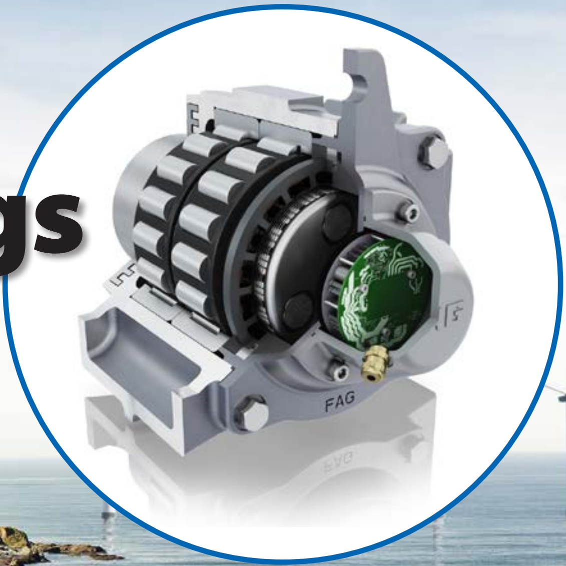
Power Transmission Engineering®

JUNE 2015

THE Path TO Smarter Bearings



The True Cost of Bearing Lubrication

A Deep Dive Into an Aerospace Gear Manufacturer

Automotive Transmissions in Transition

www.powertransmission.com

Affordable Power Transmission

high-quality components at low prices!

SureMotion

Synchronous Drives

AutomationDirect's new line of synchronous drive components provide the same positive timing action of gears or chains but with the flexibility and quiet running of belts.

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- **Timing (toothed) belt options include several popular pitches and widths and are made of fiberglass reinforced neoprene.**
- **Tapered bushings in both QD® and Taper-lock® styles are available in most popular shaft sizes for mounting a variety of pulleys or sprockets to shafts.**

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Drive Belts
starting at:
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IRONHORSE®

Worm Gearboxes

IronHorse® worm gearboxes are manufactured in an ISO9001 certified plant by one of the leading worm gear reducer manufacturers in the world today. They are available in both aluminum and cast iron with a variety of frame sizes and ratios. Dual shaft, right hand shaft, and hollow shaft options are offered and come with a one year warranty.

- **Aluminum gearboxes start at $88.00**
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SureGear®

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The SureGear® PGCN series is an exceptional gearbox for servo, stepper, and other motion control applications requiring a NEMA size input/output interface. Available in NEMA 17, NEMA 23 and NEMA 34 frames sizes with a wide range of ratios, a 20,000 hour service life, and a one year warranty.

The SureGear® PGA and PGB series of high-precision servo gear reducers are excellent choices for applications that require accuracy and reliability at an exceptional value. The PGA series is an in-line configuration while the PGB series is a right-angled reducer. Both provide a level of precision and torque that is best in class and come with a five year warranty.

- **SureGear small NEMA motor gearboxes start at $209.00**
- **SureGear servomotor gearboxes start at $398.00**

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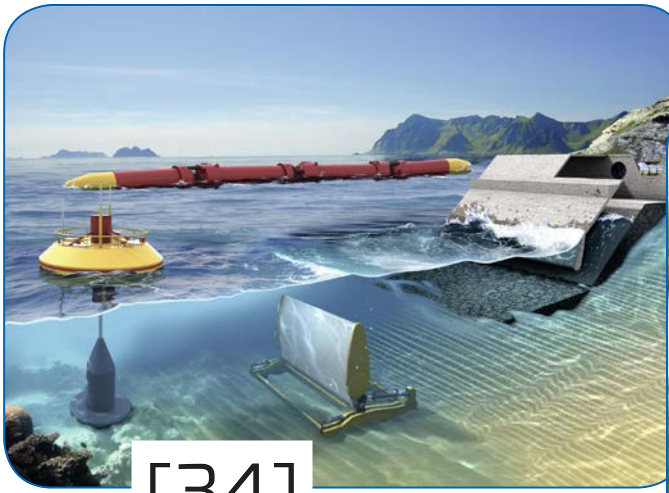

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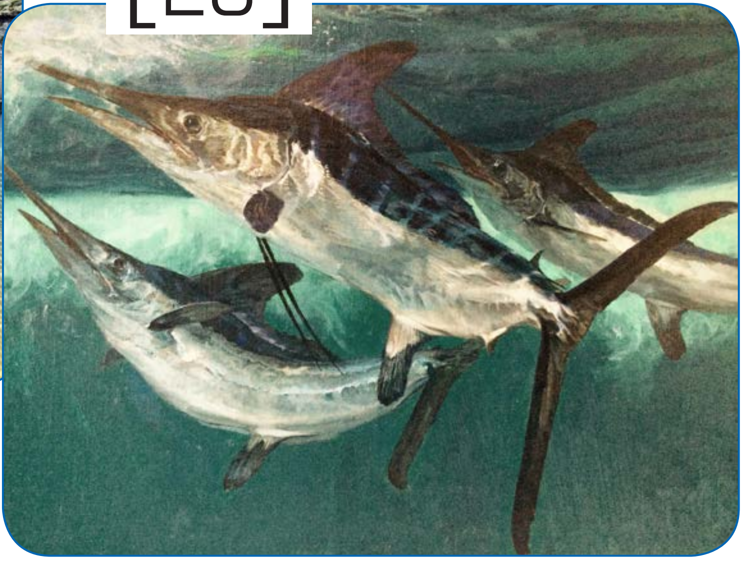

FEATURE ARTICLES

TECHNICAL ARTICLES

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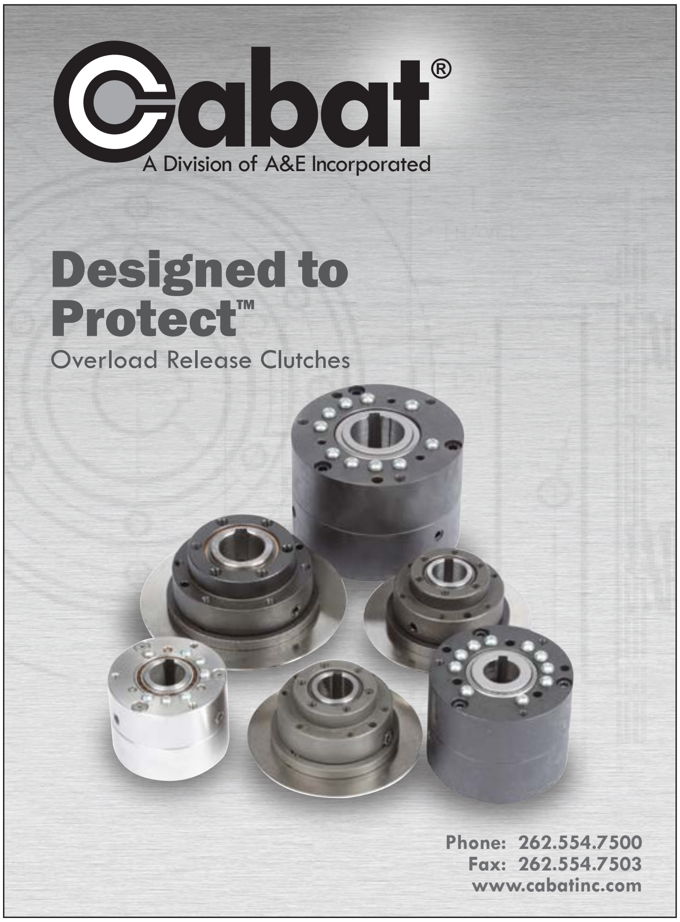

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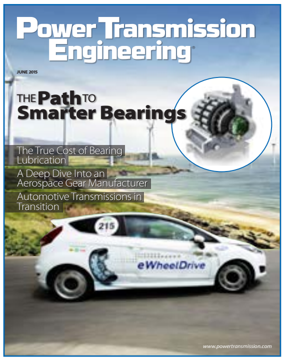
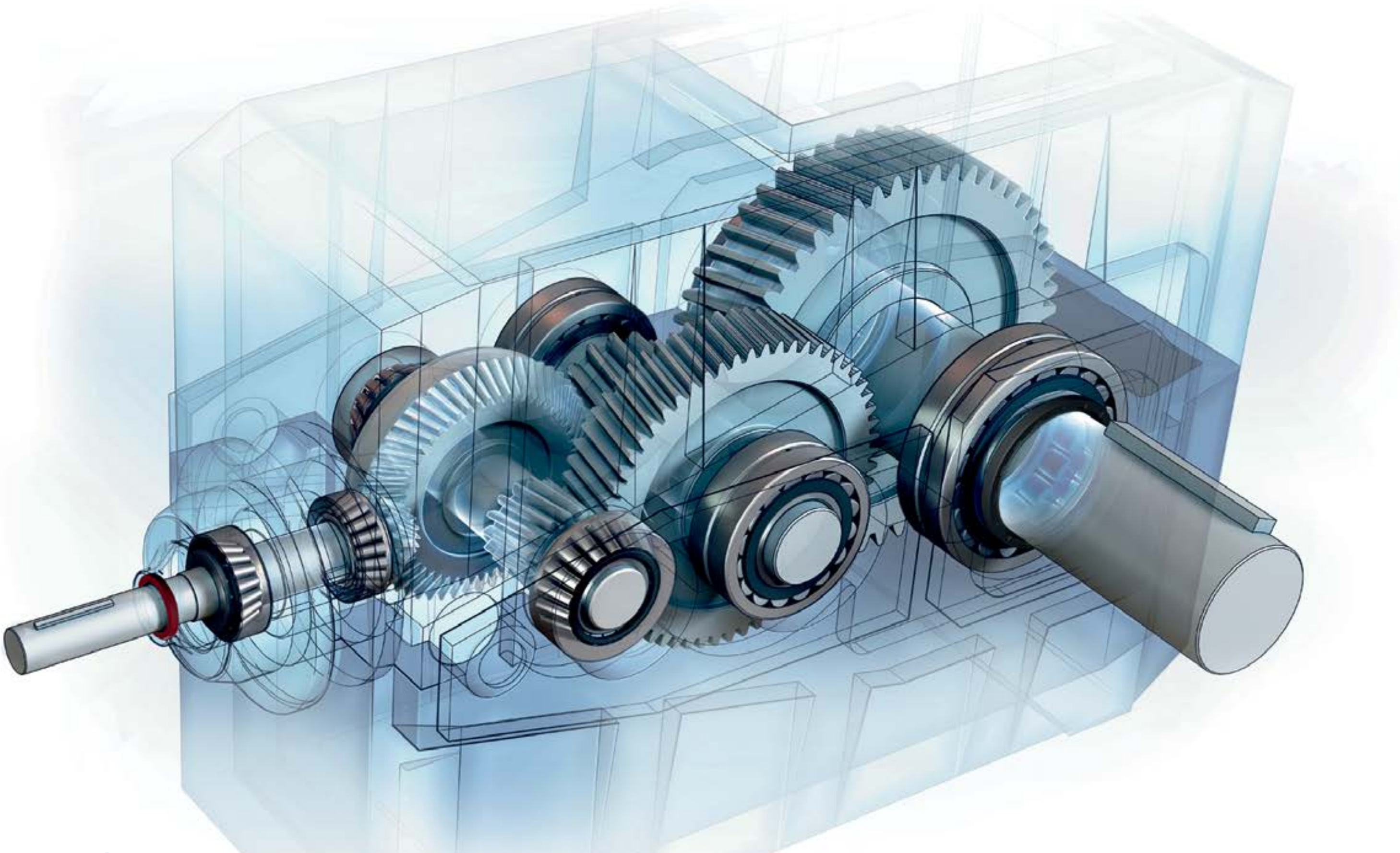
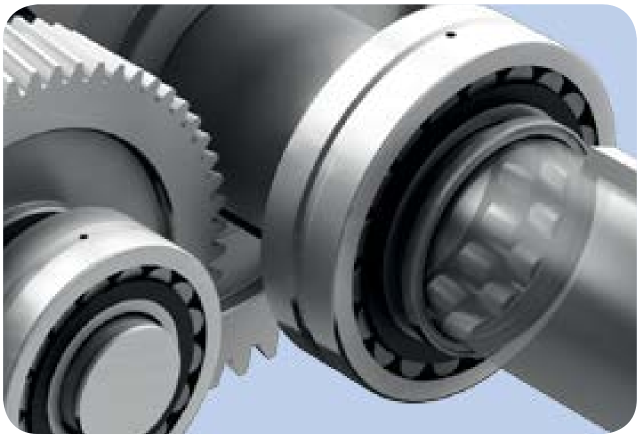
VOL. 9, NO. 4



Cover photos courtesy of the Schaeffler Group





www.powertransmission.com

More Suppliers, More Choices

We're constantly improving the online **Buyers Guide** at *powertransmission.com* by adding new suppliers of gears, bearings, belts, clutches, couplings, motors and other mechanical power transmission components. Stop by the site to see who's been added recently:

MiHow2 Video Instruction

Motion Industries produces a series of educational videos in conjunction with the major manufacturers of power transmission equipment. These videos give tips on the proper maintenance, installation and use of various products. Here are a sampling of recent topics:

- Troubleshooting Elastomeric Couplings
- How to Make Sure You Have the Correct Amount of Tension in Your Chain
- Advantages of Hypoid Gearing

Many of the videos are hosted by Tom Clark, and are part of the *Tom's Toolbox* series. To see the videos, visit *www.mihow2.com*.

Calendar (see more events)

GEAR EXPO 2015 THE DRIVE TECHNOLOGY SHOW October 20-22 • Detroit • Cobo Center Solutions: Gear Making & High Performance Drives

SEMICON West 2015 (July, 16 2015)
Moscone Center, San Francisco, CA. SEMICON West is the premier annual event for the global microelectronics industry, highlighting the la...

Ipsen U (August 6, 2015)
Cherry Valley, IL. This three-day course provides attendees with a broad overview of furnace equipment, processes and maintenan...

Asia International Gear Transmission Expo 2015 (August 8, 2015)
As Asia's most influential, professional and authoritative gear industry event, GTE has been held 10 years in a row and during that...

Upcoming Events

Powertransmission.com is your resource for the latest information on upcoming events related to design engineering and the use of mechanical power transmission products. Visit often and stay informed.

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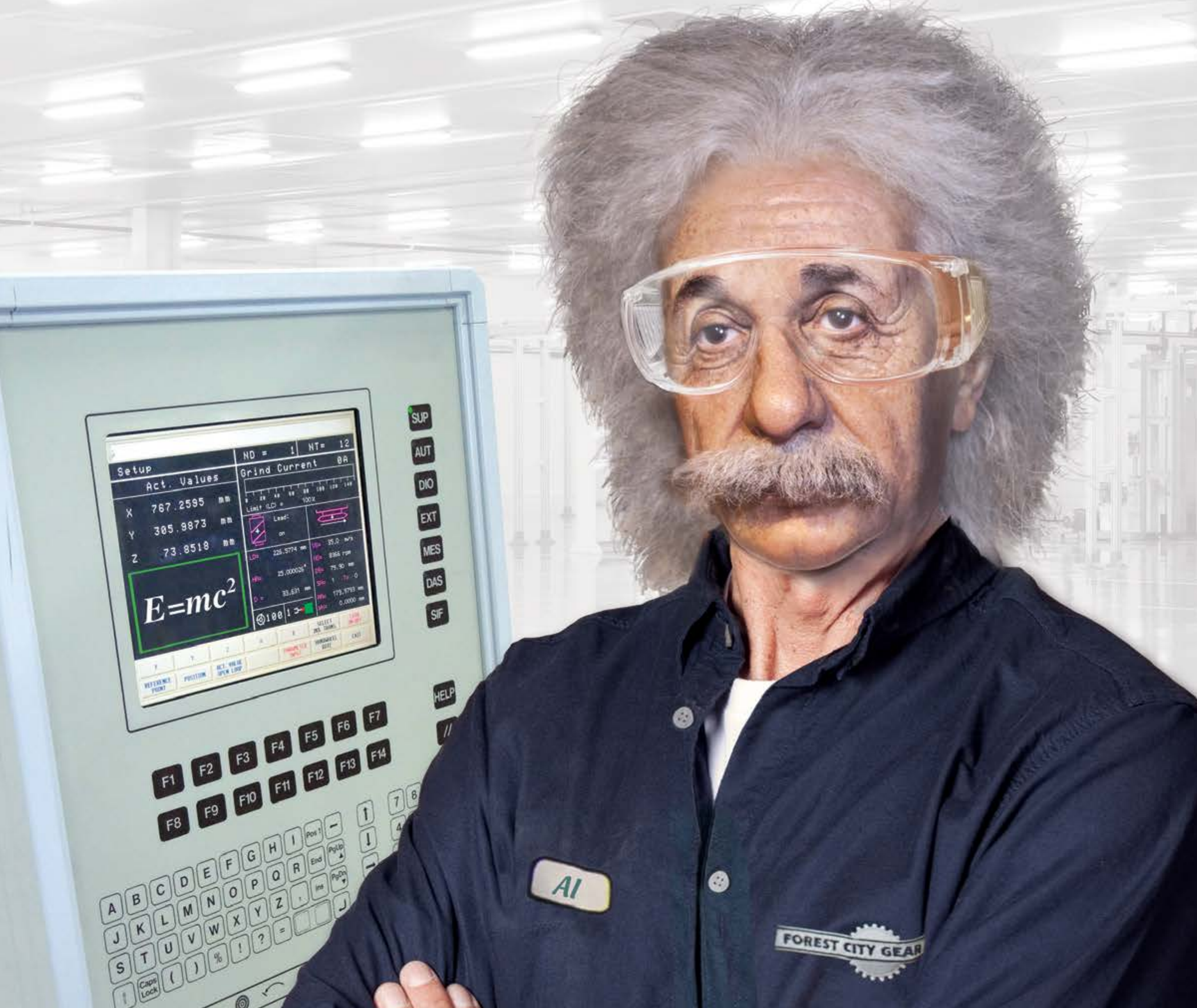
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Grind Current
AI
FOREST CITY GEAR

Randy Stott, Managing Editor

Intelligent Integration

In this issue's cover story, Stefan Hantke describes an evolving marketplace that requires smarter components and more integrated solutions. In fact, Hantke, who was recently named head of global industrial sales for the Schaeffler Group, goes so far as to predict that within a few short years, every bearing will have a wire coming out of it.

Those wires will carry all sorts of useful information about the operation of the bearing, letting maintenance staff know about any problems with lubrication, temperature or vibration. The wires will also allow various components to communicate speed, torque and other information with each other and with intelligent controls, making individual smart components even smarter by combining information and creating smart systems.

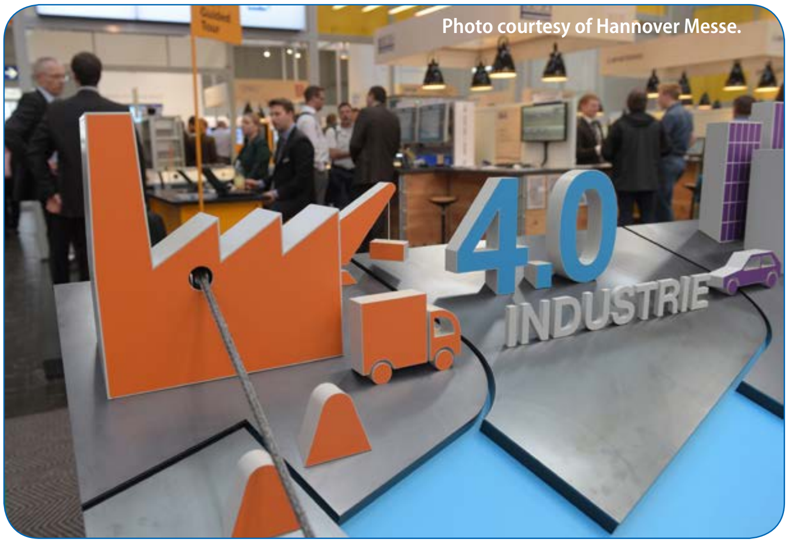
Photo courtesy of Hannover Messe.

The organizers of Hannover Messe and many of the exhibitors there focused quite heavily on Industry 4.0—the largely European concept of the fourth industrial revolution, wherein manufacturing becomes computerized and smart factories use connected systems to monitor physical processes and enable centralized control and decision making. At Hannover Messe, a lot of companies demonstrated the smart capabilities of their components.

So clearly the transition to more intelligent components isn't just Hantke's vision. It's a vision that's already begun taking shape in industries around the globe. We've noticed the trend not only at Schaeffler, and not just with bearings, but throughout the mechanical components industry.

Nowhere was that more clear than at the 9th CTI Symposium in Novi, MI, which I attended in May. There, automotive engineers gathered to discuss the future of transmission technology. Obviously electronics and controls make up a big part of that discussion: Millions of lines of code are required to control and coordinate the various mechanical functions of an automobile. On top of that, engineers are beginning to think very seriously about autonomous vehicles. Smart components are a necessary part of the solution.

But perhaps just as important at CTI was the discussion of integrated systems. Because components have to talk to each other, and because sensors and electronics have to be integrated, suppliers are being asked to provide more than they ever have in the past. Nobody wants to buy just a bearing anymore. They want to buy an integrated assembly or a complete control unit. Components are turning into component systems, and the engineering integration is being pushed down the supply chain. More and more, component suppliers are being forced to view themselves as solution providers.

So what does all of this mean for those of you who design, specify and develop products that use mechanical power transmission components?

For one, it means more and more options for what your equipment can do.

For another, it means that more than ever, you're going to have to trust your suppliers. If you're asking them to do more of the engineering in order to give you plug-in systems, you have to give up some of the control over the design process. The alternative is to develop and integrate yourself, and in today's market, that's just not often economically feasible.

Of course, the most important step in being able to trust your suppliers is being able to find suppliers you can trust. In that, at least, I hope *Power Transmission Engineering* can continue to be a vital part of the process, by presenting you with the trends and technologies that are of most interest.

Randy Stott

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Weiss

CHALLENGES AXIS OF POWER, EFFICIENCY OF COST WITH 3-AXIS DESIGN

In an effort to advance palletizing applications that do not require the traditional Selective Compliance Assembly Robot Arm (SCARA) system's 4-axis design, Weiss has designed an economically advanced 3-axis design solution.

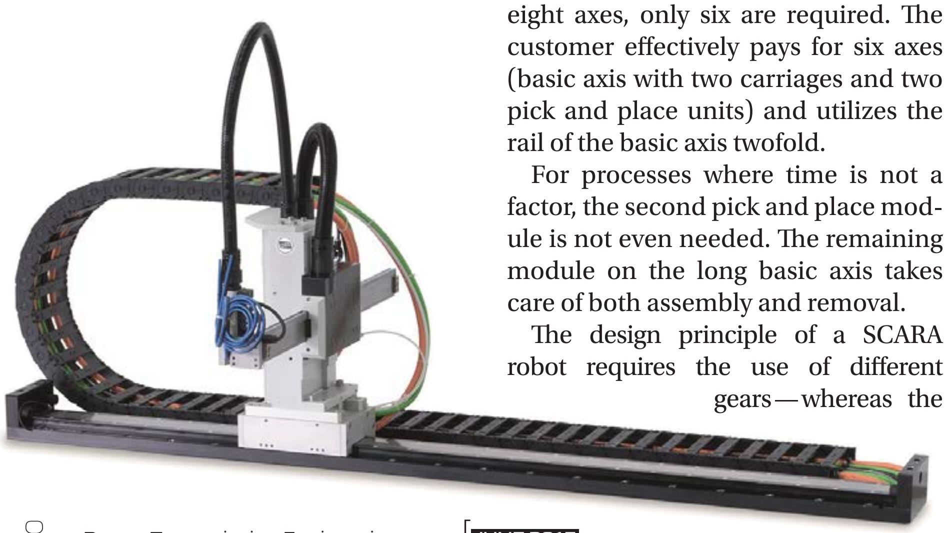
Traditional, tried-and-true SCARA robots remain a popular solution for palletizing and tray packing applications. However, their typical design configuration features four axes consisting of two rotary axes and one lifting swivel unit — which is generally not needed for most palletizing applications.

In terms of figures, a SCARA robot costs on average around the same, per axis, as a Weiss 3-axis solution. Eliminating the fourth axis when only three axes are required is more cost effective. Additionally, the work envelope of the SCARA is difficult and costly to guard. The Weiss 3-axis system offers a compact envelope allowing for a more cost effective safety solution.

The advantage of Weiss's 3-axis system is that end-users only pay for what they actually need. Thus, procurement costs for the three axes are lower when compared with a 4-axis SCARA.

The key to this handling solution relies on standard components that have been proven in thousands of applications and can be combined to create perfectly matched sub-systems. For this specific palletizing example, Weiss selected a type HN 100 linear motor axis as the basic axis.

Permanently connected to the basic axis is the HP series direct-drive pick & place module — which forms the 2nd and 3rd axes. Unlike a SCARA robot, the strokes of the axes can be matched to the dimensions of the tray.



Vital efficiency advantages in the assembly process also come to the forefront when comparing the work process of the two concepts.

The operating range of a SCARA robot is limited to a semi-circle in front of it — however, the standardized DIN pallet is always rectangular. This means the SCARA robot is often seen with only three pallets, which just fit into its working range. This semicircular arrangement then makes it difficult to achieve linear 'advancing' of the pallets within a fully automated assembly process — as is the norm in modern, flowing conveyor belt production processes. Furthermore, once pallets of different sizes come into play, the system has severe difficulties. A square pallet does not fit in with a curved robot action radius. As a result, manual intervention is often the only option for relocating, rearranging, or completely exchanging the pallets.

In the SCARA scenario, there is usually only one response to this — using one robot for assembly and one for removal. This translates to a total of eight axes — with each axis costing roughly $3,250 per unit.

Given the combination of various handling and axis units, the Weiss automated process is more flexible. For example, two pick and place units can be positioned on a basic axis with a length of up to 4 m and can work independently of each other. Instead of eight axes, only six are required. The customer effectively pays for six axes (basic axis with two carriages and two pick and place units) and utilizes the rail of the basic axis twofold.

For processes where time is not a factor, the second pick and place module is not even needed. The remaining module on the long basic axis takes care of both assembly and removal.

The design principle of a SCARA robot requires the use of different gears — whereas the handling solution from Weiss operates completely without gears, which is made possible by linear drives. This gearless design makes the handling system more precise than the SCARA robot — which offers positioning with an accuracy of up to 0.01 mm, whereas the conventional SCARA can only manage 0.05 mm or more.

Eventually with age, the imprecision increases further due to wear on the gears. The smaller the parts, the more significant this becomes. Greater precision notably pays off even for parts with an edge length of under 100 mm. The time-consuming processes required by the SCARA robot for its image processing system and position correction are no longer necessary.

Weiss's 3-axis system provides a myriad of combinations that are more economical than SCARA robots for a multitude of handling tasks.

While designed for palletizing and tray packing applications, the 3-axis system can also be leveraged for a wide range of associated applications including automotive, medical, inspection and electronics. The system is currently being used for the inspection of circuits in the production of electronic cigarettes.

Importantly, end-users can leverage the Weiss Application Software (WAS) to enable simple and intuitive commissioning of the system's most important parameters. This makes life easier for smaller and medium-sized plant engineering companies in particular. In contrast, the programming process for the software of a SCARA robot is still a barrier for these firms.

Finally, the axis combinations are not only easy to commission — the demounted individual modules can also be used in other automation processes at a later stage. This may take some time to pay off, but significant dividends are ultimately achieved.

For more information:

Weiss North America, Inc.
Phone: (888) 934-7762
www.weissna.com


Gearing your past
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Santasalo

LAUNCHES QUATRO+ PLANETARY GEARS

Santasalo recently introduced their new series of planetary gear units to the global industrial market. The new Quatro+ range offers higher torques without the requirement to increase the gear unit size or weight. In addition, an extended bearing life up to 200% higher than the original Quatro series, ensures enhanced availability of the gears and reduced operating costs.

The Quatro+ series offers nominal output torque up to 1,427 kNm, up to 30% increase on the torque of the original Quatro series but with no change to the size and weight of the gear unit. Its design can be highly customized to meet the requirements of a vast range of applications in many industries.

Santasalo showcased the Quatro+ for the first time at the 2015 Hannover Fair in Germany in April. Experts on the Santasalo planetary product range were there to represent the product launch and provide experience and knowledge on both the Quatro+ and all other planetary gears offered by the business.

"Upgrading the power rating of Santasalo's original Quatro series has allowed us to provide our customers with a new range of drives that fulfill the most demanding high torque application needs," said Pasi Jokela, senior vice president of Santasalo Capital Sales. "With the Quatro + series, we can deliver very cost competitive drive solutions for, not only new machines, but as a replacement of existing Santasalo Quatro drives and competitor gear units. We are excited to launch this advanced technology to the global market for heavy duty planetary gear units."

For more information:
Santasalo Gears Oy
Phone: +358 293 401000
www.santasalo.com

Suhner's

SU-FLOCK SILENT FLEX SHAFTS REDUCE NOISE IN POWER SEATS AND SUNROOFS

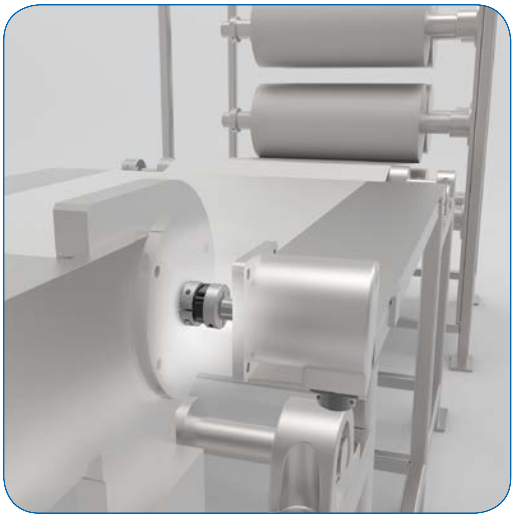
Flexible shafts do not create noise, but they can transmit vibrations from the power source, thus creating unacceptable sound levels. Suhner Mfg., Inc. has longtime expertise in flexible shafts technology and know-how in noise-dampening shafts—especially for automotive applications. They supply ready-to-use assemblies according to various specs that are: proven, simple, ready-to-use solutions; virtually maintenance-free; durably designed; and environmentally friendly.

Suhner also recently developed a heavy-duty flexshaft able to exceed 3,500 inch-pound in braking torque while offering a bend radius of less than 20 inches. This 1" core diameter shaft is characterized by its strength and flexibility, allowing it to achieve the most difficult tasks.

For more information:
Suhner Manufacturing, Inc.
www.suhner.com

Control-Flex Couplings

FROM ZERO-MAX OFFER ELECTRICALLY ISOLATED DESIGN



Control-Flex couplings from Zero-Max are designed for encoder applications. Where speed and positioning feedback in a system is critical, Control-Flex couplings help minimize a system's reaction forces for more precise and repeatable operation and longer life.

Designed with a parallel linkage-style flexible disc, Control-Flex provides radial flexibility to reduce reaction forces such as side loads on shaft bearings and seals that can be caused by shaft misalignment. The Control-Flex disc allows parallel, angular and axial shaft misalignments while maintaining constant transmission of torque and angular velocity.

Designed with aluminum clamp-style, zero backlash hubs, the Control-Flex provides a low weight/low inertia solution. Electrically insulating flex discs prevent electrical current passing between the system shafts through the coupling. These discs are made of a compound selected for its flexible durability and dielectric qualities.

Precision designed, Control-Flex couplings consist of two hubs (to be attached to the system shafts) and a center flex member. This flexible member is affixed to the hubs through quality pins that make separating easy if required. Two versions of the coupling are available: a single-flex disc version for standard torque capacity, and a two-flex disc version for increased torque capacity and torsional stiffness.

Control-Flex couplings are a better option for high-precision applications than standard beam style couplings which tend to vibrate and break. Control-Flex also offers electrical isolation and lower reaction loads than many other coupling options. Control-Flex couplings are ideal for use in packaging, medical device, machine tool, conveying and automated assembly systems that utilize encoder feedback devices.

For more information:

Zero-Max, Inc.
Phone: (763) 546-4300
www.zero-max.com

Fenner's

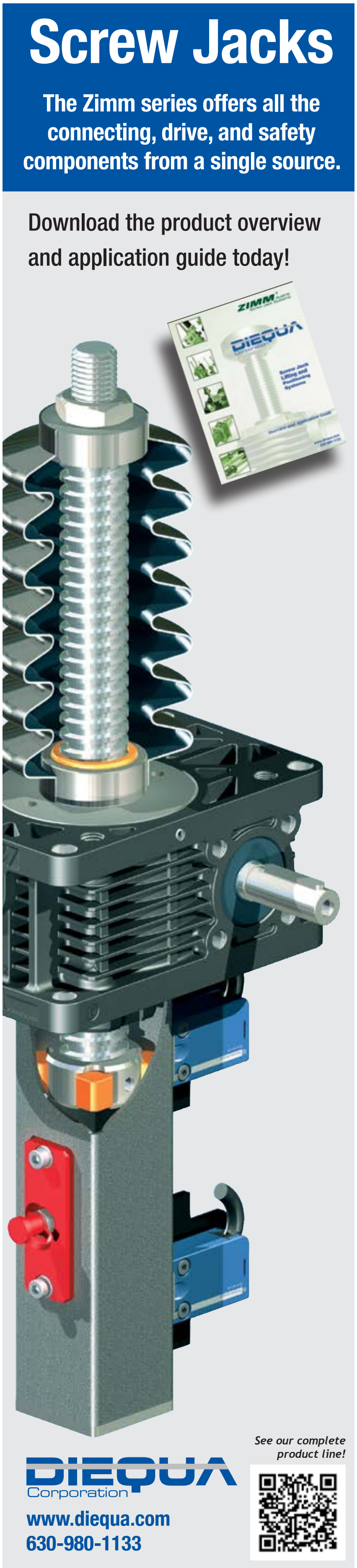
NEW HIGH PERFORMANCE CONVEYOR LINK BELTING ELIMINATES EXCESSIVE DOWNTIME

Fenner Drives recently announced the launch of a new high performance link belt for conveying: Tango Belting. Tango Belting offers customers a conveying solution without the unwanted downtime of welding. Available in standard profiles, Tango Belting drops right into existing equipment.

Tango Belting offers many benefits over traditional polyurethane belting: no welding; easy, fast installation; longer belt life; and resistance to harsh environments. Making Tango to length onsite eliminates the need to purchase and hold numerous different spare endless belt lengths.

For more information:

Fenner Drives
Phone: (717) 665-2421
www.fennerdrives.com



TB Wood's Sure-Flex Plus Sleeves

OFFER HIGHER TORQUE RATING

TB Wood's new Sure-Flex Plus EPDM and Neoprene sleeves have a 30% higher torque rating, allowing many common applications to use a one-size-smaller coupling at an average 25% cost savings. This lowers the cost of both the initial coupling purchase and future sleeve replacements.

Testing has shown that size-for-size Sure-Flex Plus sleeves last more than 3X longer than the competition. The longer service life in demanding applications reduces required maintenance and associated replacement cost.

The Sure-Flex Plus sleeve design is 100% compatible with all existing TB Wood's and competitive coupling flanges. Retrofitting a sleeve eliminates the need to replace the full coupling. A new, easy-to-use online selection program, 3-D CAD models, e-catalog, and interchange guide are available at *www.tbwoods.com/sureflexplus.*

For more information:

Altra Industrial Motion
Phone: (815) 389-6227
www.tbwoods.com

Krohne

INTRODUCES THE OPTIWAVE 5200 C/F

Krohne, Inc. recently introduced the Optiwave 5200 C/F, a new 10 GHz FMCW radar level meter for liquid applications in up to a 30m/98 foot measuring range. The cost effective 2-wire loop powered device measures level and volume in storage or process tanks with process conditions up to 250°C/482°F and pressures up to 40 bar/580 psi. for general purpose or hazardous locations. (Class 1/Div 1) Together with the recently launched Optiwave 2200 C/F TDR level meter, the Optiwave 5200 C/F has been designed and developed for use in SIL 2 safety-related systems according to IEC 61508.

The Optiwave 5200 C/F electronics are compatible with a wide selection of antennas. The PP and PTFE Wave Horn antennas are process sealed by their antenna material instead of a traditional process seal construction with "O" ring gaskets. These gasket free antennas are suited for corrosive environments. The PP antenna can be mounted on process connections as small as 1½ inch. The metallic horn and waveguide antennas use a dual seal mechanism, which is a combination of "O" ring gaskets with Krohne's Metaglas process interface design, for a completely hermetic seal in highly toxic or explosive applications.

The modular design of the housing with its unique bayonet locking system and antenna extensions ensures suitability for a variety of mounting positions and applications. To make the display screen easy to read, the quick coupling system permits 360° housing rotation. The housing can also be removed under process conditions. The remote converter version Optiwave 5200 F features full display and configuration capability up to 100 m/328 feet away from the antenna.

Fully compatible with all installed Krohne BM 70 flange systems, this new meter can also upgrade any BM 702 radar level meter with enhanced measurement performance and features and is compliant to newer requirements such as SIL and NAMUR guidelines.

For more information:

Krohne, Inc.
Phone: (978) 535-6060
us.krohne.com

Sprint Electric

EXTENDS RANGE OF DC DRIVES AVAILABLE FROM STOCK

With its recently extended ranges of DC motor controllers, Sprint Electric has a comprehensive offering of products incorporating the latest digital DC drive technology. All DC Drive products and their ancillary items are now available from stock. The product lines include a wide range of DC motor control, with over 450 models covering both 1 phase and 3 phase, regenerative and non-regenerative DC motor applications, together with field controllers, digital slip ring motor controllers and external thyristor stack controllers.

"We know how important it is for our customers to receive their orders without delay," said Gary Keen, managing director of Sprint Electric. "The ex-stock availability of our products, often with direct equivalents for competitor models, allows users to source the DC drives they need without having to suffer a lengthy lead time. We operate predominantly in the upgrade/retrofit marketplace where downtime on machines cost money."

According to Keen, up to 87% of orders get dispatched from the factory in Arundel on the day of ordering.

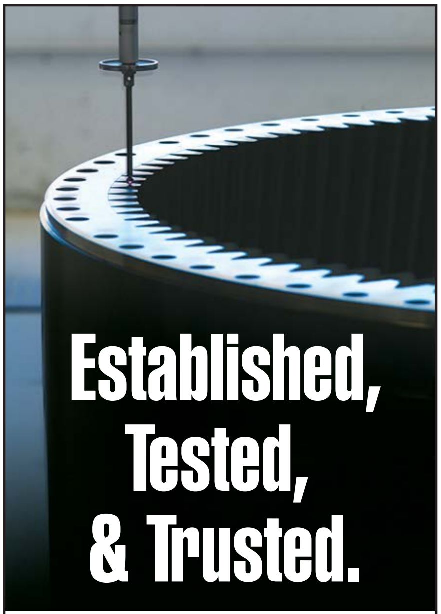
The product offering includes DC drives of the PLX range, which are able to regenerate energy back to the mains supply under braking without the need for expensive, complex intermediate storage, resistive dumping or additional power bridges. PLX DC drives are compact, powerful, flexible and easy to program, and available in current ratings between 12 and 2250 Amps at supply voltages up to 690 VAC.

Designed for use with permanent magnet brushed DC servo motors, DC motor controllers of the XLV range are rated from 2 to 12 Amps and suitable for use on DC supplies up to 48 V. The miniature, fast response DC motor speed controllers are offered in a compact, easy to use DIN rail mounting package.

The full range of products covers analogue DC drives from 2 up to 330 Amps, digital DC drives from 12 up to 2250 Amps and digital slip ring motor controllers from 12 to 1680 Amps. Whether in retrofits or original equipment, DC drives from Sprint Electric are being used in many different applications including metal processing, the pulp and paper industry, rubber and plastic processing, lifting equipment, food processing, leisure industries and many more.

For more information:

Sprint Electric Ltd.
Phone: +44 (0)1243 55 80 80
www.sprint-electric.com




WD

NKE Agri Units

MAKE AGRICULTURAL ROLLING BEARINGS SIMPLE

NKE recently introduced all-in-one bearing units designed for use in agricultural machines that require a rotating union between a disc-shaped tool and its mounting arm. They have dubbed these rolling bearings Agri Units.

Whereas producers of agricultural machinery previously often had to buy and assemble up to ten separate components, Agri Units are a single part in the form of a fully assembled bearing unit. This cuts down on costs for the customer, since purchasing, storage and spares inventories are limited to just one component and no prior assembly is needed.

One design is for use in disc harrows with a disc diameter of up to 650 mm. The design, which is comparable with existing solutions of similar size, has a number of special features: an optimized internal geometry that maximizes load capacity and resistance to tilting motions; and a high quality grease filling in a sufficiently high quantity for the operating conditions to ensure a long lubricant and therefore bearing life as well as good corrosion protection; a highly efficient combination of seals to prevent dirt ingress into the bearing (Fig. 2). In addition to the current standard version, NKE can adapt the unit's external geometry to allow customers to integrate the unit into existing designs or tailor it to new applications.

Agri Units can also be used in seeding discs and for liquid manure spreader discs. These bearing units aim to replace the conventional and often no longer satisfactory solutions consisting of deep-groove or double-row angular-contact ball bearings with an all-in-one compact bearing unit. In addition to optimizing the internal structure, lubrication, sealing and ease of handling of the bearing units for disc harrows, the designers focused on minimizing the unit's external dimensions.

Besides its new Agri Units product line, NKE offers standard and specialty bearings for applications such as balers, power take-off (PTO) gearboxes and track systems. NKE also offers comprehensive technical support, including application consulting and the development of customer-specific solutions as well as commercial and logistic services, such as just-in-time (JIT) delivery. NKE products are distributed in North America by Ritbearing.

For more information:
15151 Prater Drive
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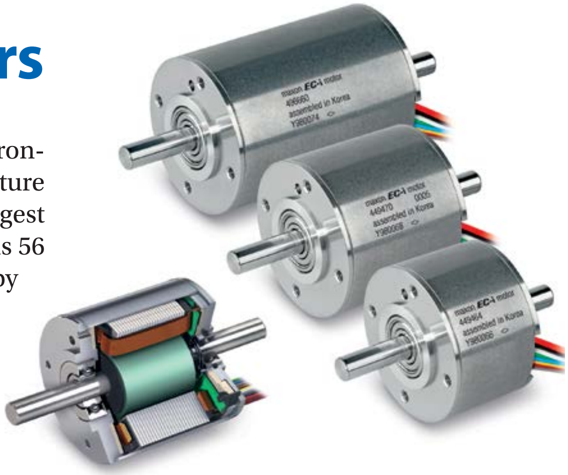
Maxon EC-i 40 Brushless Motors

70% MORE EFFICIENT THAN PRECURSOR MODEL



Maxon recently expanded its line of EC-i 40 brushless motors with three iron-core internal rotor drives. The drives have a diameter of 40 mm and feature high dynamics, a low cogging torque, and high output torque. The strongest motor in this series offers a maximum nominal torque of 234 mNm and is 56 millimeters in length. It exceeds the performance of its precursor model by up to 70%.

The three new brushless DC motors are cost-effective and targeted towards the robotics, prosthetics, and industrial automation industries. The compact design offers a solution in applications with space constraints. When needed, the EC-i 40 High Torque motors can be combined with maxon gearheads, servo controllers, or position controllers.

For more information:
101 Waldron Road
Fall River, MA 02720
(508) 677-0520 ext. 113
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www.maxonmotor.com

Etel Thermal Module

ENSURES MOTOR PROTECTION

Etel has recently introduced the IMTHP, a thermal module that serves as an accessory to Etel's torque motors, and is designed to provide absolute motor protection from overheating. It is designed to be a supplement for KTY thermistors.

KTY sensors are accurate but have a delay in their output signal if the temperature change is too quick. The IMTHP provides a corrected analog temperature signal, allowing the user to have a precise and continuous monitoring of the actual temperature in the mo-

tor. While monitoring readings from three KTY sensors (*one on each phase which is standard on all Etel torque motors*), it uses a built-in algorithm which detects any steady increase in the KTY sensor output. It also outputs a simple digital warning/error signal that can be used without complex data processing on the controller's part and has the machine properly react if any problem is ever detected. This ensures a reliable safety measure for prototype testing and the ability to handle unexpected loads.

The IMTHP is able to take the input of sensors on each of the three phases and output them as one signal so even if the controls operating the motor only have one sensor input, all three phases can still be monitored. This is also invaluable under stall conditions where one phase would have significantly more current than the other two.

The IMTHP has the advantage of allowing engineers to not have to oversize a motor for an application, or put a limit on the current input for fear of overheating. That way an optimum motor can be selected, without incurring the cost of having to order an extra-large motor.

All these benefits ensure that fewer safety measures are necessary during motor operation, allowing optimum performance of the machine and a quick response to any unexpected overheating preventing any machine downtime when operating in the field. Etel products are distributed in North America by Heidenhain.

For more information:
Heidenhain
(847) 519-4702
kstoneski@heidenhain.com
www.etelusa.com

Warner Electric Custom X-Small Magnetic Brakes

REDUCE SIZE WITHOUT SACRIFICING STRENGTH

The X-Small brakes are designed primarily for engaged/disengaged holding applications – such as seat adjustment on an aeroplane – though they can provide a low cycle rate stopping action in emergency situations. As they are electrically released, they will remain engaged in the event of a power failure, which makes them suited to applications where the integrity of the holding force is imperative.

The range consists of 6 standard sizes which range from 22 mm – 33.5 mm diameter (30g – 100g) and offer up to 50Ncm of static torque. Customized bespoke adaptor flanges are available.

For more information:
Warner Electric
Tel: +44 2380 733211
www.warnerelectric-eu.com
neil.bruce@altramotion.com

The True Cost of Bearing Lubrication

Matt Mowry, Product Manager, Igus

Introduction

Machine and equipment manufacturers today are feeling more pressure than ever to reduce costs without sacrificing machine performance — a balancing act difficult to achieve. OEMs often overlook a simple solution that can have a positive, long-term impact on profitability for themselves and their customers, i.e. — the elimination of bearing lubricant. By eliminating lubrication systems where possible, OEMs can reduce production costs while at the same time make their equipment more marketable and less expensive to operate for end users.

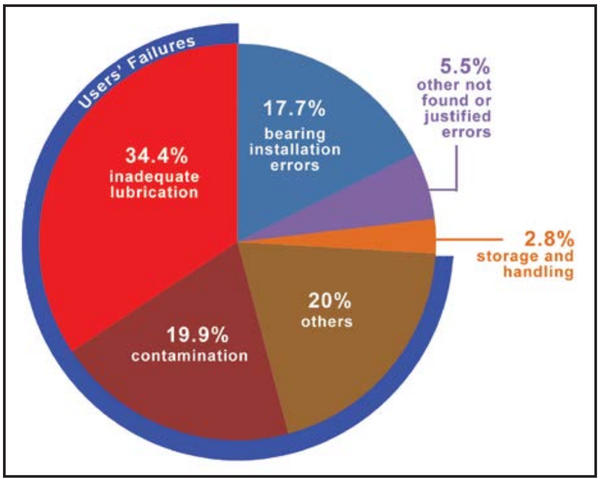

Figure 1 Types of lubricated-related bearing failures (Source: SKF, USA Inc.).

What are the issues with bearing lubricant? According to a major ball bearing company, 54 percent of bearing failures are lubrication-related (Fig. 1). In a study by the Massachusetts Institute of Technology (MIT) it was estimated approximately $240 billion is lost annually (across U.S. industries) due to downtime and repairs to manufacturing equipment damaged by poor lubrication (*http://www.azom.com/news.asp?newsID=11342*). Improper bearing lubrication or re-lubrication accounts for up to 40 to 50 percent of machine failures. By eliminating lubrication from machinery, OEMs can minimize the costs and risks associated with maintenance for the end user. At the same time, costs related to the proper disposal of oil can be eliminated and the initial expenditure for ancillary components and processes (grease lines, zerks, manifolds, etc.) can be decreased.

There is a lower-cost, easier-to-maintain machine component that eliminates the total cost of bearing lubricants, i.e. — high-performance, dry-running plastic bearings.

Hidden Costs of Lubrication

Proper lubrication delivery is critical for the operation of ball bearings, and most require continued maintenance for re-lubrication. The re-lubrication process typically requires scheduled machine downtime, which increases maintenance costs and causes a loss of production time. In addition, re-lubrication maintenance practices often fall short. While some processes are automated, the majority of re-lubrication is performed manually using a grease gun. This seemingly simple task actually involves a number of critical steps to ensure proper lubrication delivery, including correct amount of lube, the right grease gun, proper cleaning, and careful storage and handling conditions, just to name a few. In addition, it is critical to use the same grease

Figure 2 Proper lubrication is critical for the operation of ball bearings.

for the entire lifespan of a bearing. The technical training division of Life Cycle Engineering conducted a study that found 80 percent of maintenance workers surveyed scored less than 50 percent when it came to the basic technical skills needed to perform their job "Bearing lubrication" was noted first on their list of tasks (*http://www.lce.com/pdf/trainingneeds.pdf*).

Ancillary components for OEMs. Using lubricated bearings can increase manufacturing complexity and expenses. They often need to be fitted with grease zerks (fittings) and manifolds, oil lines, and sometimes oil reservoirs and pumps. Not only are there extra costs associated with purchasing these components, there are also manufacturing costs associated with the machining and assembly of the mating parts.

There are also additional parts required to protect them from contaminants. According to the McNally Institute, the leading cause of bearing failure is due to contamination of the lubrication by moisture and solid particles. If as little as 0.002 percent water pollutes the lubrication system, it increases the probability of failure by 48 percent; just six percent water can reduce the lifetime by 83 percent (*http://www.mcnallyinstitute.com/02-html/2-10.html*).

Ball bearings require seals to keep oil in and unwanted water and liquids out, as well as wipers / scrapers to keep dust and debris out as well. Seals only last so long, and do not perform well in dirty and dusty environments, and can also increase friction in the application. In agricultural machinery and lawn mowers, where dust and debris are prevalent during operation, seals and wipers may require frequent replacement.

Other Costs Not Required for Self-Lubricating Bearings

Labor. A major oil company studied the time required to manually lubricate a single grease point. The results showed manual lubrication takes an average of three-minutes-per-point. The average machine has 20 grease points to maintain. This correlates to a total labor cost of $7,300 annually for maintaining 20 grease points on one machine, every day, seven days per week (*http://www.lubricationautomation.com/ez.php?Page=2087*). Another source claims that the average plant employs 2,196 bearings and spends $60,000 in re-lubrication costs per year; of that $60,000, $57,000 is used for labor alone.

Downtime. Improper bearing lubrication or re- lubrication accounts for up to 40 to 50 percent of machine failures. When a bearing fails premature-

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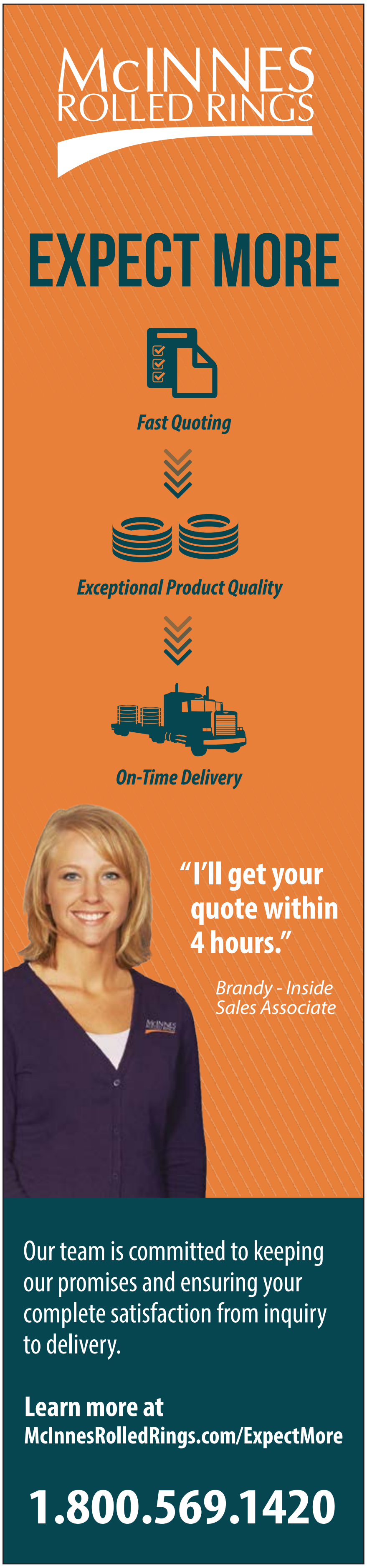

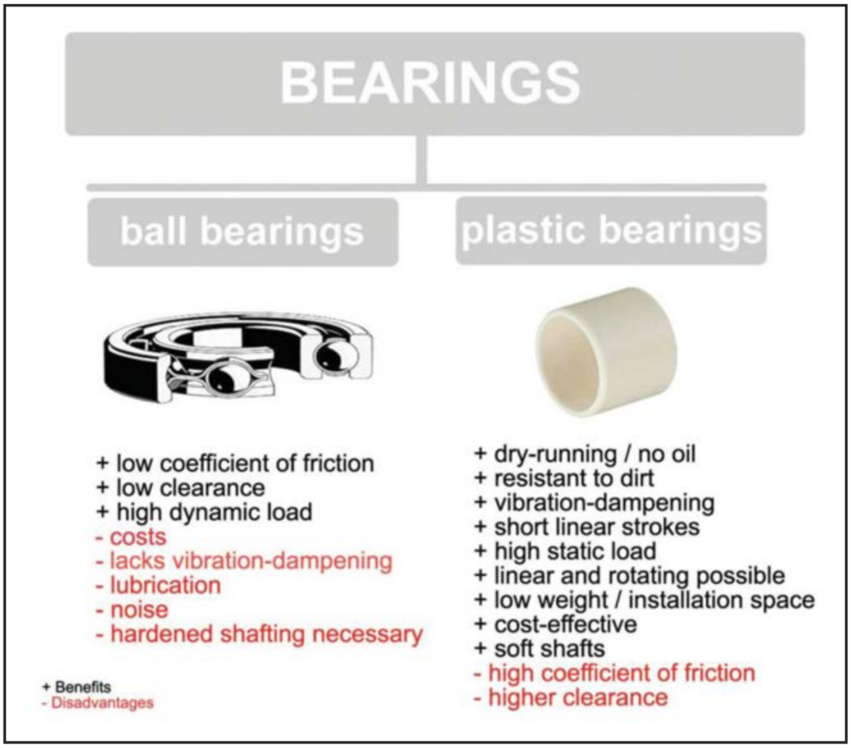

Figure 3 Comparison chart comparing ball bearings to self-lubricating, plastic plain bearings.

ly, a number of actions may need to be taken. Replacement of the bearings, shafting, and even motors and other parts can be very costly. If the machine needs to be taken off-line, expenses can potentially skyrocket. In a six-sigma lean manufacturing guide (*http://www.plant-maintenance.com/articles/lean_maintenance_for_lean_manufacturing.pdf*), it is estimated that the average cost for downtime is $500 per hour, and in some automotive and other high-volume production factories, downtime costs are considerably higher. In addition, unplanned downtime can cause a ripple effect that impacts a plant's production schedule.

Disposal costs. According to Valin (*http://www.valin.com/index.php/blog/15-filtration/117-cut-lubricant-costs-up-to-50*), proper disposal of lubricants by a process management

Figure 4 Self-lubricating plastic bearings from igus are made from high-performance polymers, which are corrosion-resistant and maintenance-free.

company can amount to approximately 20 percent of the cost of annual lubricant expenditures. This means if a plant spends $50,000 per year on lubricants, they will spend approximately $10,000 in disposal costs. In addition, the cost of the lubrication itself can impact overall expenditures, as it is normally petroleum-based and directly linked to the price of oil.

Self-Lubricating Plastic Bearings

Self-lubricating plastic bearings are made of high- performance polymers and, unlike rolling-element bearings, slide instead of roll. They consist of a base polymer that is optimized with fiber reinforcement and solid lubricants. The fiber reinforcements increase load carrying capabilities and wear-resistance, and the solid lubricants are transferred from the bearing to the microfinish of the shaft in order to reduce friction. No external oil or grease is needed for their operation; self-lubricating bearings operate completely dry. They are an ideal solution for applications in labs and food-processing machinery that require clean, oil-free operation. Plastic bearings also perform well in dirty environments since there is no oil to attract dust and dirt, like the agricultural industry. They can be used on softer shafting, even anodized aluminum, which has excellent corrosion resistance and is usually less expensive and easier to machine than case-hardened material or stainless steel.

Eliminate maintenance costs. Using high-performance, self-lubricating plastic bearings can significantly reduce maintenance costs, as well as reduce unplanned downtime due to bearing failure. OEMs that use self-lubricating plastic bearings are able to deliver a maintenance-free system that increases their end-customer's production throughput and the overall marketability of their product. In the event that a self-lubricated bearing does need replacement, the replacement part (a small, inexpensive plastic sleeve) can be purchased for a fraction of the cost of an entire re-circulating ball bearing.

Lower production costs. Plastic bearings do not require the machining and other processes required to install ball bearings. They are less expensive and do not require grease fittings, lines or pumps. Plastic bearings also can be used on less-expensive shafting, such as aluminum or cold-rolled-steel. Some companies offer online calculators to predict bearing lifetime to ensure it is ideal for the application; this eliminates the need for testing and saves time and errors in material choice.

***Application parameters not conducive for self-lubricating plastic bearings*:**

High loads with high speeds; these lead to excessive frictional heat build-up and wear.

Highly cantilevered loads; since self-lubricating plastic bearings slide (unlike ball bearings that roll), linear applications with higher coefficients of friction may result in uneven movements for highly cantilevered loads or drive forces.

Extremely precise applications; plastic bearings have a higher running clearance than ball bearings — sometimes .001" to .002" — and therefore are not ideal for applications needing extreme precision.

Extreme temperatures; plastic bearings are not recommended for applications with long-term temperatures exceeding 484° Fahrenheit.

Field Application Examples Using High-Performance Plastic Bearings

1. ***Agricultural.*** A manufacturer of equipment specifically for the farming industry produces ‘the Pick Planter’ — which creates individual planting row units using walking gauge wheels to deliver a consistent planting depth.

   Oil-impregnated bronze bearings with graphite plugs were used to facilitate this movement — until they began causing severe problems. They were even requiring replacement two to three times a season. On the (U.S.) West Coast, the bronze bearings were experiencing high wear and premature failure due to the very abrasive conditions caused by high levels of volcanic ash in the soil. On the (U.S.) East Coast, the high salt content in the air caused corrosion and seizure.

   By replacing all 144 bronze bearings with iglide self- lubricating plastic bearings from igus, the pick arms’ lifespan was increased by 500 to 600 percent. The actual bearings cost 70 to 80 percent less than bronze bearings and were more reliable.

2. ***Packaging.*** One manufacturer specializes in vertical, form, fill and seal (v/f/f/s) packaging equipment for handling a wide range of products — from green beans to candy to detergent. The machines are capable of reaching up to 160 cycles-per-minute and withstanding loads up to 15 pounds, while operating at speeds of 750 feet-per-minute.

   The manufacturer had been using metal linear ball bearings. After the metal bearings scored the shafts and leaked grease on some of the machines, the company decided to replace them with self-lubricating DryLin linear plain bearings. To date, the linear bushings have surpassed the 10-million cycle mark on some of the company’s packaging machines with little to no noticeable wear.

3. ***Medical.*** In the quest to improve the way prostate cancer is detected and treated, a team of researchers from the Worcester Polytechnic Institute

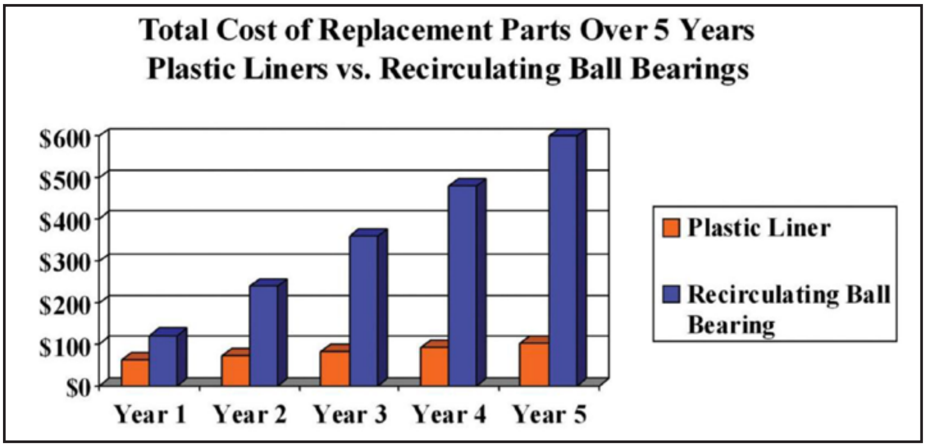

Figure 5 Note: Based on ¾ inch closed linear bearing and assuming replacement is required once per year.

(WPI) in Massachusetts have developed a specialized magnetic resonance imaging (MRI)-compatible piezoelectric actuated robot.

To facilitate different types of motion, the robot uses a DryLin linear guide system and iglide plastic self-lubricating plain bearings. The linear guides facilitate translational motion of the positioning module, which provides gross positioning for the robot's needle driver. The needle driver is a vital part of the system, as it enables the rotation and translational movement of the needle cannula: a flexible tube inserted into the patient's body cavity for MRI-guided diagnosis and therapy.

The needle driver has a needle guide sleeve, a collet locking mechanism and passive optical tracking fiducial frame. Two plastic plain bearings are used in the front and rear of the driver to constrain the needle guide. The bearings enable the robot's motor to rotate the needle using the collet mechanism by way of a timing belt. This rotating needle would reduce tissue damage while enhance targeting accuracy. Another 10 plain bearings were used to create a revolute joint, also known as a "pin joint" or "hinge joint", to provide single-axis rotation.

The linear guides chosen are comprised of hard- anodized aluminum rails and carriages and high-performance plastic sliding elements, which do not interfere with the MRI procedure. The linear slides operate without messy lubrication, which is important in a sterile medical environment. They also feature a lower-profile for applications where installation space is an issue.

The specific plastic plain bearings used were an ideal choice for the robot, as they are comprised of FDA- compliant polymers specifically designed for applications with contact to food or drugs. **PTE**

For more information:

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East Providence, RI 02914
Phone: 1-888-803-1895
sales@igus.com; www.igus.com

Re-lubrication maintenance practices fall short due to:

- Lubrication not being properly or consistently administered
- Lubrication points not being easily accessible
- Maintenance personnel not being properly trained
- Using the incorrect or improper quantity of lubricant

Ancillary components for lubricated bearings:

- Grease fittings/zerks/oil lines/pumps
- Wipers/scrapers/felt wicks/seals
- Grease guns
- Grease/oil/lubrication

Extra costs for lubricated bearings:*

- Gravity-fed oil reservoir/lines — $50 to $300
- Zerks — $2 to $40 (for four bearings and machining)
- Seals, wipers and felt wicks — $4 to $12 (per bearing)
- Automated oil reservoir/line — $1,500 or more
- Oil/grease/lubrication disposal

**Keep in mind – self-lubricating plastic bearings do not require any of these additional parts.*

Benefits of plastic bearings:

- No maintenance
- Oil free, dry-running
- Corrosion-resistant
- Cost less than ball bearings
- Resist contamination well and often do not require seals or scrapers
- Ideal for extreme short-stroke applications, unlike linear ball bearings

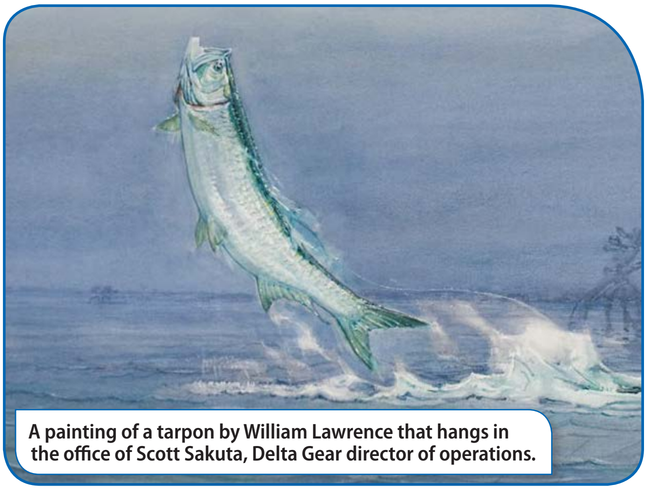
Self-lubricating bearings are ideal for:

- Harsh, extreme environments — dirt, dust, agriculture, outdoor equipment
- Sensitive, clean environments — biotech, lab machines, medical equipment
- Wash-down applications — packaging, food processing
- Weight-sensitive applications (aimed at reducing fuel consumption and/or lowering inertia of moving parts)

Don’t Tap the Glass

A deep-sea dive into Delta Gear, one of Michigan's premier aerospace gear manufacturers

Erik Schmidt, Assistant Editor



A painting of a tarpon by William Lawrence that hangs in the office of Scott Sakuta, Delta Gear director of operations.

Behind a thick sheet of unblemished glass that stretches from wall-to-wall, ceiling-to-floor at Delta Gear, just south of a shop lined with ultramodern grinding machines whirring away, is Scott Sakuta’s aquarium.

It’s a great, big tank, flooded in azure and seeped slightly in the oceanic hues of aquamarine, sea foam and sapphire. Sakuta, director of operations at Delta Gear, sits back in his chair and watches as all sorts of majestic salt water perciformes swim by.

First comes a lemon shark, stocky and powerful and the color of unripe citrus; next a streamlined blue marlin, its spear-like snout brandished proudly like a fencer’s foil; and then an inland tarpon, green-backed with streaks of silver shining through rows of scales; and lastly, a white marlin, Sakuta’s uncatchable unicorn — the one fish that has somehow eluded his reel.

The collection of billfish and shallow-water sharks swirl around Sakuta’s head, a static school of portraits wrangled together by a famous artist named Stanley Meltzoff and imprisoned peacefully on canvas prints — an art gallery 10,000 leagues under the sea yet somehow right at home inside the pristine gear shop located in Livonia, MI.

Sakuta was basically baptized in the scalding sparks of a high-powered gear grinding machines — his father, Bob, has been in the industry for over three decades and little Scott spent his formative years sweeping shop floors when he misbehaved at school — but it’s fair to say that gears weren’t his first love.

That would be fishing.

And even though it would seem that Sakuta’s two main interests mix about as well as a swordfish in a sandstorm, it hasn’t stopped him from bringing a little piece of the high seas into the decidedly dry land of Delta.

“I thinking bringing some of your personality to work is probably a benefit because people ultimately know my interests and my passions, and it encourages me to know theirs,” Scott Sakuta says. “It breaks down a communication barrier.”

If anything, Sakuta’s fish bowl takes Delta — a manufacturer of high-precision aerospace gears, shafts and assemblies — and brings it down a little bit closer to sea level.

‘Some Place Special’

It should be noted that the aquarium didn’t always exist.

Five years ago, before an extensive remodel, Delta Gear could have been considered more or less comparable with any other plant in the country. Now it’s something else entirely.

“I was in awe,” says vice president of sales Bryan Barlow on his first trip to Delta. “My jaw dropped. It’s stunning — you walk in and see this beautifully contemporary lobby, and then you look past the receptionist and you see the floor-to-ceiling, side-to-side glass wall that overlooks the shop.

“And what it overlooks is the most state-of-the-art gear manufacturing facility probably in Michigan. For a gear guy, it’s quite impressive.”

What is perhaps the most noticeable thing about Delta is just how *noticeable* everything really is — natural light pours in from giant paneled windows high above the sunken shop floor and illuminates every Reishauer and Kapp and Klingelnberg machine.

“Before you even hit the floor you can already see the state-of-the-art gear grinding equipment as far as the eye can see,” Barlow says. “That’s what really caught my attention as soon as I walked in.”

Barlow, who has been working in the aerospace gear industry since 1984, was hired at Delta in April and — not to discredit other companies he’s worked with — immediately noticed a distinct dissimilarity with the way Delta conducts its business.

It's a fish of a different color, so to speak.

"From the moment you walk in the front door you know you're some place special," Barlow says. "It defines '5S'; it defines what customers want. Customers want to see brightly lit; they want to see brand new machinery; they want to see people working; they want to see a hospital clean environment; they want to see that their parts are being handled carefully and correctly. I think Delta defines that.

"When you check a machine at the Delta facility you don't see oil on the floor. You don't see chips on the floor. There's no oil mist in the air. It's hospital clean all the time and we don't do that just for a customer tour—we live it."

Steve Rouillard, vice president of engineering—who much like Sakuta, grew up sweeping floors at his father's shop and has been in the industry nearly his whole life—was similarly impressed.

"When I walked in here I was just blown away," he says. "It's a gorgeous facility: clean, people are friendly and it's just a really nice place to work."

Of course, the shiny outer coating of Delta would be worthless if what lay underneath wasn't something of substance. But since 2004, Delta Gear


The front of Delta Gear's building in Livonia, MI.

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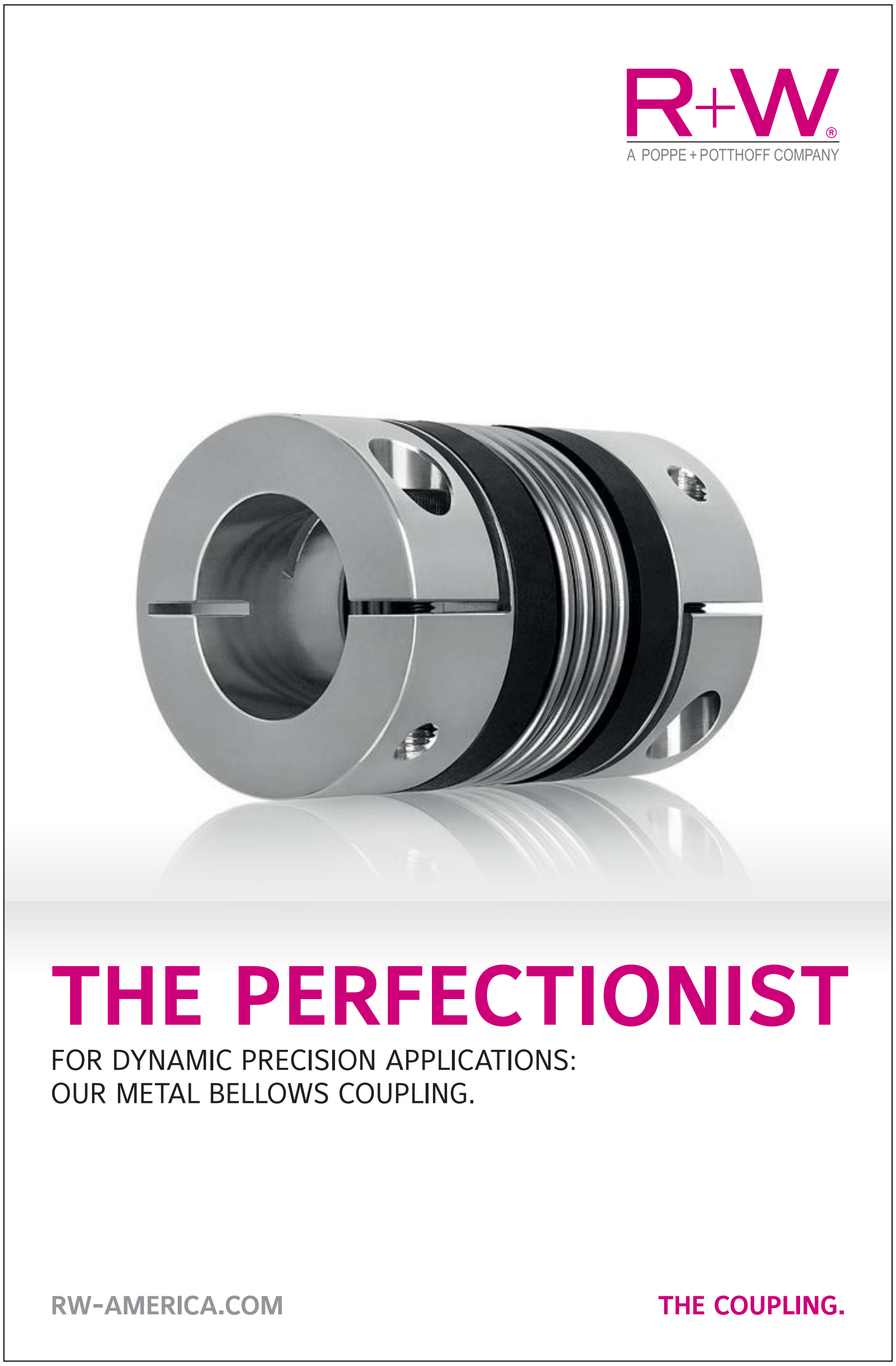
Delta Gear's newly remodeled lobby.



(formerly Tifco Gage & Gear), has operated as a truly world-class aerospace gear facility, according to Sakuta.

"We specialize in complex turbine engine gearing, helicopter drive system gearing, actuation gearing and landing gear components," Barlow says.

Unlike most other suppliers, Delta prides itself on trying to keep as much of the manufacturing operation in-house.

"We do outsource the heat treat, plating and shot peen processes, but we do not outsource super-finishing," Barlow says. "The super-finishing on our pump gears for example is done in-house. We developed our own proprietary process — our secret manufacturing methodology if you will — and we have two machines that do that." "Pump gears are typically made out of very exotic materials — CPM-10V and some other new materials that are out now — and that's one of our niches," Barlow says. "That's one of the things that differentiates us. A lot of companies make pump gears, but we make very complex, very difficult, pain-in-the-neck pump gears, and we do it day in and day out and we do it very successfully.

Another complex machining process that Delta specializes in is aerospace spiral bevel gears. Sister plant Delta Research — managed by Bob Sakuta's son-in-law Tony Werschky, vice president of operations — manufactures turbine engine and helicopter drive system spiral bevel gears utilizing their new Klingelnberg closed loop system.

"Typically, if customers have a new gear or gearbox development program, they're coming to us," Barlow says. "Why? Because we're the best."

A Punch to the Face

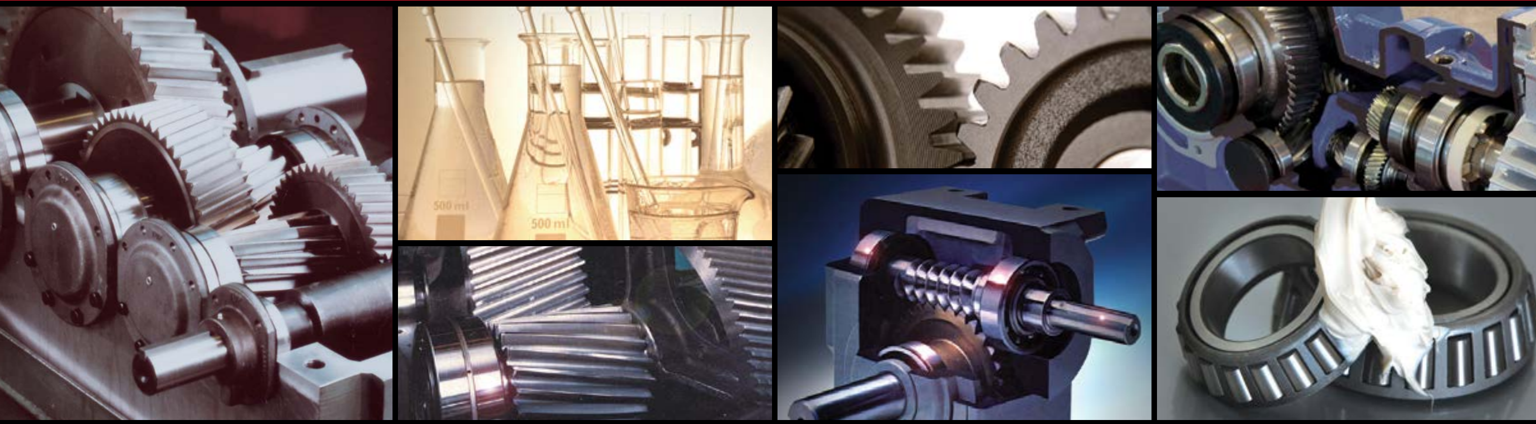
The general atmosphere at Delta doesn't quite feel like a leisurely fishing trip, but it's in the same body of water. It all starts with Bob and Scott, the father and son who bonded years ago with fishing reels in their hands and have tried to bring that same, warm, welcoming way of life from the lake to the gear shop.

It's the reason for Sakuta's aquarium.

"[The fish paintings by Meltzoff and William Lawrence] can spool some of the great conversations I have with people in my office," Scott Sakuta says. "People will say, 'You have fish on the wall, do you like beer?'"

Sakuta recalls a story, one that he regales visitors with as they sit in his of-


Delta Gear's Klingelnberg P 65 gear measuring center.



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fice while they're surrounded by creatures staring back at them with adipose eyelids.

"I was tarpon fishing with my dad and we had some of his business associates with us and an employee with Delta Research," he says. "My dad had caught a tarpon and we had fought the fish and got it into the boat. I'm generally the [person] to handle the fish because I've been around big fish more than others.

"The fish was around 150 pounds and I got it to the side of the boat, grabbed ahold of its jaw and took the hook out — and this is all at night and everyone is very excited because it's a pretty big accomplishment to catch one of these fish and release it. When you catch a fish, you want to revive the fish because the fish gets tired and you want to make sure a shark doesn't eat it or something.

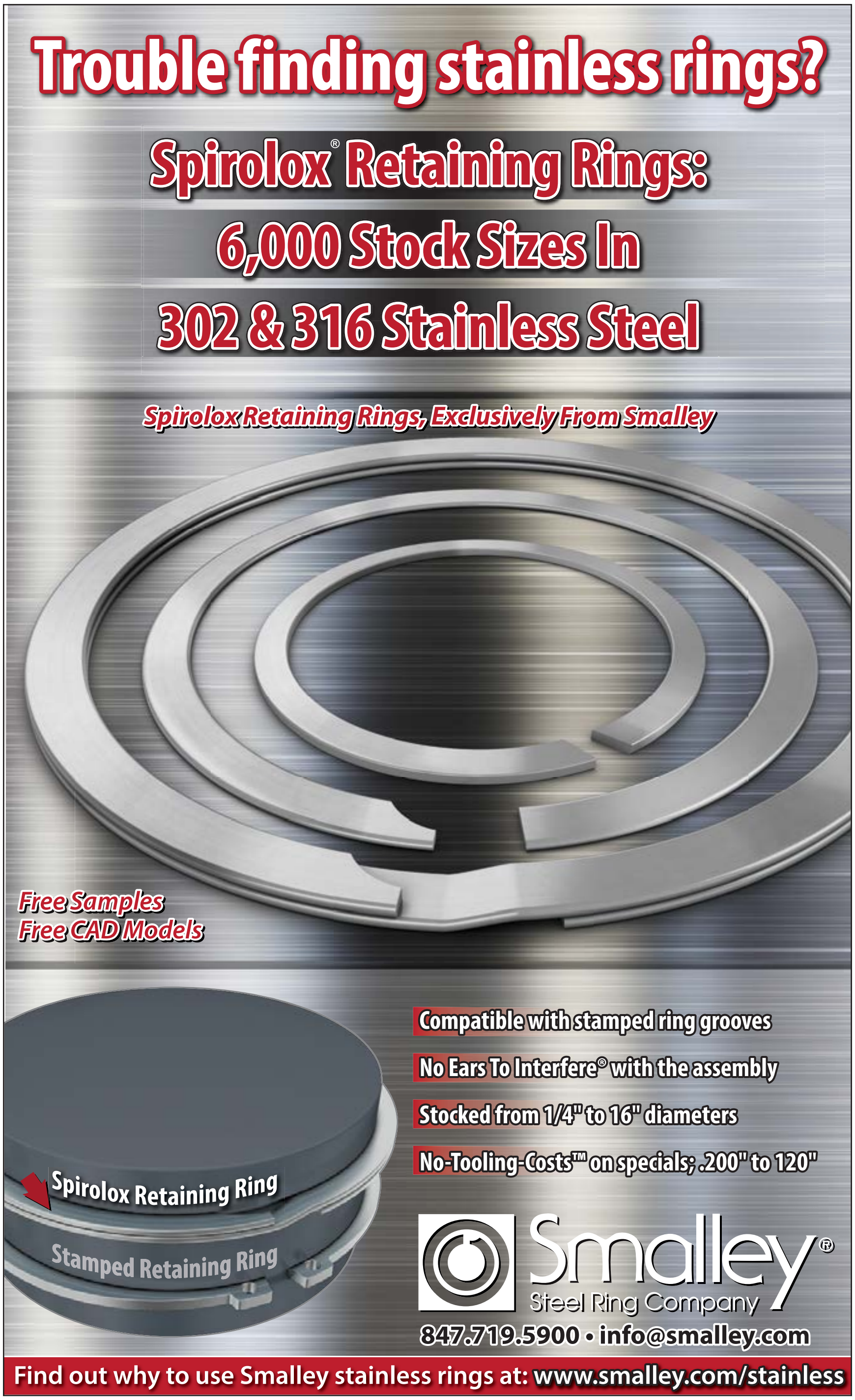
"So I'm trying to hold the fish and revive it so it can be released safely. The fish started to move and point its head towards me. I'm leaning over the boat, and the fish jumped and hit me right in the face — it was like being punched by a 150-pound punch. I saw stars and I almost went over the side of the boat.

"When I came back to work I had a big black eye and a big scratch, because this tarpon had just punched me in the face."

In some sort of masochistic tribute, a stormy blue painting of a large tarpon propelling forcefully out of the water like a torpedo with gills hangs in Sakuta's office along with the rest of his collection — a stinging reminder to what can happen if you get too complacent.

"Right now, Delta is positioning itself," Barlow says. "We're in a very good position with the depth of talent that we have — whether we're talking about manufacturing, engineering, program management, sales, and so forth. We have a lot of strengths for an aerospace gear manufacturing company. The owners have strategic plans to strengthen our position even further. Competitors would be hard-pressed to match what we have going on right now."

One of the other unique attributes and undeniable strengths of Delta is that is exists as a trichotomy: three separate, individually operated companies — Delta Gear, Delta Research



and Delta Inspection — with distinct objectives and endgames and minimal operational overlap.

Delta Gear and Delta Inspection operate out of the same, newer facility in Livonia, while Delta Research exists in the original building founded by Scott Sakuta's grandfather Alex in 1952.

"Delta Research is primarily into automotive, gearboxes, agricultural, heavy duty equipment, machining and industrial — anything that needs to be machined," Scott Sakuta says. "They're doing a lot of quick prototyping for car companies. The majority of their business is automotive, or anything that would not fly.

"Delta Gear spawned off from the aerospace company that was Tifco. Our main, core business is aircraft components or aircraft hydraulic systems or fuel systems.

"And Delta Inspection is a gear-orientated, third party inspection company. Our main focus there is the inspection, sorting and qualifying of the gears that are produced by outside customers. I think that's pretty unique. Whereas most third party inspections just have CMMs, where they would just be checking dimensions with a CMM, we actually scan the gear teeth on gear machines. We're a little bit of a hybrid."

Delta Gear's shop floor.

According to Barlow, Delta has seven CMM machines that come in varying sizes and dimensions. That falls in line with Delta's modus operandi of staying up-to-date with the market's latest technology.

"It's another differentiator," Barlow says. "We have two, newer Kapp grinders with a third one on the way; new Reishauer gear grinders; the new Kapp KX 500 Flex gear grinder; the new Klingelnberg bevel grinder, a Viper 500 gear grinder, which is one of the first in the country. We like to be the first in the industry to have the latest and best technology."

Breaking the Barrier

Barlow likes to compare Delta's collection of "best in class" gear grinders to owning high-end sports cars like Lamborghini and Ferrari. It's no secret: Delta's mission is to have the most impressive garage on the block.

"We're kind of the leader in new technology," Scott Sakuta says. "We're

A painting of a school of marlin by Stanley Metlzoff that hangs in Sakuta's office.

pretty active in what the next equipment feature we'll include, whether that's stock removal features or the ability to do more complex gear geometries on the equipment. So I think our investment in the new gear equipment in the industry sets us apart from some competition.

"And that's difficult in aerospace because people say, 'That's how it was done in the '50s and that's how we want it done. We're trying to break that barrier, coming up with more precise, quicker ways to produce parts than the way they did years and years ago."

Delta sets aside a large percentage of their annual revenue to purchase new equipment every year, and that allows the company to always be up-to-date with the best machinery on the market. Most of the machines on Delta's floor are only a few years old or newer.

"The thing that makes Delta shine above the others is they're on top of the latest and greatest technology," Rouillard says. "They're on the cutting edge of everything. To quantify that, they have 11 CNC grinders in this company, all less than five years old.

"When Bob buys a machine, he buys every single option available just in case he might need it—which is extremely intelligent to do that. Past companies I've worked at do not do that. They buy the machine and then don't tool it up right, and then you don't get your bang for your buck."

Adds Barlow: "It's clearly evident that we have our act together," he says. "Every part—not just a couple parts—is handled extremely well. There are special or custom foam holders for every part so nothing can touch. We don't have problems with nicks or chips or dings.

"We just don't have that issue at Delta because of the care we put into it."

As much as Delta puts the emphasis on its machines, that devote care and attention of the little details begins and ends with Delta's employees

"Our employees are what set us apart," Barlow says. "From the time you meet the people in the office and the management team and the employees on the shop floor—our employees on the shop floor say hello; they reach out to you; they talk to you; they're interested in showing visitors and customers what they're doing. They're interested in it because they care.

"Attitude is everything. When you walk in and talk to people at Delta Gear you can feel the difference. The morale here is very positive and it's a can-do attitude from everyone from the janitor to the CEO."

Of course, that bring us back to the Sakutas—and, conversely, fishing, which seems to tie this whole story together like a long piece of monofilament fishing line.

"Being in Michigan and surrounded by the Great Lakes, some of my earliest memories with my dad are of fishing," Scott Sakuta says. "We fished for years and years together and we fished the lakes and rivers of Michigan. Probably right around 2003 we started to investigate the warmer, more exotic climate fish."

Sakuta said he doesn't fish as much as he would like these days because "he's been so busy working and growing [Delta]," but he still makes a few trips a year—oftentimes with fellow employees.

His favorite thing to catch: good times.

"You know, I can't say I have a favorite fish," he said. "I just think the memories of being there with my dad and—we've taken employees on trips to foreign countries and fished for exotic fish—it's just about being there with people.

"I don't have a favorite. They're all great. It's just about who I was with and how it was done."

And if Delta had a catchphrase—a clever little saying displayed above the entranceway to their facility—that would probably be it.

But they don't need one. They have the lobby, and Sakuta's under-the-sea office, and that giant, wall-to-wall window that proudly displays the shop floor—and to understand the difference at Delta, all you need to do is look through it.

Just don't tap the glass. **PTE**

Delta Gear's Reishauer RZ 260 gear grinding machine.

THOTH

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Ningbo Zhongyi Hydraulic Motor Co, Ltd was found in 1971, which is the high tech mfg. expert of orbital motors, steering control units, transmission and mobile motors. At present we have two manufacturing bases, one is in Ningbo city covering an area of 44,000 square meters, the other one is in Wuhu city with an area of 80,000 square meters. Our manufacturing workshop meets the international standards and the manufacture and test equipments are leading technologically home and abroad. The staffs of Zhongyi will creat first class products, services and brand hands in hands with you.

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The Path to Smarter Bearings

Interview with Stefan Hantke

Dave Friedman, Associate Publisher

At Hannover Messe, Power Transmission Engineering had the opportunity to sit down with Stefan Hantke, president of the Industrial North America division of Schaeffler USA, to discuss the current state-of-the-art in bearings manufacturing, the trends in industrial bearings and the current state of U.S. manufacturing. (In the meantime Stefan Hantke has taken over responsibility for the global sales activities of Schaeffler Industrial)

Stefan Hantke

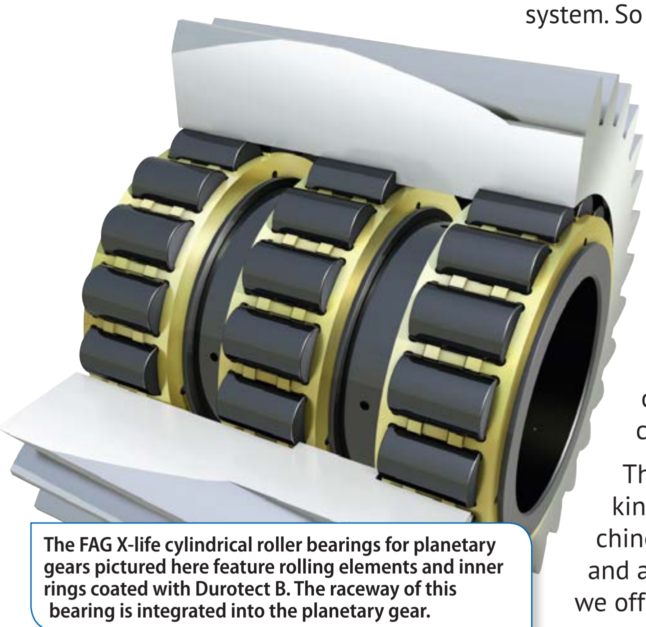
What are the main areas of technical advance with regard to bearings for large, high-power applications such as wind turbines?

What we are seeing in the industry are different trends. One clear trend is downsizing leading to higher power density. At Schaeffler, we have responded to this demand for example with the X-Life bearing program. X-Life means extended life rating. So X-Life is our best-in-class bearing—you have the highest lifetime, you have the highest load carrying capacity, you have the best bearing in its class. This is what X-Life means.

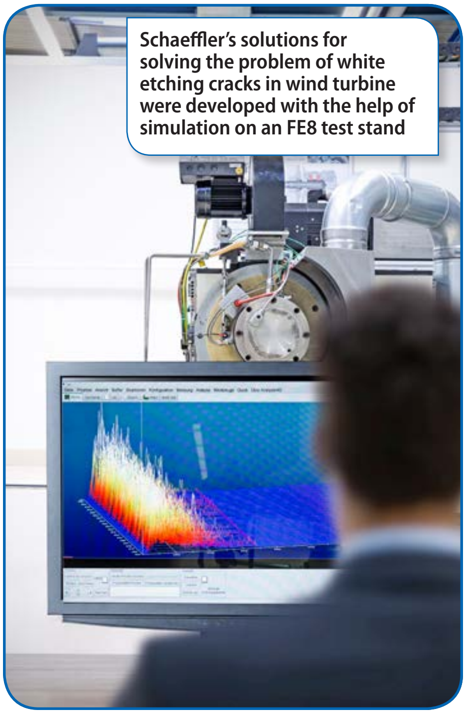
Friction reduction is another demand out of the market, because friction reduction means a reduction in energy consumption. We see this trend in every device you can see in the field—especially in Europe, but in the U.S. as well—customers are focused on the reduction of energy consumption. They are looking for the complete system and solution for energy consumption.

Further, our customers are asking more and more for predictive analysis of bearings. For example, they really want to have a clear calculation of the lifetime of the grease lubricant. And they want to know the life of the bearing. How rigid is the bearing? And not just the bearing. At the end of the day they want to know the complete system. So with our response to these demands, we are going to approach a complete system understanding. For example, with our BEARINX calculation program, you can simulate bearings as well as complete transmissions regarding, for example, lifetime or stiffness including the shaft and the bending of the shaft. Everything is considered in BEARINX.

This tool is being used for all kinds of applications: in machine tools, in the steel industry and among our distributors. And we offer online access for our customers. From my perspective it is the best calculation program for bearings and benchmark.



The FAG X-life cylindrical roller bearings for planetary gears pictured here feature rolling elements and inner rings coated with Durotect B. The raceway of this bearing is integrated into the planetary gear.



Schaeffler's solutions for solving the problem of white etching cracks in wind turbine were developed with the help of simulation on an FE8 test stand

And you asked especially about applications such as wind turbines. We are working very closely with our customers from the wind energy sector. One example: Operators of wind turbines all over the world suffer from so called white etching cracks in bearings. A phenomenon that has a negative influence on the reliability of bearings. WEC are structural changes in the material that form below the surface of the bearing. These changes result in the formation of cracks, which extend to the surface during stress conditions under different external loads. We now developed a solution combining the through hardening of the bearings in combination with black oxide coating on the inner and outer rings and the rolling elements.. A solution we developed in close cooperation with our customers in the OEM and the MRO market.

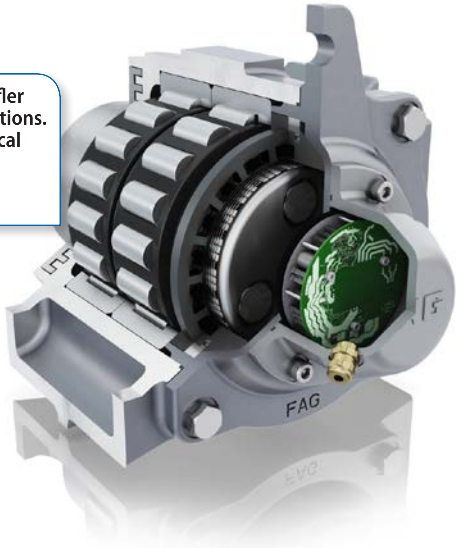
What are the main areas of technical advance for automotive and other vehicle applications?

I'm first of all responsible for industrial. But from everything I'm hearing out of the company, the CO_2 reduction is one of the main concerns of our customers including weight and size reduction. And customers are increasingly asking for complete systems. So the trends we see in automotive are similar to those we see in industrial. We see the same trends in agriculture and mining trucks. In all these cases. they are going away from just the bearing to a more complete system, for example with traction control, integrated torque sensors or sensors for lubrication and condition monitoring. There's really a trend into what I would call smart bearings. For all trends and all sectors we're thinking in the region, for the region. Because the requirements in every region are different, and you have to be close to the region, close to the customer there, to meet their requirements and to know what they really want. You have to adjust your concepts to the local markets. And this is one of the strengths of the Schaeffler group, because we are in the region, for the region—producing parts in the region and developing parts in the region, for the region.

How is Schaeffler making use of engineered coatings in bearings applications?

Coatings is from my perspective the most important add-on for bearings you can have. We recognized this 10-15 years ago. So we started developing a dedicated coating department at our headquarters. Today, from my perspective we are the leading company in the world concerning coatings for bearings.

Coatings offer advantages in almost every application. We offer a comprehensive kit of coatings including Corrotect for corrosion protection, Durotect for wear protection and Triondur for friction reduction. Additionally we have developed coatings for current insulation and also sensor coatings. Depending on the requirements of the application we can coat outer rings, inner rings, or rollers or balls. We can coat the cages. I already mentioned how important coating is for example for wind energy. With our black oxide



In response to the demands of rail freight traffic, Schaeffler is developing a range of self-powered, mechatronic solutions. A wheelset generator from FAG, which generates electrical energy, forms the core component of these systems. It provides an independent power supply for monitoring, position determination, and telemetry.

coating, we offer a reliable solution to prevent white etching cracks.

We are also using this corrosion coating in agriculture. The agricultural market needs to have good corrosion coated bearings. Also, a lot of distributors are coming to us. They see bearings failures in the field. We analyze the failures and with additional coatings, we can bring the bearing in the steel plant, in the paper plant and whatever plant, to the next level. Our distributors and their customers often consider the TCO, total cost of ownership, approach, and coatings are an effective step towards this requirement. In the field, if you consider that with a coating you can have 30% more lifetime, the customer is willing to spend a little bit more. We see a lot of good ideas and good applications coming from our distributors here.

What are the most intense areas of R&D at Schaeffler?

Aside from the areas we've already talked about, I see that we are especially supporting mechatronics. Let me say, from my perspective, the future is not just selling and providing bearings. We have to provide systems. Customers are asking for complete solutions, not just one bearing.

In North America we started a center of excellence for mechatronics, located in Fort Mill, South Carolina. With this dedicated team we develop bearing based modules and systems for rotary and linear motion, as well as multi-axis systems and complete solutions. We started five years ago, and our customers and our salespeople are recognizing that there is a deep knowledge, that there are young people who are able to combine electrical devices, controllers and bearings together to make complete systems. And this is really a value-add for the customer and for the company.

This FAG torque measurement module for agricultural applications transfers its data to the control system via the ISOBUS. All relevant parameters such as the speed and torque of the take-off shaft, the push-off speed, and the system's hydraulic pressure are recorded using sensors and then processed in the control unit.

What new technologies are you able to offer customers who are concerned with maintenance, reliability or advance prediction of bearing failure?

We already offer a wide range of condition monitoring components combining them with autonomous condition monitoring systems including services like online monitoring. With our FAG Smart Check, we can monitor vibrations in the bearing. Combined with FAG Grease Check for lubrication control and with our lubrication systems we can already offer a 360 degree condition monitoring including predictive maintenance. This helps operators to reduce downtimes for maintenance and to save money.

Another example: We designed a split spherical bearing—produced in the U.S. in Joplin, Missouri. This is very easy to assemble and disassemble. This is really a new development coming from the United States making mounting much easier and also helping to keep downtimes short.

What will the bearings of tomorrow be able to achieve that today's bearings cannot? What is the timeframe for the next level of advancements?

This is my personal vision, to be honest. I think—and this is a perfect example of coming to Industry 4.0—I think the vision and the future is not just bearings. I think the future will be a bearing with integrated sensors offering information of the actual and the future condition of the bearing but also the complete machine.

This means the bearing is telling you, "I need now to be replaced." The bearing is telling you, "I need now more grease or more lubrication." And the bearing is telling you in the plant, "I am very close to failing. Please order a new one, and please order it at Schaeffler."

"I think in the future out of every bearing there will come a wire, and we will have communicating bearings"
—Stefan Hantke.

This is my vision. I think we are on the right track. There is still a lot of R&D to be done but in the next three to five years, this will gradually turn into reality. First steps like the 360 degree condition monitoring or the torque measurement are already in the field.

What is the state of manufacturing in the United States?

From my perspective, we in the U.S. are successful everywhere where we are innovative. Examples include John Deere, one of the most innovative companies we are working with in the world; Haas, the machine tool manufacturer on the west coast; and Caterpillar. Very innovative. And these are only a few examples.

Wherever there are innovative companies, suppliers will locate their production and their headquarters. I see the trend in the last five years, especially in the U.S., that a lot of production is coming back here. Our approach is "in the region for the region," but with the highest quality standard. We have the same equipment everywhere in the world—and not cheap machines in India and expensive machines in Germany. We have everywhere the same quality standards, and this makes a difference from my perspective. To be successful in the world market, you have to have high quality, and a lot of production is coming back to the U.S. So I see a very positive future for U.S. production. **PTE**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SPIRAL BEVEL
GEAR CATALOG

Transmissions in Transition

Randy Stott, Managing Editor

Experts gathered at the 9th CTI Symposium to discuss the challenges of reducing noise, improving energy efficiency and meeting the changing demands of the marketplace

Fuel efficiency is the hottest button among hot-button topics being discussed by automobile manufacturers and their suppliers today. Virtually every component in an automobile has been reengineered over the last decade to reduce vehicle weight, decrease energy consumption and recover energy otherwise lost. Nowhere is that more true than among those involved with designing and developing automobile transmissions, as evidenced by the presentations, discussions and exhibits at the 9th International CTI Symposium, held in May in Novi, MI.

Nearly every presenter at the symposium spoke about government regulations that require auto manufacturers to reduce the fuel consumption of their fleets by targeted deadlines. In the USA, the automakers have a deadline of 2025 to meet the Corporate Average Fuel Economy (CAFE) standards. Similar regulations are in place throughout the world.

Naturally, the transmission is a key component in achieving those standards, and the amount of reengineering that's already taken place and that continues to take place has made the design and development of automobile transmissions far more complex than it used to be.

It used to be that engineers had to choose between manual and automatic, between three speeds or four. Today the discussion begins at six speeds and goes up from there. The practical limit seems to be in the 10-12 range, because every additional gear adds complexity to the device — think about the clutches and controls involved. Add in today's choices of dual-clutch transmissions, CVTs and electric motors — nearly everyone in the industry is talking about or beginning to implement some form of electrification of their transmissions — and you quickly begin to understand how much this industry has changed in recent years.

Add to that the much more rapid development cycles required by today's market for new transmission models. The lifetime of a manufacturing line for transmissions is no longer the 20 years it used to be. Today, it's more like five or six years.

All of this just explains how important conferences like the CTI Symposium are, and why the CTI Symposium continues to grow. The 2015 USA conference included more than 500 participants, more than 60 technical presentations, and 39 exhibitors. This compares with 400 participants, 47 presentations and 29 exhibitors at last year's conference. CTI holds three conferences each year: one in the USA, one in Asia and one in Germany. The upcoming 2015 conferences will take place in Shanghai (Sept. 16-18) and Berlin (Dec. 7-10), with Berlin being by far the largest of the three (last year's Berlin conference had more than 1,300 participants).

Whether or not you are directly involved in the auto industry, it pays to take note of what's going on there, because inevitably, much of the technology developed there finds its way into other industries.

The conference included two days of plenary speeches and technical presentations. Plenary speeches included:

- Welcome address and opening comments, by Ernie J. DeVincent, vice president, product development for Getrag and chairman of the conference.
- "The Getrag Approach to Enabling Global Fuel Economy Compliance," by John McDonald, chief operating officer for Getrag global operations.
- "GM's Perspective on the Evolution of the Automotive Transmission 2020 and Beyond," by Mike Harpster, director of GM's Propulsion Systems Research Lab.
- "Enablers for the Next Generation of Fuel Economy Regulations," by Don Hillebrand, director of the Center for Transportation Research at Argonne National Laboratory.
- "Efficient Future Mobility – the Road to CAFE 2025," by Philip George, director of advanced development for Schaeffler North America.
- "Can We Make That?" by Charles Gray, director of transmission & driveline engineering for Ford Motor Co.
- "Contribution to World Market by CVT Technologies," by Hiroyuki Kai, director general of JATCO Mexico.
- "Future Proofing Our Waste and Delivery Transit Infrastructure," by Ian Wright, CEO of Wrightspeed Inc.
- "Roadmap to Autonomous Driving," by Ali Maleki, vice president of business development for Ricardo Inc.

More than 500 engineers and other industry professionals gathered at the 9th CTI Symposium held in May in Novi, MI.

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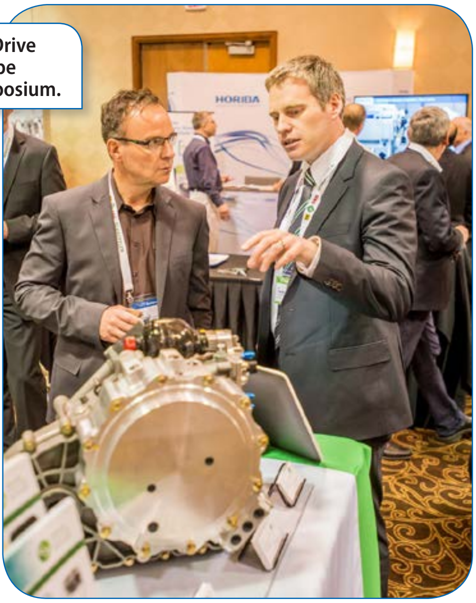


Alex Tylee-Birdsall (right), technical director of Drive System Design, explains the company's prototype transmission project to a visitor at the CTI Symposium.

In addition, technical presentations were given over the two days in the following topic areas:

- Transmission Concepts
- Drive Cycles
- Hybrid Electric Vehicles
- Diagnosis and Functional Safety
- All-Wheel Drive
- Noise, Vibration and Harshness
- Manufacturing/Transmission Components

During coffee breaks, during lunch, and between sessions, visitors had the opportunity to talk with the exhibitors in a table-top exhibit hall, where suppliers to the industry discussed their latest innovations. A number of key suppliers of materials, software, mechanical power transmission components and complete systems were a significant part of the exhibition.

Gear and Transmission Expertise on Two Continents

Drive System Design is a company specializing in the design and development of transmission, driveline and gear drives, says technical director Alex Tylee-Birdsall.

"If you look outside of automotive, we also work in off-highway, industrial transmissions — really gear drives and anything that transmits power."

Drive System Design was founded in 2007 with a staff of two. Over the years, it has grown to more than 60 people, and in 2014, the company opened a dedicated office in Farmington Hills, MI, to serve the North American market.

"We've gained a reputation for really good engineering, being right on the cutting edge of what people are doing, and analytically solving problems very quickly — like NVH issues," Tylee-Birdsall says. "We've tried to get the best engineers we possibly can in both markets. I would argue that both in the U.K. and over here we've built up the best teams of those people. I think that's one of the reasons why people come to us."

Drive System Design works on a wide variety of projects, Tylee-Birdsall says. "It can be anything from a really

small project — just design a gear — up to a full three-year transmission design and development program, all the way up to production.

"One of the smallest transmissions we ever worked on was for a mechanical hand. The transmission measured 28 mm in diameter by 10 mm in length. It was a two-speed, torque-sensing transmission. Effectively the way that worked is that if you go to grip something, it moves very quickly. Once it senses resistance and pressure, then it moves much more slowly to grip."


Mike Harpster,

The company has also done significant work in off-highway markets.

"That's a developing sort of marketplace," Tylee-Birdsall says. "People want to have better shift quality, and they want to be comfortable in their air-conditioned cabs, whereas back in the day they were quite happy with the sun beating down on them. We're seeing a lot of opportunity there in developing the control systems to make shifting better."

"We also have major projects in oil and gas," Tylee-Birdsall says. "There are quite a lot of innovative people out there looking at ways of extracting oil, and all of that stuff needs power transmission. It needs reliable gearboxes. If you take fracking, for example, there's a lot of use of conventional transmissions in that industry. They're having to run at quite high power for a long time, and they're not really designed for that. So there are a lot of people looking at proper transmissions designed just for that."


Philip George

And optimizing transmissions and the related systems is what Drive System Design specializes in. The company uses a combination of software and engineering expertise to provide solutions to customer problems.

"We're often using the ability of *MASTA* to develop transmission housings while still on the drawing board," says Shaun Mepham, president of Drive System Design, Inc., the USA


Charles Gray

branch of the company. “That allows us to engineer the housing structure such that it is quieter than what we used to do by engineering it from scratch, not doing any analysis and waiting for it to be measured on the test rig. We are computing all of the losses in all of the components, then constructing the loss of a gearbox and comparing it against three, four, five other variants, to make sure that the one that comes off the drawing board is the solution with the lowest loss.”

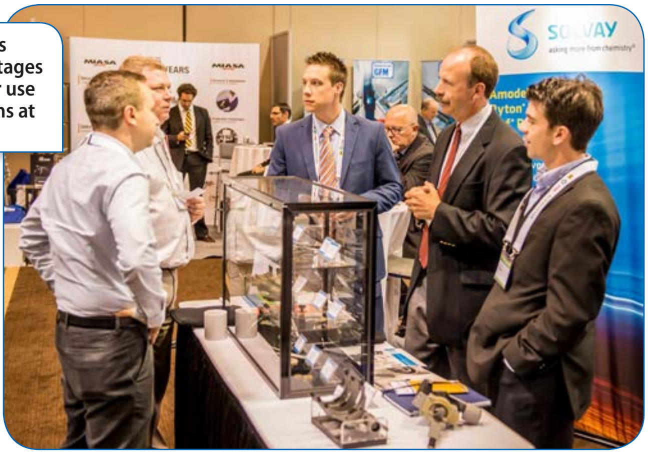
Tylee-Birdsall adds that the company’s engineers aren’t restricted to any one piece of software or tool set. They rely heavily on a wide variety of software, including very specific packages such as Klingelnberg’s *KIMOS* and Gleason’s *CAGE* software. They also work in a wide variety of CAD and FEA systems so that they can communicate designs with customers no matter what platform they use.

Of course, the company’s display at the CTI Symposium focuses specifically on automotive. One of the centerpieces of their display was a prototype transmission that the company designed, developed and produced as a demonstration of their capabilities.

“We’re a consultancy, so that means that a lot of what we do, we can’t talk about,” Tylee-Birdsall says. “We’ve signed NDAs, that sort of thing. So one of the things we decided to do about four years ago was to do our own research project.” In this case, the project involved a new way of adding electric motors to the driveline. “We looked at what everybody was doing,” Tylee-Birdsall says. “What we saw was, everyone was doing single-speed gearboxes and using very energy-hungry high-speed motors. And we thought, ‘We’re transmission engineers. We can do better than that.’”

So Drive System Design developed an architecture that includes 48V electric motors that can be easily fitted into the drivetrain and deliver extra power where needed—without the complexity, expense and need for recharging stations required by higher voltage systems. They also reduced the energy consumption of the transmission by going multi-speed.

“It’s not necessarily a product that we’re selling to market,” Tylee-Birdsall says, “but it gives a showcase that says,



Solvay Specialty Polymers demonstrated the advantages of engineered plastics for use in automotive applications at the 9th CTI Symposium.

look, we can do a full transmission design in a vehicle. We can do the control system, the hydraulics. It gives a good showcase of everything we can do. It's got all of our gear design technology in it as well. We've done an awful lot of work in low-noise gear design. In fact, a lot of the major electric vehicle manufacturers have our gear designs in them."

Tylee-Birdsall emphasizes that the company is far more than just a design consultancy.

"Along with the ability to design, do detailed analysis and write control systems, we also have a full facility in the back that allows us to do full prototype assembly. We have vehicle ramps that allow us to do vehicle build and installation. We have six test cells, including spin rigs, lubrication tilt rig, a fully loaded 310 kW loaded rig. And we have a massive four-square rig, and our own hydraulics clean room."

Hiroyuki Kai

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www.drivesystemdesign.com

Plastic Components Simplify Design, Save Space and Weight

At the Solvay Specialty Polymers booth, the emphasis was on replacing traditional metal components and systems with plastics.

"One of the main applications we're focused on is needle bearing replacement," says Brian Baleno, global automotive manager for specialty polymers. "A typical needle bearing is quite complex. With a polymeric bearing, there are several benefits. One is weight savings. But the biggest benefit is space savings."

In a typical automotive needle bearing application, you can get an average of 2 mm space savings. "That allows you to downsize the transmission casing or housing," Baleno says. "That means weight savings, which translates into less energy consumption."

The technology also can be used outside of automotive, in industrial applications, Baleno says. "Anywhere you want to realize weight savings and also improve efficiency. The nice thing about a polymeric thrust bearing is that you can design in an oil groove, so you can get oil to flow through and provide continuous lubrication as well."

"Another application that we do a lot of work on is seal rings," Baleno says, adding that today's highly engineered thermoplastic materials are better able to withstand the high temperatures and pressures required by many automotive applications. **PTE**

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Tales from the Bearings Blog

The following short articles first appeared on *www.powertransmission.com*. They are part of the ongoing series of hints, technical tidbits and inside knowledge presented by our resident blogger, Norm Parker. If you like what you see here and are interested in learning more, visit *www.powertransmission.com/blog*.

Why Are Cast Iron Housings More Problematic When Fitting Tapered Bearing Cups into Bearing Caps of Salisbury-Style Axles?

I was recently approached for the 9,000th time (at least) about fitting tapered bearing cups into bearing caps.

Bearing caps can be a fairly generic term, so let me clarify that I am specifically talking about bearing caps in a Salisbury-style axle — which are the majority style of light-duty truck axles used today.

Generally speaking, you don't want an interference fit on these bearing caps because they will distort when you tighten them down.

If only it were that easy!

For as long as bearing caps have been around, keeping them round has been the issue. Typically, the caps will be mated to carrier and machined as one assembled pieces. The prevailing theory was that if the cap bolts were tightened down enough so that the cap wouldn't move during machining, the cap should be able to be removed and reassembled with the same tolerances it was machined to — right? Wrong.

It has been found that after the cap/carrier interface is machined, the measurements may be perfect — until you loosen the bolts for the first time. The cap will often contract and give you an out-of-round cap. There are a couple of theories; I'm of the opinion that the machining operation imparts some compressive stress into the machined surface of the cap which aids in the contraction when the cap is removed.

How much does the cap contract?

It can be substantial. Substantial enough to fail a bearing at the split line location. Figure 1 is a cap that was machined to perfection prior to removing the bolts and, upon removal, measured 120 μm out-of-round at the split line location — far beyond acceptable

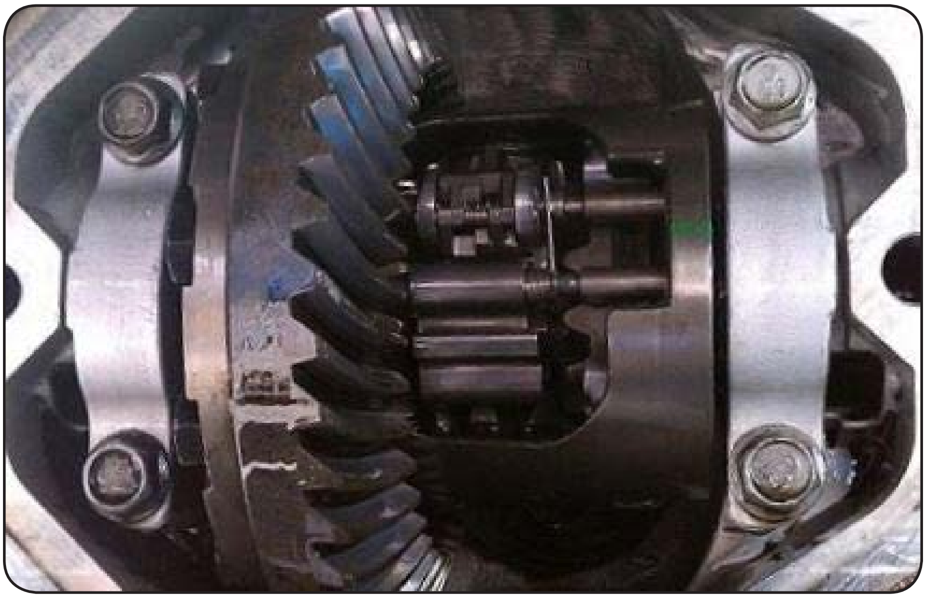


Figure 1 Rear-view Salisbury-style axle.

Figure 2 Bearing cap after machining and removal.

Figure 3 Bearing cup spalling at the cap interface.

tolerances. To make matters worse, the out-of-round is very localized — creating almost an edge at the split line. In testing, this cap wound up failing a bearing cup as the first failure in the axle, taking about one-half of the life out of the axle.

For reasons I don't yet completely understand, this problem seems to be more prevalent in cast iron housings. Aluminum housings don't seem to exhibit this problem nearly as often as iron housings. It could be because the AL doesn't get as hot during machining, but that is speculation on my part.

We'll really get into this deeper in a full article, but for now, keep your cap fits light. I like to start off somewhere around a line-to-line fit. There are occasions, if you are having really bad contraction with heavy loads, when you may have to back off farther than that.

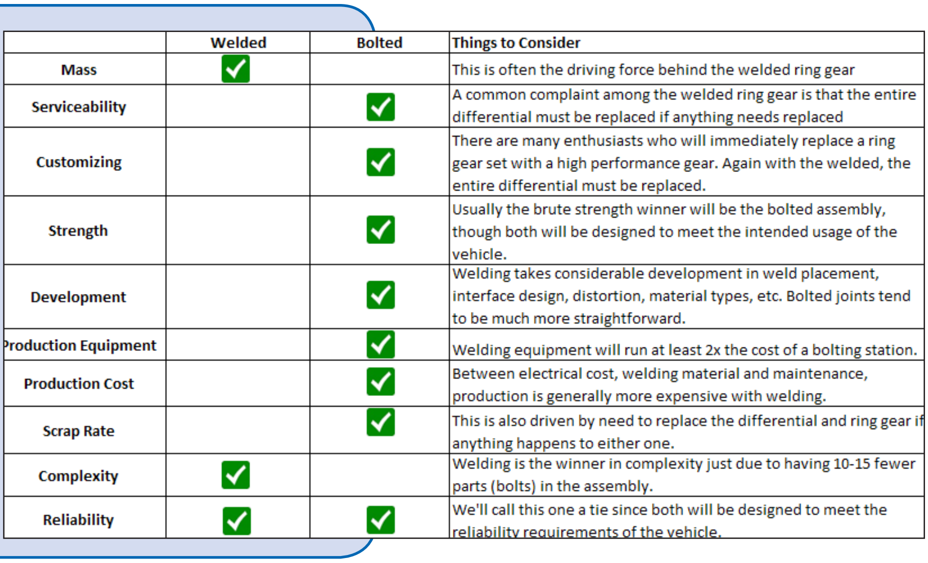
Bolted or Welded Ring Gears? Which and Why?

There is often a lively debate early in a program when we are discussing the pros and cons of laser welded ring gears vs. bolted ring gears. Just about every company that makes gears has both styles to some extent.

There is no right answer for every application. Mass savings with welding often dominates the conversation, but let's take a high level look at some of the other pros and cons to consider if you find yourself if this conversation.

There are clearly more check boxes in favor of the bolted assembly. However, if someone if offering up 1kg or more in mass savings for a welded assembly, depending on the vehicle, welding very well may be a worthwhile venture. Looking at the comparison, it becomes obvious why companies typi-

cally employ both methods. For high performance, lightweight vehicles, laser welding becomes very attractive. For larger, heavy duty type applications where mass does not have as high of a premium, bolting wins the contest. The upside to welding is that after you make the investment, you will always have both technologies available to suit any application that comes your way.



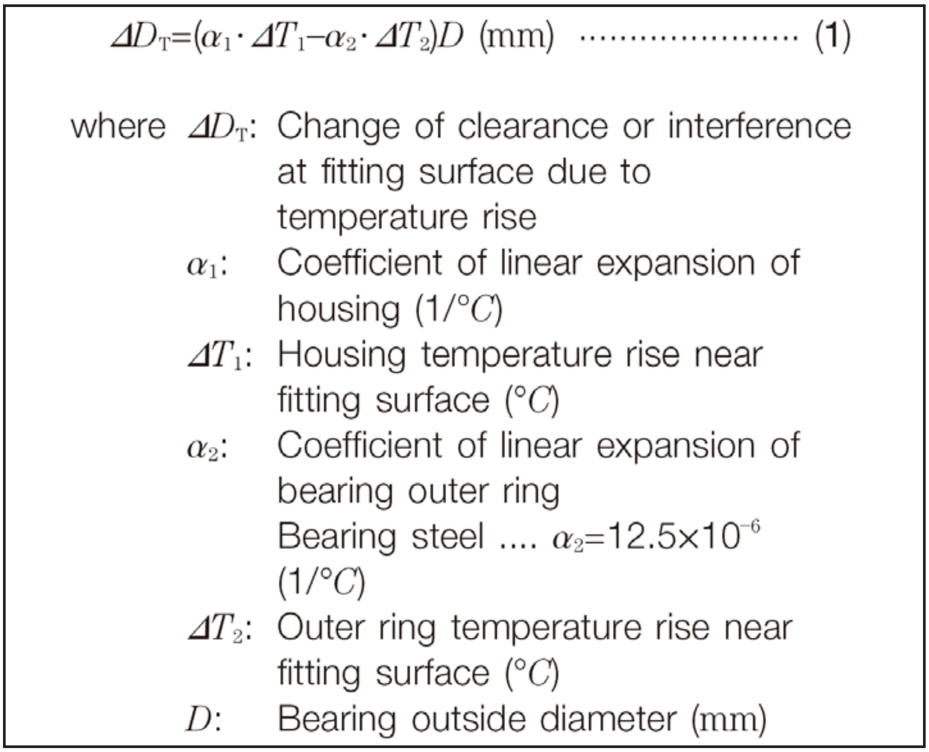
	Welded	Bolted	Things to Consider
Mass	✓		This is often the driving force behind the welded ring gear
Serviceability		✓	A common complaint among the welded ring gear is that the entire differential must be replaced if anything needs replaced
Customizing		✓	There are many enthusiasts who will immediately replace a ring gear set with a high performance gear. Again with the welded, the entire differential must be replaced.
Strength		✓	Usually the brute strength winner will be the bolted assembly, though both will be designed to meet the intended usage of the vehicle.
Development		✓	Welding takes considerable development in weld placement, interface design, distortion, material types, etc. Bolted joints tend to be much more straightforward.
Production Equipment		✓	Welding equipment will run at least 2x the cost of a bolting station.
Production Cost		✓	Between electrical cost, welding material and maintenance, production is generally more expensive with welding.
Scrap Rate		✓	This is also driven by need to replace the differential and ring gear if anything happens to either one.
Complexity	✓		Welding is the winner in complexity just due to having 10-15 fewer parts (bolts) in the assembly.
Reliability	✓	✓	We'll call this one a tie since both will be designed to meet the reliability requirements of the vehicle.

Bearing Cup Fits in Aluminum Housings

The interference fit that cups should have in an aluminum housing is a subject that comes across my desk in regular intervals. Of course, there are numerous reasons why you would need certain fits in different areas. If there is a bearing cap involved, you may have a light or loose fit. If you need something that is going to be serviced at intervals, you are likely going to want a fit as light as possible. In gear housings, the highest priority is often the stiffness of the system, which drives a cup fit that you never want to lose contact because the cups will start to float in the bore, creating misalignment in the shaft. In a perfect world we could run a CAE stress analysis to determine how the cup interferes with the housing and then run a thermal study to make sure we hold our position at peak temperature.

But as a great person once said, "Ain't nobody got time for that."

The bore expansion can be simplified to a simple diametrical expansion. It's not 100% perfect—but its close enough for our purposes. A perfect calculation would use the linear expansion around the circumference, but when you use the same simplification for both cup and cone, the end result is nearly identical as the more elaborate approach. Using this simplified equation, a 100 mm bore at 120°C will expand by 85 μm from room temperature, 25°C. If you were trying to maintain fit up to a 120°C, that is going to be



$$\varDelta D_T=(\alpha_1\cdot\varDelta T_1-\alpha_2\cdot\varDelta T_2)D \text{ (mm)} \quad \cdots\cdots\cdots\cdots \quad (1)$$

where $\varDelta D_T$: Change of clearance or interference at fitting surface due to temperature rise

α_1: Coefficient of linear expansion of housing (1/°C)

$\varDelta T_1$: Housing temperature rise near fitting surface (°C)

α_2: Coefficient of linear expansion of bearing outer ring
Bearing steel .... $\alpha_2=12.5\times10^{-6}$ (1/°C)

$\varDelta T_2$: Outer ring temperature rise near fitting surface (°C)

D: Bearing outside diameter (mm)

Figure 1 **Linear Thermal Expansion. NSK Ltd, Cat. No. E728g 2009; p 67.**

Editor's Note:

"Bearing Cup Fits in Aluminum Housings" was Part 1 of a three-part series on the issues of dealing with aluminum housings. It was originally posted on February 13. Visit *www.powertransmission.com* to see:

- Part 2, "Cup Distortion After Installation" (Feb. 20).

- Part 3, "Preload Change Due to Bearing Span Change with Temperature" (March 4).

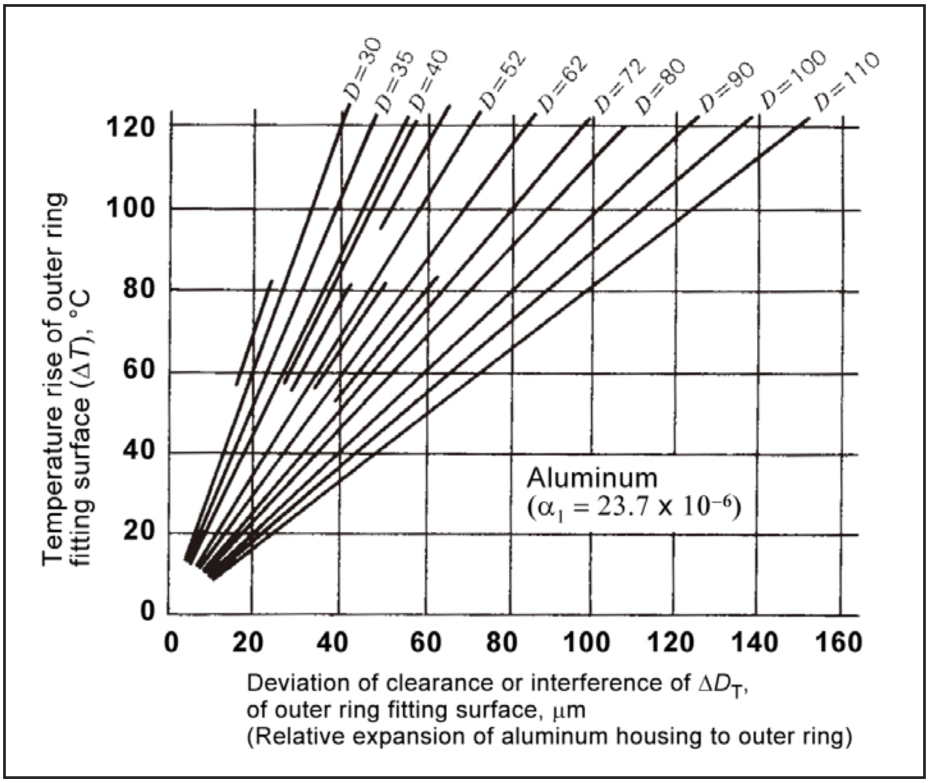


Figure 2 Chart of the Equation Above. NSK Ltd, Cat. No. E728g 2009; p 69.

your target interference fit. Depending on where your tolerances are, that might be your maximum or minimum target, with your bearing + housing tolerance defining the other end.

In my February post, I discussed how to use hoop stress calculations to determine how much the cup will grow and shrink with moving temperatures. Don't make the rookie mistake of using the 85 µm as your potential cup expansion; your cup will only expand as far as you compressed it. In a 25 mm wall housing, most of the interference is going to expand the housing wall, with the cup only compressing by as little as one-fifth of the overall interference.

Norm Parker is the bearing technical specialist for the driveline division at General Motors LLC. Located onsite at the Milford (MI) Proving Grounds, he is regularly tasked with testing theoretical models in the real world, in real time. With his bachelor and master degrees in mechanical engineering from Oakland University (Rochester, Michigan), Parker has developed a keen interest in the academic, commercial and engineering aspects of the bearing industry. Prior to joining GM, he rose through the ranks of traditional bearing companies; by so doing he acquired invaluable experience in working with some of the largest customers — with the toughest applications and demands — on the planet. Parker plans to continue expanding his expertise and providing substantial personal contributions to bearing technology through metallurgy, design and processing.

Visit *www.powertransmission.com/blog* to read more of Norm's posts and stay up-to-date on the latest in rolling bearing advice and technical tips.

Stepper Motor Actuators

THE QUESTION

How would you compare the efficiency and capabilities of hybrid stepper motor actuators vs. can stack stepper motor actuators?

Figure 1 Laminated steel stator assembly.

Figure 2 Stamped low-carbon steel field ring.

Expert response provided by Ray LaChance and Joe Rossi, Haydon-Kerk Motion Solutions

The answer to this is the efficiency of the motor itself. The average hybrid motor is about 65% efficient while the can stack actuators average about 25% efficiency. There are two primary reasons for these differences in efficiency.

The answer to this question can be found in the efficiency of the motor itself. The average hybrid motor is about 65% efficient while the can stack actuators average about 25% efficiency. There are two primary reasons for these differences in efficiency.

The first reason is the use of a laminated silicon steel stator assembly in the hybrid motor (Fig. 1), compared to a stamped low-carbon steel field ring assembly in the can stack motor (Fig. 2). The use of a laminated stator stack in the hybrid motor construction results in less eddie current loss and the silicon steel material used in the lamination construction reduces hysteresis loss. Therefore the total iron loss in the hybrid motor is less than the can stack motor, resulting in the hybrid motor's higher efficiency. series, i.e. — 1.8 degree/step and .9 degree/step (vs. 7.5 or 15 degrees for the typical can stack) will allow resolutions down to .000060 in. [0.001524 mm]/full step compared to .00025 in.[0.00635 mm]/full step in a can stack motor. Therefore the hybrid motor provides much finer positioning capability.

The second advantage is within the motor's magnetic circuit. The construction of the hybrid motor actuators allows for the air gap between the rotor and stator assembly to be about one-half of what the can stack motor actuator can be manufactured to. The air gap in the hybrid design is typically 0.003 to 0.004 inch [0.0762 to 0.1016 mm], compared to 0.007 to 0.008 inch [0.1778 to 0.2032 mm] in the can stack construction. The smaller air gap provides a more efficient magnetic coupling between the rotor and stator, resulting in higher torque (Figs. 3 and 4).

Comparing the size 17 single-stack hybrid actuator (1.7 in.^{2} [43 mm^2]) and the 46000 can stack actuator (Ø1.8 in. [Ø 46 mm]), 7 watts and 10 watts of input power respectively, with the identical lead screw; the resulting force at the same linear velocity is much higher in the hybrid version (Fig. 5).

In addition to the efficiency advantages shown above, there are other advantages that the hybrid actuators have over the can stack versions:

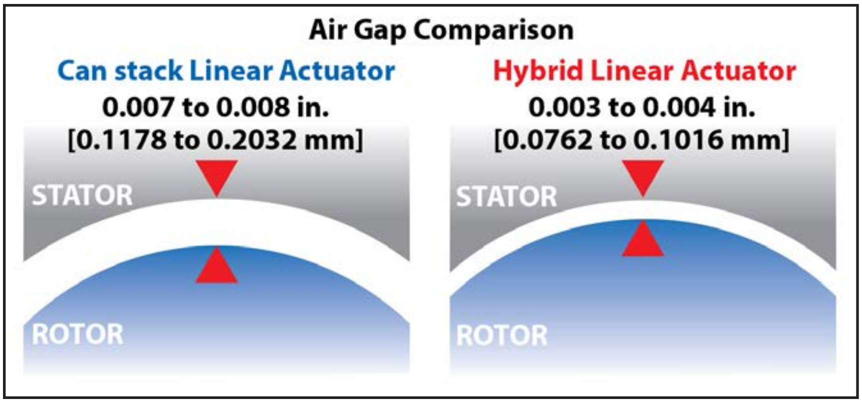


Figure 3 Air gap comparison can stack vs. hybrid linear actuators.

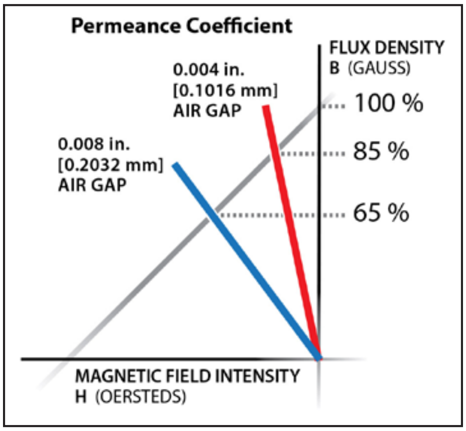


Figure 4 Effect of air gap on motor efficiency and performance.

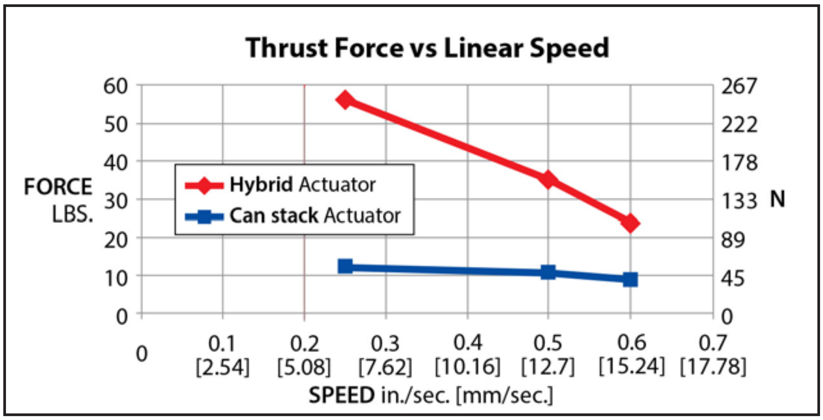


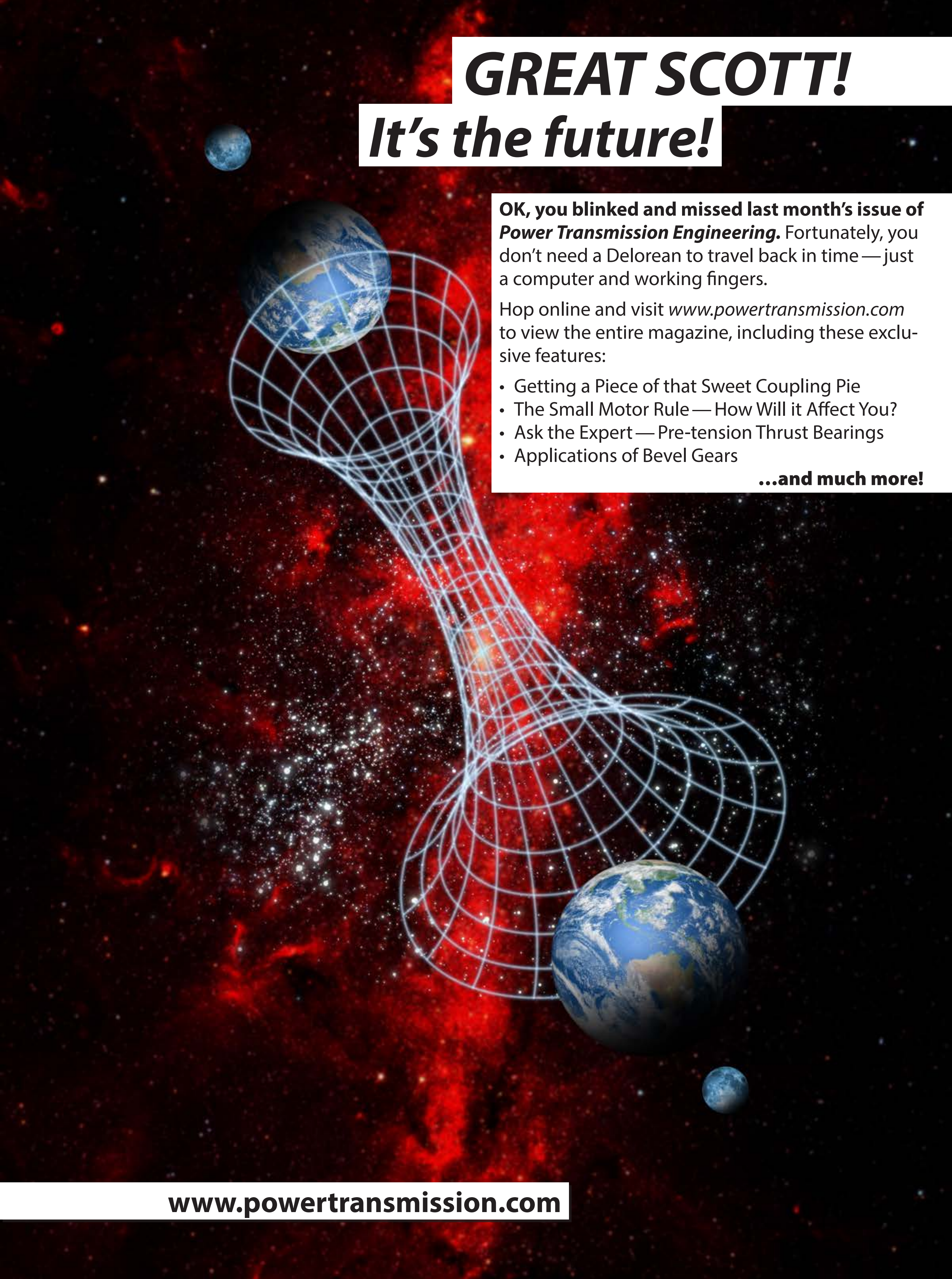
Figure 5 Comparison curves.

1. Stepper motor-based linear actuators are extremely useful in positioning applications, whereas linear motion occurs for every pulse sent to the motor's controller. The resolution of this motion is a function of the lead of the screw and the degrees-per-step of the stepper motor. The step angles available in the hybrid series — 1.8 degree/step and .9 degree/step (vs. 7.5 or 15 degrees for the typical can stack) — will allow resolutions down to .000060 in.[0.001524 mm]/full step compared to .00025 in. [0.00635 mm]/full step in a can stack motor. Therefore the hybrid motor provides much finer positioning capability.
2. Mounting of the actuator can play a critical role in overall system performance in many applications. The hybrid actuators have a locating boss on the front-end bell that is concentric to the motor bearings, thus allowing better mounting to center the actuator in the assembly (Fig. 6).
3. The ability to add encoders for closed-loop operation is easily performed on the hybrid line of actuators due to its use of a metal rotor insert compared to the plastic rotor journal used on the can stack actuators. The brass rotor insert can be machined to a tight tolerance, enabling it to have greater mechanical strength and a precise fit through the motor bearings, resulting in less run out of the encoder wheel and a more reliable encoder count when using high-resolution model encoders.
4. An increase in output power may become necessary for any given application. The hybrid motor construction allows for several output power levels for a given frame size. Its output power can be increased by creating a longer stator

stack and rotor assembly. This can be achieved at a reasonable cost. To do this on a can stack motor would involve a complete retooling of the motor that comes at considerable cost due to capital investment.

As outlined above, the hybrid stepper motor's higher efficiency—due to lower iron loss and smaller rotor to stator air gap—offers a higher output power density when compared to the can stack motor. These features do come at an increased cost, but if the can stack actuators meet the required force, speed and resolution requirements it will be a less expensive solution.

Figure 6 Locating boss feature for concentric mounting.



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Calculation of the Efficiency of Worm Gear Drives

Balázs Magyar and Bernd Sauer

This paper presents a physically grounded calculation method to determine the efficiency of worm gear drives. This computation is based on the Institute of Machine Elements, Gears, and Transmissions (MEGT) tribological simulation, which can determine the local tooth friction coefficients (Ref. 1). With this knowledge other power losses such as the bearings, oil churnings and seals power losses can also be calculated.

Introduction

Worm gears belong to the cross axis drives; with them a very high gear ratio can be realized in one stage. But this advantage is coupled with a high sliding velocity between the meshing gear teeth. Therefore the tooth friction and also the tooth friction power losses are higher than with other gear variants. By the construction of gear solutions it is important to know their future efficiency. Previous calculations can help engineers to compare the different solution principles with each other and to choose the best variant. In this case, a single-worm gearbox competes with a complex multi-stage, helical gear/bevel gear transmission. By the last variant, more responsible empirical equations exist to predict the power losses in all stages (Refs. 2–4). Unfortunately the standardized empirical calculation method (Ref. 5) for determining the efficiency of worm gear drives is not useful if the gear ratio differs from 20.5. Another disadvantage of this calculation is that it ignores the variation of lubricant oil and surface roughness. These omissions complicate the prediction of the efficiency of worm gear drives. At the University of Kaiserslautern, a calculation method to determine the tribological behavior of worm gear drives has been developed. This method is able to calculate the local tooth friction and thereby the efficiency of the gear meshing. Taking into consideration the other loss components in the gearbox, the efficiency of the complete gear unit can also be calculated. This calculation method is presented in detail in this paper.

Power Flow in Worm Gear Drives

Worm gear units are very compact; a single gearbox includes only two shafts with the coupled worm and worm wheel, bearings, seals, and oil sump. These machine elements cause power losses in the transmission. Therefore the losses in worm gear drives can basically be traced back to four reasons; tooth friction P_{ltf}; oil churning P_{lchur}; bearings P_{lbear}; and shaft seals P_{lseal} losses. The potential loss sources in a worm gearbox and the power flow assigned to the Shafts 1 and 2 in a worm gear drive are illustrated in Figure 1. To determine these power losses it is necessary to know the local loads of every machine element. The loss sources can be divided into load-dependent and no-load-dependent components. Load-dependent power losses are the tooth friction power losses and the bearing power losses. But the latter has also a no-load-dependent part. Other no-load-dependent power losses are the churning and the shaft seals power losses. In the next section the determination of power losses is described.

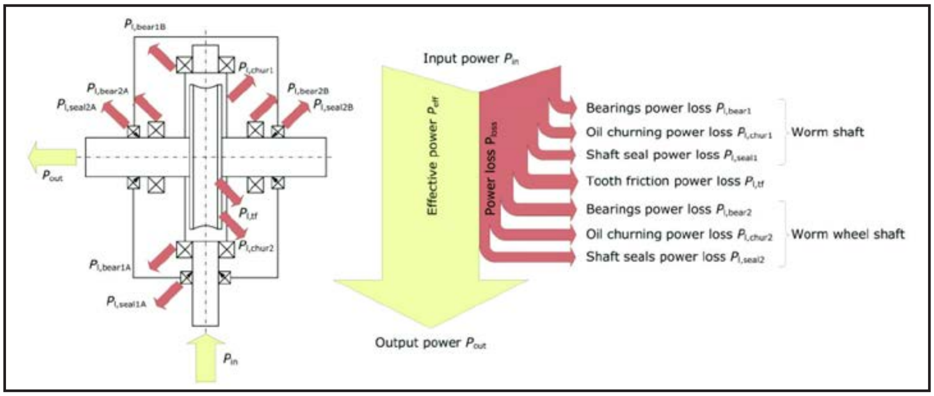

Figure 1 Power losses and power flow in a worm gear unit.

Calculation of Power Losses in Worm Gear Drives

Tooth friction power losses. To determine the tooth friction in worm gear drives, a tribological calculation method has been developed at the Institute of Machine Elements, Gears, and Transmissions (MEGT), University of Kaiserslautern (Ref. 1).This simplified tribological model of the tooth meshing by worm gears is shown in Figure 2.

The first step of this calculation is determining the contact. Worm gear drives have a line contact. Several points of the current contact line are calculated by a solution of the "equation of meshing." According to the equation of meshing, the normal vector of the common surface is perpendicular to the relative velocity vector of the bodies at the contact point (Ref. 6). Between two calculated contact points of a single

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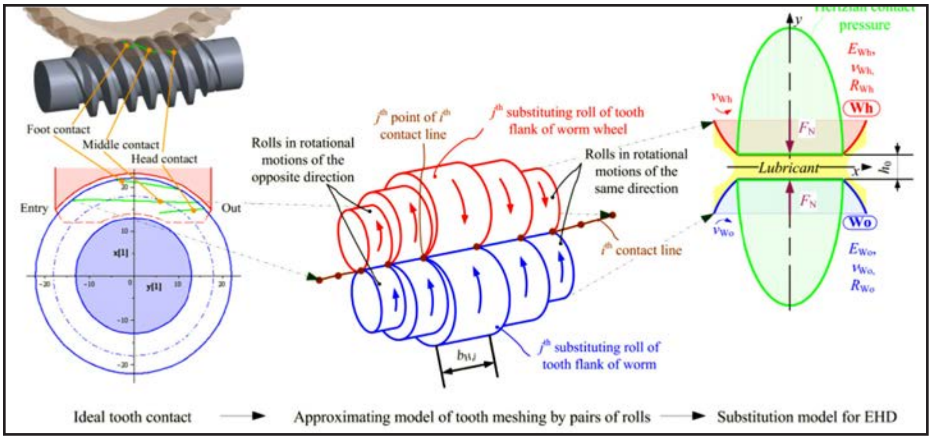

Figure 2 Simplified tribological modeling of tooth meshing by worm gear drives.

contact line — according to Niemann — the tooth flanks are substituted by rolls whose radius coincides with their reduced radius of the curvature, and the rolls perform rotational motion of the same or opposite direction as the velocity valid for the given contact point. If the pressure mound above the flattening was approached according to Hertz, then the oil film thickness between the pairs of rolls can be calculated analytically (compare Figure 2). Because worm gear drives are usually working under mixed lubrication, it is necessary to determine the local proportions of the dry and fluid friction mechanisms. It is estimated with pre-computed division curve, which represents the rate of boundary lubrication depending on the dimensionless film thickness. The generation of this curve is based upon the statistical description of the representative roughness profiles of the tooth flanks and the contact mechanics (Ref. 1). With knowledge of the film thickness and the rate of boundary lubrication, the load distribution along the contact lines can be calculated iteratively. This technique was developed by Bouché (Ref. 7) and is based on the special wear properties of worm gears with full contact pattern. In the next step of the simulation a mixed friction coefficient between a pair of rolls is recorded. The friction between the teeth generates heat rise. Therefore both the contacting surfaces and the oil film between them are heated by friction. The calculation of the surface temperature is based on the numerical solution of Fourier's law for heat conduction. Our solution-technique is founded on Plote's method with Fourier integrals (Ref. 8). The oil temperature in the contact is calculated according to the simplified energy equation of the oil film. To calculate the surface temperatures and the oil middle temperature, the Fourier and the energy equations are solved simultaneously. Knowing the distribution of the oil temperature, an oil viscosity and an oil film shearing can be calculated as well. This shearing is two-dimensional in the gap by worm gear drives. By integrating the shear stress along the penetration surface, the frictional force arising from hydrodynamic lubrication can be elaborated. In mixed lubrication, the friction coefficient consists of a component arising from boundary lubrication and one arising from hydrodynamic lubrication. These components are weight by the abovementioned division curve and so the coefficient of the mixed friction is already known. As this value was freely chosen at the beginning of the thermal calculation, the last computation steps must be repeated in an iteration loop until the error is acceptable. After this calculation the local parameter — for example, oil film thickness, contact pressure, surface temperatures and the coefficient of the tooth friction — are known.

To analyze the efficiency of the worm gear drives the average coefficient of the tooth friction was determined in every meshing position. In this paper a *ZK* profile worm gear drive with $a = 100$ mm center distance and $i = 20.5$ gear ratio was analyzed. Figure 3 shows the calculated local tooth friction coefficients above the meshing field and their average value above the meshing position. In this case the input driving speed was n_1=1,500 1/min and the output torque $T_2 = 500$ Nm. Mineral oil lubrication was used with viscosity class ISO VG 150 by sump temperature $\vartheta s = 60°C$.

Figure 3 represents that the local coefficient of the tooth friction is changing strong along a single contact line (the same color belongs to the same meshing position of the worm). It assumes its maximum value at the middle of the tooth where the sum velocity is nearly zero and therefore the boundary lubrication dominates. The average coefficient of the tooth friction μ_{tf} is also changing strongly depending on the meshing position of the worm φ_1. The curve of the gear meshing efficiency η_{mesh} follows the change in the average coefficient of the tooth friction with the reverse trend. It can be calculated by using Reference 9:

$$\eta_{mesh} = \frac{\tan(\gamma_m)}{\tan\left(\gamma_m + \arctan\left(\frac{\mu_{tf}}{\cos(\alpha_0)}\right)\right)} \tag{1}$$

γ_m is the lead angle of the worm and α_0 stands for the pressure angle. In the knowledge of the gear meshing efficiency the input torque T_1 of the gear pair can be calculated. In the next step, based on the technical mechanic, the bearing reac-

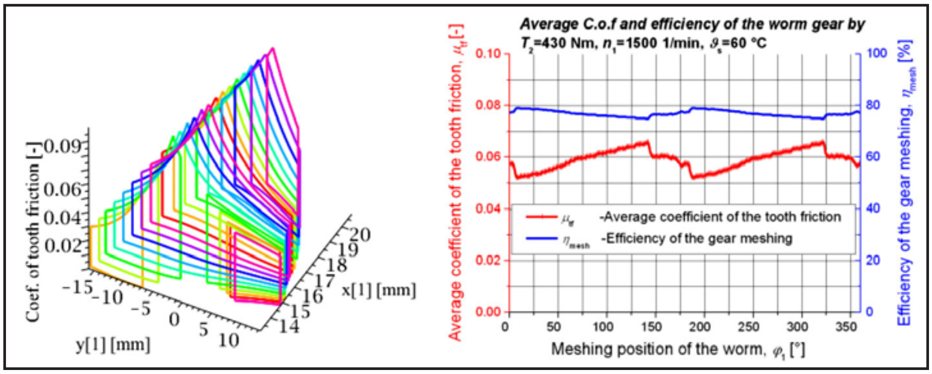

Figure 3 The calculated local tooth friction coefficient above the zone of contact (left); the average tooth friction coefficient computed from this; further the gear meshing efficiency above the meshing position (right) derived from latter.

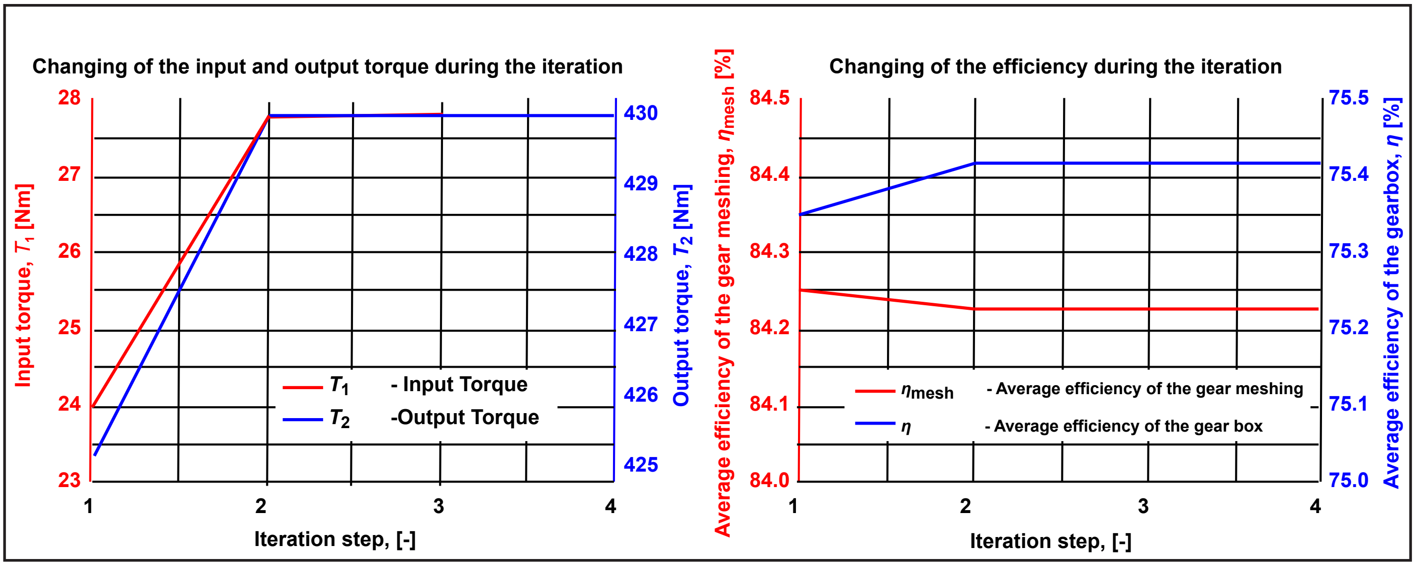

Figure 4 Changing of the input and output torques (left); and changing of the efficiency during the iteration (right).

tion forces can be determined. By worm gear drives by both shafts generally adjusted bearing arrangements were used. The additional pre-stress load of the bearing is computed according to (Ref. 10).

Bearing losses. Knowing the radial and the axial bearing forces and the rotational speed of the shaft the power loss torque by each bearing can be estimated according to the four source friction model of the SKF company (Ref. 10). This determines the total friction moment in a bearing $M_{1,bear}$ as a sum of the rolling frictional moment M_{rr}, the sliding frictional moment M_{sl}, the frictional moment of seals M_{seal} and the frictional moment of drag losses M_{drag}:

$$M_{1,bear} = M_{rr} + M_{sl} + M_{seal} + M_{drag} \tag{2}$$

The details of their calculation are described (Ref. 10); this method was used by all four bearings of the gears to determine the bearing power loss.

Oil churning power losses. At the mechanical engineering department of ECAM, a physically grounded calculation procedure was developed to determine the churning power loss of a pinion, which immerged in an oil sump (Ref. 11). A similar method by worm gear drives is unknown; therefore the mentioned calculation is also used in this paper to estimate the drag torques $M_{1,chur}$:

$$M_{1,chur} = \frac{1}{2} \cdot \rho_{oil} \cdot \left(\frac{\pi \cdot n}{30}\right) \cdot A \cdot \left(\frac{d_m}{2}\right) \cdot C_m \tag{3}$$

Where ρ_{oil} is the oil density, n the rotational speed of the pinion, A the wetted surface area of the pinion, d_m the pitch diameter of the pinion and C_m the dimensionless drag torque coefficient, which can be calculated as follows:

$$C_m = \left(\frac{2 \cdot h}{d_m}\right)^{0.45} \cdot \left(\frac{V_0}{d_m}\right)^{0.1} \cdot \mathrm{Fr}^{-0.6} \cdot \mathrm{Re}^{-0.21} \tag{4}$$

Here h means the submerged depth of the pinion, V_0 the oil volume, Fr the Froude and Re the Reynolds number. Both equations are given in the convention used with SI units.

Shaft seals power losses. To determine the frictional loss torque of the seals $M_{1,\,seal}$, the following simple equation according to Ref. 12 was used:

$$M_{1,\,seal} = \frac{d_{shaft}^2}{60} \cdot \pi^2 \cdot b_{contact} \cdot \mu \cdot p_a \tag{5}$$

Where d_{shaft} is the diameter of the shaft, $b_{contact}$ is the contact width of the sealing, μ is the coefficient of the friction in the sealing contact and p_a is the average contact pressure in the sealing contact. At this point the use of the SI units becomes necessary.

Energy balance of the worm gear unit. In the knowledge of every loss component calculated with the presented methods, the efficiency of the worm gear drives can be determined. This calculation is based on the energy balance of the worm gear unit. It expresses that the sum of the input power, the output power and the power losses is zero (compare Figure 1). Based on this principle of energy conservation, the efficiency of the worm gear unit can be calculated as follows:

$$\eta = -\frac{P_{in} - P_{loss}}{P_{in}} = -\frac{P_{out}}{P_{in}} = -\frac{P_{wheel} - \sum P_{2,bear} - \sum P_{2,chur} - \sum P_{2,seal}}{P_{worm} + \sum P_{1,bear} + \sum P_{1,chur} + \sum P_{1,seal}} \tag{6}$$

Here the power of the worm P_{worm} is increased with the power losses of the input shaft; this sum corresponds with the input power of the gearbox. The power of the worm wheel P_{wheel} is reduced with the power losses of the output shaft; this sum is the output power of the gearbox. Both the power of the worm and the power of the wheel were calculated during the tribological simulation of the worm gear drives.

Influence of the power losses on the power losses. The developed tribological simulation of worm gear drives can only determine the tooth friction power losses of the gearbox. The other power losses, such as the bearings, oil churnings and seals power losses reduce also the output power. Therefore a higher input power than used at the beginning of the tribological calculation is needed to cover the necessary output power of the gearbox. It means that an iterative calculation must be used to determine the real operational condition of the worm gear unit. Figure 4 shows the changing of the in-

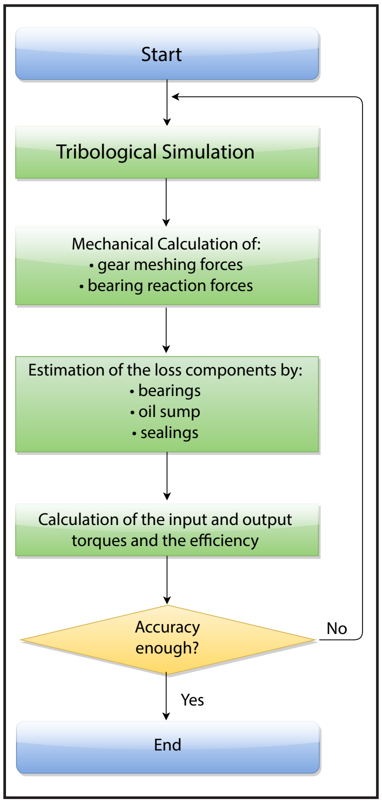

Figure 5 Flow chart of the calculation of the gearbox efficiency.

put and output torque and the changing of the efficiency during this iteration process. It can be seen that in the first calculation step the output torque of the gearbox reduced by losses is smaller than the necessary value $T_2 = 430$ Nm. In the second iteration step the input torque was increased with the loss torque, which was calculated in the first step, whereupon the determined output torque is approximately equal with the necessary value. After four iteration steps the calculated output torque of the gearbox is exactly equal with the expected torque. Nevertheless, the last two iteration steps are unnecessary from a practical point of view. Using the corrected torques in the second iteration step has little influence on the efficiency as well. The efficiency of the gear meshing is slightly decreasing and the efficiency of the gearbox is slightly growing.

Summary of the described calculation procedure. At this point a short overview about the developed simulation method will be given to determine the efficiency of worm gear drives. The calculation process is illustrated in Figure 5. In the first step of the analyses the local tooth friction coefficients of the worm gear drive were calculated according to (section *Tooth friction power losses*). Afterwards, from the local tooth friction coefficients the average tooth friction coefficient was determined, which belongs to the current meshing position. With this knowledge the gear meshing forces and the bearing reaction forces are calculated based on the static equilibrium equations. With the mentioned method in (sections *Bearing losses*; *Oil churning power losses*; *and Shaft seals power losses*), the additional power losses such as bearings, oil churnings and seals power losses can be also estimated. These power losses modify the input and output torque of the gearboxes; therefore a new tribological calculation is necessary. If the accuracy of the iteration process is acceptable, the calculation procedure can be stopped and the solutions can be put out.

Comparison of the Measurement and the Simulation

To validate the developed calculation method, a test bench was built at the laboratory of MEGT to study the efficiency of worm gear drives. During the experiment the input and output torques and speeds were detected by different operational conditions. Figure 6 shows the comparison of the efficiency calculated from the measured values and the simulated average efficiency of the abovementioned *ZK*-type gearbox by the load $T_2 = 430$ Nm, and by the sump temperature $\vartheta_s = 60°$ C. The simulated curve of the efficiency concurs very well with the measured values, so the developed simulation technique can

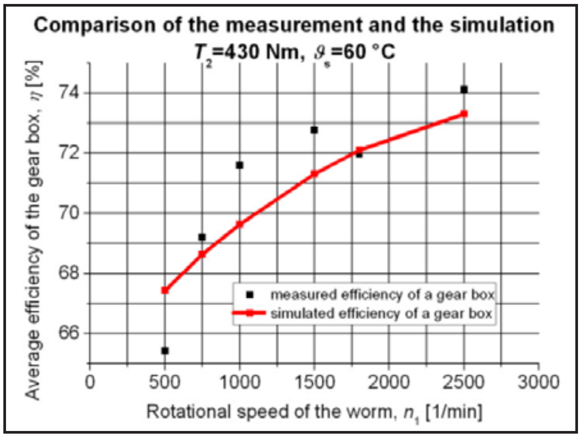

Figure 6 Comparison of the measured and simulated efficiency of the analyzed gearbox.

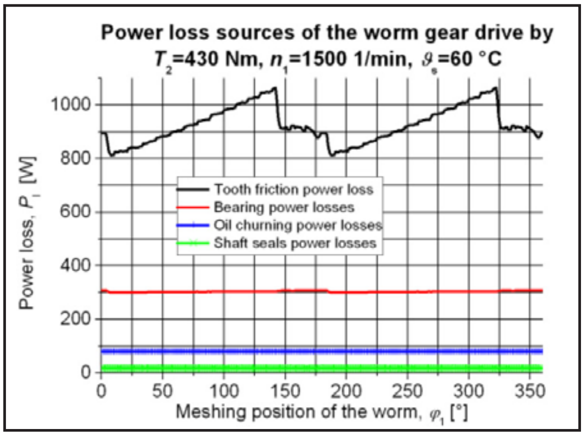

Figure 7 Power loss components of the worm gear drive above the meshing position.

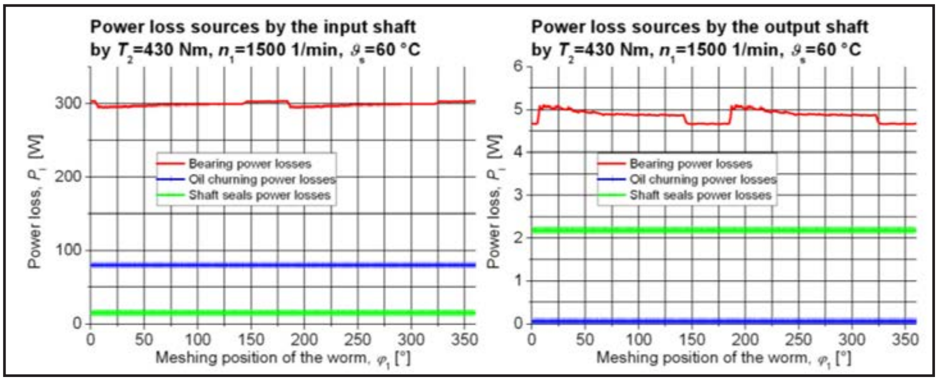

Figure 8 Power loss components of the worm gear drives by the input (left) and the output shaft (right) above the meshing position

be used as a reliable calculation method to determine the efficiency of worm gear drives.

Analysis of Power Losses

The presented, physically grounded calculation method to determine the efficiency of worm gearboxes has a singular advantage compared to conventional empirical equations. While the latter differentiate only between the load-dependent and no-load dependent power losses, the presented calculation method separates also between the power loss sources. This enables engineers to not only estimate total power loss but also to better understand every power loss source. Thus it is possible to optimize the gearboxes and reduction of losses.

Figure 7 shows the course of all four power loss sources during one rotation of the worm by the load $T_2 = 430$ Nm, and by the input rotational speed n_1=1,500 1/min. Depending on the meshing position, the tooth friction power loss changes strongly similar to the changing of the tooth friction coefficient in Figure 3. Its average value is ca. three times higher than the second largest power loss — the sum of the four bearings' power losses. This is also three times higher in the investigated operational point than the oil churning losses. The smallest share has the sum of the three shafts' seal power losses. For further analysis of the power sources the power losses were divided into two groups, depending upon the location of their generation. Figure 8 shows the power losses by the input (left) and by the output shaft (right). It also shows that the power losses by the output shaft can be ignored compared with losses of the input shaft. The no-load-dependent character of the oil churning and the shaft seals power loss should also be easily recognizable (Fig. 8). The high value of the bearing power losses can be explained with the high axial force component of the bearing reaction force and with the high rotational speed of the worm. In the investigated case the worm submerged fully in the sump; therefore the churning loss was accordingly high, whereas the wheel teeth were slightly immersed in the oil sump.

This brief study shows the potential for increasing the efficiency of worm gear drives through reducing the tooth friction power losses and reducing bearing power losses by the worm. The first is possible through the optimization of the gear geometry, reducing the surface roughness, and using adequate lubrication. As for the second, a good bearing concept can be helpful.

Conclusion

The comparison between the measured and the simulated efficiency of the investigated gearbox has shown a very good concordance. It means that the described, complex calculation method can reliably predict the efficiency of worm gear drives. This simulation is also suitable to analyze each loss component of gears, and therefore can help engineers to optimize drive solutions. **PTE**

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Theoretical and Experimental Study of the Frictional Losses of Radial Shaft Seals for Industrial Gearbox

Michel Organisciak, Pieter Baart, Stellario Barbera,
Alex Paykin and Matthew Schweig

The improvement of the energy efficiency of industrial gear motors and gearboxes is a common problem for many gear unit manufacturers and end-users. As is typical of other mechanical components, the radial lip seals used in such units generate friction and heat, thus contributing to energy losses of mechanical systems. There exist today simulation tools that are already helping improve the efficiency of mechanical systems — but accurate models for seal frictional losses need to be developed. In this paper SKF presents an engineering model for radial lip seal friction based on a physical approach.

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Introduction

Industrial gear units are widely used in power transmission systems. They are composed of shafts, gears, rolling elements bearings and dynamic lip seals. The performance of the seals is critical for the proper functioning of the system. The primary functions of the seals are to prevent the leakage of oil to the environment and to avoid the ingress of water or other contaminants into the mechanical system. Both can lead to a premature failure of the gear unit. In addition, the seals influence the system by generating friction and heat. The heat generated by the friction of the seals has an impact on the operational temperature of the gear unit as well as on the viscosity of the lubricant inside the unit. Moreover the seals contribute to the total energy losses of the mechanical system.

The improvement of the energy efficiency of industrial gear motors and gearboxes is a common challenge for OEMs and end-users. For instance energy efficiency classes are defined for electrical motors and gear motors. Moreover the power losses of gear units and seals can impact the total energy bill of an industrial installation. Therefore understanding seal friction generation and reducing it are essential challenges for seal manufacturers.

Simulation tools are commonly used to design mechanical components and systems. For the prediction of specific parameters like seal temperature or friction torque, specific models and calculation tools need to be developed. In this paper SKF presents an engineering model for the prediction of radial lip seal friction based on a physical approach. The friction model includes the generation of friction due to rubber dynamic deformation and lubricant viscous shear between the surfaces of a seal and a shaft. The friction model is coupled with a heat generation and seal thermal model. Indeed, seal friction and seal temperature are closely related: the heat generated in the sealing lip is conducted through the seal and shaft and dissipated into the environment. This changes for instance the lubricant viscosity.

The model is verified step by step in an extensive experimental study. Measurements of seal friction, seal temperature and lubricant film thickness have been performed for various dynamic lip seals. The analyzed parameters are: surface speed, oil viscosity, seal material, seal size, seal lip style and duty cycles. The correlation between model predictions and experimental friction measurements can therefore be verified.

This unique modelling capability allows selecting or developing shaft seals which would meet and exceed the demands of modern gearbox applications. It also enables gearbox manufacturers to bring to the market better performing and more reliable gearboxes.

Seal Friction Modeling

Physical phenomena influencing seal friction. The friction force, F_T, is the force resisting the relative motion of two bodies when a normal force, F_N, is applied to the contact between these bodies. The coefficient of friction, μ, can be defined as:

$$\mu = \frac{F_T}{F_N} \tag{1}$$

The coefficient of friction is not constant for radial shaft seals, which makes the prediction of seal frictional torque much more complicated. This has been demonstrated in various studies. Plath (Ref. 1) in 2005 developed a seal friction model based on finite element analysis. They assumed initially a constant coefficient of friction for the seal-shaft contact. However this led to inaccurate results and they demonstrated that it was necessary to take into account the variation of temperature of the seal due to the generated frictional heat to accurately predict seal friction.

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More recently, the studies from Haas (Refs. 2–3) have revealed the influence of surface roughness and of the duty parameter G (representing the lubricant viscosity, angular speed and contact pressure) on the friction coefficient. Their papers show that the friction coefficient follows a Stribeck-like curve (Fig. 1). A transition between mixed and fully lubricated regime is clearly shown in the evolution of the friction coefficient.

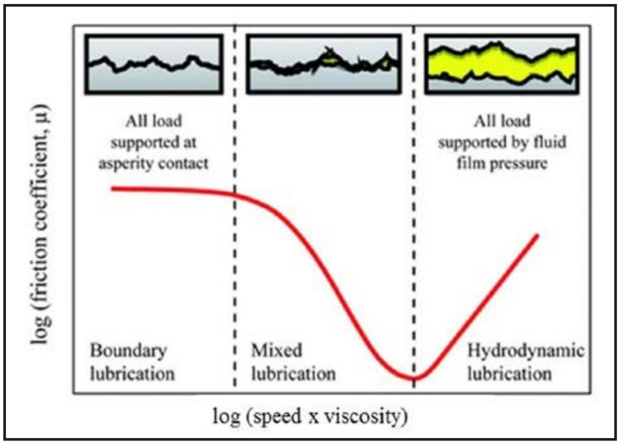

Figure 1 **Stribeck curve: coefficient of friction as a function of contact speed and lubricant viscosity.**

The variations of coefficient of friction in a radial lip seal contact can be attributed to three phenomena:

1. ***The variation of lubricant viscosity as a function of temperature***. Typical curves for standard gearbox oils are shown (Fig. 2).
2. ***The variation of the coefficient of friction between rubber and steel.*** As shown by Grosch (Ref. 4) and Hermann (Ref. 5), the coefficient of friction varies significantly — between 0.1 and 3 in extreme cases — as a function of temperature, sliding speed and pressure in dry and lubricated conditions. This is due to the fact that for rubbery material, friction is essentially governed by the dissipation of energy during the dynamic deformation of the rubbery material on the counter-face.
3. ***The variation of rubber modulus with temperature.*** A typical curve is shown in Figure 3. The prediction of seal friction is a complex task and requires a model being able to predict the temperature in the seal and in the contact and to take into account the variations mentioned in the previous paragraph.

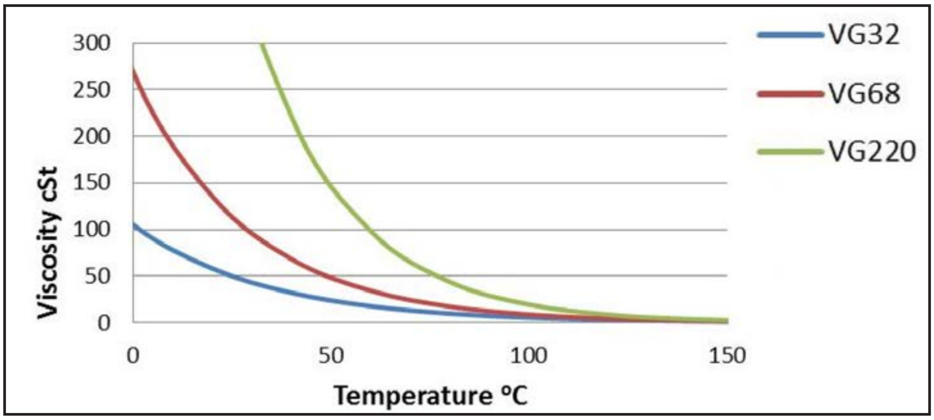

Figure 2 **Lubricant viscosity as a function of temperature for VG32, VG68 and VG220 oils.**

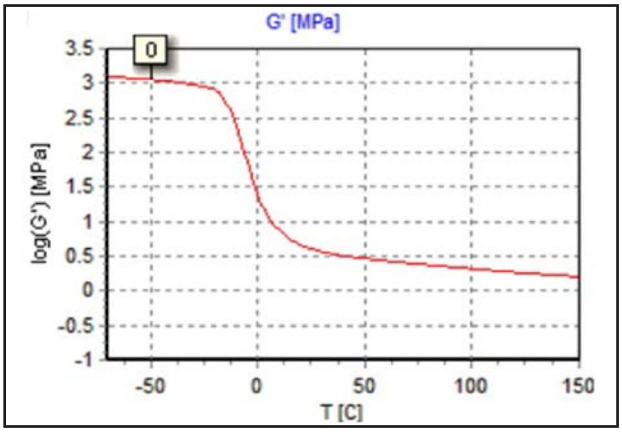

Figure 3 **Modulus as a function of temperature of a typical NBR material.**

Friction model. The friction between the seal and shaft is considered to be generated by two main governing phenomena:

1. ***Lubricant viscous shearing***. This takes place in the contact between the lip and the shaft surface. The frictional force produced in this manner is defined as F_{lub}.
2. ***Viscoelastic losses***. This is due to dissipation in the rubber as its surface is dynamically deformed by the shaft roughness asperities. The frictional force generated by the rubber material is referred as $F_{material}$.

Taking both these effects into account, the total frictional torque T_{Torque} can be expressed as:

$$T_{Torque} = (F_{lub} + F_{material}) \frac{D_{shaft}}{2} \tag{2}$$

Where

T_{Torque} is seal frictional torque Nm

F_{lub} is seal lip force N

$F_{material}$ is contribution of the material to the seal frictional force N

D_{shaft} is shaft diameter m

The material contribution is calculated following the relation below:

$$F_{material} = \mu_{dry} F_{tip} f(A_c) \tag{3}$$

Where

μ_{dry} is the coefficient of friction between the rubber and steel surface

F_{tip} is seal lip force N

f is a function of given variables

A_c is real contact area at the surface roughness level, which is calculated from contact mechanics, m^2

The lubricant contribution can be written as:

$$F_{lub} = \frac{\eta u}{h_e} S_{contact} \tag{4}$$

Where

η is lubricant viscosity in the contact, $P_a\,s$

u is surface speed, m/s

h_e is effective film thickness depending on the lip tip style (i.e., wave or plain), m

$S_{contact}$ is surface area where the lubricant is sheared, $m2$

The effective film thickness is based on elastohydrodynamic lubrication theory (Ref. 6) and can be written as:

$$h_e = f(\eta u)^{0.66} \tag{5}$$

The combination of these equations allows the calculation of the seal friction torque at any given speed and temperature.

Thermal dissipation model. The friction between a rotating shaft and a seal lip generates heat that is dissipated by the different components of the system. The power dissipated q_{disp} by the sliding contact can be written as:

$$q_{disp} = T_{Torque}\frac{2}{D_{shaft}}u \tag{6}$$

Where
q_{disp} is power dissipated in the sealing contact, W.

The generated heat flux in the seal/shaft contact is integrated into the heat conservation equation for the lip contact. The heat is then diffused in the shaft and seal according to the energy equation:

$$\frac{\rho C_P}{k}\frac{\delta T}{\delta t} = \frac{\delta^2 T}{\delta X} + \frac{\delta^2 T}{\delta Y} + \frac{\delta^2 T}{\delta Z} + f(q_{disp}) \tag{7}$$

Where
ρ is material density kg/m^3
C_P is heat capacity, J/K
k is heat conductivity, $W/(mK)$
T is temperature, K
t is time, s

The complete computational algorithm is indicated in Figure 4. Here, the friction model is combined with the thermal model. The effects of temperature change on lip force and oil viscosity are also included. The algorithm is transient, allowing computations for different speed cycles.

Experimental Techniques Used for Model Validation

The validation of the model is conducted for three parameters:

1. Lubricant film thickness in the contact (to validate Eq. 5)
2. Frictional torque
3. Seal temperature

Film thickness measurements. The measurement of an absolute value of film thickness in the sealing contact has always been a challenge. For instance in 1992, Poll and Gabelli (Ref. 7) developed a method where they use magnetic fluid as a lubricant and measure the magnetic resistance through the lubricant film in the sealing contact. In the same period, Poll (Ref. 8) used the fluorescent technique: a fluorescent dye is added to the oil and is excited with a laser. The intensity of the light can be related to the film thickness in the contact. However, both techniques require complex calibration and specific equipment.

In this work, a capacitance technique using the SKF Lubcheck set-up is applied to measure the evolutions of lubricant film thickness in a radial lip seal/shaft contact. Seals molded from a special conductive rubber compound have to be used to realize the experiments. This compound is part of the SKF compound portfolio and has similar mechanical proprieties as standard sealing materials.

Figure 5 shows the electric schematic of the measurement system. V_{mx} is the maximum voltage applied to the system; C_{ref} is a reference capacitance added to the system; C_m is the capacitance of the sealing contact; and R_m is the electrical resistance of the seal itself. After calibration using lubricants with different viscosities and simultaneous friction torque measurements, the measured voltage V_{cap} can be related to the capacitance of the sealing contact and therefore to the lubricant film thickness. The system is implemented on the test rig shown in Figure 6.

Friction torque and seal temperature measurement. Seal friction measurements are performed on a specialized SKF test rig (Fig. 6). The shaft is driven by an electrical motor allowing a very wide, programmable, range of rotational speed. The central part of the test rig is the air bearing spindle, onto which the stationary seal specimen is mounted and the friction torque sensing unit is connected. The air bearing ensures that the measured friction is only due to the seal. The seal is lubricated with an oil bath and different oil sump volumes are possible.

In addition to the frictional torque, seal temperature is constantly recorded during the tests. Thermal measurements are made using a thermocouple placed in the spring groove of

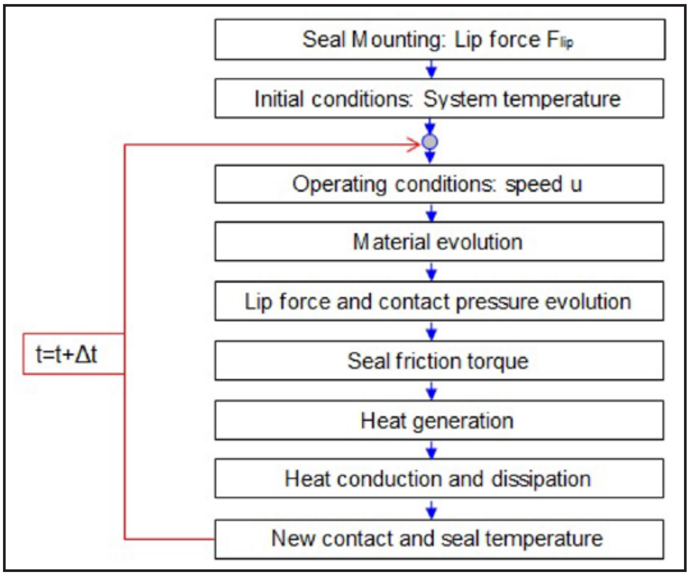

Figure 4 Calculation algorithm.

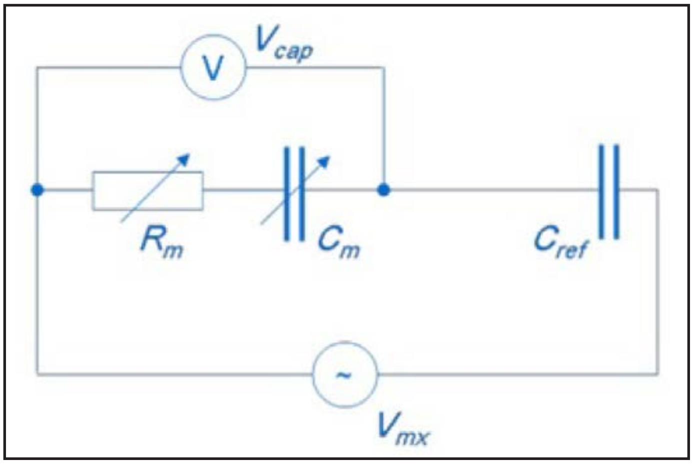

Figure 5 Electrical schematic for Lubcheck measurement.

the seal. The analysis of temperature changes is used in combination with frictional torque to validate the model.

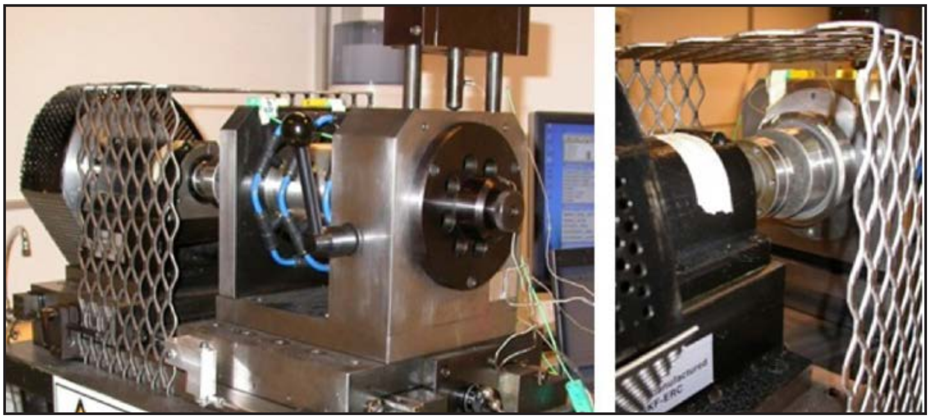

Figure 6 Seal friction measurement test rig.

Model Validation: Correlation Between the Model and Experimental Results

Film thickness. Using the set-up described earlier, the film thickness is measured for a seal with different oils having different viscosities and for different rotating speeds. Figure 7 shows the film thickness as a function of the product sliding speed u times lubricant viscosity η at the running temperature. The results can be fitted with a power law function:

$$\text{film thickness} = 3.45\,(u\eta)^{0.68} \tag{8}$$

displaying an R^2 value of more than 0.95.

The result from Equation 5 used in the model is added to the figure (in red). Equation 5 assumes a power 0.66 applied to the product ($u\eta$), which is very close to the numerical fit (Eq. 8). This shows a very good agreement qualitative between the theoretical formula and the measured film thickness, validating the approach in the model.

Model validation: seal friction and temperature. Measurements and seal friction and temperature calculations are performed for molded wave seals and trimmed plain lip seals (HMS 5 RG and V seals; Fig. 8). The two seal types are standard seals used in industrial applications, such as in gearboxes.

A typical example of experimental results and model predictions is shown in Figure 9. The graph on the left displays the used speed cycle, with different steps of speed between 10 and 1,000 rpm. The graph in the middle displays the predicted and measured frictional torque. The graph on the right shows the predicted and measured garter spring groove temperature, with additionally the predicted temperature in the contact. The graphs show that the model predictions are close to the measured friction and temperature.

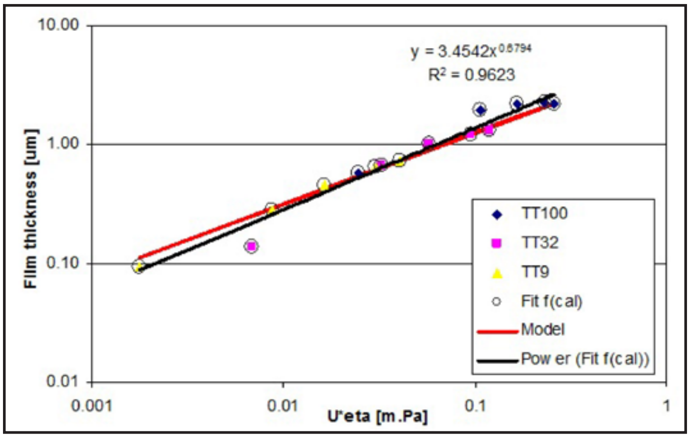

Figure 7 Measured film thickness for different oils with different viscosities and sliding speeds (points). Power fit of the experimental results (in black) and prediction by Equation 5 (in red).

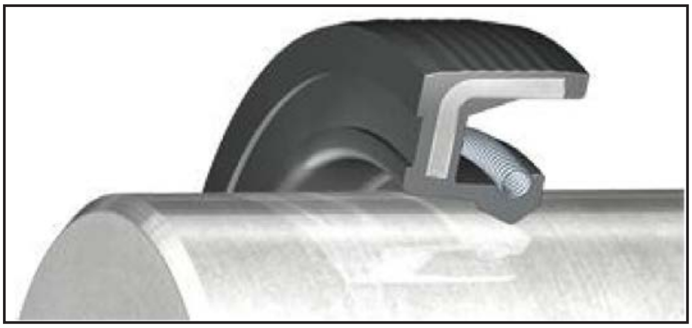

Figure 8 Typical cross-section of a trimmed plain lip HMS5 seal.

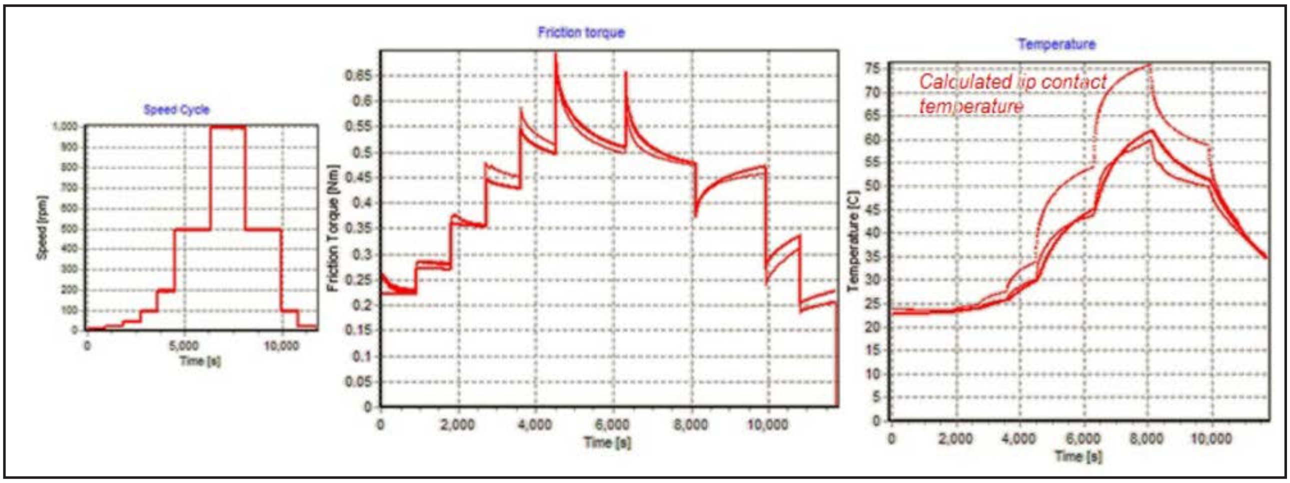

Figure 9 Speed cycle (left), friction torque (middle) and temperature (left) for a typical study case. Measurements are displayed with thin lines. Model predictions are displayed with bold red lines. The dashed line in the temperature plot (right) is the predicted contact temperature.

An extensive number of test conditions, different compounds (NBR and FKM) and lubricants have been used to validate the model. The left graph in Figure 10 depicts the correlation between the model predictions and the measurements for all tests for molded wave seals. The right graph in Figure 10 depicts the correlation for trimmed plain lip seals. For the purposes of the comparison, only the average friction obtained in the last 30 seconds at the end of each speed step is considered. The correlation plot shows that all the predictions are within 20% of the measurements results. The resulting correlation is high, showing an R^2 value of more than 95%.

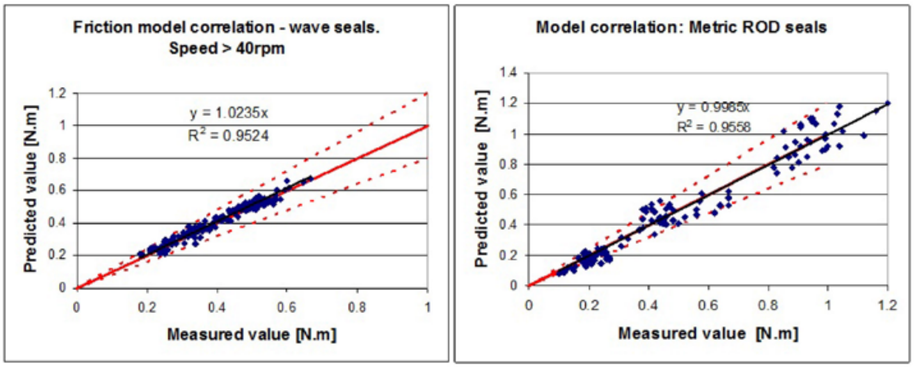

Figure 10 Predicted friction torque as a function of the measured friction torque for wave seals (left) and plain seals (right). The red dashed lines represent the interval at ± 20%.

With the very good correlations for the film thickness, frictional torque and seal temperature, we can conclude that the developed approach is validated and can be used for the prediction of seal frictional torque in an application.

Applications of the Model

Comparison between molded wave and trimmed plain lips seals. The model presented in this paper can be applied to trimmed plain lip seals or to molded wave seals (Ref. 9). As shown in Figure 11, the wave seal has a special sinusoidal contact patch on the running counter face. This enables a better lubricant flow at the vicinity of the lip and a higher lubricant film in the contact. This also enables a better heat exchange between the lip and shaft.

In order to study the difference between plain and wave seals, seals with the same cross-section and material are used for the experimental study. Seal friction and temperature are calculated in parallel with the model described in this paper. Figure 12 represents an example of the results for the speed cycle displayed in Figure 9. There is a clear difference in the friction between the two lip geometries. The wave lip reduces by about 20% the frictional torque during the tests. The friction reduction has a direct influence on the temperature, with a self-induced temperature decreasing by more than 10°C.

Figure 12 further illustrates the good match between the measured values of frictional torque and temperature and the model predictions, thus confirming the quality of the model. This also enables the usage of this approach to predict the seal torque and temperature in a mechanical system.

Influence of oil sump volume on seal friction. The volume of oil in a gear unit can vary for different applications. It influences the friction of different mechanical components and the temperature of the mechanical system. The model is used in order to study the influence of the oil sump volume on seal temperature and seal friction. The volume of oil has an impact on the dissipation of the heat generated in the sealing contact and therefore on the friction and temperature of the seal.

Seal friction measurements are also carried out with an oil sump of a volume 0.2 and 3 liters but maintaining the same oil level relative to the center of the shaft. The results of the model and of the measurements are displayed (Fig. 13). First they show a very good agreement between the model and the measurements. Secondly, both the model and the experiments confirm that the oil sump volume has an influence on the frictional losses. A system with more oil has a lower operating temperature because it is able to better dissipate the heat from the sealing contact. Consequently, the oil viscosity is higher, which results in a higher friction. Therefore it is very difficult to give an absolute value of seal friction in operations since it

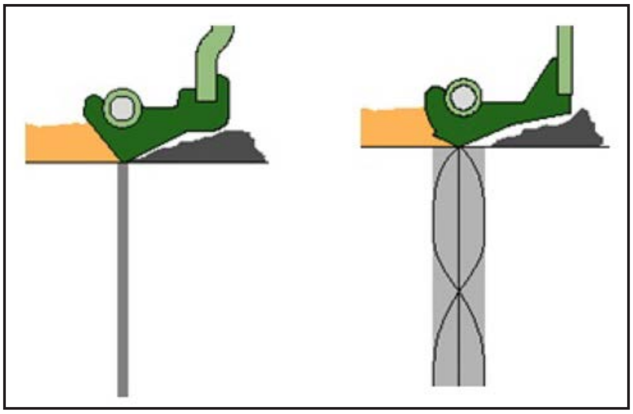

Figure 11 Difference of the contact patch between a plain seal (left) and a wave seal (right).

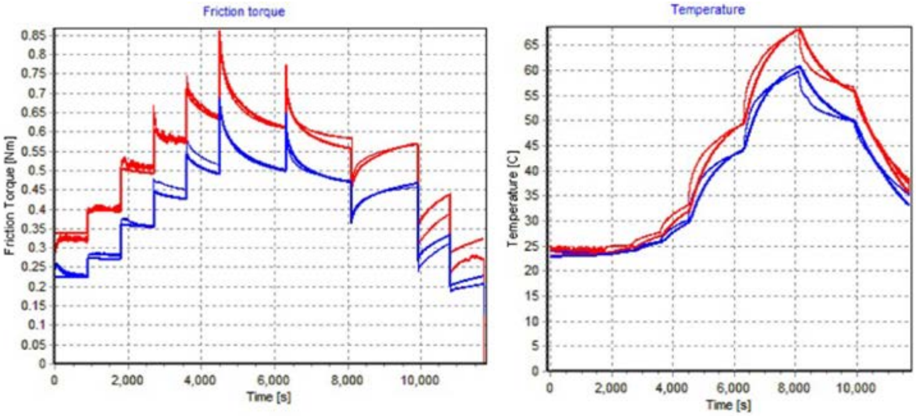

Figure 12 Friction torque (left) and temperature (right) measurements as a function of time for a wave seal (blue) and plain (red) seal. The thin lines are measurements; the thick lines are model predictions.

is highly dependent on the environment in which the seal operates. Only a combined seal frictional and thermal model is able to predict seal friction and frictional losses in an application.

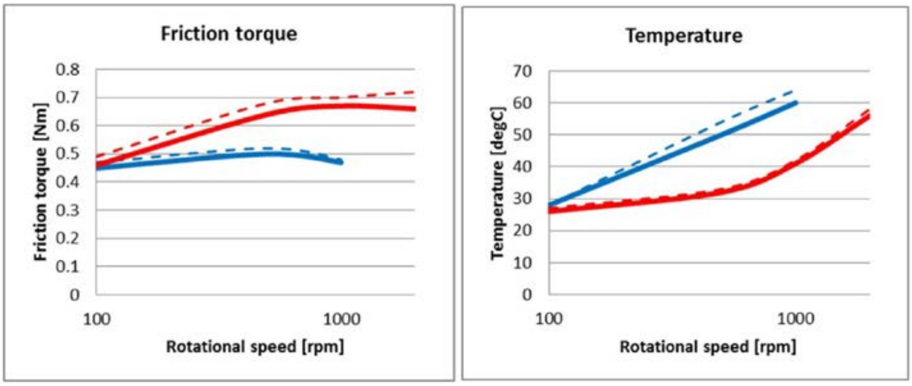

Figure 13 Measured (dotted line) and predicted (solid line) frictional torque (left) and seal temperature (right) for a 0.2 L oil sump (blue) and 3 L oil sump (red).

General Conclusion

The paper has presented a physical model to analyze and predict frictional torque and temperature of radial lip seals with a plain or wave lip geometry. A good correlation between experimental and theoretical results has been obtained. It has been shown that the reduction of friction has a direct effect on the self-induced temperature in the seal. Lowering seal friction decreases the operating temperature which in its turn can have a positive impact on other performance parameters such as material life and lubricant life.

The results have also shown the importance of considering the effect of operating conditions and temperature in the prediction of seal frictional torque in any environment and system. The heat induced by the friction of the sealing contact needs to be dissipated in the other elements of the mechanical system. Therefore the real operating temperature and frictional losses of a seal can only be accurately predicted if the friction model is coupled to a heat generation and heat dissipation model. This modelling approach is complementary to the simulation techniques for a complete gear unit presented by Wemekamp (Ref. 10).

In conclusion, the approach can therefore be used confidently to:

- Predict the seal friction in an application
- Optimize seal design by acting on the parameters influencing the friction and prediction the final outcome
- Together with other SKF simulation tools, analyze the performance of the seal in the application

These unique modelling capabilities will allow selecting and developing shaft seals which would meet and exceed the demands of modern gearbox applications. They enable also the design of better performing and more reliable gear units.

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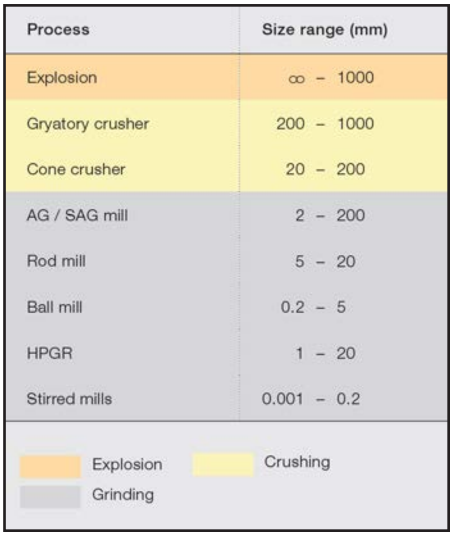
When it Comes to Mining, Bigger is Best

Gearless mill drives may be the key to maintaining throughput

Venkat Nadipuram

One of the key challenges in the mining industry today is maintaining throughput in the face of ore grade quality that has declined by 40 percent in the last decade. Returns must be attractive even with energy costs and environmental regulations increasing. Industry analysts expect the mining industry to register modest growth in the coming decades, thereby making higher productivity essential. As an industry leader in mill drives, ABB combines its extensive industry knowledge with its application experience to provide a diverse portfolio of drive solutions for the mining industry.

At the most basic level, mining is about freeing trapped valuable metal from its ore. However, there is nothing basic about the comminution of raw ore. Complex processes using a variety of different mills are carried out in order to reduce the size of the raw ore pieces to a more usable form (Fig. 1). Comminution circuits are typically connected by conveyor belts. Crushing and grinding are the two main and critical processes in a comminution setup, with each requiring reliable and



Process	Size range (mm)
Explosion	∞ – 1000
Gryatory crusher	200 – 1000
Cone crusher	20 – 200
AG / SAG mill	2 – 200
Rod mill	5 – 20
Ball mill	0.2 – 5
HPGR	1 – 20
Stirred mills	0.001 – 0.2

Figure 1 Different processes used in comminution.

ABB drive solutions help operate the enormous mills being used in the mining industry today. This is the GMD at Esperanza Copper mine in Chile.

Figure 2 Ball mill at Boliden Aitik copper mine.

energy-efficient equipment that also includes drive systems.

Comminution circuits are generally classified as either autogenous-ball milling-crushing (ABC) or semi-autogenous-ball milling-crushing (SABC) circuits. An ABC circuit consists of an autogenous grinding (AG) mill, ball mill and crusher. An SABC circuit consists of a semi-autogenous grinding (SAG) mill, ball mill, and crusher. A ball mill is a slightly inclined, horizontal rotating cylinder, partially filled with ceramic balls, flint pebbles or stainless steel balls, that grinds material to the necessary fineness by friction and impact with tumbling balls (Fig. 2).

An example of an industry-standard comminution circuit providing high throughputs can be seen in (Fig. 3). This circuit, however, has a high, specific energy consumption per ton of ore processed, driven primarily by the low efficiency of the ball mills and the need to use steel media for grinding.

Ring-geared mill drive. Throughout the comminution process, different mills are driven by different types of electrical drives. ABB provides a variety of different types of drive solutions for the mining industry.

For example, ring-geared mill drive (RMD) systems are good solutions when the power required to drive the mill is under 18 MW, i.e., a maximum of 9 MW per pinion (Fig. 4). Yet as tube mills grow in size in order to meet the demand for larger throughputs, the power required to drive them increases. Although ABB can manufacture drive systems for very large power ratings, the physical limitation of a mechanical gear limits its application for driving tube mills where the power required is over 18 MW.

Gearless mill drive. The limitation of an RMD system was overcome by ABB when it introduced the first gear-

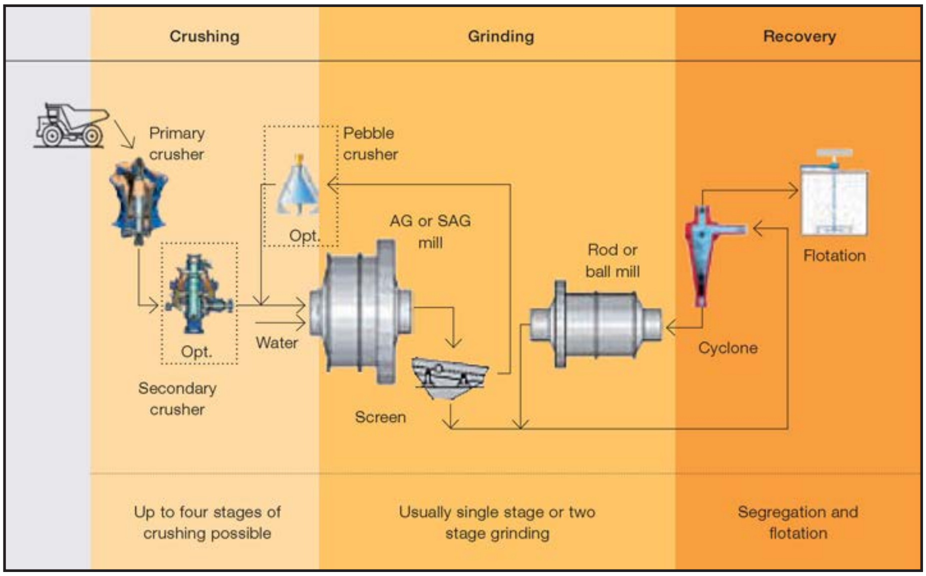


Figure 3 SABC flow sheet.

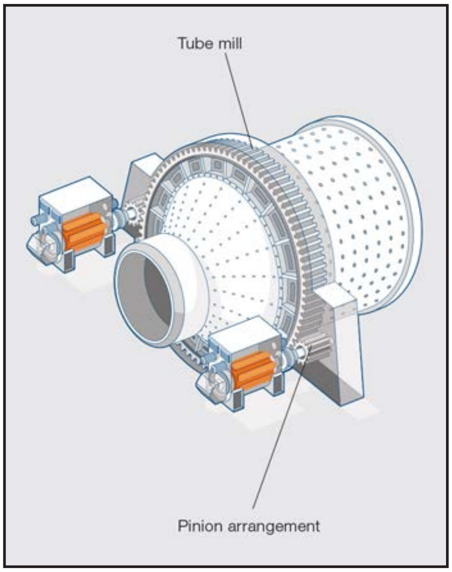


Figure 4 Ring-geared mill drive solutions.

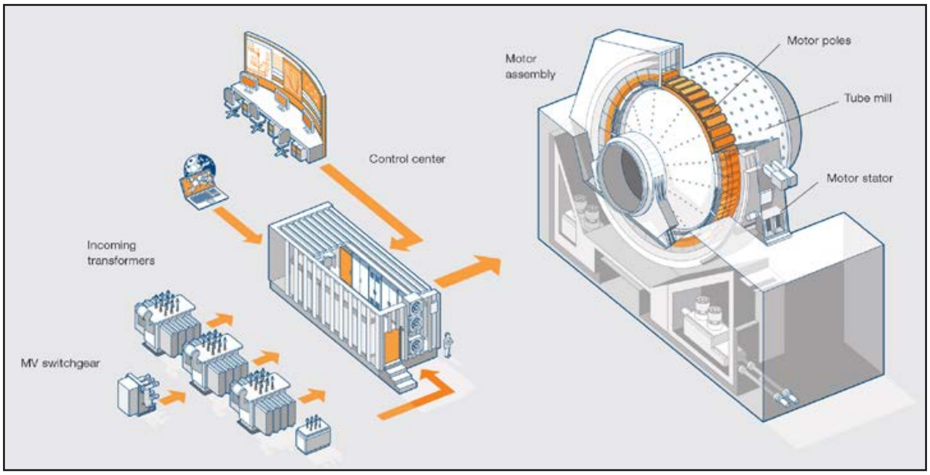


Figure 5 Gearless mill drive solution.

less mill drive (GMD) in 1969 for the cement industry. ABB introduced the first GMD into the minerals industry in 1985 and since then it has become the de facto standard equipment for mines with larger throughput requirements. ABB has sold and installed over 120 GMD units worldwide.

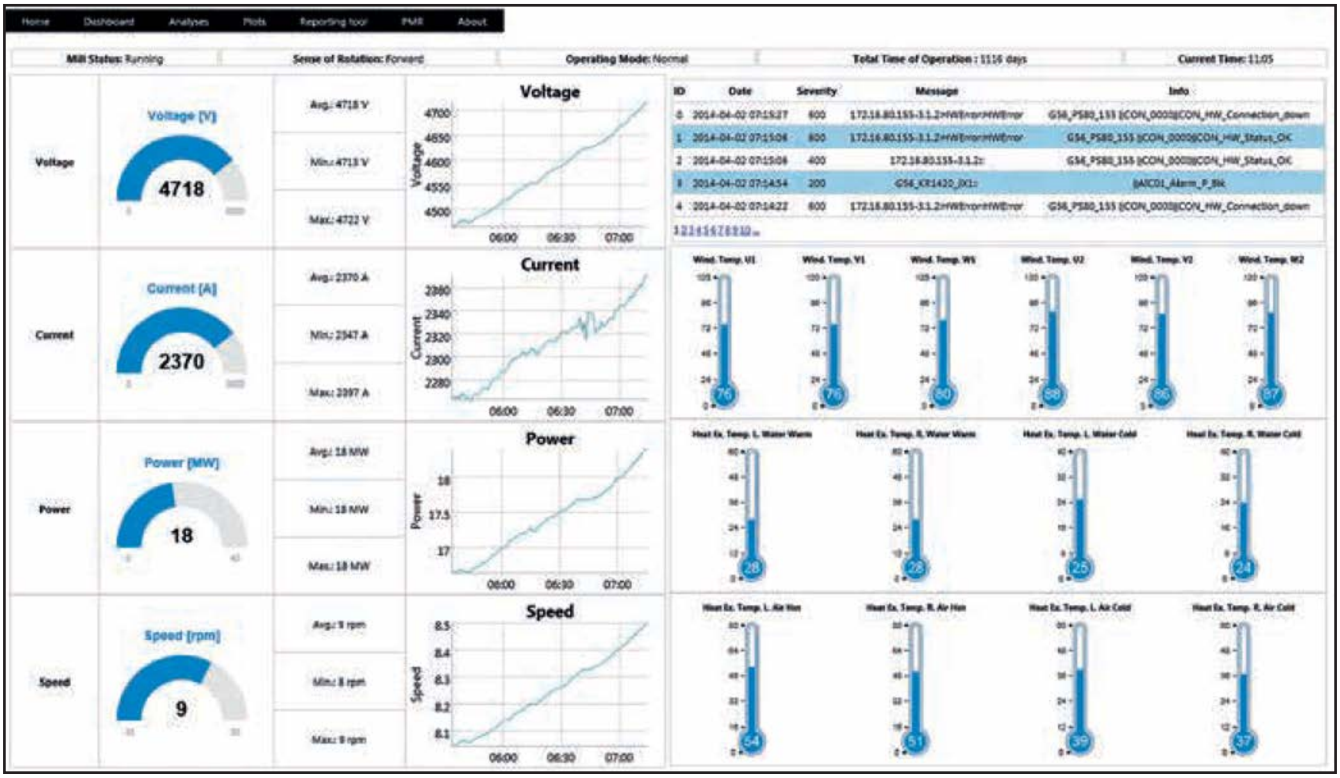
The advantages of a GMD application in the minerals grinding process have been well established over the past 40 years, with the benefits increasing exponentially as the mills get bigger.

In the GMD solution the drum of the mill forms the rotor of the motor, with the motor poles mounted along the external circumference of the drum (Fig. 5). The stator is mounted around the pole assembly. The operation is carried out with high precision so that the final gap between the poles and the stator is no more than 14–16 mm, depending on the mill size. By not having a gearbox (gear and pinion), the mechanical limitation associated with gears is eliminated. This allows mill diameters to increase as required. The world's largest GMD, with a diameter of 12.8 meters, will be delivered by ABB to the Conga mine in Peru.

Eliminating gears improves the efficiency and availability of the mills and reduces maintenance work. The intrinsic ability of GMDs to provide variable speed improves the overall efficiency of the grinding process in terms of energy used and grinding result. Variable speed also reduces network sags during mill startup and allows features like frozen charge protection, controlled roll back and positioning for mill maintenance needs.

> Throughout the comminution process, different mills are driven by different types of electrical drives.

Figure 6 Full vacuum pressure impregnation for windings.



Mill Status: Running **Sense of Rotation:** Forward **Operating Mode:** Normal **Total Time of Operation :** 1116 days **Current Time:** 11:05

Avg.: 4718 V
Min.: 4713 V
Max.: 4722 V

Avg.: 2370 A
Min.: 2347 A
Max.: 2397 A

Avg.: 18 MW
Min.: 18 MW
Max.: 18 MW

Avg.: 9 rpm
Min.: 8 rpm
Max.: 9 rpm

ID	Date	Severity	Message	Info
0	2014-04-02 07:15:27	600	172.16.80.155-3.1.2=HWError:HWError	G56_PS80_155 ||CON_0003||CON_HW_Connection_down
1	2014-04-02 07:15:06	800	172.16.80.155-3.1.2=HWError:HWError	G56_PS80_155 ||CON_0003||CON_HW_Status_OK
2	2014-04-02 07:15:06	400	172.16.80.155-3.1.2:	G56_PS80_155 ||CON_0003||CON_HW_Status_OK
3	2014-04-02 07:14:54	200	G56_KR1420_JX1:	|AIC01_Alarm_P_Blk
4	2014-04-02 07:14:22	600	172.16.80.155-3.1.2=HWError:HWError	G56_PS80_155 ||CON_0003||CON_HW_Connection_down

12345678910...

Figure 7 Screen shot of an ABB remote GMD condition monitoring console.

Design improvements. Since the introduction of GMDs, ABB has delivered customized solutions for every individual mine and process requirement, from power ratings and size to site altitude. ABB's most recent achievement in this area was commissioning a 28 MW system at 4,600 m above sea level.

ABB continues to develop new features and designs to guarantee higher availability and reduced maintenance, particularly for high-altitude and remotely located mines.

For example, particular attention has been given to the stator winding insulation. The stator winding consists of a bar winding with individually insulated strands that are intertwined to use the entire copper cross section almost evenly while reducing losses and lowering eddy currents (Fig. 6). These strands are packed in a mica-based VPI insulation. The whole stator bar is "VPIed," including the slot section and the winding overhang area, which is important for high-altitude applications. The stator core sheets are pressed together to increase the overall stiffness, which minimizes the retightening work required during the ring motor lifetime.

GMD condition monitoring. ABB has developed advanced remote diagnostic tools for troubleshooting as well as predictive maintenance. For example, with up-to-date operation information from the system, operators are notified of any potential problem long before an automatic alarm or trip is activated. Notifications are sent by e-mail or text messages to the mine operators as well as ABB remote diagnostic engineers (Fig. 7).

The diagnostic tools monitor a wide range of signals from all the key components of the GMD system including transformers, cyclo-convertors and the ring motor. This allows for continuous analysis of the system status and the ability to inform the customer in a reliable and timely manner of any potential problems that may arise during operation.

A maturing grinding technology, today's mining industry is increasingly facing a new challenge: how to develop bigger grinding machines to sustain throughput with steadily declining grades, while at the same time minimizing energy consumption.

One way of meeting the challenge is to use high-pressure grinding rolls (HPGRs). HPGRs have proven to be extremely effective for grinding mineral raw materials, especially since manu-

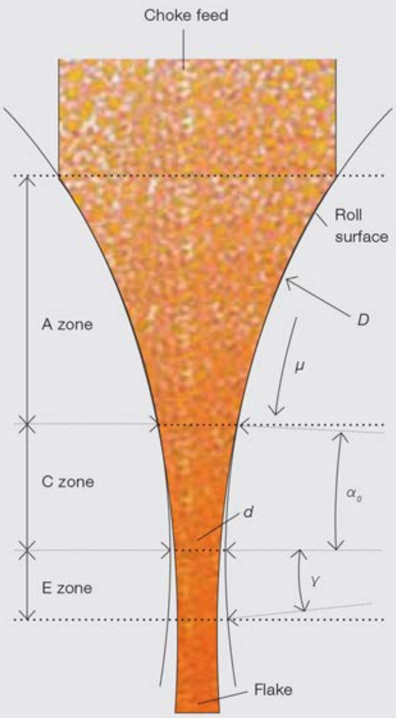
Eliminating gears improves the efficiency and availability of the mills and less maintenance work is needed.

High-pressure grinding is achieved by using an advanced type of grinding roll. The machine consists of two counter-rotating rolls. One of the rollers is fixed and the other is movable in a horizontal direction.
A constant pressure is applied to the moving roller via hydraulic cylinders to impart pressure to the material.

Contrary to conventional crushing rolls, the particles are broken by compression in a packed particle bed, and not by direct nipping of the particles between the two rolls. This particle bed is created between two choke-fed, counter-rotating rolls. Between these rolls, a particle bed is pressed to a density of up to roughly 85 percent of the actual material density.

This compression is achieved by using high pressure of up to nearly 300 Mpa, exceeding the compression strength of the feed ore. During this compacting process the material is ground to a wide particle size distribution with a large proportion of fines, compacted into flakes.

The figure shown here indicates the flow of the material between the two rollers. The figure also depicts different zones, namely the "A zone" in which the material is pushed or accelerated toward the compaction zone; the "C zone," where the material is pressed; and then discharged into the "E zone."



A zone = Acceleration zone
C zone = Compaction zone
E zone = Expansion zone
D = Diameter of rolls
d = Flake thickness
α_0 = Angle of compaction zone
γ = Angle of expansion zone
μ = Circumferential speed

Figure 8 Operating principle for a HPGR.

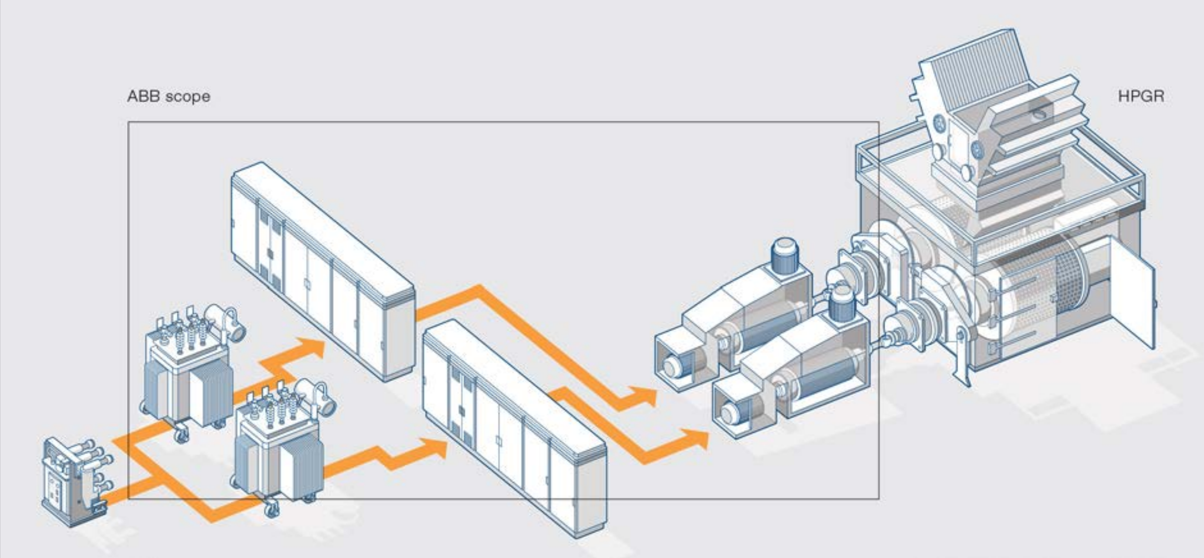


Figure 9 ABB HPGR (high-pressure grinding roll) drive system.

facturers have developed roll-wear protection systems to better deal with hard and abrasive ores (Fig. 8).

Additionally, the grinding process with HPGRs is a dry process, thus saving water, which is a scarce resource in many mining sites, e.g., Chile.

Comminution circuits with HPGRs. The multiple benefits of including an HPGR mill in communition circuits has operators looking to combine them with other types of mills in order to optimize the total specific energy consumption of a comminution setup.

There are numerous benefits of using HPGRs in communition circuits in comparison with conventional grinding processes using SAG mills. The most significant benefit is an up to 20 percent increase in energy savings. Also, metal liberation is improved, a reduced grindability index is reached, commissioning times are shortened and designs are more compact.

HPGRs have been used successfully in mining operations over the years, indicating an increasing maturity of the product. As units become larger with higher throughput and deliver better reduction ratios than tertiary crushers, the combining of secondary crushers with HPGRs to replace SAG mills is occurring more often (Fig. 10).

ABB offerings. ABB provides optimized, state-of-the-art drive solutions for HPGR mills and currently has the largest installed base for the over 2 MW power range (Fig. 9). The ABB HPGR drive solution provides identical load sharing between both rolls at the desired speed. Being able to adjust the speed to fit actual ore properties decreases mechanical stress on the grinding application. The drive system is capable of compensating the reduction of circumferential speed caused through roll wear by increasing the motor speed (rpm). In this manner, the throughput can be maintained at optimized values over the rolls' lifetime. The direct torque control (DTC) feature provides the fastest torque/speed response on the market, enabling quick and accurate adjustment to the frequent load transients typical in HPGR applications as different sizes of material enter.

HPGRs are poised to play an important role in the comminution circuits to help reduce energy costs, water requirements and footprint compared with the traditional SABC circuits. While being a standard solution in mineral processing, HPGR technology continues to undergo constant development. ABB is at the forefront of this development with many new features being added to further optimize drive system performance. **PTE**

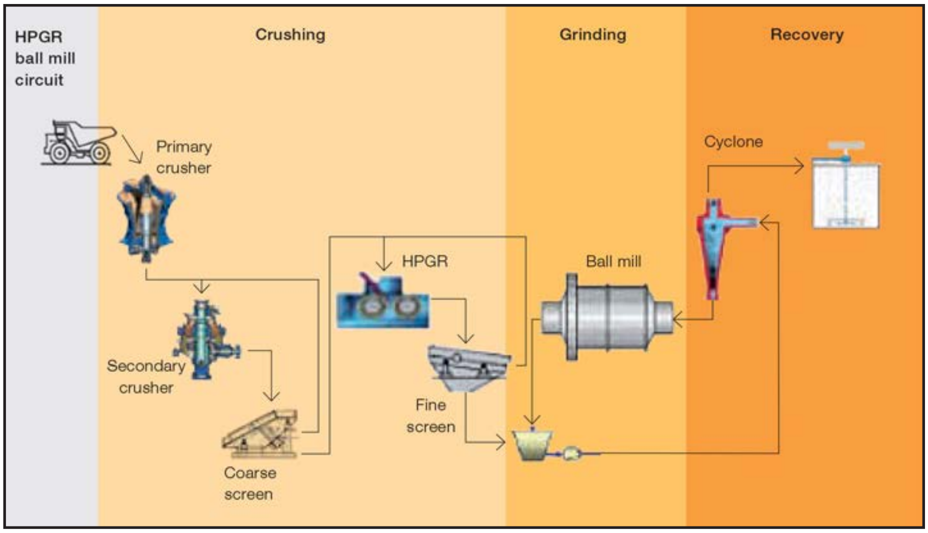


Figure 10 A comminution setup using HPGRs replacing SAG in primary grinding process.

ABB provides 6 Full vacuum pressure impregnation for windings optimized, state-of-the-art drive solutions for HPGR mills and currently has the largest installed base for the over 2 MW power range.

Venkat Nadipuram is ABB Switzerland Ltd. global product manager for drive systems, managing the product portfolio for medium-voltage drive system applications in the mining sector. He holds a bachelor of engineering degree in instrumentation & electronics from the University of Bangalore, India and has been working in the energy sector for more than 15 years. Nadipuram began his career with GE, in design engineering, where he continued to take on roles with increasing responsibilities across businesses and geographies in strategic positions. He joined ABB in 2012, assuming his current position.

Global Industrial Outlook: Slow Growth Ahead; Farm Belt No Help

Brian Langenberg

First quarter results confirmed our view. Capital expenditures are being slashed in the oil sector, the stronger U.S. dollar is enabling Japanese machinery competitors to gain share in the Middle East and Latin America, and lower soft commodity prices translate into a continuing North American decline in demand for farm equipment.

Let's review the key headwinds:

Oil. The Saudis continue to step on the gas, driving and keeping prices low; as a result, North American capital spending continues to decline.

Currency. Combination of strong dollar, weak Euro resulted in 2-3% earnings guidance haircuts across the broader industrial sector. Machinery companies are particularly challenged by the weak Japanese Yen— particularly in international markets (Middle East, Latin America).

Outlook

Here is our outlook for key geographic regions and end markets:

U.S. remains best growth spot. Non-residential construction, consumer durables (auto, housing) and gradually improving employment will offset weaker commodity-based demand. U.S. first quarter GDP was quite weak but largely owing to weather. Export markets will start to take a hit.

Europe. Weak commodity prices weighing on Nordics, Russia, but weak Euro starting to help Germany, France and others.

Middle East. Saudis continue to step on the gas — pun intended — to take out high-cost U.S. oil fracking. Oil & Gas activity remains strong because mature fields require more capital and the region is seeking to capture more of the value stream. Increased Japanese construction equipment competition remains a negative for U.S. manufacturers.

Latin America. Mexico is doing well, while weak commodity prices hinder the rest of the region.

Oil & Gas. Huge capex cuts in upstream exploration and production drove a number of weak first-quarter results for industrial companies, and we see no respite for the next 2-4 quarters before stabilizing at a lower spending level.

Mining. Not just awful — may in fact be *worsening* in the U.S. — given continued deterioration in coal fundamentals.

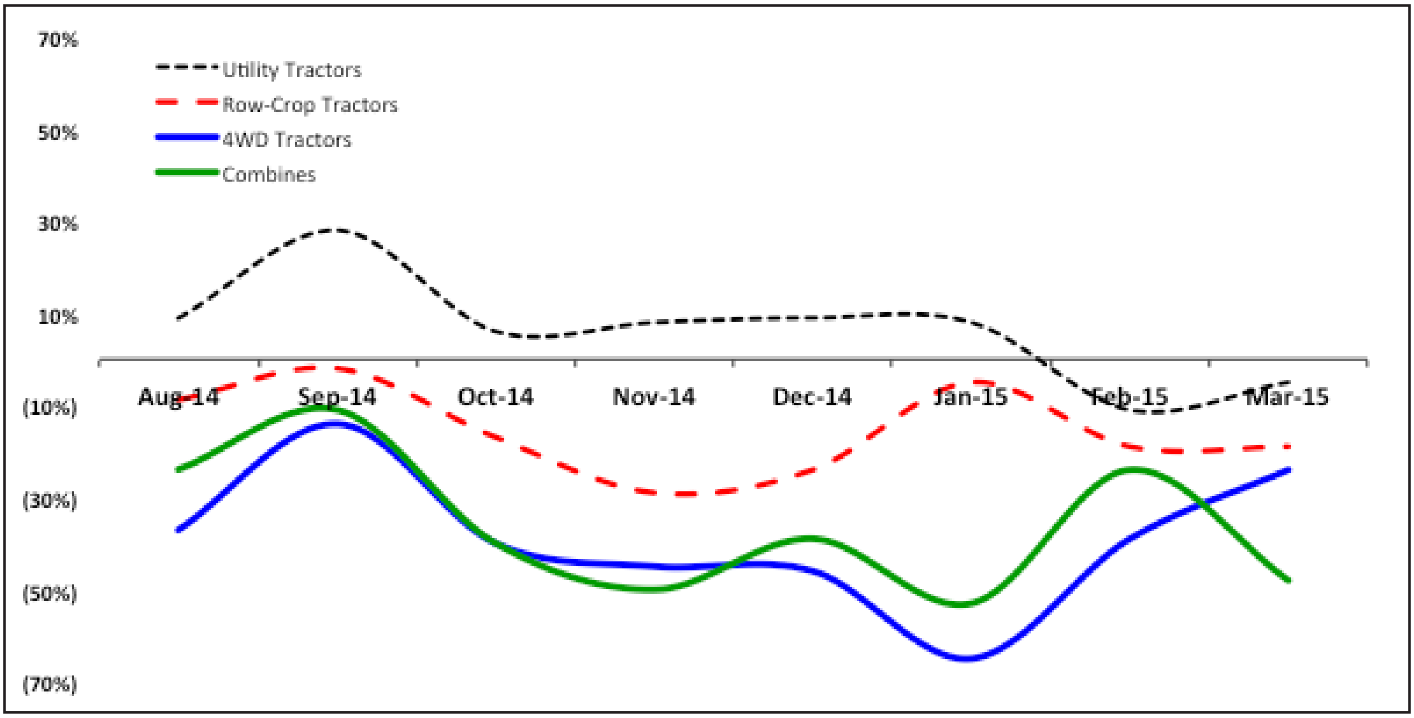
Power generation. No change; U.S. power generation remains weak; Wind (band aids) owing to efficiency gains throughout the economy and lack of regulatory support for new construction.

Transportation infrastructure. We expect stability if not modest growth over the next 12-18 months, but no major infrastructure upgrade anytime soon. If anything, weakening shale oil fundamentals could lessen the growth profile for shale oil shipments by rail.

Machinery. Modest incremental demand from non-residential and residential construction markets is the best news — but more than offset by soft crane and agricultural markets.

Consumer (auto, appliances). Old cars = continued U.S. strength. Auto-related end markets will remain solid. Auto investment in Latin America, particularly Mexico, continues to increase. U.S. residential recovery is on track and will further support construction equipment demand. Weak Euro and Yen are already hurting competitiveness in Middle East and Latin America.

Aerospace/Defense. We just attended an investor meeting with senior executives of Boeing. As always, they are optimistic about everything. On the commercial side, this is completely justified by commercial demand — airlines are flush with cash and recapitalizing their fleets. We expect a U.S. defense recapitalization, but not before 2017 authorization given the current



Administration. Foreign policy matters; e.g. — ISIS has grabbed significant turf in Iraq, Syrian conflict is ongoing and the current U.S. naval fleet is too small. In case you were watching, China continues to militarize the Southwest Pacific.

Focus Company: John Deere & Company

U.S. Agriculture means John Deere, which holds about 65% market share. Nothing runs like a Deere, but Deere sales trends are in the tank across every product area and particularly with larger, high-margin tractors and highly seasonal combines.

After an eight-to-nine-year farm capital spending up-cycle the U.S. farmer is well capitalized with modern equipment and has little urgency to spend given lower commodity prices and thus farm income.

SPECIAL OFFER: PTE readers can subscribe to all our written research for a discounted rate of $995 per year. You will receive, *at a minimum*, 20 Integrated Company Dashboards (ICDs)* each quarter on major U.S. and European machinery manufacturers, aerospace engine producers and key industrial companies. You can also expect to receive analyses of major company events, think pieces and topical reports as they occur. We are also happy to accommodate bulk subscriptions at attractive rates.

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Brian K. Langenberg, CFA, has been recognized as a member of the Institutional Investor All-America Research Team, a *Wall Street Journal* All-Star, and *Forbes/Starmine* (#1 earnings estimator for industrials). Langenberg speaks and meets regularly with CEOs and senior executives of companies with over $1 trillion in global revenue. His team publishes the *Quarterly Earnings Monitor/Survey* — gathering intelligence and global insight to support decision-making. You can reach him at *Brian@Langenberg-llc.com* or his website at *www.Langenberg-LLC.com*.

Parker Hannifin

CHOSEN BY VICTORY RACING TO PROVIDE GVM ELECTRIC MOTOR FOR ISLE OF MAN CHALLENGE

Parker Hannifin recently (Elk Grove, IL) announced that it is sponsoring Victory Motorcycles as they compete in the 2015 Isle of Man TT Zero Challenge on June 10.

In addition to being a sponsor, Parker's race-proven, high-performance Global Vehicle Motor (GVM) PMAC electric motors have been selected to power Victory Racing's prototype electric race bikes.

This competition, taking place on the Irish Sea Island, is one of the most demanding races in the world for electric motorcycles. It involves one lap around the island's 37.73-mile mountain course.

"Parker is thrilled to be participating with Victory Motorcycles as they battle for the trophy," said Jay Schultz, Parker's business development manager for vehicle electrification. "In order to improve their chances of winning, we needed to focus on delivering the power density to be capable of producing up to 175 horsepower out of this compact, 8-inch-diameter-by-5-inch-long motor, while providing the efficiency to have the motor help the battery last the entire 37.73 miles of the race. It is very challenging because this is the longest electric motorcycle race in the world. Your battery pack has to last through very high average speeds, approaching 120 miles an hour. Plus, near the end of the race, they have to go up and over a mountain to reach the finish line."

Since 2012, Parker has been supplying GVM motors to power all-electric motorcycles for other competitions — including Daytona International Speedway. The GVM product has evolved through the experience and lessons learned on the track, inspiring Parker engineers to examine many facets of motor design, including the cooling system, the type of magnets used and increasing the peak torque. These efforts have resulted in several patentable design characteristics of the GVM and created a durable, powerful motor for electric and hybrid vehicles.

"The entire Victory team is excited to make history with this effort," said Rod Krois, Victory general manager. "We know that [professional rider] William Dunlop's experience and the continued Victory Motorcycles development of this electric race bike through work with Parker will propel us into a strong future with electric motorcycles."

Added Josh Katt, Victory's product manager:

"Victory Racing selected the Parker GVM series of internal permanent magnet AC motors to power our prototype Victory electric race bikes based on the strength, flexibility and reliability of these motors. Parker's GVM series of motors allowed us to select an ideal motor configuration in both length and diameter and then fine tune the winding to meet our specific performance requirements. This level of flexibility, added to the fact that the motor can be provided as a 'kit' for assembly into our own custom developed housings, made the Parker an ideal fit for our racing bikes, and provides one of the most power dense EV traction motors available. We also appreciate that the Parker GVM series is manufactured in the USA, and that their team provides unrivaled engineering support for custom traction motor development."

EFD Induction

AWARDED ORDERS FOR INDUCTION SCANNERS TO HARDEN SUN GEARS AND OUTPUT SHAFTS

EFD Induction USA (Madison Heights, MI) recently won major orders from two American tier-one automotive suppliers.

The orders involve EFD Induction 'HardLine' type induction scanning systems for the hardening of sun gears and output shafts. Each system comprises an induction scanner, a power source and various optional features.

The first order comprises an EFD Induction Rotary Table (HardLine RT 550) hardening system for treating sun gears, and a vertical scanner system (HardLine VM 1000) for hardening output shafts.

The second order is for two vertical scanner systems, a HardLine VS 300 for hardening sun gears, and a HardLine VL 1000 for treating shafts.

All the systems are powered by EFD Induction Sinac power sources, and feature CNC-based control systems. Each machine also features a closed-loop cooling system. HardLine is EFD Induction's family of systems for surface and through-hardening, with equipment available to handle everything from small gears with complex geometries up to the giant slewing rings used in modern wind turbines. The vertical scanners supports a range of optional subsystems, including: automated loading/unloading solutions, indexing tables with unlimited position control, double tailstocks and centers for the simultaneous hardening of two workpieces, a HF/MF chuck connection for quick changeovers between high and medium frequencies.

The hardening system can also be paired with an integrated or separate tempering station.

PTDA

WELCOMES THREE NEW DISTRIBUTOR MEMBERS

The Power Transmission Distributors Association (Chicago, IL) recently welcomed three new distributor member companies:

BK Industrial Solutions, LLC (Beaumont, Texas) is a distributor of motors, material handling/conveyor systems and components, bearings and mechanical power transmission products.

SAECOWilson Limited (Auckland, New Zealand) distributes bearings, motors, material handling/conveyor systems and components, electrical/electronic drives, motor/motion control, hydraulics and pneumatics and mechanical power transmission products.

Warrior Industrial, LLC (McKinney, Texas) is a bearings, motors, linear motion and mechanical power transmission products distributor.

"We are forecasting a tremendous amount of growth over the next several years and we feel as though PTDA will help us accomplish our goals faster," said Greg Bynum, CEO of Warrior Industrial.

GAM

CELEBRATES 25TH ANNIVERSARY

GAM, a manufacturer of high precision gear reducers, servo couplings, and linear mounting kits, recently celebrated its 25th anniversary.

GAM Enterprises began in 1990 when Gary Michalek saw an opportunity to start a long-term relationship with Jakob Antriebstechnik, a German based company that introduced the first servo bellows coupling into the machine tool market. In 1998, GAM Gear was formed with current GAM president Craig Van den Avont to start GAM's high precision gearbox company to complement the coupling product line. For 17 years, GAM shared a space with Quality Control Corporation (Harwood Heights, IL), until 2007 when GAM moved to Mount Prospect, IL.

"We started off with just one product and built the company one customer at a time," said Gary Michalek, founder and CEO of GAM. "It is amazing to think about just how far we've come, but I'm excited to see where the company goes in the next twenty five years."

In addition to leading the organization, both Michalek and Van den Avont are actively involved in the community. Van den Avont has developed close relationships with schools in local district 214, mentoring students interested in STEM (Science, Technology, Engineering, and Math), and hosting field trips and career days at GAM so students can get a first-hand view of the opportunities that exist in engineering and manufacturing.

"Building a great company and culture is extremely important to me," said Van den Avont. "However, I am also very passionate about helping students get excited about engineering and manufacturing."

Bauer

OPENS FLAGSHIP PRODUCTION FACILITIES TO HALVE LEAD TIME

Bauer recently opened a new production facility at the company headquarters in Esslingen, Germany.

Bauer Gear Motor has been a leading manufacturer and supplier of gear motors since 1927, when the company's founder, Wilhelm Bauer, first began eliminating the transmission shaft from machine tools and production machinery. Since then it has developed a reputation for producing reliable solutions which are carefully engineered to the requirements of the customer to ensure that the maximum possible efficiency gains are achieved.

Bauer's acquisition by Altra Industrial Motion in 2011 allowed it to expand its global footprint and make investments to advance its engineering facilities and create an integrated, lean manufacturing process which keeps delivery times low, even for completely bespoke, one-off gear motors.

"This new facility represents the next step in Bauer's production concept, which will eventually expand to our key regions around the world," said Karl-Peter Simon, managing director of Bauer Gear Motor. "We have adapted our production facilities to operate as one piece flow, moving assembly lines. This prepares us for fast delivery of both small and large customer orders.

"We have been able to create a connected factory concept whereby our production facilities in Germany are supported with just-in time deliveries from our production factory in Slovakia. With this concept we are prepared for implementing Industry 4.0.

"This means that the two sites are operating on the same production schedule, so there is no delay in the delivery process between customer sign-off of the order and the completion of the order. This will allow us to reduce our current standard production time for configurable gear motors from 10 days to five days."

"As a business we believe that growth comes from investment," said Carl Christenson, Altra Industrial Motion CEO. "Bauer Gear Motor offers our customers the most reliable, efficient Gear Motor solution whether they need a batch run of standard products or a specialized solution e.g. customized motors or shafts. Our investment will allow it to continue to improve our flexibility: to work more closely with customers, to reduce lead times and to grow the customer base around the world.

"We are committed to supporting the continued growth of Bauer both in Germany and around the world. We intend to continue investing in the Slovakian factory and have plans to extend the new production concept to our facilities in the USA, China and Brazil."

The new facilities wholly owned by Bauer Gear Motor GmbH and cover an area of approximately 30,000 m2 in Esslingen, Bauer's hometown. In addition to the new production facilities, the new building includes open plan offices, a conference center and new canteen area with its own kitchen for the staff. The implementation of energy efficiency measures means that energy requirements on-site will be reduced by 30%.

Dr. Stefan Spindler

NAMED NEW CEO INDUSTRIAL AT SCHAEFFLER AG

The Supervisory Board of Schaeffler AG recently appointed **Dr. Stefan Spindler** as member of the board of managing directors at Schaeffler AG, as of May 1.

Before joining the Schaeffler Group, Spindler was a Member of the Executive Board at Bosch Rexroth responsible for the "mobile applications" business division. He is successor to Robert Schullan, who left the Schaeffler Group at his own request to pursue new career opportunities.

"With Dr. Spindler, we are gaining a very experienced executive manager for our Industrial division who will consistently continue Mr. Schullan's work, in particular with regard to the worldwide customer business," said Georg F. W. Schaeffler, chairman of the supervisory board of Schaeffler AG. "Mr. Schullan has been working for the Schaeffler Group for approximately 30 years. During this time, he has made an outstanding contribution to the successful development of the Schaeffler Group's industrial business. We thank Mr. Schullan for his contribution over the last three decades at the Schaeffler Group and wish him all the very best for his future career. We wish Dr. Spindler every success in his new and challenging role."

Paul Cooke

APPOINTED PRESIDENT AND CEO OF BOSCH REXROTH U.S.

Paul Cooke was recently appointed regional president Americas and president and CEO of Bosch Rexroth Corporation U.S., effective July 1. Cooke will continue as senior vice president sales within the business unit industrial applications at the headquarters in Lohr, Germany until the end of June 2015.

Cooke joined Bosch Rexroth in 1982 and has served in positions of senior leadership at Bosch Rexroth in the United Kingdom and Germany, most recently as senior vice president sales and industry sector management for machinery and engineering. Cooke has over 30 years of experience in both industrial technology and general management. He received his bachelor with honors degree in mechanical engineering from The University of Newcastle upon Tyne, England.

Berend Bracht, who is currently regional president Americas and president and CEO of Bosch Rexroth Corporation U.S. is resigning from the organization for personal reasons.

"We thank Mr. Bracht for his high level of commitment in the many years of service to Bosch Rexroth. We wish him all the best for the future," said Dr. Karl Tragl, the chairman of the executive board of Bosch Rexroth.

Wittenstein AG

WINS THE 2015 HERMES AWARD

Wittenstein AG was recently named the recipient of the 2015 Hermes Award. The award was presented to the company on April 12 at the Hannover Messe Opening Ceremony.

"Wittenstein AG is synonymous with technological expertise and innovative spirit," said Dr. Jochen Köckler, member of the managing board at Deutsche Messe. "The company has been exhibiting at Hannover Messe for many years and, year after year, has been showcasing new products in the field of high-precision electromechanical drives. The winning product is a completely new type of gearhead featuring Industry 4.0 connectivity. This makes it an excellent fit for this year's lead theme: 'Integrated Industry — Join the Network.'"

Wittenstein AG received the Hermes Award for its product "Galaxie" — a high-performance gearhead with independently movable gear teeth arranged in such a way that all surfaces of each tooth are able to engage with the teeth of the fixed outer ring gear. As a result, the Galaxie's force-transmitting surface contact is more than six times greater than that of conventional gearheads. The teeth are driven by a combination of a polygon on the input shaft and, on the output side, a segmented antifriction bearing and a tooth carrier with segmented outer bearing ring. The meshing pattern is a logarithmic spiral — another first.

The Hermes Award was presented by Dr. Johanna Wanka, federal minister for education and research.

"The Galaxie high-precision gearhead is an outstanding development and a prime example of Germany's innovative drive," Wanka said. "Wittenstein AG has proved that with courage, creativity and determination a completely new kind of gearhead can be created. The company has also succeeded in embodying the future of industry — the networking of production and services — in its gearbox."

July 14-16—SEMICON West 2015 Moscone Center, San Francisco, CA. SEMICON West is the premier annual event for the global microelectronics industry, highlighting the latest innovations, products, processes, and services for the design and manufacture of today's most sophisticated electronics. SEMICON West showcases innovations across the microelectronics supply chain, from silicon to system and everything in between. From the latest research on the cutting-edge of transistor technology, to solutions breathing new life into legacy fabs, SEMICON West is the place to connect to what's new and what's next in microelectronics. For more information, visit *www.semiconwest2015.org*.

August 6-8—Asia International Gear Transmission Expo 2015 As Asia's most influential, professional and authoritative gear industry event, GTE has been held 10 years in a row and during that time has obtained the affirmation of a large number of exhibitors and buyers. The exhibition will work with multiple marketplace platforms to create the Asia gear industry's most influential international showcase. With a planned area of 45,000 square meters, the exhibition expects more than 500 exhibitors and 40,000 professional visitors from home and abroad. For more information, visit *www.gte-asia.com*.

August 10-12—MPIF's Basic PM Short Course Penn Stater Conference Center Hotel, State College, PA. This intensive 3-day course is designed especially for you, if you are starting out in the field and looking for an introduction to powder metallurgy (PM); updating your knowledge of recent developments in PM; seeking to expand your current knowledge of the PM industry; a user of PM parts or are considering PM. This course is designed for engineers, tool designers, metallurgists, supervisors and technicians. For more information, visit *www.mpif.org*.

September 13-15—TECHINDIA 2015 Bombay Exhibition Centre, Mumbai, India. TECHINDIA will be the ultimate facilitator for b2b cooperation between manufacturers and consumers of all hues connected to the engineering, machinery and manufacturing industry. This leading business event is co-located with five other industry events to make it an extended platform for metal, engineering, manufacturing and machine tools industry: World of Metal—International Exhibition on Metal Producing, Metal Processing and Metal Working Industry; CWE – International Exhibition on Cutting and Welding Equipment; IMEX – International Exhibition on Machine Tools and Engineering Products; UMEX – International Exhibition on Used Machineries; Hand Tools and Fasteners Expo – International Exhibition on Hand Tools and Fasteners. The co-location of industry events will maximize business opportunities for industry professionals. For more information, visit *techindiaexpo.com*.

September 21-23—Gear Failure Analysis Big Sky Resort, Big Sky, MT. Explore gear failure analysis in this hands-on seminar where students not only see slides of failed gears but can hold and examine those same field samples close up. Experience the use of microscope and take your own contact pattern from field samples. Cost is $1,600 for members and $2,100 for nonmembers. For more information, visit *www.agma.org*.

September 29-October 1—2015 Gear Manufacturing Hyatt Regency, Rochester, NY. This seminar provides the gear design engineer with a broad understanding of the methods used to manufacture and inspect gears and how the resultant information can be applied and interpreted in the design process. Following this seminar, participants will be able to identify methods of manufacturing external and internal spur, single and double helical, and bevel and worm gears, describe the methodology ad underlying theory for basic manufacture and inspection of each, and much more. Cost is $1,430 for member and $1,930 for nonmembers. For more information, visit *www.agma.org*.

November 3-5—2015 Detailed Gear Design Beyond Simple Service Factors Hyatt Place Las Vegas, Las Vegas, NV. This course explores all factors going into good gear design from life cycle, load, torque, tooth optimization, and evaluating consequences. Students should have a good understanding of basic gear theory and nomenclature. Interact with a group of your peers and with a talented and well-respected instructor who will push your thinking beyond its normal boundaries. Cost is $1,395 for members and $1,895 for nonmembers. For more information, visit *www.agma.org*.

November 13-19—2015 International Mechanical Engineering Congress & Exposition Houston, TX. ASME's International Mechanical Engineering Congress and Exposition (IMECE) is the largest interdisciplinary mechanical engineering conference in the world. IMECE plays a significant role in stimulating innovation from basic discovery to translational application. It fosters new collaborations that engage stakeholders and partners not only from academia, but also from national laboratories, industry, research settings, and funding bodies. Among the 4,000 attendees from 75+ countries are mechanical engineers in advanced manufacturing, aerospace, advanced energy, fluids engineering, heat transfer, design engineering, materials and energy recovery, applied mechanics, power, rail transportation, nanotechnology, bioengineering, internal combustion engines, environmental engineering, and more. For more information, visit *www.asmeconferences.org*.

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Surviving the Robot Revolution

Erik Schmidt, Assistant Editor

I saw it and it saw me, three eyes between us, locked in a frozen moment among a backdrop of frenetic motion.

It had no arms or legs to speak of; no fleshy, meaty exterior or squishy insides; no heart, no brain, no soul. It was just a protracted steel body, long and spindly, a rectangular "head" at the end, and one glowing sensor. It wasn't alive. It wasn't sentient. It was a robot.

But it could *see* me.

A slight pang of uneasiness gripped me as I stared at it, flapping my humanoid eyelids up and down with nervous gusto. It peered back coldly, unblinking, *unmoving*. Several seconds went by, man and machine locked in a lopsided staring contest I had already lost several times over. It just kept *staring, staring, staring*.

And then it whirred away.

I exhaled. Boy, that was weird.

I turned around and took in the spectacle before me: machines to my left, machines to my right, machines straight away and to my back, with wide-eyed humans scattered sporadically all in between. It wasn't exactly the Robot Revolution, but it was close. And that's the kind of emotional response that Automate elicits — it makes you feel like you're not the dominant species in the room.

This is basically how I spent the better part of March 24 in downtown Chicago (before you ask, yes it was cold), weighing my own personal "chicken or the egg" scenario: What's smarter, this robot that can play beer pong or the men that created it?

Yes, a beer pong-playing robot is a thing that exists. No, it doesn't adhere to the elbow rule.

The contraption, designed by Empire Robotics, was not built for the sole purpose of shooting a ping pong ball into red Solo cups — though college students at the nearby University of Illinois-Chicago may argue it's the most *important* function. The robot utilizes Versaball technology, a lime green, flexible "robotic gripper that leverages the phase transition of granular materials, enabling secure grasping of varying object shapes with a single tool."

I sat and watched the mushy sphere — think Flubber sans limbs and you get the picture — arc shots across Empire's booth at a pyramid of cups for about 15 minutes. Its accuracy was questionable (but then again, whose isn't several hours of Beirut?) but the tech was pretty slick. The gripper's ability to carefully mold around the ping pong ball — it also demonstrated the ability to pick up bricks and light bulbs — was both deft and ingenious.

Now, if it *is* accuracy that you want, check out Comau Robotics' Racer 1.4.The Racer is a 6-axis, anthropomorphous robot that can — get this — shoot free throws like Shaquille O'Neal's worst nightmare.

Comau's booth had two basketball hoops set up, one for the Racer and one for whoever wanted to lose to it. While the human competitors had a distinct speed advantage over what Comau describes as "the world's fastest robot in its class," the Racer — incongruous from its name– was comparatively slow and steady, but deadly accurate.

As orange leather spilled all over the booth due to missed shots careening off the challengers' rim, the Racer demonstrated cold, hard robotic resolve:

It dipped its crimson arm low to scoop up the ball before twisting around backwards to catapult the shot skyward in a sort of Bizarro World Rick Barry, underhand motion — strange, but infallibly effective. With a repeatability of .05 mm, the Racer never missed. Not once.

After the Racer dispatched each victim, it would primp and prose in a rather eerie, unnatural victory dance.

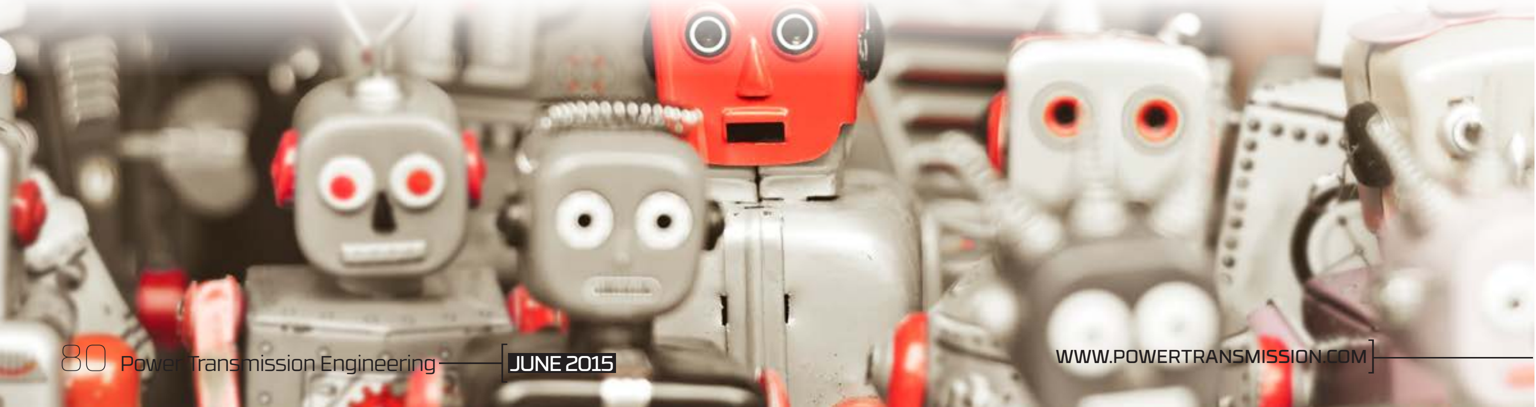
This whole sideshow was quite fun to watch, but deep down I was tremendously disturbed.

Not because I knew that this unfeeling automaton could make it rain on the hardwood better than I ever could; not because it seemed to be taunting all of us with its dominance — guest of honor and NBA great Bill Walton included; but because I knew that if these prodigious machines ever rose up against us and mankind was forced to fend them off in a "Space Jam" type gauntlet of athletic prowess, we would undoubtedly be doomed.

And the Robot Revolution would rage on.

As I drove away from the convention center that day, apocalyptic thoughts swirling around my head, I took a gander at the inside of my car, filled with power locks and windows and built by robots similar to the ones I had just seen — a metallic prison built by the enemy.

"*Tommorow,* I thought, "*I'm walking to work.*" **PTE**



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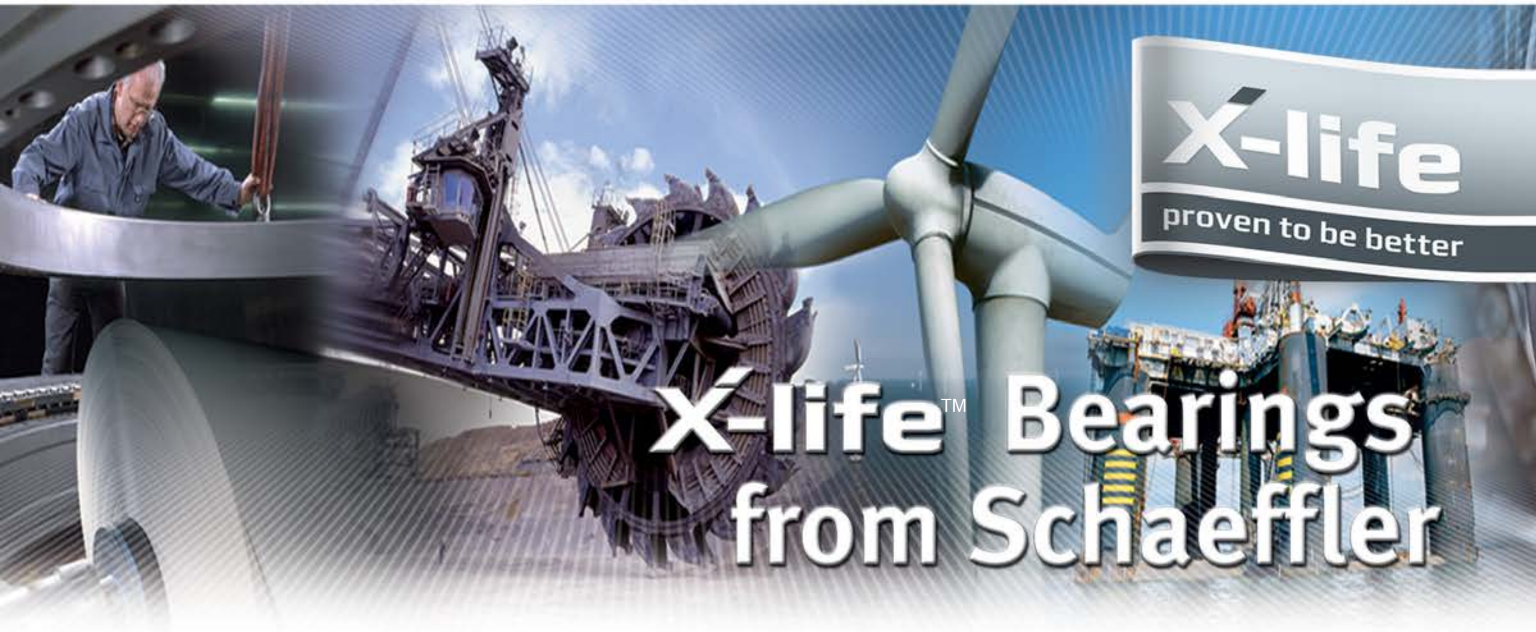
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