, coolant header and workholding. The coolant header has small blocks that can easily be swapped out by hand, while the grinding wheel can be released hydraulically. Some of the other significant features of the Phoenix 280G include:

Reliability – A well-designed work chamber ensures optimum swarf evacuation. The wheel dresser, for example, telescopes completely out of the work chamber to reduce the wiring/piping typically found there. The tool-less, quick-change coolant header design features a laser guidance device that makes part-to-part pipe alignment more efficient and repeatable when compared to manual alignment.

Productivity – High-speed direct-drive spindles combine with quick-change wheel, arbor and coolant header designs and automatic stock dividing (simultaneously with wheel dressing) to deliver faster floor-to-floor times.

Accuracy – Featuring the extreme rigidity of the Phoenix monolithic column, cast from advanced polymer composite material to achieve very high thermal stability and damping characteristics.

Easy to operate and maintain – Powerful Fanuc 30i or Siemens 840D CNC controls, along with Gleason's user-friendly software, empower even less experienced operators; Phoenix design simplifies installation, integration with robots and gantry-type automation, and maintenance.

Automatic stock divider- The 280G's Automatic Stock Divider, mounted in close proximity to the work spindle, helps ensure consistently high gear quality. The unit automatically determines the tooth slot position of the pre-finished gear to provide accurate and reliable stock division, helping eliminate operator errors.

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

EMAG

OFFERS NEW TECHNOLOGIES AT WESTEC AND SOUTH-TEC

Forecasted growth rates of 6.3 percent in sales of automobiles in the USA clearly demonstrate one thing: that the USA is and will remain one of the most important trading partners for Germany and German industry. The USA is traditionally an important market for EMAG. This is emphasized by the fact that EMAG has been present in Farmington Hills, Michigan, for many years now. Thanks to the deep roots that EMAG has in the USA, it is not only an important employer in the region near the "Motor City" of Detroit, but it is also a reliable business partner for numerous companies throughout North America. Many of EMAG's machines were recently demonstrated at trade shows including Westec and South-tec including:

VL 2-P

Workpieces up to 100 mm in diameter can be machined on the VL 2-P with short cycle times. While there is a pause on other machines to allow the workpiece to be changed, the next workpiece is directly ready to machine on the VL 2-P. The key is that 2 spindles are used and these load themselves alternately while the tool turret swings between the machining positions. When machining is completed on one spindle, the tool slide moves to the second spindle to start a new machining process. Loading and unloading of the spindles which now occur in parallel with machining are virtually eliminated from the machining process and reduce idle times to an absolute minimum.

VT 2-4

The vertical, 4-axis pick-up-turning machine VT 2-4 allows machining of shafts with a length of up to 400 mm and a diameter of up to 100 mm. Our consistent demand for maximum productivity is demonstrated by integration of the automation solution whereby the machine loads itself with raw parts using workpiece grippers. It takes approximately six seconds to change the workpieces and this thus leads to short idle times and, consequently, lower component costs. The actual turning process for which two tool turrets, each with eleven tool positions, are available (fitted with turning tools or driven tools) is performed at a speed of 6,000 rpm in extremely short cycles.

VL 2

The VL 2 vertical pick-up turning machine is just the right choice for machining chuck parts with a maximum

diameter of up to 100 mm and a length of up to 150 mm. At the same time, the VL 2 offers a whole range of clever design details and hi-tech components. These include the pick-up spindle which loads itself with raw parts from the integrated conveyor belt and the tool turret equipped with 12 tool positions which allows diverse machining scenarios. The machine body made of mineralit polymer concrete ensures high strength and excellent vibration damping which is indispensable particularly when machining small chuck components.

VL 5i

Be it small or large series production, the EMAG VL 5i is the ideal manufacturing solution for turned parts up to 250 mm. The VL 5i is an interesting manufacturing solution above all for small- and medium-sized component producers, thanks to its excellent characteristics (e.g. short retooling times and fast programming). An automation system functioning on the basis of the drag-frame principle is integrated to round off the equipment features. This automation system, combined with the pick-up technology from EMAG, is the basis for the high productivity of the VL 5i. The workpieces are conveyed to the inside of the machine via the revolving automation system. The pick-up spindle loads itself there and it also deposits the finished workpiece back on the conveyor after machining. The advantages are obvious: the revolving automation system allows simple and very reliable loading and unloading of the parts, while the self-loading spindle ensures maximum machining reliability since clamping errors are virtually completely eliminated.

For more information:
EMAG LLC
Phone: (248) 477-7440
www.emag.com

Schunk

INTEGRATES GRIPPERS WITH SENSING TECHNOLOGY

Schunk has enlarged its number of available sensors for the modular system of grippers with the new OAS sensor. When grippers such as the PGN-plus and the MPG-plus are equipped with an integrated distance and presence sensor, both modules quickly transform into seeing grippers without needing an expensive vision system. The optical system can be directly integrated into the gripping center and continuously supplies the control unit with information, such as measuring the distance of the gripper to the component. This is done during the process without any loss of time. With the OAS, PGN-plus and MPG-plus grippers can differentiate components, recognize position, pick parts from a running belt, detect wrongly gripped components, and increase the reliability of the gripping operation.

The optical sensor works with infrared light at a wavelength of 850 nm. It functions at environmental temperatures between 14° and 131°F, and fulfills the standards for protection class IP65. The sensor module is multi-functional, and can also be combined with other grippers and automated modules. For example, it can be used for analog position monitoring of long-stroke grippers, by integrating it in one of the two base jaws. Combined with grippers and rotary modules, the sensor can be aligned inwards instead of outwards, which assures piston monitoring.

For more information:
Schunk
Phone: (800) 772-4865
www.schunk.com

Sodick

LAUNCHES EDM MACHINE

Sodick, Inc. hosted their Smart Technology Event on Oct 3-4. The event was located at their corporate headquarters in Schaumburg, Illinois, and brought in over 200 attendees. The event aimed to introduce visitors to a new range of rigid, linear motor driven wire EDM machines and a new electrode machining center. An SL Series wire EDM machine was launched at the event. The SL Series features four models in two specification levels SL-G and SL-Q. The SL600G Wire EDM was displayed during the event. This machine is a rigid linear motor driven EDM that is coupled with glass scales on the X, Y, U and V axes, ensuring the highest possible precision and positioning accuracy. The rigid linear motors have the optimum flat design and come with a 10-year positioning accuracy guarantee.

The SL600G has an X, Y, Z travel of 23.62"×15.75"×13.78" (600×400×350 mm). Wire diameter can range from .002" to .012" (.05 to .30 mm). The machine can accommodate workpieces up to 2,204 lbs (1,000 kg). Amongst the many new enhancements on the SL Series is the new Sodick Control SPW (Smart Pulse Wire), which uses the Windows 7 operating system and functions similar to a tablet. The operation screen can switch between the traditional Sodick screen and the new tablet style screen to suite the operators preference. Additionally, a new Smart Pulse Generator reduces the number of cuts and time it takes to achieve the target surface finish. Resulting in up to a 40% time savings compared to previous models.

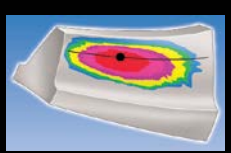
The new TT1-400A was also introduced at the Smart Technology Event. Although the TT1-400A concept was first shown at IMTS 2012, the latest version of the machine was highlighted during this event, and is now available to the US market. The TT1-400A is a high speed electrode machining center designed for precision graphite and copper electrode machining; it uses a 40,000 rpm high toque high speed HSK-E25 spindle.

For more information:
Sodick Inc.
Phone: (847) 310-9000
www.sodick.com

High Quality Gears for the Helicopter Industry

Every day, thousands of pilots around the world rely on the exacting quality from every component of their Robinson Helicopter - especially the gears which are produced by Arrow Gear Company.

With over 65 years experience, Arrow Gear's products have been used in the most advanced aerospace systems produced by our civilization. With a state-of-the-art production facility and dedicated personnel who are among the best in the business, Arrow Gear offers the expertise and precision for the most demanding quality requirements.



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With manufacturing beginning in April 2012, numerous Rexnord associates — almost 100 — took part in making this giant gear a reality. "From engineering, through the foundry and the machine shop, Rexnord associates have worked efficiently with the customer to produce a high-quality, high-power gearing solution," says Dave Olson, Director, Commercial Operations, Mill Products. "Through this tremendous accomplishment, we are demonstrating our company's expertise and dedication to the industry."

Gear fast facts:

- Bore size: 443 inches (11,252 millimeters)
- External diameter: 522 inches (13,259 millimeters)
- Face width: 40 inches (1,016 millimeters)
- Number of teeth: 344 teeth
- Tooth depth: 3.4 inches (86 millimeters)
- Tooth spacing tolerance: .0016 inches (.04 millimeters)

For more than 100 years, Rexnord Falk Mill Products have provided high-quality solutions for a diversified range of industries. With a base of more than 5,000 installed ring gears and pinions, Rexnord Falk Mill Products provide solutions for some of the world's most rugged applications. You can find Rexnord Falk Mill Products in the mining, cement, automotive, construction, manufacturing, paper and power generation industries.

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U.S. Gear Industry: Doing Well, but Challenges Await

By Jack McGuinn, Senior Editor

If you are like most navigators of the printed page, the first thing you read in this final 2013 issue of *Gear Technology* was our State of the Gear Industry Survey. And who would blame you? It's not *Sabermetrics,* but once you've read it you'll have a pretty clear snapshot of last year and a peek into the next.

But if you also like to get a little closer to the bone about things, what follows are the collected opinions of five well-regarded people in the gear industry speaking to a number of issues with relevance. Our group — our "Gang of Five," let's say — includes: Joe T. Franklin, president of the American Gear Manufacturers Association; David Goodfellow, CEO of Star SU LLC; Rod Kleiss, president of Kleiss Gears; Dr. Suren Rao, longtime managing director of the Gear Research Institute; and Fred Young, CEO of Forest City Gear.

All of the above — in one capacity or another — have over the years seen quite a bit of what there is to see in the gear industry — not least of which the Great Recession, which began in 2007/2008 — and is only recently losing its grip on the economy. They've met payrolls, trained tomorrow's engineers, transcended customer expectations or directed a trade association through times good and bad. And while "Gang of Five" may at first blush remind you of a truly Red, socialistic state, is there a more patriotic, interconnected, collegial industry in these United States than the gear industry? Just one Gear Expo experience — as exhibitor or attendee — answers that question.

We start the discussion with asking the group to assign the gear industry a letter grade for 2013, excepting their own company or association performance. The open-ended question elicited some interesting reactions. Rod Kleiss gets things rolling:

"I can only speak of the plastic gear industry, and I would grade ourselves at a solid D. We as an industry are barely succeeding at bringing plastic-molded gears to their full capability in the marketplace. Hearsay and innuendo rule the day in plastic transmission application. There is very little fundamental research with legitimate scientific design of experiments."

As AGMA president, Joe Franklin does here one of the things he's paid to do: turn lemons into lemonade. And, as well — avoid doling out letter grades. But as he candidly notes here, the numbers for 2013 started well but soon went pear-shaped.

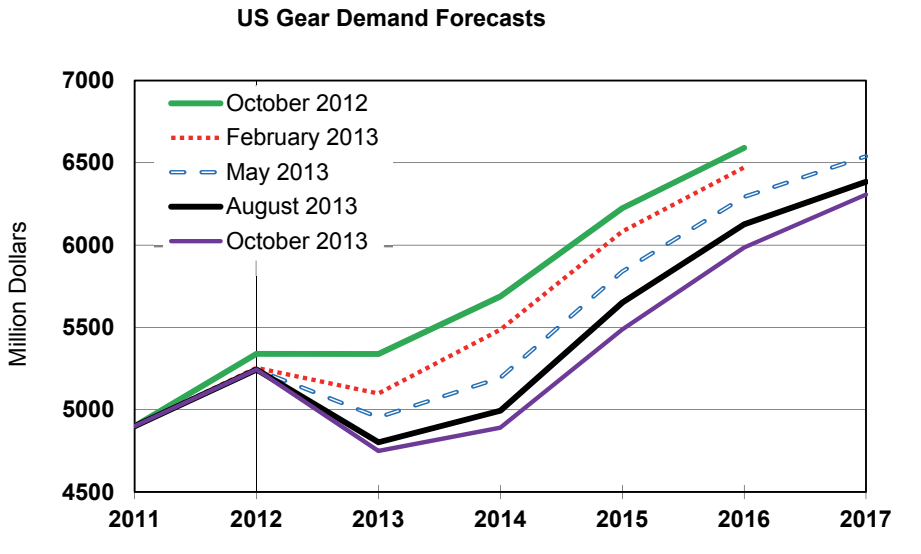
"The year 2013 began with a nice burst of energy in the industry and a forecast for modest growth over the excellent growth we saw in 2012. Unfortunately, as the year progressed we saw the overall macro economy slowed to the point that growth in the power transmission sector was revised to a loss.

"As you can see from the graph provided by AGMA's economic counsel, IHS Global Insight, from the baseline forecast in October 2012, each successive report has been more negative than the one before. Finally, this past October, (IHS's) forecast had been revised downward more than $500 million."

Here comes the lemonade.

"Fortunately, the U.S. industry is extremely resilient and well-pointed with the cyclicality that comes with being a capital goods manufacturer. So if we consider the forces within control of the companies, I would give them a high grade for being able to manage unexpected change this year, and in most years since 2008."

One who would certainly agree with Franklin's "high grade" rating is Fred Young, who gives 2013 a B+. "Some work is returning to the United States because we are regaining a better reputation for quality and reliability. At least some, if not many, U.S. gear producers have upgraded their equipment, increased inspection, and improved lead times." And David Goodfellow, adds that "While the automotive industry performed well, business was substantially down in other industries such as Wind Energy due to huge reductions of outsourcing from the OEMs. With the exception of automotive, the U.S. gear industry struggled. Grade B."



(Source: proprietary report for AGMA by IHS Global Insight)

Also bringing down the grade curve for 2013 with another solid D is Suren Rao of the Gear Research Institute. Some reading his response may think the man sounds bitter. In truth, he is angry — many would say with good reason. "(I assign) the letter grade D," says Rao. "The gear industry appears to be busy and prosperous. However, in spite of the "greying" of their workforce, their desire for educating their next generation of gear engineers—by supporting entities like the Gear Research Institute—appears to be non-existent. Yet I get a few phone calls a month from total strangers enquiring if I can recommend graduating engineers to potential, gear-related, job openings in their organizations. Ultimately, I think (the gear industry) will pay a heavy price for their reluctance to expend resources now for future human resources."

And then there's wind — or the lack of it. What once offered so much promise say, five or six years ago, seems to be losing its headwind. Wind energy is not exactly dead in the water — that would be offshore wind energy — but it is definitely slowing. And we can't keep blaming it on the never-ending political food fight over the energy tax credit, although had there been adult supervision in Washington early on, the wind picture might look decidedly different. No, blame it now on fracking, a mining process that enables much easier — and supposedly greener — access to an abundance of shale rock and the natural gas it contains. And, as mentioned — offshore wind energy continues to be a nonstarter. Witness the Cape Wind project on Cape Cod: planning begun back in *2009* and the project is still fending off opposition litigation while trying to secure financing — from a European bank, no less (Barclays).

Rao agrees wind energy is in a somewhat fallow state here — but for different reasons.

"It appears that the push in Europe for 'green' energy may be backfiring with extremely high electricity costs. Also, stories of how the bird population is being decimated by wind turbines are cropping up. With cheap natural gas (here) for the foreseeable future, my take would be that wind energy and offshore wind energy may not have a bright future in the USA."

Franklin is not optimistic over wind's future either.

"While it's impossible for me to predict the long-term future for the wind turbine industry in the United States, I believe several factors beyond this sector's control will make expansive growth quite difficult. The adoption of new technologies (fracking etc.) is allowing the production of large quantities of natural gas at very low prices. We're already seeing growth in the establishment of companies that use natural gas, for example chemical manufacturers, and those who can convert equipment to use natural gas.

"I do think there will be places where wind power is the correct answer to the problem but because of alternative sources of energy and the lack of an economic subsidy, I doubt it will be "as aggressive as many thought it would be a few years back."

Goodfellow points out that "Wind energy has dropped globally and has been hit especially hard in North America. The lack of subsidies limits the potential for growth in the U.S."

In our survey, more than 63% of respondents said their companies were experiencing a shortage of skilled labor. We asked our group what government's role should be in providing technical training for youngsters and oldsters.

"We need to partner with universities for fundamental research,which will also help us to find and train the next generation of plastics engineers," says Kleiss. "The government must help in making our universities accessible to young driven students to study engineering without incurring exorbitant debt."

"I don't believe the government alone will or could produce the skilled engineers and craftsmen this industry needs," Franklin declares. "Solving the issue of attracting talent into our industry rests first with the companies in the industry working in conjunction with schools and local, state and federal governments.

"I think we demonstrated over the past few years that no one has "the answer," and the more I talk with executives in the industry, the more I'm coming to believe that we are not asking the same question. All companies certainly don't have the same needs.

"For more than two decades, AGMA has worked to build education programs for our existing employees and others who want to come into the industry. Our staff, the AGMA Foundation and the AGMA Education Committee, work collaboratively to provide resources and funding to encourage educational institutions to teach more gearing-oriented courses.

"Working closely with professionals in the industry, we have developed a large array of education courses, seminars and workshops to help bring existing workers up to speed in a variety of technologies and manufacturing skills.

"Fortunately we have a number of newer instructors who will be bringing courses online in 2014 and we have demanding members who challenge our committees and staff to continue improving the quality and breadth of the material we teach.

"One of the most recent tools that has been created by the industry and is available on the AGMA website is a 'skills assessment tool' that allows companies in our industry to assess each worker's abilities against a standard that the company sets and then to identify and obtain resources to help their workers learn the material to master the topics they need to know to meet the requirements of the company."

Young declares, "It is absolutely critical and vital to develop a new generation of skilled workers. Currently, this issue is an impediment to our company's growth." Rao is of the opinion that "the government should stay out of it but the private sector should focus on the long term. This would have to include developing their future employees."

As we happen to have an article in this very issue on magnetic gearing, it's appropriate to ask these folks what impact they think gearless motor drives, gearboxes, etc., will have on the industry.

"For most of the applications that AGMA's members are involved in, gear-

less motors will not be a significant threat — at least not in the near term," says Franklin. "Gearless drives have different characteristics than gear drives, and therefore have a natural constituency. However, the reality is gearless drives come with their own issues, their own requirements, and a cost that far exceeds what most users are willing to pay."

For Young, gearless is a non-starter: "We have not noticed any substantial penetration with gearless motors." Goodfellow, ditto: "The wind energy sector continues the push for gearless systems. I have so far not heard it impacting the gear industry."

For Rao, there's a good backstory — and perhaps a rosy future — for gears.

"Gearless systems have made a significant impact in the marine gear business, but we may have partially come full circle. Let me explain. This industry sector has, in the last decade, made the push to 'all-electric' drives. While a substantial segment of this industry sector — especially the civilian side — has transitioned successfully to 'all electric' — the military side may be having second thoughts. Development of 'all electric' drive systems for the duty cycle a Navy combatant may encounter, within the space and weight constraints of a Navy platform, has been more difficult and more expensive than first imagined. Further, with the strategic scarcity of 'rare earths' for permanent magnet motors, I believe the Navy may be back to considering geared systems for marine propulsion. This would be good for the gear business."

One last topic before we close: customer expectations — perhaps the two most dreaded words in a manufacturer's lexicon. And then, of course, the manufacturer must *exceeeeed* those expectations — assuming they are even realistic. It must be quite the tap dance when a customer is demanding something that is — in this physical world, at any rate — impossible to do, and the manufacturer must somehow break the news to him gently. How does that work without losing the sale, if not the customer?

"There is a degree of tough love that must be part of any customer relation, but in the science of plastic gears, with so many unknowns, I think it is most valuable to share our insights and our uncertainties," says Kleiss. "We may know what won't work, but quite often we can't really say what just might work. The challenge is to maximize the cost-effectiveness of that search, which is really an exciting challenge."

From a trade association's perspective:

"Customers of our industry's products — gearing and mechanical power transmission — are quite different from someone who walks into a retail store, looks at four items that are essentially the same differentiated by clever packaging, price and possibly some of the ingredients," Franklin explains. "Our members and others producers in the industry predominantly respond to requests for custom products that require skilled engineering and precise manufacturing.

"All manufactures value their customers; however, at times customer demands may outweigh the business advantage of keeping them. It is important for manufacturers to convince their key customers that they are in fact offering a competitive price and a competitive product. (Assuming they are.)

"One way to help customers understand the value that you bring to their products is to make sure that (the customer's) engineers are involved in the process and are able to see the value that your staff and manufacturing brings not only to your component but to the final product.

"Of course closer relationships ultimately result in better partnerships and better solutions to common problems. However, some customers have discovered it is possible to go too far, to demand too much, to push too hard and to end up with few or no high-quality suppliers.

"Good manufacturers understand that demanding customers make them better. Demanding customers force the manufacturers to keep their technology up-to-date, to keep their staff educated and well-trained, and to in turn seek the best from their suppliers. Engagement of the full supply chain helps ensure that the final product will better serve all of us."

For Rao, it might be even tougher. His "customers" are actually clients; i.e., usually corporation types with almost boss-like project authority. "It is hard to avoid the 'customer is always right' situation, even in the contract research business. We always encounter unrealistic time and cost situations with our customers. However, any 'hard-nosed' push back would result in a loss of business. Working with the sponsor and providing absolute transparency in both expenditures and technical progress always appears to resolve the situation."

At Forest City Gear, "Many of us are adopting lean manufacturing and updating our equipment to meet the demands of cheaper and faster," says Young. "We do continually point out that a lengthy supply chain — India, China, Europe — could put them out of business if it fails. We remind them of the threat of piracy by companies with fewer scruples. We also remind them that cheaper and faster does not include payment in 90 – 250 days."

Goodfellow might consider a cranky customer as just another opportunity. "In the marketplace today, customers have outsourced capability they have traditionally had in-house to support product and engineering. We see an opportunity to supply these services as an added value proposition at a reasonable cost."

We end with affording those in the group interested in making some final comments.

Kleiss: "I love working with plastic molded technology because it is truly an infant science with unexplored possibilities. For many years my company struggled just to make the slightest headway in this new world. We have enough traction now that good engineers are agreeing to try designs and parts in applications we think promising. The questions above are really quite pertinent. For us to be successful in the long run, we will need the next generation of engineers. We will also need more fundamental research that should be within the framework of an interconnected university system. We need to keep truly open channels of communication with our customers so that we all learn the proper lessons and succeed with knowledge rather than dumb luck."

Young: "Most customers have no way to inspect the gears and splines they purchase and accept them if they are functional and meet the size they can document. Unfortunately, this may not satisfy the quality, longevity and advanced technology that will keep them competitive in global competition.

"We recommend that everyone verify that what they purchase actually meets all of their specifications even if they have to send it to an independent service for verification. We find many gears and splines may function but not meet the quality. As an example, I believe a majority of the splines manufactured here would not meet ANSI standards for involute profile lead and index variation. Most manufacturers use composite gages which accept deviant parts. This is a dangerous shortcut that is harmful in the long run."

And from Suren Rao: who knew?

"I cannot vouch that this is happening, but I have anecdotally observed, in the last few years, a very disturbing trend in the U.S. automotive gear industry. The 'Big Three' shed a lot of gear engineers during the last downturn (2008). However, when they came back, instead of refilling their ranks they have decided to seek gear design and manufacturing process expertise from Europe. While the manufacturing plants in the U.S. are churning out transmissions, these are being increasingly designed in Europe and even the processing is being duplicated from the Europeans. If this is true, it is a very troubling scenario for the U.S. gear industry, especially for the U.S.-based suppliers of process technology, gear manufacturing tooling, and other hardware. I wish the U.S. automotive industry would reconsider this approach."

And the very last word goes to Mr. Kleiss:

"It's always a challenge, isn't it?"

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2013 State of the Gear Industry

Reader Survey Results

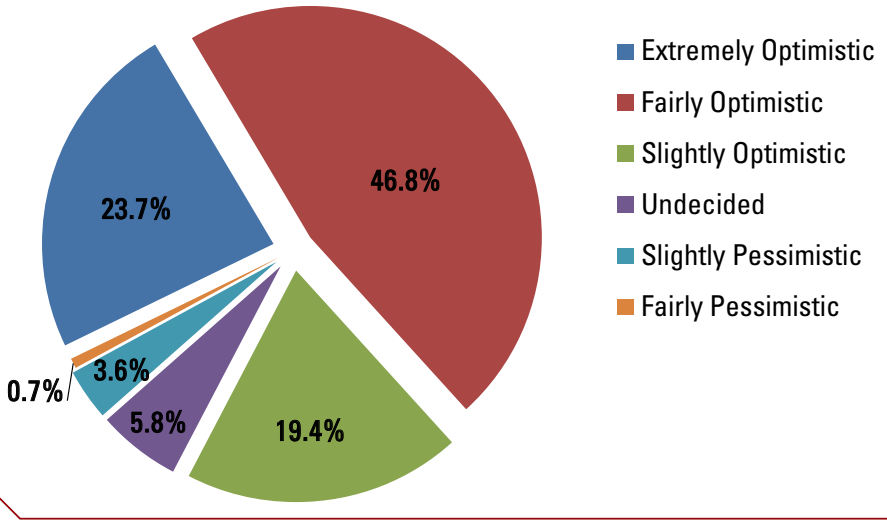
***Gear Technology*'s annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry.** As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear manufacturing companies around the world.

Hundreds of 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 respondents can be found at the end of this article.

Please describe your level of optimism regarding your company's ability to compete over the next five years.



Gear Industry Optimism – About Average

Over the past eight years, approximately 89% of respondents indicated some level of optimism regarding their companies' ability to compete. However, this year's respondents were less enthusiastically optimistic than average (a greater proportion were only "slightly optimistic").

Significant Challenges

The general economic climate and the difficulty in finding and keeping skilled labor appear to be the major challenges facing gear manufacturers today.

"Problem finding engineers."

"Unemployment."

"Uncertainty by customer forecast."

"Eroding margins versus 10 years ago (via stiffer competition)."

"Obama."

"Cost of labor."

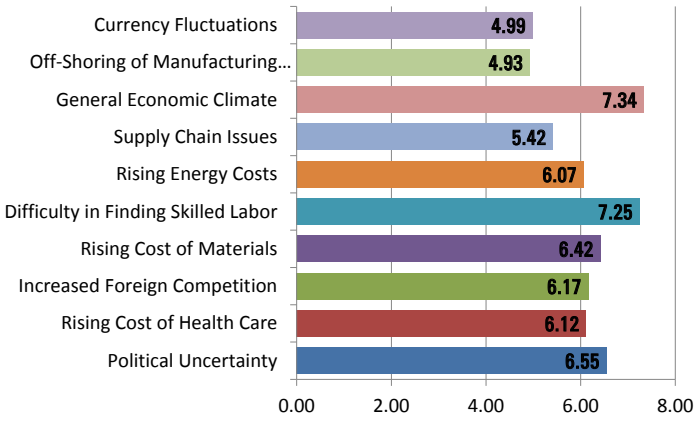
"Our import/export fees are skewed to a 25% disadvantage for us. Six years ago I purchased a machine from Italy for 325K. I paid a 7K import fee imposed by the U.S. government I have a hard quote, if I were selling to Italy? Their fee on us? 77K This whole story that we cannot compete, all this unemployment, it's all a bunch of malarkey."

"Competent help."

"CO_2 regulation in automotive."

"High taxes."

Rate the following challenges in order of significance to your business, with 10 being the most significant



"Cost control, reduction in volumes & JIT supplies."

"Time-to-market for new products."

"High taxes!"

"Overall forecast for medium and heavy duty."

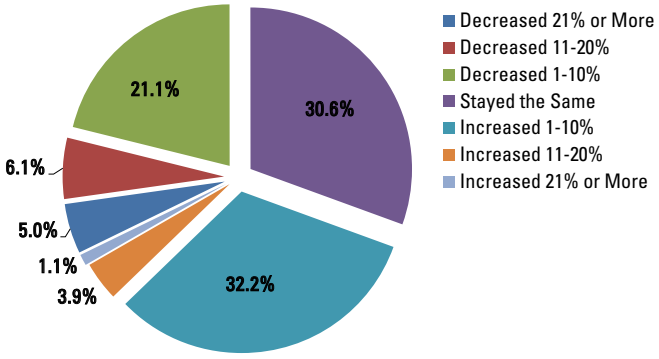
"Business conditions for our customers."

"EPA regulation, other domestic competition."

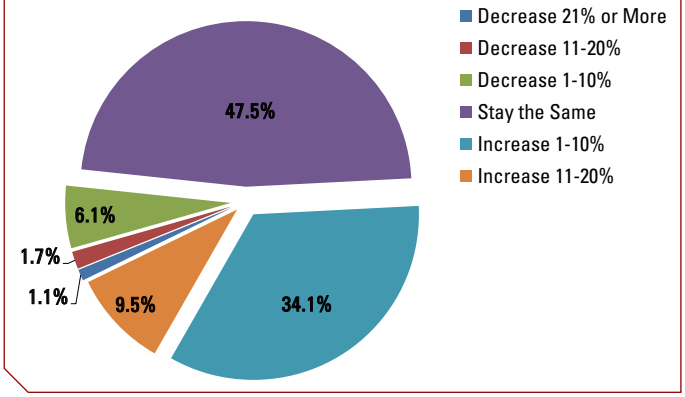
Employment

Responses were about equally divided between companies who added employees and those who downsized in 2013. According to the extended responses, many of those who downsized did so because of increased automation and more efficient manufacturing processes. Other declines were due to softening in specific customer industries, such as mining and construction. Those who added employees cited increased business and introduction of new products/product lines.

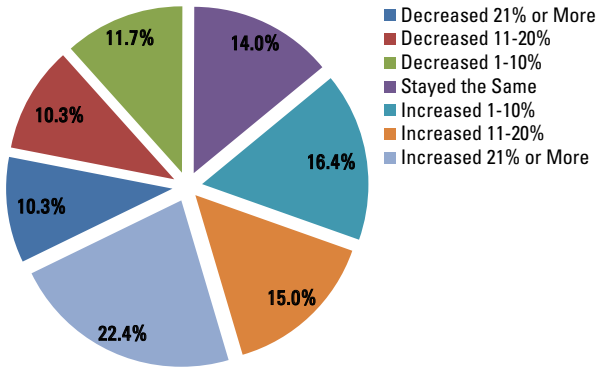
How has your location's LEVEL OF EMPLOYMENT changed in calendar year 2013 vs. 2012?



How do you anticipate your location's level of employment will change in 2014 vs. 2013?

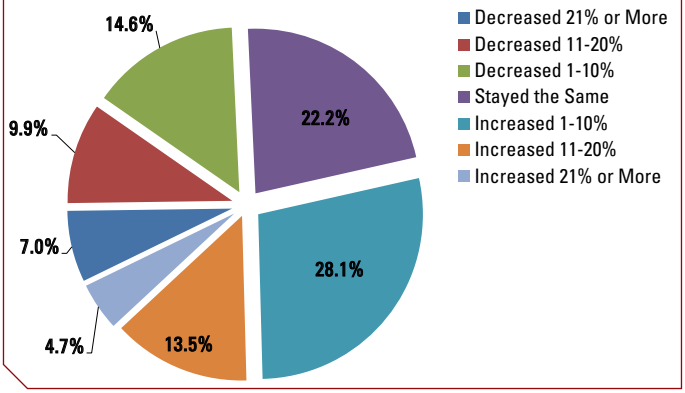


How does your location's employment level compare with its employment level 10 years ago?

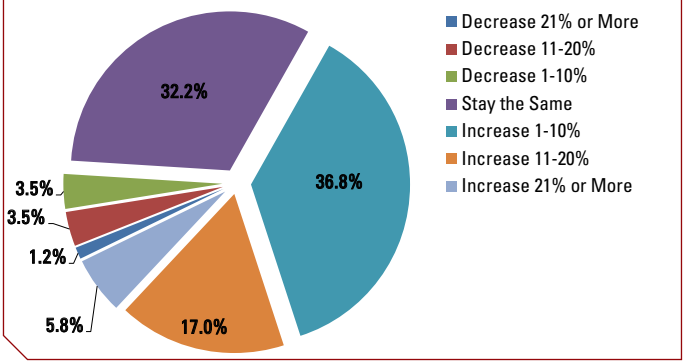


Production Output

How has total PRODUCTION OUTPUT (unit volume) changed over the last 12 months?

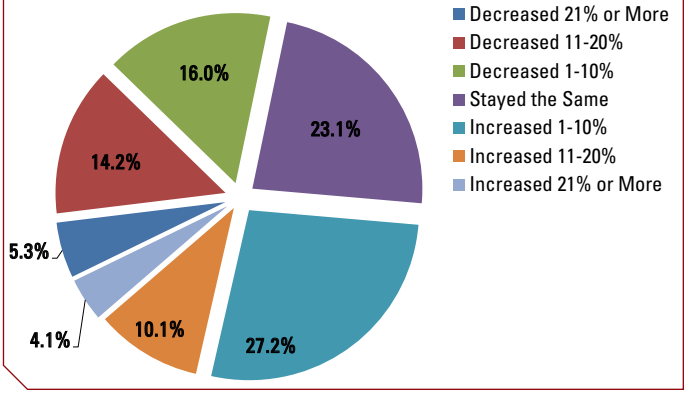


How much do you expect production output (unit volume) to change over the NEXT 12 MONTHS?

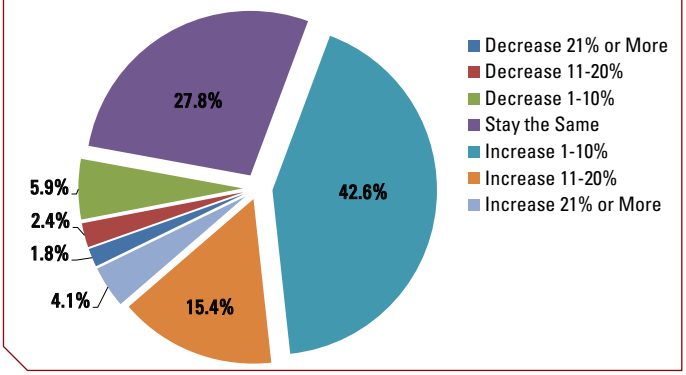


Sales Volume

How has total SALES VOLUME changed over the last 12 months?

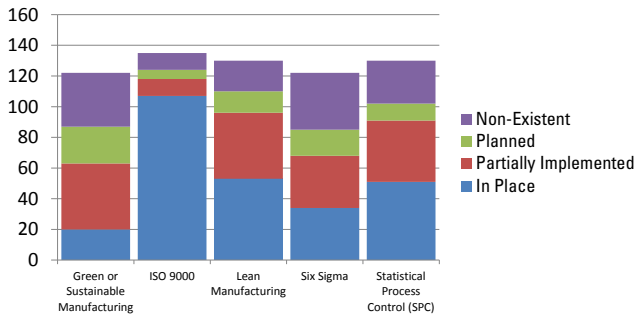


How much do you expect SALES volume to change over the NEXT 12 MONTHS?

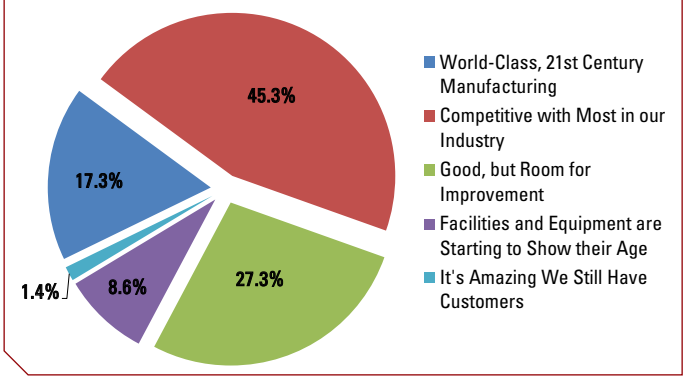


Quality

Choose how each of the following quality processes/philosophies is used at your location.



Classify your company's manufacturing operations and technology.



80% of respondents work at ISO 9000 accredited locations

How GREEN is your location?

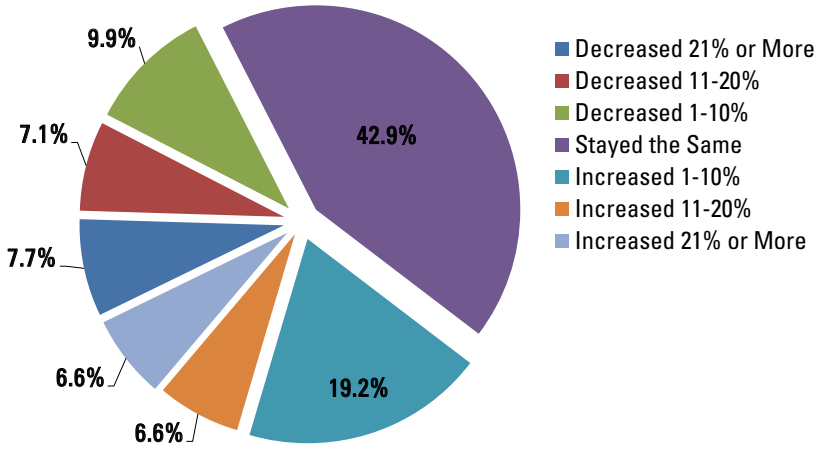
18% have green or sustainable manufacturing practices in place, 34% have them partially implemented, 20% are planning to implement them, and 27% say green or sustainable manufacturing is nonexistent at their location.

How LEAN is your location?

42% say lean manufacturing is in place at their location, 33% say it's partially implemented, 11% say it's planned, and 14% say it's nonexistent

Capital Spending

How did your location's CAPITAL SPENDING in 2013 compare with last year?



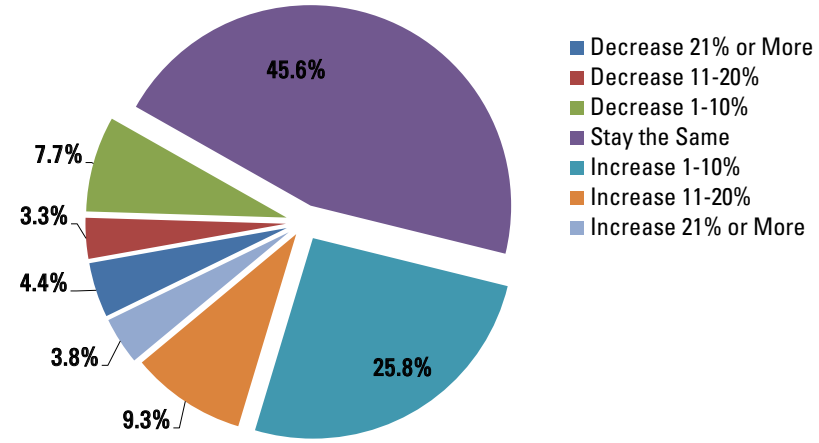
83% of respondents work at locations that spent more than $100,000 on capital equipment in 2013.

38% of respondents work at locations that spent more than $1 million

25% of respondents' companies spent less than last year.

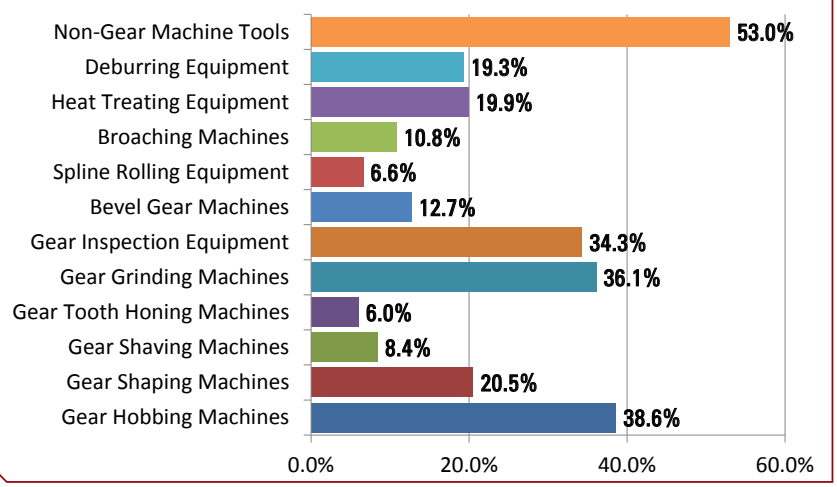
33% of respondents' companies spent more.

How do you expect your location's 2014 capital spending to compare with 2013?



Compared with last year, there appears to be less interest in general-purpose machine tools and hobbing machines, while there appears to be more interest in grinding machines, deburring equipment and heat treating equipment.

For which production functions do you expect to purchase equipment in 2014?



Skilled Labor

"Hard to find young people with interest and solid high school training like it used to be back in the day."

"We are short 30 employees right now."

"Need more manufacturing engineers, and the machinery, the non-gear cutting equipment, is more complex than ever before— multiple spindles, and nine programmable axes. Also creating splines and gears with new technology, on mill-turn machines, and lathes."

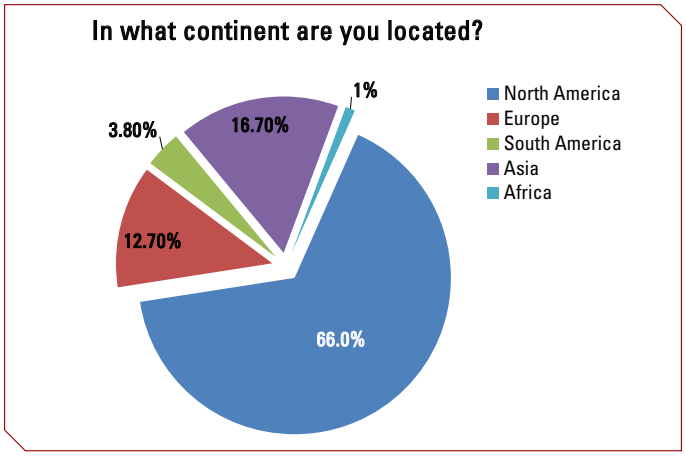
"Skilled help is the delimiter to growth—not work, not financing— but skilled help. The manufacturing technology now available has surpassed the level of available skilled help!"

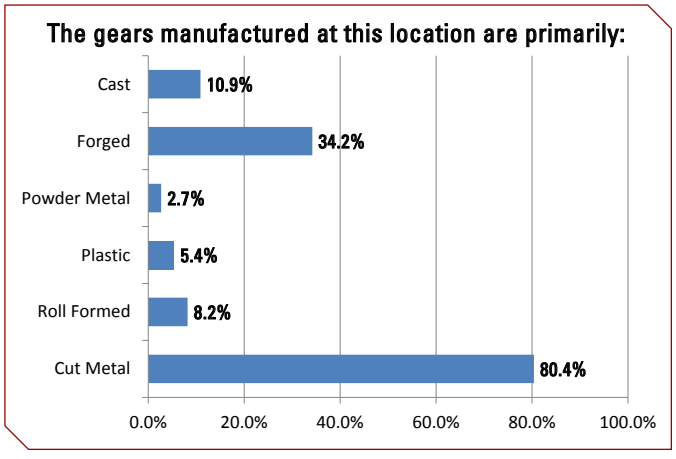
"We can get all the people we want, but they don´t have the skills. We have to teach them. Only for turning and milling it´s not a problem."

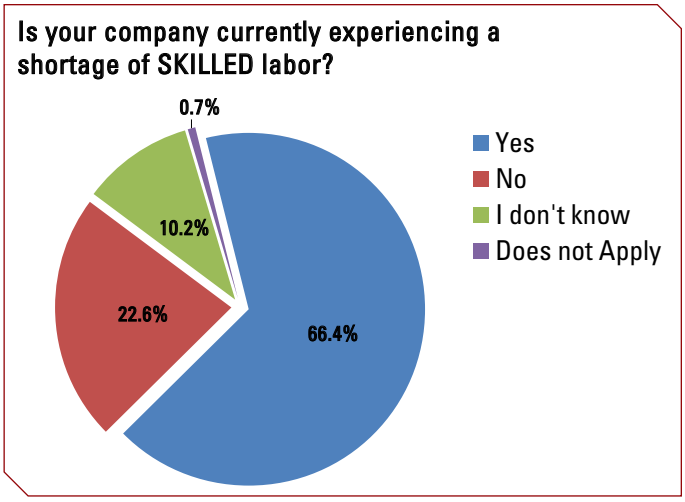
"We have enough skilled workers. However, they are all over 35, and several are over 50..."

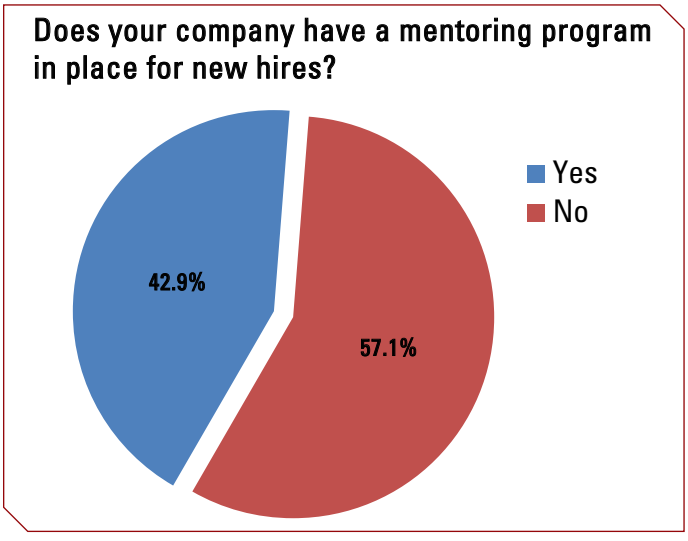
The percentage of companies experiencing a shortage of skilled labor has remained the same since last year.

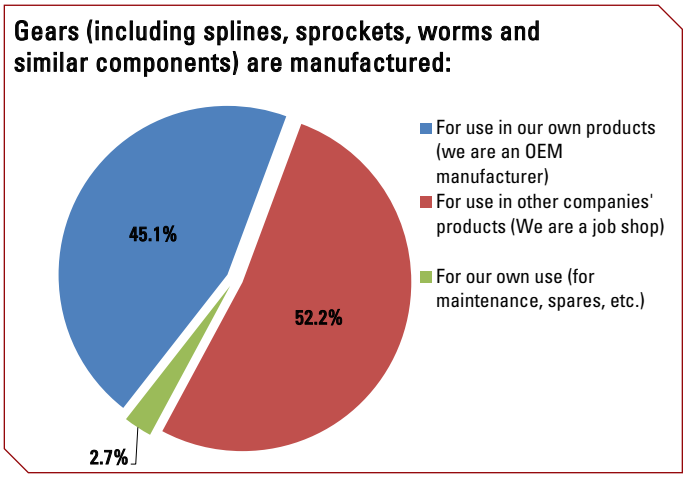
Demographics





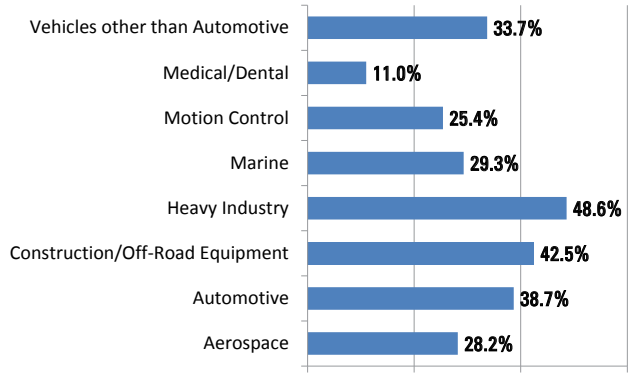




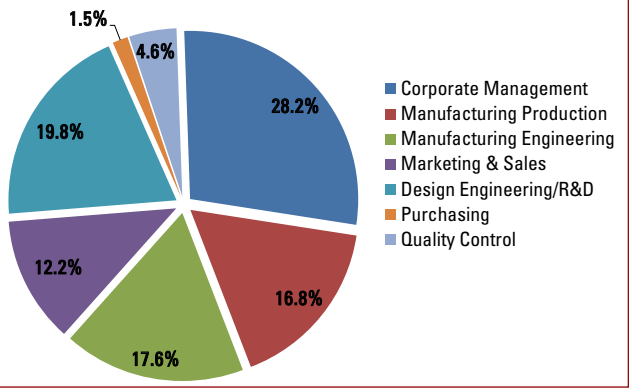


Demographics

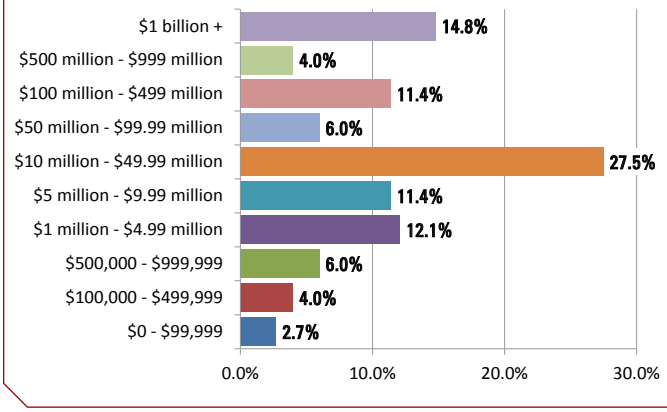
The gears (including sprockets, splines, worms and similar components) made at this facility are used primarily for:

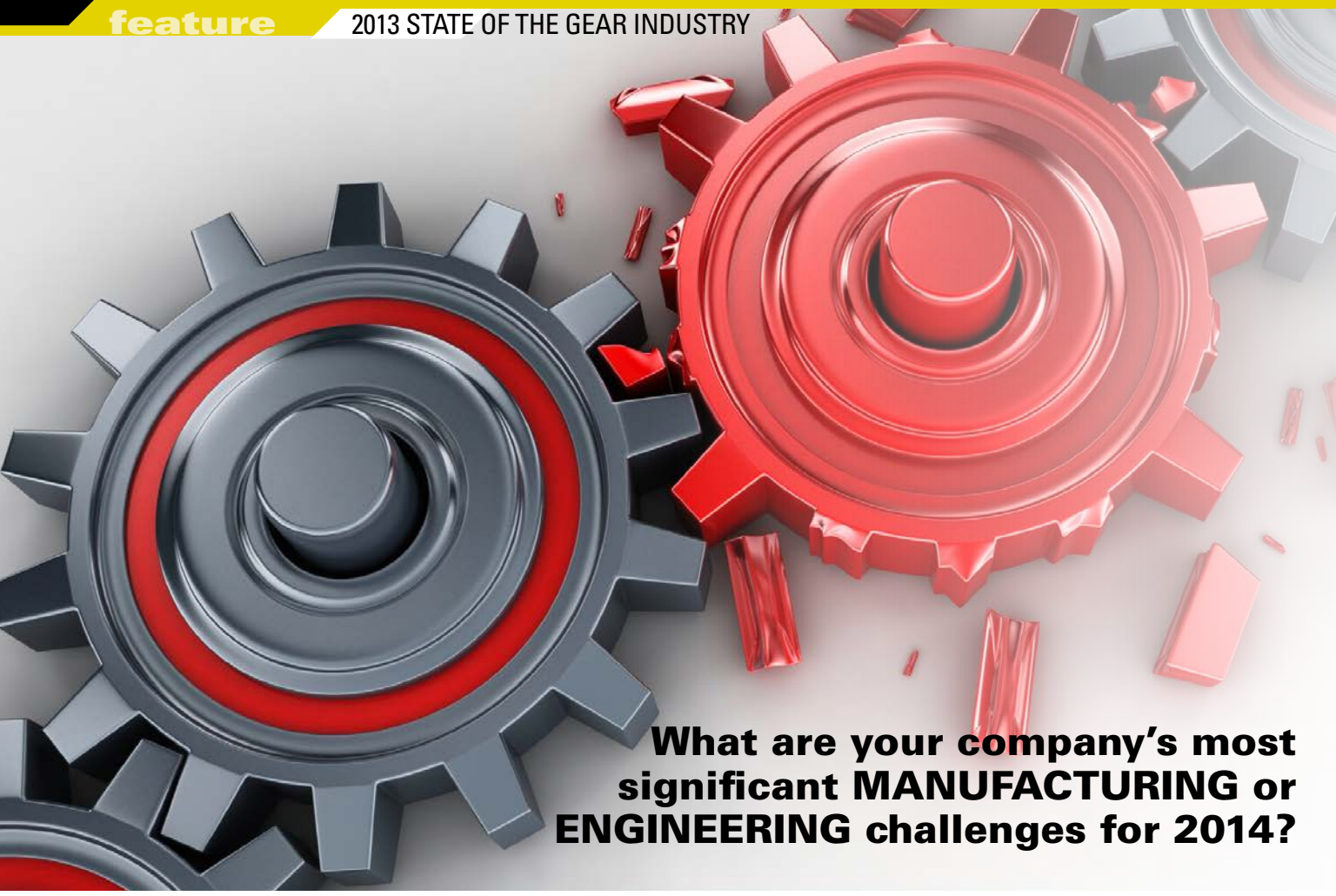


Which category best describes your job title/function?



What is the approximate annual revenue for your company?





What are your company's most significant MANUFACTURING or ENGINEERING challenges for 2014?

"Finding skilled labor."

"Skilled labor."

"Productivity, quality and lower costs."

"Many new developments."

"Staying competitive."

"Increasing in-house tool room efficiency and quality."

"Improve quality production level."

"Cost competitiveness, equipment uptime."

"Scrap and efficiency."

"Efficiency increase."

"Entering into highly technology oriented market."

"Machining hindrance to newer type of gear steels (tool life improvements needed)."

"New programs."

"Controlling cost."

"Improved scheduling and job tracking."

"Faster, more powerful machines at same cost."

"Sales."

"Planning and implementing volume increase while maintaing launch schedules."

"Finding good employees."

"Delivery 95% on time."

"Sustain quality."

"Keeping up with new technology."

"Trained candidate availability."

"Advancing core technology to new machining process. Redesign core product to reduce cost and increase robustness."

"Heat treat distortion and handling."

"Technically qualified operators of expensive equipment."

"Cutting costs to meet customer expectations for price point."

"Attain world-class quality level in manufacturing."

"New software development, tool development, general production improvement."

To develop gear boxes for off-road vehicles."

"Development of cost-effective products."

"Finding competent people. Too much free money out there!"

"On-time delivery."

"Introduction of new product."

"To install and validate capacity increase up to 40%."

"Ramping up production on many new products while keeping profit margins healthy."

"Keeping sustainable growth."

"Skilled labor, marketing of products."

"Finding qualified engineering help."

"Bringing new products to market with the same staff."

"New business."

"Finding experienced gear processing engineers."

"Cost reductions."

"Improve equipment."

"Manufacturing engineering and skilled help (machinists, electrical and mechanical technicians)."

"Finding skilled labor."

"Sales."

"Managing growth."

"Balancing newer technology with an aging workforce."

"Quality and cost-effectiveness."

"Keeping up with software changes."

"Increased production."

"Skilled labor."

"Equipment getting old with no money to invest in upgrades."

"To meet reductions demanded by OEM in sales price, sustainability in low volume processing."

"Roll out of new product on schedule."

"Manufacturing cost and how gear processes and methods are to be developed to get maximum productivity and keeping cost on lower side to counter competition."

"Sustainable precision and accuracy in product. Also consistency in productivity."

"On-time delivery."

"Government interference from a host of government agencies."

"Finding new customers that match our value propostion"

"Upgrading aging machinery."

"Engineering development lead time is too long."

"We need to install more flexible automation."

"Maintaining sales growth and keeping work force under 50."

"Winning new, incremental business."

"Finding skilled labor."

"Drive cost out with continuous improvement."

"To perform the same amount of job, with the same quality and with less people. (We had a head count adjust this year.)"

"Designing for value versus cost plus."

"Skilled people."

"Political uncertainty of military funding."

"Cost control."

"Flawless new program launching, continual cost savings."

"The biggest challenge we currently face is finding and/or developing skilled labor."

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Magnetic Gears

Sleeping Giant or Toothless Tiger?

For Related Articles Search magnetic at www.geartechnology.com

By Jack McGuinn, Senior Editor

When is a gear not a gear? Pardon my Zen, but that is a bit like asking, "What is the sound of one hand clapping?" Or there's the old bromide, "If it walks like a duck, talks like a duck," etc.

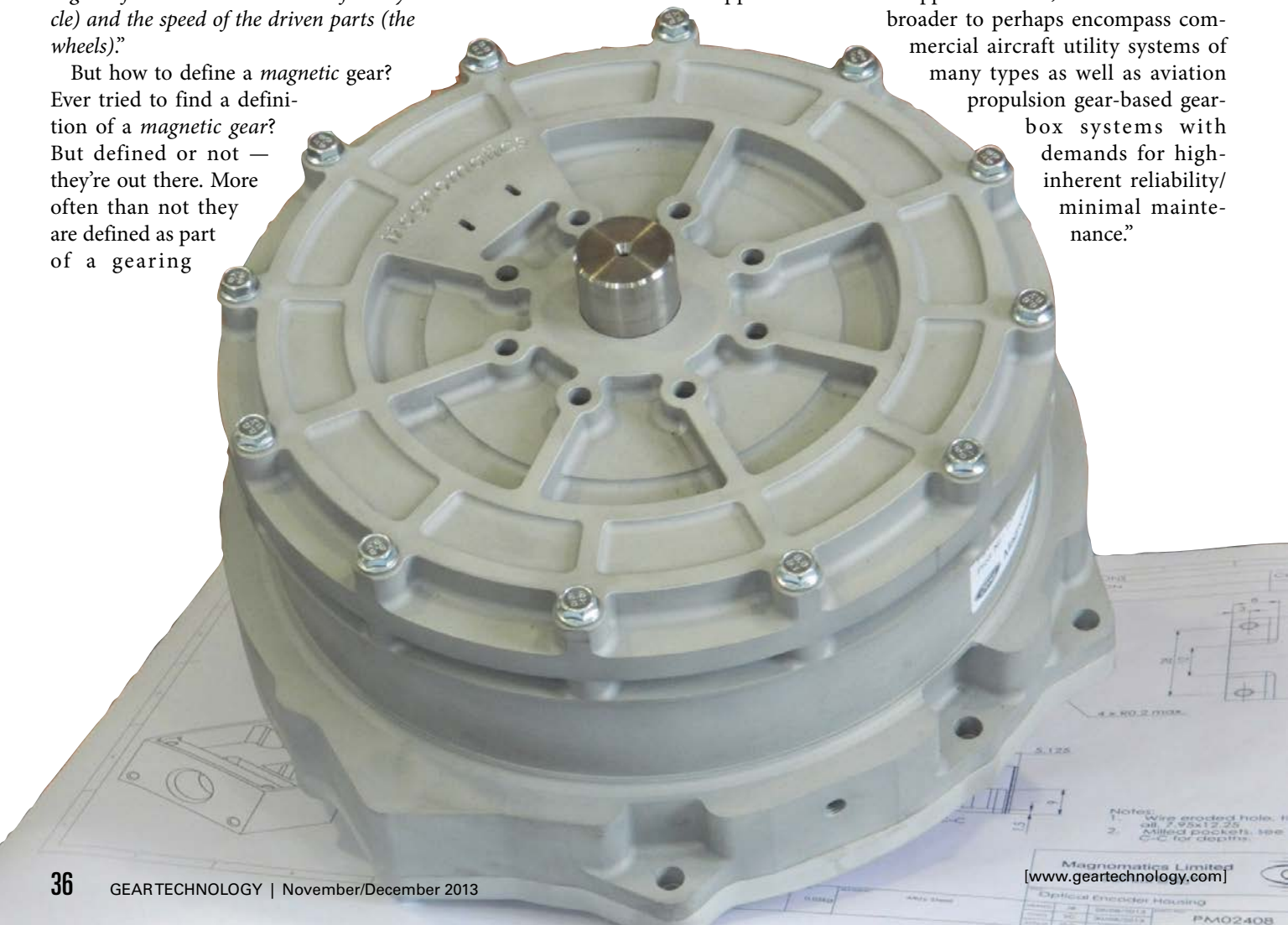
Just work with me here…

The *Gear Gospel According to Dudley* defines a gear as "*A geometric shape that has teeth uniformly spaced around the circumference. In general, a gear is made to mesh its teeth with another gear.*" A typical dictionary definition goes something like this, and for the purposes of this article, is in some ways better suited: "*One of a set of toothed wheels that work together to alter the relation between the speed of a driving mechanism (such as the engine of a vehicle or the crank of a bicycle) and the speed of the driven parts (the wheels).*"

But how to define a *magnetic* gear? Ever tried to find a definition of a *magnetic gear*? But defined or not — they're out there. More often than not they are defined as part of a gearing "system" — a gearbox, for example. But here's the thing: magnetic gears have no *teeth*. Oh, they mesh and all that, in their own unique way, and make things move; *but they have no teeth*.

The U.S. Navy certainly knows its magnetic gears, because they are found specified in Department of Defense RFPs, much like this one from 2010 (Magnetic Gears for Utility Actuation Gearbox Applications Navy SBIR 2010.2 — Topic N102-115): "Objective: Develop and demonstrate an airworthy magnetic gear-based gearbox suitable for utility actuation winch applications. Magnetic gear-based gearbox suitable for utility actuation winch applications" has become a common specification for a common winch application — one of many applications magnetic gear systems are now handling in lieu of traditional wrought-gear systems.

Indeed, the above-referenced RFP goes on to enumerate various other applications — existing or possible — that are commercially suitable for "magnetic gear-based winch gearbox systems," including: "winching/reeling systems on commercial aircraft such as search and rescue aircraft; police/security helicopters; logging operation aircraft; and off-shore oil rig aircraft operation. Other potential applications include industrial control and heavy equipment used in construction and mining operations. Indirect application of the technology to other non-winch gearbox systems appears feasible, and could be even broader to perhaps encompass commercial aircraft utility systems of many types as well as aviation propulsion gear-based gearbox systems with demands for high-inherent reliability/minimal maintenance."



[www.geartechnology.com]

To get closer to the can-do capabilities of magnetic gears we questioned David Latimer, business development manager of Yorkshire-based Magnomatics in the UK.

Accounts vary, but according to Latimer, "The first magnetic gears were proposed as far back as 1968. Magnomatics has developed these early ideas and can produce some very high-torque devices."

"Magnetic gears work by creating harmonics in magnetic fields," Latimer explains. "Predicting the effects of these harmonic fields has historically been very difficult," But he points out that, by employing "the most advanced finite element analysis tools, combined with in-house design methods," the company is able to "predict and understand these harmonics."

Those proprietary "in-house design methods" would appear to be the key to the puzzle.

At the company's technological heart — and where its growth depends — is in its three core offerings: 1) Magnetic Gears — A contactless, high-efficiency, high-torque transmission with inherent overload protection; 2) Magnetic CVT (mCVT) — A contactless, high-efficiency, continuously variable transmission system with inherent overload protection (MAGSPLIT, designed to duplicate the mCVT's capabilities and more, does so by providing the same functionality, but requiring much less real estate. MAGSPLIT also substantially improves the system efficiency and therefore fuel economy, compared to the mechanical gear and motor/generator combination found in many of today's hybrid cars; and 3) Pseudo Direct Drive (PDD) — An electrical machine, with fully integrated magnetic gearing offering unrivaled torque density.

By most accounts, the Holy Grail of magnetic gearing — both in the U.S. and around the world — is how to develop a magnetically geared — i.e. — electric — continuously variable transmission (CVT) — designed for use in *all* types of vehicles — large, small, personal and commercial. The benefits that accrue — better mileage, less pollution and smoother ride — are goals that automakers have pursued since the discovery of the combustion engine. And for Magnomatics, its techno trinity is sufficient justification for continued R&D in pursuit of that goal. What's more, recently announced — if not yet in practice — pollution mandates around the world — particularly in Europe, for now — render the need to succeed even more critical. Latimer points out that electric CVTs in fact already exist in compact hybrids from Toyota and Ford that "combine a planetary gear and an electric motor generator (see *http://eahart.com/prius/psd*)." And while the need continues to exist for larger, faster, more durable vehicles for both personal and commercial use, Latimer says that Magnomatics has "MAGSPLIT units being tested on rigs" — both in-house and at customer sites.

In the meantime, says Latimer, Magnomatics designs gear systems for "down bore-hole pumps, marine propulsion, wheel motors, hybrid powertrains and aerospace actuation." Clients include Messier-Bugatti, Goodrich, Turbo Technologies, Ultra Electronics and Macon.

Maybe by now, rather than wondering *why* magnetic gears, you are wondering *why not*. After all, according to Magnomatics they are: contactless (a magnetic gear uses those permanent magnets to transmit torque between an input and output shaft without mechanical contact; since there is no mechanical contact between the moving parts, there is no wear and lubrication is not required); highly efficient (torque densities "comparable" to mechanical gears can be achieved with an efficiency > 99 percent at full-load and with "much higher" part load efficiencies than a mechanical gear); high in torque transmission (for higher power ratings a magnetic gear will be smaller, lighter and lower cost than a mechanical gear); fail-safe-overload-protected (magnetic gears inherently protect against overloads by harmlessly slipping if an overload torque is applied, and automatically and safely re-engaging when the fault torque is removed). Other pluses include: significant reduction in harmful drivetrain pulsations; allows for misalignment/vibration of shafts; very low acoustic noise and vibration; gear ratios of 50:1 down to 1.01:1, with almost zero torque ripple are readily achievable.

But we don't have to take a commercial entity's word for all this. Let's return to that Navy RFP for the straight scuttlebutt on some of these same points.

According to the U.S. Navy:

Application: "Modern rotary wing aircraft have a number of utility winching/reeling systems for cargo, rescue, and sensor deployment applications."

Wrought gears. "Degradation or failure of these systems through wear of gear teeth can cause serious mission, reliability, maintenance, and logistical impacts."

Magnetic gears. "Magnetic gears afford the opportunity to provide speed and torque multiplication similar to a traditional geared gearbox or transmission, but by using magnetic attraction between rotating members rather than actual physical contact, as between gear teeth. It may be possible to greatly reduce, or potentially eliminate, lubrication requirements, compared to existing traditional gearboxes. A magnetic gear-based gearbox for winch applications could increase reliability and mission availability by reducing — or perhaps eliminating — wear-related gearbox failures attributable to traditional tooth-to-tooth contact."

But beyond what-if, blue-sky thinking, what is the application sweet-spot for magnetic gearing in the here-and-now?

"Our first production application is to drive a down bore-hole pump for artificial lift to improve yield in an oil and gas application," says Latimer. "The gear comes into its own because it can be made to work in a small diameter and is very reliable (the pump's installation, downtime and removal costs are high)."

In general, according to Latimer, and beyond the examples already cited, magnetic gearing's capabilities are dictated by "the speeds, torques and space available."

And here's a good news (for bearing manufacturers), bad news (for design engineers) fact of magnetic gearing life: bearings are required, just as with steel gears. And just as with steel gears, says Latimer, "The most likely weak point of

a magnetic gearing system will be the bearings."

As for AGMA or ISO standards, "We have not seen any particular impact as yet and tend to use (IEEE) standards intended for electrical machines as a reference."

So here we are on the doorstep of 2014, some of us still waiting for magnetic gears' big roll-out. What's the hang-up?

Could it be because China controls approximately 90 percent of the rare earth materials needed for the magnets that constitute magnetic gears? That would seem to keep prices artificially high and induce supply chain management nightmares in any design team contemplating magnetic gearing technology in any significant way.

Latimer doesn't see it that way.

"We think it just takes time for a new technology to be adopted. Our gears use the same magnet materials commonly found in permanent magnet electric machines, and those sell in abundance. We have seen magnet prices reduce and stabilize recently. The Chinese now realize that if they force up the price it becomes economical to open mines elsewhere."

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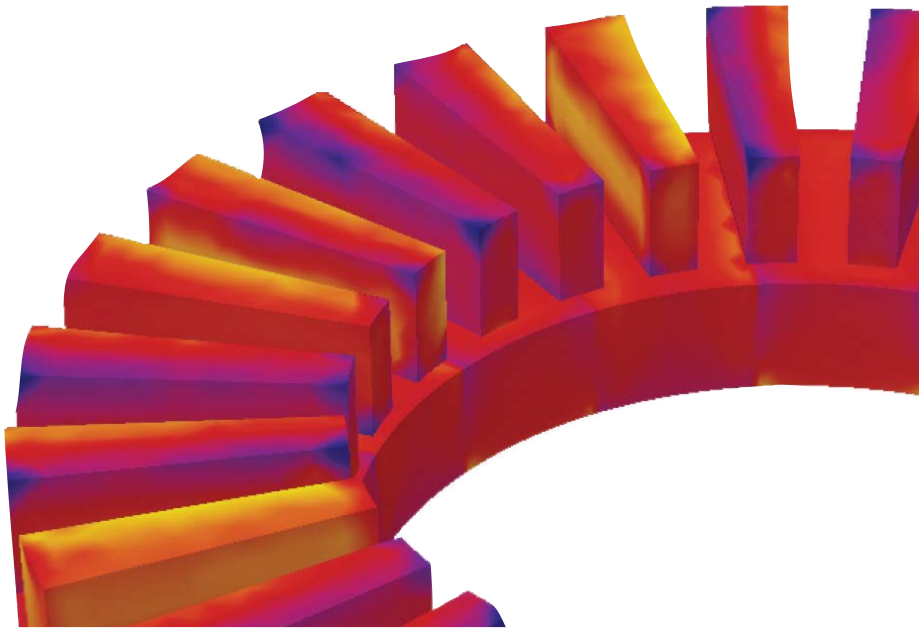
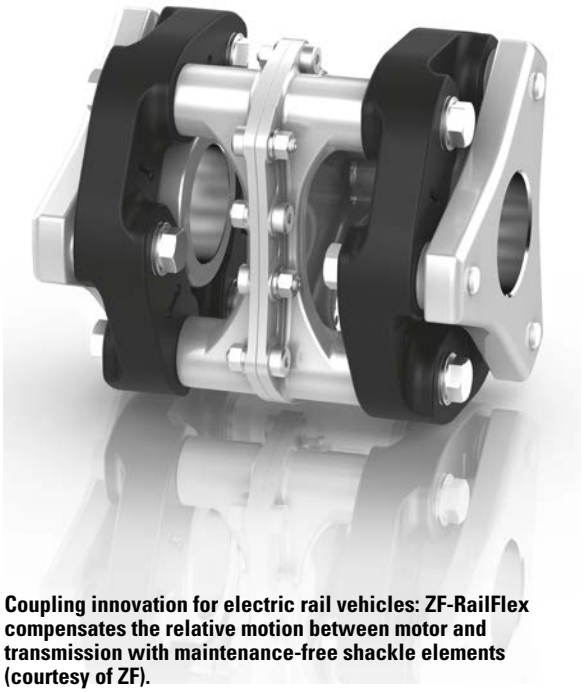


Riding the Rails

Are Trains Still a Growth Industry Prospect for Manufacturers?

Matthew Jaster, Senior Editor



Coupling innovation for electric rail vehicles: ZF-RailFlex compensates the relative motion between motor and transmission with maintenance-free shackle elements (courtesy of ZF).

On May 26, 1934, the Burlington Railroad's Pioneer Zephyr No. 9900 made its grand debut with a record-setting 1,000-mile dawn-to-dusk run from Denver to Chicago in 13 hours. Appropriately enough, the Zephyr was named after the Greek god of the west winds. The train was powered by a Winton 8-201A 600-hp, two-cycle diesel engine designed to travel at speeds of approximately 110 mph. Not only was the Pioneer Zephyr faster and lighter than its predecessors, it also reduced the cost of passenger train operation. A new era in railroading history had begun (*courtesy of the ASME*).

Today, the Pioneer Zephyr sits in the lobby of the Museum of Science and Industry in Chicago, a relic from an industry that was mostly replaced by highways and airports back in the 1950s. For many years since, the U.S. rail industry (outside of freight) has been a transportation afterthought. But thanks to high-speed rail programs in Europe and Asia, the debate continues on the manufacturing and transportation benefits of expanding the rail industry in the United States.

"Europe already uses rail as transportation all across the continent," said Kerry Klein, sales manager at Overton Chicago Gear. "Because of the differences in geography, cross country travel is not as prominent in the United States. The new high-speed trains may change that, but it's still too soon to tell."

"Efficient and reliable mass transit systems are some of the key levers for many cities around the globe to tackle the challenge of sustainable urban development," said Rama Iyer, business development manager at Siemens. "Whereas the more mature markets like Europe and the United States have a strong focus on upgrading existing fleets, the emerging markets, mainly Asia but also Eastern Europe and Russia, are planning and building new state-of-the-art mass transit networks."

Whether you're onboard or on the fence on the merits of high-speed rail, there's no disputing the fact that traffic is terrible, energy costs are rising and greenhouse gases are impacting the environment. While the automobile industry is a necessary evil, engineers have been working for years on alternative and sustainable modes of transportation. Some have been around for decades while others are in the early stages of development. High-speed rail, particularly in Europe, China and Japan is a very plausible transportation solution and projects are being developed in the United States to mirror global high-speed rail applications.

Overton Chicago Gear provides gearing for diesel engines, traction drives and light rail vehicles (courtesy of Overton).

Of course, it's a political issue like anything else where Republicans and Democrats argue over funding and regulations and anything else left to fight about, but here's what we do know: the global rail industry (including high-speed, light rail, commuter rail and freight) still offers unique opportunities for gear and gearbox manufacturers.

Rail Product Placement

"Overton was founded in May 1956 and has been servicing the rail (locomotive) industry ever since," said Klein. "Overton Chicago Gear provides gearing for the diesel engines, traction drives and light rail vehicles."

"Siemens has provided gearboxes and couplings for the rail industry for over 15 years," said Iyer. "We provide rail gearboxes in different configurations, including helical and bevel helical, complete with torque arm and couplings."

"ZF Friedrichshafen AG is recognized as a reliable partner for innovative driveline and chassis technology," said George Ehling, head of marketing and business development at ZF. "Based on an over 60-year tradition in the rail business with manufacturers and operators of rail vehicles, ZF stands for flawless, reliable, and long-lasting driveline and chassis products in future-oriented rail travel applications."

Companies like these and others have been optimizing rail components for years, both standard and customized products.

"All of our business is custom-made parts to customer supplied drawings," said Overton's Klein. "We're always adding new manufacturing equipment to serve our customers since we manufacture to their specifications."

"Siemens has locally available service personnel in Elgin, Illinois and Bakersfield, California," said Iyer. "We rebuild and service gearboxes at these facilities. Additionally, we've developed customized solutions for a number of rail projects in the last year."

ZF focuses on short routes and faster service to accommodate its rail customers. "Our high-coverage service network for maximum quality covers the entire life cycle. Seven days a week, round the clock, ZF has its own sales and service companies where staff is always available as local customer contacts and problem solvers. With over 700 authorized ZF After Sales Service Centers, the company can offer flexible and timely intensive support – backed up by fast delivery of spare parts," said Ehling.

Similar to applications in the wind, automotive or aerospace industries, rail has its own unique set of market challenges. "Staying competitive with the worldwide supply chain is one of the greatest challenges," said Klein.

"As this market involves funding from the government or other agencies, there are delays which affect costing. Smaller product companies compete on price and when the product fails or has a problem, exit the market due to the high liabilities involved. Shorter lead times in a competitive market demand first-class performance during the development and engineering of gear units. This again is only possible based on stable processes and abundant experience, both of which Siemens has in place," said Iyer. "Energy efficiency, safety and easy maintenance are the key factors in 2013."

"The things that manufacturers and operators of rail vehicles expect in the future have already been turned into practical reality in the form of ZF products: Increased driving comfort and safety with reduced fuel consumption and lower emissions. Highly integrated products and superlative systems expertise is the key to this. All driveline components are provided from a single source," said Ehling.

Making rail traffic significantly more comfortable, economical, and safe is the important industry objective ZF focuses on. "ZF brings a clear added value to all different kinds of train types. The newly developed ZF-RailFlex fiber composite coupling, for example, achieves two contradicting requirements: It increases passenger comfort and at the same time reduces the life cycle costs of electric trains. Since it is installed in the partly suspended bogie, it does not only have to transmit torque but also needs to effectively compensate the relative motion between motor and transmission," added Ehling. "ZF-RailFlex uses a technology which has been tried and tested millions of times in automotive engineering and is now used in rail vehicles for the first time. Since ZF-RailFlex does not need any additional components, there are further advantages: installation is especially easy and the coupling's weight is reduced — although it is still a high-performance component."

High cost-effectiveness and economy play a decisive role for trains operated not only nationwide but also for urban public transport. "ZF developed the new E-Rail-SH 15 F metro transmission, which reduces life cycle costs and has already been used successfully in trains of Moscow's metro.

The Canadian city of Calgary recently awarded Siemens an order to supply 60 S200 light rail vehicles, worth more than 135 million euros. The LRVs will be built at the Siemens factory in Sacramento, USA and are due to be delivered starting in summer 2015. The full order is to be completed by December 2016. This is the first order for the new light rail generation from Siemens. "The 60 LRVs will continue our more than thirty-year success story in Calgary. The new generation of vehicles delivers exactly what this modern and constantly growing Canadian metropolis needs. The LRVs are energy-efficient and provide passengers with even higher levels of comfort and safety," said Jochen Eickholt, CEO Siemens Rail Systems, in a recent press release.

Calgary is the third largest city in Canada and its population has grown

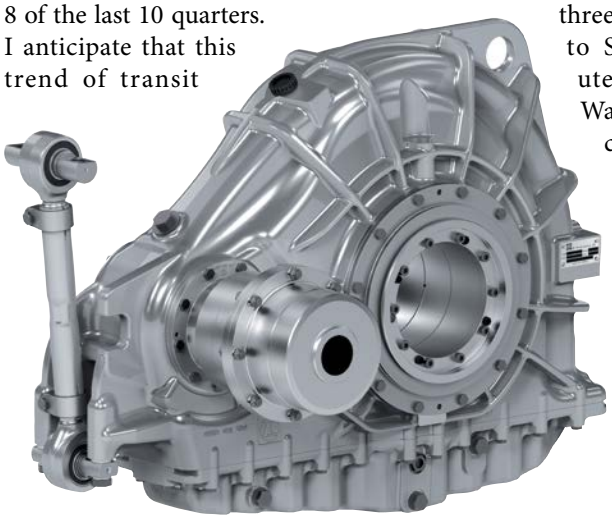
The ASEF 380 helical gearbox from Siemens.

Calgary recently awarded Siemens an order to supply 60 S200 light rail vehicles, worth more than 135 million euros (courtesy of Siemens).

since 2006 by one quarter to over one million. As the population has grown, so has the number of passengers using the light rail system. Passenger volumes have increased by 50 percent in the last ten years alone. Today the LRT system is the busiest in North America and the second busiest in the world, transporting more than 300,000 passengers every day. The network is around 56 kilometers long and has 44 stations. The fleet consists entirely of Siemens vehicles and, in total, 156 LRVs are in service in Calgary.

Public Transportation Thriving

Nationally, nearly 2.7 billion trips were taken on U.S. public transportation in the second quarter of 2013, according to a report released in September by the American Public Transportation Association (APTA). Compared to the second quarter of 2012, this year's second quarter increased by 1.2 percent, with nearly 31 million more trips taken from April through June. In comparison, vehicle miles traveled (VMT) on our nation's roads was up by 0.5 percent. Noting that in eight of the last 10 quarters, ridership on U.S. public transportation has increased, APTA President and CEO Michael Melaniphy said, "In big and small communities, demand for public transportation continues to grow. Public transit ridership has increased in 8 of the last 10 quarters. I anticipate that this trend of transit ridership growth throughout the United States will continue."



ZF's E-Rail-SH 15 F metro transmission is equipped with innovative tapered thrust washers that serve as the basis for longer service life, thermal resistance, and less maintenance efforts (courtesy of ZF).

In the second quarter, some cities saw ridership increases due to economic recovery. They include: Birmingham, AL; Los Angeles, CA; San Francisco, CA; Miami, FL; Denver, CO; Champaign-Urbana, IL; Chapel Hill, NC; Ithaca, NY; Houston, TX; Hampton Roads, VA; and Seattle, WA.

"As the local economy continues to recover, public transportation ridership continues to increase in those communities where jobs are increasing," said Melaniphy. "Since nearly 60 percent of trips taken on public transportation are for work commutes, it makes sense that ridership goes up when employment goes up."

In conclusion, the U.S. high-speed rail phenomenon is a real possibility if politicians can get on the same page and cut through all the red tape. Imagine a three-hour ride from Los Angles to San Francisco or 60-minutes from New York City to Washington D.C. A passenger could get similar treatment between Midwest cities like Minneapolis, St. Louis, Chicago and Detroit.

The U.S. High-Speed Rail Association sees a future where a national rail system forms the backbone to a completely sustainable transportation system including regional and commuter rail, light rail, streetcars, trams, electric buses and bicycles. We look at the future in simpler terms: more trains, more jobs, more work for the manufacturing industry.

For more information:

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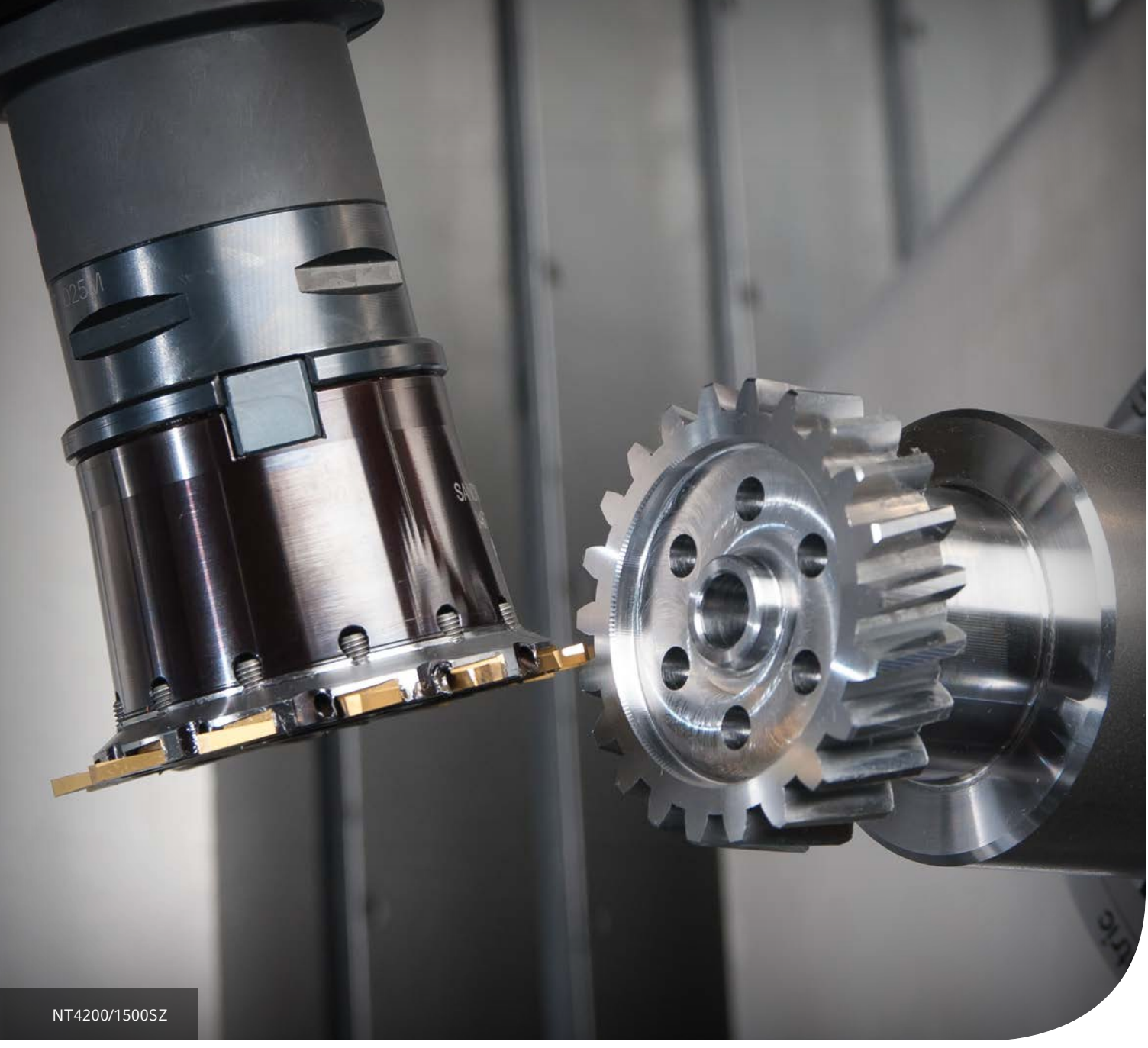

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The 2013 *Gear Technology* Buyers Guide was compiled to provide you with a handy resource containing the contact information for significant suppliers of machinery, tooling, supplies and services used in gear manufacturing.

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

But Wait! Where are the Gear Manufacturers Listed?

If you are looking for suppliers of gears, splines, sprockets, gear drives or other power transmission components, see our listing of this issue's power transmission component advertisers on page 59. In addition, you will find our comprehensive directory in the December 2013 issue of *Power Transmission Engineering* as well as in our online directory at *www.powertransmission.com*.

Handy Online Resources

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

www.geartechnology.com/dir/

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

www.powertransmission.com/directory/

How to Get Listed in the Buyers Guide

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

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Fax: (248) 370-0991
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www.marposs.com

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george.boon@schnyder.com
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Fax: (847) 649-0112
sales@starcutter.com
www.starcutter.com

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sales@star-su.com
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PATIALA PUNJAB 147001
INDIA
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Fax: +(91) 175-2212963
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Fax: (248) 589-1062
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sales@ipsenusa.com
www.IpsenUSA.com

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www.gleason.com

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MACOMB, MI 48042
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rodney.soenen@involutegearmachine.com
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sales@zoller-usa.com
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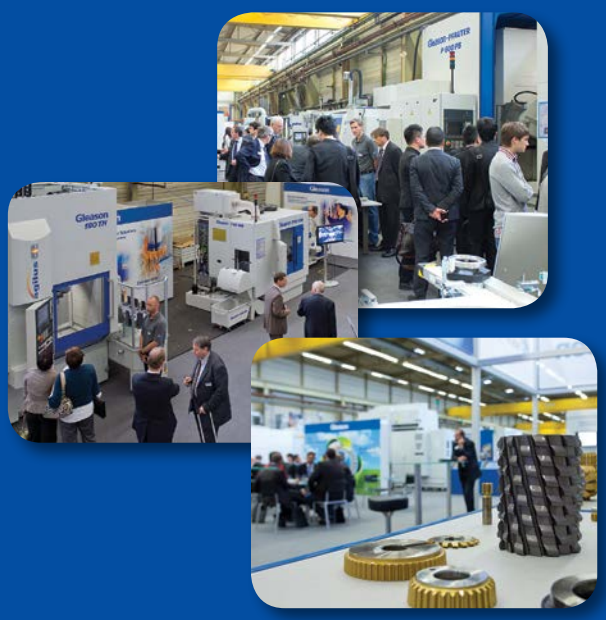

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Ed's Note: This is the seventh and last article in an "reality" series on implementing Continuous Improvement at Hoerbiger Corporation. Throughout 2013, Dr. Shahrukh Irani will report on his progress applying the job shop lean strategies he developed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

Shahrukh A. Irani, Hoerbiger Corporation of America

Background

FLEAN (Flexible+Lean) cells are the foundation for implementing Job Shop Lean in any complex high-mix low-volume (HMLV) facility. The core steps in the process for implementing Job Shop Lean in any high-mix low-volume facility require leadership to (i) identify the stable part families in their product mix, (ii) implement a FLEAN manufacturing cell to produce each part family that has a stable demand and (iii) utilize Finite Capacity Scheduling to schedule the daily operations in each cell. But, after they are done with the design and implementation of each FLEAN cell and its support systems, the real challenge of implementing the cell lies ahead. And that is the challenge of educating and training cell employees and company managers to embrace a new way of working together. If the cell is to operate as an ABU (Autonomous Business Unit), the cell's team must be given full responsibility for fulfilling all customer orders loaded on their cell. Therefore, in this column, I will describe all the educational and training resources that I am aware of, or have personally developed, that I am utilizing in my current job to educate and prepare our people to work in FLEAN cells.

See How Others Did It

Sometimes all that it takes to get the people in your own company fired up about lean is for them to see how other companies succeeded with lean. Successful implementation of lean does not always have to be a complete bolt-by-bolt rearrangement of the entire facility. Some of the inspirational videos that I use to create a basic awareness about lean are:

(**Vendor:** *www.sme.org*) *Introduction to Lean Manufacturing* (DV03PUB46), *Lean Manufacturing at Miller SQA* (DV03PUB47), *Lean Manufacturing at TAC* (DV03PUB48)

(**Vendor:** *www.gbmp.org*) The Greater Boston Manufacturing Partnership (GBMP) has developed a mini-library of videos that feature some of their successful clients, such as Jotul, Madico, The Gem Group, VIBCO, AbioMed, etc.

And now some words of caution about over-relying on videos about lean to educate and train people in your company. At some point, you have to demonstrate that you know a lot more than what is offered in those videos. So be prepared to frequently stop any video and explain details that are not displayed or verbalized in the video. For example, when a video shows a shadow board for tools, stop the video and explain that it is the responsibility of every operator to not put back a broken tool and walk away.

Make Full Use of Facility Walkthroughs

Nothing is better than recording actual examples of the Seven Types of Waste (Overproduction, Transportation, Scrap/Rework, Operator Motion, Overprocessing, Waiting and Inventory) in your own facility. All it takes is a facility walkthrough armed with a camera. However, it is important that you plan this walk based on the routing of a key component (or product) that you make, or better yet, an entire part family. Figure 1a shows the manufacturing path followed by a forged part. The locations of the different machines that feature in

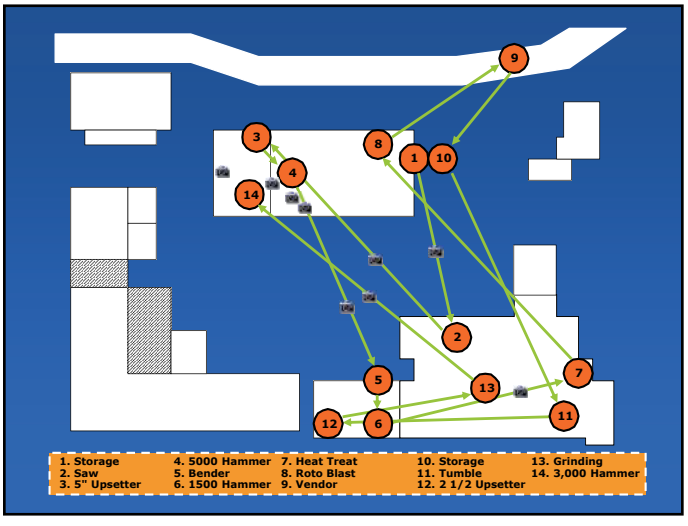

Figure 1a Spaghetti Diagram for a Single Forged Component.

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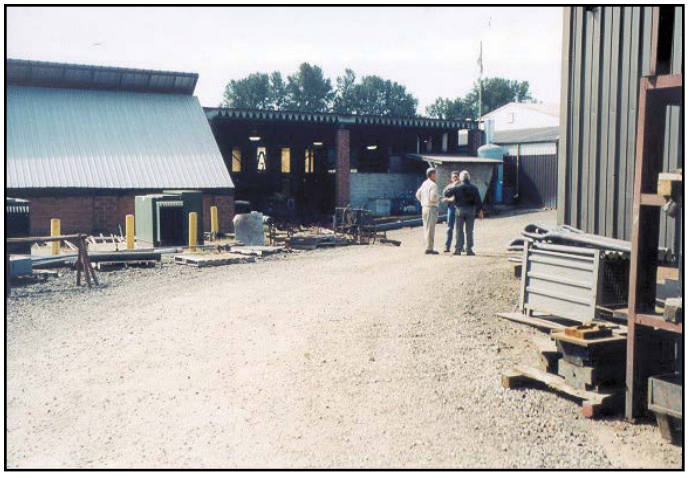

Figure 1b Wastes due to transportation between consecutive operations.

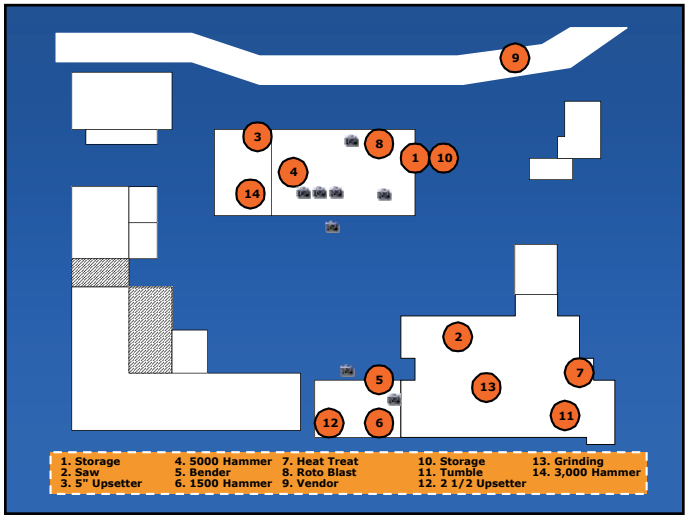

Figure 2a Locations at or near different machines where wastes were photographed.

Figure 2b Wastes due to inefficient storage of raw materials.

that part's routing and the sequence in which they are used are shown on the diagram. ***To capture the waste between all pairs of consecutive operations***, stand at the location of each operation, look in the direction of the location where the next operation will be done and take a photograph. For example, Figure 1b captures the distance of travel and the absence of line of sight (LOS = 0) between the locations of Operation #1 (the partially-shown building on the right in the photo) and Operation #2 (the building on the left in the photo). Which of the seven types of waste are caused by the transportation between these two consecutive operations to produce this forging?

Next, ***to capture the wastes at the location of every operation***, stand at the location of each operation and take a wide-angle photograph of the machine and its vicinity. Figure 2a shows different locations at which I took photographs related to the machines used to make the forging. For example, Figure 2b shows how bar stock delivered by the suppliers was stored outside the building that housed the presses. Which of the seven types of waste are caused by the absence of any visual indicators to distinguish the different types of bar stock stored on the racks?

For free information on how to do a walkthrough of your facility and conduct an effective morning meeting to report your observations, you may find helpful these videos posted on YouTube: (i) *Morning Improvement Walk* and (ii) *Lean, The Morning Meeting at FastCap*.

Make Your Own In-House Training Video

Next, you could take on the challenge of making a video based on your own shop, like the one titled *How a Job Shop Developed their In-House Training Video on Waste Elimination* that PR Machine Works (*www.prmachineworks.com*) made. It is based entirely on the videotape of a facility walkthrough that was led by their president, Mark Romanchuk. This video was the basis for a step-by-step tutorial on waste identification and elimination that I taught to their key managers. However, my all-time favorite is the video titled *A Program to Initiate Job Shop Lean at Bula Forge & Machine Inc.* that was made by Bryan Wang, a former IE graduate student at The Ohio State University. He single-handedly produced the video that documented his three-month summer internship in a custom forge shop. They hired him to do a pilot project to implement Job Shop Lean in their facility. Find an interested employee in your company and let him/her loose on this video project to enhance your company's lean training curriculum.

You Must Include These Videos in your Company's Lean Training Curriculum

I am referring to *Toast Kaizen* (**Vendor:** *www.gbmp.org*) which is one of the best educational videos on lean ever made, in my honest opinion. In fact, this video is at the heart of an advanced half-day workshop on continuous improvement that I have developed to teach "Lean IE" to our interns and lean six sigma staff. Beyond discussing the superb examples of the seven types of waste explained in this video, I also teach how to develop a flow process chart, spaghetti diagram, 5 whys tree, Ishikawa (cause and effect) diagram, constraint-driven thinking, tree diagram and Gantt chart to expand their problem-solving and system design skills.

The second video that I highly recommend, in spite of its intimidating price tag, is *The Goal* (*www.goldratt.com*). It introduced the world to Eliyahu Goldratt's theory of constraints (TOC). The trouble I have with lean's over-emphasis on waste elimination with employee-led kaizens is that it is very easy to unleash a frenzy of factory-wide waste elimination efforts with no overarching goal. Instead, I favor integrating TOC and lean as follows: (a) select a key value stream (or part family) and (b) focus on eliminating waste first and foremost on the bottleneck in the value stream for the single assembly (or value network for the part family). As I did in the case of *Toast Kaizen*, so also in the case of *The Goal*, I have created a list of questions that I ask those who are watching the video to answer while they watch the video. Every time that I show *The Goal*, I keep checking the answers I wrote for each of the existing questions in my question bank. It amazes me that I keep improving the answers to the questions I already have. But I keep adding questions because I find new nuggets of knowledge embedded in this classic educational video.

Putting it all Together

There comes a time when it is important to demonstrate how to bring together all this education and training to design and operate an actual cell. Figures 3a-3g provide a simple example using a forging cell. In the case of this cell, the bar stock was stored in a different building (LOC #1 in Figure 3a) and transported in large tubs to the cell by a forklift ("MHE" = material handling equipment in Figure 3a). Notice that the large tubs were put down by the forklift driver a considerable distance away from the oven. From where he stood in front of the drop hammer, the cell operator would walk to the tubs, pick up and cradle several billets in his hands, walk back behind the oven and place them one-by-one on its conveyor. Then he would walk around the oven and wait for a heated billet to emerge from the oven. As soon as a heated billet emerged from the oven, he would pick it up with a pair of tongs, load it into the drop hammer and forge the part.

Figure 3a presents a high-level visualization of the material flow of each forging produced in this cell. Figure 3b is a simplified value stream map to display the operational parameters for all the activities performed in the cell. Figure 3c shows the location where tubs full of sawn billets are delivered from another facility. Do you think that the current inter-facility logistics is

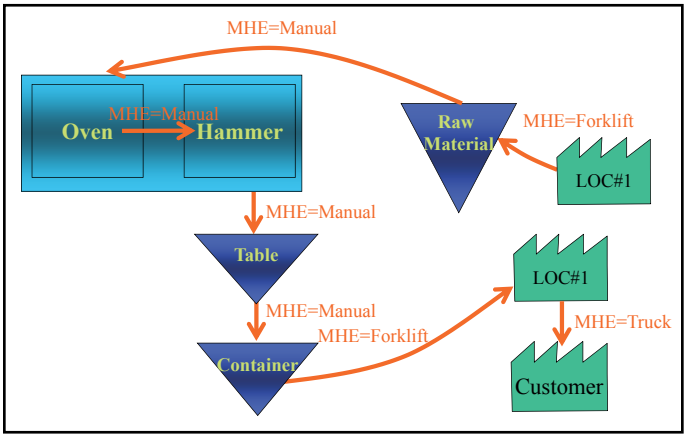

Figure 3a Factory-level material flow for the cell.

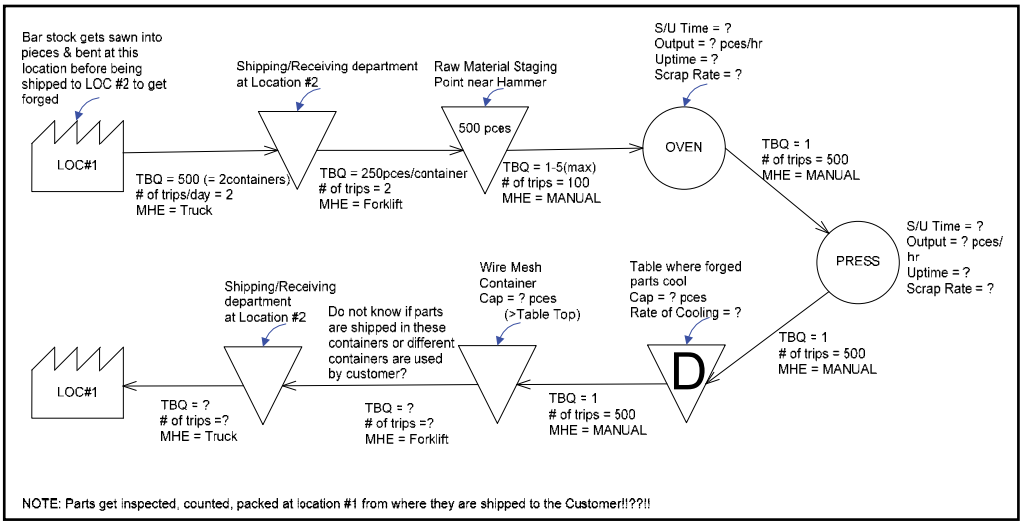

Figure 3b Shopfloor-level value stream map for the cell.

Figure 3c Location where tubs full of sawn billets are delivered from another facility.

Figure 3d Tubs full of sawn billets delivered to the cell.

Figure 3e Relative positions of oven and hammer in the cell.

wasteful? And what about the traditional seven types of waste in this storage area? Figure 3d shows two tubs full of billets that are delivered to the cell. Would you know how many billets are contained in each tub? And does that quantity relate to the daily demand that should pace the production rate of the cell? And will it be easy for the operator to reach into the tub to pick the last few billets off the bottom? Figure 3e shows the relative locations of two key pieces of equipment in the forging cell. The oven needs to be used first before the drop hammer. But their positions appear to be interchanged, right? And the two tubs full of billets are dropped off to the right of the hammer. Sadly, the OSU graduate intern and I worked on this project way back in 2004. I knew even less about lean back then. So it completely escaped both of us to sit down with the shop owners and point out such a simple opportunity to score a win with lean. This one-piece flow cell had none of the complexity of a FLEAN cell and could have been improved using value stream mapping.

Figure 3f shows the relative locations of in-process and finished forgings produced in the cell. Again, back then in 2004, it did not strike me why they would put the forgings coming hot off the hammer to cool down on a table, and then expend labor to pick them off that table one-by-one and drop them into the

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wire mesh container. Nor did I ask if later they would empty that wire mesh container into a sturdier tub that would be used to transport the entire batch of finished forgings to the facility that supplied the billets. So here is my question to all of you readers—could a fixture be designed that would serve as the surface of the table but could be placed on top of the wire mesh container? That way, the operator would take hot forgings from the hammer and drop them on this surface. Then, say with the palm of his hand he sensed that the hot forgings had cooled off, he would simply tilt the fixture to drop the forgings into the container. Why unnecessarily accept the delays and costs of wWaiting and inventory wastes due to the current arrangement?

Figure 3g presents the improved layout that was designed for the cell to eliminate NVA (non-value added) activities. How does the circular layout of the cell eliminate operator motion waste?

Moving On to More In-Depth Training

Having completed the preliminary lean training with this simple forging cell, I next utilize videos to teach the details about relevant lean tools and best practices that are essential to make a cell operate like an autonomous business unit (ABU). Some videos that I use to teach how 5S, setup reduction, cross-training, visual control, continuous flow, etc. make a cell operate as an ABU are:

Customer Focused Manufacturing **(Vendor: *www.sme.org*, DV03PUB53)**: I use this video to emphasize that continuous improvement efforts must be made by everybody at all levels of the organizational chart—business, factory, shop, cell and machine. For example, at the *business* level, this video has segments that show top executives receiving training on strategic planning to help them decide that manufacturing cells were a key component of their strategy to be globally competitive. Similarly, at the *machine* level, this video shows poka-yoke devices for quickly checking product quality, tools hanging within easy reach of every operator, wheeled containers designed to hold a specific number of parts ("***cart***ban"), ergonomically safe ways to lift heavy containers from pallets onto racks, etc.

Single Piece Flow **(Vendor: *www.sme.org*, DV06PUB13)**: I use this video in conjunction with a write-up I prepared to describe every lean/Job Shop Lean best practice that is shown being used in the video. For example, the digital counter on the assembly machine displays the Takt time (TT) for the cell. Okay, so TT may not be relevant in a high-mix machining or fabrication cell. Still, it is important to explain that the display is clearly visible both to the cell operator and anyone outside the cell and that it displays a single metric that drives cell performance. In this video, I especially like the segment on the water strider. He/she is not just a material handler but also an expeditor who ensures that orders are on-time, that replenishments signaled by kanban cards are made, etc.

Once again, as I had said earlier in this column, I will stress that you cannot just rely on books and videos to teach and train your employees and managers about lean or Job Shop Lean. Either you or someone else has to become good

Figure 3f Relative locations of wip and finished forgings in the cell.

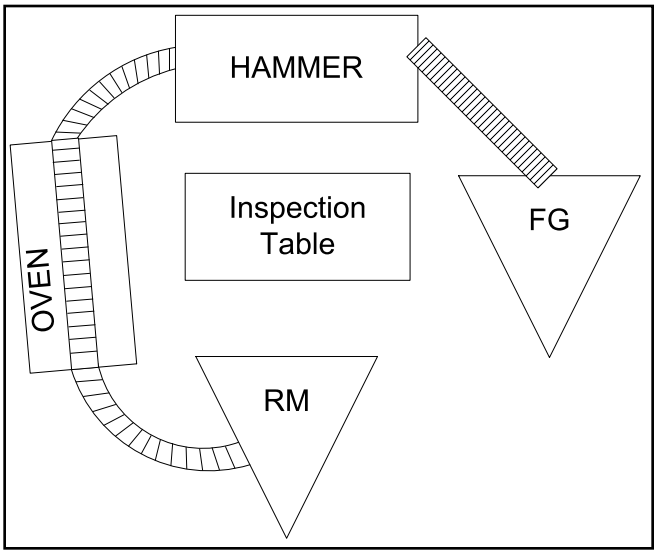


Figure 3g Improved layout for the cell.

enough to at least be the in-house expert who will repeatedly stop these videos to offer more details about a useful tool or a best practice or a behavior trait. Personally, I find it okay to not know because it puts pressure on me to keep learning so that I can try to be a better teacher. For free information on work cells, you may find helpful these videos posted on YouTube: (i) *Why Do You Use "U" Shape Cells at FastCap?*, (ii) *Manufacturing Work Cell Optimization* and (iii) *Subway is a Lean Work Cell – Be a Money Belt!*.

Beg, Borrow, ~~Steal~~, Adapt, Improve, maybe Innovate too!

I have never hesitated to borrow every relevant concept, tool and system from the Lean body of knowledge and embed it into the Job Shop Lean body of knowledge. I have realized that Toyota has pioneered and continues to practice to this day an IE curriculum that we simply are not teaching in the 100+ IE departments in the United States. Even though Job Shop Lean is built on IE science, I find the proven, simple, practical tools of Lean to be invaluable. Let me give you a personal example of this "use whatever works" mindset of mine.

Soon after joining HCA, the Tiger Team for Continuous Improvement at HCA-TX had to be given basic Lean train-

ing. This team is an informal group of employees and managers who have volunteered to learn and do Continuous Improvement projects that the team opts to do. But when we were re-designing the MPC cell, the challenge arose to demonstrate to the employees working in the cell why, even if they did not use one-piece flow between machines, that at least they could split any Order Batch into two or more (smaller) Transfer Batches. So, first I went on YouTube and watched this video titled *One Piece Flow versus Batch Production – Lean Manufacturing*. Then I developed a simple paper-and-pencil tabletop simulation to demonstrate to our Tiger Team the differences between Order Batch, Transfer Batch and One-Piece Flow (Batch Size = 1). The complete details of this game that I developed based on the YouTube video are presented in the Appendix. Figure 4 provides a sample for the part's route sheet that you could use for this game. I assure you that the impact of splitting the single batch of 6 parts into two smaller batches of 3 parts apiece will impact how quickly the order gets done.

Part XXX	Lot Size: 6	Part # of 6
Operation #	Machine Used	Operation Time
1	M1	24
2	M2	18
3	M3	12
4	M4	22
5	M5	20

Figure 4 Route Sheet for the Part.

So, I played this game with our Tiger Team. Now, it so happened that one of its members, Luong Dam, also worked in the MPC Cell where an IE graduate intern was working with me to completely re-design that cell. The three of us discussed (and argued a lot too) why one-piece flow was surely not possible between the Haas Mill and the group of three Cincinnati Mills that Dam ran. But, we felt that it was unacceptable that operators at two machines which were a few steps apart continued to use a batch-and-queue policy instead of using transfer batches. Figure 5 shows Dam's idea to start pulling just enough pieces off the Haas Mill that he could pack on the arbor used on each of his three mills. Thereby, the same order could be run in parallel on all three machines. Such is the power of education given to employees who are empowered to exercise their creativity.

A Training Game for Teaching Job Shop Lean

Interactive games (aka simulations) are an extremely effective way to educate a large group of shop employees and managers. Job shops are among the most complex high-mix low-volume (HMLV) manufacturers. They must cope with different manufacturing routings with varying setup and cycle times at consecutive operations, orders with different lot sizes, production schedules based on due dates, etc. The ***JobshopLean Simulation*** is a low-cost interactive simulation to teach the following best practices for high-mix low-volume manufacturing that may be hard to teach using a typical Lean simulation that models a standard assembly line:

- Use Cash Flow Velocity as a single metric that drives cell performance
- Segment the parts into multiple segments based on Volume and Value in order to assign priorities when releasing orders into the cell, especially at the bottleneck machine in the cell
- Identify part families in the product mix
- Group machines into manufacturing cells to make the part families
- Design a U-shaped layout for a manufacturing cell with different routings
- Plan the equipment allocations to the cells based on Workload vs. Available Capacity
- Identify certain routings that have "misfit" operations that complicate flow logistics inside a cell
- Train material handlers to become "Water Striders" on the shopfloor
- Cross-train employees to attend to multiple machines within a cell
- Introduce multi-function flexible automation to reduce the # of machines in a cell
- Schedule a cell subject to finite capacity constraints and to control release of orders into the cell
- Encourage feedback and ideas from the cell employees
- Exploit visual management to guide "visual pull" of orders into the cell

Throughout the simulation I play the role of the Water Strider moving jobs between different machines. This allows me to have fun, as well as entertain and instruct the class. Throughout the simulation, I repeatedly emphasize that standard Lean tools, such as 5S, SMED, TPM, Visual Workplace, etc., are universally applicable.

A Simpler Version of the JobshopLean Simulation

The *JobshopLean Simulation* requires at least a half-day to run. Instead, a simpler version of that simulation, the *Stamping Cell*

Figure 5 Transfer Batch determined by the Fixture used on the Mill.

Layout game, could achieve almost the same learning objectives. The cell needs to produce a number of different license plates. The class is asked to design a layout for this cell that makes it (i) flexible, (ii) fast and (iii) cost-effective to operate. The cell consists of six stamping presses and a location R/S. The location R/S is the combination of two departments: "R" = Receiving (for receipt and storage of raw materials) and "S" = Shipping (for receipt and shipping of finished products). Six volunteers are chosen to role play as the "stamping presses". They each receive an inkpad and a stamp with one of the six letters – W, E, T, A, H, C. They would stamp their letter on each license plate that has a word with that letter in it. The set of license plates that must be produced is as follows:

Wheat	Thaw	Etch
Cheat	What	Whet
Teach	Chew	Each
Chat	Hate	Ache
Watch	Heat	

Each license plate is assigned to a different person in the class. Each license plate will start at the location R/S visit the appropriate sequence of presses one-by-one, get the sequence of letters stamped on it at the different presses and, after all the needed letters have been stamped on their plate, they return to the location R/S. When a license plate reaches a particular press to get their next letter stamped, they wait their turn in the queue to get stamped before they can move to the next press to collect the next letter stamp, and so on. The person carrying a license plate must keep a count of the total number of steps that he/she walked on their route, beginning and ending at the location R/S. On completion of his/her manufacturing route, each person reports the total number of steps that they walked to the person acting as the R/S clerk sitting near the cell.

So, what are some of the challenging questions that I ask the class to answer after they are done playing this seemingly simple game? Here are the key questions:

- Which of the 720 possible layouts for the cell would minimize the total distance travelled by all the license plates?
- Where should the R/S station be located with respect to the six presses in the cell?
- What is the sequence in which the plates should be released to the cell to minimize the total time it takes the cell to complete all the license plates? Hint: If you wish to answer this question, you will need to learn about Job Shop Scheduling then go online and download the free *LEKIN Academic Scheduling Software*.
- Would they release all the plates for production at the same time? If not, would they release similar plates such as WHEAT, WHAT and HEAT one after the other? Or would they prefer to release dissimilar plates such as WATCH, HEAT and CHAT one after the other?

This game provides insights into some of the key differentiators between Job Shop Lean from Lean. None of the above questions can be answered right off the bat. It is not easy to implement Job Shop Lean. If Lean takes years to embed into a large company's culture, it takes a similar amount of time, if not more time, to truly convince the owner of a small or medium-size job shop to invest time and money, especially their own, to implement Job Shop Lean.

Advanced Education and Training on Job Shop Lean

I find that games and simulations on Job Shop Lean are entertaining and effective for explaining concepts and strategies. But, they are incapable of teaching the methods and tools that actually ***solve*** the operational issues that plague HMLV manufacturers. This is why I have developed the following workshops to teach advanced Job Shop Lean and IE tools to our interns, IE's and Lean Six Sigma staff:

- (5-day workshop) *Fundamental Methods and Tools of Lean Manufacturing*
- (1-day workshop) *IE Software to Extend the Lean Tools*
- (3-day workshop) *Fundamentals of Finite Capacity Scheduling*
- (1-day workshop) *Practical Cell Scheduling using Scheduling Algorithms, Lean and TOC*
- (5-day workshop) *Building a High-Mix Low-Volume Manufacturing Facility using Production Flow Analysis*

The Good Ol' Days

Until September 2012, when I was on the faculty of the Department of Integrated Systems Engineering at The Ohio State University, whenever I ran the Job Shop Lean Simulation in any of my courses, I would also teach my students how software tools like *PFAST* (for part family formation), *STORM* (for cell layout), *LEKIN* (for cell scheduling), *TIMER PRO*, *MINITAB*, *MS PROJECT*, etc. facilitate the design and operation of FLEAN cells. I sorely miss teaching and developing students whom job shops all over the United States would hire as interns who I would mentor and guide to implement Job Shop Lean.

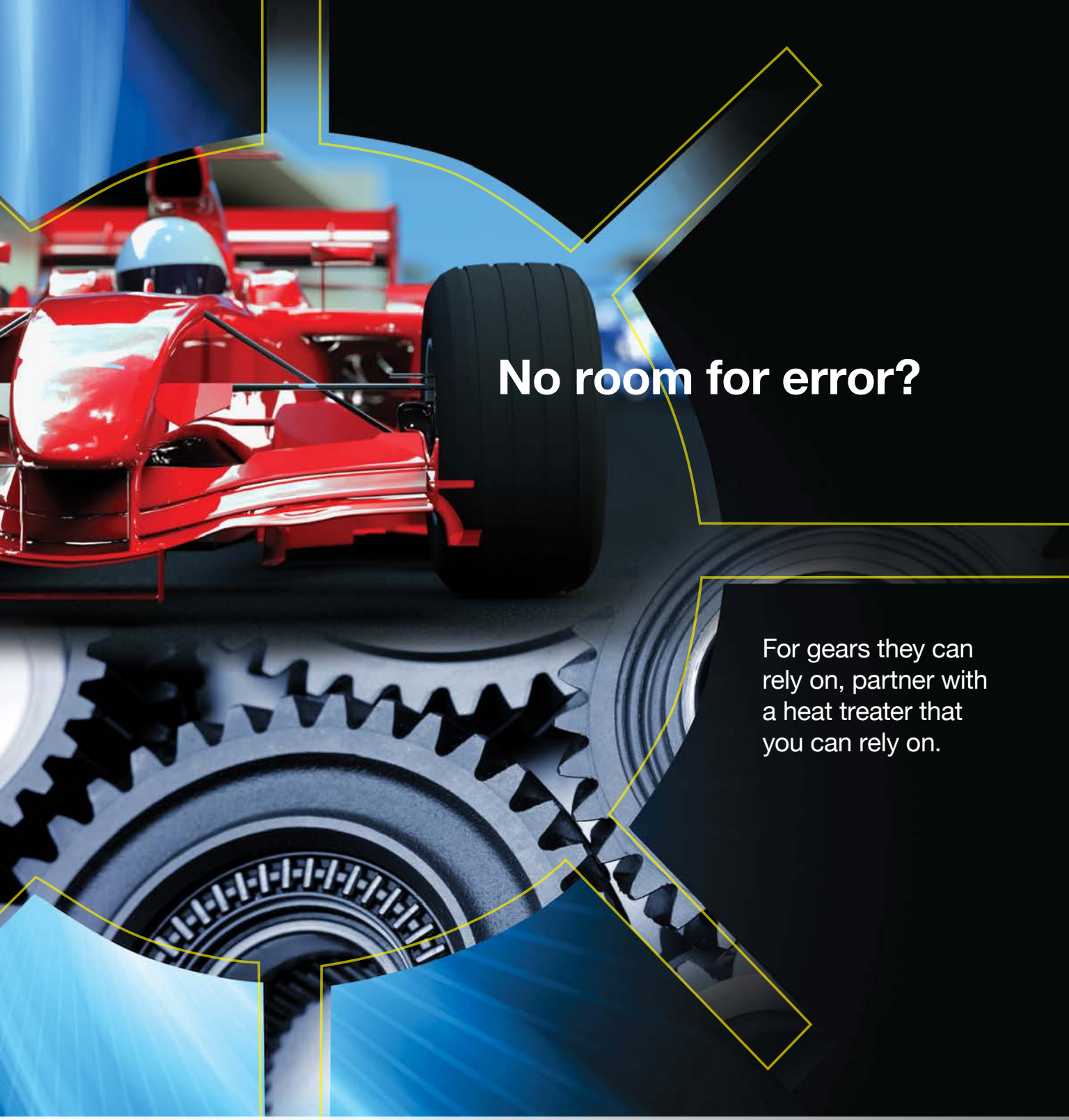
In Conclusion

Nobody taught Toyota how to develop the revolutionary Toyota Production System on the pillars of *Just In Time* and *Respect for People*. They just did it on their own. They had the confidence and internal experts who were courageous enough to learn novel problem-solving tools via a try-and-try-again process. And that is what is driving me to implement, improve and enhance the implementation of Job Shop Lean in our ***high***-mix ***low***-volume manufacturing facility here in HCA-TX.

Acknowledgements

I am grateful for the assistance that Max Wittmann and Herwig Aigner, IE undergraduate interns from the University of Applied Sciences FH Joanneum in Austria, gave me during the writing of this column. Also, I wish to sincerely thank the Editors of *Gear Technology* magazine for giving me this honor and opportunity to share my research, teaching and experience gained from myself being an integral part of the implementation of Job Shop Lean at HCA-TX.

Dr. Shahrukh Irani is the Director of Industrial Engineering (IE) Research at Hoerbiger Corporation of America (www.hoerbiger.com). In his current job, he has two concurrent responsibilities: (1) To undertake continuous improvement projects in partnership with employees as well as provide them on-the-job training relevant to those projects and (2) To facilitate the implementation of Job Shop Lean in HCA's U.S. plants.



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APPENDIX

The purpose of this game is to compare the impact of using different batching policies to process the same order inside a flowline-type manufacturing cell. If it is not possible to have a true one-piece flow cell, consider splitting an order batch into at least two smaller batches (aka transfer batches). Due to proximity between consecutive machines used to machine any part, it is possible to break up the Process Batch (aka Order Batch) into smaller batches as follows:

- Process Batch (= Order Size i.e. this is the quantity ordered by the customer)
- Transfer Batch (= a fraction of the Process Batch ex. 1/2, 1/3, etc.)
- Single Piece Flow (Make One Part Move that Part)

For example, the table below lists the generic manufacturing sequence of steps for any Packing Ring produced in the MPC Cell:

Step #	Description of Machining Operation
1	Turn on HAAS Lathe (or Mori Seiki)
2	Grind on Melchiorre
3	Mill on HAAS Mill
4	Slit on Cincinnati Mill
5	Hand Deburr + Install Spring
6	Drill Hole + Insert Pin
7	Rebore on LeBlonde + Light Tight

Currently, Steps 1 and 2 are not done inside the cell, and Step 2, 4 and 7 are batch, while the others are single-piece.

Please understand that the game is a highly simplified version of the real cell! For the sake of simplicity, it is structured as follows:

- A single part will be made.
- The manufacturing sequence of operations for producing this part contains five steps: 1, 2, …, 5.
- The cell layout would be M1→M2→M3→M4→M5. The individuals who will be the five different "machines" can be seated in a line (or U) at a table in the appropriate sequence.
- Each machine must X out their machine's cycle time squares on the page for each part in the batch that arrives at their machine. Please see the handout that shows examples of Good vs. Bad ways for Xing out each square.

RUNNING THE GAME

The game must be run three times as follows:

RUN #1: This is the case of Transfer Batch = Process Batch = 6. NOTES FOR THE INSTRUCTOR: All 6 pages are stapled together to represent the Process Batch. Each page represents an individual part. Place the Process Batch in front of Machine #1. The entire batch of 6 parts must be processed at each machine before the batch can be transferred to the next machine.

RUN #2: This is the case of Transfer Batch = 3. NOTES FOR THE INSTRUCTOR: The 6 pages are split up into two sets of 3 pages apiece. Each page represents an individual part. Each set of 3 pages is stapled together to create a Transfer Batch. Place the two Transfer Batches on top of each other in front of Machine #1. Each Transfer Batch of 3 pages can (and must) be processed at each machine before that batch can be transferred to the next machine.

RUN #3: This is the case of Transfer Batch = 1 (Single Piece Flow). NOTES FOR THE INSTRUCTOR: Place the 6 pages together in a loose pile in front of Machine #1! No staples! No paper clip! Each page represents an individual part. As soon as a single page is processed at each machine, it can be transferred to the next machine.

FOR EVERY RUN, the following data must be collected on this CELL PERFORMANCE TRACKER sheet that has been provided to the team:

Run	TRANSFER BATCH SIZE	START TIME (hh:mm:ss)	END TIME (hh:mm:ss)	FLOW TIME (sec)
1	6 (= Order Batch)			
2	3 (= ½ Order Batch)			
3	1 (= ⅙ Order Batch) Single-Piece Flow			

DISCUSSION ITEMS

- Are the results as expected? Why?
- Besides the impact on Flow Time for the order, how does the change of Transfer Batch Size impact other metrics such as :
  - WIP?
  - Cash Flow Velocity ($ shipped per second)?
  - Floorspace requirements?
  - Quality feedback between operators at the different machines?
  - Other KPI's (Key Performance Indicators)?
- If more than one part were being made in the cell, how could you still use the same ideas taught via Run #2 and Run #3 if these parts had (i) **the same routing** (M1→M2→M3→M4→M5), (ii) different values for Process Batch, (iii) different processing times on the five machines?
- If more than one part were being made in the cell, how could you still use the same ideas taught via Run #2 and Run #3 if these parts had (i) **different routings** (Examples: M1→M2→M5, M1→M2→M3→M4, M2→M3→M4, etc.), (ii) different values for Process Batch, (iii) different processing times on the five machines?
- How does a FTT (First Time Through) Quality Cost get impacted with the reductions in Transfer Batch Size from 6 to 3 to 1?

OPTIONAL DISCUSSION ITEMS

I first used this game on 05/15/2013 to train the Tiger Team at HCA-TX. The discussion topic was the feasibility of using Transfer Batches inside the MPC Cell. I would observe that within the cell it was necessary to batch parts per the machining requirements only at the Cincinnati Mills and LeBlonde Lathes. Else, at all other machines in the cell, the operator could have made one part and put it in queue at the next machine. Yet, that was not the case. Even inside the cell, the Transfer Batch for an order was the same as the Process Batch. That observation raised the following questions:

- What are the constraints that currently prevent the use of Transfer Batches in the cell? And can they be eliminated?
- What are the constraints that currently prevent the use of One-Piece Flow in the cell? And can they be eliminated?

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High-Temperature Gear Materials

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

QUESTION #1

What gear material is suitable for high-temperature (350 – 550° C), high-vacuum (10 –8 torr), clean-environment use?

Expert response provided by Dr. Philip Terry:

From time to time, general questions arise concerning the maximum temperature at which gear materials can operate — or specific questions about what material is suitable for a specific — usually elevated — temperature. When faced with these questions, gear metallurgists and material technologists usually look at the limits imposed by virtue of the previous thermal processing of the gear materials. Gears are rated (that is, the ability of the gear teeth to carry Hertzian contact stresses and bending loads) as a function of the hardness of the material and, in particular, the surface hardness of the tooth.

The hardness of gear steels is typically achieved by through-hardening (quenching and tempering), nitriding or carburizing.

In the production of through-hardened gears, the part is taken to a high temperature to austenitize the material, and then quenched in oil, water or other cooling medium to produce a hard, martensitic, metallurgical structure finally tempered to impart toughness and ductility. The tempering temperature is typically in the range 900 to 1,150°F. Following this final temper, any exposure to temperatures at or close to the selected tempering temperature will reduce the hardness of the material and, consequently, lower the load-carrying capability of the material when used for gearing.

Nitriding is also typically performed in the region of 900°F, and so material intended to be nitrided is normally tempered at around 950°F to avoid overtempering during the nitriding process. Nitrided gears are, therefore, constrained to running temperatures below 900°F to prevent softening in service.

The highest hardness material used in industrial gears and therefore the gears with the greatest load carrying capability are those which are surface hardened by carburizing. However the final tempering temperature used on carburized gears immediately prior t°Finishing is in the region of 375°F, and although carburized gears have the highest known load capacity, this low tempering temperature restricts the temperature at which they can be used to around 300°F.

Below is a summary table based on ensuring that gear hardness does not drop as a result of exposure to high temperature in service based on a maximum temperature 50°F below the final temperature used on the material during thermal processing.

Temperature limits for gear materials	
Process Temperature Limit	**°F**
Through-hardened	850
Nitrided	850
Carburized	300

The values shown in the table are typical levels; if details of a specific heat treatment cycle are known, and higher final temperatures are used, the limits can be raised to within 50°F of the actual temperature. Similarly, if a specific service temperature needs to be accommodated, lower limits can be imposed on the tempering temperature to ensure that parts will not soften due to overtempering in service.

The temperatures quoted here are for the commercial alloys most frequently used for gear manufacture; other more specialized alloys exist which have been specifically designed for higher temperature applications such as the Pyrowear family of alloys for carburized parts. Some of these alloys are tempered after carburizing at 550°F, thus extending their range of application up to 500°F.

The comments in this article refer to the temperature limits of the steel base material of gears, and do not discuss the issue of temperature limitations for gear lubricants, which need to be evaluated separately.

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Dr. Philip Terry was born and educated in the U.K., receiving in 1972 his doctorate in materials science/fracture mechanics. He has decades of metallurgy-and-materials experience in various design and managerial capacities at companies such as British Steel Corp., Cameron Iron Works, and, for 15 years until his retirement in 2011 — Lufkin Industries. Terry has also been an invaluable AGMA member over the years, having served on or chaired many of its materials- or heat treat-related committees. He currently serves as the standing U.S. representative on ISO TC 60 WG 14 – Metallurgy. Terry is now *un-retired,* working as an independent consultant specializing in material selection, heat treatment, welding-and-fabrication, and failure analysis *(Philip.terry@orange.fr).*

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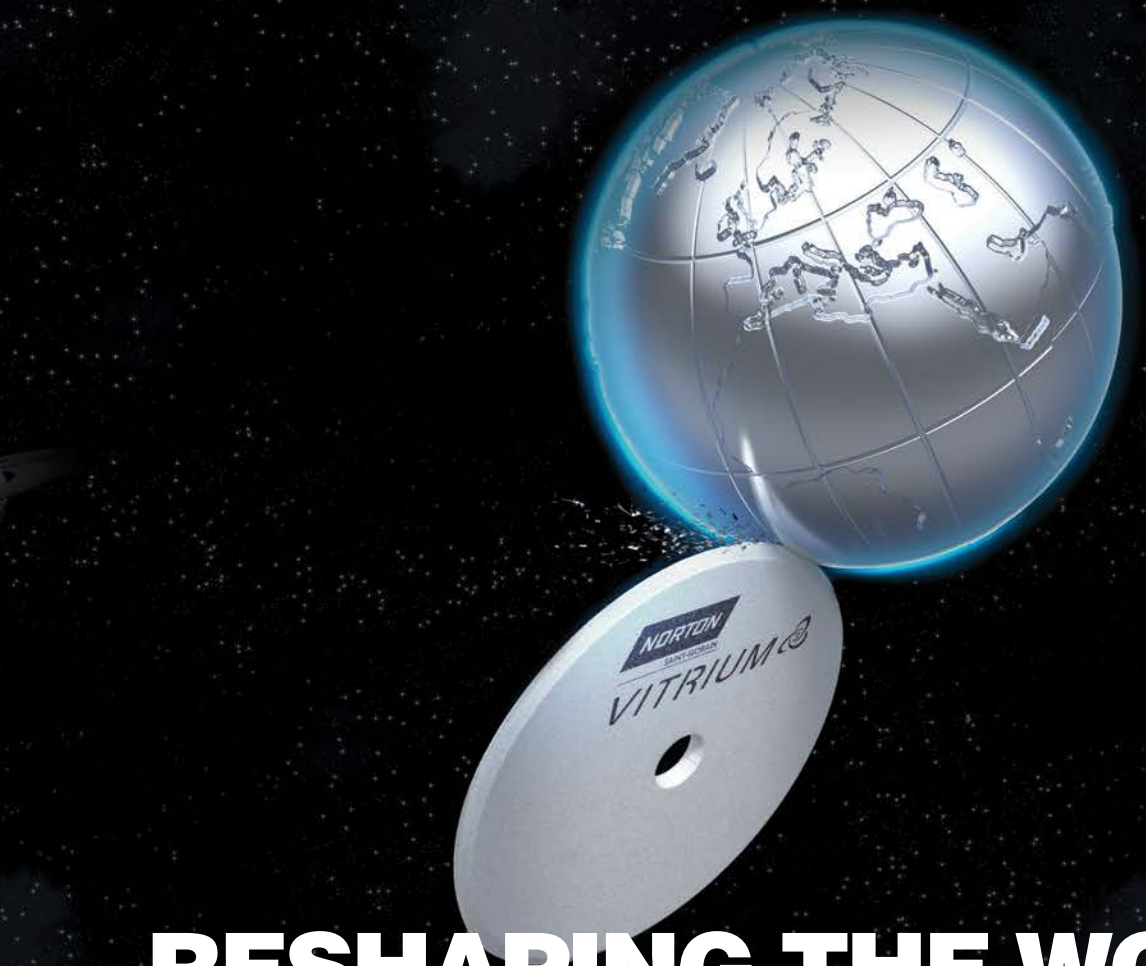

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Design and Optimization of Planetary Gears Considering All Relevant Influences

Tobias Schulze

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Gear Design Process

Light-weight construction and consideration of available resources result in gearbox designs with high load capacity and power density. At the same time, expectations for gear reliability are high. Additionally, there is a diversity of planetary gears for different applications. Gears with one or more stages and with one or more gearbox inputs and outputs are not uncommon. Furthermore, different kinds of teeth exist: e.g., spur and helical gears, and also double-helical gears are doable. For the mounting of shafts and gearings, roller bearings and sliding bearing are used (Fig. 1).

All of these conditions require exceptional and robust design criteria, including maximum load and dynamic loads under different load situations. Experience with drivetrains with stiff foundations and constant, external loads is not directly applicable, due to unique boundary conditions, dynamic excitation of the structure, and changing influences by external conditions (Ref. 12).

The product design process of a gear typically begins with the load calculation, followed by gear and component layout, to the point of structure analysis (Fig. 2).

Only at a test bench, or in industrial use as a component in the whole drivetrain, can the quasi-static and dynamic behavior of the gear in actual conditions be verified. This long chain in the process does not allow for an efficient gear calculation — especially considering the insecurities of the load assumptions — and with that the inevitable, inaccurate stress of the single machine elements and resulting strains.

In these cases the highly precise and, in part, standardized calculations of machine elements can only be applicable as far as the accuracy of the load assumptions allow. Any interactions of the single elements within the stressed gear (e.g., the influence of axle bending on the load dispersion of the gearing) are thereby lost. Furthermore, the gear must —especially with flexible shafts, housing or dynamic excitation — be understood as a sub-system of the drivetrain; only in this way can a realistic load gradient be constructed (Ref. 13).

An evenly balanced calculation model for drivetrains that connects all concerned sub-disciplines (external conditions, drivetrain dynamics, structure dynamics, electrical phenomena and machine regulation) in a comparative model depth does not exist (Fig. 3). And yet, only such a balanced model allowing for all needed conditions can deliver the realistic and reliable statements on dynamic strains needed to make the safe design of drive components possible (Ref. 15).

The resulting problems and damages cannot be fully explained through mere analysis of the single modules. In fact, the essential influences of the surrounding system components must be accounted for and included in the computation. Here arises the

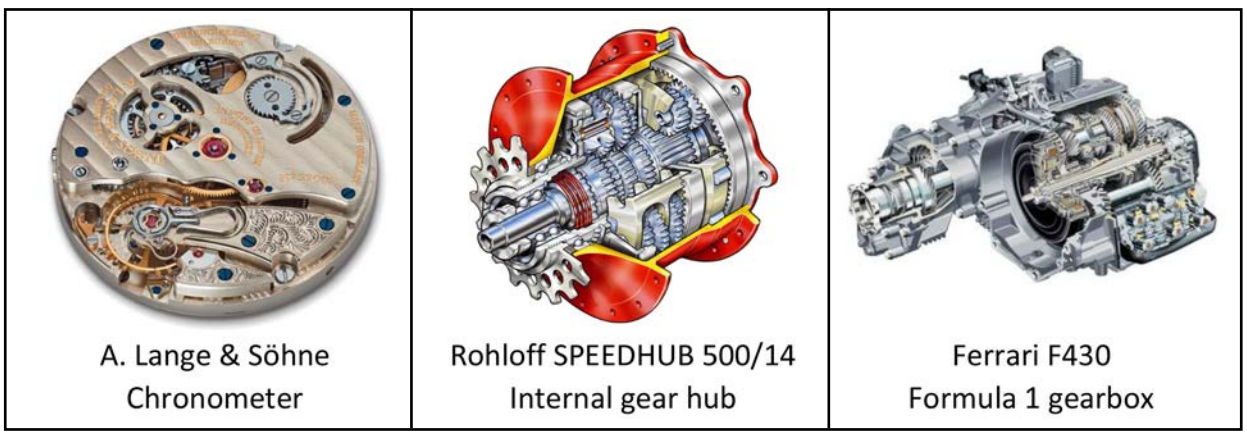

Figure 1 Application of planetary gears (Ref. 13).

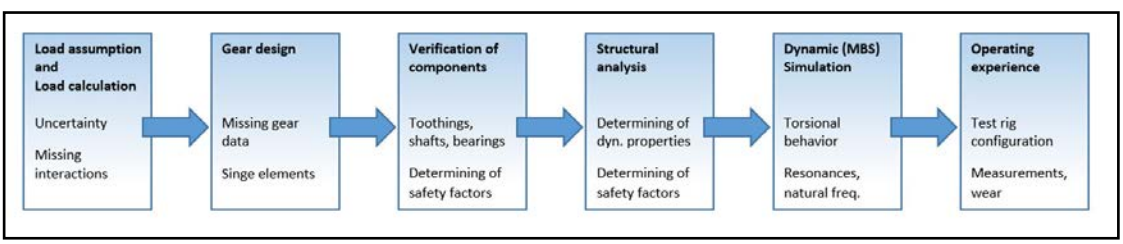

Figure 2 Classic product design process.

real difficulty of finding the necessary system parameters to solve the respective question, which is why the product development process of the future is moving more and more to system analysis, rather than the design of single machine elements. Vital to gear development is continuous — mostly software-supported — analysis, result-conditioning and data maintenance to the point of supervision of the lifecycle of a gear. On one side, all calculations of the machine elements — gear, axle, bearing, axle-hub connection, screw connection, etc. — are to be implemented following the current standards. These must be supplemented through detailed examination of load gradients and load distribution — and to the point of optimization of single target parameters (mass, stiffness).

Gearbox Development and Calculation According to Standards

Especially for design concepts of planetary and spur gearboxes, the newest software development of DriveConcepts GmbH — *MDESIGNgearbox* — is established. This calculation software gives complete product information in the early phase of the product lifecycle (PLC). The calculation cannot replace measurements and test drives, but iteration steps can be reduced economically. The software allows for an intuitive and easy handling in the design process of the entire gearbox — dimensioning of the machine elements (shafts, bearings and toothings) — all according to the existing standards (Refs. 5–7).

For toothing:

- DIN 3990:1987 T1–T6
- ISO 6336:2008 T1–T3, T5 and Technical Corrigendum 1:2008

Future work for toothings:

- Micropitting according to ISO/TR 15144–1
- Scuffing according to ISO/TR 13989 1 and 2, AGMA 925
- Gear mesh efficiency/loss factor H_V and H_{VL}

The shafts of the gearbox are calculated according to:

- DIN 743:2008 T1–T4 and Beiblatt 1, 2
- Different calculations possible for the roller bearings:
- Lifetime L_{H10} according to DIN ISO 281:2009
- Modified lifetime according to DIN ISO 281:2009, Beiblatt 1, 3
- Advanced modified lifetime according to DIN ISO 281:2009, Beiblatt 1, 3
- Lifetime according to ISO/TR 16281:2009

The software enables calculation of the system gearbox in one step, including a complete documentation into a PDF/A document, according to ISO 19005–1:2005 (Fig. 4).

Gear Optimization (Macrogeometry)

The following shows the gear optimization in some case studies:

Load distribution. Next to the load distribution factor $K_{H\beta}$ one of the important tasks of gear development is to optimize

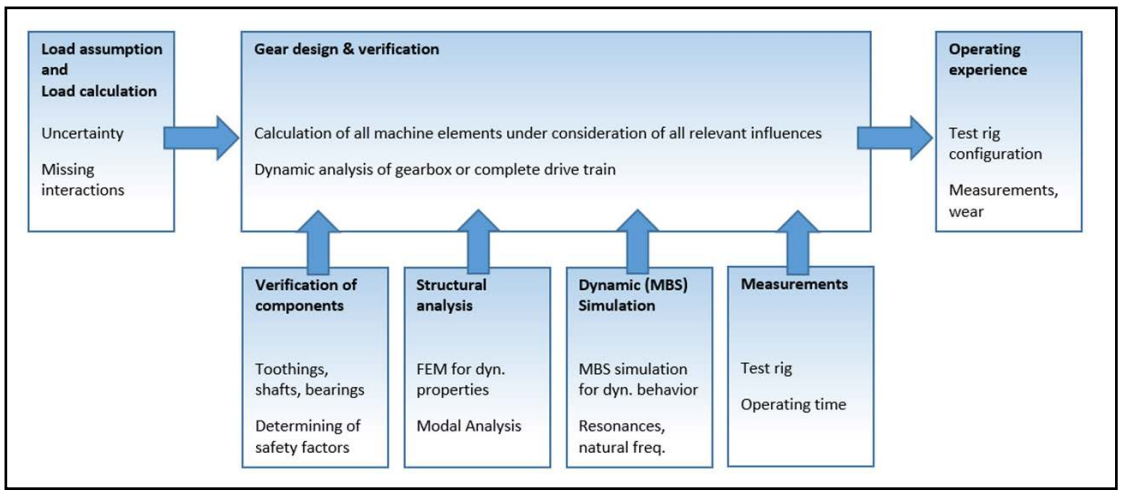

Figure 3 Design process of a gear as a system.

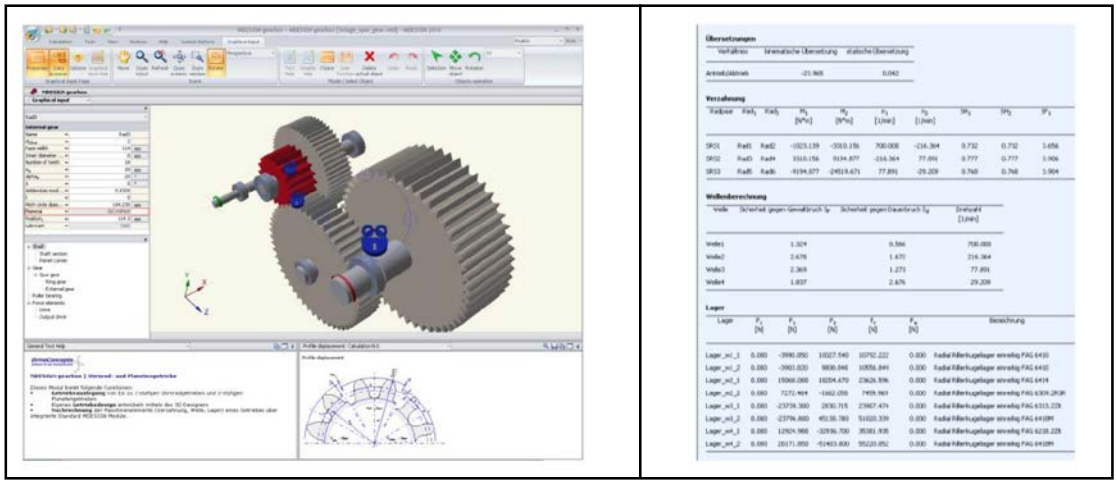

Figure 4 User interface of *MDESIGN* gearbox with *3-D-GearDesigner* and result page (Ref. 10).

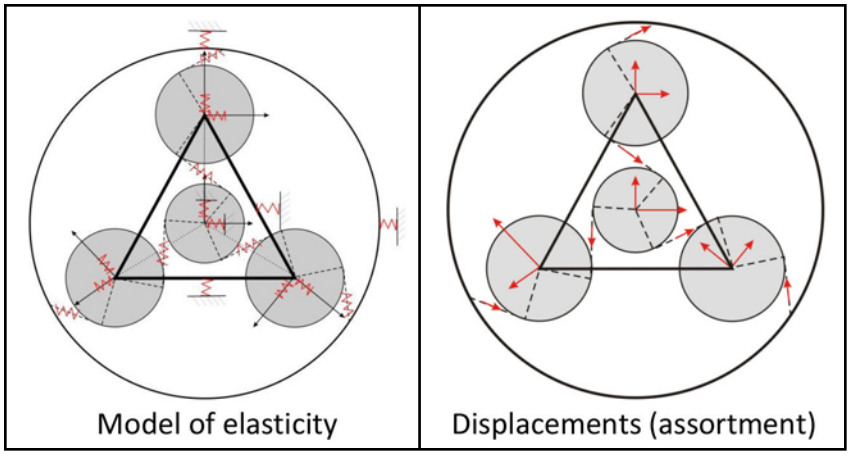

Figure 5 Computation model for load distribution $K_{H\beta}$.

the load distribution of each planet gear. This is done using a pure statistic model that determines load distribution factor *K*. The load distribution factor is defined as "the ratio of the maximum tooth normal force to the median tooth normal force at the speed of zero." Dynamic factors are represented by the factor K_v. The median contact stiffness from the load gradient calculation is used for the analysis, as well as wheel body stiffness (sun, ring gear), bearing stiffness and bearing clearances (sun, planet, ring gear and planet carrier). The following deviations can be accommodated (Fig. 5):

- Single-pitch deviation — sun and ring gear
- Tooth width variations — planet gear
- Center distance deviation and planet carrier pitch deviations
- Displacement — sun, planet carrier, ring gear

The computation of the load distribution allows statements on suitable tolerances or tolerable location variations with exact knowledge of the real load for every single planet. These investigations allow, for example, single parameters to be analyzed with regard to their influence on the load-bearing capacity of the gearing (Fig. 6).

Suitable construction parameters, as well as sensible tolerances of gearings and location variations, can be defined. Research on load distribution (K_γ and $K_{H\beta}$) has shown that only a simultaneous optimization of load distribution on flank ($K_{H\beta}$) and planets (K_γ) results in an optimal gear (Fig. 7). An effective instrument for a balanced load distribution is the use of optimized, flexible planet gear bearings. The impact is due to the targeted overlapping of bolt and bushing bending, with the goal of minimizing the tilt angle of the planet, which in turn is determined by the deformation of the bushing (Ref. 16).

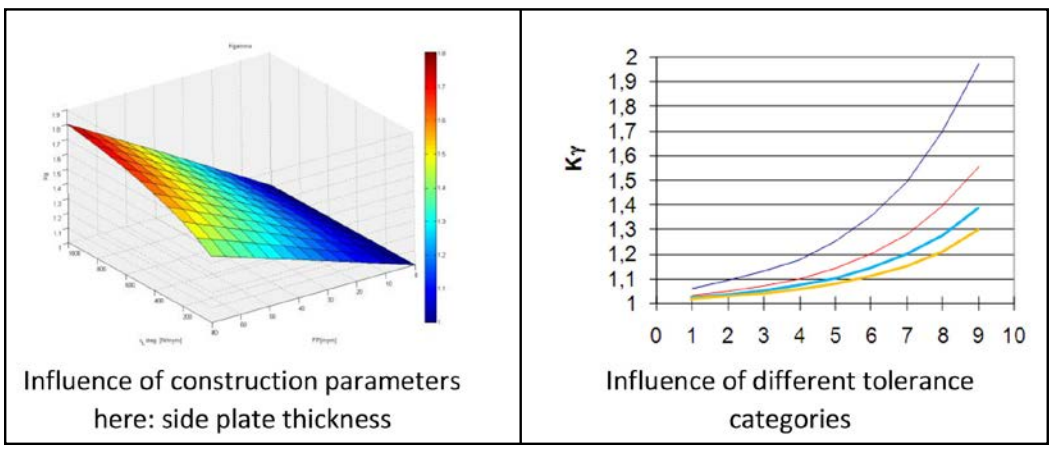

Figure 6 Variation studies for load distribution $K_{H\beta}$

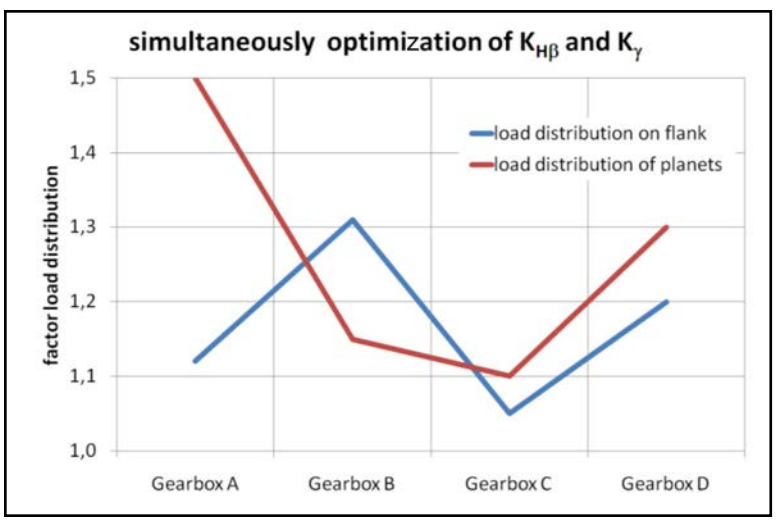

Figure 7 Variation studies for load distribution $K_{H\beta}$ and $K_{H\beta}$.

Stiffness optimization. The optimization of construction parameters with the goal of optimal stiffness of all relevant gear elements is probably one of the most complex development tasks in the design process. Typical is the description of the following variation analysis of a planet mount: "the goal is a design with the least possible mass while retaining necessary stiffness requirements needed in view of the load gradient (Fig. 12)." Both one-sided and two-sided samples can be considered; they can be constructed with a round or optimized outline (triangular, square) (Fig.8).

The geometric parameters to be varied in such a study are shown (Fig. 9). Through the large amount of parameters it is necessary to use software programs

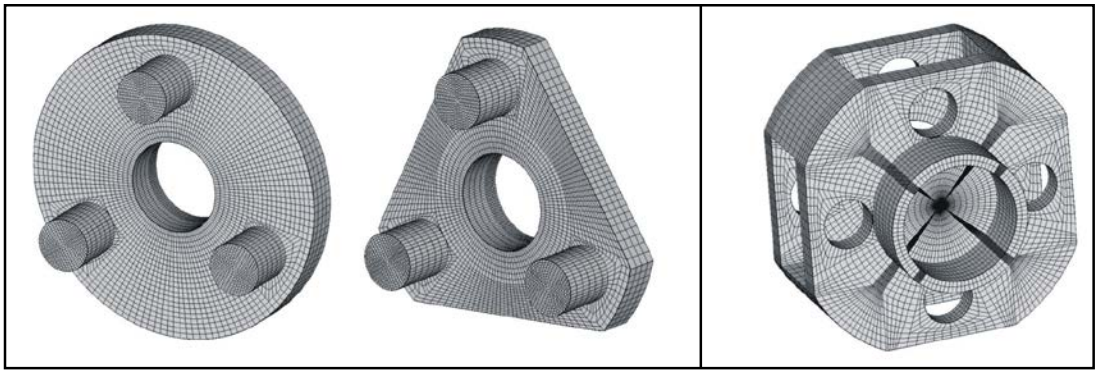

Figure 8 Variants of planet carriers: single-plate (left); double-plate (right) (Ref. 3).

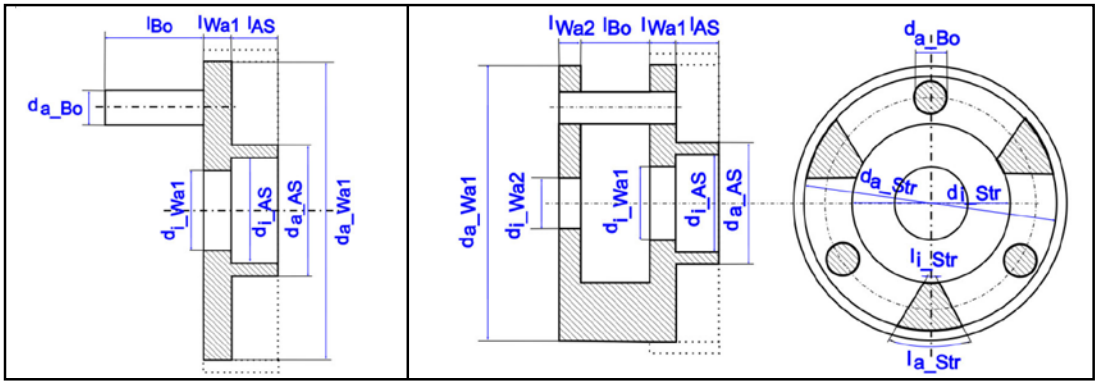

Figure 9 Geometric parameters of planet carriers: single-plate (left); double-plate (right).

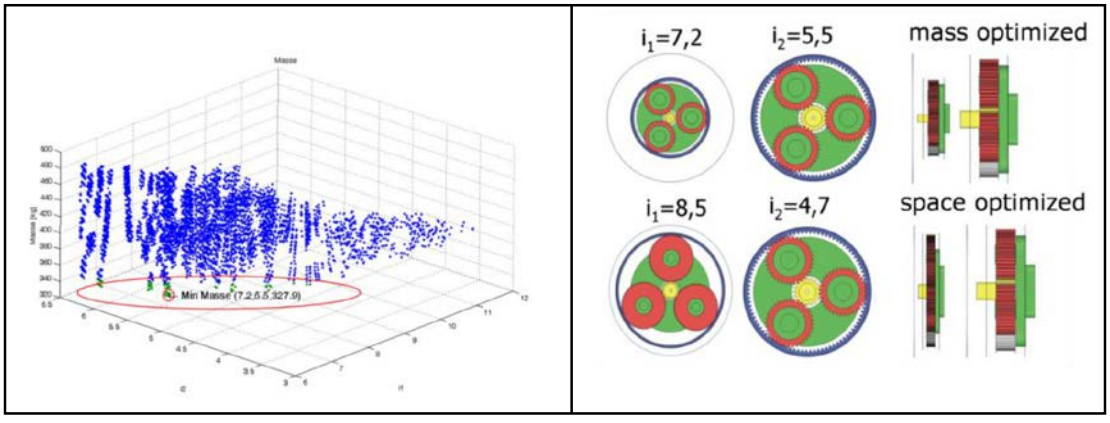

Figure 10 Optimization mass and design space.

with integrated FE solvers for calculating stiffness parameters; only in this way can optimal configurations be found for the entire parameter area.

Mass/design space optimization. Not only has the just-introduced stiffness optimization led the engineer to a number of detail problems; the search for a mass, construction-size optimized gear is a highly complex question due to the number of overlapping influences. Figure 10 shows the field of results of a variation study for a constant, given total gear ratio and defined load.

The investigation can be used for improving present gear solutions, as well as for new designs. Using an existing design as an example, the following shows how great the potential can be (Fig. 11).

At similar dimensions for the ring gear outer diameter d_3 of gear Stage 2, one arrives at a mass savings by adjusting the ring gear diameter for Stage 1 and reducing the tooth width. *MDESIGNgearbox* avoids the over-dimensioning of planet gears by pre-setting safety factors for the gearbox machine elements. The mass of the original is at $m_{ges} \approx$ 2,200 kg. All generated, optimized solutions arrive at a mass reduction in comparison to the actual gear. The mass, optimized preferred variation is shown (Fig. 12, right).

In this example the mass savings amount to about 25 percent, in respect to the original design. At the same time the optimization of the construction space amounts to 15 percent (Fig. 3). In a second step the consideration of CAD geometry data of housings will be possible. Therefore the software imports a standard geometry format, generates finite element models, calculates stiffness matrices for the housing, and delivers this information to the design process of *MDESIGgearbox* (Fig. 14).

Optimization of microgeometry. The calculation of load distribution in a planetary gear system essentially depends on the helix angle deviation between the contact flanks of the gear

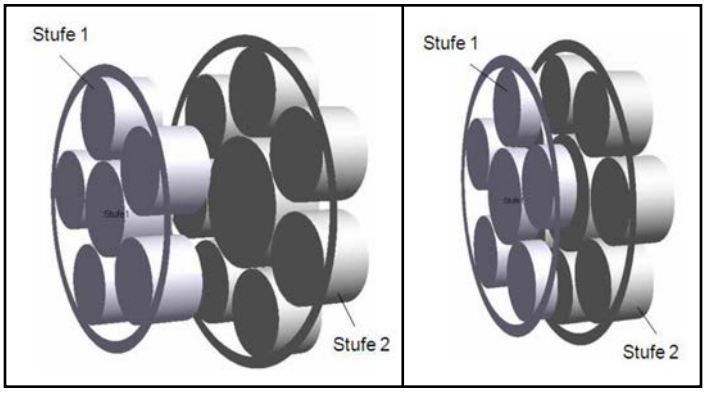

Figure 11 Variation study mass optimization: initial state (left); mass optimized gear (right).

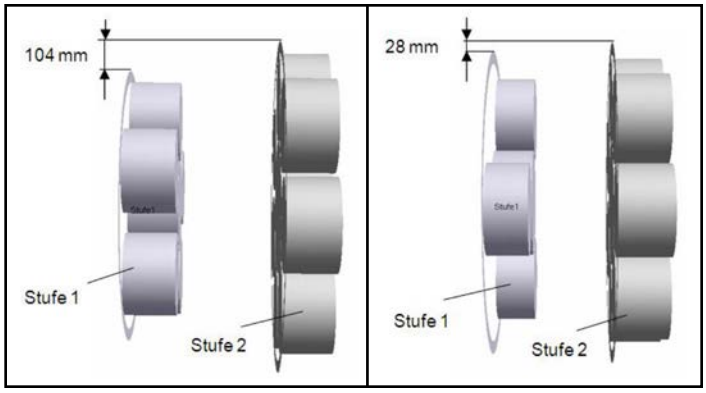

Figure 12 Variation study design space: Initial state (left); space-optimized gear (right).

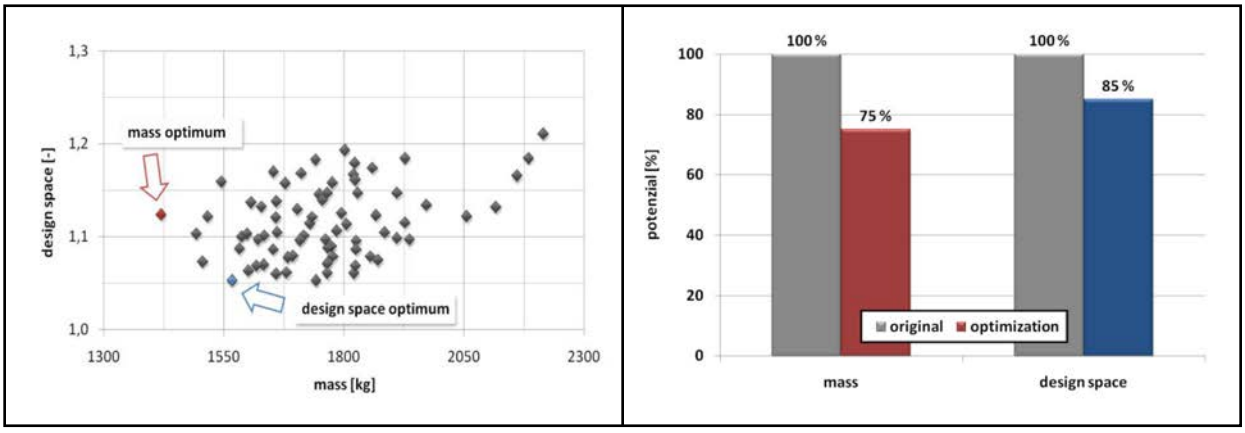

Figure 13 Savings potential: mass (left); design space (right).

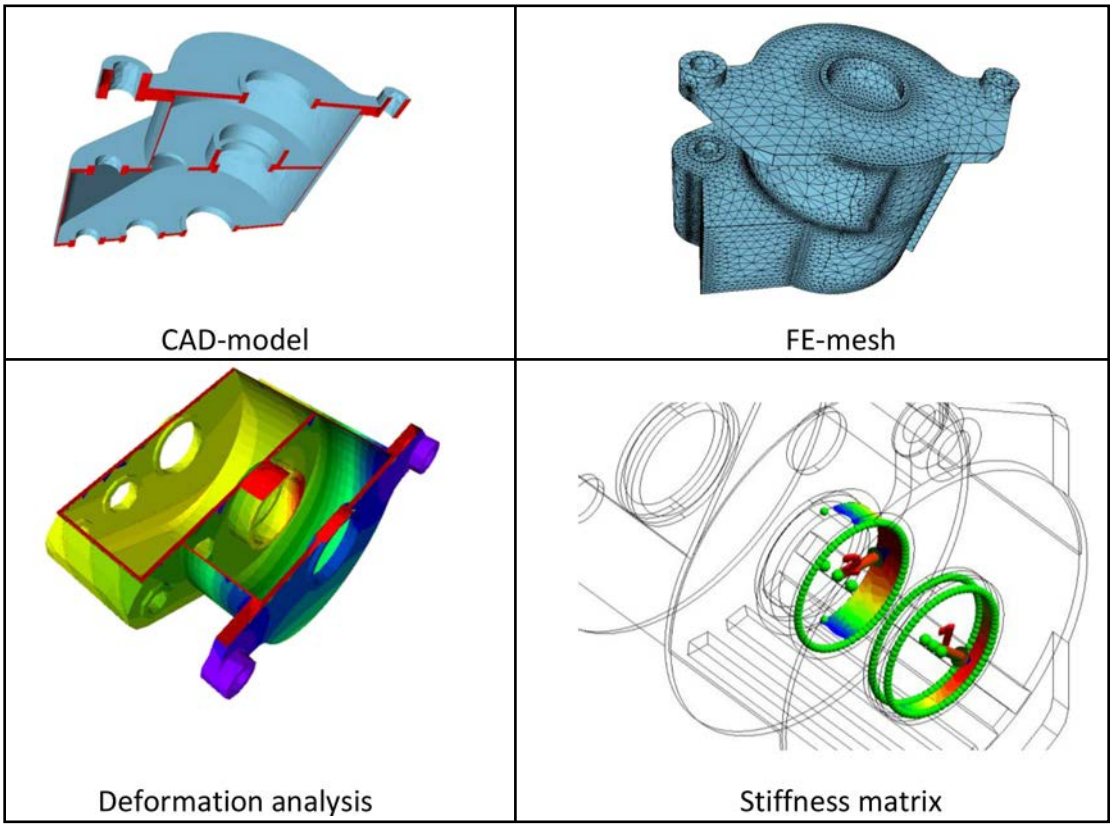

Figure 14 Determining of stiffness matrices in *3-D-HousingDesigner*.

pairs; it can be understood as the sum of different influences. It is assumed that the effects are overlying independently, thus the sum of contact line deviation can be calculated with the single deviations (Ref. 11).

The calculation of single displacements and deformations of all gearbox bodies — especially the planet carrier, the coupling of ring gear and gear wheel bodies and the deformation of teeth — is more complex in planetary gearboxes than in spur gearboxes. To determine the load distribution, the flank deviation for the tooth contact sun/planet and the tooth contact planet/ring gear is calculated by the new software *MDESIGNLVR*^{planet} (Refs. 8 and 9). The result of the calculation is the excessive line load, which is expressed by the factor $K_{H\beta}$. In general, the excessive line load is on the flank side opposite the deviated flank side.

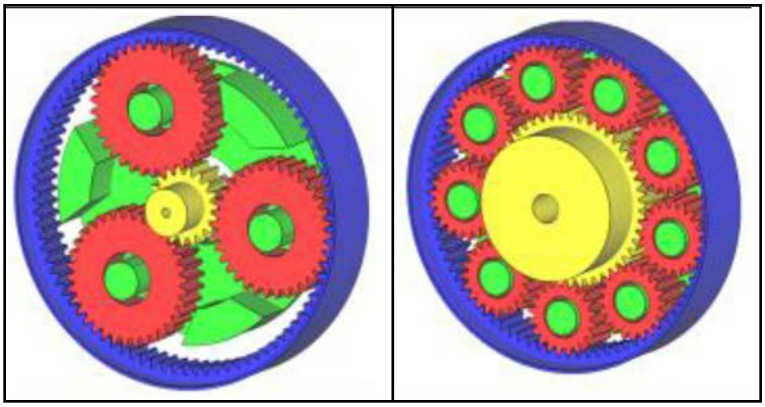

Figure 15 Verification of planetary gear stages.

Next to the calculation of the ratio of maximum and middle line load, the software gives detailed information about tooth flank pressure and tooth root stress distribution (Fig. 15).

The flank deviation (FLKM) consists of the following parts:

- Elastic deformation of gear body (ve_{RK})
- Elastic tilting difference of roller bearings /17/ (ve_{WL})
- Torsion deformation of planet carrier (ve_{PT})
- Tilting of planet due to of sliding bearing ($verkipp_{PL}$)
- Effective helix angle modification ($f_{H\beta eff}$)
- Elastic deformation of tooth flank
- Elastic deformation difference of planet carrier bearing
- Deformation of housing

The helix angle deviation for tooth contact sun/planet is calculated by the following equation:

$$FLKM_{1/2} = ve_1 + ve_{2_{1/2}} + ve_{WL1/2} + ve_{PT1/2}\ verkipp_{PL1/2} + f_{H\beta eff1/2} \quad (1)$$

The helix angle deviation for tooth contact planet/ring gear is calculated by the following equation:

$$FLKM_{2/3} = ve_1 + ve_{2_{2/3}} + ve_{WL2/3} + ve_{PT2/3}\ verkipp_{PL2/3} + f_{H\beta eff2/3} \quad (2)$$

ve_1 = deformation difference of sun
ve_2 = deformation difference of planet
ve_3 = deformation difference of ring gear

The deformation is calculated by FE method and is then added to the flank deviation. All parts of the helix angle deviation have to be added as values normal to the flank. The database of the calculation is saved in *XML* format. With this, a structured depositing of design, modification, deviation, load and control data is possible. Furthermore, the program has a project management capability for saving projects, standard examples and more calculation guidelines (Ref. 14).

After input of all necessary parameters: all data are checked, the design models are generated and the FE models for the gears with coupling design and the planet carrier are created. For an efficient calculation it is necessary and reasonable to use drive technology software. DriveConcepts GmbH develops software solutions for drive technology, which is characterized by clear and intuitive handling of all data. In the background, academic-established calculation kernels and consistent, structured interfaces help solve the actual task efficiently.

Case Study

The example of a wind turbine with 2,000 kW output power should show the consequences of different flank modifications with constant load (Ref. 12). The main gearbox consists of one planetary gear stage and two spur gear stages (helical gearing). The detailed parameters of the first planetary gear stage are listed (Fig. 16). The initial state of unmodified gearing under

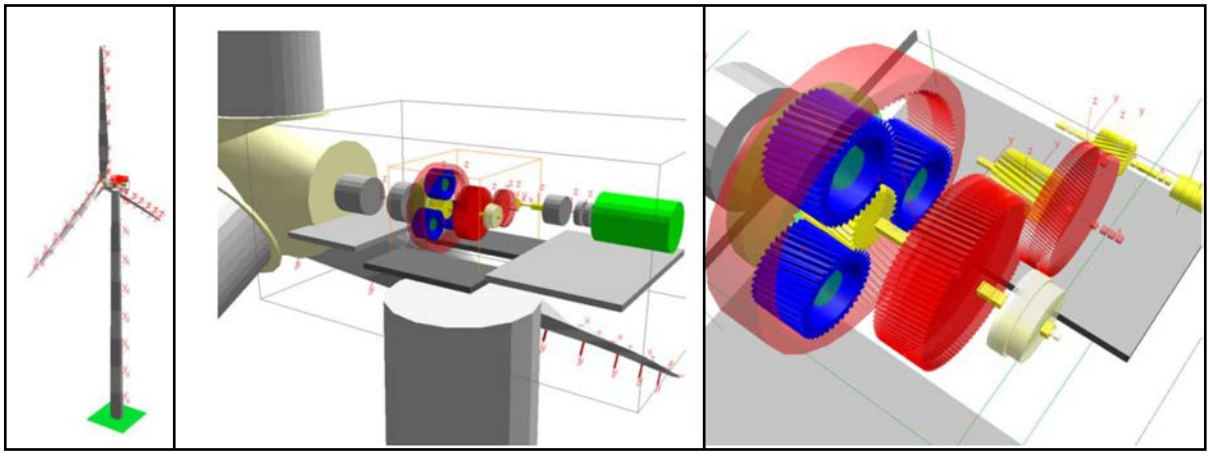

Figure 16 Application case.

module	m	16 mm	face width	$b_{1\|2\|3}$	310 mm
number of teeth	$z_{1\|2\|3}$	20 | 36 | -91	add. modification sun	x_1	0.4
center of distance	a	463 mm	add. modification planet	x_2	0.3156
pressure angle	α	20°	add. modification ring gear	x_3	-1,6429
helix angle	β	8°			

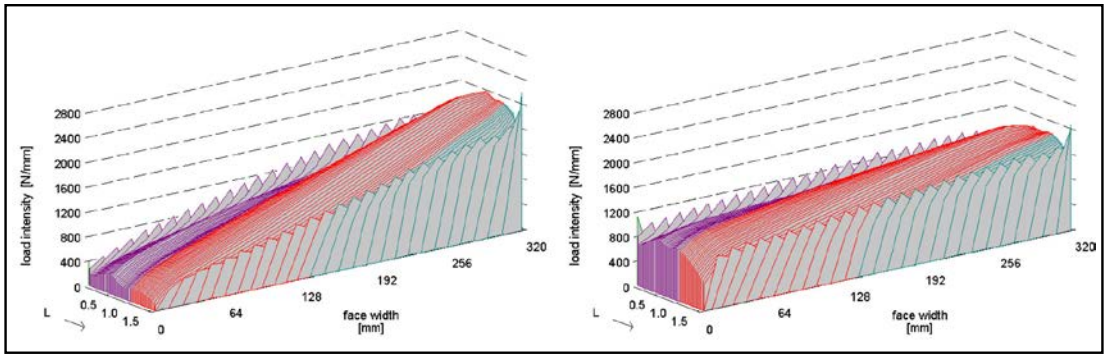

Figure 17 Initial state (left side); first optimization (right side).

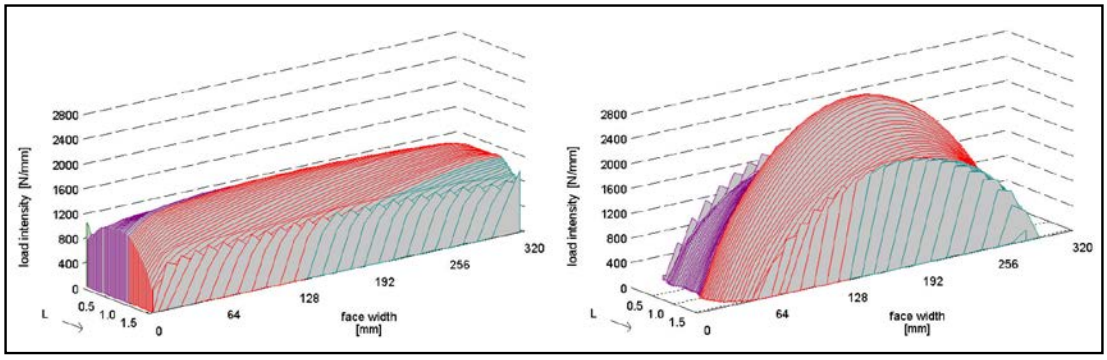

Figure 18 Final design (left side); bad solution with too much lead crowning (right side).

nominal load is shown (Fig. 17, left side). In this case the ratio of maximum and mean value of line load is 1.67.

In the first step of optimization with a helix flank modification, the factor can be reduced to $K_{H\beta}$ = 1.23 (Fig. 17).

The rest of the unbalanced distribution along the face width — which comes from planet carrier torsion deformation — can be offset with an optimal lead crowning. The ratio of maximum and middle-line load can be reduced to $K_{H\beta}$ = 1.16 (Fig. 18, left).

At the right side of Figure 18 it is shown that an oversized lead crowning can also lead to poor conditions. In this case the lead load distribution changes to $K_{H\beta}$ = 1.98. The example shows the necessity of the right dimension of macrogeometry and also of used modifications. If these are correct, the lead load distribution $K_{H\beta}$ can be reduced from 1.67 to 1.16; but with unfavorable modifications, the opposite will be the result.

This case study shows advantages of *MDESIGN 2010* with the libraries *LVR, LVR*^{planet} and *gearbox* to develop gearboxes in a very efficiency way.

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Dr.-Ing. Tobias Schulze studied (1996-2001) drivetrain and gear technology at the TU Dresden. From 2001-2006 he was a scientific assistant at the TU Dresden in the analysis of the dynamic behavior of drivetrains with multi-body simulation, including the influence of holes in ring gears with FEM, and the influence of manufactured deviations on bevel gear stress run on a servo-hydraulic test stand for steering systems. Since 2006, Schulze has served as managing director of DriveConcepts GmbH, Dresden.

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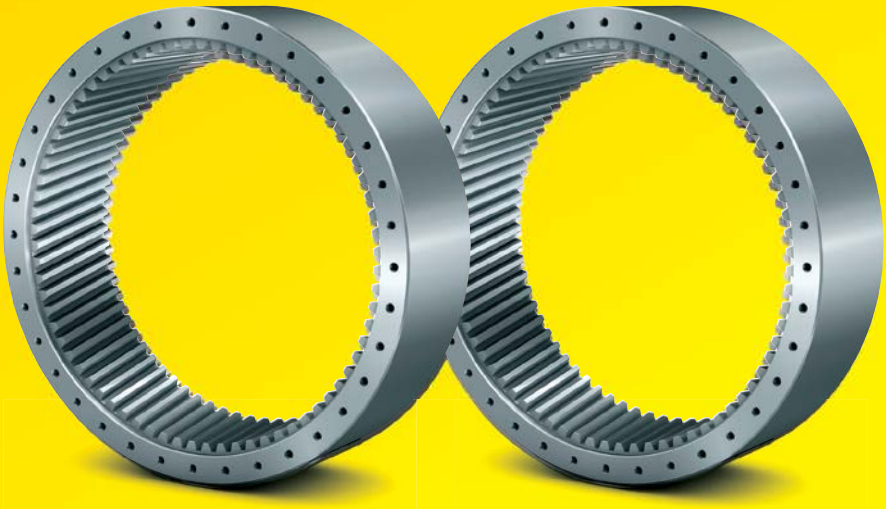

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Understanding Oil Analysis: How It Can Improve Reliability of Wind Turbine Gearboxes

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Michael P. Barrett and Justin Stover

Historically, wind turbine gearbox failures have plagued the industry. Yet an effective oil analysis program will increase the reliability and availability of your machinery, while minimizing maintenance costs associated with oil change-outs, labor, repairs and downtime. Practical action steps are presented here to improve reliability.

Introduction

Lubricating oil is the lifeblood of the gearbox. It is required to carry out specific functions in order to keep the gearbox running. In wind turbines, the lubricant is subjected to extreme temperatures, varying load weights and contamination. Lubricant performance deteriorates under these conditions, and thus oil analysis becomes essential to monitor lubricant condition.

Oil analysis is used extensively to help companies maintain their equipment. In order to take full benefit from the test data, it is important to understand the basic properties of a lubricant. Equally important is the understanding of how these properties affect the ability of the lubricant to function. Lastly, knowledge of the common test methods and instrumentation used to analyze oil will aid in data interpretation and lead to more productive corrective action. After gaining a fundamental understanding of lubrication, we will apply these fundamentals to wind turbine gearboxes to demonstrate the unique challenges inherent in this industry.

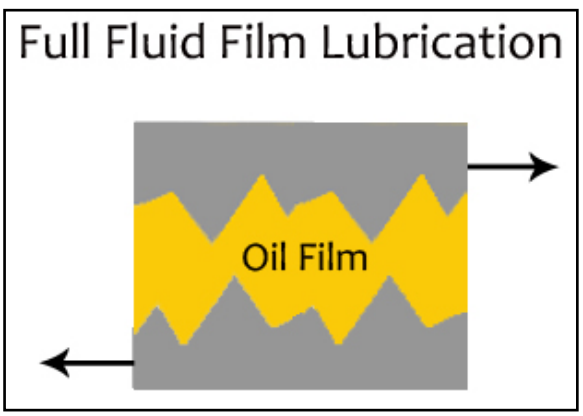
Lubricant Role

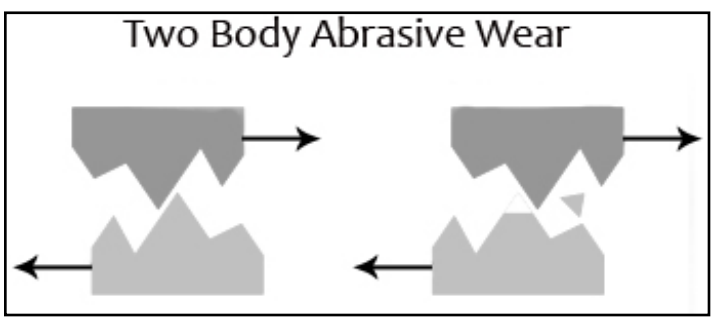
To effectively monitor how well a lubricant is functioning, you must first examine what the functions of the lubricant actually are. The primary function of a lubricant is quite obviously to *lubricate*. Lubrication can be defined as the reduction of friction. By reducing friction, wear is reduced, as is the amount of energy required to perform the work.

In 1699, the French physicist Guillaume Amontons (1663 – 1705) deduced that friction is the result of surface roughness. Since no solid surface is perfectly smooth, opposing friction surfaces have peaks — "asperities" — that come in contact with one another. Ideally, a lubricant will physically separate these asperities with an oil film; this is called "full-fluid" film lubrication (Fig. 1).

When the proper lubricant is used, and the proper load is applied, the asperities are not in contact and, in theory, no wear will occur. But when inadequate lubrication is present, or the load is increased, the oil film will not be thick enough to fully separate the asperities. "Mixed lubrication" — a cross between boundary and hydrodynamic lubrication — occurs when the oil film thickness is equal to the average asperity height. The largest asperities will come in contact, resulting in increased wear.

Many oils are fortified with anti-wear additives to combat wear under these circumstances. As load continues to increase, or lubrication degrades, boundary lubrication occurs and the oil film thickness cannot separate the friction surfaces. This can result in metal-to-metal contact. At this point, asperities are adhering to one another, causing severe machine wear. This can also manifest itself during periods of shock loading, start-up or shutdown. Extreme pressure additives are used in oils that frequently encounter these types of situations.





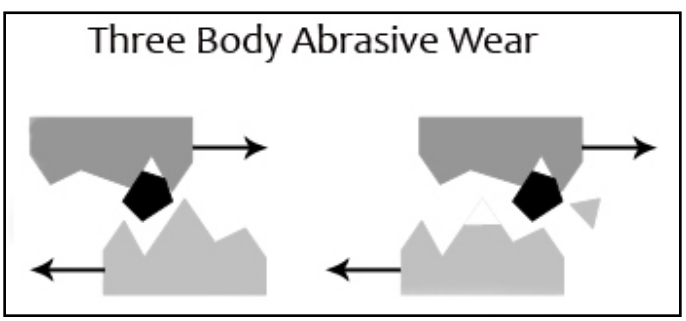


Figure 1 Friction is the result of surface roughness — asperities — that come in contact with one another. Full-fluid film lubrication will physically separate these asperities.

Lubricants are also tasked with controlling the temperature of your equipment. Oil absorbs heat generated at the friction surface and carries it away to be dispersed. Many systems incorporate heat exchangers or radiators to aid in removing heat from the system. Along with heat, lubricants transport dirt and other debris away from the friction surface.

Particulate contamination leads to increased wear through abrasion and reduced oil flow. Some oil additive packages contain agents that break contaminants up and hold them in suspension to be filtered out or settle in the reservoir. This prevents harmful deposits and varnishes from forming within the equipment. Alkaline additives also protect the components by neutralizing acids and preventing corrosion.

Hydraulic oils have the added function of transmitting power. To function properly, hydraulic oil must be clean and free of contaminants. Many contaminants will cause oil to foam and entrain air or water. Entrained air causes the oil to compress under pressure, resulting in a loss of power. Particulate contaminants will cause valves to malfunction and restrict the oil flow.

Role of Oil Analysis

Selecting the proper lubricant, along with careful maintenance of that lubricant, is essential to ensure adequate protection to any machine. Proper lubrication is defined as a correct amount of the correct lubricant at the correct time.

Maintaining your lubricants means ensuring that you are using the correct viscosity and have the necessary additives for the application. You must also take steps to keep the lubricant clean and serviceable. Bottom line — oil analysis is the most effective way to prolong the useful life of your lubricants while maintaining maximum protection of your equipment.

Oil analysis tests reveal information that can be broken down into three categories:

1. ***Lubricant condition***. Assessment of the lubricant condition reveals whether the system fluid is healthy and fit for further service, or is ready for a change.
2. ***Contaminants***. Increased contaminants from the surrounding environment in the form of dirt, water and process contamination are the leading cause of premature machine degradation and failure. Increased contamination alerts you to take action in order to save the oil and avoid unnecessary machine wear.
3. ***Machine wear.*** An unhealthy machine generates wear particles at an exponential rate. The detection and analysis of these particles assist in making critical maintenance decisions. Machine failure due to worn out components can be avoided. Remember — healthy and clean oil lead to the minimization of machine wear.

Lubricant condition is monitored with tests that quantify the physical properties of the oil to ensure that it is serviceable. Metals and debris associated with component wear are measured to monitor equipment health. Lastly, some tests target specific contaminants that are commonly found in oils. It is imperative to select the proper blend of tests to monitor the machine's lubricant condition, wear debris and contaminants in order to meet the goals of successful oil analysis.

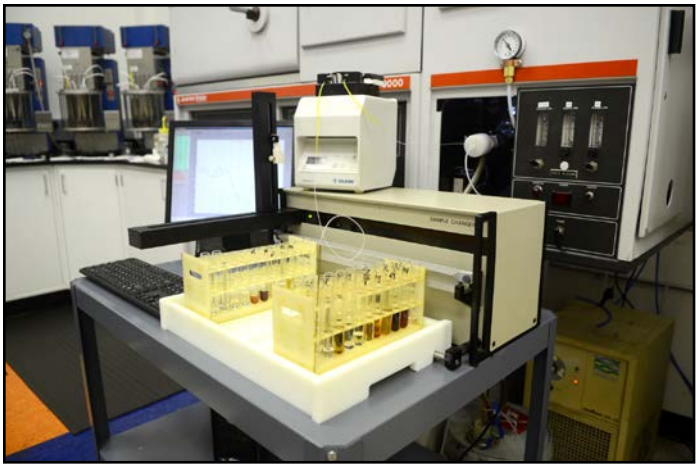


Figure 2 There are typically 20 elements measured by spectroscopy and reported in parts per million (ppm).

Elemental Spectroscopy

Elemental spectroscopy is a test that has the distinction of monitoring all three categories — lubricant condition, wear debris and contaminants. A spectrometer is used to measure the levels of specific chemical elements present in an oil.

Two types of spectrometers are commonly used. Arc emission spectrometers apply energy in the form of an electric arc to the sample. This excites the atoms into vapor form, creating a spectrum where light is generated. Individual light frequencies in the spectrum are measured and quantified to determine the presence and quantities of specific elements present. The other common type of spectrometer is the ICP (inductively coupled plasma) spectrometer. This operates on a similar principle, except that the energy is applied to the sample by a plasma flame rather than an electric arc.

There are typically 20 elements measured by spectroscopy and reported in parts-per-million (ppm) (Fig. 2). These measurements represent elements in solution. Spectroscopy is not able to measure solid particles larger than roughly seven µm, which leaves this test blind to larger solid particles.

Typical levels of wear can vary greatly, depending on the type of equipment being sampled. For example, a gearbox will normally have much higher levels of iron than a hydraulic system. Levels of wear metals can vary across different units of the same type, depending on oil hours, operating conditions and loading levels or other conditions. For this reason it is impossible to establish firm limits for any piece of equipment based solely on the equipment type. To take full advantage of monitoring wear, a trend should be established to provide an operational baseline of data. This will ensure detection of abnormal wear rates as they develop while allowing for the fact that similar equipment may not wear at the same rate.

Monitoring the additive levels provides information to ensure that the proper lubricant is being used for the application and for topping off. Four types of lubricants are generally used in most industrial applications, and each has different additive levels. It is important to note that an oil's level of additives measured by spectroscopy is not necessarily an indication of the oil's quality.

- ***Engine oils*** will typically contain anti-wear additives composed of zinc and phosphorus. One should expect to see these

elements present in approximately 1,000 ppm (± 200 ppm). A detergent package should also be present, composed of some configuration of barium, magnesium and calcium. These levels will vary, depending on the oil.

- ***Extreme pressure oils*** are typically for gear applications. It is common to see significant amounts of phosphorus.
- ***Anti-wear oils*** include many bearing oils, some gear oils and hydraulic fluids. These oils contain both zinc and phosphorus from 200 to 600 ppm. There may be very low levels of detergent (magnesium or calcium) present also.
- ***Rust and oxidation inhibiting oils*** are the easiest to identify. They include turbine oils, compressor oil, and some bearing and hydraulic oils. These oils have no metallic additives that can be measured by spectroscopy, so there should be extremely low numbers for all additive metals.

It is not uncommon to see low levels (<20 ppm) of some additive metals where they are not expected. This is usually the result of residual contamination in the equipment or storage tanks. There are oils that do not fit into these descriptions. Many oils are formulated for specific applications and alternative additives must be used. An example would be oils formulated for some stationary and electro-motive diesel engines. In many cases, operating conditions or emission concerns call for a less traditional additive package.

As with any type of testing, spectroscopy is subject to inherent variance. High water levels can cause interference in the spectrum, as can the matrix of some synthetic base stocks. In short, always double-check with another sample before taking any invasive maintenance action. Never rely on just one piece of data when making a maintenance decision.

Viscosity

Viscosity is considered oil's most important property. The most common technique for measuring an oil's viscosity is following ASTM D445, using a viscometer (ASTM, 2011). A small sample of the oil is drawn into a calibrated capillary tube in a constant-temperature bath. Once the sample comes to temperature, it is allowed to flow down the tube a predetermined distance. The viscosity is the product of the flow time and tube calibration factor. The results are reported as the oil's kinematic viscosity in centistokes (cSt).

Industrial oils are identified by their ISO viscosity grade (ISO VG). The ISO VG refers to the oil's kinematic viscosity at 40°C (104°F). An oil's weight commonly refers to its kinematic viscosity at 100°C (212°F). The weight of multi-grade oils is represented by the second number in the rating. A 10W30 would be 30-weight oil. The 10 before the W, which stands for winter, refers to how the oil performs in cold weather conditions.

When an oil's viscosity increases, it is usually due to oxidation, degradation or contamination. This is the result of extended oil drain intervals, high operating temperatures, or the presence of water or another oxidation catalyst. Increased viscosity can also be the result of excessive contamination with solids such as soot or dirt, as well as topping off with a higher grade lube. Water contamination can also cause high viscosity.

A decrease in the oil's viscosity is most commonly due to contamination with fuel or a solvent. An oil's viscosity also can be affected if the wrong oil is used for top-off or replenishment.

Figure 3 If a lubricant does not have the proper viscosity, it cannot properly perform its functions.

If a lubricant does not have the proper viscosity, it cannot properly perform its functions (Fig. 3). If the viscosity is not correct for the load, the oil film cannot be established at the friction point. Heat and contamination are not carried away at the proper rates, and the oil cannot adequately protect the machine.

Acid Number

Acid number (AN) is an indicator of oil health. It is useful in monitoring acid buildup in oils due to depletion of antioxidants. Oil oxidation causes acidic byproducts to form. High acid levels can indicate excessive oil oxidation or depletion of the oil additives and can lead to corrosion of the internal components. By monitoring the acid level, the oil can be changed before any damage occurs (Fig. 4).

An oil analyst is looking for a sudden increase. When your oil is flagged for high acid levels, it indicates accelerated oil oxidation, and you should change the oil as soon as possible. If any of the remaining highly acidic oil is left, it will quickly deplete the antioxidants in the new oil.

Acid number is measured by titration using ASTM D664 or D974. Both methods involve diluting the oil sample and adding incremental amounts of an alkaline solution until a neutral endpoint is achieved.

Figure 4 By monitoring the acid level, the oil can be changed before any damage occurs; an oil analyst is looking for a sudden increase.

The acid number of a new oil will vary, dependent upon the base oil additive package. An R&O oil will usually have a very low AN, around 0.03. An AW or EP oil will have a slightly higher value, typically around 0.5. Engine oils commonly have a higher AN, in the neighborhood of 1.5.

Base Number

Base number testing is very similar to acid number testing except that the properties are reversed. The sample is titrated with an acidic solution to measure the oil's alkaline reserve. ASTM D2896 and ASTM D4739 are the most commonly used methods to measure the base number (ASTM, 2007; ASTM, 2008).

Many oils (especially motor oils) are fortified with alkaline additives to neutralize acids that are formed as a result of combustion. In diesel engine applications, acid is formed in the combustion chamber when moisture combines with sulfur under pressure. Measuring the base number will help ensure that a sufficient amount of additives have been added to the oil to help resist oxidation due to acid (Fig. 5).

The base number of oil is highest when the oil is new and decreases with use. Once again, condemning limits are based on the application. As a rule, the base number should not drop below half of its original value. Base number values for new engine oils very greatly depending on the application.

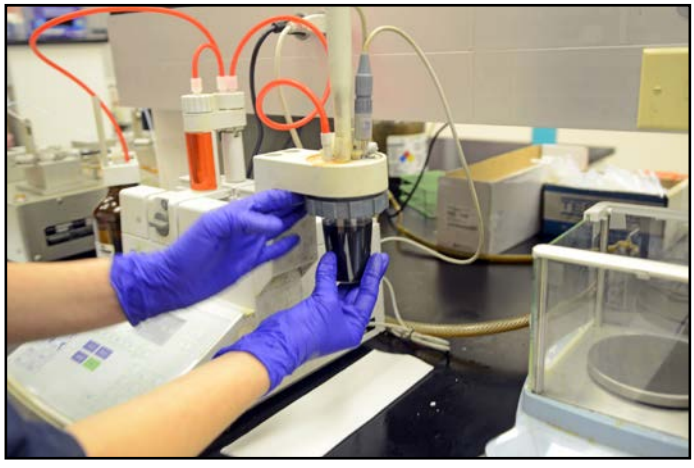


Figure 5 Measuring the base number will help ensure that a sufficient amount of additives have been added to the oil to help resist oxidation due to acid.

Figure 6 If a crackle test is positive, further testing is needed to quantify the amount of water by using Karl Fischer titration by ASTM D6304 (ASTM, 2007).

Water Contamination

Water contamination is detrimental to any lubricant. A simple crackle test is used to determine if water is present in oil. A small volume of the lubricant is dropped onto a hot plate and, if bubbles or crackles occur, water is present.

If a crackle test is positive, further testing is needed to quantify the amount of water by using Karl Fischer (*Ed.'s Note: German chemist, 1900–1958*) titration by ASTM D6304 (ASTM, 2007) (Fig. 6). A measured amount of oil is introduced into a titration chamber. This solution is titrated with Karl Fischer reagent to a specific end-point. The amount of reagent used and the sample volume are calculated and converted to ppm (percent by mass).

Low levels of water (<0.5%) are typically the result of condensation. Higher levels can indicate a source of water ingress. Water can enter a system through seals, breathers, hatches and fill caps. Internal leaks from heat exchangers and water jackets are other potential sources.

When free water (non-emulsified) is present in oil, it poses a serious threat to the equipment. Water is a very poor lubricant and promotes rust and corrosion to the components. Dissolved water in oil (emulsified) will promote oil oxidation and reduce the load handling ability of the oil. Water in any form will cause accelerated wear, increased friction, and high operating temperatures. If left unchecked, water will lead to premature machine failure. In most systems, water should not exceed 500 ppm.

Particle Count

Particulate contamination has negative effects on all types of equipment. Particle count testing is a way to monitor the level of solid contamination in the oil. Two types of automatic particle counters are used to test oil cleanliness: light blockage and pore blockage.

- ***Light blockage***: The light blockage technique involves passing a sample through a small orifice that has a laser light source on one side and an optical sensor on the other side. Particles interrupting the light beam are counted, and size is determined by the degree of light blockage. Light blockage particle counting is not effective when oil is contaminated with water or when air is entrained in the oil. In these circumstances, water or air bubbles will be counted as particles, causing erroneous results.
- ***Pore blockage***: The pore blockage or flow decay technique passes the sample through a mesh filter. As a filter clogs, the flow of the sample is slowed. The amount of flow decay is calculated, and the particle count can then be extrapolated. Because water droplets and entrained air will not restrict the fluid flow, there is no interference from these contaminants.

Results are reported as particles-per-milliliter in six size ranges: >4; >6; >14; >25; >50; and >100. ISO cleanliness codes are then assigned for particles in 4, 6 and 14 µm ranges (ISO 4406:1999). The result is reported by three numbers with a slash between them; the first number refers to particles in the >4 µm range; the second to particles in the >6 µm range; and the third in the >14 µm range. The lower the numbers in the ISO cleanliness code — ISO 4406 — the cleaner the fluid.

Figure 7 Particulate contamination is a measurement of the effectiveness of filtration and can indicate when excessive external contamination is occurring.

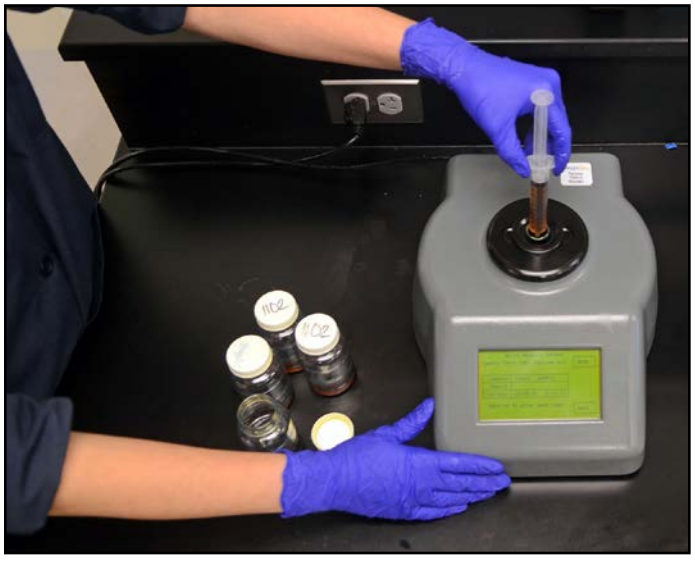


Figure 8 A wear particle analyzer quantifies the amount of ferrous material present in a sample of fluid.

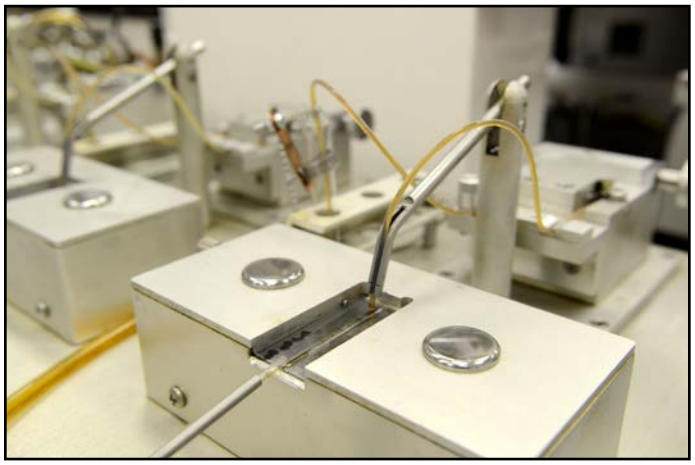


Figure 9 Analytical ferrography is able to identify wear particles, their composition and their origin by visually analyzing them microscopically.

Particulate contamination is a measurement of the effectiveness of filtration, and can indicate when excessive external contamination is occurring (Fig. 7). Advanced machine wear will also cause increased particle counts. Generally, the lower size ranges are considered indicative of contamination and silt, while the larger size ranges point to wear problems.

Ferrous Wear Concentration

In some cases a particle count is not an effective test because the sample is inherently dirty and filtering the oil may not be plausible. A particle count indicates that the sample is extremely dirty, but it does not give any indication of ferrous wear. In gearboxes, ferrous wear may be more important than overall particle count. In such an application, ferrous wear concentration is a good substitution for a particle count test.

A wear particle analyzer quantifies the amount of ferrous material present in a sample of fluid (Fig. 8). A measured amount of sample is inserted into the analyzer and amount of ferrous material is determined by a change in magnetic flux. This change is then converted into ferrous concentration in parts-per-million. Using this method, there are no interferences with non-ferrous particles.

One advantage of a ferrous debris monitor is that it will measure ferrous wear debris in all types of oil, from gearbox lubricants through hydraulics; another key benefit is that it will also measure ferrous wear debris found in grease.

A test similar to the ferrous debris monitor is DR (direct read) ferrography. DR ferrography collects positively charged particles on two light sources and measures the amount of blocked light to determine the level of ferrous contaminants present in an oil. Although these two tests provide the same information, they are not interchangeable.

Analytical Ferrography

Analytical ferrography is used to separate solid contamination and wear debris from a lubricant for microscopic evaluation. As stated earlier, spectroscopy is not able to measure wear particles larger than 7 µm in size. While particle counting, ferrous wear concentration and DR ferrography are able to detect the presence of larger particles, they cannot qualify their composition or origin. Analytical ferrography is able to identify wear particles, their composition and their origin by visually analyzing them microscopically (Fig. 9).

A diluted oil sample is allowed to flow over a specially treated slide positioned at an angle over a strong magnet. The ferrous (iron) particles are attracted to the magnet and deposited onto the slide in decreasing size as the oil flows down the substrate. Nonferrous particles are deposited randomly, while ferrous particles line up in chains as a result of the magnetic flux. The result is a microscopic slide with the particles separated by size and composition.

Microscopic examination of the debris reveals information about the condition of the equipment. Observing the concentration, size, shape, composition and condition of the particles indicates where and how they were generated. Particles are categorized based on these characteristics, and conclusions can be drawn regarding the wear rate and health of the machine.

The composition of the particles can be identified by color. Heat treating the slide causes specific color changes to occur in

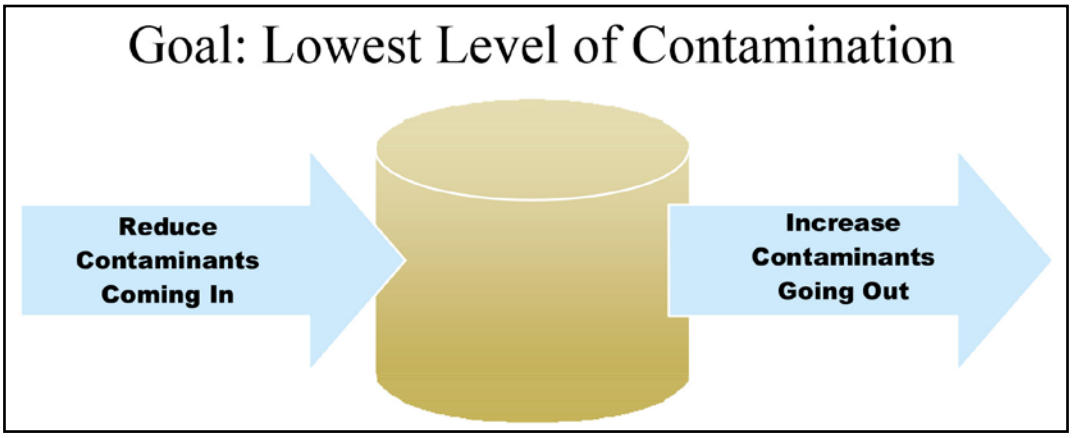


Figure 10 The goal is the lowest possible evidence of contamination.

various types of metals and alloys. The particle's composition indicates its source. The particle's shape reveals how it was generated. Abrasion, adhesion, fatigue, sliding and rolling contact wear modes each generate a characteristic particle type in terms of its shape and surface condition.

Solid contaminants can also be visually identified, provided they are of a commonly found origin. Sand and dirt, fibers, oxidation products, rust and metal oxides are examples of contamination debris that can be identified.

Taking Action with Oil Analysis

This article has covered the basics of common oil analysis tests and their significance. While the results of these tests are a powerful maintenance tool, they are useless if not monitored and acted upon.

Every particle, including soft ones, introduced to a rolling element bearing has the potential of damaging the bearing. The damage will appear when the roller passes the particle and it is indented in the metal. These debris dents cause a loss of the elastohydrodynamic (EHL) film thickness. The results are stress concentrations at the crater rim around dents. Cyclic contacts at these sites produce a pressure surge. Plastic deformation and tensile residual stresses can ultimately initiate micropits, which may grow into macropits.

Researchers from London's Imperial College, R.S. Sayles and P.B. Macpherson, showed that rolling element bearing life can be increased up to seven times by simply changing from a 40-mm filter to a 3-mm filter. Therefore, monitoring and controlling smaller particles is essential. A good rule of thumb is that 'dirt generates more dirt'. Greater reliability is achieved when small destructive particles such as dirt and wear debris are removed.

Reliability is enhanced when particles are controlled. The goal should be to lower contamination to an acceptable level (Fig. 10).

The majority of particles in the oil are typically iron. Because iron acts as a catalyst, it will break down the oil and interfere with the elastohydrodynamic lubrication so critical in the gearbox. In short, it causes wear. Particles will wear down to the size of the lubrication film and even smaller. Microscopic images of these submicron particles in gear oil appear as round spheres. Like rocks on a beach, they have been worn round by countless passes through the gears. These particles appear black on a membrane. Theses membranes can be lifted by a magnet, because the small black particles are iron and they are magnetic.

Therefore, it is imperative that action be taken to control contamination. How can that be done? The goal for wind turbine owners and operators should not be the least expensive approach. Rather, the focus should be on three simple steps to enhance reliability. After all, we buy filters. But reliability is what we do. There are three steps to achieving this goal:

Step 1: ***set oil cleanliness targets.*** The proper cleanliness level is difficult to state in general. It is important to note that no gearbox has ever failed because the gear oil was too clean. Where availability and reliability are of great importance, the oil cleanliness target shall be higher. The American Wind Energy Association and the American Gear Manufacturers Association has released a technical standard that sets forth reasonable and attainable targets. Committee members took an engineering approach in setting lubricant cleanliness guidelines. The standard is entitled ANSI/AGMA/AWEA 6006-A01: Design and Specification of Gearboxes for Wind Turbines. The targets are found in Section 6 — Lubrication (Fig. 11).

Source of sample	ISO Code
Oil added to gearbox	16/14/11
Gearbox after factory test	17/15/12
Gearbox after 24 hour service	17/15/12
Gearbox in service	18/16/13

Figure 11 The American Wind Energy Association and the American Gear Manufacturers Association have released a technical standard that addresses four contamination areas of particular importance.

Water is a second key parameter to monitor and act upon. The AGMA/AWEA standard also includes guidelines for moisture contamination in Annex F. The caution level is 0.05% (500 ppm) and the critical level is 0.10% (1,000 ppm). So an effective contamination control program should aim for 0.05% or lower.

Step 2: ***take action to reach targets.*** Two specific actions are required. First, reduce contaminant ingression. In other words, keep particles from entering the gearbox. This requires good housekeeping procedures in the storage, handling, and dispensing of oil. Ensure the oil is kept clean and dry. Do not mix oils of

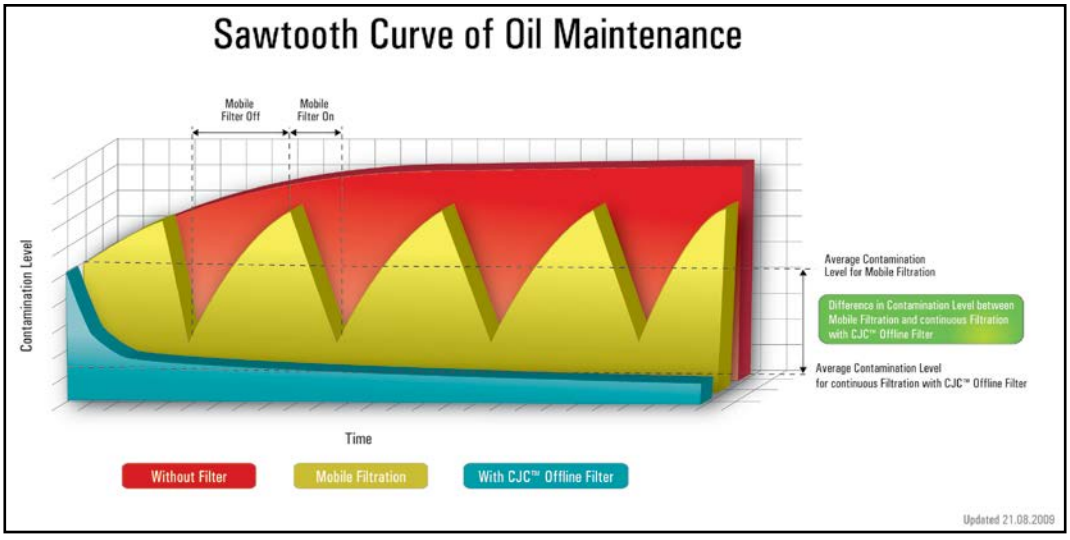


Figure 12 While a filter cart will clean oil for a limited time, experience shows that when the filter cart is disconnected, the particle count quickly rises; i.e.—the "saw-tooth curve."

an unknown origin. Avoid cross contamination by clearly labeling containers with the oil type.

New oil should always be introduced into the gearbox by means of a sufficiently fine filter (i.e., 3 microns). Studies show that new oil is often highly contaminated. Therefore, use offline filters and filter carts to clean and dispense new oil from drums and totes. New oil should be considered contaminated until the opposite is proved. Portable containers can be directly filled from the cart. During maintenance events take great care to minimize the entry of contaminants. Add oil with the filter cart using quick disconnect fittings. Breathers should have a filter and desiccant to remove ambient dirt and moisture; use labyrinth seals and V-rings.

Next, improve filtration. Remove particles and water quickly. A well designed filtration system will effectively remove not only solid particles but also moisture.

Most large wind turbines have an inline filter located in the cooling system. However, these filters must out of necessity have a larger pore size than the oil film thickness, typically 10 micron or larger. Because the oil flow rates required by the cooler are high, a finer filter is not an option as this would make the inline filter too large for the nacelle. As a consequence these filters have a low dirt holding capacity and in some cases require frequent changes.

The solution is to supplement the inline filter with an offline filter. Offline filters are installed independent of the gearbox. Here a finer filter can be used, typically around three microns, because the oil flow requirements are less than 1 gallon per minute. Offline filters are depth type filters, meaning that they have a larger surface area than inline filters. Therefore they have a higher dirt holding capacity, providing a longer service life. Furthermore, the offline filter can run continuously, even during shutdown. Cellulose-based offline filters have the added capability of removing moisture via absorption.

Portable filters are not the ideal solution to maintain the oil cleanliness level. While a filter cart will clean the oil for a limited time, experience shows that when the filter cart is disconnected, the particle count quickly rises. This is known as the "saw-tooth curve," as Figure 12 illustrates.

A well designed contamination control system incorporating inline and offline filters will reach oil cleanliness targets and provide operational economy (Fig. 13). A common myth is that increased filtration costs outweigh the benefits of achieving cleaner oil. Savings usually outweigh costs by great margins because of longer filter service life, lower oil consumption, and extended gearbox and bearing lifetime.

Figure 13 Offline filters (aka kidney loop filters) are commonly used in the wind industry and provide the optimum level of contamination control.

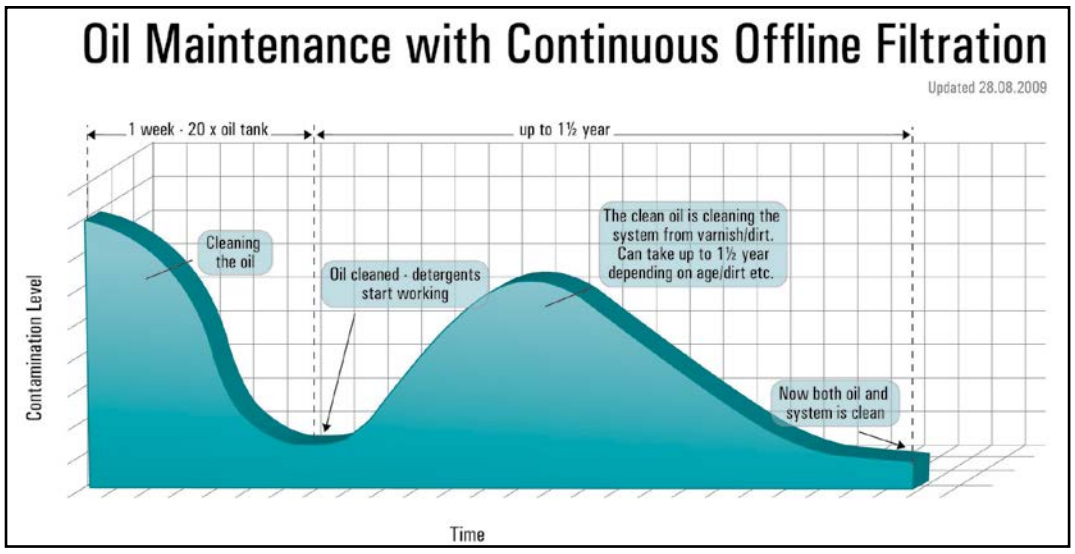


Figure 14 Oil analysis is an essential component of improving wind turbine gearbox reliability; decisive action taken in response to the data collected will ensure a successful program.

In turbines where only an inline filter is installed, the replacement interval is six months or less. However, when an offline filter system is also installed, both filters only require replacement annually. The offline filter pump makes sure that all the contaminated oil from the bottom of the gearbox is filtered and effectively used again.

Another improvement by installing the offline filter system is that it is able to filter gear oil even when the turbine is not connected to the grid. This is a major advantage during periods with low wind. In this condition the turbine may not be in constant operation. During this period the offline filter will continuously operate. In this way the gear oil will be clean when the turbine starts again.

The offline filter system is simple and easy to install; the benefits of the offline filter include:

- Improved lifetime of the gear oil
- Improved lifetime of gearbox bearings
- Reduced wear and tear on gearbox bearings
- Reduced the risk of bearing damage due to poor oil cleanliness
- Improved oil filtering

Offline and inline filters are common in the wind industry and provide the optimum level of contamination control.

Step 3: *monitor and maintain oil cleanliness.* Oil analysis will provide continual feedback on the condition of the gearbox and lubricant. It will also verify whether or not cleanliness goals are being met. If not, Step 2 — Take Action — can be applied.

Conclusion

Oil analysis is an essential component of improving wind turbine gearbox reliability. Decisive action taken in response to the data collected will ensure a successful program.

In summary, the three steps to improving reliability are:

1. Define targets for particle and water contamination.
2. Instigate remedial action as necessary to reach targets.
   a. Reduce ingression of contaminants.
   b. Improve removal of contaminants.
3. Monitor contamination levels against target levels and maintain safe levels.

Significant savings are achieved through longer oil and component lifetime. The relationship between lubrication quality and maintenance costs is inversely proportional. In other words, financial gains are made when the gear oil quality and cleanliness level are improved. It may take time to realize the benefits of this practice, but it is worth the effort. Figure 14 illustrates that time is required, but the results are indeed worthwhile. With this perspective in mind, oil analysis and upgraded filtration does not cost — it *pays* — to implement.

A successful oil analysis program will be one where the test data and analysis are coupled with the maintenance department's knowledge and expertise to provide the most effective maintenance practices.

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3. Skriver, S. "Large Turbines Need Offline Filters," *WindStats Newsletter*, Summer 2000, Vol. 13, No. 3.
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Michael Barrett, TestOil vice president for sales & marketing, has been with the company for 20 years, in a variety of positions. In 2005 he led TestOil's effort in developing a solution for helping customers understand varnish's potential in their equipment. Today he is responsible for directing TestOil's marketing and sales efforts. Barrett helped design an expert system rule base for assessing and evaluating lubricant and machine condition, and has spoken at conferences on the subject of oil analysis. Barrett has a BA in economics from Kenyon College, and a Master's degree in business administration from Case Western Reserve University.

Justin Stover earned his degree in 2001 in fluid power technology. He has more than 10 years' experience in helping end-users and OEMs in the wind industry implement, develop and deploy contamination control programs. Stover is certified by the International Council for Machinery Lubrication as a Level 1 machinery lubricant analyst.

Klingelnberg
RECEIVES DOCUMENTATION AWARDS

Klingelnberg once again received two awards for its outstanding operating instruction quality at the ceremony for the renowned tekom documentation award on November 7th, 2013 in Wiesbaden, Germany.

The European professional association for technical communication, tekom (Gesellschaft für Technische Kommunikation e.V.), has been honoring user manuals and operating instructions for consumer and capital equipment as well as online help for software products with awards every year since 2005.

In order to determine which documentation should win the award, tekom hands the submitted instructions over to an independent team of experts in technical documentation for evaluation according to a specified catalog of criteria. This year Klingelnberg Group once again proved the quality of its operating manuals for the third time in a row: The instructions for the spiral bevel gear testing machine Oerlikon T 60 and the cutter head setting and checking device Oerlikon CS 200 received the coveted seal of quality this year with a high-scoring grade of 1.7 (according to the German school grading system where 1 is best and 6 is worst).

Pascal Kesselmark, head of technical documentation at Klingelnberg Group, accepted the awards in person during the ceremony: "We are incredibly thrilled about this honor, which more than confirms our 2008 decision to completely rework our technical documentation. Now we are looking back at eight awards since 2011."

Pascal Kesselmark, head of technical documentation at Klingelnberg Group, accepted the awards during the ceremony.

Dr. Hartmuth Müller, CTO of Klingelnberg Group, also seemed extremely happy with the results: "Our customers expect the highest degree of quality and safety from our products. Naturally, this also includes technical documentation. It has to be written in an understandable way, needs to meet all legal and standard-related requirements and must allow operators to use our products efficiently and safely at all times. That is why this award represents an affirmation of our continuous work as a quality-conscious company."

ALCprecision
CHANGES NAME TO PRECIPART

Precipart Group, a global supplier of precision custom mechanical components, gears and motion control assemblies for medical technology, aerospace, homeland security and industrial markets, has changed the name of its ALCprecision operating company to Precipart. The name change coincides with the launch of a new Precipart informational website at *www.precipart.com*.

Based in Farmingdale, NY, the ALCprecision business unit provides custom solutions for high-precision machined parts, technical ceramic components, custom mechanical assemblies and miniature parts in various materials. Tracing its origin back to the mid-1800s and the invention of the Swiss Screw Machine, the company offers value-added services on a global basis — from design through high-volume production and delivery logistics.

The name change is effective immediately. However, the company's structure, ownership, processes, quality systems, staff and location will not change, according to Robert Marchese, Precipart president and CEO of Precipart's Mechanical Components and Assemblies business unit. "The name change from ALCprecision to Precipart correlates with the alignment of our operating companies in strategy and process under one common brand," explained Marchese. "Together, the Precipart Group family of companies is expanding its reach and capabilities beyond component production to offer added value for its customers. Not only are we growing by providing systems and assemblies, but we see opportunities for growth and strategic sourcing in new geographic markets. The transition to a common brand identity is part of that vision for expansion."

In addition to the name change and new website, Precipart is expanding its campus in New York, adding a new building with more than 21,000 square feet of manufacturing space. Precipart Group has operations in Farmingdale, NY; Lyss, Switzerland; and Hampshire, England.

Solar Atmospheres

HIRES REGIONAL SALES MANAGER

Solar Atmospheres recently announced that **Michael Paponetti** has accepted the position of regional sales manager. He will be utilizing his 18 years of heat treating/brazing technical knowledge to maintain and promote sales throughout the country. Prior to accepting this position, he served as president of Expert Brazing and Heat Treating, which is located in Massillon, Ohio. Paponetti brings experience and a proven track record of success, as a longtime AWS and ASM member, which will be invaluable in meeting Solar Atmospheres of Western PA's goals and objectives. SAWPA president, Bob Hill says, "Please join me in welcoming Michael to Solar Atmospheres of Western PA. I am confident that he will be an excellent match for this position and a strong asset to our Solar team."

Mitutoyo America

CELEBRATES NEW CORPORATE HEADQUARTERS

Mitutoyo America Corporation celebrated the grand opening of their new corporate headquarters on October 14 - 15 at 965 Corporate Boulevard, Aurora, Illinois. The two-day "Building the Foundation for the Next Fifty" celebration included ribbon cutting ceremonies, M3 Solution Center and facility tours, product introductions and seminars, and a 50th anniversary gala celebration for Mitutoyo customers, distributors and distinguished guests. "We are so excited that the grand opening of our new facility could occur simultaneously with our 50th anniversary milestone. Our new advanced facility will provide Mitutoyo America with all the essential resources necessary so we are able to hold true to our number one commitment — to prevail as the leader in the metrology market achieved through a culture which recognizes lasting relationships are only built on a solid foundation which embraces trust and honor," says Shigeyuki Sasaki, president of Mitutoyo America Corporation.

Hwacheon Machinery

APPOINTS VP OF SALES

Hwacheon Machinery America, Vernon Hills, Illinois, has appointed **Robert Nedler** to the position of vice president – sales, a new position, according to Michael Huggett, president. Nedler previously was product manager – milling at Hwacheon. He has been with the company since 2012. "A dynamic and results-focused sales leader, Bob brings to Hwacheon his more than 27-years' experience in identifying and successfully capitalizing on market opportunities, which he earned at the Starrag Group, DMG and Yamazen," Huggett said. "Bob will play an essential role in the company as we work to expand our market share in North and South America."

"One of my primary goals is to develop a responsive sales and service team that will provide the highest level of support to our growing dealer network and to our customers in the general machining, mold and die, energy, and aerospace markets," Nedler said.

GMTA

APPOINTS MANAGER OF CONTROLS ENGINEERING AND PROGRAMMING

Effective October 1, **Maik Schminke** was named manager of controls engineering and programming at the Ann Arbor facility of GMTA. According to GMTA President Walter Friedrich, "This appointment fills our need to provide and support customers with machine tool controls, SPS, PLC and CNC programming." Schminke has worked for the past 12 years at the German partner to GMTA, Diskus, part of the large DVS Group in Germany. Prior to Diskus, he worked at Pittler, another GMTA partner company in Germany and also a DVS Group company. Schminke completed his apprenticeship program while at Pittler. In other GMTA news, plans are underway to have an open house at the newly renovated GMTA facility in Ann Arbor, Michigan. This expanded facility now houses parts and service, a full machine demo center, sales and corporate

management for this growing machine tool company. GMTA is the exclusive North American distributor for leading German machine tool builders and tooling suppliers, concentrated in the gear and spline production machine markets.

Holroyd Precision

SECURES MACHINE TOOL ORDERS IN CHINA AND GERMANY

Holroyd Precision Ltd., the specialist machine tool design, manufacture and supply division of U.K.-based Precision Technologies Group (PTG), has secured machine orders totaling more than £4 million from leading air compressor manufacturers in China and Germany. Valued at £3.3 million, the order from China is for a Holroyd 8EX rotor milling machine that is capable of milling profiles of up to 850 mm in diameter, and a Holroyd TG350E (350 mm diameter capability) rotor grinding machine. Offering 'next generation' production technologies, both models are renowned across industry for their high stock removal rates and high levels of accuracy. The customer concerned is a manufacturer of specialist oil-free air compressors that are used in the medical and textile sectors. The TG350E rotor grinding machine will be shipped in December 2013; the 8EX rotor milling machine will follow in early 2014. The order from Germany is for a Holroyd 3EX-R rotor milling machine. Valued at £1 million, it has a 350mm maximum diameter capability and will be used by a premier air compressor manufacturer for the milling of screw profiles.

Metallized Carbon

APPOINTS QUALITY ASSURANCE MANAGER

Roxanne Andrian will fill the position of quality assurance manager and will oversee the operations of the quality assurance department and ensure that all products produced are of the highest quality and comply with internal and external requirements. "We are delighted to have Roxanne join the Metcar team," says President and CEO, Matthew Brennan, "Her experience will ensure we can continue to produce the high quality products our customers have learned to expect."

Andrian holds a Ph.D. in mechanical engineering from the University of Montreal and has more than 13 years of experience in quality assurance in the aerospace, automotive, petrochemical, and oil and gas production industries. Furthermore, Andrian holds a certification as a Six Sigma "Master Black Belt." Her extensive QA expertise will be necessary to meet the high standards of Metallized Carbon's carbon-graphite products that are required to survive and function under the harshest conditions. In addition, Andrian is dedicated to promoting communication between employees and management, and is committed to lean manufacturing principles. In past roles she has helped her former companies significantly reduce waste and raw material needs and she hopes to continue this focus at Metallized Carbon.

Moventas

REBRANDS INDUSTRIAL AND WIND GEAR BUSINESS

Moventas is in the process of rebranding and differentiating its industrial and wind gear businesses. Changes in its operational structure and branding will take place by the end of the year. As part of the operational arrangements, group President & CEO Mikael Laine has set forth his resignation. Moventas is preparing to rebrand its industrial gear business, and to run the two core businesses more independently of each other than before, in order to better serve its customers in both segments. The company's legal structure will remain as it is, but its operational structure will be developed to enable more flexibility in fulfilling customer needs on a global scale for both businesses.

The renowned Santasalo brand will now be reintroduced by making it Moventas' industrial gear brand. Moventas, a recognized brand in the renewables industry, will remain as the wind industry brand. Moventas' after sales business will be branded Santasalo Moventas, which will also be the company's new corporate identity. Both the rebranding and the related operational changes will take place by the end of the year.

Santasalo is Moventas' predecessor and a major part of the Moventas history and legacy since the 1940s. Santasalo is a

Moventas-owned trademark. With industrial gear manufacturing facilities in Germany, Finland and China and a network of nine service and repair facilities globally, the Industrial Gears business is an important contributor to the Moventas business. Recent investments in new service centers, additional sales resource and some exciting new product developments provide a strong platform for further growth in the Santasalo business.

Moventas' Industrial Gears and Wind Gears business areas will be led by the current Senior Vice Presidents, Gerwin Klaner and Arto Lahtela. In addition, the owner's representatives and Moventas board members Alex Stewart and Gavin McCallum from Clyde Blowers will also take a more leading and operative role in the implementation of the differentiation plan.

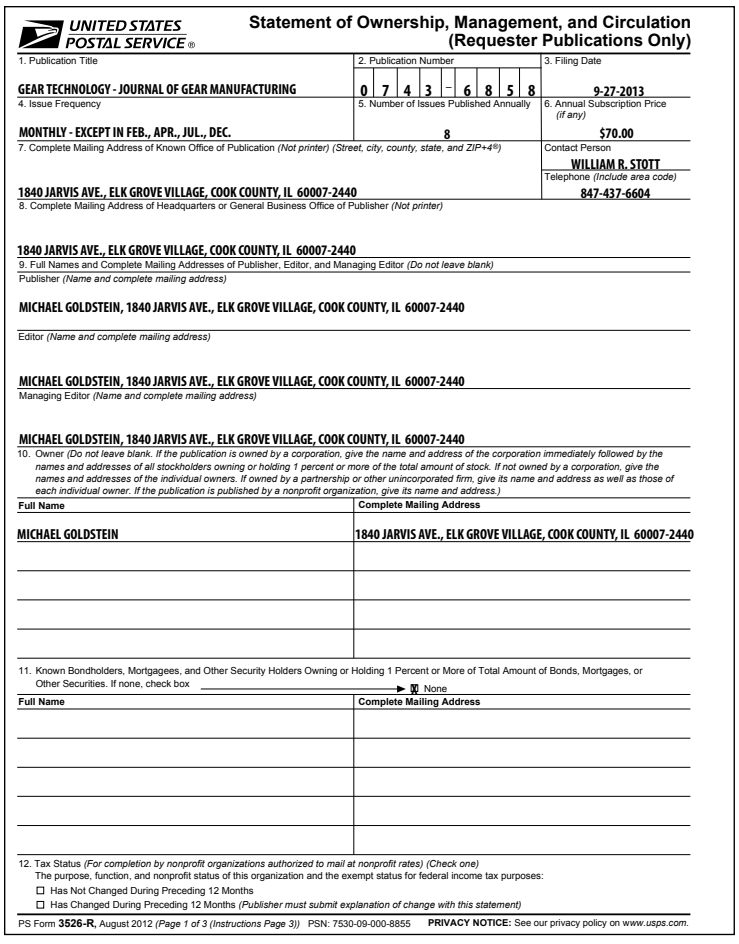
Ionbond

OPENS NEW CORPORATE HEADQUARTERS

Ionbond, a provider of PVD, CVD and PACVD coating services and CVD coating equipment, announced that it recently opened its new corporate headquarters offices in Zürich. The move follows the acquisition of Ionbond by the IHI Corporation of Japan at the end of last year. The new headquarters will be home to Ionbond's corporate management. IHI, which also owns Hauzer Techno Coating in Venlo, Netherlands, a leader in PVD and PACVD coating equipment, sees the new headquarters in Zürich as a central coordination point for their growth in coating services and equipment worldwide.

Ionbond's Chairman of the Board Yoshinori Kawasaki who will be based in the new headquarters said: "Zürich is an excellent location from which to coordinate our worldwide activities in this market. It is a convenient meeting point for our executives from IHI, Hauzer, and Ionbond as well as our customers. We would like to invite our customers and partners to meet with us in our new offices here in Zürich".

Ionbond's CEO Joe Haggerty added: "We are very pleased to open our new headquarters in Zürich. Centralized functions such as group finance, marketing, and human resources will be based here. This location allows us to receive customers more easily upon their arrival in Switzerland and allows for more efficient coordination with our coating network. It also provides access to the large support network of suppliers of corporate services and to the excellent employee talent pool available in the Zürich area. Our management for the equipment division as well as the Swiss coating services will remain based in our Olten Competence Center, about one hour west of the headquarters".



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February 10–12—Gear Materials: Selection, Metallurgy, Heat Treatment and Quality Control. Sheraton Sand Key Hotel, Clearwater Beach, Florida. The presenters have designed gear systems as a collaborative effort, together, for more than 40 years. This seminar is their effort to convey both their experience in the process of working as a team and the expertise they have developed for the complete design of geared systems over these many years. Instructed by Raymond Drago and Roy Cunningham from Drive Systems Technology, this course will cover material selection, heat treating processes, engineering development, inspection and more. Gear design engineers, management, metallurgists, lab techs, QA engineers, furnace design engineers and equipment suppliers would benefit from the course work. For more information, visit *www.agma.org*.

February 25–27—AeroDef Manufacturing 2014. Long Beach, California. AeroDef Manufacturing is the leading technical summit and exposition for the aerospace and defense manufacturing industry. Produced by SME, in partnership with industry OEMs, its mission is to foster innovation across the extended enterprise to reduce costs, expedite production times and maintain manufacturing competitiveness in the global economy. AeroDef 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 and will discuss topics on 3-D manufacturing, cybersecurity, workforce development, globalization and innovation. AeroDef's show floor is divided into Technology Zones reflecting the entire manufacturing enterprise – from design to manufacture to sustainability. At the center of it all is The Deck – the hub of the expo show floor and host to morning keynote presentations, daytime panel discussions, and afternoon networking receptions. For more information, visit *www.aerodefevent.com*.

February 27–March 1—IPTEX 2014. Bombay Exhibition Center, Mumbai, India. The 3rd International Power Transmission Expo is dedicated to the gear and power transmission industries. India is rapidly turning into a global manufacturing hub, thanks to the country's manufacturing and engineering capabilities, vast pool of skilled expertise and its size. These qualities offer it a strategic advantage for the manufacturing segment. A large number of international companies in varied segments have already set up a manufacturing base in India and others are following suit. Exhibitors include those involved in gear processing equipment, cutting tools, gear inspection and testing instruments, chains and belt drives. Key participants include Gleason and Klingelnberg. IPTEX is supported by the AGMA and its media partner is *Gear Technology India*. GRINDEX, an exposition on grinding and finishing processes, will run concurrently with IPTEX. GRINDEX is designed to meet the emerging demand for precision driven applications as manufacturing needs new technology and solutions. For more information, visit *www.iptexpo.com*.

March 5–6—Lean Transformation Summit 2014. Orlando, Florida. Continuously improving management systems allow companies to provide better quality, more reliable delivery, better service and lower costs. The summit provides attendees with relevant, real-world learning sessions to enhance their lean efforts. Plenary sessions offer feedback from organizations that have developed successful lean programs including Cardinal Health, Food Bank for New York City and GE. Breakout sessions follow that give a firsthand account of the challenges faced during the lean transformation. Additionally, small interactive learning sessions allow attendees to reflect on applications and methodologies on the leading edge of lean thinking. For more information, visit *www.lean.org*.

March 11–13—Gearbox CSI: Forensic Analysis of Gear and Bearing Failures. Sheraton Suites, Philadelphia Airport, Philadelphia. Determining the cause of a failure in a gearbox is like a "who done it" mystery. What caused the failure? The bearings, a gear, the lubrication or a shaft problem? Where do you start, and how can you tell? This seminar helps gear designers gain a better understanding of various types of gears and bearings. Learn about the limitations and capabilities of rolling element bearings and the gears that they support so you can properly apply the best gear-bearing combination to any gearbox, whether simple or complex. A certificate will be awarded upon completion of the seminar. For more information, visit *www.agma.org*.

March 17–20—MODEX 2014. Georgia World Congress Center, Atlanta. MODEX 2014 is the industry's newest expo for the manufacturing and supply chain industries. At MODEX attendees will meet 800 of the leading providers in the supply chain industry. The MODEX Supply Chain Conference includes 150 sessions with keynote presentations from Edward H. Bastian, president of Delta Air Lines; former Walmart CEO Lee Scott; and Scott Sopher, principal with Deloitte Consulting. Some of the areas of interest include: material handling equipment, packaging equipment, dock and warehouse equipment, supply chain management and education. For more information, visit *www.modexshow.com*.

April 7–11—MACH 2014. Birmingham, United Kingdom. MACH is a showcase for advances in the manufacturing industry by the Manufacturing Technologies Association (MTA), a U.K. based trade association dealing specifically with engineering based manufacturing. It is a biannual exhibition which brings together innovations and developments from the manufacturing technologies sectors under one roof. The machine tool industry, not surprisingly, is well represented with the likes of Mills CNC, DMG Mori Seiki and Yamazaki Mazak. Tooling companies include Dormer Tools, WNT and Guhring. Metrology also has a strong presence featuring Carl Zeiss, Nikon and Renishaw. For more information, visit *www.machexhibition.com*.

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- ❑ Product Design, R&D Department (I)
- ❑ Purchasing (L)
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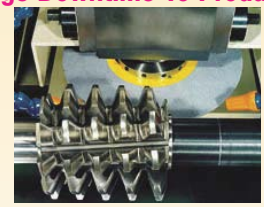

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THE NATURAL

Issus Develops Working Gears in Response to Selective Pressure

Which came first, the mechanical gear or the natural one? This is a question the science community is now debating after zoologists from Cambridge discovered interesting footage that showed off some complex machining taking place in the body of one jumpy insect. Malcom Burrows, emeritus professor of Zoology, University of Cambridge, U.K., recently discovered working mechanical gears in the body of an issus, a small garden-variety bug found in backyards around the globe. "We had seen the gears when looking at the anatomy of the insect, but the exciting revelation came from the use of high speed video (5,000 images/second) that showed the gear teeth spinning past each other when the insect jumped," says Burrows. "These videos left little doubt in our mind that the structures both looked like gears, rotated and enmeshed like gears and functioned like gears."

The issus developed this gear-like structure in order to accomplish acrobatic leaps across plants—most likely to escape danger from predators. "A jump is propelled by the rapid extension of the two hind legs (insects have 3 pairs of legs). The inside of the thighs are curved and are very close to each other. They have a row of gear teeth which intermesh with each other which are not present on the other two pairs of legs. If the commands from the brain initiating the propulsive movements of one hind leg start before those of the other hind leg, then the contact between the gears will ensure that both will move in synchrony. The intermeshing of the gears during the whole of the rapid jumping movement means that the two hind legs always remain in synchrony."

The gears would appear to have evolved in response to a particular selective pressure, according to Burrows. "The movements of the propulsive legs have to be tightly synchronized to enable the insect to jump away and hence escape from predators. If the legs move asynchronously, the jump will be less effective and the predators are more likely to be successful."

There are biological structures in this world that have gear-like appearances, but this is the first discovery of actual interacting gears in any animal. "In other insects there are many mechanical devices that are similar to devices that we have invented; for example, devices like poppers (press studs) and interlocking (Velcro-like) or abrasive surfaces for holding body parts together, or grasping structures like pincers," Burrows says.

So how are these gears different than the gears covered in each issue of this magazine?

"The main difference is their asymmetric shape," Burrows says. "Synchronization and any power transference is only really necessary in one direction, during the very rapid (1-2 ms) propulsive movements of the legs. In the opposite direction, when the legs are being moved in their position in preparation for a jump, the movement is slow (several hundred ms)."

What's truly fascinating to those involved in both science and engineering is that the issus represents the possibility that the idea of gears had arrived via natural selection long before man created the first mechanical device.

"The millions of years over which evolution has worked has almost certainly produced mechanisms that we have not discovered for ourselves and which our relatively short period of technology has not independently thought about yet," Burrows says. "I think the emphasis is that animals face similar problems to those we have faced in building machines. Natural selection has resulted in a solution that is similar to that devised by humans for dealing with similar requirements of movement control."

For more information on the issus and its working gears, visit *www.cam.ac.uk*.

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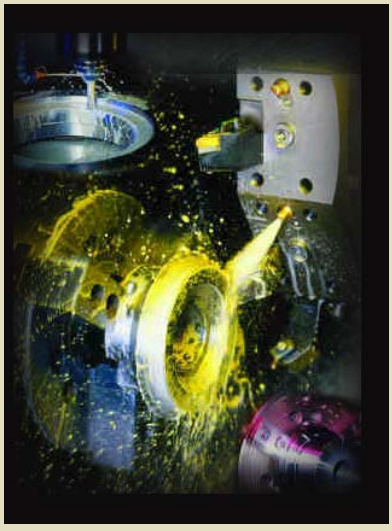

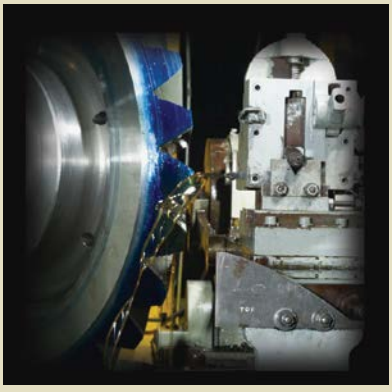

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