January/February 2009

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

25 YEARS 1984-2009

Features

- Wind Initiatives Continue Despite Shaky Economy
- Big-Gear Applications: Quality is King
- Help on the Way for Skilled Jobs?

Technical Articles

- Super-Finished Components Enhance Fuel Economy, Part I
- Gear Failure Analysis and Grinding Burn
- How Gear Surface Parameters Affect Gear Life

Plus

- Addendum: Gears Help Prayer Wheel Rock

THE GEAR INDUSTRY'S INFORMATION SOURCE

WIND, OIL & COAL ARE TRANSFORMED INTO ENERGY...THROUGH DEVICES MADE ON OUR MACHINES

BOURN & KOCH FELLOWS HS1280-300 CNC HYDROSTROKE GEARLESS GEAR SHAPERS

Application	Wind Energy, Oilfield and Mining
Benefits	Provides productive, precise, and powerful methods for producing large, long-face-width, coarse-pitch internal gears
Models Available	This new series of large Hydrostroke Gearless Gear shapers includes five models – HS650-200, HS1280-300, HS1280-450, HS1800-400, and HS2550-400

Star-SU LLC
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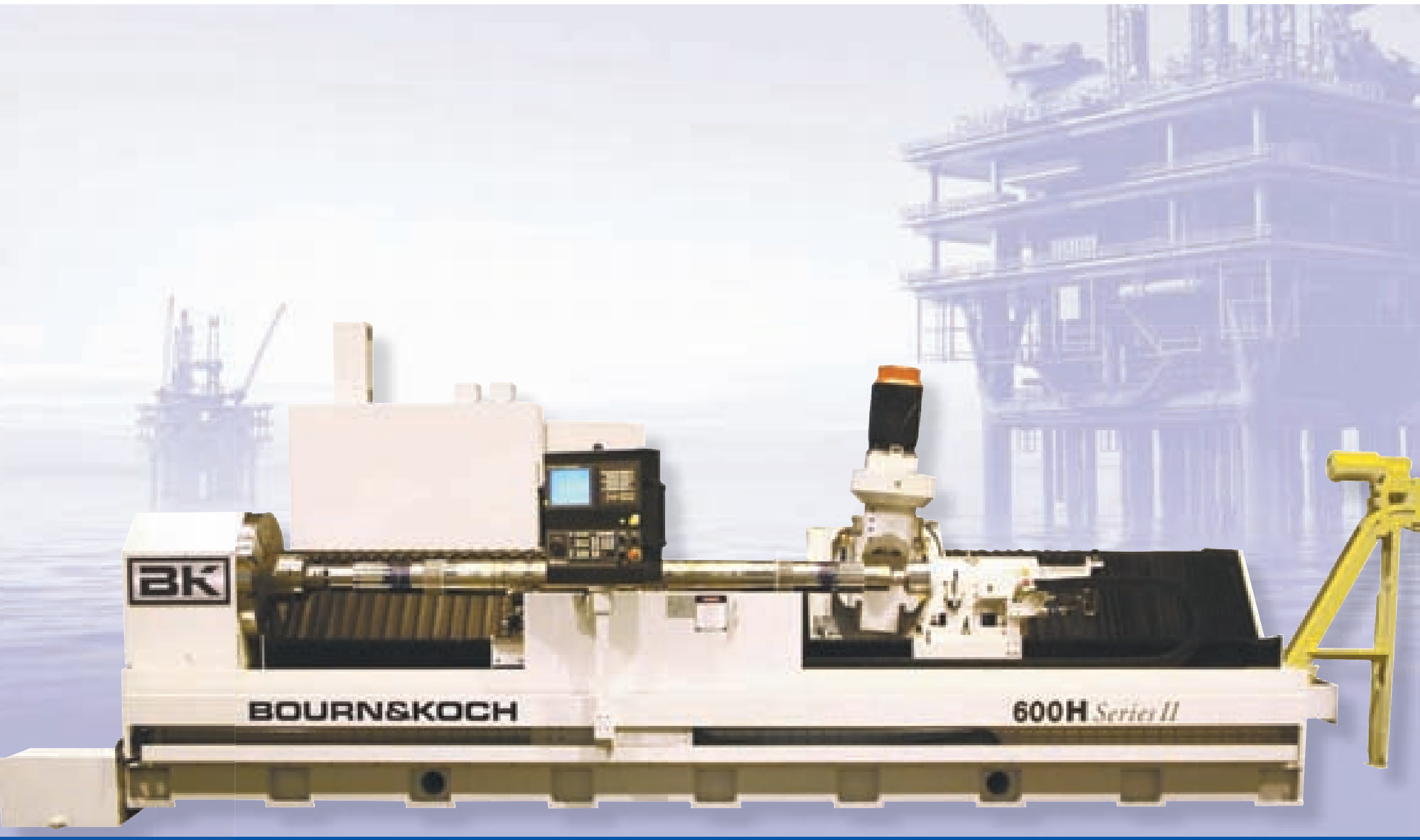
BIG JOBS CALL FOR BIGGER MACHINES



BOURN & KOCH 600H CNC HORIZONTAL HOBBING/MILLING MACHINES

Application	Energy, Oilfield and Mining
Benefits	Longer, more productive machines for hobbing and milling teeth on shaft lengths from 100" to 280"
Available Now	600H machines currently in assembly at Bourn & Koch include 100", 180" and 280" shaft lengths

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Gear Grinding Machines – Vertical & Horizontal
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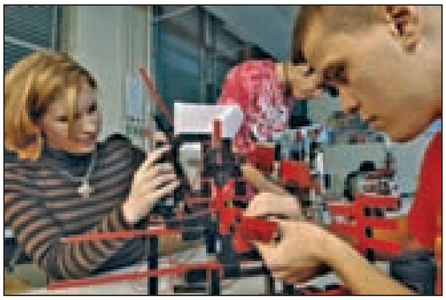

TECHNICAL ARTICLES

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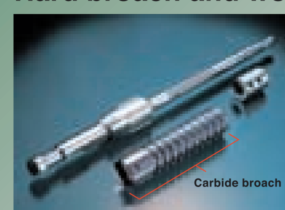
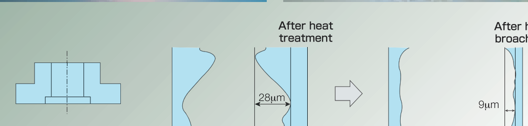
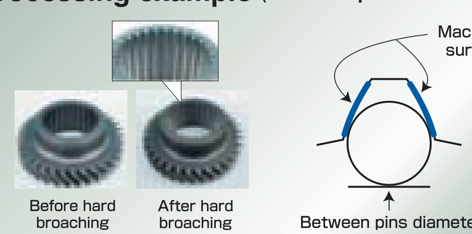




Processing example (involute spline toothed surface)



Hard Broaching Machine Hi-5010

GPA - An alliance providing total solutions for gear manufacturing equipment.

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NACHI AMERICA INC.

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Green Gravy

Step right up! Get your U.S. government gravy here! We're the U.S. Treasury Department's Troubled Asset Relief Program, and we're printing money like we're—well—the U.S. Treasury. If you've got trouble, then get your assets in line!

What's that you say? You're from the U.S. automobile industry? Ahem. Well. Hmm. I mean, manufacturing is nice and all, but without all these bankers, insurers and Wall Street wizards, who's going to sell all those credit default swaps, collateralized mortgage obligations and other fancy-sounding financial instruments? Those guys really keep the economy going, don't they?

What do you mean, you're important too? You actually make things and provide jobs? Oh, all right. Here's a few billion to tide you over. But you better spend it wisely, and don't come crawling back here until you've shown that you can be responsible.

Does all of this seem out of whack to anyone besides me?

There seems to be a double-standard (or maybe a lack of standards) when it comes to our government bailing out industries. When Wall Street crashed, the government reacted out of fear, quickly pouring money into financial companies like AIG, whose products and services scarcely anybody understands. AIG has so far received $150 billion in bailout money.

When the Big Three first went to Washington with hats in hand, they were sent home with their tails between their legs, albeit on their private jets. Although they were asking for a much smaller amount, it seemed lawmakers were more intent on examining their operations.

It's hard to deny that automotive management and labor have collectively displayed a lack of leadership, vision and cooperation, resulting in a bloated structure that's only profitable at the highest volumes. Increasingly, the Big Three don't seem to design or build what the buyers want, except for America's on-again, off-again love affair with pickups and SUVs.

So part of me understands why Congress has criticized the auto industry so heavily, and why, as of this writing, they've only came up with a package of about $20 billion.

But whether it's $150 billion or $20 billion, what we're doing now is a short-term, emergency solution that amounts to little more than a Band-Aid. What is all that money being spent on? Maybe the taxpayers get a few more months of relative normalcy, but what then?

Rather than just give the money to Detroit, I would like to invest our nation's money to help the Big Three reinvent themselves. I think we can do it in a way that simultaneously helps decrease our dependence on foreign oil, helps the environment and keeps manufacturing jobs in America. These are all ideas that our incoming president has made a cornerstone of his agenda, and which most of us would enthusiastically support.

I propose that the federal government should immediately begin the replacement of its entire fleet of gasoline-powered vehicles with alternative energy vehicles—hybrid, electric or natural gas. I don't mean just the small-scale programs already in place. I mean everything—from the post office to the White House and every government agency in between. Our government uses a lot of vehicles to move people and freight around. For the most part, those vehicles are still powered by gasoline. Instead of just asking our citizens to support these technologies and telling our manufacturers to produce them, our government should take a leadership role to make this change happen.

By placing orders for these vehicles for delivery over a short time period, the government would provide the Big Three with the volumes they need to achieve the economies of scale required for profitability. Having the government own and operate an increasing number of alternative vehicles would also provide the incentive needed to build the infrastructure necessary to support and service these new vehicles. So, the Big Three and their supplier base and infrastructure would be reinvented.

At the same time, the government would reduce its own dependence on foreign oil by reducing its consumption of gasoline-based products.

But it doesn't stop there. Once the Big Three achieve the right economies of scale, prices would come down. Then, many consumers would be interested in these highly efficient, environmentally friendly cars, especially if the government provides additional incentive by increasing taxes on gasoline.

The program should be extended to provide money to state and municipal governments so they can upgrade their fleets in the same way. Then, the process should be repeated in 3–4 years, so the government would have the latest, evolving technologies, and their used vehicles would then be put on the market to replace other gasoline-powered vehicles.

This is a win-win strategy for all concerned. The Big Three get the volumes they need, their employees get to keep their jobs, the government reduces its consumption of oil-based energy, consumers get better choices, and together we help the environment. Instead of propping up a dilapidated industry, America can rebuild it and give it a viable future. Don't just give the Big Three money. Change the game by giving them customers and putting them on a new path to competitiveness and prosperity.

Michael Goldstein
Publisher & Editor-in-Chief


Shifting into a new gear
This is no time to slow down.
We are already a world leader in machine tools — now we're shifting into a new gear. Grounded in over 74 years of history, yet building on our tradition of entirely new thought, Mitsubishi Heavy Industries America is leveraging our global network to bring advances never before seen in the gear market. Advances like new machines that benefit our customers financially by reducing waste and energy consumption. Machines that ease environmental impact by operating coolant-free. We're delivering even greater accuracy, productivity, and reliability. In these exciting times, we continue to focus on our customers. With machines that share a common user interface, we help customers flatten the learning curve and reduce setup and down times. By sharing new concepts with our customers and suppliers, we both create and support the next big idea. And with gear hobbing, shaping, shaving and grinding machines to suit your unique needs, we will help you find your new gear, too. mitsubishigearcenter.com
MITSUBISHI
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Machine Tool Division • Gear Technology Center
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248.669.6136

David Brown Girth Gear

SETS SIZE RECORD

David Brown engineers inspect the 12.4 m diameter girth gear under construction at the Benoni plant in South Africa.

David Brown delivered a girth gear weighing more than 65,000 kilograms to FL Smidth Minerals for a mining operation in Zangezour, Armenia. The original order was delivered in early 2008, and the company is currently working on a second girth gear order for 2009.

The single helical SAG mill girth gear, which is cast in four pieces, has 362 teeth, 0.75 DP, 863.6 mm face width, 12.4 m outside diameter and a 10.5 m diameter bore. It's manufactured from steel with a hardness range of 269/321 BHN, and gear teeth cut to AGMA grade 10.

David Brown also supplied three mill pinions to suit the girth gear, each having 18 teeth, 3,810 mm overall length, and weighing 5,090 kilograms, according to the company's press release. The company was able to meet the demands of its client due to a partnership with casting specialist Scaw Metals and an investment in a 14 m Maag gear cutting machine. The casting specifications were developed jointly by Scaw and David Brown during the past 15 years.

Besides the obvious engineering challenges of a gear this size, one of the major difficulties was the location where the equipment was installed. Armenia is the smallest of the former Soviet republics and is landlocked by Georgia in the north, Azerbaijan in the east, Iran to the south and Turkey to the west. The operation extended over a year and a half as the company dealt with the logistics of shipping and the breakdown of the girth gear into four separate parts.

"The SAG mill is 34 ft. in diameter, dual pinion with 12,000 hp," says Neal Biege Sr., head of global marketing for FL Smidth. "The ball mill is 20 ft. in diameter with 8,580 hp. The gears should be operational by mid 2009."

With investments in machining and gear-cutting technology, along with development of new materials used in the manufacturing process, David Brown has seen a reduction in lead times and the ability to achieve standards of accuracy to AGMA Level 13 and beyond.

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info@flsmidth.com
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MEASURE GEARS UP TO 4.5 METERS

WITH LEITZ PMM-G

Hexagon Metrology of Wetzlar, Germany has introduced two new models of the Leitz PMM-G, a gantry-type CMM designed for precise inspection of large gears, gearbox housings and other components.

The new models come with shorter z-axis travels (1,200 mm and 1,600 mm) and are aimed specifically at gear manufacturers who may not need the additional height required to inspect housings or other components. The original models were introduced in 2006 with z-axis travels of 2,000, 2,500 and 3,000 mm.

"We have just introduced the new

series with short z-rams, especially for the gear business," says Juergen Roos, Asia-Pacific regional manager and Leitz technical specialist. "And we are going to introduce them aggressively in the gear industry."

In addition to the new z-axis options, the PMM-G is available in three different diameter ranges. Machines are available for measuring gears up to 2,950 mm (116"), 3,950 mm (155") and 4,450 mm (177").

The PMM-G machines do not employ a rotary table, as traditional dedicated gear inspection systems do. This is especially an advantage when it comes to measuring larger gears, Roos says.

For one thing, because there is no rotary table, there is no weight restriction on the part being measured. In addition, the weight of the part has no effect on the accuracy of the measurement results.

"Also, the setup of the gear is very simple," Roos adds. "It can be placed anywhere in the measuring volume. An alignment or centering is not required. Because of this method, Leitz machines can measure gears on pallets."

According to Roos, the measuring speed for smaller gears is comparable to that of a dedicated gear tester, but the larger the gear, the greater the speed advantage of the PMM-G. "For large and heavy gears, the Leitz machines are faster," he says.

Another potential big gear advantage is that gears manufactured in segments can also be inspected. After measuring the individual segments, the software can even put them together and evaluate pitch and runout of the gear.

Finally, the PMM-G is capable of inspecting multiple gears and splines on shafts up to 7 meters long.

Leitz machines use *QUINDOS* software. The software was originally introduced for gear inspection in 1986, and inspection modules are available

for cylindrical gears, straight bevel gears, spiral bevel gears, worms, worm wheels and cutting tools, including hobs, shaving cutters, shaper cutters and broaches. In 2008, Leitz added a module for inspecting curvic couplings, as well.

Evaluations can be performed according to most common gear inspection standards, including AGMA, ANSI, ISO, DIN, JIS, CNOMO and CAT.

The larger the diameter of the gear, the better the price of a Leitz gear inspection systems compares with traditional dedicated gear checkers, Roos says. For small gears, up to 400 mm diameter, dedicated gear testers are less expensive. For medium-sized gears, the prices are comparable between dedicated gear checkers and the Leitz systems. But for gears larger than one meter, the price advantage swings toward the Leitz systems, Roos says.

So far, Leitz has sold about a dozen of these large-size gear inspection machines, including a number to wind turbine gearbox manufacturers in Europe and China.

"We see an ongoing high demand from the world's leading producers of big gears, in particular from the fast growing wind power industry," says Sebastian Henry, Leitz product manager. "It proves that we were right with both our machine concept and the…high quality standards we have set with the PMM-G."

For More Information:

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Phone: (401) 886-2422
Peter.Edge@hexagonmetrology.com
www.Hexagonmetrology.us

Gleason Grinder

CUTS PRODUCTION TIMES

The Genesis 160TWG threaded wheel grinder from Gleason is capable of hard finish grinding of cylindrical gears with diameters up to 160 mm emphasizing speed and flexibility. A high-speed, cam-driven, double-grip loader helps cut production times while

continued

a stock dividing sensor integrated into the grinding head speeds up setup time.

The 160TWG features several dressing systems to maximize dressing speed or flexibility depending on user preferences. A diamond-plated master dressing system incorporated into the clamping fixture is utilized for high volumes at high productivity; it can dress multi-start grinding wheels in 10–20 percent less time than traditional dressers. A CNC dressing unit with a single-flank dressing tool focuses on flexibility by creating any profile adjustment. A conventional CNC dressing unit with a double-flank dressing tool is capable of dressing both flanks concurrently.

Other features include an anti-twist capability to help control flank twist, and Gleason's VRM grinding process makes delicate kinematic modifications in the grinding process to make quieter gears.

As one of Gleason's Genesis machines, the 160TWG has a single-piece frame cast from a polymer material used for accuracy and rigidity. The platform allows for a compact footprint and requires no special lifting equipment or foundations to move the machine.

For more information:
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Rochester, NY 14692-2970
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sales@gleason.com
www.gleason.com

Helical Gearboxes

DELIVER POWER DENSITY WITHOUT LOSING EFFICIENCY

Distributed by the Richard Alan Group, Pumps and Gearboxes Limited, the Yilmaz monoblock M series gearboxes are in-line units displaying high strength and designed for flange or shaft mounting in demanding applications, such as quarrying, mining, mixing, crushing, winding and materials handling. A European footprint enables them to be interchanged with most makes on the market.

"The engineering expertise within the Richard Alan Group means that we are the only Yilmaz distributor in Europe authorized to stock gearboxes in component form," says Steve Gill of Pumps and Gearboxes. "This provides great flexibility and security for the user, as it enables us to assemble gearboxes to exact customer specifications at very short notice."

The M series units are capable of single, two or three stages in one housing, so they have a high power rating, with nominal torques up to 8,547 Nm, which is produced from the smallest product envelope. The gearbox's efficiency is not compromised by the power density. Several cooling options support the units including heat exchangers, cooling coils, fan cooling and forced lubrication systems.

As monoblock units, the Yilmaz M series gearboxes are built from one-piece housings for rigidity, gear strength, operating noise levels and oil integrity. The gearbox bearings are not supported by cover plates but by the housing. Each axis is machined at the same mounting plate for precision and tight tolerances. The M series' design offers higher bearing and gear life.

Options for the Yilmaz M series gearboxes include ATEX specification, extended and hollow shafts, cooling and lubrication systems, synthetic lubricants, shrink disks, brakes, variable speed drives and IEC frame custom motors, according to the company's press release.

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Fax: +44 (0) 1924 454377
info@richardalangroup.co.uk

Bison VWDIR Line Expands,

VERDANT DUTY GEARMOTORS CONSERVE ENERGY

A right-angle AC gearmotor in six standard models is the latest product released in the Von Weise Drop-In Replacement gearmotor line from Bison Gear and Engineering Corp. The gearmotors have 1/12 hp or 62 watts dual voltage, dual frequency and single-phase permanent split capacitor electric motors.

The integral gear reducers use hardened steel worm gearing and cast iron output gears with ratios from 37:1 to 1,205:1. Fixed output speeds are from 40 to 1.5 rpm with continuous torque rating from 89 to 250 in-lbs. They are available with left, right or dual output shafts; they are reversible and have all-position foot mounting with overhung load capability of 100 lbs.

The VWDIR33 AC right-angle gearmotors are designed for commercial and industrial applications from food service equipment to welding positioners. UL and CSA recognition are standard.

"This is the 10th new Von Weise Drop-In Replacement Gearmotor we have introduced in the past three months, and there are more to come," says John Morehead, vice president, strategic planning and marketing for Bison Gear. "We're finding that OEM customers for these products are particularly interested in shortening their supply chain with dependable deliveries of a quality product. We're able to meet those requirements by manufacturing these gearmotors here in our St. Charles, Illinois facility to Bison's high quality standards to ensure reliable, long-life operation."

Bison also recently introduced the 107 series Verdant Duty gearmotors in response to customer demand for improved efficiency in equipment using fractional horsepower electric motors. They come in five standard, off-the-shelf models rated at 1.20 hp (37.3 watt) at 230 volt and 60 Hz. The three-phase gearmotors operate between 6 and 90 Hz, supplying a 15:1 range of adjustable output speeds in maintenance-free applications.

The Verdant Duty gearmotors have enclosed, non-ventilated AC motors built with insulation systems that guarantee long life if driven by compact, economic frequency inverters that convert conventional AC single-phase to three-phase power. They use integral gear reducers with gear ratios from 6.7:1 to 95.5:1 to provide output speeds from 368 to 1.7 rpm and output torques up to 100 in-lbs. They are RoHS compliant, UL, cRUus and CE certified, and Bison can customize models to meet individual OEM requirements.

"Our customers require more efficient products, and being able to utilize three-phase over single-phase fractional horsepower gearmotors provides an immediate payback in reduced energy consumption with improved efficiency," says Matt Hanson, VP, portfolio management for Bison. "These new Verdant Duty products are a wise choice for variable speed applications, such as packaging equipment, machine drives and conveyors."

For more information:
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St. Charles, IL 60174
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www.bisongear.com

ER Collet Chuck

ENHANCES RIGIDITY, REPEATABILITY

BIG Kaiser's ER collet chuck is a standard collet system using the precision tooling company's dual contact spindle system, the BIG-PLUS interface. The BIG-PLUS tool holders enhance rigidity and repeatability for higher metal removal rates, higher accuracy, improved surface finish and longer tool life, according to the company's press release. Fret corrosion is also avoided by the tool holder's ability to keep vibration to a minimum; it reduces cutter deflection, and no axial movement occurs under high-speed operation.

The ER16 and ER32 collet chucks come in BIG-PLUS CAT40 and 50 tapers, and they can supply coolant through either the spindle itself or the spindle flange. The ER16 is available in gauge lengths of 2.5, 4 and 6 inches for 40 taper as well as 3.5, 5 and 6 inch gauge lengths for 50 tapers. The ER32 chuck comes in 3, 4 and 6 inch gauge lengths for 40 taper and 3.5, 5 and 6 inch lengths for 50 tapers.

The ER series chucks come with the tool body and collet nut, and they can accept ER collets or sealed nuts from any manufacturer.

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www.bigkaiser.com

Baldor

EXPANDS WORM GEAR REDUCER LINE

The Dodge Ultra Kleen right-angle worm gear reducer line has been expanded by Baldor Electric Company. Housed in 316 stainless steel for washdown protection, the reducers come in quill and three-piece coupled input with solid or hollow output.

The units come in 17, 21, 23, 26 and 30 sizes with center distances starting at 1.75 to 3.00 inches. They feature an enclosed, ventless sealing system with factory-filled H1 food-grade synthetic lubricant, so routine oil changes are not required. A two-piece harsh-duty output sealing system with lip and wave seal protects the reducers, which are used for washdown protection or where "paint free" specification is required. Most sizes can be shipped in 24 to 48 hours.

For more information:
Baldor Electric Company
5711 R.S. Boreham, Jr. St.
Fort Smith, AR 72901
Phone: (479) 646-4711
Fax: (479) 648-5792
www.baldor.com

Heavy-Duty, Non-Toxic Coolant Biodegrades

A heavy-duty machining and grinding coolant that is biodegradable and non-toxic has been released by the International Chemical Company. International's compound 1691 uses vegetable oil with surfactants, inhibitors and bio-stable emulsifiers that produce a coolant suitable for all metals and operations. Field studies have shown 25 percent increases in productivity and tool life gains up to 50 percent. Contact the company for a free sample.

For more information:
International Chemical Company
2628-48 N. Mascher St.
Philadelphia, PA 19133
Phone: (215) 739-2313
Fax: (215) 423-7171

ONLINE

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Surface Grinder

OPERATES WITH MAXIMUM PRODUCTIVITY, MINIMUM CYCLE TIMES

The TechMaster 844, from Jones and Shipman, offers 800 mm x 400 mm grinding capacity with a vertical capacity of 360 mm. The machine is highly accurate and stiff, has both a high capacity and metal removal rate, and it is designed for toolrooms and mold-making facilities.

Jones and Shipman's software, which the TechMaster is equipped with, is a key to the machine's productivity and user-friendly features. Operators are not responsible for an input code, so training, setup and changeover times are all reduced, while productivity is maximized and cycle times minimized.

The TechMaster 844 has a rigid construction with component parts spaced out. The wheelhead, which moves vertically on Turcite coated slides, has a hardened and precision-ground spindle that rotates in angular contact. The table and saddle slideways are also coated with Turcite, hand scraped and automatically lubricated for low friction. The Y and Z axes are controlled and positioned by GE-Fanuc AC servo motors, and the table axis is powered hydraulically by a modular power pack.

A "dress on demand" feature allows straight formed wheel dressing to take place at any point in the cycle. The machine automatically returns to its last position to pick up where it left off in the dressing procedure.

For more information:

Jones & Shipman–Holroyd
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Leicester LE3 1UW, UK
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Fax: +44 (0) 116 201 3002
www.jonesshipman.com

Affordable Blohm Surface Grinder

DESIGNED FOR MODULARITY

The RedLine S surface grinder from Blohm, distributed by United Grinding, Inc., intends to merge performance and cost. The modular grinder uses cast iron components and is thermal and vibration optimized with 3D-CAD and finite-element analysis.

There are three main axes, which are driven by AC servos and ground re-circulating ball screws. Each axis has hardened and ground monorail guideways. The RedLine S has the option between two control systems jointly developed by Blohm and Siemens.

The Blohm eco operator control system is for surface grinding applications with features that make setup quick and easy and offers the choice between manual or automatic mode. The easy touch control system allows for simple operation and uses the machine's highest performance features.

A new dressing concept, adaptive dressing control or ADC, begins the dressing cycle automatically once the power consumption of the grinding spindle drive increases. This takes place when the grinding wheel is loaded and reaches a pre-determined value.

For more information:
United Grinding Inc.
510 Earl Boulevard
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Fax: 937-859-1115
www.grinding.com

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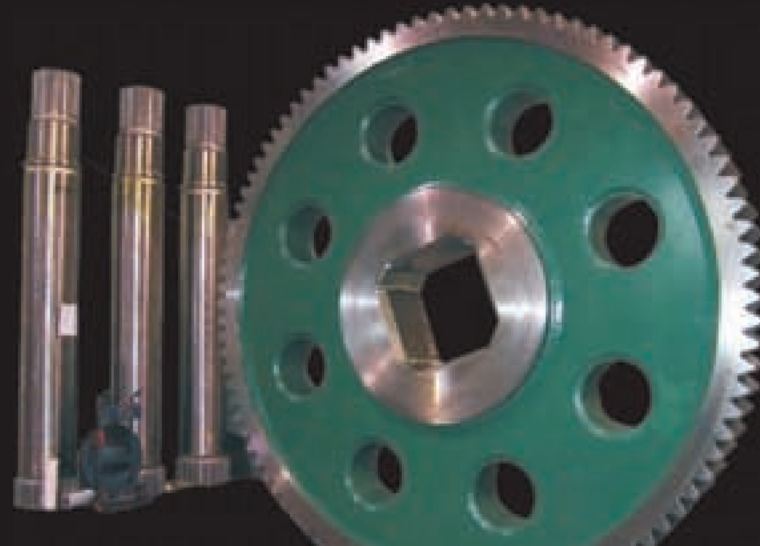

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Optimism in Wind Abounds

DESPITE ECONOMIC CHALLENGES

Lindsey Snyder, Assistant Editor

A wind turbine gearbox being moved at Hansen Transmission's Lommel, Belgium facility. Courtesy Hansen Transmissions.

Big gears and wind turbines go together like bees and honey, peas and carrots, bread and butter and—well, you get the idea. Wind isn't just big right now, it's huge. The wind industry means tremendous things for the energy-dependent world we live in and especially big things for gear manufacturers and other beleaguered American industries. Turbines represent progress, innovation, investment, capital and job opportunities—an integral part of the "green" revolution.

"In the last few years, we've seen nothing but increased growth and increased demand for more and more gears for the wind industry," says Louis Ertel, president and CEO of Overton Chicago Gear.

In 2007, 20,000 MW of new wind energy capacity was installed on a global level, which is 31 percent more than was installed in 2006, according to the *Global Wind Energy Outlook 2008*, published by the Global Wind Energy Council (GWEC). One megawatt of wind power, on average, can power 250 to 300 homes, according to the U.S. Department of Energy. The GWEC report also states that for the first time in decades, over half of the annual wind market was outside of Europe. Between 2006 and 2007 the Chinese wind market grew by 145 percent, and this is just the beginning for China.

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The United States reported 5,244 MW were installed in 2007 which is more than twice the amount installed in 2006, and overall generating capacity increased by 45 percent in 2007, according to the GWEC. The American Wind Energy Association (AWEA) says 1,389 MW were installed in the third quarter, according to the market report published for that financial period. This brings the total capacity installed in 2008 to 4,204 MW at the time of the report. AWEA expects the installed capacity to reach 7,500 MW in 2008, which is enough electricity for approximately 2.2 million homes.

Clearly the U.S. wind industry has progressed significantly over the past few years, but there is even more development being planned and executed as you read this. AWEA reports that in the United States eight wind turbine component manufacturing facilities have been opened in 2008, nine have been expanded and 19 new facilities have been announced, which translates to an estimated 9,000 new green jobs.

Brevini is one such manufacturer, announcing in October construction of a 150,000-square-foot plant to produce planetary gearboxes for wind turbines. Moventas announced plans in September for a new assembly plant in Faribault, Minnesota. "Expansion of production in North America is a significant step closer to our customers and it strengthens our ability to meet the after-sales service demands in the market," says Ilkka Hakala, CEO and president of Finland-based Moventas.

Winergy Drive Systems, one of a small handful of U.S. turbine gearbox assemblers, is in the midst of expanding with a 175,000-square-foot plant scheduled to open in March 2009. There are already plans to double the size of the new facility in the next two years. The current plant will mostly be reserved for service and parts, according to Parthiv Amin, president of Winergy. It will eventually begin producing a small portion of gears and other parts, which are currently imported from their German facilities.

Hansen Transmissions is another wind gearbox manufacturer with ambitious expansion in the works. The company recently completed a major addition to its Belgian plant in Lommel. The facility is now capable of producing gearboxes for turbines up to 6 MW. Turbines with that size capacity are currently used for offshore projects, which are the largest wind ventures existing today. "Further expansion is in progress in India and China, where we are building respective 5 and 3 MW plants," says Ivan Brems, CEO of Hansen Transmissions.

An assembled wind turbine gearbox. Courtesy Winergy Drive Systems.

Brems views Hansen's expansion as "a testimony of the strength and growth potential of the wind energy sector."

Brems expects these new projects to be the biggest challenges Hansen will face in the next year. Supply chain woes and a volatile economy don't top the list of concerns for Hansen, where business continues to grow. "We have a full order book till the end of 2009, and already a lot of orders till 2011," Brems says.

Overton Chicago Gear has also expanded recently. "We've added a 20,000-square-foot facility here in Addison (IL). We've added 10,000 square feet to our heat treat facility, and we've purchased Chicago Gear, so we've had tremendous expansion," Ertel says.

"The heat treat expansion was specifically aimed at gaining more heat treat capacity for wind," he says. "In order to make room for some larger tooth grinders, we moved all our small tooth grinders offsite to a new facility. That was all pretty much looking at the wind industry requirements."

Another indication that the wind energy market is thriving is the investment by oil companies, such as BP, which anticipated generating over 1,000 MW of zero-carbon electricity from its wind projects by the end of 2008, according to a press release. The company already has wind operations in Colorado, California and two in Texas that started commercial production in October. Currently under construction by BP is a wind farm near Wichita, Kansas and one near Indianapolis.

Many other non-energy related corporations are jumping on the wind wagon, including retailers like Wal-Mart, which announced in November that it is purchasing wind power capable of supplying 15 percent of the total energy used by 360 Texas stores and other Wal-Mart facilities. JCPenney recently announced a pilot program to install wind turbines at a distribution center in Reno, Nevada.

"While there was a market for wind turbines a decade ago, there is no comparison to the market we have today," says Lyle Nuhring, vice president of sales and marketing for Columbia Gear Corp, which supplies gears to the wind industry.

The Economic Specter Looms Large

The general consensus in regards to the economy is that the wind industry, while not immune, is uniquely poised to ride the recession out more successfully than other industries, due largely to the current social and political climate.

"Despite adverse economic conditions nationwide, investors view wind as a sound strategic investment, and prospects for long-term growth in the wind energy industry continue to be bright," says Randall Swisher, executive director of AWEA.

"The convenient truth here is that wind power provides a stimulus for our economy, as well as a climate change and energy security solution," Swisher says. "The market, in spite of all its turmoil, clearly points to wind power as one of the most attractive energy options available today."

According to Brent Reardon, chair of AGMA's wind turbine gear committee and manager of the turbine group at wind energy consulting firm Garrad Hassan, the wind industry is "a little more insulated from the downturn in the market.

"The financial markets as a whole are a concern, but there is a lot of interest in green and alternative energies," he says.

"We've seen slowdown in the general market, but not significantly."

Reardon projects tremendous growth for the future.

"This is a very strong market," affirms Winergy's Amin.

He expects the current economic conditions to impact business at Winergy starting the second quarter of 2009. He believes the rate of growth will remain high for the long term; although, for now he foresees slower growth. For 2011 and beyond, he predicts a 30-40 percent growth per year.

Regardless of the success many in the wind industry are experiencing, the global financial crisis remains a threat to business in the near future. "The credit crunch has affected the timing of certain programs. There is a certain softness in the demand side of the gear business that hasn't been there for awhile," says Chuck Schultz, gear industry veteran, founder of consulting firm Beyta Gear Service and technical editor for *Gear Technology*.

Hoisting a drivetrain up to its nacelle home. Courtesy Paul Anderson.

Ertel considers financial turmoil as the biggest challenge facing the wind industry as a whole because there are many projects in various stages of development.

For Columbia Gear Corp., the biggest challenge to overcome in the next year will be "reacting quickly to how current economic issues and the new administration's programs will affect the market," Nuhring says.

Schultz believes there is a cautious optimism coming from gear manufacturers involved in the wind industry. "We were just starting to get some of the supply issues worked out, and now this uncertainty comes in, so we kind of have to hope that

continued

the momentum will stay there towards solving the problems," he says. "Everyone involved in the industry I think believes that this is only a temporary speed bump.

"I think by May or June we'll have the credit crunch fairly under control, and it will start building up again," he predicts.

Supply Chain

The supply chain and a new element of doubt is at hand due to the economy. In particular, a shortage in steel supply and significant demand has been an obstacle; however, the ongoing economic and automotive crises have caused a considerable drop in steel demand just in the past few months. According to the American Iron and Steel Institute (AISI), U.S. steel shipments dropped 6.8 percent from the correlating 2007 figure.

Reardon believes steel costs may continue coming down in the near future, which will serve to free up the supply chain.

"Material was an issue in the past," Ertel says. "But I think that situation has improved dramatically, and I don't see material as being an issue anymore."

When asked why, he says, "Because they've qualified some domestic suppliers, and steel is being purchased domestically as opposed to all of it coming from overseas."

Nuhring notes, "Raw material deliveries for gears have improved. However, the availability of other components has indirectly affected the rate at which our customers' gearboxes can be assembled and therefore have affected our schedules."

Nuhring believes it's too early to tell if current economic conditions will change this in the near future.

For Winergy, Amin says, "An overall challenge is the growing supply chain at the quality we need.

"Demand with steel is huge, but also the quality and type of steel."

Quality is the biggest concern at Winergy because most steel mills don't require the degree of chemistry and purity in material that is necessary for wind projects, according to Amin. He also says Winergy, like most companies, deals with bearing limitations. Winergy started an initiative about two years ago to grow their supply chain by pursuing potential suppliers and educating them about the wind market's growth and viability. "It took awhile to get to the right management people," he says, but "now they're enjoying [the benefits of] the market."

A regional wind power supply chain workshop sharing a similar purpose was recently cosponsored by the Jane Addams Resource Corporation (JARC), a not-for-profit Illinois community development organization that provides technical training to metalworking trades.

"We are optimistic about the potential wind power has to add to the customer base of the companies we serve and to create manufacturing jobs here in Illinois. We believe that supply chain development is the most effective response," according to the JARC website. "Through identification of original equipment manufacturers (OEMs), first-tier suppliers, and the regional suppliers able to meet their needs, we intend to match supply to demand and bring business to the region."

Schultz attended the October seminar and says, "A lot of states are trying to do some really interesting things with this."

Iowa and Colorado are just two states actively recruiting wind-related businesses to set up shop within their borders. For those with supply chain issues, "People would be well advised to contact their local economic development officials and see what kind of help they can get," Schultz says.

Ushering in the Next Generation of Turbine Technology

New trends in turbine technology seem focused on bigger and lighter. In part, this caters to the offshore wind market, which is predominantly a European market so far. Offshore turbines require more size because they are fixed to the seabed and must optimize foundations. Technology for offshore wind turbines is currently being deployed with 6 MW capacities, and manufacturers will continue to cater to these larger-size needs.

Most turbines on land average a 1.5 to 3 MW capacity, and many designers don't expect this to change greatly in the near future, primarily because of transportation challenges that are already a significant issue when dealing with such large infrastructure, according to the U.S. Department of Energy in its "20 Percent Wind Energy by 2030" report. The new report evaluates and asserts that the United States can viably generate 20 percent of its energy from wind resources by 2030.

There are different predictions for what technological innovations will impact the industry. Gearbox failure is one of the biggest concerns with drivetrain development due in part to steep repair costs. There are various methods being used to minimize gearbox failure.

"One technology some people are using has to do with some sort of device to decouple, like slip-clutch. From an electrical standpoint, people are using different means to vary the speed and power going through the generator," says Andy Milburn, president of Milburn Engineering. "One of the big problems with the failures of gearboxes in wind turbines is that the load is so variable. They get a lot of turbulence in wind gusts. The blade tries to speed up and the generator is basically connected to the grid, and it wants to stay one speed, and so the gearbox takes all the abuse between the blade and generator."

One way to do away with gear losses resides in the direct drive solution. Although gearless, this is a trend gear makers may want to keep their eyes on. "Improved direct drive wind turbines are in the design/test stages," according to Nuhring.

Ertel believes direct drive technology is more of a trend in Europe and not a big concern for American manufacturers at the moment.

Amin expects to see changes in gear configurations, manufacturing methods, tolerance and heat treating. As a trend, he says, "[there is] a lot of drive to reduce weight in all components."

Courtesy of Hansen Transmisssions.

Schultz says, "I think you're going to see more use of the superfinishing technologies, and it may move into larger components than it has before. [Superfinishing] helps with lubrication problems. As the parts get bigger the process is more complicated."

Setting the Standards

In the world of wind turbine gearing, standards play an important role, as industry players indicate.

"[Gear standards] create a uniform reference point and contribute to making products more reliable," Hansen's Brems explains.

"Standards provide guidance for gear manufacturers, other manufacturers and consumers on expectations of wind turbine gearboxes," Reardon says. "They help provide a level playing field."

According to Schultz, "Standards have made a tremendous difference. AGMA/AWEA 6006 is probably the best gearbox standard ever written on any subject, but it is specifically about wind energy. And the feeling is that in the five years since it was originally adopted, machines designed using that standard have been much better performers than those that were designed before that. Anybody that wants to do anything in wind gearing probably needs to memorize that standard."

AGMA 6006 was the first original gear standard developed specifically for wind energy. The Wind Turbine Gear Committee, a joint effort between AGMA and AWEA, meets two to three times a year in different locations.

The standard was adopted by ISO—known as ISO 81400-4—about three or four years ago, according to Charlie Fisher, AGMA technical division vice president and staff liaison to the committee. "The standards on the street now, AGMA 6006 or the ISO equivalent, are the documents being cited in customer specifications and, just as importantly, by the certification bodies," he says.

As an international standard now, representatives from all the different countries involved meet as a joint working group to write comments on what is primarily a working draft. "We met in Tokyo this summer to try to resolve all

continued

those comments," says Milburn, a member of the committee. "We only got about a third of the comments resolved. This next meeting we'll continue trying to resolve more of these comments."

For the upcoming meeting, Reardon says, "We're hoping to get through the rest of the comments submitted. We expect to have another working draft to go to the committee."

Some hot topics of discussion for the joint working group include updates on manufacturing technology, gear rating practices, bearing selection, calculations of bearings life and the criteria for them as well as the practices people use to rate or size the bearings used in drives.

"All these major topics are talked about at nearly every one of these meetings, with specific concentration on the bearing issues—bearing selection and bearing life calculations," Fischer says. "But they continue to develop the other sections of the standard, dealing with lubrication and rating and operation and maintenance and structural design and the like. They're touching on all the different aspects of the standard."

There are also some new parts to the working draft that weren't part of the current standard. "There's a lot more information on loads, and there's a lot of information on housings and other components," Milburn says.

Bearings seem to be the main area of disagreement. "They have historically been a source of failure in the wind industry," Reardon explains. "The biggest challenge is reconciling expectations for bearings."

Workers constructing a wind turbine in Didima, Greece. Courtesy Vestas.

Reardon cites a wide variety of opinions concerning this issue.

"The main area that is causing most of the disagreement at this point is bearings ratings," Milburn reinforces. "There's no agreement on how people should be calculating bearing life. One of the reasons is because bearings have been such a big problem. Certain groups want to keep doing what has been done in the past. Then there are others that say 'If we're having problems, why would we want to keep doing the same as we did before?'"

Milburn explains the U.S. position on the issue. "What we've been trying to do in the United States is reduce the life from L10 to, say, L3, which means we're going to run these same hundred bearings, and we want only three of them to fail, not ten. But to do that, you have to either reduce the loads or increase the bearing size. So far, the U.S. position has been shot down. Right now we're in the minority."

The committee members seem optimistic and focused on future plans, which include "moving the standard along and coming to compromise agreements between all the international delegations on all the technical issues that they continue to address," Fischer says.

Legislation

According to "Wind Energy for a New Era: an Agenda for the New President and Congress," a report published by AWEA, "With the right policies in place, wind power can make a major contribution to the effort to protect the planet's climate, while spurring tens of billions of dollars in economic investment, supporting hundreds of thousands of new American jobs, making America more independent and secure, and saving consumers more than $100 billion."

AWEA's report, which can be found at *www.awea.org*, details several areas where the federal government can help promote wind energy. The report reflects other views in the industry that the federal government should be doing its part to promote the wind industry.

"Federal policies have an important effect on the wind industry at large," Hansen's Brems says. "Driven by the growing need for energy, the concern for the environment and the need for security of energy supplies, we expect increased support from governments all over the world for wind energy."

Amin believes that many in the industry are "waiting for clarity," in legislative form.

He believes federal legislation will provide end-users incentive and a long-term sustainable vision for the industry. He and others seem to have high hopes for this with the new administration and Congress. Amin is "looking forward to a lot that is going to affect business positively," and he hopes the new administration "will set the record straight."

There are several ways the U.S. government could foster wind industry growth through legislation. The wind production tax credit, which was eventually extended for the usual one-year allotment, could be made long term; AWEA

continued

recommends a minimum five-year extension. Known as the PTC, the tax incentive has been criticized for its year-to-year uncertainty as causing the industry to stagnate. In years that the PTC was not extended, a significant drop in additional installed capacity occurred—a 93 percent drop in 2000, 73 percent in 2002 and 77 percent in 2004, according to AWEA. "When they're dragging their feet passing the PTC, what happens is the industry drops off dramatically," Ertel says. "The last three or four years, when they've been able to pass the PTC, even though it's been on a year-to-year basis, we've seen dramatic growth in the industry.

"I think federal policy has a dramatic effect on what's going on in the wind industry."

Wind farms require long-term investment, and with only a yearlong tax credit that is applicable to completed projects, there is not much left for planning beyond a year's time. "It gives a long-term view to investors," Amin says of federal policy.

A national renewable electricity standard (RES) or renewable portfolio standard is another legislative action that would foster growth in wind development. Each state would be mandated to acquire a minimum percentage of power from renewable sources. So far, 28 states have enacted such a law, but enacting an RES at the federal level would broaden its effects to span the country.

Another measure stemming from the federal government includes stricter climate change legislation, which should involve a cap-and-trade system. This policy sets a limit on greenhouse gas emissions by companies, or, in the case of companies that are not successful in doing so, requires them to buy "carbon permits" from those that earn them by reducing emissions below the required limit. Revenue generated would go to financing renewable projects and providing further incentives to manufacturers.

Other policies include increasing federal R&D for renewable energies and funding individual projects, including a large-scale expansion of transmission lines. The state of the current transmission system remains a major impediment to developing wind as a viable alternative energy source.

"The industry is transmission constrained," says John Dunlop, senior technical services engineer for AWEA. "And we (AWEA) have had some very aggressive, but very doable and responsible, suggestions for establishing an electron superhighway across America. It's basically a transmission system that would overlay the existing transmission system. That would allow for a long distance transport of electricity that we can't currently do."

The U.S. Department of Energy estimates the cost of this proposed network to stand at $60 or 70 billion, Dunlop says, but "Relative to the trillion dollars that frees up, it is a relatively insignificant number."

The European Union recently endorsed an ambitious climate and energy package with emphasis on wind, and there is every indication that the United States will follow

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suit. So far, every energy and environmental measure taken by the president-elect indicates a much stronger support for alternative energies than ever before in the United States.

"Federal programs promoting renewable energy will increase the demand for wind turbines and therefore have a positive effect on our business," Nuhring says. "At this time, it appears the new administration will promote renewables."

Is it too late to reap the benefits?

While Amin and others encourage suppliers to take advantage of the opportunity the wind industry has to offer, it begs the question: Is it too late in the game for gear manufacturers to get involved in the wind industry?

"Those companies that do not have the ability to manufacture the type/size of gears used in wind turbines will need to make significant investments to enter the market—it's something they need to evaluate," Nuhring says.

Challenges seem to be more of a subject for non-wind gear companies than those involved in the wind industry.

"I think the machinery required to get into it, either from a heat treating standpoint or a gear manufacturing standpoint, that equipment is probably a year and a half to two years away if you tried to order it today," Ertel says. "And for people who aren't involved in high-accuracy, high-quality gearing, I think that is the other challenge. The wind business is all serial production, so it's not easy gearing to manufacture."

Brems echoes this view. "The entry barriers are enormous; for any new entrant it will be a very time- and cost-consuming experience to get a place amongst the established and experienced wind turbine gearbox suppliers."

But gear manufacturers interested in testing the wind waters at this point need not be completely dispelled by long machinery lead times. It's hardly a universal opinion that the challenges render entrance into the wind market impossible. "I don't think it's too late to be involved," Schultz says. Although, "it maybe be too late to be involved in the main drive components."

Amin says, "It's not too late yet."

But he does anticipate the window of opportunity narrowing, and it may be too late in a few more years.

One thing is for sure. With all elements combined, the wind industry is here to stay—in a big way.

A worker prepares the drivetrain for installation. Courtesy Paul Anderson.

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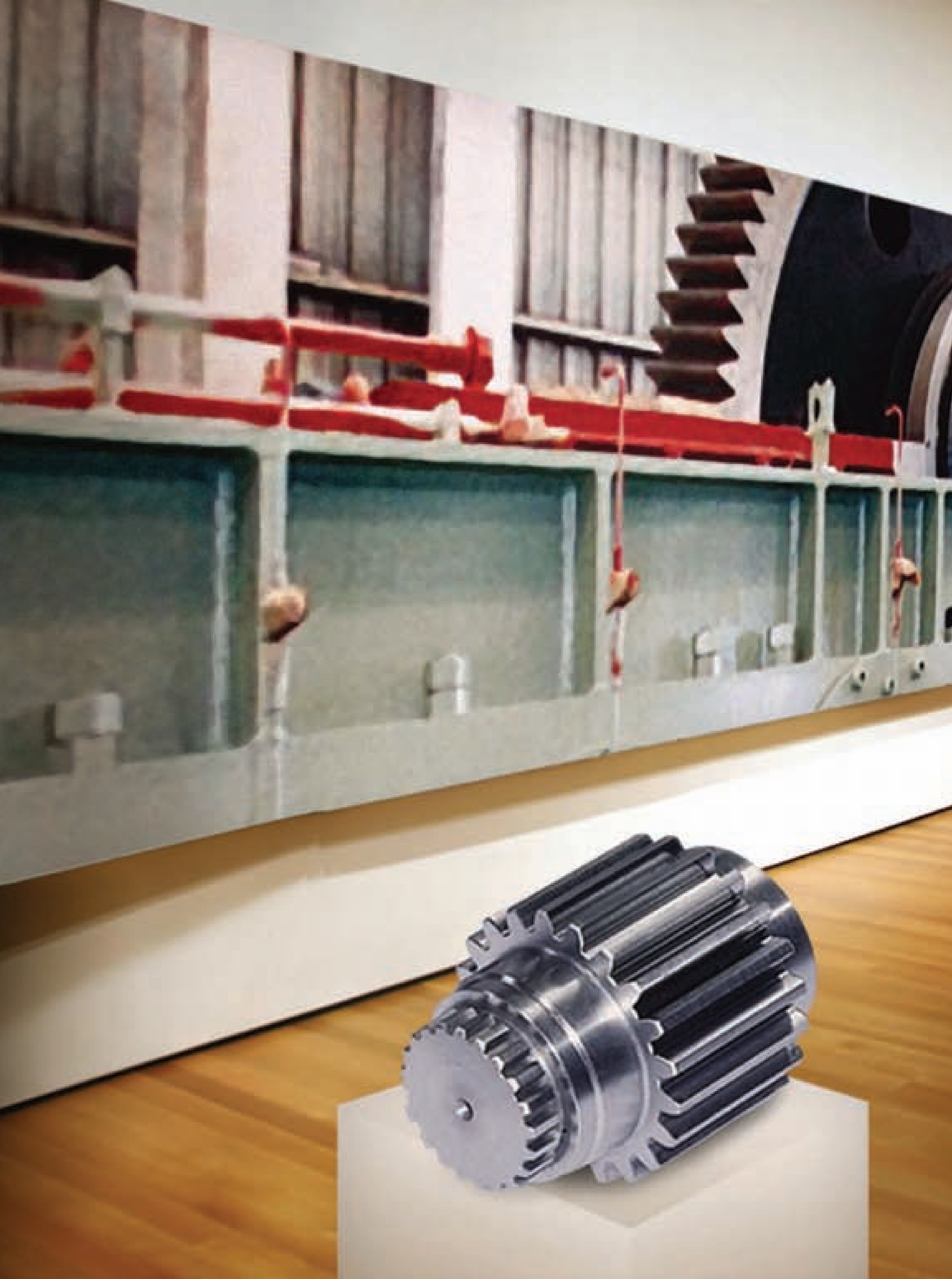

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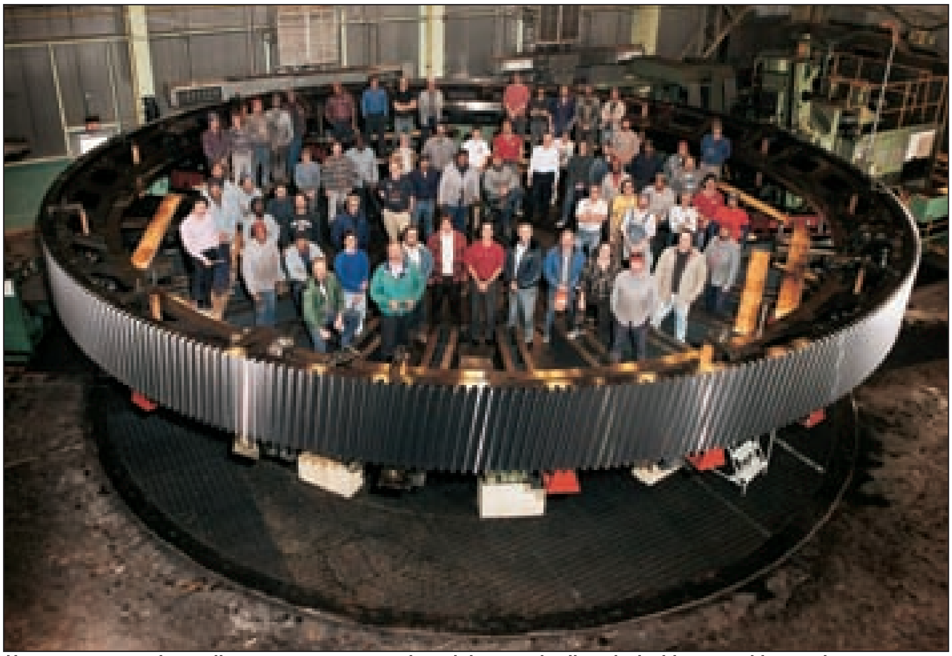
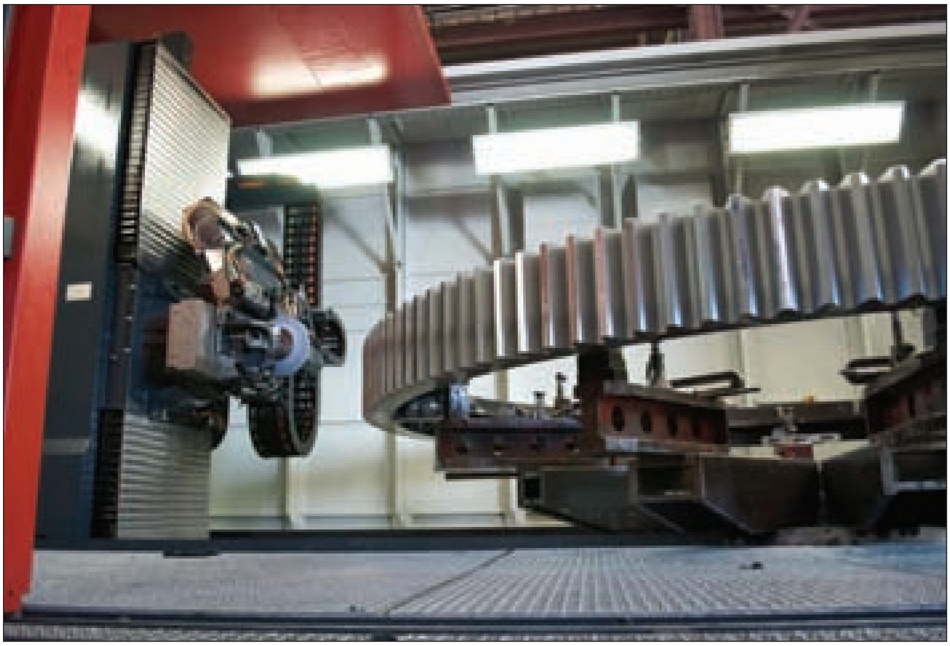


Huge gears such as these are common in mining and other industries requiring extreme power. Photo/Rexnord.



Photo/HMC.

Natural resources—minerals, coal, oil, agricultural products, etc.—are the blessings that Mother Earth confers upon the nations of the world. But it takes unnaturally large gears to extract them. Whether it's draglines and conveyors for the mining industry, or roughing stands and finishing stands for steel production, the equipment used in these endeavors all employ very large gears.

But what, exactly, constitutes a big gear? It depends which manufacturer you're talking to. For some shops, a 60-inch diameter gear would be considered large. For others, gears seven feet and more in diameter are common. But one thing that all of these companies would agree on is that it is a very good time to be in the big gear market.

"Right now, I can make this statement with high confidence—I have got probably an 18-month backlog," says Nick Sudzum, general manager and chief operating officer of B&R Machine and Gear, in Sharon, Tennessee.

At Vancouver Gear Works, in Richmond, British Columbia—same story.

"Right now is a very good time with what's going on in mining," says Jim Mantei, general manager. "We've never been as good as we are right now, and as far as we see, it's all going to continue well into next year. Being a jobbing-related shop traditionally, we don't usually see business much more than a month or two out, and we're six months into next year."

And at Princeton, Indiana's HMC and Milwaukee's Falk-Rexnord, there's more of the same—up to a point.

"I think it's about as strong as I've ever seen it," says HMC's John Schnarr, sales manager.

"We had a great run here with metals like copper and also gold going from $400 to $800 an ounce," says Craig Danecki, vice president, global gearing for Rexnord. "Iron ore took off like crazy, and we had a real good run on all that. But back in September-October we began to see a softening in those areas. Most people we talked with didn't think (the slowdown) was going to be anything significant or long term, but now people are questioning that, and there's the bank issues. People being able to get access to cash for all these big projects—you're talking about some pretty big capital investments."

Aside from any slowdown in mining, the only drawback in all of this prosperity has more to do with the availability of material and the large machines needed to produce, test and inspect outsized gearing. Given that lead times for machines and materials can be more than a year, a start-up company entering the large gear market would

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probably need years, not months—and a lot of money—to get up and running.

"I wish I had another couple large machines, but there's none on the market," says Sudzum. "If you buy a new machine, you're looking at three to four years delivery. That's my understanding, anyway. There are a couple companies out there retrofitting older pieces of equipment with CNC controls and such—I just don't believe in that. It's like Gleason Works designed a machine, and now here comes along a guy who's going to put controllers on it, doing away with the gear trains and such. I don't know the longevity of them. The factory didn't build them that way, and here we're going to put this servo motor in to replace the entire gear train. Essentially, I don't think the machine is going to last as long as it would if you kept it all original."

The most consistent bottleneck in the supply chain is bearings. Whether for a behemoth wind turbine or mill equipment for processing sugar cane, the bearings needed for that equipment are in short supply. Indeed, a central reason for the long lead times on new machines is that they, too, require high-quality bearings. In short, if the bearings specified for a certain design are out of stock, waits of a year or longer are not uncommon.

"Some of our machines—CNCs, hobbers, grinders—they use large bearings, and a lot of times the lead time for the machines is pushed back purely based on the availability of bearings," says John Belton, business and development manager at Vancouver. "Typically, bearings have the longest lead time on any project.

"I think it's because they're building bigger machines now; they're running faster, and so, things have become more sophisticated. They have to, quite possibly, build new machines to build the bearings."

"Bearings have been the biggest issue," agrees Cal Tanck, Rexnord marketing manager. "(A certain bearings supplier) has been the poorest regarding their commitment dates, and it hurts us especially when it's a week or two before the order and we're getting ready to box it up and we're just waiting for the bearings and—bang—it's another three months."

And although Rexnord is not in the wind turbine market—they prefer to concentrate on their industrial customers—Danecki believes that the booming market is in part to blame for the bearings shortage and, to some extent, steel as well.

"There was a pretty significant impact on all of this from the wind


Photo/Vancouver Gear Works.

market," he says. "The wind market really bit into capacity out there."

B&R Gear and HMC are two other gear manufacturers that have opted out of the wind turbine market and concentrated on what they do best.

"We would enter that market, but right now it's saturated with manufacturers trying to get in it, and it's very, very competitive," says B&R's Sudzum. "But we're seeing that it has loosened up some in the jobbing area. Several shops have become nothing but wind power, and that's opened up the market for shops like ourselves to be introduced to people that we've never done business with before in general replacement gearing."

But when it comes to steel availability, much depends on which steel has been specified by the design engineer. And that has been a problem of sorts for a company like Vancouver Gear, which uses both foreign and domestic steel in its large gears.

"What we're finding is that a lot of these gear box designs are coming from Europe, so they've used materials readily available in Europe, and we don't have those available to us in North America," says Mantei. "We work with their engineers to see if there's a material that's close enough that we can use, maybe a 40 C 40 or a 40 C 20, etc. In some cases they say no, all their engineering has been based on these specific materials, so we then have to source those materials from Europe."

Conversely, steel is not a problem for B&R Gear. That's because they use only U.S.-manufactured material. "In fact, a lot of our customers insist on—and we don't stock—anything but U.S.-manufactured, U.S.-certified, SAE grades," says Sudzum.

Ditto for Rexnord. They in fact have their own steel alloy foundry, where they produce much of the steel for their ring gears.

Aside from the exorbitant cost of the machinery needed to produce big gears, heat treating is another component of the equation. Many companies making big gears do their own, and in fact—like Rexnord and Vancouver Gear—do commercial heat treating as well in order to defray costs and provide capital for reinvestment. HMC,

continued

Large gears also require large pinions. Photo/Vancouver Gear Works.

on the other hand, chooses to outsource heat treating. HMC's Schnarr gives an example that illustrates the complexity of heat treating big gears, and perhaps a reason why some companies choose to outsource rather than own the process.

"Essentially, the biggest challenge you have with heat treating large gears is distortion that's inherent with heating large masses of steel," he says. "And that calculation, a certain amount can be anticipated and expected, but there are always surprises. So what you end up doing is roughing a gear to a specific size and then, depending upon the depth of the heat treating, you have to allow—because you're going to bring that gear back—for the fact that you're going to finish cut it or grind it.

"So if you want to end up, say, with an eighth, and you anticipate that you're going to have another eighth of distortion, you have to go in and say, 'OK, we want a depth of a quarter because we anticipate an eighth of an inch distortion, which we're going to have to clean up when we bring (the gear) back."

If there is one trend in the big-gear industry that stands out in our conversation with these four companies, it is the higher AGMA/quality standards that customers are insisting upon. And it's a trend that has not been seen before in the industry. Designer-specified AGMA standards of 12 to 15 are common and have been a bit of a game-changer for many companies.

"The biggest difference for us is that the quality level has increased substantially," says Vancouver's Mantei. "Today the requirements are up there at AGMA 14 and 15 levels for wind generation, and with that, it's one thing to claim (high AGMA standards); it's another thing to back it up. The new machines come with onboard inspection and the new-generation machines can certainly hit those levels relatively easily—certainly much easier than the old machines. With the old machines, we were lucky if we could produce a quality 11 or 12. Today, we're able to do 14-15 much easier than we could produce a 12 in the past."

And because Vancouver is a player in the wind generation industry, the quality challenges are even more daunting.

"It's not just the quality level, but the actual gear geometry of the gears for the wind industry," says Vancouver's Delton. "We've seen some double-helical gears where they have different helix angles. It's quite challenging."

"We are seeing higher AGMA requirements," agrees Schnarr, "and that's where we've focused our capabilities on in being able to provide the absolute highest quality on large gears. It comes down to value. When you run the calculations, higher AGMA standards mean better service and accuracy, and extended life of the product."

Says Danecki, echoing that sentiment, "Our markets aren't interested in product that they have to replace in three to five years," he says. "They're

continued

expecting our products to last 10, 15, 20 years, depending on the product."

And at B&R, "Everybody is looking for a higher-quality gear size—AGMA 11 and 12—which is customer driven," says Sudzum. "Engineers are sitting down at computers and crunching numbers and so forth, and they're deciding that a smooth finish—the fillet being a nice mirror finish blended into the root, so on and so forth—means that their longevity and strength factors increase."

And speaking of trends, Sudzum addresses another one affecting his company.

"I am seeing less and less large corporations keeping spare parts in their storage departments," he says. "They'd rather wait for that breakdown situation to happen and pay more money for somebody to produce that set of gears in a timely fashion, as opposed to putting the money out now and putting (the parts) on their shelf for five years.

"I'm old-school; I'd rather have the parts on my shelf. If I make one set of gears for, let's say, a Model 26 Gleason, I'm going to make five sets because I've got seven machines. It's easier for me to do that. Eventually, I know we're going to use it—it might be 10 years from now, it might not be in my lifetime—but somebody will use them."

Revisiting the supply chain issue, other components common to big gearing that are in short supply are castings and forgings. Depending on the shop, some use relatively few while companies like Rexnord use quite a lot. It basically depends upon application and manufacturing requirements. The lack of their ready availability can be a problem if you don't plan ahead.

"Sometimes the forgings become a problem," says Mantei. "For some of our repeat business, we know what it is, and we have some forgings on-hand. So we're able to turn around a five-, six-foot-span gear in about three to four weeks."

"There are real difficulties still in getting castings," says Schnarr. "There's limited sourcing for large castings in North America—about a year lead time—they're backlogged. Sometimes they have problems doing their patterns and initial pours, and they end up scrapping and starting over. We're inclined to use more forge-fabricated than designs that have castings. But some still call for that." Because Rexnord uses a good deal of forgings, their wait time is not as extreme, as they have preferred suppliers who fill the demand.

"We deal with four to five forge shops, and we move that around quite a bit," says Danecki.

As for B&R, "Some of the larger gears, you pretty much have to have a casting made for it because the original was a cast form," says Sudzum. "If we can't make just a ring gear, and it's made integral through the hub, then a casting is required. Casting lead times I have found—even for a quote—for a pattern charge and a casting, sometimes we'll send it out to four or five different casting facilities, and we're looking

continued

at seven-eight weeks just to get a response."

And to what does Sudzum attribute the long wait?

"The old-time pattern makers? They don't exist anymore."

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Heat treating is a crucial component in the manufacture of large gears and pinions. Photo/Rexnord.

The Capacity of Superfinished Vehicle Components to Increase Fuel Economy

Part I

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Management Summary

The lubricant industry is emphasizing the use of low-viscosity lubricants to increase fuel economy. Fuel mileage increases as high as 8% are claimed when conventional engine and driveline lubricants are replaced with new-generation products. Low viscosity lubricants, however, must contain more robust anti-wear and extreme pressure additives to counteract their reduced λ ratio. Consequently, switching to lower viscosity lubricants in order to gain fuel economy entails risk. Should the additive package fail to perform, engine, transmission and drivetrain components will be seriously damaged.

It seems appropriate, then, to attempt to increase the λ ratio for low-viscosity lubricants. This, of course, can be done by reducing surface roughness. Superfinishing the surface using chemically accelerated vibratory finishing is a practical and well proven approach for accomplishing this. This paper will present data from both laboratory and field testing demonstrating that superfinished components exhibit lower friction, operating temperature, wear and/or higher horsepower, all of which translate directly into increased fuel economy.

Introduction

Engineers are exploring many different opportunities for increasing fuel efficiency of gas- and diesel-powered vehicles. One area of particular interest is the reduction of frictional losses, often referred to as parasitic friction. Fuel efficiency increases as more energy becomes available to propel the vehicle and less energy is wasted on frictional losses. Currently, less than 15% of fuel energy is converted to useful energy that either propels a car down the road or powers its accessories. The lubrication industry has made great strides in developing low-viscosity lubricants to improve fuel efficiency. Replacing the engine oil alone has increased fuel efficiency by 1 to 5% for passenger cars and 4 to 8% for heavy-duty trucks. The higher value was for a Class 8 truck in which not only the engine oil but also transmission and drive axle lubrication were replaced. Figure 1 clearly illustrates that even a 1% increase in fuel savings will have a significant effect not only on the American economy but also on vehicle pollutants.

A typical engine lubricant is composed of 75% to 95% base oil, with the rest being additives. The additives package is a complex blend of chemicals: friction modifiers, anti-wear agents, extreme pressure additives, corrosion inhibitors, antioxidants, detergents, dispersants, anti-foam additives and viscosity modifiers (Ref. 2). The additives must be chemically compatible with each other as well as with the base oil. Their protective properties must perform under a wide range of operating parameters, and at the same time have little negative impact on the performance of the catalytic converter (Ref. 3). Many traditional additives contain zinc, sulfur, boron and phosphorous, but since some of these elements can lower the performance of the catalytic converter, there is constant regulatory pressure to lower their concentrations. It is important to recognize that additives can also have adverse effects on the system. For example, it has been proposed that anti-wear additives actually penetrate the surface of the metal, causing a reduction in nanohardness, and that extreme pressure additives can form corrosive chemicals that hasten the onset of corrosion and micropitting (Ref. 4). Although higher viscosity grades of oil provide sufficient wear protection, they also produce higher frictional losses. Lowering viscosity will reduce frictional losses, but unless the additive package is optimized, the product may fail to provide adequate protection because the lubricating film is a good deal thinner. Moreover, most traditional additives are classified as hazardous and may worsen the growing global pollution problem.

Lowering lubrication viscosity must be done with care to avoid inadvertently increasing equipment wear as a result of increased, premature micropitting and/or scuffing. A thinner lubricating film, for example, may exacerbate micropitting. Since the phenomenon of micropitting is tied to fatigue, it may not reveal itself until much later in the vehicle's duty cycle. It is conceivable that the vehicle will exhibit increased fuel efficiency in an EPA test cycle, but this could come at the expense of major mechanical overhauls further down the road. For this reason, concocting the ideal package of additives is a balancing act for the lubricant formulator.

It is possible, however, to reduce viscosity while simultaneously maintaining or even increasing the λ ratio. One way to accomplish this is to employ chemically-accelerated vibratory finishing on the working surfaces of gears, shafts and bearings. This superfinishing technique can partially or completely remove peak and valley asperities. Chemically accelerated vibratory finishing, (referred to in this paper as "superfinishing") has been commercially used for more than 20 years to improve the performance of working surfaces. It is important to remember that this process not only creates a planarized surface, but also removes distressed metal left over from machining, grinding and/or heat treatment processes.

Superfinishing is performed in vibratory finishing bowls or tubs in two separate steps: a refinement step and a burnishing step. In the refinement step, proprietary active chemistry is used in the vibratory machine in conjunction with high-density, non-abrasive ceramic media. When introduced into the machine, this active chemistry produces a stable, soft conversion coating on the surface of the metal part being processed. The rubbing motion across the part developed by the machine and media effectively wipes the conversion coating off the "peaks" of the part's surfaces, but leaves the "valleys" untouched. (No finishing occurs where media is unable to contact or rub.) The conversion coating is continually reformed and rubbed off during this stage, producing a surface-smoothing mechanism. This process is continued in the vibratory machine until the surfaces of the part are free of asperities. In the burnishing step, the active chemistry is rinsed from the machine with a neutral soap. The conversion coating is rubbed off the part one final time to produce the superfinished surface. In this final step, no metal is removed.

By reviewing the images in Figure 2, it is easy to see how this superfinishing process produces a highly desirable surface with regards to improving the performance of working surfaces like those found on gears and bearings. The starting surface of gears or bearings are machined and/or ground, resulting in a starting surface that has peak and valley asperities as well

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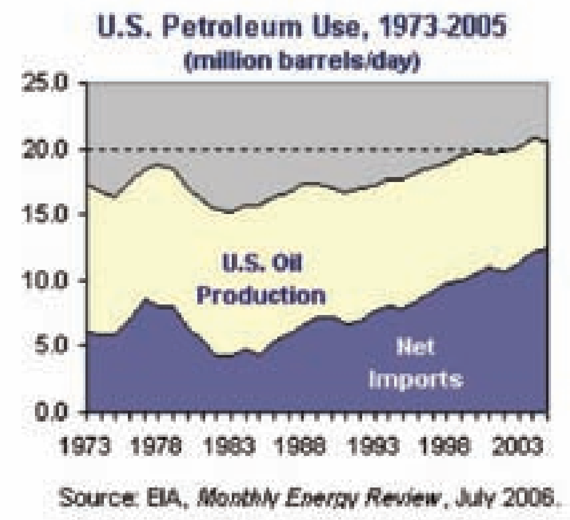


Figure 1—Graph showing U.S. oil use from 1973 to 1975 (Ref. 1).

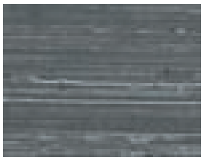
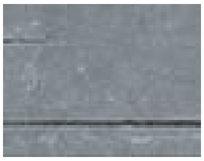
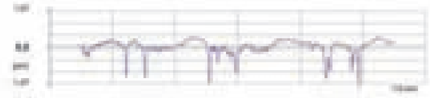
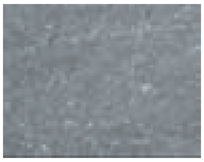
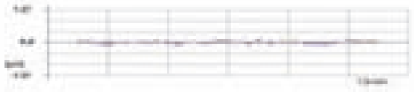
Performance	Surface at 500X Magnification	Roughness Average
Worst **Starting Condition:** Ground surface having peak and valley asperities along with a distressed layer of metal at the surface.		R_a: 0.58 μm R_z: 3.5 μm
		
Good **Stage 1:** Partially superfinished surface where the peak asperities have been planarized.		R_a: 0.30 μm R_z: 2.0 μm
		
Better **Stage 2:** Superfinished where only a few valley asperities remain on the surface.		R_a: 0.13 μm R_z: 1.1 μm
		
Best **Final Condition:** Superfinished surface with all asperities removed while displaying the beneficial and inherent micro-texture.		R_a: 0.025 μm R_z: 0.17 μm
		

Figure 2—SEM images at 500X and profilometer traces of the surface condition of a ground or machined gear or bearing as it progresses through the superfinishing process.

as a distressed surface layer. In stage 1 of the superfinishing process, the peak asperities are planarized, resulting in a surface that has significantly improved performance properties since no asperities are present to penetrate the lubricating film. As the superfinishing process is continued, as shown in stage 2, the valleys begin to disappear. As the superfinishing process advances further, the final condition is attained. This is the optimum surface since all peaks and valleys have been removed along with the distressed surface layer, leaving a micro-textured isotropic surface that facilitates lubrication. The rationale for the above was discussed in several other publications. The Vehicle Bloc at the Gear Research Institute at Pennsylvania State University tested rolling sliding contact-fatigue specimens that were superfinished to conditions similar to that shown in Figure 3 (Ref. 5). The best performance was achieved with a smooth (< 0.1 μm Ra) and textured surface. In another study, a smooth (< 0.1 μm Ra) and non-textured surface was evaluated for scuffing resistance. Although the non-textured surface significantly outperformed the ground baseline specimens, it fell short of the performance achieved by a smooth (< 0.1 μm Ra) and textured surface (Ref. 6). Bell Helicopter Textron recently questioned if the superfinished surface was actually excessively smooth in a way that hinders adequate lubrication. They concluded that the superfinished surface increased the λ ratio such that the gear performed well despite operating under extreme temperature and load conditions (Ref. 7).

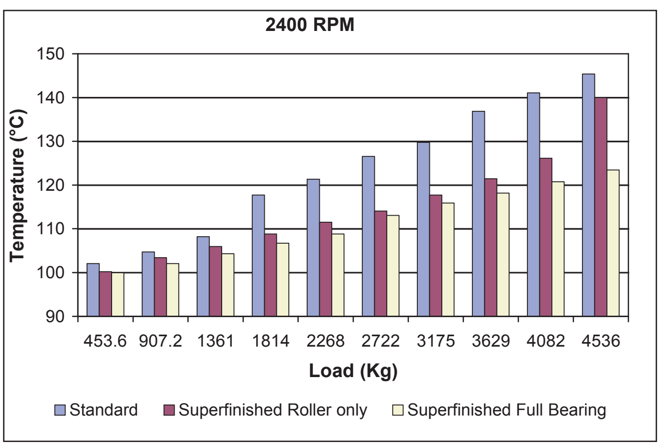


Figure 3—Temperature versus load for superfinished and standard spherical roller bearings.

Figure 4—SEM image of the superfinished surface at approximately 500X, showing isotropic micro-texturing.

Chemically accelerated vibratory finishing is currently being used by major companies in the automotive racing, aerospace, heavy-axle and wind turbine industries. In each case, superfinishing was adopted only after a tremendous amount of forethought as well as extensive laboratory and field testing (Refs. 8–14). Unfortunately, much of this data is proprietary and confidential.

This paper will present an overview of a number of laboratory and field tests conducted over the years on gears, bearings and test specimens. Some of the data in this paper has been presented in widely scattered publications (full details can be found within the references) while other portions are a result of internal communications with proprietary customers. The results illustrate that superfinishing reduces friction, operating temperature, power loss and wear. It is hoped that this process will be more widely utilized in the future as a way to improve the fuel efficiency of gasoline and diesel-powered vehicles. At the same time, it should make it easier for the lubricant industry to formulate the next generation of lubricant packages since fewer and reduced concentrations of additives will be required for superfinished parts.

Testing

Friction manifests itself as heat, wear, and power loss. Increased fuel efficiency can be expected when friction is reduced. The following are a series of laboratory and field tests that illustrate superfinishing's contributions to reducing parasitic friction.

Laboratory Testing:

- Temperature reduction of spherical roller bearings (SRB)
- Temperature and friction reduction of roller bearings (U.S. Patent # 5,503,481)
- Friction and wear reduction—Falex ring on block
- Friction reduction—Falex 3 ball on flat
- Friction and scuffing reduction—Falex washer-on-ring
- Power gain of spur gears
- Frictional reduction of NASCAR transmission
- Horsepower gain of NASCAR rear differential
- Efficiency gain and temperature reduction of rear axle ring and pinion
- Friction reduction of automotive valvetrain

Field testing:

- Temperature reduction of truck rear axle
- Temperature reduction of S-76 helicopter transmission

Laboratory Testing

Temperature reduction of spherical roller bearings (Ref. 15). The effect of superfinishing on the operating temperature of spherical roller bearings and assemblies was evaluated. Testing was conducted on a variable speed spherical roller bearing test rig in a Mobil DTE extra-heavy oil bath. Two bearings were superfinished—one having just the rollers superfinished and the other with both the rings and rollers superfinished. The baseline was a standard production honed bearing. Steps were taken to ensure that internal clearance was not a variable in the comparison. The procedure consisted of running each bearing at 2,400 rpm and allowing them to heat stabilize at radial loads from zero to 4,536 kg. After stabilization, the bearing temperature was recorded and load increased by 454 kg. Figure 3 is an example of the test data obtained at 2,400 rpm. Optimum performance benefits were achieved when both the rollers and rings were superfinished. Bearings with only the rollers superfinished showed a notable but lower improvement. At a load of 4,082 kg, the completely superfinished bearing ran 22°C cooler than the standard production honed bearing.

Temperature and friction reduction of roller bearings (U.S. Patent # 5,503,481; Ref. 16). The Timken Co. evaluated superfinished roller bearings for the purpose of reducing friction and thereby enhancing load-bearing capability. The superfinished and the enhanced roller bearings (final grind is carried a bit farther on the working surface to reduce the run-in time) were compared. The enhanced-performance superfinished bearings were patented: U.S. Patent # 5,503,481, Bearing Surface with Isotropic Finish.

Enhanced roller bearings are typically finished with a final grinding step followed by a honing step to achieve between a 0.075 to 0.2 μm Ra. The superfinished bearings had <0.075 μm Ra. Grinding and honing, however, produce a directional surface texture having peak and valley asperities with these surface irregularities extending in the circumferential direction. The tests proved that a surface with isotropic irregularities (one which has no particular orientation) is superior to those of irregularities extended longitudinally or transversely in the direction of movement. Figure 4 is an image of the superfinished surface taken from the patent. At a magnification of approximately 500X, the SEM image clearly shows the isotropic micro-texturing.

Figure 5 plots operating temperature versus time; Figure 6 plots torque versus time. During run-in, the bearing having the enhanced surface finish shows obvious torque and temperature spikes. Both charts show that the superfinished bearings did not require run-in. No run-in spikes are observed since the superfinished bearing has no peak asperities. Note that the superfinished bearing operates with lower friction and lower temperature than the enhanced surface finish bearing.

Friction and wear reduction—Falex ring-on-block (Ref. 17). This study employed a simple sliding test to examine how superfinishing improves tribological contact performance. Two sets of rings and blocks were used for this evaluation. One set was finished with the conventional grinding method to a 0.6 μm Ra. The other set was superfinished to <0.1 μm Ra. (See Figure 7.)

Tests were run at ambient starting temperature and using an applied load of 3.64 kg. The lubricant was SAE 20 grade containing only rust and oxidation inhibitors. It had a viscosity of 55.72 cst at 40°C and 8.15 cst at 100°C. The rotational

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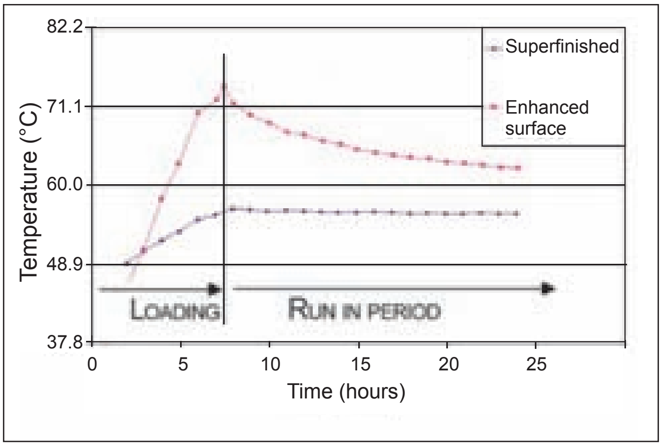

Figure 5—Roller bearing temperature versus time.

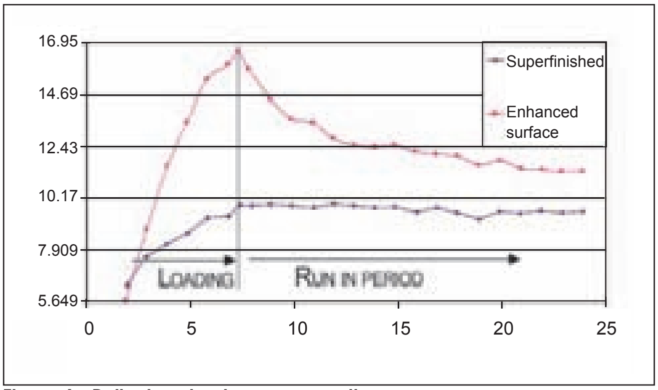

Figure 6—Roller bearing torque versus time.

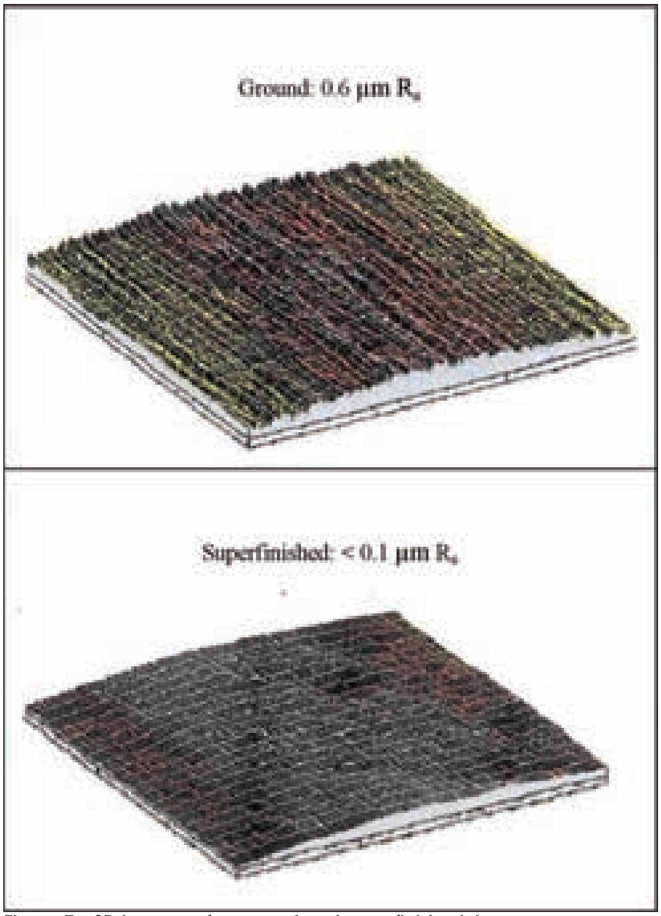

Figure 7—3D images of a ground and superfinished ring.

Table 1—Friction and temperature results for Falex ring-on-block test: superfinished versus ground.		
	Superfinished 0.058 µm R_a	Ground 0.58 µm R_a
Friction Force of Sliding Contacts (Newtons)	6.1	57.6
Temperature (˚C)	46.8	65.1

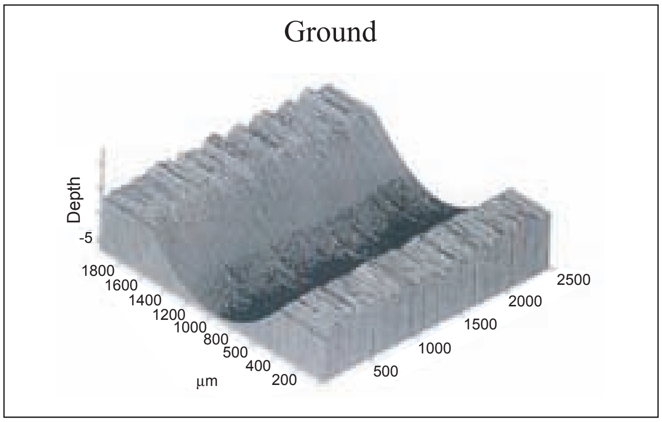

Figure 8—Wear pattern on the ground block at the end of the test.

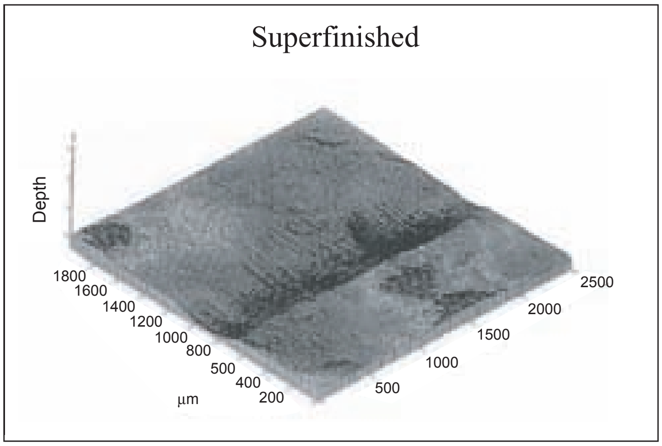

Figure 9—Wear pattern on the superfinished block at the end of the test.

Table 2—Specifications of the baseline balls and disk.		
	Balls	**Disk**
Steel	AISI 52100	SAE 8620
Diameter (mm)	12.7	38.0
Surface HRc	64	61
R_a (µm)	0.025	0.525

Table 3—Testing parameters.	
Total Load	136 kg
Speed	300 rpm, 0.64 m/s
S/R Ratio	Pure Sliding
Hertz Stress	438 ksi, 3 GPa initial
Max Shear Stress	136 ksi, 938 MPa
Lubricant	SAE 75W-90 EP Synthetic
Kinematic Viscosity (cst)	119.7 at 40˚C 16.68 at 100˚C
Test Time	30 minutes
Temperature	20˚C at start

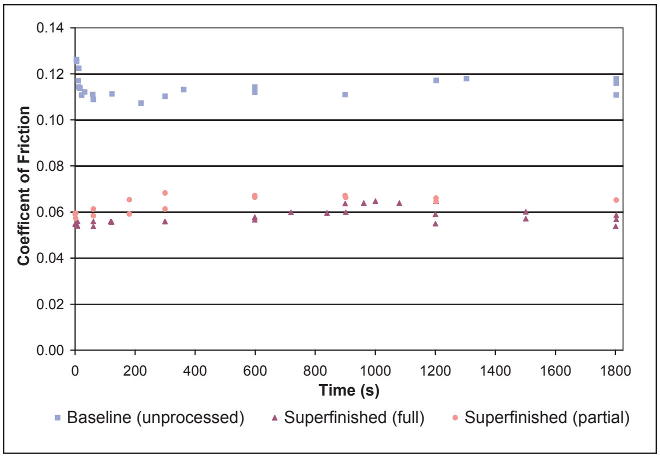

Figure 10—Coefficient of friction versus time for the Falex 3 Ball-on-Flat.

Table 4—Conditions for Falex washer-on-ring test.	
Total Load	256 kg constant
Speed	Ramp up from 100 to 900 rpm at 100-rpm increments.
S/R Ratio	2, simple sliding
Contact Stress	3.90 - 5.52 MPa
Lubricant	Mobile 80W-90 Mineral. Oil drained before testing
Test Time	1.0 minute at each speed
Temperature	20˚C at start

Table 5—Test gear design parameters.		
Parameter	Fine Pitch 40T	Course Pitch 23T
Number of Teeth	40	23
Operating Dimetral Pitch	11.104	6.39
Diametral Pitch	10.955	6.43
Module	2.319	3.950
Operating Pressure Angle	26.5	25.9
Pressure Angle	28	25
Face Width, mm	26.67	19.4818
Contact Ratio	1.40/1.45	1.53/1.56
Tip Thickness, mm	1.1176	1.2446
Tip Clearance, mm	0.5334	0.6096
Backlash, mm	0.114/0.191	0.119/0.196
Operating Center Distance, mm	91.501	91.501

speed of the ring was 800 rpm and the test duration was 6.0 hours. The test ring diameter was 50 mm. Frictional force and sump temperature were monitored during each test.

Frictional force and sump temperature of the operating system for each test specimen and their respective surface finishes are shown in Table 1. The frictional force was approximately nine times higher on the ground set than the superfinished set. The sump temperature showed a reduction of approximately 18°C for the superfinished set.

The study also focused on the wear pattern (scars) present on the blocks after the test was completed. The wear patterns on the ground and superfinished blocks are shown in Figure 8 and Figure 9, respectively. The wear pattern on the ground block was severe and showed significant weight loss. Meanwhile, the superfinished block showed very little wear and almost no weight loss at the end of the test.

Friction—Falex 3 ball-on-flat. An automotive supplier of drivetrain components performed the following Falex 3 ball-on-flat test to determine the effects of superfinishing on wear and friction. The specifications for the baseline balls and disks are given in Table 2; test parameters are given in Table 3.

Rings were superfinished to two different conditions: Full finish (refinement and burnish cycles) and partial finish (refinement cycle only). The full and partial finishes had a 0.04 µm and 0.0725 µm Ra, respectively.

The test results are presented in Figure 10. The baseline samples have an initial coefficient of friction of approximately 0.125. After run-in, it falls to approximately 0.11. Both the partial and fully finished superfinished samples had a coefficient of friction of approximately 0.06. Note that the superfinished samples did not show a run-in spike. The fully superfinished samples had a slightly lower coefficient of friction than the partially superfinished samples.

Friction and scuffing reduction—Falex washer-on-ring. An automotive supplier of drivetrain components employed a Falex washer-on-ring sliding test to determine how superfinishing affects scuffing resistance. Two baseline sets having 0.425 µm to 0.75 µm Ra were tested and compared to five sets superfinished to 0.0475 µm to 0.0725 µm Ra. The test conditions are presented in Table 4.

Both baseline samples had a coefficient of friction of approximately 0.11. Both baseline samples scuffed at approximately 600 rpm. All five superfinished sets had a coefficient of friction of approximately 0.03 to 0.04. Four superfinished samples did not scuff even at the highest rotational speed. The test was eventually suspended. One superfinished sample scuffed at 580 rpm. No explanation was provided for the single failure, but it was suspected that the starting sample was out of geometric tolerance.

Power gain of spur gears (Ref. 18). General Motors Corporation, Powertrain Division, measured the impact of superfinishing on gear efficiency at the Gear Dynamics and Gear Noise Research Laboratory at The Ohio State University. The superfinished gears were compared to baseline ground gears. The test also compared alternative low-friction lubricants with the standard baseline lubricant. Measurements of power loss under both loaded and unloaded conditions were reported in order to distinguish between load-independent (spin) losses and friction-induced mechanical power losses.

The efficiency test machine was designed to accommodate rotational speeds as high as 10,000 rpm and loads up to 690 Nm, which correspond to a maximum transmitted power of nearly 710 kW. A jet lubrication system was developed to cool and lubricate the gears. A dry sump system minimized churning losses. An external heating and cooling system was used to maintain oil temperature and pressure during testing. The baseline lubricant (Lubricant A) in these tests was synthetic 75W–90 oil supplied to the gearboxes at 110°C.

This experiment also evaluated how pitch affects efficiency. Fine-pitched gears lower sliding velocity, which has been known to reduce power loss, but at the expense of lower bending fatigue. 23T (coarse-pitch) and 40T (fine-pitch) gears were used for this test. The gears were superfinished to a 0.06 to 0.09 µm Ra while the hard ground surfaces had 0.25 to 0.47 µm Ra. The gear design parameters and test conditions for this study are shown in Table 5 and Table 6, respectively.

Fine-pitch gears are more efficient than coarse-pitch gears by roughly 34%, due to the lower sliding velocities generated in these gears. Superfinishing improves the efficiency of both fine- and coarse-pitch gears by approximately 17%. See Figure 11 and Figure 12. Low-viscosity lubricants can improve spin loss in spur gears through reduction in rolling losses, but the lubricants tested in this study had little effect on loaded power loss.

Two other lubricants (lubricant B and lubricant C) were tested with the same gears to quantify their impact on gear

continued

Table 6—Test conditions used in this study.

Test	Speed (rpm)	Torque (N-m)
1	6,000	406
2	6,000	542
3	6,000	677
4	8,000	406
5	8,000	542
6	8,000	677
7	10,000	406
8	10,000	542
9	10,000	677
10	10,000	0
11	8,000	0
12	6,000	0
13	4,000	0
14	2,000	0

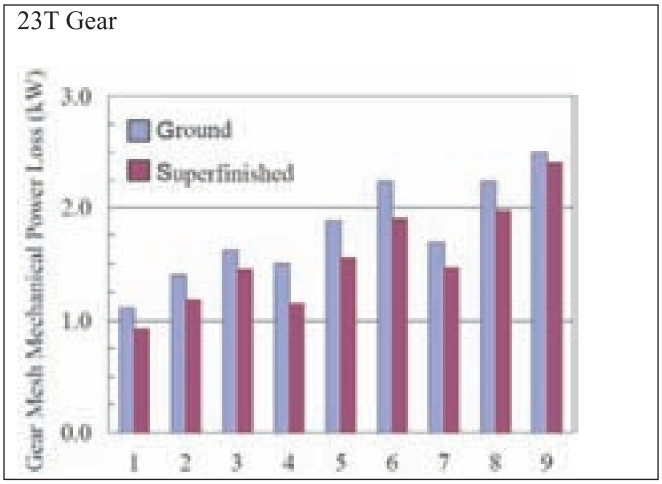

Figure 11—The effect of superfinishing on mechanical gear mesh power losses for 23T Gear; lubricant A at 110°C.

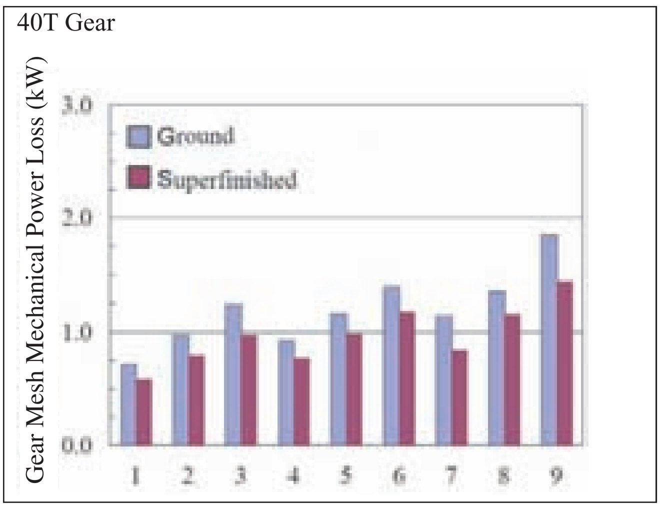

Figure 12—The effect of superfinishing on mechanical gear mesh power losses for 40T Gear; lubricant A at 110°C.

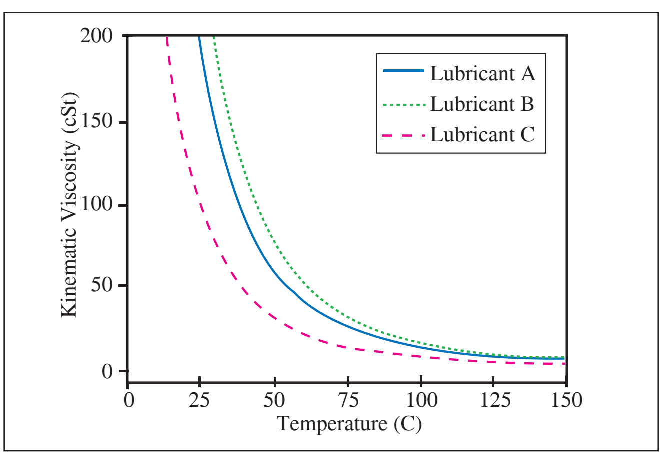

Figure 13—Viscosity-temperature characteristics of lubricants used in this study.

efficiency. The viscosity-temperature characteristics shown in Figure 13 display the relative viscosities of lubricants A, B and C, with lubricant B being the most viscous.

The salient features in Figure 13 are the significantly thinner oil film developed with lubricant C (due to its lower viscosity) and the effect of superfinishing on the λ ratio. A less viscous lubricant is thought to result in lower rolling losses due to reduced shear resistance, but at the expense of higher sliding losses due to increased asperity contact. Consequently, reducing surface roughness through superfinishing permits the use of a less viscous lubricant while maintaining the same λ ratio. Extending this rationale to the gear-mesh mechanical-power loss measurements of Figures 14–17, several conclusions can be drawn:

- Ground surfaces performed best with lubricant B because this lubricant resulted in the largest film thickness. Since λ ratio for these gears was consistently less than unity, the reduction in sliding power loss was more significant than the increase in rolling power loss.
- Superfinished 23-tooth gears performed best with lubricant C because rolling loss was minimized, but sliding loss was not significantly affected since the λ ratio remained near unity. This observation is further supported by the increasing margin of improvement over the more viscous lubricants as speed increased. Hence, the lower viscosity of lubricant C results in power-loss improvements if the λ ratio is near unity and pitch-line velocity is sufficiently high.
- Superfinished, 40-tooth gear power-loss trends cannot be explained by the λ ratio alone. Since sliding velocities are significantly lower than 23-tooth gears, the influence of friction coefficient—and therefore sliding power loss—is less significant.

Frictional reduction of NASCAR transmission (Ref. 19). An independent testing facility conducted this test using a dynamometer to measure the effect of superfinishing on horsepower. A pair of T101 transmissions (Nextel Cup Auto Racing) was used as the test articles. Third gear was selected for the comparison tests. One transmission had standard ground gears while the other had superfinished components. The tests were carried out in sequence on the same dynamometer test stand with the same engine. During each test, the engine and transmission were preheated by idling until the transmission oil (Unocal 90W) reached 82°C. The engine was then cooled back down to normal operating temperature before running with the applied load to measure horsepower losses through the transmission. Driveshaft angles were monitored to ensure a consistent angle for all runs. Figure 18 shows that approximately 1.0% horsepower was recovered with superfinished transmission components.

Increased horsepower at NASCAR rear differential (Ref. 20). A paper presented at the 2003 SAE Performance Racing Industry (PRI) Conference and later published by *Circle Track* magazine documented the increased efficiency of a high performance differential containing a superfinished ring and pinion gearset. The test specimens used were a standard quick-change differential with standard bearings and seals, and a quick-change differential with low-friction bearings, seals, and superfinished ring and pinion gears known as a "Tiger" in the racing industry. This study used a Dynojet Model 248 chassis dynamometer (as used to monitor NASCAR Nextel Cup cars) to measure output of the engine on run-up in fourth gear and then the amount of resistance at two speed intervals, 137 and 160 km/h, while the car was coasting. The run was stopped after coasting down to 137 km/h. The results showed an average gain of 14.25 horsepower and a reduction in parasitic friction losses through the rear end by 50 percent at 137 km/h and 52 percent at 160 km/h. These test results are shown in Table 7.

Efficiency gain and temperature reduction of rear axle ring & pinion (Ref. 21). Ford tested the effect of superfinishing rear axle ring and pinion gears on overall fuel efficiency. Results are published in the *Handbook of Lubrication and Tribology, Volume 1*. A rear axle ring and pinion gearset was superfinished to a 0.07 µm Ra. Chassis roll dynamometer tests under metro/highway cycles were conducted. Figure 19 compares axle efficiency between the superfinished processed gears and production gears at 1,000 rpm.

The superfinished ring and pinion showed improved efficiency that improved fuel economy by about 0.5%. The operating temperature of the rear axle was significantly reduced with superfinished gears. See U.S. patent application 2005/0202921 for more details (Ref. 22).

Friction reduction of automotive valvetrains (Ref. 23). Only 6 to 10% of an engine's total frictional loss occurs in the valvetrain. Even though this is a small number, it can be significantly and easily reduced by superfinishing the components. Virtually all major racing teams, including those in NASCAR and Formula 1, use superfinishing on their entire valvetrain (camshaft and lifters). Unfortunately, due to the competitive nature of the sport, no published data was found for a NASCAR late model with a 5.7-liter engine running a two-barrel carburetor. For this test, the dynamometer was used to measure horsepower as engine speed climbed and during the coast-down. The goal was to measure maximum horsepower documenting fuel efficiency gains. It can be said with confidence, however, that many racing teams are superfinishing their valvetrain components to <0.025 µm Ra. The composite roughness of their mating components is

continued

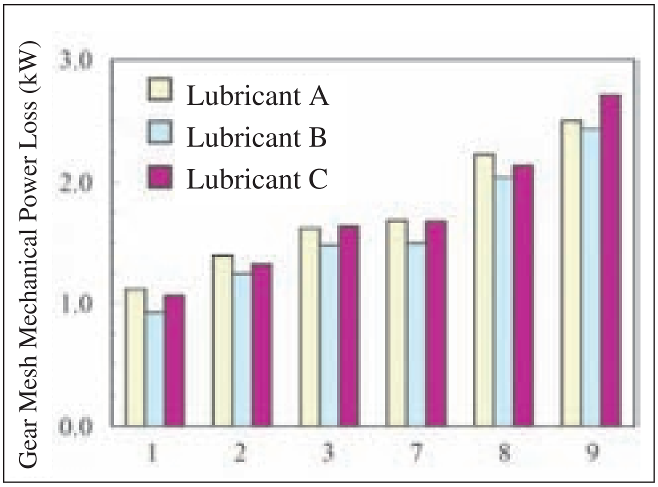

Figure 14—Effect of lubricant type on gear mesh mechanical power losses – 23T ground.

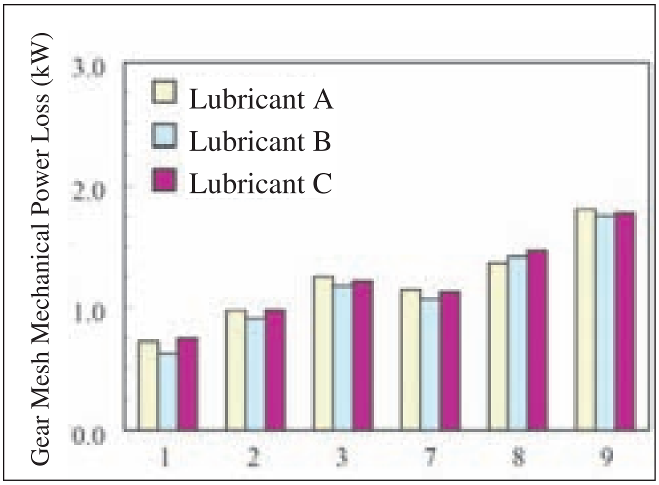

Figure 16—Effect of lubricant type on gear mesh mechanical power losses – 40T ground.

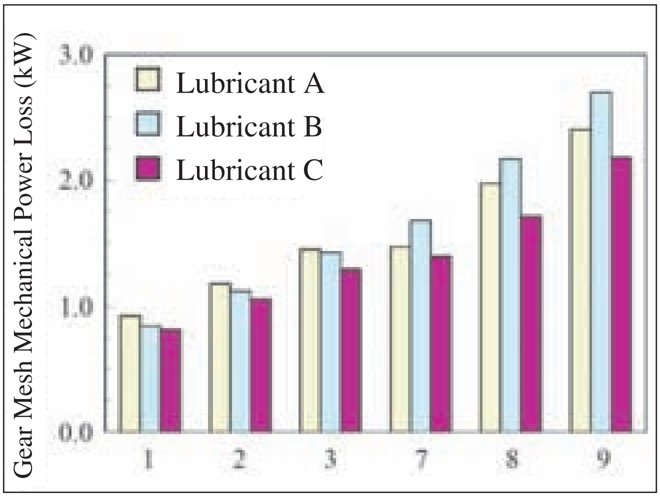

Figure 15—Effect of lubricant type on gear mesh mechanical power losses – 23T superfinished.

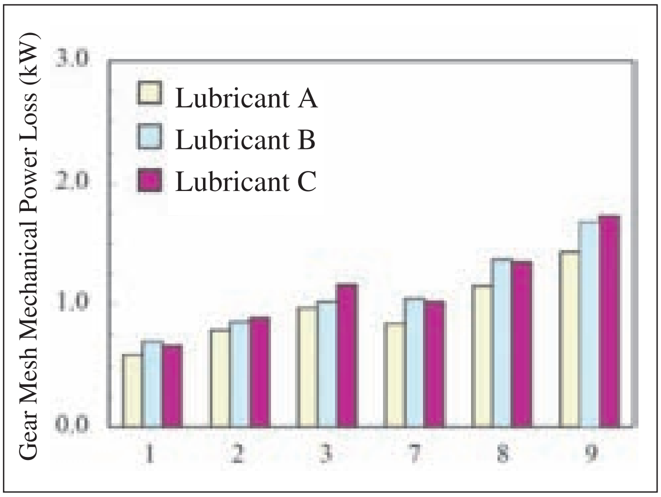

Figure 17—Effect of lubricant type on gear mesh mechanical power losses – 40T superfinished.

therefore <0.035 μm Ra.

Ford Research Laboratory conducted a study to determine the effect of superfinishing valvetrain components on friction reduction. The valvetrain components (cams and tappets) are made of nitrided steel. One objective of the test was to evaluate the effect of superfinishing on frictional torque compared with a production tappet insert. The production tappet insert had an 8-μm manganese phosphate coating to facilitate break-in. The superfinished tappet insert had a surface finish of approximately 0.06 μm Ra. The researchers compared production and superfinished valvetrain components with regular SAE 5W-30 and a special version of SAE 5W-30 formulated by adding a friction modifier, MoDTC. A new broken-in (i.e., not superfinished) cam lobe having a nominal 0.55 μm Ra was used for each tappet insert material. It should be noted that between the two sets of experiments using the different lubricants, some modifications were made to the apparatus to prevent oil leakage and a new higher-sensitivity torque meter was used. Therefore the frictional torque measurements from the two experiments may not be directly comparable.

The test rig ran at speeds ranging from 400 to 1,600 rpm for 50 hours. Frictional torque was recorded for both superfinished and production tappet inserts, using both a modified low-friction lubricant and a non-modified lubricant (Fig. 20).

Using SAE 5W-30 without friction modification, the superfinished valvetrain showed a significant decrease in frictional torque compared to the standard production insert. Interestingly, when using the special friction-modified SAE 5W-30, the standard production insert performed as well as the superfinished. As stated, however, the frictional torques of the two experiments cannot be compared. Nevertheless, it is important to note that optimum performance benefits are expected when both mating surfaces (cam and insert) are superfinished to a <0.025 μm Ra. Whereas racing teams are superfinishing their valvetrain components to <0.035 μm composite Ra, the composite Ra in this study was approximately 0.55 μm. It would be interesting to repeat this testing with both the cam and the inserts superfinished to a <0.025 μm Ra.

Field Testing

Temperature reduction of a truck rear axle. A leading truck manufacturer conducted this experiment to determine the effect of superfinishing on rear-axle operating temperature in their full-size pickup truck while towing a 4,091-kg trailer in hot weather and hilly terrain. The testing was conducted with the vehicles tuned to the 2008 power output. Their current production vehicles are tuned for 514 Nm; the 2008 model will produce 549 Nm. The vehicles used for this testing were tuned to produce 549 Nm torque.

A high-speed tow test was used to determine the effect of high speeds and minor elevation changes. The loop was 151 km in length with a 228 m change in elevation. Test speed was dependent on wind conditions and ranged from 96 to 120 km/h. A 4,086-kg trailer with a large frontal area was used. The test truck was equipped with sensors for axle sump temperature, ambient air temperature, axle torque of each rear wheel, transmission temperature and vehicle speed.

The superfinished axle ran 32°C cooler than the standard axle.

Hill test. The test route consisted of steep grades and high winds. The test route rose 853 meters in 19 km and quickly produced extremely high axle temperatures. Once over the

Table 7—Results of chassis dynamometer testing of standard and superfinished quick-change differentials in a NASCAR late model car.

	Standard Quick-Change Bearings & Seals					Superfinished Gears with Low-Friction Bearings and Seals				
	Run #1	Run #2	Run #3	Run #4	Run #5	Run #1	Run #2	Run #3	Run #4	Run #5
Max. HP	286.5	284.4	282.3	285.3	280.9	296.8	297.16	296.80	299.80	300.10
Coast @ 137 km/h	N/A	N/A	17.5	16.5	16.1	9.60	8.56	8.13	8.00	7.70
Coast @ 160 km/h	N/A	N/A	24.0	25.5	22.3	13.40	11.66	10.97	10.67	10.40
Average:										
Maximum HP			**283.88**					**298.13**		
137 km/h Coast			**16.70**					**8.40**		
160 km/h Coast			**23.93**					**11.42**		
Gains:										
Maximum HP		**-14.25**	=5% gain in HP							
137 km/h Coast-down		**-8.30**	=50% reduction							
160 km/h Coast-down		**-12.51**	=52% reduction							

peak, the truck was driven 8 km to a turn-around area. The return run also generated high temperatures due to the axle temperature generated on the climb. Test speed was limited to 64 km/h by the vehicle "failsafe" once engine temperature reached three-quarters hot. A 4,086-kg trailer with a large frontal area was used. The test truck was equipped with sensors for axle sump temperature, ambient air temperature, axle torque of each rear wheel, transmission temperature and vehicle speed. Test conditions for hill testing were not consistent due to changes in wind conditions and when the vehicle would enter failsafe mode. The variable test conditions made it difficult to produce repeatable results. The superfinished axle ran 53°C cooler than the standard axle.

Temperature reduction of S-76 helicopter transmission (Ref. 24). Sikorsky performed this test to determine how superfinishing affects the temperature of the S-76 helicopter drivetrain. Acceptance test procedure (ATP) was employed to simulate typical torque loading experienced by the main gearbox, measure oil-out temperature at various torque loadings, and measure vibration levels (noise levels). The surface roughness data of the ground gears and superfinished gears are given in Table 8 and Table 9, respectively. The gearbox passed the 200-hour endurance test and has become flight operational.

The superfinished transmission components showed the following performance improvements:

- A 2.8°C reduction of the oil-out temperature
- A 3.7 dB reduction at the second stage bevel gears
- A 7.0 dB reduction of the first harmonic of the bull gear

Conclusions

- Extensive laboratory and field testing have documented that superfinished gears and bearings have significantly reduced friction, temperature and wear.
- The superfinished surface is the ideal surface for low-viscosity lubricants since peak asperities are absent, resulting in a higher λ ratio.
- The aerospace, high-performance-racing, wind-turbine and heavy-axle-vehicle industries are

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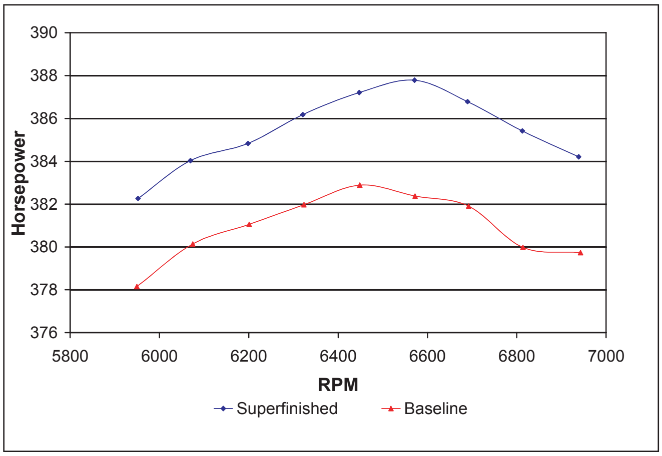

Figure 18—T-101 horsepower output of a superfinished versus standard ground transmission in third gear measured on a chassis dynamometer.

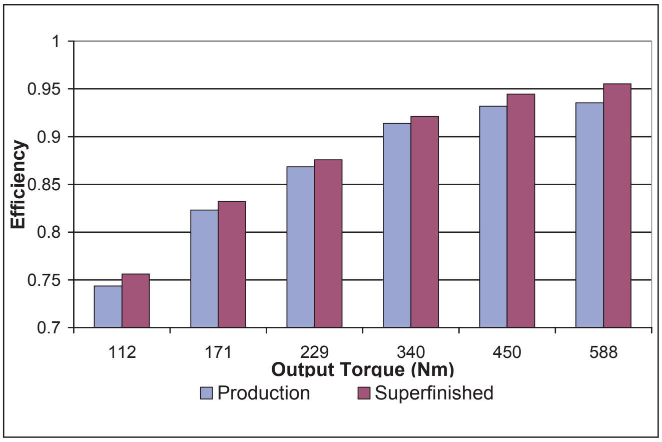

Figure 19—Axle efficiency of the superfinished ring and pinion.

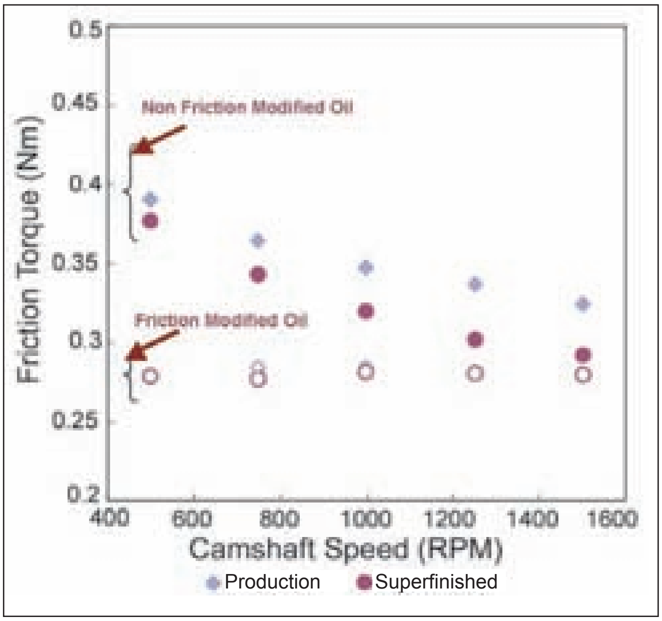

Figure 20—Friction reduction achieved with superfinished tappets.

Table 8—Roughness parameters for ground aerospace gears.

	Bevel Pinions & Gears	Spur Pinions	Bull Gears
	µm	µm	µm
R_a	0.330 to 0.457	0.0406 to 0.432	0.033 to 0.432
R_z	2.032 to 2.921	2.463 to 2.565	2.108 to 2.870
R_{max}	2.769 to 4.242	3.023 to 3.277	3.378 to 3.581

Table 9—Roughness parameters for superfinished aerospace gears.

	Bevel Pinions & Gears	Spur Pinions	Bull Gears
	µm	µm	µm
R_a	0.330 to 0.457	0.0406 to 0.432	0.033 to 0.432
R_z	2.032 to 2.921	2.463 to 2.565	2.108 to 2.870
R_{max}	2.769 to 4.242	3.023 to 3.277	3.378 to 3.581

making use of this unique surface to reduce friction, temperature, power loss and wear with the accompanying gains in fuel efficiency.
- Lubricant formulations can be simplified for gears and/or bearings that have their working surfaces superfinished. Superfinished surfaces operate at lower temperatures and are much less prone to micropit, scuff or wear. Therefore, fewer and/or lower concentrations of detergents, friction modifiers, antioxidants, anti-wear, extreme-pressure additives, etc. are required. These lubricants will be more environmentally friendly.

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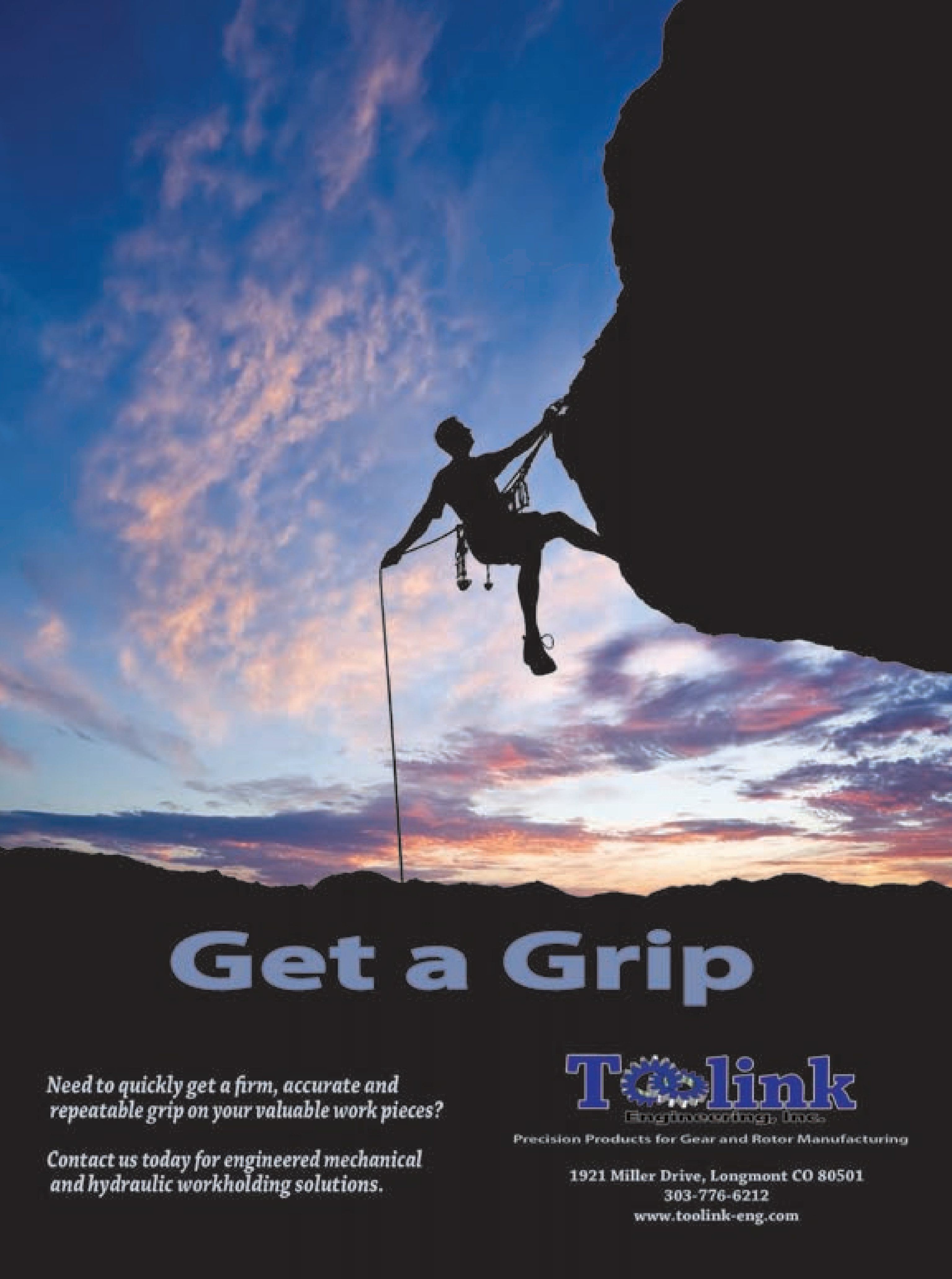
Matt Bell *joined REM Chemicals, Inc. in 2006 as a Research Chemist after completing a bachelor's degree in chemistry at Texas A&M with an emphasis on environmental chemistry in late 2005. Since then he has been involved in product and process development and regulatory compliance. Mr. Bell has also co-authored several articles highlighting the benefits of superfinishing gears. He is also a member of the American Chemical Society.*

Omer El-Saeed *is a Texas A&M University graduate with a degree in industrial engineering. He is currently an R&D engineer with REM Research Group in Brenham, Texas. He joined in 2005 after a stint with Alexandria Metal Finishers in Lorton, VA. As a member of the research group, he developed multiple products and processes for superfinishing various metal components such as gears and bearings. He co-authored and presented multiple technical papers for STLE, AGMA and ASME.*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Gear Failure Analysis Involving Grinding Burn

G. Blake, M. Margetts and W. Silverthorne

Management Summary

When gears are case-hardened, it is known that some growth and redistribution of stresses that result in geometric distortion will occur. Aerospace gears require post case-hardening grinding of the gear teeth to achieve necessary accuracy. Tempering of the case-hardened surface, commonly known as grinding burn, occurs in the manufacturing process when control of the heat generation at the surface is lost. Excessive heat generated at the surface can induce surface tempering and/or reaustenitize the surface in a localized area. The localized area will have reduced or altered mechanical properties in addition to an unfavorable residual stress state (Ref. 1).

Linear cracks along the dedendum of the working gear tooth face were found in three adjacent teeth during visual inspection of a gearbox. No teeth had been liberated. A detailed inspection of the gearbox found no other components with distress.

Metallurgical evaluation determined that the cracks initiated at the boundary of a localized grinding burn, which had reaustenitized. The cracks propagated inward from the tooth surface in fatigue to a depth greater than the depth of the case.

The metallurgical evaluation could not conclude if the crack trajectory would propagate across the tooth cross section or radially into the gear rim. A cross section trajectory results in the liberation of teeth. Linear elastic fracture mechanics (LEFM) analysis was then used to predict the cracks' future propagation path based on assumptions from the one subject gear.

The subject gear was processed for grinding burn using an ammonium persulfate etch solution. A design of experiments was conducted to understand the effects of the factors and interactions that impact the capability of the ammonium persulfate process used in production to detect grinding burn.

Presented are the metallurgical findings, load distribution analysis of actual geometry, crack propagation analysis, and design of experiment results of the ammonium persulfate etch process.

Overview of Gear System

The subject gearbox had accumulated 1,650 hours of use at the time of inspection. A partial illustration of the gear train and the gear is shown in Figure 1. The gear and mating pinion are carburized, ground and shot peened AMS6265. The engine torque path is also shown in Figure 1.

Background

The gearbox has a chip detector in the scavenge oil passage. The technicians removed the chip detector and found a large sliver of material clinging to the end. The size of the sliver is shown in Figure 2.

Typically, wearing or pitting components will generate very fine particles that, when mixed with oil, create a paste. The paste is what most technicians expect to find when investigating a chip light indication. The size of the debris found on the plug was cause for removal of the gearbox.

Tear-Down Inspection

Cracks were found in the first-stage spur gear as shown in Figure 3. Tooth number eight, shown in Figure 3, was found to have a divot close in size to the metallic sliver found on the chip detector. The cracks were located in three adjacent teeth on the driven side. The cracks stretched across the central 75% of the face width within the active tooth profile. The cracks were arc shaped, higher on the active tooth profile at the ends than in the center.

The visual cracks and distress of the gear were confined to the three teeth shown in Figure 3. The remainder of the gear teeth showed no evidence of distress.

A detailed inspection was performed on all other parts of the gearbox. No other components showed any signs of degradation or indications of high load experience. The mating pinion gear showed no signs of surface distress or maldistributed load as shown in Figure 4.

Magnetic particle inspection (MPI) was performed on the subject gear at the manufacturer. No cracks, in addition to those found visually, were found. No etch inspection was performed at this time to prevent altering the crack surfaces, as the cracks were to be evaluated in detail as part of the destructive metallurgical investigation.

Inspection of the pinion and subject gear tooth geometry was performed. The geometry of both members was within specification and was of high quality.

Metallurgical Evaluation

A photographic montage through the crack on tooth 6 (see Figure 3) is presented in Figure 5. The crack was approximately 0.103" long and 0.061" in depth. Several smaller cracks were observed branching from the main crack. The crack intersected the surface at approximately 0.23" from the tooth tip.

Figure 5 shows the crack trajectory to be inward from the tooth surface. Analysis will be presented in the later portion of this paper to bound the crack propagation path.

The cross section was etched as shown in Figure 6 and grinding abuse was observed on both sides of the tooth. Detailed views of the grinding abuse are shown in Figures 7 and 8. The grinding abuse produced a rehardened layer on the surface measuring up to 0.007" deep. The crack followed the heat-affected zone, as illustrated in the upper image in Figure 7.

Similar grinding abuse was observed on the coast side of the tooth, as shown in Figure 8. The dotted lines in Figure 8 show the approximate location of the five hardness surveys. The hardness was reduced in the over-

continued

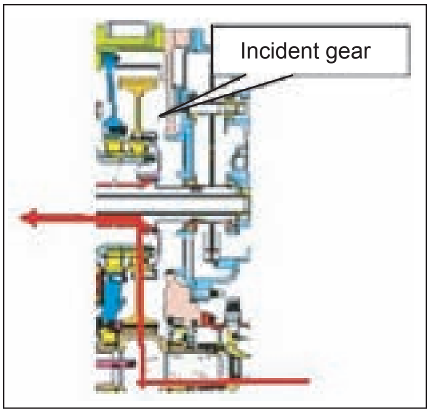

Figure 1—Partial illustration of gear train showing torque path.

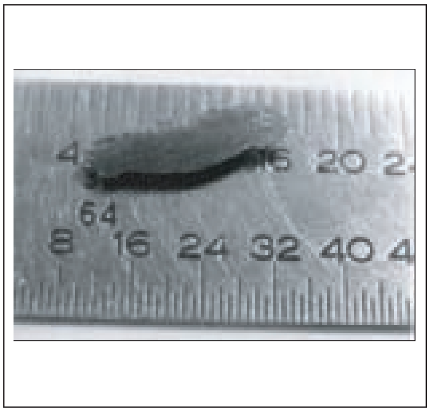

Figure 2—Debris found on chip detector.

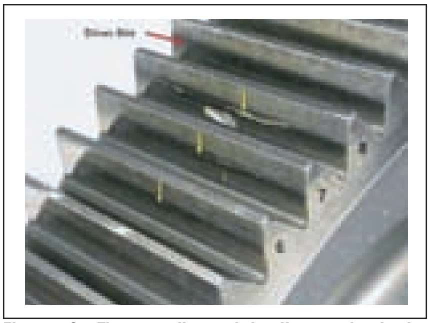

Figure 3—Three adjacent teeth cracked observable without MPI or magnification.

Figure 4—Mating pinion showing no surface distress or evidence of maldistributed load.

Figure 5—Photo montage of crack from tooth surface.

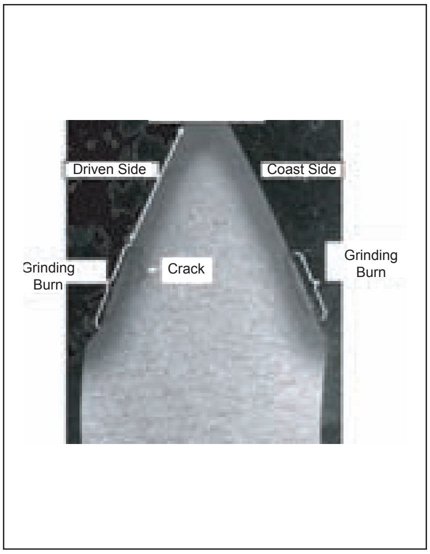

Figure 6—Etch cross section showing tempered and rehardened (burned) zone in dedendum area of the driven and coast side of the gear tooth.

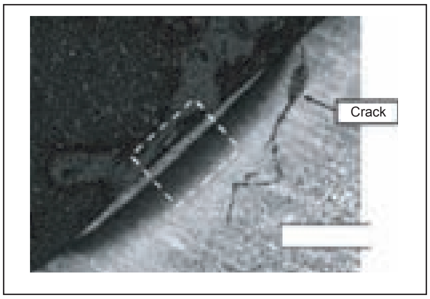

Figure 7—Detailed views of the grinding abuse and crack on the driven side. Etchant 5% Nital.

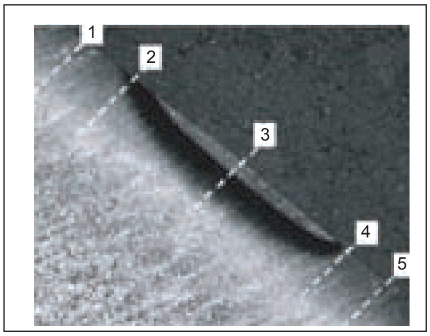

Figure 8—Coast side showing rehardened and tempered zone and locations of hardness traverses.

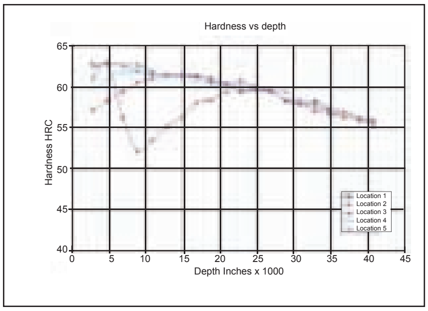

Figure 9—Hardness vs. depth at locations with and outside of the rehardened zone.

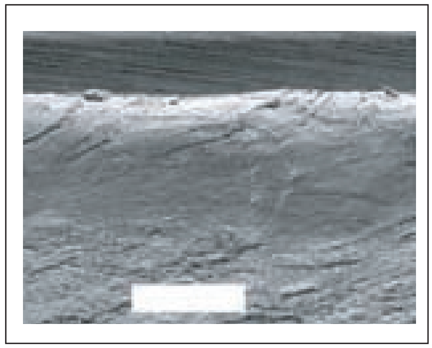

Figure 10—SEM photo showing fatigue direction from mid face towards end face.

Table 1—AGMA Index MOS

	MOS
Bending	1.30
Contact	1.10
Flash Temperature	1.08

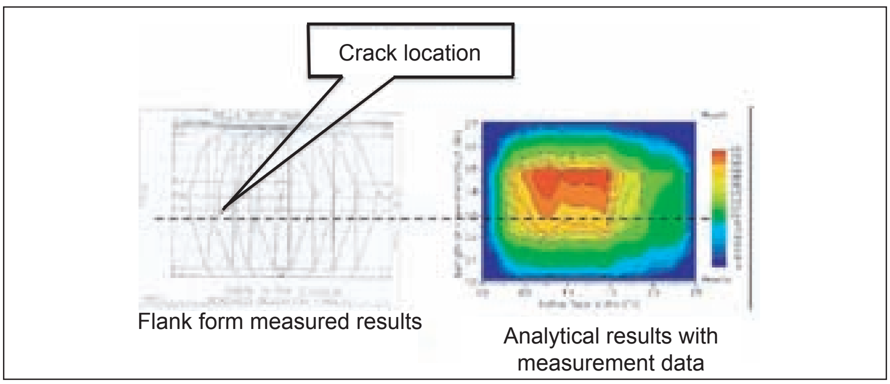

Figure 11—Approximate crack location vs. contact stress distribution.

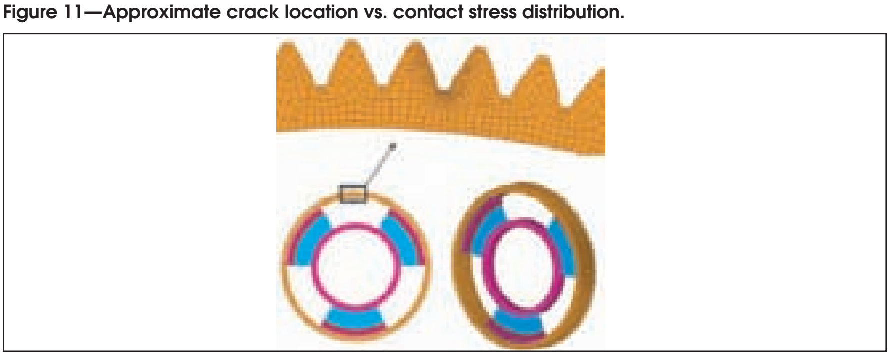

Figure 12—2D FEA model of incident gear with tooth geometry.

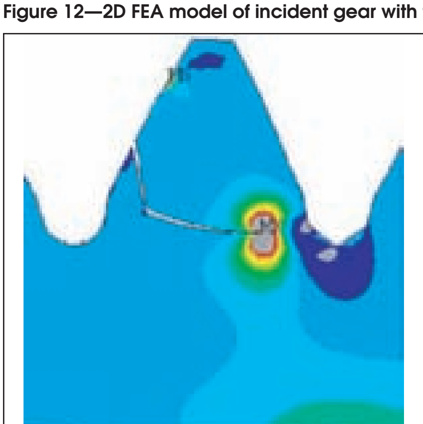

Figure 13—Crack trajectory solution starting from initial crack using maximum continuous torque and speed – first principal stress contours shown.

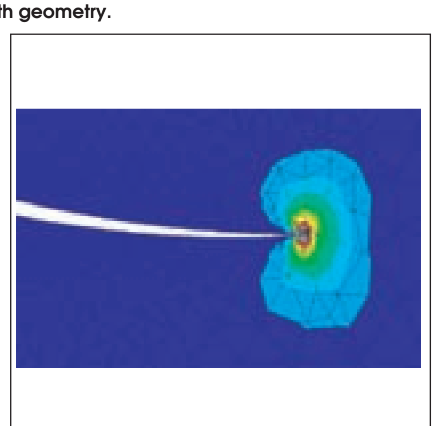

Figure 14—Quarter-point rosette used to model crack tip.

tempered areas (dark colored zone), as shown in Figure 9.

The No. 6 gear tooth section was laboratory-fractured to expose the crack surface. The crack could not be completely opened due to its shallow depth and orientation. A SEM (scanning electron microscope) photograph of the fracture is shown in Figure 10. The crack morphology was indicative of fatigue progression from mid face towards end face, as illustrated in Figure 10. The arrows indicate the direction of local fatigue crack progression.

Analysis

Analysis was performed to understand the location, shape and expected crack trajectory. A crack trajectory that results in the ejection of a single tooth or multiple teeth has a different end result than one that propagates into the gear blank.

The flank form inspection of the incident gear located the approximate radial position of the crack. The profile traces were made at the mid face of each tooth. The profile chart shown in Figure 11 shows four adjacent teeth, three of which contain the cracked teeth. The approximate location of the crack is shown as a rapid change (bump) in the lower 25% of the profile chart.

Load distribution vs. crack location. *Load Distribution Program version 10.9* was used to predict the gear load distribution. The actual measured geometry of the pinion and incident gear was input.

The contact stress distribution of the gear relative to the approximate crack location is shown in Figure 11. The crack location is near the start of single-tooth contact of the gear but not in the area of highest contact stress. However, the crack seems to follow the contour of the surface stress in the axial direction.

The margin of safety (MOS), using the AGMA index method, was greater than 1.0, as shown in Table 1. None of the AGMA index MOS would suggest premature crack initiation.

Crack trajectory analysis. Analysis was performed to predict the crack trajectory. A 2D finite element model (FEA) with actual tooth geometry was created as shown in Figure 12.

The crack as measured in Figure 5 was added to the model. Linear elastic fracture mechanics (LEFM) was then used to predict the crack trajectory from this initial point. The solution is shown in Figure 13. The crack tip was modeled as a quarter-point rosette, as shown in Figure 14. The solution shown represents maximum continuous speed and maximum continuous torque applied at the highest point of single tooth contact.

The depth of the initial crack depth is slightly below the case-core transition point. The model assumed no residual stress in this area of the gear.

The model was then used to predict the effects of speed on crack trajectory. Reference 2 highlights the effects of rotational speed on crack trajectory. At maximum continuous speed, the crack trajectory was across the tooth. The trajectory changed toward the blank center as speed increased, given the same applied torque (Figure 15).

Published analytical and test results in References 2–4 were used to validate the model. Reference 5 highlights the effects of rim thickness on the alternating stress range experienced in the gear tooth root. The supporting geometry is therefore expected to have a strong influence on crack trajectory.

Etch Inspection Design of Experiments

A design of experiments (DOE) was conducted to understand the effects of the factors and interactions that impact the capability of the ammonium persulfate process to detect grinding burn.

The DOE was a full factorial with replication, two levels per factor, with center point. The variables were % ammonium persulfate and % HCL. The response variable was burn indication (faint, light, dark).

The etch process was replicated in the Failure Analysis Laboratory as shown in Figure 16. The process steps for the DOE are shown in Table 2.

The maximum observed concentration levels were used as upper

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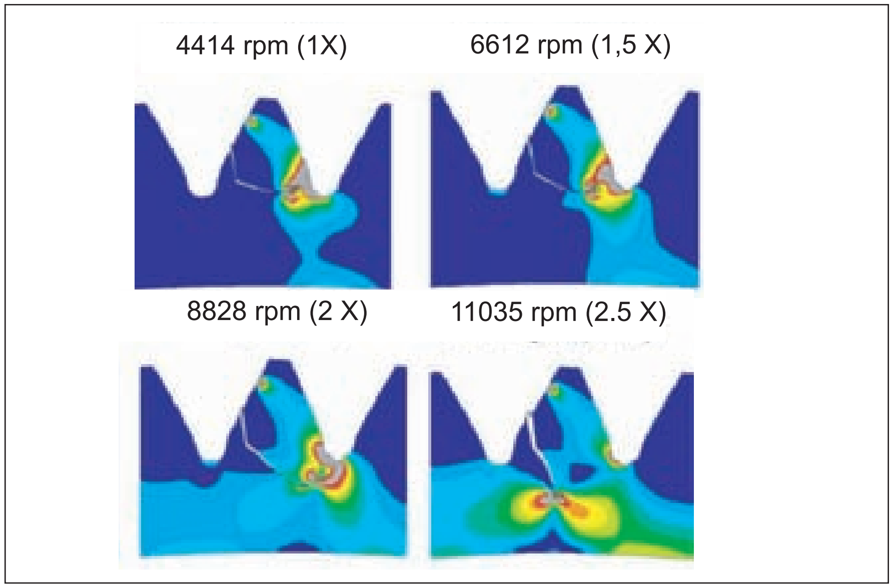

Figure 15—Crack trajectory vs. rotational speed.

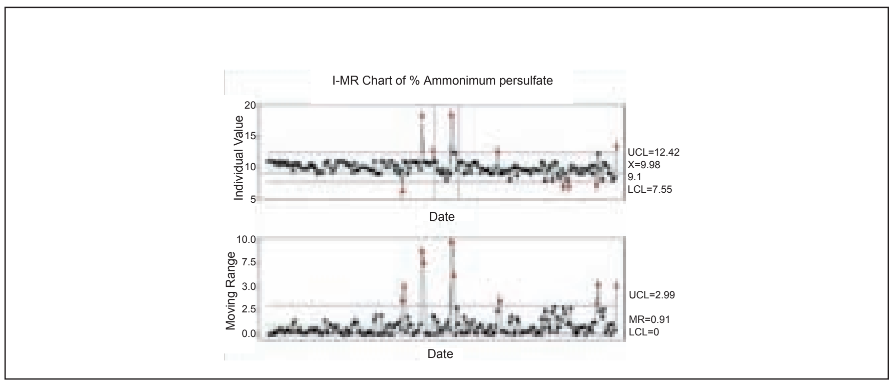

Figure 16—Run chart of ammonium persulfate concentration levels pre- and post-time of quality escape.

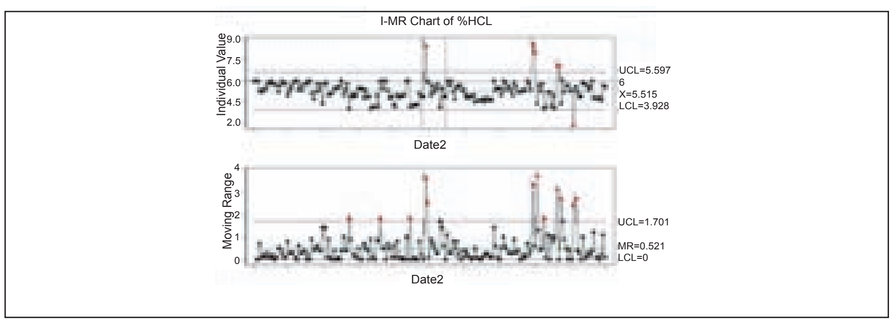

Figure 17—Run chart of HCL concentration levels pre- and post-quality escape time period.

Table 2 DOE Etch Process	
Step 1	Heat Specimen to 170˚ F for 3 mins.
Step 2	Blow dry.
Step 3	Immerse in enchant chemical 10.0 (min spec) secs.
Step 4	Rinse cold H_20.
Step 5	Heat specimen to 170˚ F for 1 min.
Step 6	Blow dry.
Step 7	Immerse in bleach solution 10.0 (max spec) secs.
Step 8	Rinse in cold H_20.
Step 9	Blow dry.

Gregory Blake *is a senior specialist, mechanical engineer, at Rolls Royce Corporation and holds the organizational position of product definition manager of gearboxes. Blake was granted a Bachelor of Science and a Master of Science degree from Purdue University. He has 15 years of professional experience in the areas of gear manufacturing, design, product development, and technology. He holds a special appointment to the Purdue University graduate school faculty. Blake was awarded the Rolls Royce Chief Executive Quality Award for Delivering Innovative Solutions and the Rolls Royce Executive Vice-Presidents Award for Customer Satisfaction. He has three patents for mechanical systems pending and has authored papers on the subjects of gear manufacturing, technology and failure analysis.*

Michael Margetts *is sub system design lead for the RB282-10 compressor. Prior, he was the structural analysis lead for the Transmissions and Structures group, primarily focused on the JSF Liftfan. Margetts has over 11 years of structural analysis experience which includes four years with Rolls Royce and seven years at General Electric. He completed his undergraduate degree at the Massachusetts Institute of Technology, following with graduate work at Tufts University in mechanical engineering.*

Wilson Silverthorne *currently serves as of Head of Engineering Quality & Improvement Programs for Rolls-Royce Corporation in Indianapolis, Indiana. Silverthorne joined Rolls-Royce in 2002 and previously held positions at Rolls-Royce in failure analysis, applications engineering and program engineering. He has over 15 years of engineering experience in the areas of metallurgy, gear heat treating and sintered friction material development. Silverthorne holds a BS in Materials Engineering from Purdue University, as well as an MBA from the University of Indianapolis. He is a special appointee to the Purdue University Graduate School faculty and has been awarded the Rolls Royce Executive Vice-President's Award for Customer Satisfaction and the Rolls-Royce Engineering and Technology Quality Award. He has authored and presented papers on various topics, including induction hardening and friction material technology.*

Table 3—DOE Test Matrix with Post Etch Results.

Test	Ammonium Persulfate %		HCl %		Detection of Etch Indications
1	18.6	Max	9.0	Max	↑
2	18.6	Max	3.0	Min	↑
3	6.0	Min	9.0	Max	→
4	6.0	Min	3.0	Min	→
5	9.1	Typical	6.0	Typical	↗
7	6.0	Min & min time	9.0	Max and max time	↘
8	6.0	Min & min time No glass bead	9.0	Max and max time	↓

and low test points. Table 3 details the concentration levels for each test. Further, the maximum and minimum time for exposure to the ammonium persulfate and HCL were tested.

The specimens were standard four-point bending specimens made from carburized AMS6265 material. The specimens were ground with aggressive parameters to induce surface temper.

Figure 17 shows the specimens, post processing. Each end of each specimen was etched separately, thus allowing for more test points. The use of both ends created an overlap area in the middle that must be excluded during final evaluation.

A qualitative scale was then created and the specimens evaluated by engineering. Table 3 contains the test matrix with the qualitative results.

An upward arrow indicates dark etch of tempered areas. The downward arrow indicates faint indications of the tempered area. The relative angle of the arrow is proportional to the degree of darkness of the etched indications.

Conclusions

- FEA and LEFM model predicted that crack would propagate across the tooth section.
- The grind etch DOE demonstrated that the ammonium persulfate process is robust and that concentration levels were adequate to detect grinding temper.
- Human factors are significant in non-destructive testing, such as etch inspection.

Recommendations for Future Work

- Additional data is needed to characterize the effects of the carburization on crack growth rate and trajectory.
- Processes should continue to be developed that minimize human factors in the detection of grinding abuse.

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Effects of Gear Surface Parameters on Flank Wear

J.C. Wang, J. Chakraborty and Hai Xu

Management Summary

Non-uniform gear wear changes gear topology and affects the noise performance of a hypoid gear set. The aggregate results under certain vehicle driving conditions could potentially result in unacceptable vehicle noise performance in a short period of time. This paper presents the effects of gear surface parameters on gear wear and the measurement/testing methods used to quantify the flank wear in laboratory tests.

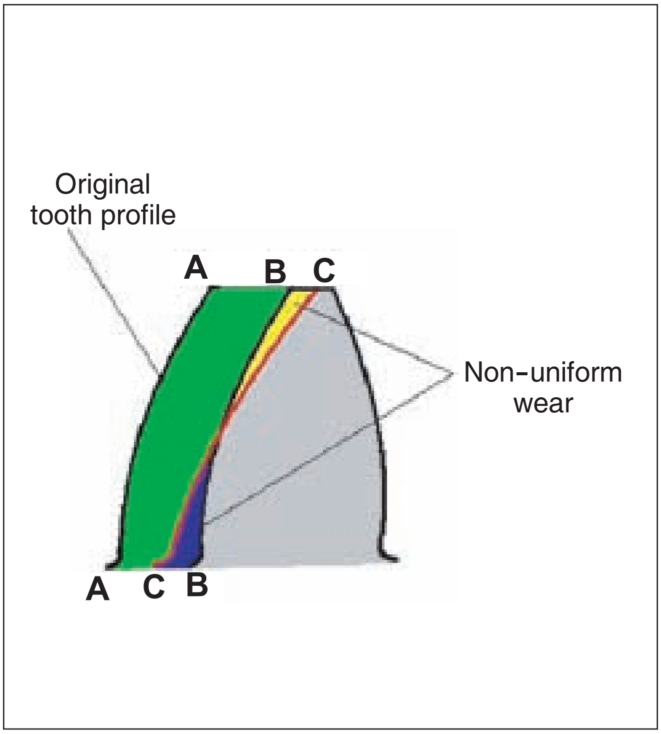

Figure 1—Gear wear.

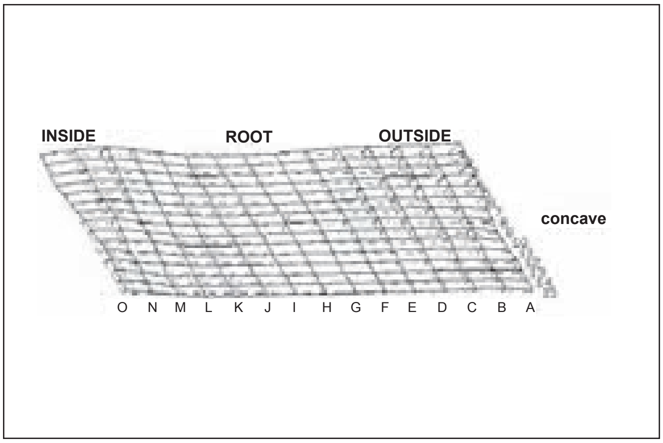

Figure 2—Pre-test pinion CMM results.

Introduction

Gear tooth profile, transmission error (TE), gear tooth surface finish determined by cutting and gear tooth surface finish determined by other processes are the factors considered in this paper. The measurements include transmission error, coordinate measurement machine (CMM), pattern rating and surface roughness pre- and post-test. An ASTM L37-based (Ref. 1) dynamometer test procedure is adopted for the wear study with good correlation to field samples. The laboratory test samples are established based on the design of experiment (DOE) considering the controlled factors. The effects and interaction between the controlled factors provided the information for product improvement. The results of this study are anticipated to significantly improve product reliability and customer satisfaction.

The laboratory test samples are established based on design of experiment (Ref. 2) in considering the controlled factors.

Gear wear can be separated into two different types: one is the uniform wear of tooth surface that doesn't affect noise performance; and the other is the non-uniform wear of tooth surface that affects noise performance. The differences are shown schematically in Figure 1. Curve AA represents the original tooth profile. A uniform wear will remove material from the tooth and create a new profile BB. Due to the non-uniform wear, the actual profile is as shown by curve CC. The discussions in this paper are focused on the non-uniform gear wear.

Gear Surface Parameters

The parameters considered for the DOE include:

- Gear tooth profile
- Gear set TE (transmission error)
- Gear tooth surface finish determined by cutting and lapping
- Gear tooth surface finish determined by processes post-hardening test

Other factors affecting uniform gear wear are identified in the test procedure development stage and are excluded from the DOE for reasons explained above.

Measurement Methods

Both objective and subjective ratings are used in pre-test and post-test stages for comparison purposes.

- TE measurements (single flank tester): The first-order drive side TEs are measured pre-test and post-test. The difference in TE measurements pre- and post-test (Delta TE) is an important indicator of the uneven wear. This TE measurement process is defined as a hardening test. It is performed after lapping and prior to final processing.
- CMM measurements: The sum of squared errors compared to a master is a good way of measuring non-uniform gear wear. The sum of squared errors is the sum of the square of error at each grid point— Sum of squared errors = $\Sigma_{i,j}=1$ to N (Deviation at row i and column j)^2.

The uniform gear wear is covered by the tooth thickness change from CMM measurement results. The ratio of the post-test sum of squared errors versus the pre-test number is an indicator of the non-uniform wear based on appropriate resolution of mesh points. Figure 2 shows a typical pinion measured on a CMM prior to gear wear testing. Figure 3

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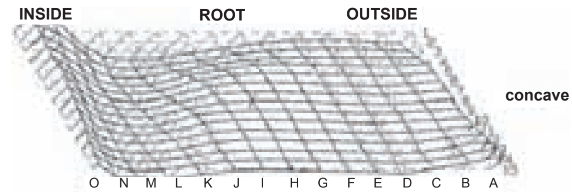

Figure 3—Post-test pinion CMM results with less non-uniform wear.

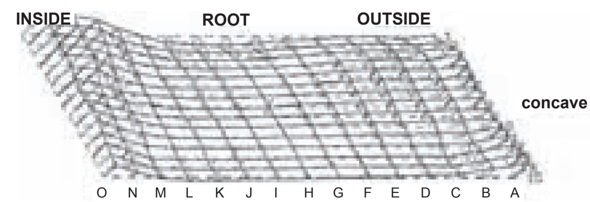

Figure 4—Post-test pinion CMM results with more non-uniform wear.

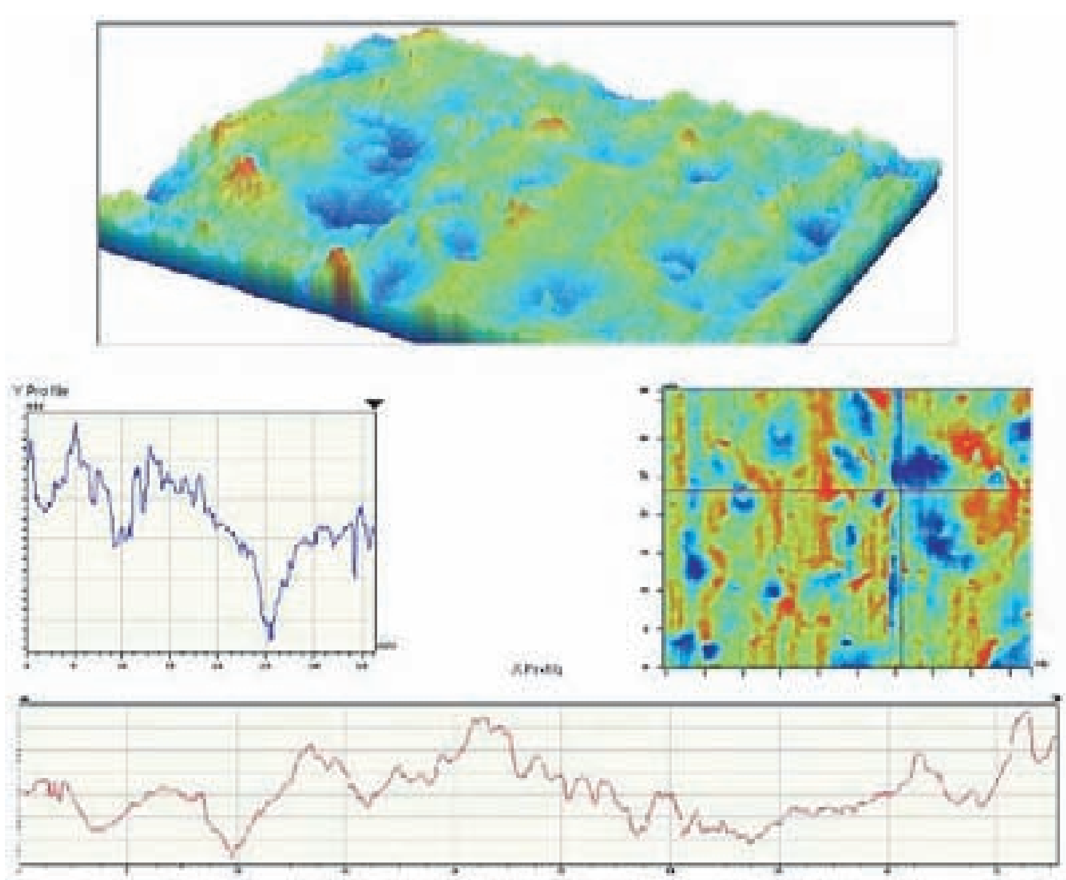

Figure 5—Typical gear tooth surface roughness.

shows a pinion with less non-uniform gear wear after wear testing. Figure 4 shows a pinion tooth surface with more non-uniform wear after wear testing.

- Pattern rating: This is a subjective rating helpful during development of the test procedure. The ratings range from 1 to 10 with 10 as the best pattern and 1 the worst. The patterns of the test gear set are taken and documented before and after testing. A qualified gear set representing the development has been used as the semi-masters. Patterns of pinion and gear rolled against semi-masters separately after testing are also documented to identify the wear on each part.
- Surface roughness: The pre-test and post-test surface finishes are part of the measurements. A typical hypoid gear tooth surface roughness is as shown in Figure 5. The three-dimensional surface can be established by scanning an area. The surface roughness numbers used in the DOE are along the tooth profile direction.

Test Method

The developed lab test is based on ASTM L37 dynamometer testing. The test load and speed were selected on the basis of testing several similar gear sets and observing the induced tooth wear. Care was taken to obtain a set of accelerated test parameters that induce only tooth wear and not any other type of system failure. It is a high-load, low-speed test intended to duplicate non-uniform gear wear with the gear contact pattern in Figure 8. A 24-hour test procedure is effective in differentiating the non-uniform gear wear of samples with different parameters. The test equipment is shown in Figure 6. A typical pinion after wear testing is shown in Figure 7.

A typical contact pattern from the field return is shown in Figure 8. The worn patterns are typically narrow in the profile direction and toward the root. Figure 9 and Figure 10 are the post-test patterns from the wear testing. The contact pattern in Figure 9 exhibits patterns typical of a worn gear set. A lesser amount of pattern narrowing and position movement along the profile direction can be observed in Figure 10.

DOE Samples

The dimensions of the tested gear set are listed in Table 1.

A full factorial of three controlled parameters is considered in the DOE. Each parameter is tested at high/low levels. A total of 16 samples were tested, with two duplicated samples for each test condition.

- 1st parameter: Gear set process post-hard test. Two different processes are considered in the DOE.

Figure 6—Test equipment.

Figure 7—A typical pinion post-test.

Figure 8—A typical contact pattern from field return.

Figure 9—Post-test contact pattern from wear test sample.

Level 1 is the current process post-hard test. Level 2 is the proposed new process.

- 2nd parameter: Gear set assembly backlash at high/low levels. This parameter is to control the pat tern position to simulate tooth profile change and TE change due to cutting and lapping processes.
- 3rd parameter: Gear set process pre-hard testing. Two levels of lapping processes are considered. Level 1 is the current production lapping cycles. The lapping cycles in Level 2 were modified to reflect different surface conditions.

Both pre-test and post-test measurements include TE, sum of squared error, contact pattern and surface roughness.

Test Results

Minitab was used for the test result analysis (Ref. 3). A Pareto chart is essentially a bar chart in which the bars are ordered from highest to lowest. A factor with a standardized effect of more than 2.306 is statistically significant. The main effect is the difference between the factor level mean and the overall mean. An interaction is present when the response at a factor level depends upon the level of other factors.

The hypoid pinion is the part showing the most significant non-uniform wear. This is shown in the patterns rolled with the semi-master. Figure 11 shows the pattern rolled between a tested gear and the semi-master pinion. It doesn't show obvious pattern narrowing or position change, as in Figure 9. Figure 12 shows the pattern rolled between a tested pinion and the semi-master gear. It is similar to that in Figure 9 with narrowing pattern and position change. The patterns rolled with semi-masters suggest that the test pinions are the primary source of non-uniform wear. CMM measurements also confirm the trend, as shown in the sum of squared errors.

All the test data are included in Figure 13. "Delta TE" is the difference between post-test TE and pre-test TE divided by pre-test TE. "Delta Pin Surf" represents the difference between post-test surface roughness and pre-test surface roughness for the pinion divided by the pre-test number. "Delta Gear Surf" presents the numbers for the gear with the same definition as the pinion. "Pin Sum of Sqrd" is the ratio of the post-test sum of squared errors divided by the pre-test sum of squared errors for the pinion. "Gear Sum of Sqrd" is the ratio of the post-test sum of squared errors divided by the pre-test sum of squared errors for the gear. The numbers were normalized to have a commonality for comparison between different measurements.

The most significant factor in this study is the post-process after hard testing. Gear sets from process two show better results than gear sets from process one in the pinion sum of squared errors ratio, Delta TE and subjective pattern ratings (Figure 10 versus Figure 9) in Figure 13. Delta pinion surface finish, Delta gear surface finish and gear sum of squared errors ratio are not closely related to the post-test pattern, as shown in Figure 13.

The Pareto charts, main effects plots, and interaction plots

continued

Figure 10—Post-test contact pattern from wear test sample with less severity.

Table 1 Tested Gear Set

Item	Number
Ratio	4.88
Diametral pitch, 1/in.	3.2
Offset, in.	1.4
Pitch diameter, in.	12.2

Figure 11—Post-test contact pattern between tested ring gear and semi-master pinion.

Figure 12—Post-test contact pattern between tested pinion and semi-master ring gear.

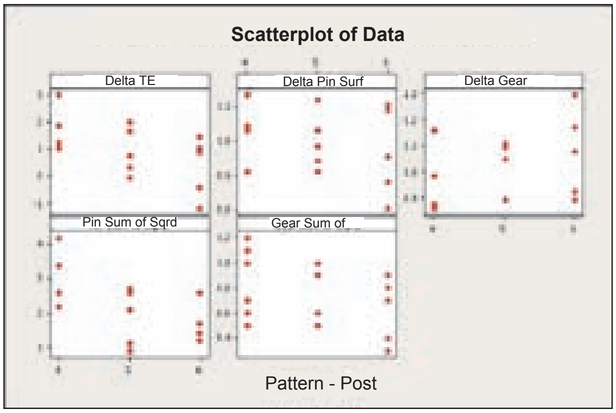

Figure 13—Scatter plot of all data—delta TE; delta pinion surface roughness; delta gear surface roughness; pinion sum of squared errors; and gear sum of squared errors.

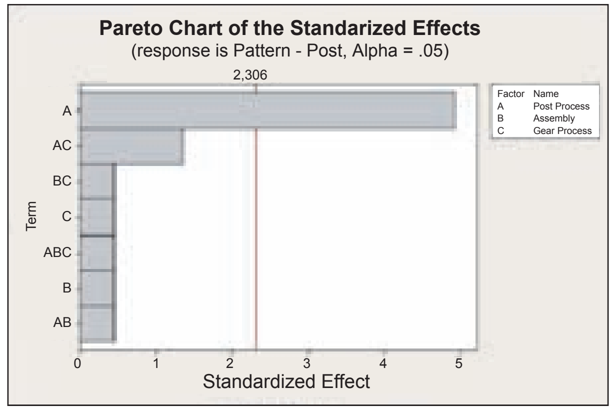

Figure 14—Post-test pattern rating Pareto chart.

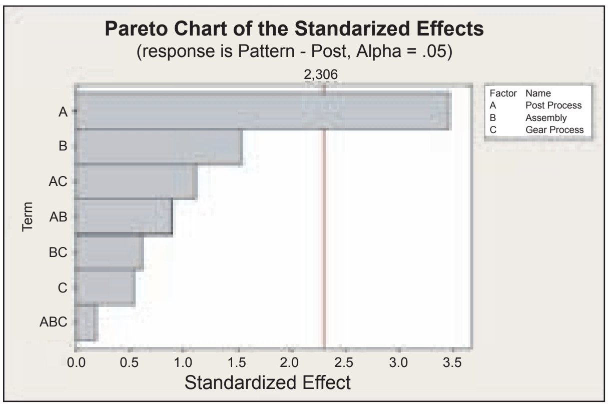

Figure 15—Pinion sum of squared errors ratio Pareto chart.

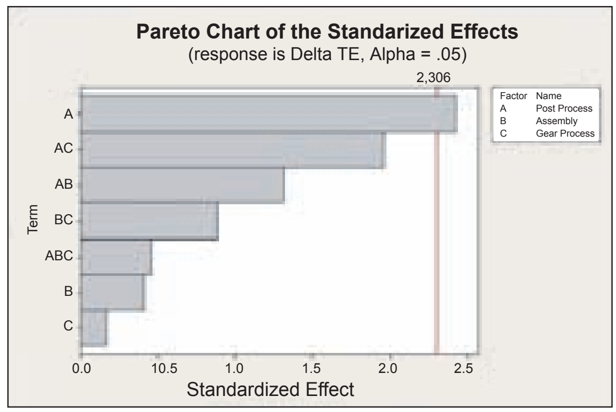

Figure 16—Delta TE Pareto chart.

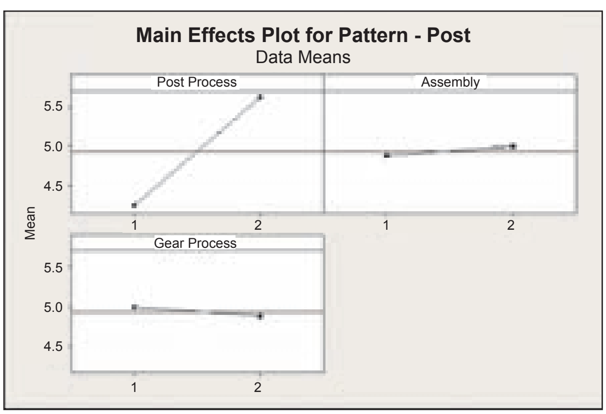

Figure 17—Post-test pattern rating main effects.

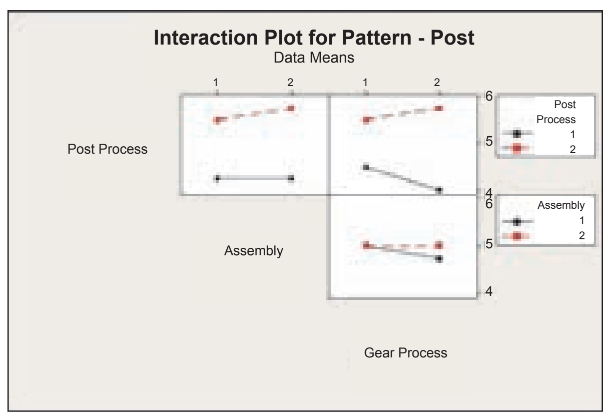

Figure 18—Post-test pattern rating interaction.

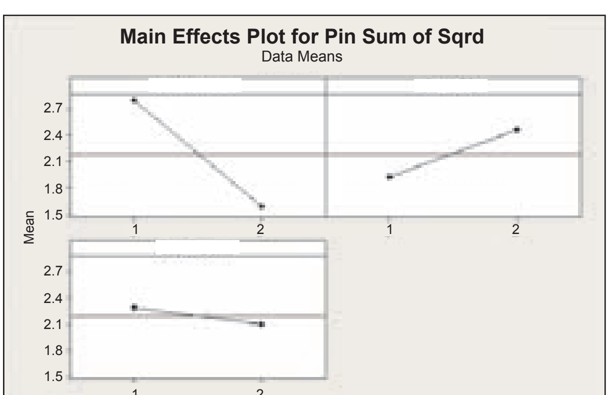

Figure 19—Pinion sum of squared errors ratio main effects.

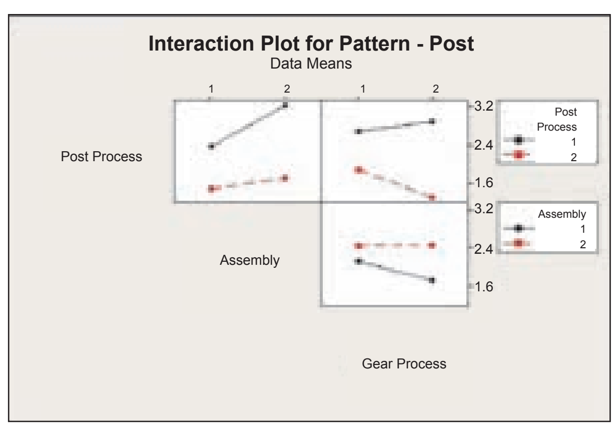

Figure 20—Pinion sum of squared errors ratio interaction.

for post-test pattern rating, pin sum of squared errors and Delta TE are shown in the following figures. The factors shown in the figures are abbreviated due to software limitations. "Post process" refers to the gear set process post-hardening testing. "Assembly" means gear set assembly backlash at high/low levels. "Gear Process" is the gear set process pre-hardening testing.

The post process after hardening testing is clearly the most significant factor that affects the results. The Pareto charts in Figure 14, Figure 15 and Figure 16 demonstrate that only factor A is statistically significant in the effects of post-test pattern rating, pinion sum of squared errors and Delta TE.

The plots in Figures 17, 19 and 21 show "Post-Process" as the most significant factor for post-test pattern rating, pinion sum of squared errors ratio and Delta TE. Figures 18, 20, and 22 indicate different level of interactions between "Post-Process," "Assembly" and "Gear Process." The amount of interaction is not significant enough to change the importance of the factors.

Conclusion

The test procedure and measurement methods discussed in this paper prove to be a feasible approach in determining the cause of non-uniform gear wear within acceptable time constraints. The effects and interaction between controlled factors provided the information for product improvement without specifically identifying the root causes of non-uniform gear wear. The action resulted from this study is anticipated to significantly improve product reliability and customer satisfaction. Further studies with enhanced control of factors can contribute to the identification of non-uniform gear wear phenomena in the future.

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2. Bhote, Keri R. and Ade K. Bhote. "World-Class Quality using Design of Experiments to Make It Happen," *American Management Association*, 2000.
3. *Minitab*, Minitab Inc., 2006.

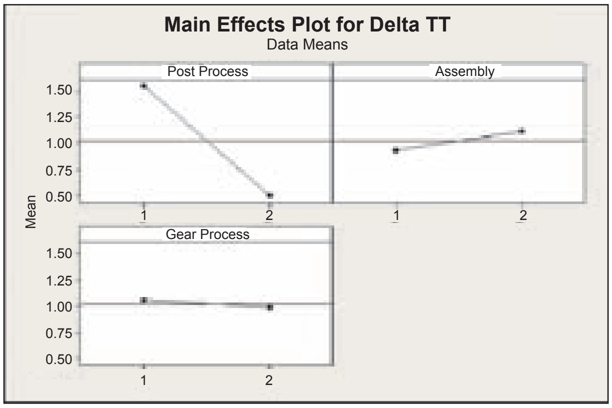

Figure 21—Delta TE main effects.

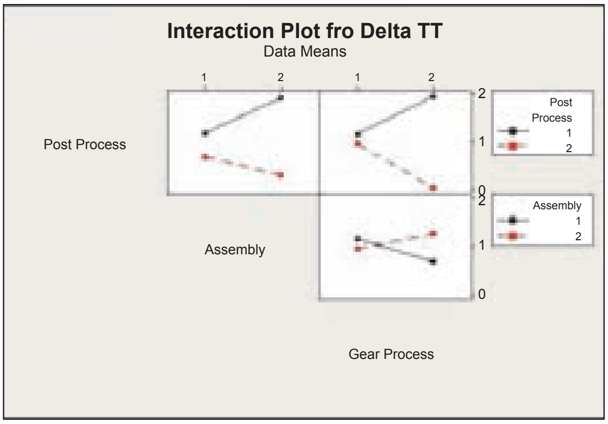

Figure 22—Delta TE interaction.

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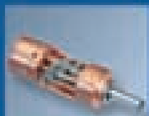
Hai Xu *is currently working in the Gear Engineering Department of Dana Holding Corporation in Kalamazoo, Michigan. He is responsible for design, development and research of axle gearings with main interests in hypoid gearing fatigue life, noise, wear, friction and efficiency. He obtained a masters of science degree in mechanical engineering from the University of Michigan-Dearborn in 2002, and a Ph.D. in mechanical engineering from The Ohio State University in 2005. He is a member of ASME, SAE and Sigma Xi.*



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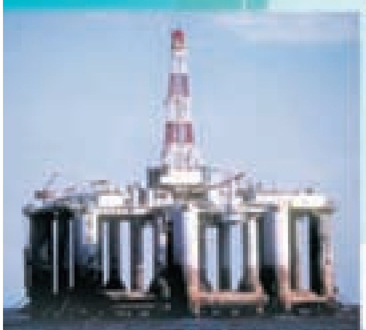

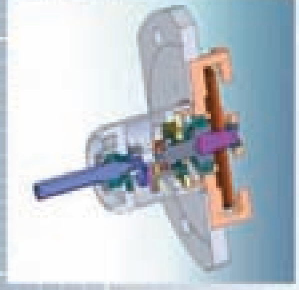

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The Replacements

TAKING STEPS TO STRENGTHEN THE FUTURE SKILLED WORKFORCE

Matthew Jaster, Associate Editor

Sarah Williamson (left), Nathan Young (center) and Christopher Melton (right) work on an engineering project at Morton High School in Morton, IL. Photo courtesy of A3 Creative Group.

For years, politicians, educators and business leaders have generated various ideas to revitalize U.S. manufacturing and engineering. These include manufacturing initiatives, internal training programs and an emphasis on science, technology, engineering and mathematics (STEM) in the classroom. The declining expertise in these fields, however, continues to be a growing problem in every facet of manufacturing and engineering.

Each year, many respondents to *Gear Technology*'s "State of the Gear Industry" survey voice their concerns about the lack of skilled workers available in the United States. In 2009, retirements, resignations and various cutbacks will force many companies to look toward the next generation of workers to pick up the slack. If you're worried this incoming workforce might not live up to expectations, you're not alone.

Whether it is inadequate math and science skills, misguided education programs or simply the 1950s perception of manufacturing by parents, students and teachers, things will need to change in order to better prepare future manufacturers and engineers for careers in these fields.

The government and the academic community are tackling the issue, but it's the manufacturers themselves that must take a more proactive role.

A New Direction in Manufacturing

Joe Arvin, president of Arrow Gear, attended vocation night at a local high school in Downers Grove, Illinois. He noticed students packing into rooms for information on careers in computer programming, marketing and sales. The room for manufacturing jobs was empty most of the night.

"Two students came in," Arvin says. "One said he had come because his father told him he had to and the other said he came in just to accompany his friend."

Training and recruitment are vital to the success of Arrow Gear. The company has attended job fairs, visited trade schools and universities and produced a video to communicate to students that a job in manufacturing is not a dirty, oily job.

"We have a clean, modern and well lit factory with CNC machine tools. The operators do not get hit with hot chips and there is no oil being sprayed on them."

continued

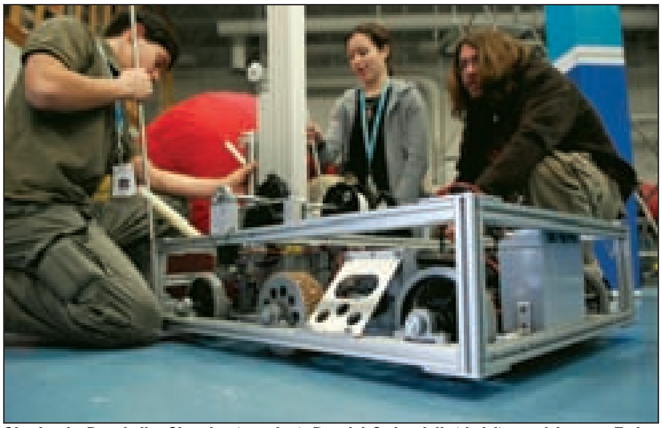
Unfortunately, the perception of manufacturing is stuck in the past.

"We need an immediate change in perception in regards to engineering and manufacturing, not only the impression of the students, but the parents," says Niel Tebbano, vice president of operations for Project Lead the Way (PLTW), a foundation developing engineering curriculum at the pre-college level. "Many parents still carry the antiquated impression of manufacturing as it was 50 years ago."

Tebbano sees a growing need to market contemporary engineering and manufacturing to students interested in relationships and life sciences, particularly young women.

"How does manufacturing and engineering contribute to saving lives? Emphasizing what's possible in these fields in terms of improving human life is so important," Tebbano says. "These are the kinds of things that resonate with young people and the approach that needs to be taken."

Student Christopher Moss gets hands-on with an engineering assignment at Riverside University High School in Milwaukee, WI. Photo courtesy of A3 Creative Group.



Students Daniella Shada (center) David Schmidt (right) and Lucas Zahn (right) participate in a PLTW program at the Lakeview Technology Academy in Kenosha, WI. Photo courtesy of A3 Creative Group.

Sylvia Wetzel, chief learning officer at Bison Gear, knows how important it is to deliver a consistent message to students on the value of manufacturing careers.

"There is certainly a need for STEM education awareness," Wetzel says. "We need programs that are sponsored towards the positive side of manufacturing, programs young people see as a challenging, productive path for their careers."

Bison works closely with educators, counselors, students and teachers to deliver this message. The organization hosts tours for students that provide an in-depth overview of manufacturing careers, a history of the industry and a firsthand look at production.

"I'm hoping the new administration supports and creates initiatives that help manufacturing companies excel and provides the career paths that are so desperately needed for young people to succeed in life," Wetzel says.

Initiatives are being developed by the Obama administration to boost the renewable energy sector, create five million new green jobs and put major investments into the next generation of scientists and innovators. The administration also plans to double the funding of the Manufacturing Extension Partnership (MEP), a program to improve efficiency, implement new technology and strengthen company growth in the manufacturing sector.

"While the new administration is well intended with what it would like to do, there are certainly one or two other items on their agenda," Tebbano says.

That leaves the task up to the manufacturers themselves. In order to bolster the next generation of skilled workers, companies must be more involved in education programs and manufacturing initiatives.

Fine-Tuning Early Education

While manufacturing initiatives continue to educate, many feel these programs are missing one important ingredient–the manufacturers.

"The overall attitude on science and engineering education is that it's the responsibility of the state and local districts and not the manufacturers and engineers. I believe there is too much at stake for these organizations not to be directly involved," Tebbano says.

PLTW reinforces relationships between corporations and schools through its partnership teams. These teams consist of local business leaders, educators and parents and serves as a resource for local teachers involved in a PLTW program.

"We've had enormous success with these partnership teams," Tebbano says. "I applaud companies like Lockheed Martin, the Society of Manufacturing Engineers (SME), and Rockwell Automation for making a full commitment to our program."

Rockwell Automation, headquartered in Wisconsin, has strong relationships with the Milwaukee Public School District. The company supports STEM education programs such as PLTW and For Inspiration and Recognition of Science and Technology (FIRST), an afterschool programming initiative.

"Rockwell provides opportunities for public school students in K-12, as well as students participating in summer technology programs," says Mary Lou Young, director of global community relations at Rockwell. "Our employees support many of our STEM partnerships as volunteers and mentors. We're excited about the growing number of participants in STEM programming and encourage other companies to do what they can to help the next generation."

Another area where companies can contribute to these initiatives is by sponsoring various community projects.

"Rockwell has developed a hands-on learning vehicle called the Rockwell Automation Dream Machine at Discovery World in Milwaukee," Young says. "We also helped fund the Toymaker 3000 exhibit at the Museum of Science and Industry in Chicago. Both of these exhibits help to excite and engage students and promote an interest in technology."

The goal, according to Tebbano, is to break the mindset that corporations shouldn't be involved in STEM education.

"Corporations are the best resource to gauge what the future workforce requires. They are in the perfect position to make sure these education programs are heading in the right direction," Tebbano says. "There's a significant difference between what academia sees as essential skills and knowledge compared to what corporations believe is necessary."

A study conducted by the National Academy of Engineering (NAE) entitled "Changing the Conversation: Messages

continued on p.79

PLTW Instructor Armando Dominguez and students Evelyn Correa (front) and Damaris Santoyo (center) at Escuela Vieau School in Milwaukee, WI. Photo courtesy of A3 Creative Group.

Wind Education Opportunities

Iowa Lakes Community College offers a wind technician training program for college students that features a Vestas wind turbine on-campus for hands-on training. Photo courtesy of Iowa Lakes Community College.

The National Science and Technology Council reports that the number of college graduates receiving degrees in science and engineering declines each year in the United States. Bad news considering industries like wind power will require a substantial number of skilled workers for all the major expansion projects planned.

"The expansion of wind power in the United States requires training and hiring skilled personnel to design, build, operate, maintain and advance wind power equipment and technology, according to a report by the U.S. Department of Energy," says Christine Real de Azua, assistant director of communications at the American Wind Energy Association (AWEA). "The wind energy industry is reaching out to academic programs and to companies along the supply chain and across the country, to make them aware of the tremendous employment and business opportunities available thanks to wind power."

Support from industry, trade organizations and government offices will ensure that university programs will be made available to students interested in careers within the wind power sector. Real de Azua states that many wind programs are at different stages of development and interested students and corporations should contact colleges directly to get involved in these programs.

Wind Power Programs in the United States

University of Arkansas–Supply Chain Management Research Center
Phone: (479) 575-2000 ***http://scmr.uark.edu***

Cuyamaca College
Phone: (619) 660-4020

University of California, Davis
Phone: (530) 752-7741 ***http://cwec.ucdavis.edu***

Iowa Lakes Community College
Phone: (712) 632-8374 ***www.iowalakes.edu***

The University of Iowa
Phone: (319) 335-5934 ***www.icaen.uiowa.edu/~ankusiak***

Boise State University
Phone: (208) 426-4078 ***www.boisestate.edu***

Sauk Valley Community College
Phone: (815) 835-6218 *www.svcc.edu*

Cloud County Community College
Phone: (800) 729-5101 *www.cloud.edu*

Cape Cod Community College
Phone: (508) 362-2131 *www.capecod.edu*

University of Maine–AEWC Composites Center
Phone: (207) 581-2121 *www.aewc.umaine.edu*

Lansing Community College
Phone: (517) 483-1339 *www.lcc.edu*

Minnesota West Community and Technical College
Phone: (507) 223-7252 *www.mnwest.edu/human-resources*

Mesalands Community College
Phone: (505) 461-4413 *www.mesalands.edu/wind*

Alfred University
Phone: (607) 871-2623 *www.alfred.edu*

Clarkston University
Phone: (315) 268-6509

Wayne Technical and Career Center
Phone: (315) 589-2600 *www.wflboces.org/wtcc*

Oklahoma State University–Oklahoma City
Phone: (405) 945-3376 *www.osuokc.edu*

Columbia Gorge Community College
Phone: (541) 506-6031 *www.cgcc.cc.or.us*

Penn State University
(814) 865-2569 *www.psiee.psu.edu/windenergy*

Holland College
Phone: (902) 888-6730 *www.hollandcollege.com*

Mitchell Technical Institute
Phone: (800) 952-0042 *www.mitchelltech.edu*

Texas Tech University Wind Science and Engineering Research Center
Phone: (806) 742-3476 *www.wind.ttu.edu*

University of Houston Wind Energy Center
Phone: (713) 743-5053 *www.egr.uh.edu/wind/*

University of Texas Continuing Legal Education
Phone: (512) 232-1110 *www.utcle.org*

Utah State University
Phone: (435) 797-7051 *www.usu.edu*

University of Wisconsin–Madison
Phone: (608) 263-3064 *www.epd.engr.wisc.edu*

West Virginia University
Phone: (304) 293-7872 *www.wvu.edu*

for Improving the Public Understanding of Engineering," asked Americans to identify careers they felt carried great prestige in today's workforce.

In the study, firefighters, doctors, nurses, scientists, teachers and military officers were at the top of the list. Engineers came in below farmers, priests and police officers but higher than architects, lawyers, accountants and journalists. Manufacturers didn't make the list.

"Both teenagers and adults don't have a strong perception of what engineering and manufacturing is or how it contributes to the quality of our lives," says Greg Pearson, senior program officer at the NAE. "This lack of awareness contributes to kids not considering careers in these various fields."

The NAE has seen strong signs that kids who are exposed early on to engineering—late elementary school—have a greater chance of pursuing careers in technical fields.

"It seems to be around this age that turnoff really seems to kick in," Pearson says.

While educational programs like PLTW, Engineering is Elementary and Infinity Project are developing engineering curriculum at the pre-college level, there is currently not a nationwide system in place.

"We know through preliminary studies that half a dozen countries offer pre-college engineering courses, but we don't know the effect these courses are having on the students," Pearson says. "England, Australia, Israel, France, the Netherlands and South Africa all have some sort of engineering activity before students go to college."

Pearson says one potential problem in the United States is that many teachers don't have the right background for engineering and manufacturing instruction.

"These classes are being taught by industrial arts or technology educators. Some engineers are teaching K-12 graders, but not enough to make a significant impact."

Reinforcing the Talent Pool

As the academic community stresses the importance of early education in these fields, another essential tool is recruiting at the high school and college level. Michael Sloan, associate dean of agricultural and industrial technologies at Illinois Central College (ICC), believes companies should take a more active role in the recruitment process.

"I think local manufacturers could spend some time with their high school administrators and faculty. Invite teachers to make your company a field trip destination. Focus on capturing the imagination of your young visitors. They need to think about creating internship experiences and growing their talent locally," Sloan says. "Manufacturers can teach educators about process improvements."

ICC, located in East Peoria, is receiving a $200,000 federal grant to develop interdisciplinary coursework that can be taught to high school students and adults in order to build reading, math and communication skills through manufacturing programs.

"Unlike professions in the healthcare industry, many

continued

occupations within manufacturing are not well defined," Sloan says. "It would help those interested in manufacturing to better understand how they can develop the necessary skills to perform the unique duties associated with a CNC machinist, production welder or maintenance person, etc."

Sloan says students and job seekers typically don't know what manufacturing positions are available to them and what skills are necessary to succeed.

"Those entering the labor force would feel more comfortable knowing how their skills are valued," Sloan says. "If more students understand the concept of value-added business and support local and regional companies, they may be more inclined to work for these organizations. Education, healthcare and other community needs are enhanced when manufacturing is strong within a region."

At Arrow Gear, the company is involved in the Manufacturing Skills Standards Council (MSSC), an industry-led training, assessment and certification system focused on the core skills and knowledge needed by the nation's production workers.

"While a move in the right direction, the MSSC does not go the full nine yards. It stops short of what we need to fill a skilled craftsman's job at our gear manufacturing plant," Arvin says. "The National Association of Manufacturers is working on a new program that will take the MSSC to the technical college level and produce people for the manufacturing industry that will have the basic skill levels required."

Wetzel at Bison believes that setting consistent, repeatable and sustainable standards is helpful in defining what is needed and deploying it in a process that is easy and attainable.

"Ron Bullock, our chairman, worked passionately towards defining the specific requirements needed by manufacturers in order to have those seeking employment prepared with the required core skill sets. These skills were encompassed in the MSSC that benefit all in safety, quality practices and measurement, process/production and maintenance awareness."

Before learning manufacturing skills, however, the next generation of skilled workers needs to concentrate on basic math and science.

"Young students are so technology savvy today," Wetzel says. They create YouTube messages and Facebook pages with graphics as if they were marketing experts. As for math and science skills, well, we're all aware that many students need to take remedial courses after graduation. This must be addressed in order to improve our socioeconomic crisis."

PLTW's Tebbano states that the resurgence of U.S. manufacturing and engineering will ultimately occur when all parties—the manufacturers, the educators and the government officials—come together for the common good.

"This nation has a real opportunity to reestablish its place in the competitive global market," Tebbano says. "The key will be our ability to innovate and create. This is the edge that American manufacturing, engineering and science have always had over the rest of the world."

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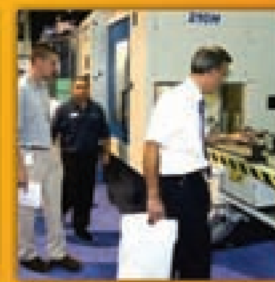

Windpower 2009

RELOCATES IN LIGHT OF RECORD GROWTH

It's not too often a trade show so far surpasses organizers' expectations for size that it must be relocated. This was just the dilemma the American Wind Energy Association (AWEA) faced with the Windpower 2009 Conference and Exhibition, which was originally scheduled to take place in Minneapolis, but will now be held at McCormick Place, Chicago.

"Subsequent to our initial decision to go to Minneapolis, there was an unprecedented explosion in demand for Windpower exhibition space and hotel rooms, which superseded even our association's aggressive planning for growth," says Randall Swisher, executive director of AWEA. "This was caused in part by the recent dramatic increase in interest in wind power by both government and business sectors. AWEA had planned for annual expansion of 20 percent to 40 percent based on growth over the past five years, but for Windpower 2008, attendance and the number of exhibiting companies were 85 percent higher than in 2007. The demand for show floor space for 2009, almost one year before the event, exceeds the entire available exhibition space in the Minneapolis Convention Center."

By August, exhibition space sold for the show already exceeded the entire scope of Windpower 2008. Attendance grew from 1,000 attendees at the 2001 event to 13,000 last year. At this size, only a handful of U.S. convention centers are large enough to host the show at all.

The event features over 776 exhibitors, 13,000 wind energy professionals, a day of pre-conference sessions, three days of conference sessions and—of course—endless networking opportunities.

Attendees span every area of the wind industry including project developers and operators, turbine manufacturers, component and accessory equipment suppliers, construction and transportation companies, government agencies, academic institutes and non-profit organizations. Gear-related companies with booths to visit include Columbia Gear Corp., Winergy Drive Systems, Moventas, AGMA, The Gear Works-Seattle, Bonfiglioli, Brad Foote (Broadwind Energy), Centa Corp., Comer Inudstries, Emerson Power Transmission, Oerlikon Fairfield and Jahnel-Kestermann Getriebewerke. Last but not least, don't forget to stop by the Gear Technology booth, number tktk.

The conference program features over 300 speakers and moderators, 150 poster presentations and 50 sessions on wind energy topics focusing on policy, business and technical subjects. The 2009 conference theme is Wind Power: Securing America's Energy Future.

Several day-long pre-conference seminars are offered in a range of subjects for more detailed technical education. As of press time, these topics had not yet been released, but last year's pre-conference seminars included the fundamentals of wind energy, what makes the development process successful, wind energy forecasting and safety.

"We are excited to be coming back to Chicago," Swisher says—Windpower 2004 was in Chicago. "The 'windy city' offers an ideal mix of hospitality and exhibition facilities in a vibrant downtown setting. We're excited to hold this event in a state that ranked in the top five for new wind project construction in 2007, and where new manufacturing jobs are being created thanks to this technology's rapid expansion."

Illinois legislation requires that 25 percent of all power for residential and small commercial customers be provided from renewable energy resources. Illinois investment in new wind projects is expected to hit $8 billion by 2025, according to the AWEA.

Windpower 2009 Conference and Exhibition takes place May 4–7 2009 at McCormick Place, Chicago. For more information on exhibit space, email *exhibition@awea.org* or visit *www.windpowerexpo.com*.

February 5-6—Root Cause Analysis Seminar. Holiday Inn Select Airport South, College Park, GA. Attendees will learn to perform root cause analysis using techniques including change, failure mode and effects, hazard-barrier-effects, fishbone diagram/cause & effects and timeline analysis. The seminar is designed for those responsible for identifying and reporting off-normal conditions, evaluating the conditions and their effects, identifying causal factors, recommending various types of corrective actions, tracking the implementation of corrective actions and managing the overall system. Instructor Ben Marguglio teaches how to use data codification, data grouping, data analysis and extent of condition as well as how to design, apply and manage problem reporting and corrective action systems. For more information, contact BW (Ben) Marguglio, (845) 265-0123, *ben@hightechnologyseminars.com*, or visit *www.hightechnologyseminars.com*.

February 19-20—Lean IT Workshop with Jean Cunningham. Holiday Inn-Elk Grove, 1000 Busse Road, Elk Grove Village, IL. If an IT system has a choke hold on the company's lean journey simply because the internal systems are hampered by outdated processes linked to the old batch and queue, this workshop with 2004 Shingo Prize for Research recipient Jean Cunningham will help jump-start the transition to lean. From 8 a.m. to 5 p.m. on Thursday and 8 a.m. to noon on Friday, Cunningham shares her own experiences as CFO and leader of IT for Lantech and Marshfield Door Systems in a presentation designed to benefit CIOs and CFOs, information application analysts, accounting managers, cost accountants, purchasing management planners and lean leaders in manufacturing companies. Cost is $845 for AME members and $995 for non-members. Advance registration recommended. Visit *www.ame.org* for more information on speakers, event logistics/cancellation policy.

March 2-7—Taipei International Machine Tool Show TWTC and Nangang Exhibition Halls, Taipei, Taiwan. Known by the acronym TIMTOS, this machine tool show has expanded into the newly constructed Nangang Exhibition complex to offer twice as much space as before. Last year TIMTOS attendance grew by 17.75 percent from the previous show in 2005, attracting 4,180 international visitors from 88 countries. This year organizers expect attendance to exceed 4,500 international visitors and 30,000 local players in the machine tool industry. Exhibitors include Mazak, DMG, Haas, Sodick, Siemens, Mitsubishi, Heidenhain and Bosch Rexroth. Taiwan has maintained double-digit growth in machine tool production and is the fourth largest exporting country after Germany, Japan and Italy. For more information, visit *www.timtos.com.tw*.

March 3-4—PIM2009. Royal Plaza Hotel, Lake Buena Vista, Orlando, FL. PIM2009 is the international conference on powder injection molding held by the Metal Powder Industries Federation (MPIF) and its affiliate APMI International. The conference follows a one-day PIM tutorial on March 2 and precedes a two-day workshop on medical applications of powder injection molding. The workshop will look at bio-micro manufacturing, promote R&D and foster networking. The conference objective is to continue exploring major technological advances, help transfer technology and pursue new developments in PIM of metals, ceramics and carbides. For more information, visit *www.mpif.org*.

May 4-8—PMI Spring Short Course. Porous Materials, Inc. headquarters, Ithaca, NY. Porous Materials, Inc. holds a short course twice a year gathering their experts in pore structure and characterization in addition to technical specialists from industries, research labs and universities. The course includes three days of intensive lectures, discussion and hands-on practice. Curriculum addresses theory and application of methods for determining pore structure and distribution in a wide variety of materials. Attendees will learn about the latest in porosity characterization techniques. It includes one-on-one discussions with staff, and each day ends dining out in Ithaca. For more information contact Al Teal at (607) 257-5544, (607) 257-5639 or visit *www.pmiapp.com/shortcourse*.

March 16—Kanban/Pull System/Inventory Reduction. Decatur Conference Center & Hotel, US Highway 36, Decatur, IL. A key component of most lean manufacturing strategies, this one-day Kanban workshop incorporates basic skills necessary to participate in Kanban implementation. Designed for individuals who may use or facilitate the use of Kanbans to move material and reduce waste. Kanban automates manufactured and purchased parts inventory cycles to reduce unwanted inventory and create waste-free processes. This event is sponsored by the Illinois Manufacturers' Association and the Manufacturers' Institute for Training, and it is also being held March 17 in Naperville, IL. For more information, contact Judy Parker at (800) 875-4462 x 3036, *jparker@ima-net.org* or *www.ima-net.org/MIT/iso.cfm*.

SARJ

REPAIRS SHOW PROMISE FOR SPACE STATION SOLAR POWER

Jack McGuinn, Senior Editor

Several spacewalks were required to make repairs to the SARJ. Photo/NASA.

Much has happened since we last reported on the malfunctioning solar array rotary joint (SARJ) attached to the International Space Station. Space shuttle Endeavour dropped in for a two-week visit in November during which repairs were made and invaluable data collected.

"We were able to clean, lubricate or replace 11 of the 12 trundle bearings assemblies (TBAs) on the starboard side (where the problem first arose)," says Kevin Window, NASA SARJ recovery team leader. "It took the better part of three EVAs (spacewalks); a pretty extensive job."

And, comically—in hindsight—a job not without incident. You may recall that during the initial EVA a tool bag containing a grease gun, a putty tool-like scraper and some other items slipped from the grasp of astronaut Heidemarie Stefanyshyn-Piper—lost in space, never to be seen again. Luckily, there was another set of tools onboard and the scheduled repairs were made without further incident.

From the beginning, the areas of greatest concern for flight engineers on the ground were the build-up of grit-like particles on the raceway of the TBAs, vibration in the SARJ truss and a spike upward in the motor current powering the system. As reported previously, these problems resulted in the SARJ being in disabled mode since its installation.

Window lays out the bearings issue.

"The trundle bearing is made up of three separate bearings—they have a bearing that rolls on each of the three surfaces of the race ring," he explains. "The inner- and outer-canted surfaces are at a 45 degree angle, the other is a flat surface. The bearings themselves have lubricant internal to the bearings and that's Braycote 601. But the lubricant that was utilized to lube the inner face between the trundle bearings roller and the race ring itself was gold—a solid lubricant. What we have determined in tests is that the lack of lubrication on that inner face causes excessive friction, which we have proven in a vacuum test that that excessive friction causes the bearings to tip on-edge, which increases our surface stress, and the surface stress was high enough to crack the nitride layer. That is what we have determined was the root cause."

Window adds that a few unresolved issues remain on his fault tree, but their resolution will come only when the hardware returns to earth for a hands-on inspection.

As for the repairs done in space, things went reasonably well.

"We went out there with a scraping tool, some wipes and Braycote 602, and we cleaned away as much debris (grit) as we possibly could," says Window. "We reapplied a one-eighth bead of lubricant all the way around on all three surfaces. We replaced the trundle bearings, and since then we have rotated (the SARJ) two complete revolutions. And what we have found is that the motor current that we had seen prior to lubrication has gone down tremendously. We had seen motor currents of .9 amps, and we're down to an average of .17 amps. We're

continued

back down close to where we first started the solar SARJ. The average current when we first started was .15."

Keep in mind, the vibrations caused by the amped-up motor are what set the alarm bells off at mission control. Looking into that problem is what led to the discovery of the debris build-up on the TBAs.

"The vibration is what concerned us tremendously, and it's why we stopped rotating the SARJ," says Window. "Vibrations like that can cause damage to a lot of other things. This is promising data that shows that most of those vibrations have gone away."

As for the debris, Window explains that its origin was the solid—or gold—lubed bearings. The recovery team determined that these bearings were compromised before the shuttle ever launched. Poor application of the gold at the factory was the root cause for that issue. That is what led to the team decision to re-lubricate the bearings with the Braycote. And just to be safe, they also added it to the bearings on the port side solar array.

"We did not replace any hardware on the port side. The port side at this point has no known damage to the race rings. We've inspected several different areas of it, and we haven't seen any damage to the race ring surface."

Once the repairs were made, the SARJ was put through two revolutions and data was collected. It is that data that will help in going forward.

"We're going to conduct another set of rotations and gather that data as well," says Window. "We're putting it in auto track, where the software moves it according to the rotation of the space station," as it was designed to do in the first place.

"We're then going to take that collected data and develop a new spectrum that the structures and dynamics folks can use in their model to determine what impact any vibrations that we see have on the structure itself. Previously, the damage that we were seeing after the vibrations—before we cleaned and lubed—was going to cause us problems. What we hope is that this new spectrum will show that those vibrations are basically in the noise and will not cause any structural damage to the truss. That's the hope. We'll see."

At this writing, the plan is to fly two additional solar arrays to the station in February. Both of them will be added to the existing arrays on the starboard side. Once that is done, more testing will be done and data collected.

"That will drive us to a decision that we need to make on what to do as far as any type of repair, or if we need to do a repair on the truss. We do have plans in place."

As for lessons learned, "We have learned that the lack of gold causes problems," says Window. "In addition to that—and I'm sure that there will be papers written on this and published—we had trundle bearings that flew on the starboard side that we have documented evidence that the gold was flaked off of the rolling surface prior to its use. There was an issue associated with how that gold plating was done. We also found that the gold wears off quicker than expected.

"One of the things that we found on the port side is some of the Braycote 601 that was internal to the bearing housing. It leaked out and that lubricant fell onto the race ring (thus re-lubricating the deficient gold-plated bearings). And that could have been enough to keep the port side from having a failure."

Irving Laskin

RECEIVES AGMA LIFETIME ACHIEVEMENT AWARD

Irving Laskin, a consultant in gear technology specializing in fine-pitch gearing and *Gear Technology* technical editor, received the AGMA Lifetime Achievement Award for his dedicated career in the gear industry. He accepted the award at the annual awards luncheon at the Fall Technical Meeting. Laskin has been involved in AGMA's technical committees for more than 25 years, serving as chairman of the Fine Pitch Gearing, Plastics Gearing and Powder Metallurgy Gearing Committees. Laskin was also a member of AGMA's Technical Division Executive Committee.

Laskin played a pivotal role in establishing the plastics and powder metallurgy segments of the industry within AGMA, and has been instrumental in recruiting many companies to become members. The award is given to a member of the industry who demonstrates vision and leadership, sharing knowledge and experience for the advancement of the gear community.

"Irving Laskin has been a mentor to many in the plastic gearing industry. He exhibits an unequaled thirst for knowledge of gearing issues and is always willing to disseminate that knowledge freely and passionately with many," says Richard Wheeler, president of plastic gear manufacturer ABA-PGT. "His devotion to the industry in preparing industry standards continues to this day and his contribution to the development of AGMA standards is unmatched based upon our experience. We applaud AGMA for their recognition of Irving Laskin."

American Axle

ANNOUNCES AGREEMENT WITH FORMTECH

American Axle & Manufacturing (AAM) recently announced a purchase agreement with FormTech Industries LLC. The agreement has American Axle exchanging its hub and spindle forging business for FormTech's differential gear, hypoid pinion and ring gear forging business.

In order to compensate for the difference in value, American Axle made a cash payment to FormTech. The parties also exchanged certain direct and indirect inventories, fixed assets and tooling related to the businesses.

"Through this asset purchase agreement, AAM has strategically acquired new forging process technology," says Richard Dauch, co-founder and chairman at AAM. "This strengthens our competitive position in the North American automotive forging market and enhances our ability to expand and diversify AAM's market penetration into transaxle components for passenger cars and crossover vehicles, as well as transfer case and all-wheel-drive components."

Hansen

APPOINTS DECLERCQ TO WIND ENERGY POSITION


Dr. Jan Declercq

Dr. Jan Declercq has been appointed director of business development/sales and marketing for Hansen Transmissions Wind Energy business unit. He joins Hansen after serving as technology development manager and business manager with Pauwels Trafo Belgium, a transformer manufacturer.

Declercq holds a doctorate in applied sciences from the University of Leuven, Belgium

continued

and several other university degrees. He's the chairman of the Agoria Renewable Energy Club, a network of experienced Belgian companies that provide solutions, products and services in the renewable energy field. Declercq is also a member of several international technology councils.

"We are very happy to welcome Jan on board our wind energy business," says Ivan Brems, CEO of Hansen Transmissions. "Jan has been familiar with the wind industry for many years and his experience and knowledge will contribute to the success of our further development in wind energy."

Siemens

SUPPLYING MAJOR DANISH OFFSHORE WIND FARM

E.ON has enlisted Siemens Energy to supply 90 wind turbines for its Rødsand II offshore wind farm, which will be one of the world's largest with a 207 MW capacity. The project will span 35 square km located south of the Danish island of Lolland in the Baltic Sea and 3 km west of the Rødsand I farm connected in 2003.

The Rødsand II wind farm will feature 90 Siemens 2.3 MW wind turbines with 93-meter rotor diameters and will save 700,000 tons of carbon dioxide emission per year. According to the Danish Energy Authority, around 200,000 households will annually be supplied electricity by the new wind farm, which is about 2 percent of Danish electricity use.

"We are building on the offshore experience of Rødsand I. It is a successful model, which we will replicate in the construction of Rødsand II," says Cord Landsmann, CFO of E.ON Climate and Renewables. "We are fortunate to have great engineers and great technology to get the job done."

Forest City Gear

INVESTS IN CAPITAL EQUIPMENT

Forest City Gear has announced it has invested more than $6 million in the purchase of new capital equipment during the last 18 months. This reinvestment was primarily made to expand the company's manufacturing capabilities and to maintain Forest City's manufacturing technology reputation.

Forest City Gear CEO Fred Young inspects a gear.

"Our customers expect Forest City Gear to lead the way in devising new production techniques to make better gears for them, at competitive cost with superior service. That's a tall order, but it's one we welcome," says Fred Young, CEO. "Our track record speaks for itself in this area, as Forest City Gear has invested an average between 25 and 40 percent of our annual revenue for the last 30 years in the purchase of gearmaking machinery and ancillary equipment."

One impetus for these new purchases was the company's success in supplying many of the gears on the 2011 Mars Rover, a win achieved in part because of the previous investment in technology. "We never wait until we get an order to buy machines with enhanced capability," Young says. "We already have it and have developed it, before we start exploring new opportunities."

Young also mentions that Forest City Gear frequently sells gears to its competitors, based on technology developed at his company. "We really believe in raising the bar for our entire industry. It gives us a competitive advantage, of course, but it's also a benefit to American manufacturers who represent our customer base and our future in business."

Broadwind Energy

ANNOUNCES EXPANDED ORGANIZATIONAL STRUCTURE

Broadwind Energy recently announced an expanded organizational structure and leadership team to support its wind and alternative energy business in North America. The structure will be comprised of key operating platforms, including towers, service, gearing, transportation and heavy fabrication.

Don Nabb has been named president of Broadwind's Gearing Platform. Prior to joining Broadwind, he was president

continued

of Smiths Interconnect and held executive positions with various manufacturing companies in the medical, aerospace, industrial and defense markets. Nabb earned his bachelor's degree in electrical engineering from the University of Wisconsin-Madison and holds an MBA from Notre Dame.

"It's an exciting time to join Brad Foote and continue the expansion of our largest carburizing and tooth grinding facilities to meet the growing demands of the wind industry," Nabb says.

Paul Smith has been named vice president and chief operating officer of Broadwind's tower platform. In his new role, Smith will oversee the Manitowoc, WI operations as well as the Sioux Falls, SD and Abilene, TX plants currently under construction. He has served as an executive consultant for Tower Tech since January 2008. Previously, Smith was general manager of DMI Canada, a manufacturer of wind towers. He holds an industrial engineering degree from Niagara College and has prior experience in the aerospace and automotive industries.

"By segmenting our operating units and adding seasoned top level executives to focus on execution excellence, Broadwind will be able to support the extraordinary growth we expect in the wind energy market," says J. Cameron Drecoll, CEO of Broadwind. "We are delighted that Broadwind is able to attract the caliber of talent required to support our customers' needs."

Sandvik Coromant

OPENS CHICAGO PRODUCTIVITY CENTER

Sandvik Coromant launched the Chicago Productivity Center with a ribbon cutting ceremony and open house November 12–13. The new facility, located in Schaumburg, Illinois, is designed to help manufacturers take advantage of their metalcutting operations. It joins three other similar North American centers in Fair Lawn, NJ, Mississauga, Ontario, and Monterrey, Mexico.

The Chicago Productivity Center houses classrooms, meeting areas, a tooling showroom and a machining floor with tools from Deckel Maho, Gildemeister, Haas, Mazak, Mori Seiki and Okuma. Customers and distributors visiting the

center will be presented with live demonstrations, seminars and advanced theory-based training courses. The focus is for American manufacturers to maximize productivity and profitability through understanding and application of the latest technologies in cutting tools, machine tools and machine processes.

"We've talked a lot over the past year of our dedication to maximizing support to our customers as they think smart, work smart and earn smart," says John Israelsson, president of Sandvik Coromant in North America. "The new Chicago Productivity Center is the physical embodiment of our commitment. Through it we will assist American manufacturers in staying at the forefront of new technologies."

Star SU

REPRESENTING FEDERAL BROACH

Federal Broach and Machine Company LLC has appointed Star SU LLC as a sales agent in North America for broach cutting tools and broaching machines. An agreement was signed November 1, between Federal Broach CEO Daniel T. Bickersteth and David W. Goodfellow, president of Star SU, as part of Federal's aggressive approach to expand its marketing worldwide. The two companies have a joint venture service center operation in Queretaro, Mexico, for regrinding, resharpening and recoating services for broaches, hobs and shaving cutters.

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Devotion in Motion

Om Mani Padme Hum—say what?

The Addendum staff had to delve deep into our Sanskrit vocabulary to come up with this sacred Buddhist mantra. There's no clear English translation, and interpretations of the meaning vary from source to source, but the phrase is universally invoked to infuse compassion during meditation and prayer.

The mantra can be found adorning Buddhist prayer wheels, known as, 'khor. Each cylindrical wheel is mounted on a spindle made from materials like metal, wood, leather or coarse cotton. Spinning the wheel is synonymous with reciting a prayer.

As far as the Addendum staff is concerned, there have been no known prayer wheels powered by gears—until now.

"Devotion @ 50 rpm" is an artistic installation of five translucent cylinders modeled after the Buddhist prayer wheels. Instead of manually spinning the wheels, artist Erich Schrempp automated them with small gearmotors. He chose to substitute the traditional mantra with brilliantly painted gears on Duratrans transparencies, which are illuminated by LED automotive bulbs inside the cylinders.

Schrempp's materials also consisted of threaded steel rods, soldered brass and copper fittings, 50 rpm gearmotors, superwhite LED automotive bulbs, 110 VAC to 12 VDC power supply, aluminum fan blades, steel hardware and copper wiring, in addition to melamine board, foam disc, interval timer and fabric. The display is powered on a total of 21.5 watts.

Aside from the artistic and conceptual concepts Schrempp developed, he had some more practical factors to consider in production. "Vibration was what concerned me most," he says. "Vibration's destructive force is like the tide: slow but relentless. With five motors turning 4,000 rpm each (geared 80:1 down to a manageable 50 rpm), I imagined the piece dismantling itself in pretty short order. Being old school when it comes to these things, I opted for dozens and dozens of lockwashers and tightened down all the nuts on the threaded rods to within an inch of their lives."

The kinetic sculpture held up perfectly for the eight-week installment at Sullivan Galleries in Chicago.

Vibration wasn't the only technical concern Schrempp had. "The practical aspects of making this thing work for 400 hours of operation were always on my mind. I wanted it to use as little power as possible, seeing how its Tibetan counterparts relied on the outstretched palms of passers-by for propulsion," he says. "This led to using the LED automotive bulbs, which together with the motors consumed a paltry 22 watts or so. This, in turn, solved the heat problem. The fact that the wheels were pretty flammable also argued for keeping the heat down. Going with existing automotive technology meant that everything could be 12 Volts DC, and a great many parts were to be had at Pep Boys."

The Addendum staff is grateful people are still finding practical, convenient uses for automotive parts.

"Devotion @ 50 rpm" was a joint venture between Schrempp and Winzeler Gear, but the idea materialized from some Instamatic camera pictures Schrempp's mother took decades ago on a vacation. "My mother was certainly the one who first told me about the prayer wheels. I wish I had a great story to tell about this, but the fact is that the image of those spinning cylinders pretty much gathered dust in the back of my mind for about thirty years before the opportunity to do a piece for the Sullivan Galleries came up," he says. "I started designing much wider, shallower cylinders in the first sketches, and then noticed the resemblance to the Tibetan wheels and changed the proportions accordingly."

Personal dogma wasn't an inspiration for the piece. Schrempp doesn't consider himself a religious person; although he holds a special respect for the peaceful nature of Buddhism. "It's the one major religion that isn't armed to the teeth, so you have to give them some credit for practicing what they preach," he says.

"Whether you believe every word of the Bible or think that God is Santa Claus for grown-ups, you can't ignore how profoundly the world is affected by the faith people put in ideas that can never be proven or disproven," he says. "It's about as far from engineering as you can get, which is why I enjoyed joining the two in this piece."