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APRIL 2019

BEARINGS

CLUTCHES & BRAKES

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FEATURE ARTICLES

TECHNICAL ARTICLES

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Power Transmission Engineering
VOL. 13, NO. 3


90 MISSILES
330 SAILORS
1,100 MILES OUT TO SEA
ZERO ROOM FOR GEAR DRIVE FAILURE.

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PTE Videos

SKF Remanufacturing Process

This video offers a look at the remanufacturing process at SKF's Birmingham, Alabama facility located in the USA. The facility offers an extensive range of SKF services and solutions, including application and reliability engineering, customized machined sealing solutions, mechanical services, asset diagnostic services and a full spectrum of training courses

www.powertransmission.com/videos/SKF-Examines-Remanufacturing-Process-/

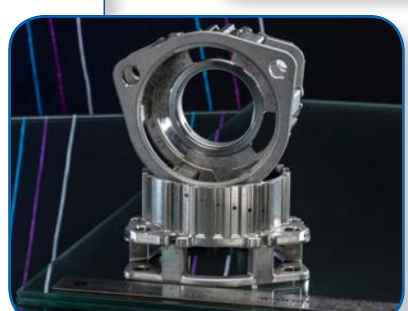
Kollmorgen AKD-N Overview

Two Minutes of Motion: This video is a brief explanation on the system connections and how the decentralized servo system can save on space and cabling. The servo drives are IP67 and mounted near the servo motor, reducing cabling on the machine.

www.powertransmission.com/videos/Kollmorgen-AKD-N-Overview-/

Event Spotlight: Powdermet 2019

The North American technical conference on powder metallurgy and particulate materials, Powdermet 2019 is a hub for technology transfer for professionals from every part of the industry, including buyers and specifiers of metal powders, tooling and compacting presses, sintering furnaces, furnace belts, powder handling, blending equipment, and more. This year's show takes place in Phoenix, Arizona.



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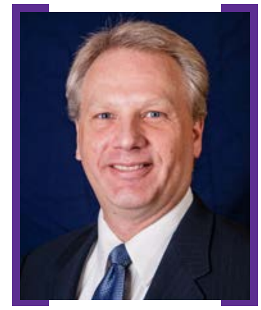
Randy Stott, Managing Editor



Plugged In

At the recently concluded Automate 2019 and Promat trade shows (held in Chicago in April), we saw a lot of new technology aimed at making factories more efficient and productive. The Industry 4.0 concept continues to evolve, and the Industrial Internet of Things (IIoT) continues to expand the way we design, manufacture and maintain mechanical equipment.

Bearings, gearmotors and gear drives are no longer just dumb components, tasked with doing the same job over and over. Power transmission components are getting plugged in. They're being fitted with sensors, encoders and controls that allow information about their performance to be collected, analyzed and acted upon.

And we're not talking about academic endeavors here, either. Real-time information about temperature, vibration, torque and speed is making its way into the hands of plant managers and maintenance professionals via their cell phones and tablets. Failures are being anticipated and planned for, and productivity is being maintained.

That same information is being collected, sent to the cloud and analyzed by artificial intelligence, so that engineers designing the next generation of systems are equipped with the data they need to make those systems more productive, robust and efficient.

Over the next several issues, we look forward to bringing you some of those stories.

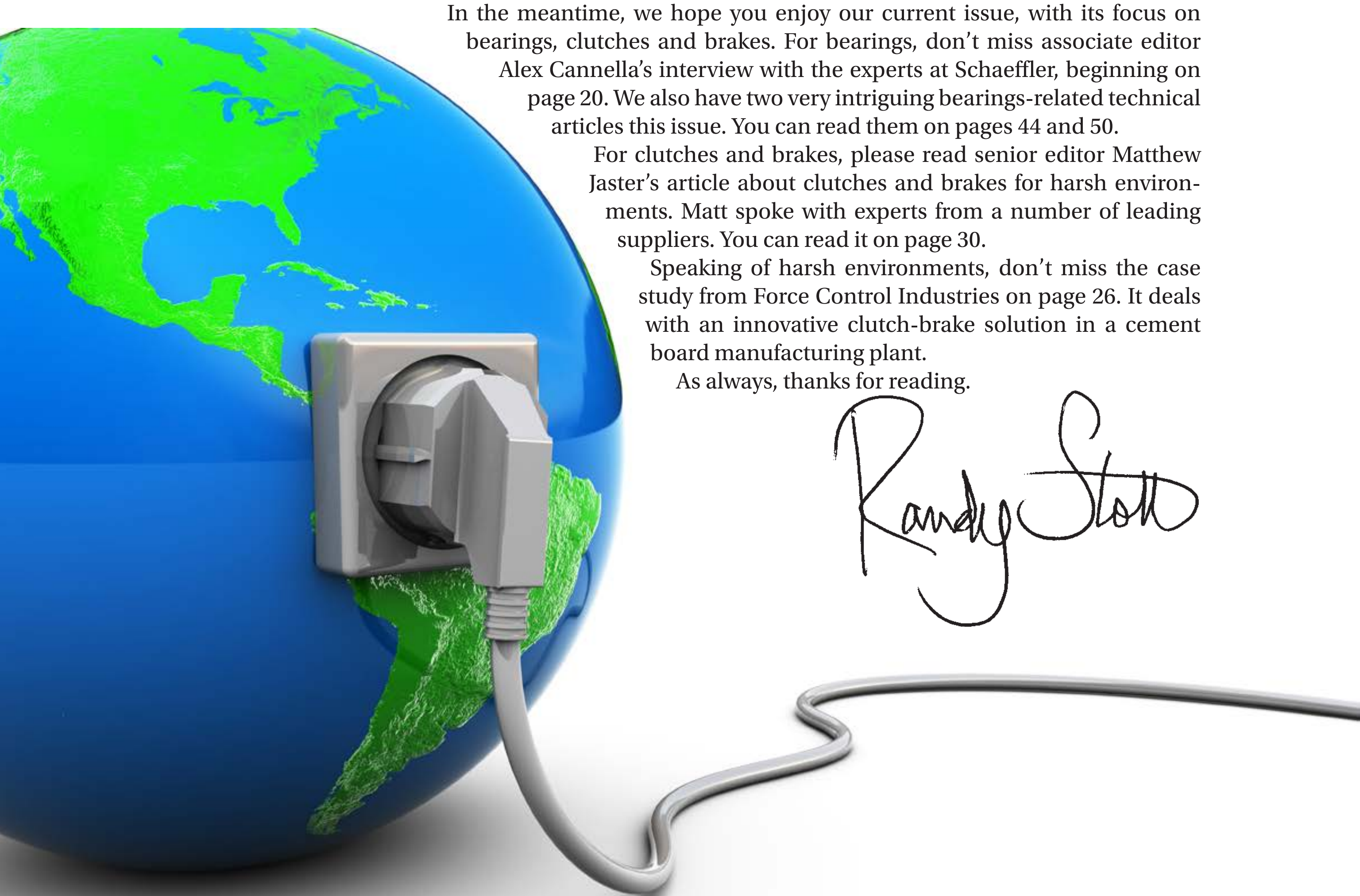
In the meantime, we hope you enjoy our current issue, with its focus on bearings, clutches and brakes. For bearings, don't miss associate editor Alex Cannella's interview with the experts at Schaeffler, beginning on page 20. We also have two very intriguing bearings-related technical articles this issue. You can read them on pages 44 and 50.

For clutches and brakes, please read senior editor Matthew Jaster's article about clutches and brakes for harsh environments. Matt spoke with experts from a number of leading suppliers. You can read it on page 30.

Speaking of harsh environments, don't miss the case study from Force Control Industries on page 26. It deals with an innovative clutch-brake solution in a cement board manufacturing plant.

As always, thanks for reading.

Randy Stott



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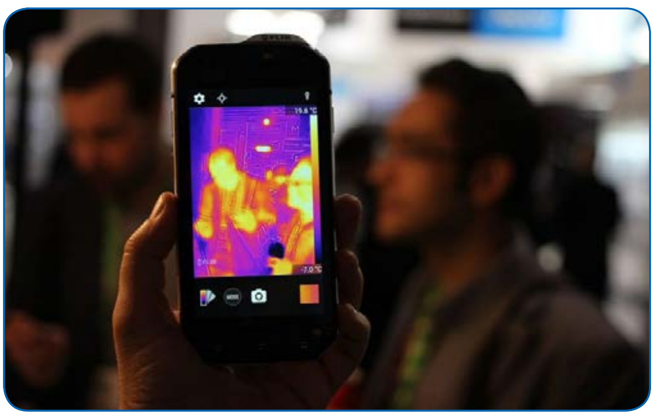
Troubleshooting: Use ALL of Your Senses

Donald P. Labriola II

Troubleshooting infrequent intermittent problems can be one of the most frustrating engineering areas. It is also a great opportunity to use system knowledge and all of your senses and sleuthing abilities. The knowledge learned can also help to design future systems that are easier to isolate.

One example was a large blood chemistry analyzer. The system had an intermittent noise on one of the analytical channels. Field service had literally replaced every printed circuit board in the system, including the backplane to no avail. The unit was replaced with a new unit and returned to the service group in the factory to do a root cause analysis of the system. Every board (around 30–40 boards) was swapped with a working system in field service, the problem remained stuck. No change in either system. Next every cable was swapped between systems, as well as all of the sensors. Still the analog glitch firmly remained in the failed system.



The system was finally brought up to engineering after about 3 months of frustrating the field service group. I was pulled in from a different project to try to put this issue to rest. We had a good digital oscilloscope connected up to the analog channel having the issue, and ran multiple runs on the instrument, occasionally observing a glitch on the oscilloscope. I noticed that I heard the click of a solenoid coincident with the glitch (there were many on this instrument to control fluid flow). I felt through the banks on the solenoids until I found which solenoid click coincided with the oscilloscope glitch. A close look revealed that the catch diode on the solenoid — which was physically located at the solenoid — had been broken. The solenoid was in an unrelated chemistry that was showing no issues, and so was never inspected or replaced. All in all, about 15–20 minutes to locate the issue and cure it.

The underlying cause was that a +12-volt power supply had been shared between operating the solenoids and powering the op-amps of the various analog channels. In a properly operating system, the catch diodes limited the interaction, and the system worked well. In the failed system, this back-door unintended interface provided means for an unwanted interaction that stymied correction and fixing.

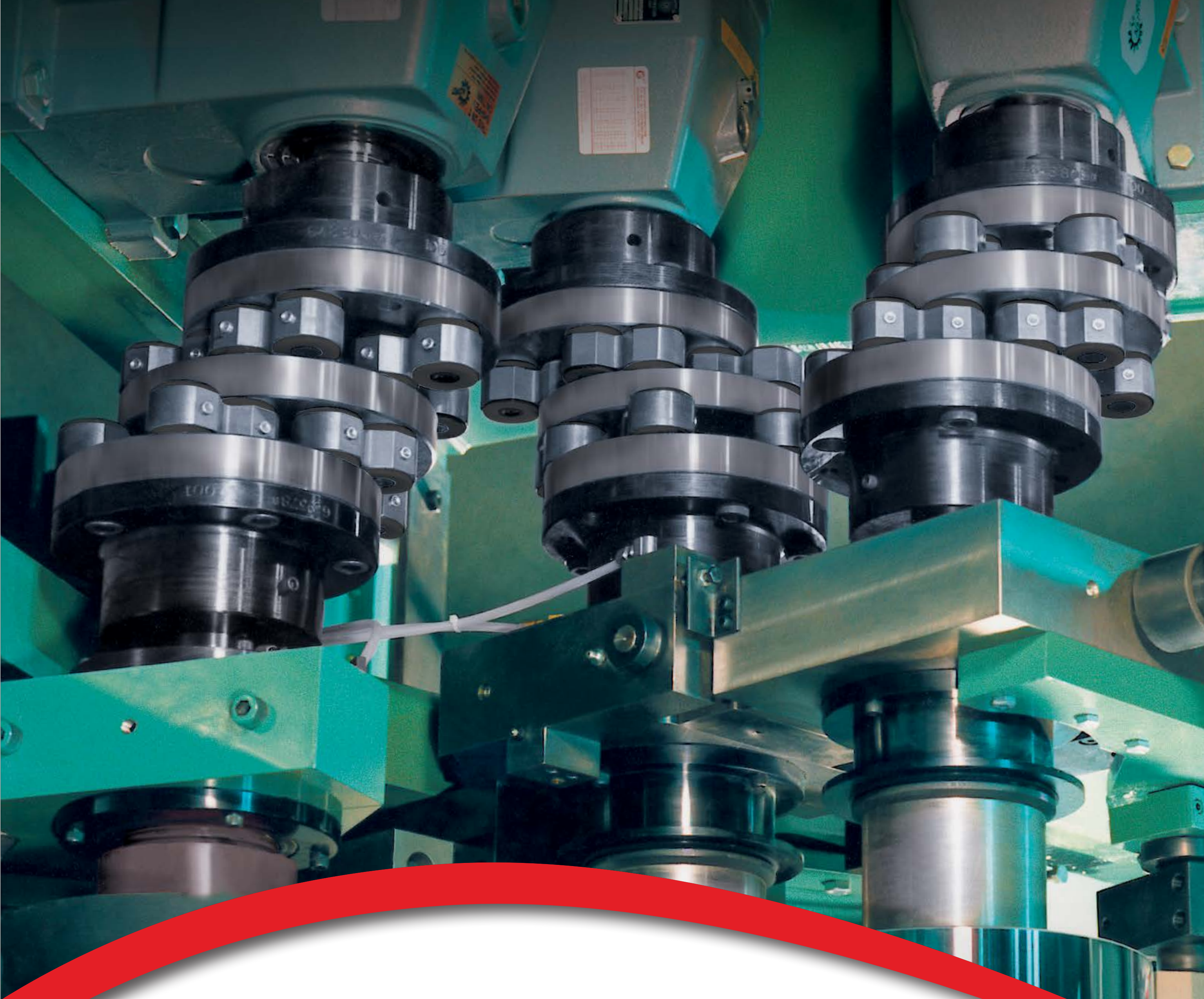
A course on system engineering in aerospace did a nice quantification of the issue: the number of possible interactions goes up by the factorial (n!) of the number of interfaces. This includes the intentional and the unintentional interfaces — like the shared power supplies. Take care in system design to isolate sections as much as practical and to make the remaining interfaces robust and testable.

A good nose can also help you to quickly pinpoint many issues. An overheating through hole resistor causes the phenolic case to release phenol, which has its own unique smell (some sore throat medicines are based on phenol) — this is somewhat of a sweet odor. The epoxy plastic used to encapsulate IC's have a harsher acidic smell when an IC overheats. Inductor and transformer varnishes from different sources each have their own signature odor when overheating, as do various motors. Varnish smells vary from almost a cherry pipe tobacco odor for some parts from the far east, to a musty odor for some of the domestic sources. Remember these as you would spices and you can quickly locate the culprit.

Recently small FLIR cameras that plug into cellphones have become relatively inexpensive. These allow you to visualize heating. Applying a controlled current through a voltage/current limiting power supply to a PCB can allow you to quickly locate a shorted capacitor across a power plane as that will be the only component heating up a few degrees with only a few tenths of a volt across the power supply. These cameras are also very useful when validating designs and early testing. We make the habit of looking at all new designs for hot components. This testing can allow the designs which would have failed in the field from a stressed component to be corrected at the prototype stage, for example by changing a diode in a switching supply to a faster or softer recovery variety. Easy to fix once the problem is revealed.

When you design, try to minimize the interactions at the system architecture, if at all possible, but when this fails, use all of your senses! **PTE**

Donald P. Labriola II, president and founder of QuickSilver Controls, Inc. (*www.QuickSilverControls.com*), specializes in servo controllers and motors, with a special focus on cost-effective motion control. He has been granted eleven US patents as well as numerous international patents. His background includes over 40 years of motion control including 20 years in medical instrument design. He enjoys gardening, camping and Ham radio — and motion control!



Freudenberg

HELPS MANUFACTURERS OPTIMIZE HYDRAULIC CYLINDER SEALING SYSTEMS

With the goal of helping customers reduce the manufactured cost of hydraulic cylinders while optimizing performance and lifespan of their production equipment, Freudenberg-NOK Sealing Technologies has announced its new Freudenberg Perfect Cylinder program, a collaborative engineering and design approach with customers. Freudenberg-NOK runs the business operations for Freudenberg Sealing Technologies in the Americas.

Large-scale manufacturers, such as those found in the agriculture and construction industries, often find themselves faced with the daunting task of upgrading entire pieces of expensive equipment to keep production running smoothly. With the Freudenberg Perfect Cylinder program, the experts at Freudenberg-NOK work with cylinder distributors to reengineer cylinder components for hydraulic systems and pair them with the appropriate sealing solutions to maximize system efficiency on existing machines while eliminating the need for costly equipment replacement.

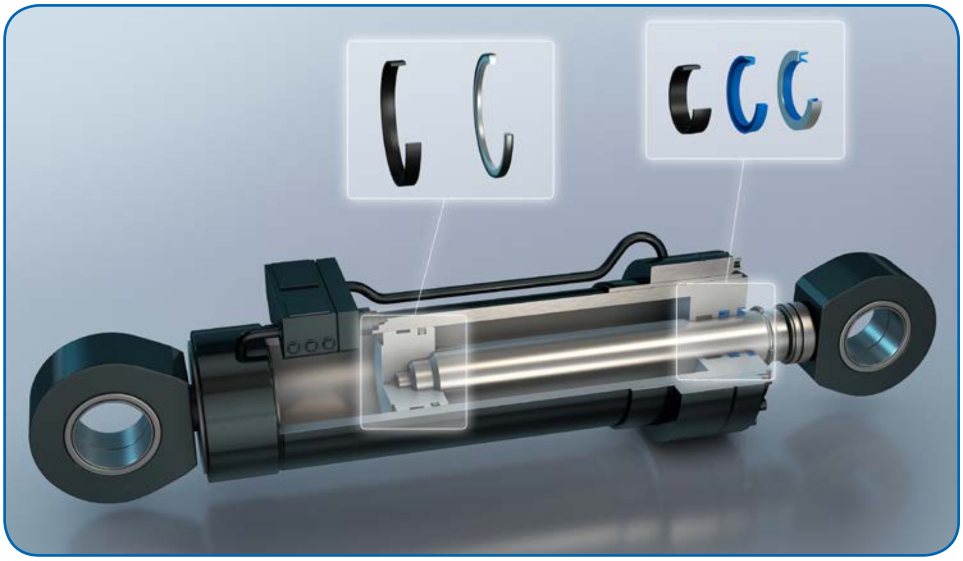
"We're known for our sealing products but our expertise can reach beyond that to assist our customers in new ways," said John Plut, director, fluid power partners, North America, Freudenberg-NOK. "With the Freudenberg Perfect Cylinder program, we can substantially reduce cylinder costs by collaborating at the engineering level to help create an enhanced system of cylinders and seals."

Once cylinders are re-engineered, they are be paired with sealing products from Freudenberg's vast catalog of industry leading solutions, resulting in an optimized sealing solution that uses premium, high performance seals while still saving customers as much as 40 percent on total material and production expenditures, Plut explained. In addition, Freudenberg's portfolio of sealing options continues to grow.

One of the company's latest sealing innovations in this area, for example, is the newly launched imperial-sized Guivex series guide bands, which are profiled piston and rod guide bands made with a new carbon-fiber filled polyamide material. The Guivex bands can be used in Perfect Cylinder-optimized sealing systems and in long-stroke cylinder, short stroke, short guiding distance, and high-side-load applications.

The size of the Guivex bands allows manufacturers to use them in radial load capacities that are 40 percent higher than standard guide bands, and they can be utilized in all fluids normally found in hydraulic systems, replacing standard ⅛" cross section piston guide bands in current housings.

"The new Guivex bands can enable the reduction of cylinder gland widths and lengths, reducing costs and increasing design flexibility," said Jay White, product marketing manager, fluid power, Freudenberg-NOK. "They are less abrasive to sliding surfaces as well, resulting in no jamming and quieter operation."



Other sealing technologies that can used in the Perfect Cylinder program include the HDP 330 high-pressure piston seal, plus seals made from the new 94 AU 30000 polyurethane material.

The HDP 330 is a special polyamide seal that can withstand extreme pressure (up to 800 bar) and allows for use of rougher cylinder liner surfaces, which can also cut cylinder production costs

Seals made from the 94 AU 30000 material last longer than current, standard seal solutions and have high resistance to hydrolysis, even in temperatures ranging from –35°C to 120°C and can remain stable in operating pressures up to 50 MPa/7,250 psi.

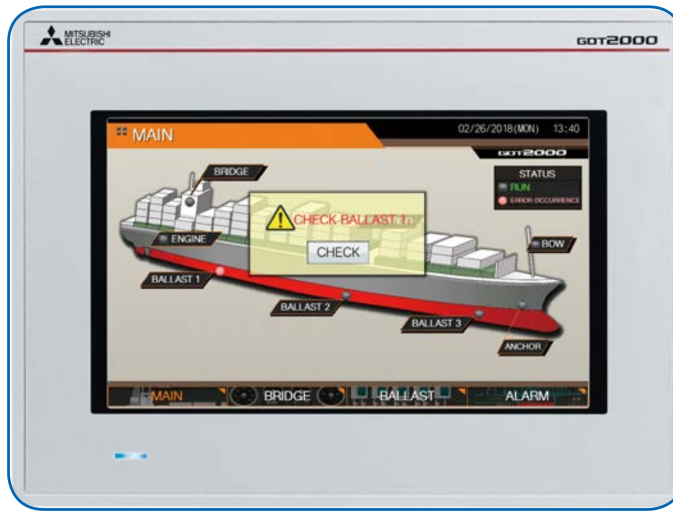
For more information:
Freudenberg Sealing Technologies
Phone: (734) 354-5505
www.freudenberg.com

Mitsubishi Electric

OFFERS HMI TO WITHSTAND EXTREME CONDITIONS

The GT25 Rugged Series HMI is suited for outdoor use where equipment damage is a significant risk.

Machine designers and end-users in outdoor industries or where exposure to harsh elements is inevitable will be interested in the new GT25 Rugged human machine interface (HMI) from Mitsubishi Electric Automation, Inc. Reinforced with metal housing and equipped with an extra bright screen visible under direct sunlight, this interface is engineered for environments that would damage or destroy more vulnerable HMIs.



The GT25 Rugged can function at temperatures between –5 and 150°F (–20 to 65°C) and is resistant to vibration and shock. The metal housing also protects the internal components from direct blasts from high-pressure water jets and UV rays. This makes it an ideal choice as a monitor screen or control panel for applications that require outside installation, or risk exposure to harsh environments and procedures, such as automated parking systems, power conditioners, electric car charging stations, heavy machinery and food processing systems that use pressurized jets to clean equipment.

The sturdy hardware offers the same functions and capabilities found on the broader GT25 Series of HMIs, such as a flexible configuration, a convenient maintenance platform, remote connectivity, expanded memory (32 MB ROM for storage; 128 MB RAM for operation) and device monitoring functions.

"Most HMIs are not viable in outdoor, exposed environments," said Lee Cheung, product marketing engineer at Mitsubishi Electric Automation, Inc. "The GT25 Rugged presents an opportunity to improve machines and systems that typically do not have a specialized HMI built for them."

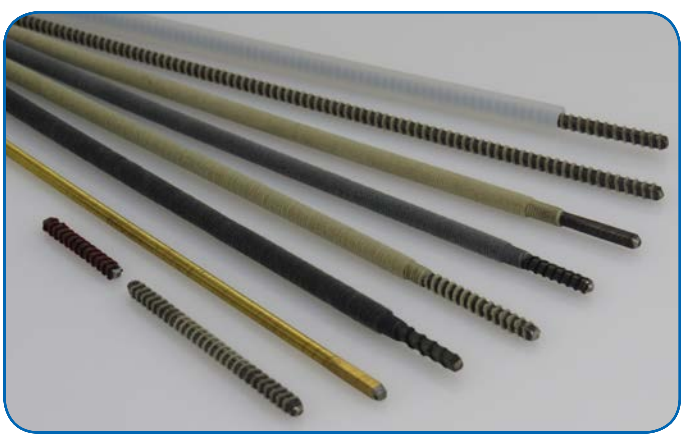
For more information:
Mitsubishi Electric Automation
Phone: (847) 478-2415
us.mitsubishielectric.com/fa/en

S.S. White Technologies

ANNOUNCES FLEXIBLE SHAFTS FOR AUTOMOTIVE APPLICATIONS

S.S. White Technologies recently announced their flexible shaft solutions for automotive industry applications. Flexible shafts are a technology that transmit rotary motion much like a solid shaft, but can be routed over, under, and around obstacles that would make using a solid shaft impractical. Flexible shafts are used in a variety of automotive applications, including in power seats, power sliding doors, pedal adjuster systems, and power rear lift gates, among others.

Among the many automotive applications for which S.S. White flexible shafts are used is to transmit rotary motion generated by electric motors in various "powered" amenities in vehicles. The most common application of flexible shafts in this area is in power seats. This is one example of how flexible shafts can be widely customized to fit their application, as the shafts in this application are specialized "flocked" shafts, which are coated in flocked yarn to dampen the noise created during operation — a critical feature in the automotive industry. In addition, compared to the use of rigid shafts, flexible shafts used in power seats feature a number of advantages. The assembly process is easier with flexible shafts, and, due to their flexibility, flexible shafts give the movement of the power seats a greater degree of smoothness compared to rigid shafts.



Flexible shafts are the preferred rotary motion technology in many automotive applications because they help eliminate alignment problems, are less costly in terms of installation and needed parts, and they provide greater design freedom than rigid shaft technologies.

S.S. White provides flexible shaft assemblies as part of a custom solution. Every application in which a flexible shaft would be beneficial is different, and S.S. White not only manufactures the flexible shaft technologies, but also provides the technical expertise to create solutions to engineering challenges.

For more information:
S.S. White Technologies
Phone: (732) 474-1700
www.sswhite.net

SKF

DEVELOPS PORTABLE SENSOR FOR MACHINE MONITORING

SKF Pulse combines an easy-to-use handheld sensor with a new mobile app, allowing users to quickly monitor rotating equipment and machine health to predict issues and improve reliability before operations are impacted.

For more advanced analysis, users can request an SKF Pulse Check directly via the app. The request goes to an SKF diagnostics center where experts remotely analyze the machine data and respond with recommended corrective actions to improve equipment performance, if required.

SKF Pulse has an intuitive visual interface that guides users through the data collection process. Users enter asset information that automatically configures alarm thresholds based on ISO standards. Thresholds can also be customized if desired.

The durable SKF Pulse sensor features: Velocity, acceleration and temperature measurement of rotating equipment; Bluetooth communication with iOS mobile devices; rugged industrial design — drop test of six feet and water- and dust-resistant (IP65) and a rechargeable lithium battery (with eight hours normal usage)

Designed for MRO managers and staff in a wide range of industries — including food and beverage, cement, marine, oil and gas, pulp and paper, steel, mining, chemical processing and other industries — SKF Pulse provides a cost-effective entry point for a do-it-yourself, preventive maintenance program.

Unlimited assets can be monitored with one sensor. For extra scalability, more sensors can be added as part of a broader vibration analysis program. Data and asset information can be shared throughout the facility.

"Customers wanted an easier way to conduct routine vibration checks with the ability to quickly get expert help if they need it," said Josh Flemming, strategic marketing, SKF USA Inc. "SKF Pulse offers a combination of features that our competitors don't, including easy setup, portability, effortless data collection and immediate insight, regardless of the equipment manufacturer."

For more information:
SKF USA Inc.
Phone: (800) 440-4753
www.skfusa.com

KTR Corporation

INTRODUCES TORSIONALLY-RIGID, CURVED-TOOTH FLANGE COUPLING

With hydrostatic drives in construction and agricultural machines, I.C.-engines and hydraulic pumps are directly coupled. Both units are connected by a flange coupling. This connection has to meet a number of requirements — though primarily it has to transmit the power reliably enabling the machine to perform the pending operations as requested.

BoWex FLE-PAC is a torsionally rigid curved-tooth flange coupling. Its hub is made of steel and the flange toothing of carbon fiber reinforced nylon. This material combination provides the coupling with high dimensional stability even with temperatures up to 130°C allowing for a long and maintenance-free permanent operation thanks to optimized coefficients of friction in the tooth combination.

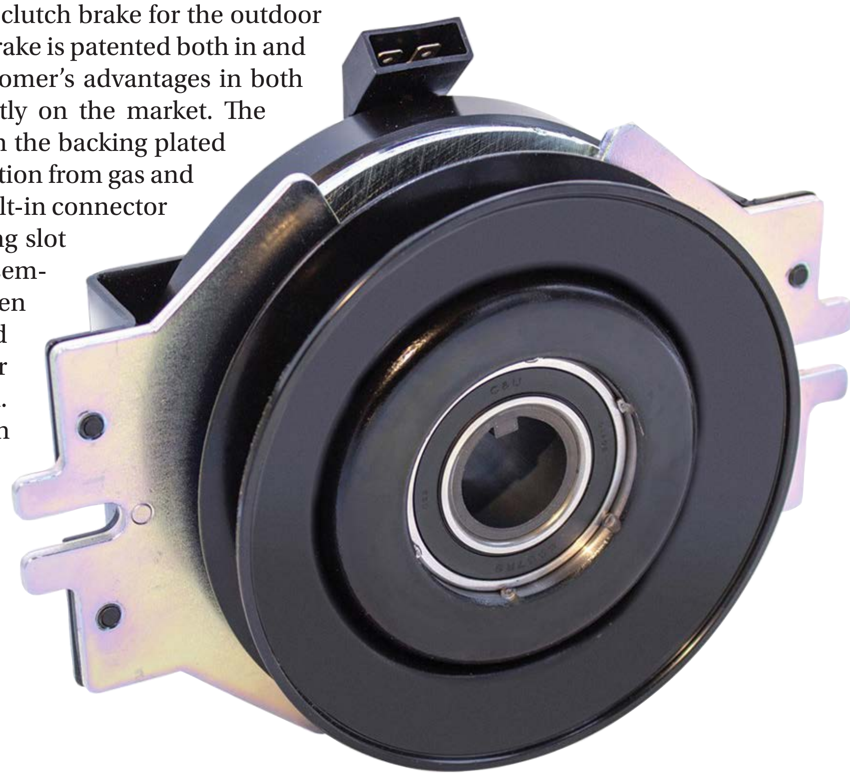
"Years of experience with applications at customer sites and extensive test series in the KTR test field in Rheine enabled us to determine potentials with this type allowing for an increase of torques of up to 25 percent," said Andreas Hücker, product manager for flange couplings. "Especially the low wear of contacts and the excellent dimensional accuracy of the coupling were decisive for the torque increase. The increased coupling torques result in a bigger performance range with drives up to 800 kW. Thus the customers will be in a position to use smaller coupling sizes in their machines in the future."

For more information:
KTR Corporation
Phone: (219) 872-9100
www.ktr.com/us

Ogura

PTO CLUTCH BRAKE OFFERS PERFORMANCE ADVANTAGES FOR OUTDOOR POWER EQUIPMENT

Ogura has developed a new model, GT2.75, clutch brake for the outdoor power equipment market. This new clutch brake is patented both in and outside of the United States and offers customer's advantages in both design and cost over older designs currently on the market. The clutch incorporates a six hard rivet design in the backing plated field shell that resists separation due to vibration from gas and diesel engines. The new design also has a built-in connector for easy wire attachment. A simple mounting slot on both sides of the clutch makes for easy assembly. The big advantage for the end user is when the brake plate wears, the plate can be flipped and the end user can gain additional wear cycles without having to replace the clutch. All units come with an integral key and high strength roll formed low inertia pulleys. To handle high inertia loads, a six-spring, 12 rivet design was used between the pulley and armature.



For more information:
Ogura Industrial Corp.
Phone: (732) 271-7361
www.ogura-clutch.com

Bonfiglioli

INTRODUCES ELECTRIC SLEW AND TRACK DRIVE FOR MINI-EXCAVATORS

These two new products by the Italian drive specialist Bonfiglioli allow customers to get a complete drive solution for 2–3 ton mini-excavators. Bonfiglioli offers a fully electric alternative to the conventional axial piston hydraulic unit, allowing the machine to reduce noise levels and CO_2 emissions to zero.

The complete electric powertrain dramatically improves the efficiency of the machine and extends the maintenance interval providing a significant reduction of the total cost of ownership. While the gear units benefit from over 65 years of experience by Bonfiglioli in the field of conventional hydraulic applications, the electric motors have been specifically designed and developed to match the demanding requirements of the market in terms of energy efficiency, compact dimensions and high power density.

Each motor has been designed to perfectly fit the space available for the slew and the track system minimizing the requirements and modifications to the frame and the entire system. Its rugged and compact design is guaranteed thanks to the stator's technology design, made with concentrated winding and IPM (Internal Permanent Magnet) technology.

For more information:
Bonfiglioli
Phone: (859) 334-3333
www.bonfiglioli.com

Gates

OFFERS HIGH-TORQUE SYNCHRONOUS BELT FOR INDUSTRIAL APPLICATIONS

Gates, a global provider of application-specific fluid power and power transmission solutions, introduces the PowerGrip GT4 belt, a newly designed ethylene elastomer (EE) high-torque synchronous belt for industrial markets.

The PowerGrip GT4 reflects Gates' dedication to innovation in materials science and process engineering. Many of the elastomer synchronous belts in the market today are made using chloroprene, a material that has performance limitations. The new Gates PowerGrip GT4 belt construction replaces chloroprene with a special EE formulation that delivers much higher performance. The company pioneered ethylene elastomer technology with its line of Micro-V belts in automotive markets and applied that materials science technology to PowerGrip GT4 for industrial markets.

PowerGrip GT4 has the highest power-carrying capacity in the segment, a larger temperature range and improved chemical resistance. This allows for narrower drives and a broader range of applications to be served. For machine builders, this creates design flexibility and improves the ability to fit a belt drive into smaller spaces or to utilize more torque. Distributors can differentiate with a higher-performance offering and end-users running industrial drives as part of their operations experience a lower total cost of ownership. The improved performance characteristics also support additional market opportunities with the conversion of roller chain to belt drive solutions, enabling a transformation from a high-maintenance chain to a high-performance belt.

"PowerGrip GT4 extends the success we've had with the PowerGrip family of industrial belts over many years by upping the performance bar," said Tom Pitstick, CMO and senior vice president of Product Line Management for Gates. "It's right at home in heavy-duty industrial environments driving pumps, conveyor systems and other machinery where efficiency, reliability and high quality are required. PowerGrip GT4 belts eliminate the need for lubrication and maintenance, run quietly and reduce contamination risks, further extending our ability to replace traditional chain drives in key end markets."

Gates will offer a full portfolio of PowerGrip GT4 belts in 8 mm and 14 mm tooth pitches, and lengths exceeding 6.5 meters. Samples are available now with full-scale production beginning in North America and Europe in Q2 2019, with Asia to follow later in the year.

For more information:
Gates Corporation
Phone: (303) 744-5800
www.gates.com

Automotive Adjustment

The automotive industry is shifting for everyone, bearings manufacturers included. Here's what you need to know to make sure you're shifting with it.

Alex Cannella, Associate Editor

The automotive industry has been prepping for a big shift for years now: the shift to electric transmissions. I doubt anyone's a stranger to the discussion surrounding the direction the industry's heading — after all, it's had a perpetual place in the industry-wide discourse for years at this point. And during that time, the jump to electric-based transmissions has morphed from a conversation about "if" the industry would shift to a conversation about "when."

But along with the increased certainty of that conversation, there's one more important thing to talk about: how to shift with it. In *Power Transmission Engineering*, as well as our sister magazine, *Gear Technology*, we've already talked at length on numerous occasions about how this is going to affect gear manufacturing, most notably by drastically reducing the number of speeds, and therefore gears, needed per transmission. But the ever-mounting market pressure to switch to electrified powertrains is going to affect far more than just that.

> "The drive units for electric vehicles mainly involve precision ground ball and roller bearings. The main performance requirements for these bearings are higher speeds, lower friction and NVH, improved power density and increased efficiency."

Gears may be ground zero for this particular shift in the industry landscape, but that doesn't mean that other fields shouldn't be paying attention, as well, and preparing to adjust accordingly.

"These changes will have an impact on the bearing industry as well," Jitesh Modi, engineering director of transmission applications at Schaeffler, said. "The current 8/9/10 speed planetary automatic transmissions involve a large quantity of drawn and stamped bearing products like radial and thrust needle bearings. The drive units for electric vehicles mainly involve precision ground ball and roller bearings. The main performance requirements for these bearings are higher speeds, lower friction and NVH, improved power density and increased efficiency."

So what are people working with bearings going to need to know to meet those shifting industry demands? Well, we sat down with Schaeffler to talk about what skills you might want to brush up on to make sure you're ready to not just survive, but thrive in this changing market.

First, let's talk about the shift itself. Ball and roller bearings are far from unknown in the automotive market. They're currently seeing use primarily as main shaft and gear support bearings in more conventional transmissions, but according to Modi, they're going to be rising to increased prominence and taking center stage along with electrified transmissions. And along with that comes a few extra design considerations bearing manufacturers will have to think around.

"Their application in electric vehicles, especially in electric motors, certainly requires design optimization and precision manufacturing to provide necessary running accuracy and desired performance at high speeds to an extent of 20,000 rpm and even above in the near future," Modi said. "In addition, creep damage and electric current passage through bearings can pose additional challenges in electrified powertrains."

As an example, Modi pointed to how the higher speeds in electric motors lead to an entire host of considerations that require manufacturers to focus on the bearing cage design.

"The cage geometry, pocket clearance, cage guidance and its overall strength play an important role in bearing performance," Modi said. "For sealed bearings, the sealing design can influence bearing limiting speeds due to friction and heat generation. The seal wear can lead to grease leakage and subsequent bearing failures. The compatibility between sealing material and grease becomes a key consideration as well."

While none of these factors are necessarily "new" considerations when designing a bearing, they'll all require some reconsideration for electric transmission applications. Those higher speeds that electric motors run at will require sturdier, higher quality bearings alongside them. Much like it is for the gearing market, electrified transmissions will make increased quality demands of bearing manufacturers, and cage design is a primary method Modi pointed to meet those demands.

Bearing designers and manufacturers aren't the only ones that are going to need to adjust to how the industry's shifting. There will be a whole host of fresh demands placed on maintenance professionals and the aftermarket, as well, mostly in the form of new kinds of damage you might not be used to in bearings used in conventional transmissions.

On the maintenance side of the bearing market, however, Modi's advice is pretty straightforward.

"Overall knowledge and understanding of typical bearing failures in electrified powertrains will be important for the maintenance professionals," Modi said. "Familiarity with bearing diagnostic tools and techniques can be really helpful for efficient troubleshooting."

The advice more or less amounts to "keep doing what you're doing," except in a slightly different field. But while the core competencies to get the job done might be the same, that doesn't mean that maintenance professionals won't have to learn something new. Much like with bearing design, the increased speeds and electrical currents running through these new powertrains can cause all manner of issues that you'll need to brush up on. The electric current itself can induce craters or fluting damage in a bearing, and then, of course, there's the already mentioned increased strain placed on the bearing cage due to the motor's increased speed to worry about.

"The higher speeds of electric motors can lead to bearing cage failures if it is not designed suitably for the given speeds," Modi said. "If electric motor bearings operate at high speeds with very low loads, bearing failures can result from skidding or slippage damage and also lead to NVH issues."

Naturally, these are all issues a maintenance shop will be called on to handle. Some of these failure states aren't usually present in conventional transmissions, but as electrified transmissions work towards becoming the norm, those unique problems will become more and more common thorns in the industry's side — perhaps all the more so during the technology's early years if manufacturers take a bit to get the cage design right.

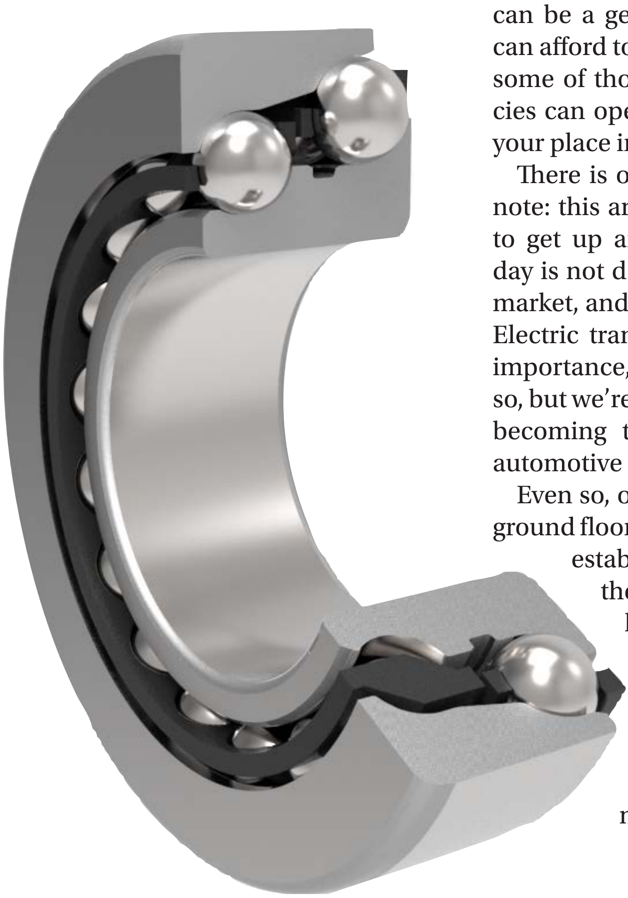
Modi also pointed to a list of skills and knowledge sets that will be important for keeping competitive in the maintenance market in the future, citing "knowledge regarding bearing condition monitoring using vibration analysis, preload adjustment, seal wear and grease leakage, evaluation of mating parts and bearing damage analysis."

For everyone involved, however, there are a few other non-bearing matters you might want to brush up on while you're at it. Most obvious, make sure you understand how electric motors function, why they function the way they do, and their different industrial applications.

Sure, *you* might not make motors personally, but like with everything else in manufacturing, a bearing is only a single component of a much larger system, and how it fits into that larger system is important. Understanding the other components that bearing's going to have to play with can go a long way towards helping design a quality part that will last for years — or, if the worst comes to happen and a part fails, understand what went wrong and why.

For other supplemental skills, Modi pointed to "assessing the needs of condition monitoring, sensor technology, surface treatments and material technology advancements in the bearing industry." While many of these skills might not be necessary to craft a quality bearing, Modi believes that they offer opportunities for value-added integration into electrified powertrains. All those bells and whistles can be a genuine selling point if you can afford to include them, and having some of those extra credit competencies can open new avenues to finding your place in the market.

> "The higher speeds of electric motors can lead to bearing cage failures if it is not designed suitably for the given speeds."



There is one last important thing to note: this article isn't a blaring klaxon to get up and get moving. Judgment day is not dawning on the automotive market, and life will continue to go on. Electric transmissions are growing in importance, and will continue to do so, but we're still years away from them becoming the primary force in the automotive market.

Even so, one can never get in on the ground floor too early when it comes to establishing oneself as a force in the industry, and major shifts like the push for electrification that create new opportunities to do just that don't come every day. Competitiveness is a perpetually moving metric, and right now, that metric is moving in favor of electric-powered drivetrains. And while this isn't a comprehensive checklist of what you'll need to stay competitive in the years to come, it'll hopefully at least do a little to get you thinking about how to move in lockstep with the times. **PTE**

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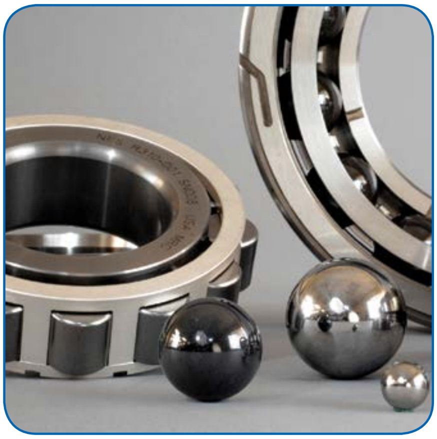

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Keeping Production Running

Cement Backer Board Plant Utilizes Oil Shear Clutch Brake

Stan Porter, Force Control Industries & Jim Wahl, Wahl Marketing Communications

Fin Pan Inc. (Hamilton, Ohio) is an industry leader in the commercial and residential construction products market. They are the oldest process manufacturer of cement backer board, having invented the process in the mid 1970's. In that time the rest of the country has elected 7 presidents, watched 12 Olympics, and crowned 43 different baseball teams as World Champions. At least one thing hasn't changed in the 30-plus years, and that is the oil shear technology that keeps Fin Pan's original cement backer board production line running.

Pioneering the creation of a product is never simple or straightforward. And when you are dealing with a dusty, dirty process like making cement backer board, with a weight of 9.9 pounds per lineal foot in 3-foot wide sections, service life for components used for the forming, moving, cutting and stacking of the finished sheets can be a challenge. Fin Pan Owner and former president Ted Clear was instrumental in the design of the process and specifying the components. He wanted maximum production with minimal downtime, so he turned to Force Control Oil Shear clutch brakes to keep the process going. The fact that this technology is still operating is proof that the oil shear clutch brakes have delivered on Clear's vision.

How the Process Works

Each cement backer board is made on a carrier sheet. These sheets are placed end-to-end on the main conveyor as it is moving, by a Force Control clutch brake which indexes each time the carrier sheets feed onto the main conveyor. This clutch brake is the original Posidyne model 2.5 that has been in service since the line first started, with a single rebuild in 2002.

When the sheets are in line, cement coated fiberglass mesh is placed on top of the carrier sheets. Zero slump lightweight concrete is placed on top of the fiberglass mesh and spread evenly across the width of the boards, 39.37" wide and ¾" deep. A second layer of cement coated fiberglass mesh is placed over the concrete core. A position sensor senses the end of the product and activates the cut-off system. A Posidyne model 03, driven by the conveyer, is engaged to accelerate the cut-off shuttle to match the main conveyor speed.

The cut-off knife then cuts across the product while at line speed — 64–70 feet per minute — to ensure a uniform product size. The continuous line of cement board is then cut into lengths with a cutter and then stacked and placed into a curing rack. The line is capable of producing 27,000–30,000 L.F per day, in an 8-hour shift. Fin Pan produces 4', 5', 64", 6', and 8' lines, with the most common being 5'.

The Success of the Process is On the Line

The motion control components used throughout this intricate process must work together to achieve the desired result. Activating the cutter head without matching the main conveyor line speed will yield off-spec sheets and rejects. Operations manager Mark Drake estimates that the plant makes approximately 5,000 cuts per day in a single shift, or approximately 1.25 million cycles (cuts) annually (5000 cuts/day × 5 days × 50 weeks = 1,250,000).

Wear on the manufacturing line components mainly stems from the abrasiveness of the lightweight concrete. When the Posidyne model 03 clutches have reached the end of their service life they are swapped out and rebuilt at Force Control Industries Inc., which is located literally around the corner. Replacing the clutches requires approximately 2 hours and is accomplished after the shift to eliminate downtime. Originally, the design called for size 02 clutches, which were operated from the early 1980's for about 18 years. At that point they replaced the model 02 with a model 03 to achieve some additional longevity. That seems to have been a good move, as the larger Model 03 has more than tripled the service life.

The clutch brake used to start and stop the main conveyor belt on the

Fin Pan turned to Force Control to keep production of its cement backer boards running effectively (all photos courtesy of Force Control).

forming line is a Posidyne model 2.5 manufactured by Force Control was replaced in 2002, the only record they have of replacing that clutch brake. Assuming 150 cycles per day, 5 days per week and 50 weeks per year, that's an average of 37,500 cycles per year, or 525,000 cycles since it was re-installed, and counting.

Clutch brake on main conveyor line.

How Oil Shear Technology Works

Normal dry clutch brakes employ a sacrificial surface — the brake disc or pad — to engage the load. Having no good way to remove the heat caused from engagement between the disk and plate, this material must absorb the heat. These extremely high temperatures will eventually degrade the friction material. As the friction surface wears away and begins to glaze, the ensuing torque fade causes positioning errors, which then require adjustment or replacement of the friction surface.

Oil-shear technology plays a major role in ensuring that the backer board production line at Fin Pan operates at peak efficiency. A fluid film flows between the friction surfaces, and is compressed as the brake is engaged. The Automatic Transmission Fluid (ATF) particles in shear transmit torque to the other side. This torque transmission causes the stationary surface to turn, bringing it up to the same relative speed as the moving surface. Since most of the work is done by the fluid particles in shear, by the time the surfaces actually meet or "lock up" wear is virtually eliminated.

In addition to transmitting torque, the ATF also helps to dissipate heat, thanks to a patented fluid recirculation system. Along with torque transmission and heat removal, the fluid also serves to continually lubricate all components — thus extending their service

Clutch brake on flying shear.

life. Oil Shear Technology also provides a "cushioned" stop that reduces shock to the drive system—further extending service life. Unlike dry clutch brakes, the totally enclosed oil shear system is impervious to external elements such as wet, dusty or dirty environments, as are common in many manufacturing plants. Since the layer of oil eliminates wear, the Posidyne clutch brake provides a long service life. With elimination of wear comes elimination of adjustment—and increased "uptime" for Fin Pan.

The reliability and durability of oil shear technology helps plants with a critical pathway maintain high production. Oil shear technology has helped Fin Pan's plant maintain production and eliminate downtime. The fact that Posidyne clutch brakes have operated for so long with no maintenance and no adjustment is testament to Ted Clear's vision of production components with a long service life. Clearly Oil Shear technology has cemented its place in this active backer board plant. **PTE**

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Another look at the clutch brake on flying shear.

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Planning Ahead

Navigating Clutch/Brake Operation in Harsh Environmental Conditions

Matthew Jaster, Senior Editor

The new construction series of Mayr EAS-HT High-Torque Element Clutches convinces through its improved performance density and also stands for a substantially wider selection of possible bores.

Chemicals, saltwater, food particles, heat, dust, and electrical corrosion are just a few of the many issues that can cause clutches and brakes to fail prematurely. Nobody wants to have the conversation about lost production time, growing cost concerns, or system disruptions *after* a failure has occurred. The strength of these components is in the information collected over years of service in hazardous environments and applying this knowledge to future clutch/brake technologies.

Think About the Future

Mechanical engineers have spent careers planning for system failures. They tweak, upgrade, refurbish, and redesign mechanical systems until they get it just right for the environment in question—and then something else fails (too much exposure to heat or a contaminate, for example). Perhaps it's simply a liquid getting in the wrong place. When planning to run mechanical systems in these environments, start with the basics.

As a starting point, customers should consider exposure of the friction facings to damaging contamination.

"Damage at the friction faces can disable a unit immediately," said Greg Cober, training manager, Altra Industrial Motion. "Other issues to be concerned with are exposure of electrical connections to liquids or exposure of bearings to high pressure washdown. If customer's can keep friction faces clean and dry that will help them to achieve design life. Sometimes a simple shroud is sufficient, but in other cases use of an enclosed design is appropriate."

For the most part, electromagnetic clutches do not require maintenance since the armatures and rotors are designed to run as a set pair throughout the life of the clutch or brake.

The three top factors Ogura considers for harsh environments are external heat, heavy vibration, and exposure to oil or grease.

"So, 'harsh' for *us* means an abnormally difficult environment, such as potential for contamination/corrosion and/or heat which is the enemy for most clutches and brakes. For electromagnetic units, the best prevention is to keep chemicals or other corrosives away from the clutch and to make sure it is not exposed to a high external heat source," said Brian Mather, industrial products manager at Ogura Industrial Corp.

Clutch/Brake Considerations

Cober believes three factors to consider when installing these components in harsh environments are (1) exposure to lubricants that might damage the coefficient of friction at the friction faces, (2) exposure of friction faces to abrasive contaminants, and (3) exposure to chemicals or liquids that might affect electrical connections.

For a company like Ogura, the best thing to know when clutches or brakes are becoming worn would be simple cycle monitors.

"Every time a clutch or brake engages, wear occurs between the faces. Depending upon the inertia and the speed of engagement, we can calculate how much wear occurs. That wear rate can then be calculated into a cycle rate, so if we know the cycles that are on a clutch or brake, we know that it is coming to the end of its projected

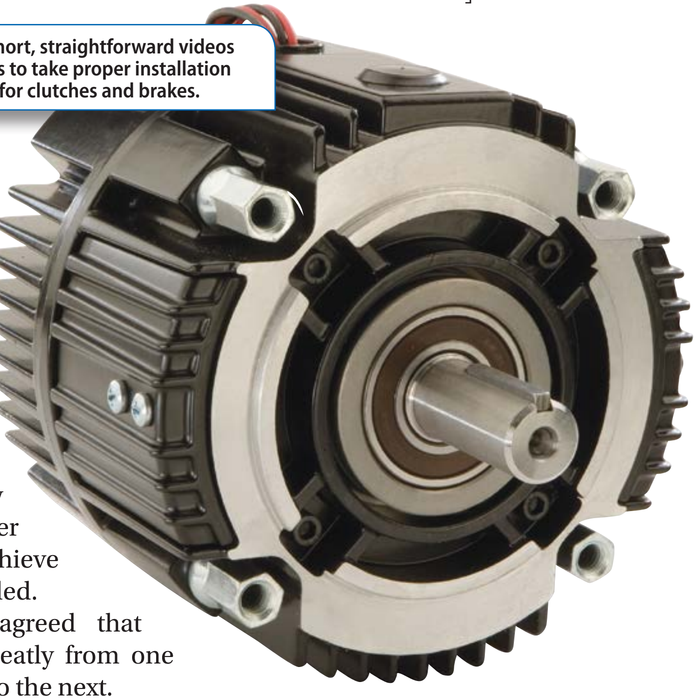
life. In this way, a maintenance person can then replace a clutch or brake prior to having a complete failure to engage," Mather said.

A key step in this process is working closely with the OEM on a preventative maintenance plan.

"Any time there is a failure at a customer, the clutch or brake is either sent back to their facility and reviewed there or sent directly back to our main facility and reviewed by our service department. We do a no charge analysis for each return and explain to the customer what failed and why we think it failed. This allows our OEM's to make changes to their equipment to prevent future failures and to reduce their overall maintenance, warranty and service costs," Mather said.

Operating Challenges

The operating challenges in these environments greatly depend upon the application itself. Just like bearings or gears, improper installation is a major operating challenge that can alter the performance of a clutch and/or brake.



Warner Electric has created short, straightforward videos that can enable new installers to take proper installation steps to achieve best results for clutches and brakes.

"Improper installation is definitely one of the major challenges that result in poor clutch/brake performance. To address this, Warner Electric has created short, straight forward videos that can enable new installers to take proper installation steps to achieve best results," Cober added.

Mather at Ogura agreed that the challenges vary greatly from one industrial application to the next.

"For example, you may have a micro clutch operating in a network printer that can be exposed to toner (a potential contaminant) and heat from motors, but in an outdoor application like a stump grinder where the clutch is mounted directly on the engine shaft, you have heat and vibration from the engine to contend with as well as water and dirt," Mather said. "So, in our products, we have to modify them to meet those environments. With the micro clutches and printers, we can create shielded armatures that prevent toner getting in between the clutch faces and causing the clutch to slip. In outdoor environments, we remove friction material from the clutches so it is a steel-on-steel engagement. Also, we epoxy protect the electric coil which helps not only prevent water contamination, but also keeps the coil seated in heavy vibration."

Another challenge is keeping up with technological demands of automation. The degree of automation is increasing as humans and robots are cooperating more closely together on the factory floor. Therefore, machines and systems are increasing in performance density as well as operating speed which translates to higher demands on individual components.

Mayr Power Transmission displayed small, high-performance safety brakes like the ROBA-ServoStop construction series recently during Hannover Messe. These brakes are tailored to robotic requirements through their slim design and low weight. In addition, the company has a fluid-free linear brake in its portfolio with its ROBA-LinearStop in electromagnetic design, which has been designed to secure gravity-loaded vertical axes. These brakes are used in applications in which compressors or units for compressed air or oil hydraulics are not available or are unwanted, such as in medical technology or the food or pharmaceutical industry, where high hygiene standards are required.

The Mayr ROBA-Brake-Checker module also opens up new possibilities for brake monitoring in these application fields. With a new module design and thanks to even more accurate evaluation, it is now possible to also supply and monitor small brake sizes from a braking torque of 0.7 Nm.

The Environmental Aspect

Custom-made components play a pivotal role in places where the environment can cause potential failures.

Any wet environment, for example, is a challenge for friction clutches and brakes, according to Lesli Riehemann, president at Mach III.

"A wet friction disc can swell, taking up clearances and preventing proper clutch or brake function. Mach III regularly addresses the potential for fluid contamination through designing custom products with enclosed and sealed housings. An example is a slip clutch which was developed for a food processing application. Used on a machine which produces beef jerky, it is washed-down daily. In addition to being fully enclosed and sealed with O-rings, all exposed components are made from stainless steel to prevent corrosion."

Riehemann said another cause for concern is particulate contamination.

"This can also be a problem since it causes premature wear of seals and friction materials, and if abundant, can take up clearances. In dusty environments, we often make a minor modification of a catalog design to incorporate a cover. Our combination clutch-brake is a good example of this. Both the catalog model and the modified version are shown in the photo. In this case, we simply increased the outside diameter of the cylinder and machined it to cover the open portion of the clutch-brake," Riehemann said.

Smart solutions, (clutches and brakes with condition monitoring capabilities) can offer advantages

In dusty environments, Mach III offers a cover modification by increasing the outside diameter of the cylinder and machining it to cover the open portion of the clutch-brake.

regarding temperature, wear and condition of the component in question.

The intelligent Mayr ROBA-Brake-Checker module, for example, works without the use of sensors. Instead, it detects the movements of the armature disk by analyzing voltage and current, and knows what condition the brake is in at all times. In addition to switching condition, temperature and wear, it also monitors the tension path or tensile force reserve, i.e. whether the magnet is still able to attract the armature disk.

The module represents a cost-effective solution, especially for small quantities. The fact that brakes in standard design are used for monitoring with the ROBA-Brake-Checker not only offers advantages in terms of costs and delivery time, but also for example with regard to corrosion protection as the brakes can be painted over easily, quickly and safely — for example, if the corrosion risk is very high and protective measures are required in compliance with the DIN EN ISO 12944 standard Protective Measures (C5), for example on wind power plants or on applications in the maritime sector.

Cober discussed three specific areas that might be considered harsh for clutches and brakes.

Areas where units are exposed to lubricants either as a mist or as the result of spatter from roller chain or leaks from damaged gearbox seals. Metal bending, forming or die cutting processes often require lubricants to facilitate their processes. Many conveyors use roller chain drives connected to clutch/brakes and lubricant from chain can migrate from the chain onto the friction faces of clutch/brakes.

A second would be environments with high levels of ambient contamination such as grit or dust that might be found in a foundry or mine, according to Cober. This contamination might serve to increase wear rates on clutch/brakes in foundries and mills that are used primarily in conveying processes.

“Lastly, high moisture that can damage friction faces or creates corrosion at electrical connections. High moisture levels are not uncommon in food processing facilities where washdowns are a routine part of their process. Industrial product cleaning and degreasing can also negatively impact clutch/brakes used on conveyor drives,” Cober said.

Mather at Ogura returned to the topic of heat when discussing challenges for


For Ogura electromagnetic units the best prevention is to keep chemicals or other corrosives away from the clutch and to make sure it is not exposed to a high external heat source.

clutches and brakes.

"Heat is the main one because every time a clutch or brake engages, it generates heat. That heat has to be dissipated. If too many cycles occur, a clutch or brake cannot dissipate the heat properly and will then burn up. Also, with electromagnetic clutches, if a constant current power supply is not used, then flux can degrade as temperature increases. It is therefore important to keep environmental heat away from a clutch or brake to also help it maintain maximum torque," Mather added.

Another area Mather notes as a concern is the effect that vibration has on the bearings in clutches (most brakes do not contain bearings).

"In some applications, there can be long periods of time where there is no rotation between bearing rings. If this happens under heavy vibration, false brinelling can occur in the bearing races, which over time will cause grooves and cause the bearings to be noisy," Mather said.

"The industries that cause us the most challenges are anywhere a clutch is mounted directly on an engine shaft. In an outdoor power equipment application, any or all of the above can occur. We have made adaptations to handle many of these, but it is still much more challenging than putting a clutch on a piece of office equipment," he added.

Future Tech

Mather said that advances in electrical controls will continue to help make electromagnetic clutches or brakes better.

"In recent years, we have utilized a soft start control that helps clutches engage more smoothly, reducing initial shock. This helps reduce the shock of other components like drive belts in our customers machines and in some cases, has doubled the life of the belts," Mather said. "We are also working on controls that integrate a slip detector which will tell the clutch or brake that it is slipping in excess which will prevent it from burning out, saving the customer downtime and replacement costs."

In addition to safety brakes and the associated control and monitoring modules, Mayr has for decades developed and manufactured its tried and tested torque limiters and shaft couplings, and represents reliable complete solutions from a single source. Products such as the new construction series of EAS-HT High-Torque Element Clutches or EAS-Compact Overload Clutches cater to the increasing demands put on speed and dynamics. Future production procedures will ensure favorable prices and shorter lead times.

"There has also been some migration from roller chain to synchronous belt drives in recent years. Since this eliminates a source of contamination by lubricants (chain needs to be lubricated, belts do not) it eliminates a source of failure," Cober said. "In mobile applications there has been a trend of OEMs requesting that Warner Electric create and deliver completely assembled product solutions, where in the past the OEMs did much of the assembly integration."

The more control you have of the system, the more knowledge you have of how the components will operate under different environmental conditions. **PTE**

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Deep-Sea Microbe Research

Faulhaber motors help seek climate answers in deep-sea trenches

The project team developed robots that independently descend to the sea floor and then carry out preprogrammed studies.

Mars is many million kilometers away from Earth. And yet its surface is better studied than the floors of the deep-sea trenches, which lie only eight to eleven kilometers below the sea surface. The biological and chemical processes that transpire there are, in fact, still largely unknown. A research project, appropriately named "Hades-ERC," is aiming to change this and supply completely new insights into the depths of the oceans. It was initiated by Professor Ronnie Glud from the University of South Denmark in Odense.

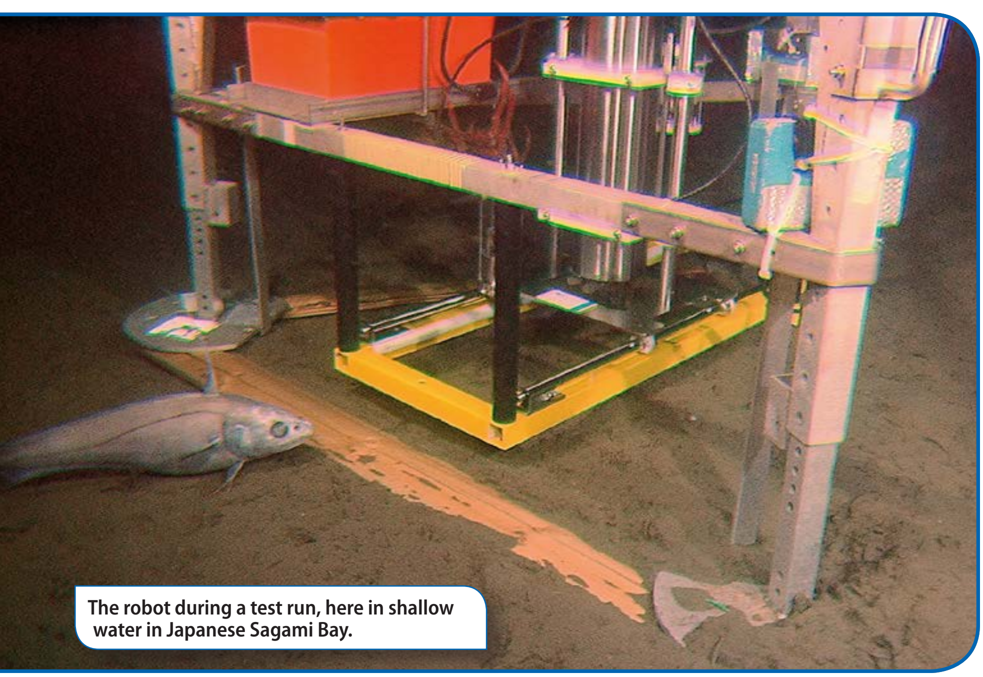
"In marine biology, there is actually a simple basic rule," Glud said. "The deeper you go, the less life one finds." Because with increasing depth, it becomes colder and darker. Less of the food produced in near surface water reach the great depths. Moreover, the water pressure increases by 1 bar every ten meters. At a depth of 10,000 meters, the pressure of approximately 1,000 bar is a thousand times higher than on the ocean shore. "But gravity exerts its effects even in this environment. A portion of the organic material that sinks to the deep ocean floor ultimately lands in the trenches, where it collects," Glud added.

Collection basin for organic material

Thus, it was no surprise to Professor Glud as he found highly active microbial communities at a depth of nearly eleven kilometers back in 2013. At that time, he had descended the instruments into the Mariana Trench in the Western Pacific.

"We found more organic matter at depths below 10,000 meters than at 6,000 meters," the marine researcher explained. "We therefore assume that the trenches have a disproportionately high influence on the nitrogen and carbon balance of the seas. Although they account for only two percent of the ocean area, they could have a disproportionately high effect on the carbon footprint and climatic occurrences."

The Hades-ERC project aims to — literally — get to the bottom of such questions and enable better understanding of the processes in the trenches. It is financed by the European Research Council, which belongs to the EU. A so-called Advanced Grant totaling 2.5 million euros allows the scientists to conduct long-term, open-ended basic research. In addition to Glud's department in Odense, marine biologists at the University of Copenhagen as well as marine research institutes from Germany, Japan and Scotland are involved. The sophisticated instrumentation is developed as a joint venture between the team in Odense and a German team headed by Dr. Frank



The robot during a test run, here in shallow water in Japanese Sagami Bay.

Wenzhoefer that is based at the Max Planck Institute in Bremen. The project is scheduled to last five years. The studies began last autumn in three Pacific trenches — the Japan Trench, the Atacama Trench and the Kermadec Trench — at depths between 8,100 and 10,900 meters. These formations were selected because the organic load in the waters above them is much different. They therefore offer their microbial inhabitants widely varying conditions.

Robots instead of submarines

While manned dives have already taken place to such depths, the use of submarines would not be practical for extensive research of bottom sediment. The project team therefore developed robots that independently descend to the sea floor and then carry out preprogrammed studies. They are equipped with sensors which, among other things, can measure the oxygen intake of the bacteria — a value from which one can make deductions on the quantity of the processed organic material. Other sensors help answer the question of whether deep-sea microbes breathe oxygen, nitrate or sulfate.

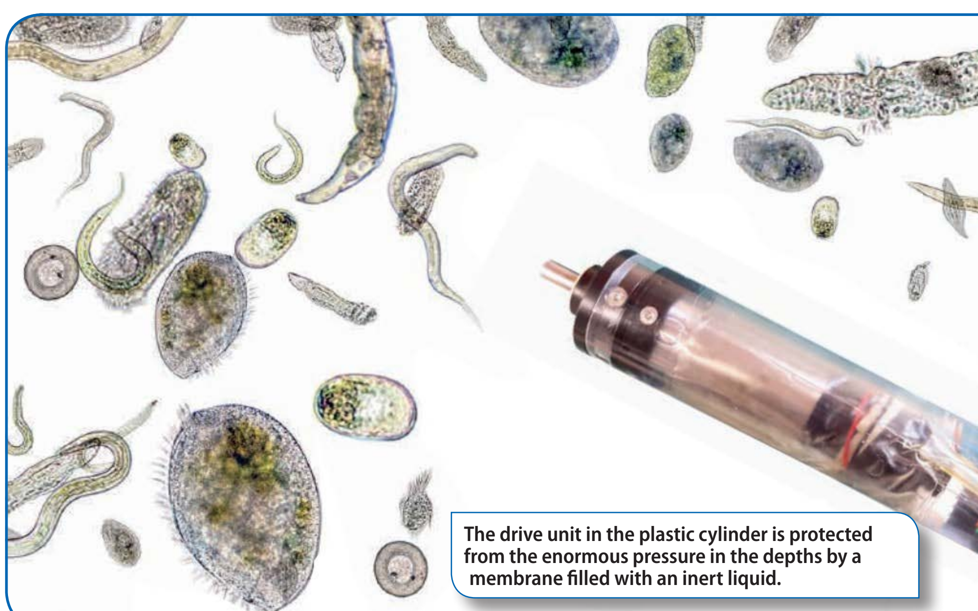
"To survive under the extreme conditions of the deep sea, the bacteria must be much different than their relatives in shallower waters," Glud said. "For example, their membranes and enzymes must function in a completely different way. How exactly, that's what we want to learn."

It is a special challenge to study the microbes themselves. Because they have adapted to an environment with enormous water pressure, they cannot simply be brought to the surface. They would turn into a "soup" on the way up, as the Danish researcher illustratively describes. The Hades-ERC robots are, therefore, provided with equipment that can inject a fixing agent into the sediment, which keeps the microorganisms intact during recovery.

Prerequisite: pressure resistance

While the microbes need to be protected from the decreasing pressure as they are brought to the surface, special precautions must be taken for the equipment in the robots to protect them from the extreme pressure in the trenches. The sensors as well as the tools for handling the sediment are specially equipped for this environment and can withstand the pressure. To perform their work, they do, however, need to come into contact with the sediment and must be moved into various positions.

Responsible for this movement are DC-micromotors from Faulhaber, provided with encoder and the



The drive unit in the plastic cylinder is protected from the enormous pressure in the depths by a membrane filled with an inert liquid.

appropriate planetary gearheads. While some components are housed in a pressure stable titanium cylinder, some devices like the motors and gearboxes can only perform their work when in contact with the surroundings that are to be studied.

"We therefore inserted these components into another cylinder in a small flexible membrane which is filled with an inert fluid," Glud explained. "The membrane ensures that the water pressure effects the enclosed components without a pressure difference occurring. Because this would crush the motors."

In an earlier version of the robot, various motors were still used for the different tasks. In practical tests, the team has come to the conclusion that it makes more sense to work with just a single, especially robust motor type.

"The robot remains at its operation site for many hours before returning to the surface with the samples. During this time, it operates completely autonomously," Glud said. "Our success is dependent on — among other things — the flawless function of the devices during this time. Thus, the motor needs to be extremely reliable, compact and strong. The model from Faulhaber has proven outstanding in the depths and is ideally suited for use under these extreme conditions." **PTE**

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Experimental Determination of Oil Rheology Parameters to be Implemented in Power Loss Predictions of Gears and Rolling Element Bearings

E. Athanasopoulos and A. Mihailidis

Introduction

Rheology models express the way tribological conditions translate to shear stress of the lubricant and friction force on the interacting surfaces. Due to the complexity of the lubricant rheology, the friction coefficient is usually obtained experimentally either under the same operating conditions or by curve fitting in a properly chosen friction map. The current study aims at determining the rheological parameters of a lubricant based on friction measurements carried out on a commercial, readily available ball-on-disc machine. They can then be implemented in power loss prediction methods that utilize state of the art thermo-elastohydrodynamic numerical models considering the non-Newtonian lubricant behaviour and the dependency on pressure and temperature of the lubricant properties.

Lubricants are commonly macro-molecular chains that behave like polymers in elastohydrodynamic lubrication. These chains follow a Newtonian linear law during steady state or shear rates close to zero. However, they deviate greatly under conditions of high pressure and high shear rate such as those in a typical gear mesh or a rolling element bearing. Under those conditions, the maximum friction typically peaks and reaches a plateau at around 0.08, far less compared to that a linear law would predict. Evans and Johnson (Ref. 1) using the extended rheology equation by Johnson and Tevaarwerk (Ref. 2) classified the behavior of the lubricant into four distinct regions, which indicate if it stems from the non-linear viscous or linear-elastic regime. The classification is based on the Deborah number defined as the ratio of the relaxation time of the lubricant to the time needed to pass through the contact. When it becomes greater than unity, which is typical for EHD contacts, the traction curve (friction coefficient over slide-to-roll ratio) is linear-elastic at first and then non-linear with a potential peak. The extended rheology equation uses a hyperbolic sinus function which is attributed to the studies of Eyring (Ref. 3) on polymers. The *sinh()* function is used to model the thermal activation theory of a molecule which defines the amount of work a molecule must perform to jump from an energy well to the next.

This aspect is known to be affected by both temperature and pressure and hence it is reasonable to expect a similar dependence in lubricants as well. Indeed, there are many different models proposed, such as those by Johnson and Tevaarwerk (Ref. 2), Houpert et al (Ref. 4), and Mihailidis and Panagiotidis (Ref. 5). Some contain both parameters while others omit temperature in favour of a simpler formulation.

Friction would still rise with the increase of shear rate even if the thermal influence on viscosity were negligible, due to the term. Limiting shear stress introduces a threshold to the maximum shear stress that a material could sustain before actually deforming as a "plastic" one. The theory was first proposed in 1960 by Smith (Ref. 6), although hinted in a previous work of Petrusevich in 1951 (Ref. 7). The flow mechanism of thermally activated zones and viscous flow has been shown in polymers to give its place to a different one in shear stress above $G/30$, where G is the shear modulus. The new mechanism is the formation of a shear band. A straightforward separation of the thermal effects due to shearing is almost impossible (Johnson and Greenwood (Ref. 8)). Experiments by Bair and Winer (Ref. 9) in low shear rates but very high pressures in an isothermal disc machine showed a clear and distinct maximum of the friction coefficient indicating a limiting shear stress. Further calculations and later microflow images of shear bands have been presented by Bair (Ref. 10). On the other hand, there have been additional phenomena observed, such as wall slip — especially in dissimilar, interfacing materials (Guo et al (Ref. 11)) that may also contribute to the reduction of the friction. Despite that, in steel on steel friction these phenomena have been only observed under extreme sliding, thus the limiting shear stress can arguably be considered the most probable explanation.

Various models for implementing in simulation the theory of the limiting shear stress have been proposed. Initially, Bair (Ref. 12) attempted an analytic approach in order to develop a parameter that would contain physical properties such as bond strength of the molecular structure. The calculation of such parameter is quite difficult and in practice it was experimentally obtained. In fact, this is an issue, since the temperature effect on the oil viscosity under high pressure is very difficult to isolate and calculate outside of an EHL contact. The second issue relates to the fact that an EHL contact is not at constant pressure overall, which in turn means that the total friction force is a sum over the contact area that includes both thermally activated zones and shear bands. Temperature and pressure have a strong impact on the shear band formation by affecting the shear modulus. Houpert (Ref. 4) presented in his dissertation an exponential model concerning the effect of temperature on the limiting shear stress. Wang and Zhang in 1987 (Ref. 13) also utilized an exponential law, which was later modified by Hsiao and Hamrock in 1992

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(Ref. 14). Roshetov and Gryazon, as mentioned by Wikström and Höglund (Ref. 15), presented an equation that includes first degree factors concerning pressure and temperature, which are multiplied. Kleemola and Lehtovaara in 2008 (Ref. 16) presented two models, a simplified and a more complex multi-parametric one including both second order and exponential laws. The present study incorporates a simple relationship to model the influence of temperature and pressure without exponential function that could generate instability in a solver.

The present study describes an experimental-analytical procedure that has been developed, in order determine the Eyring stress and the limiting shear stress of a given oil as functions of temperature and pressure. Special care has been taken to use commercially available equipment and standard experimental procedures. These data could then be used as input to any EHL model that would require them in order to calculate the friction coefficient accurately. As an example, the rheological parameters of the FVA (Forschungsvereinigung Antriebstechnik) reference oil Nr. 4 are determined.

Rheology Parameter Extraction Workflow

The lubricant rheology can be described using two equations.

- General rheology (Eyring) equation that requires two additional models
  - $\tau_E(p, T)$ Eyring stress
  - $\tau_L(p, T)$ Limiting shear stress
- Lubricant viscosity $\eta(p, T)$

The general rheology equation (Eq. 1) incorporates two terms — the linear-elastic and the non-linear viscous.

$$\dot{\gamma} = \dot{\gamma}_e + \dot{\gamma}_v = \frac{1}{G}\frac{d\tau}{dt} + \frac{\tau_E}{\eta} sinh\left(\frac{\tau}{\tau_E}\right) \quad (1)$$

For the EHD contacts considered, such as those found in gears and rolling element bearings the first term of Equation 1 can be neglected (Ref. 1).

The Eyring stress included in the above equation is affected by pressure and temperature. Many models have been proposed (Table 1).

Table 1 Eyring stress models including temperature and pressure effects

Johnson & Tevaarwerk	$\tau_E(p) = \tau_{E0}(1 + a_\tau p)$	(2)
Houpert et al	$\tau_E(p, T) = (a_\tau p + \tau_{E0}) e^{\beta_\tau\left(\frac{1}{T} - \frac{1}{T_o}\right)}$	(3)
Mihailidis & Panagiotidis	$\tau_E(p, T) = \tau_{E0}(1 + a_\tau p)(1 + \beta_\tau(T - T_0))$	(4)
Present study	$\tau_E(p, T) = \tau_{E0}(1 + a_\tau p) + (\beta_\tau(T - T_0))$	(5)

Equation 1 is valid up to the shear rate, where the limiting shear stress is reached. It is also a function of temperature and pressure, for which the models in Table 2 have been proposed.

Table 2 Limiting shear stress models, including temperature and pressure effects

Bair	$\tau_L(p) = \Lambda p$	(6)
Johnson & Tevaarwerk	$\tau_L(p) = c_0 + c_1 p$	(7)
Houpert	$\tau_L(p, T) = \tau_{L0} \exp\left(a_{\tau L} p + \beta_{\tau L}\left(\frac{1}{T} - \frac{1}{T_o}\right)\right)$	(8)
Houpert et al	$\tau_L(p, T) = (0.015p - 1.88 * 10^{-3}) e^{\left[585\left(\frac{1}{T_m + 273} - \frac{1}{+313}\right)\right]}$	(9)
Hsiao & Hamrock	$\tau_L(p, T_m) = \tau_0 E' + \gamma p) e^{\left[B\left(\frac{1}{T_m + 273} - \frac{1}{T_0 + 273}\right)\right]}$	(10)
Bair	$\tau_L(p) = c_1 p(1 + \beta_{\tau L}(T - T_0))$	(11)
Zhang & Wen	$\tau_L(p) = \begin{cases} \tau_{L0} & p < p_s \\ \tau_{L0} + a_{\tau L}(p - p_s) & p > p_s \end{cases}$	(12)
Kleemola & Lehtovaara	$\tau_L(p) = c_1 p + c_2 p^2$	(13)
Kleemola & Lehtovaara	$\tau_L(p, T) = (\tau_0 + \alpha_1 p + \alpha_2 p^2)(\alpha_3 - (\alpha_4(T - T_0)^{\alpha_5}))$	(14)
Lohner et al	$\tau_L(p, T, v_\Sigma) = \frac{4}{\pi}\left(a_1 p_m + a_2 + a_3 \lambda n\left(v_\Sigma * 1\frac{s}{m}\right) + a_4 T_0\right) \sinh\left(\frac{T_0}{T}\right)$	(15)
Present study	$\tau_L(p, T) = (c_1 p + c_2 p^2)(1 + \beta_{\tau L}(T - T_0))$	(16)

The present study proposes the use of the models described by Equations 5 and 16. Equation 5 is proposed since, disassociating the pressure from the temperature influence, results in a more gradual increase of the Eyring stress closer to that observed by Johnson and Tevaarwerk (Ref. 2) and the findings of the present study as well. The use of Equation 16 is proposed due to the observed measurements and the need for a simpler model.

The workflow presented will lead to the calculation of 6 parameters, i.e. — 3 for each of these equations.

Calculating the correct Eyring stress depends on having a correct estimation of the viscosity. According to Evans and Johnson (Ref. 1), using the rheology law, the oil viscosity values could also be obtained if the Eyring stress is known. In reality, the Eyring stress is not known while viscosity may be known within a rather limited pressure and temperature range. For each experiment, an Eyring stress and a viscosity value can be actually determined by fitting the rheology law in the region where the lubricant behavior is non-Newtonian. This is observed as a straight line in semi-log plot of the friction coefficient over the shear rate. The viscosity value at the mean pressure calculated according to a viscosity model can also be used and compared. Comparing the four most commonly used viscosity equations (Roeland (Ref. 17), Rodermund (Ref. 18), Doolittle (Ref. 19) and Shilling (Ref. 20)) showed huge differences in the predicted viscosity. This issue arises because the parameters are estimated from measurements under 200 MPa and extrapolated to 1 GPa. Using the rheology law to estimate the viscosity at higher pressure and comparing the values to those extrapolated from measured viscosity data at pressures less than 200 MPa showed that, the best fit was given by the equations of Roeland (17) and Rodermund (18), the latter of which is used in the current study (Eq. 17).

$$\eta(p, T) = \mathrm{A} * \exp\left(\frac{\mathrm{B}}{T + C - 273}\left(1 + \frac{p}{2 \cdot 10^8}\right)^{\mathrm{D} + \mathrm{E}\frac{\mathrm{B}}{T + C - 273}}\right) \quad (17)$$

where:

$\eta\left[\frac{N}{ms}\right]$: viscosity; $T[K]$: temperature; $p[Pa]$. pressure and

$\mathrm{A}\left[\frac{N}{ms}\right]$; B[K]; C[K]; D[–]; E[–]: parameters

The extraction workflow proposed is composed of four steps. Firstly, the experimental conditions have to be identified for nine experiments. Secondly, the conditions selected are run in a suitable ball on disc machine capable of as close as possible to isothermal testing. Thirdly, the calculation algorithm for the Eyring stress at each test point is performed. Finally, using these values, the parameters for the models of τ_0 and τ_L are extracted. These steps have to be performed once for the Eyring equation (Eq. 7) and once for the limiting shear stress (Eq. 16). Ideal selection of the test conditions can allow for the process to be run only once.

Experimental conditions and test rig. The Eyring stress is extracted from friction measurements. But, utilizing measured friction coefficient values to extract parameters that will be later used in EHL models to calculate the friction coefficient may result in a logical loop, which must be avoided. The present work does so by discarding the experiments included in the workflow of parameter extraction from any further validation or comparison. Only significantly different conditions or different test rigs, contact geometries etc. can be examined and simulated for validation of the previously obtained parameters.

In a ball-on-disc machine, the shear heating can be limited by setting the rolling speed and the normal force low. Provided that the geometry of the specimens is properly chosen, the contact pressure can be sufficiently high. In this way, quasi isothermal test conditions are maintained enabling thus the calculation of the Eyring stress.

The first step of the workflow is to determine the experimental conditions. The calculation process requires a set of nine traction curves which are spread across a typical temperature range such as 50 to 110°C, and across a pressure range within the specifications of the test rig — typically 0.5 to 1.25 GPa. The maximum-selectable temperature and pressure depends on the viscosity of the lubricant under evaluation and the calculated central film thickness. The method is limited to pure EHL under fully flooded conditions, since no surface interaction is considered. After an evaluation of the three most commonly used film thickness equations (Hamrock et al (Ref. 21), Chittenden (Ref. 22), Moes (Ref. 23)) and tests on an EHD2 (*The EHD2 machine is a ball-on-disc machine that utilizes a semi-transparent chrome-coated glass disc allowing optical interferometer measurements.*) machine (Fig. 1), the first two provided the best approximation for circular contacts when multiplied by the thermal parameter C_t, introduced by Gupta et al (Ref. 24). As the conditions used for the parameter extraction, the experiments are quasi-isothermal and, therefore, the equation of Hamrock et al (Eq. 18) provides sufficient accuracy without the thermal parameter

$$H_c = \frac{h_c}{R_x} = 2.69U^{0.67}G^{0.53}W^{-0.067}\left(1-0.61e^{-0.73\mathrm{k}}\right) \tag{18}$$

where

$$W=\frac{F_N}{E'R_x^2};\ U=\frac{\eta_0 V_x}{E'R_x};\ H=\frac{h}{R_x};\ G=aE';\ \mathrm{k}=\left(\frac{R_y}{R_x}\right)^{\frac{2}{\pi}} \text{and } V_x=\frac{V_{x1}+V_{x2}}{2}$$

The selected slide-to-roll-ratio (SRR) range should contain all three regimes of a traction curve. Typically, a maximum value 50% should be sufficient as to not increase the temperature significantly or risk mixed lubrication occurring. The required number of SRR settings should be quite dense near the low values, with roughly 30 points being sufficient to cover the whole range. The rolling speed selection requires calculation of the maximum temperature increase (at the contact to ensure that, it is less than +2 degrees. Calculating the limiting shear stress is not straightforward because the tests where the limit is reached must be identified first. In order to observe any limit occurring, higher pressures and speeds may be required. It is possible, that certain high viscosity oils may prove difficult to attain this condition without significant shear heating. Ideally, a clear maximum is needed at a rather low slide to roll ratio (or slip). Values in the range of 0.5 to 2 m/s for lubricants with ISO VG 460 to 100 may be used. Using the previous calculations, 9 condition sets for temperature, pressure and a common speed for calculating the Eyring stress model parameters, as well as another nine conditions sets for the limiting shear stress evaluations are defined. Repeat experiments may be run to verify the error margin, but generally for fully flooded EHL conditions it is low.

Eyring stress. Having experimentally obtained the friction coefficient vs. SRR curves for the selected conditions, the parameters for the Eyring stress equations are extracted in an automated way using software developed in the L.M.E.M.D (*Laboratory of Machine Elements and Machine Design, Aristotle University of Thessaloniki*). The algorithm is presented below.

At first, for each experimental point, the mean film thickness and the resulting mean shear rate are calculated using Eq. 19.

$$\dot{\gamma}_m = \frac{V_{x1}-V_{x2}}{h_m}, \text{ where } h_m \approx h_m \tag{19}$$

Then, for each given set of experimental conditions, namely temperature and mean pressure, the resulting friction coefficient versus mean shear rate diagram is considered. In a semi-logarithmic plot, such as the one shown (Fig. 2), it is typically composed of three discrete sections: an initial almost flat section, a second quite pronounced linear with a constant slope and a final third non-linear that has varying slope as the shear rate increases. The second linear section is used to calculate the Eyring stress by numerically solving the following equation:

$$\dot{\gamma}_m = \frac{\tau_E}{\eta_{p_m}} \sinh \frac{\mu p_m}{\tau_E} \tag{20}$$

It is derived from the general rheology equation (Eq. 1) when the linear-elastic term is neglected and the shear stress τ

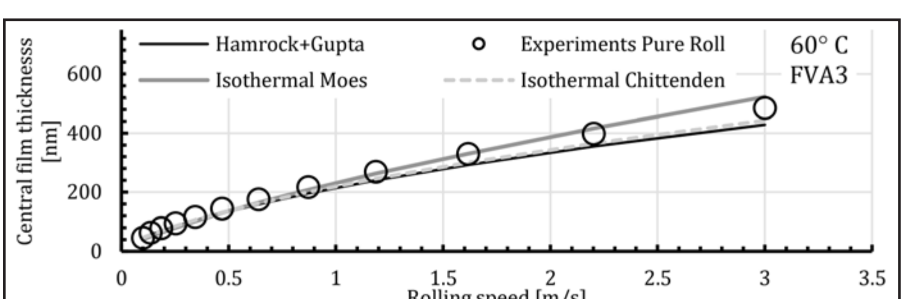

Figure 1 Comparison of the calculated and measured central film thickness.

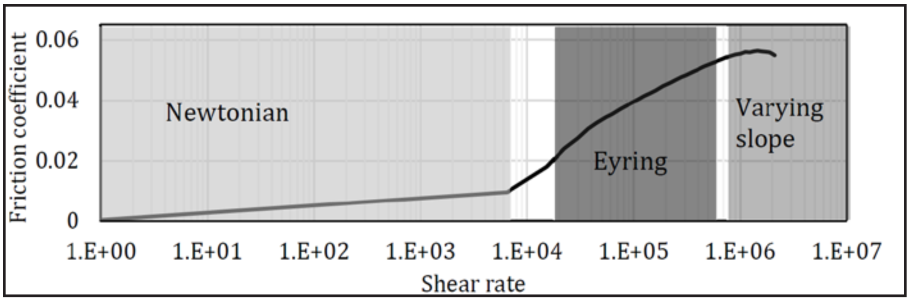

Figure 2 Coefficient of friction on a semi-logarithmic diagram versus shear rate presenting three main sections.

substituted by μp_m. For convenience, the following form of Eq. 20 can be used with sufficient accuracy, which results by expanding the *sinh()* function in Taylor series:

$$\frac{\tau_m}{p_m}\ln\left(\dot{\gamma}_m\frac{\eta_{pm}}{\tau_E}+\sqrt{\left(\dot{\gamma}_m\frac{\eta_{pm}}{\tau_E}\right)^2+1}\right)=\mu \tag{21}$$

Finally, the parameters of Equation 5 are calculated by using the resulting Eyring stress of all testing conditions.

Limiting shear stress. The point, where the maximum friction occurs is used to determine the limiting shear stress under the corresponding temperature and pressure.

$$\tau_L=\mu_{max}p_m \tag{22}$$

Then the parameters of Equation 16 are obtained by curve fitting to the limiting stress values obtained from all testing conditions.

This is an approximation, since the measured friction coefficient is mainly a result of the shear stress created in the high-pressure area of the contact where the oil has reached its shear stress limit. The contact area encompasses some very low pressures near the edge, that do not contribute significantly to the shear stress or the mean pressure integral.

If a clear maximum is not obtainable under the selected conditions, higher pressures may be required resulting in a exceeding 2 degrees. In such case, the limiting shear stress is assumed at the mean contact temperature.

EHL Model

Aiming to compare the measured friction coefficient against calculated values, an EHL model is used (Mihailidis et al (Ref. 25)). It combines non-Newtonian lubricant behavior, thermal effects, as well as the influence of pressure and temperature on the thermal properties of the lubricant. The solution is performed in a multi-grid multi-level manner. For the present study the local EHL pressure spike is of small interest so the starting grid is limited to 25 × 25 nodes symmetrical around the oil entrainment axis, and the depth is limited to 3 levels resulting into a 100 × 100 fine mesh grid. A line relaxation of the Reynolds equation is used, while the convergence criteria are limited to 6e-4 for the pressure and 2e-3 for the temperature. The solution space is limited from -3.5 to 2.5 in the X axis, and -2.5 to 2.5 for the Y axis. The temperature field in the Z axis is composed of 9 nodes in the film equally spaced, and 5 nodes in the contacting surfaces with a geometrically increased spacing where the first two nodes are spaced equally to those in the film for convergence reasons. The numerical solution of EHL requires adjustment of solution process due to abrupt changes in pressure as well as due to the mutual dependence of oil characteristics on temperature and pressure. The initial film thickness estimation plays an important role in the convergence. The selection of its value is based on the equations of Kudish (Ref. 26). The use of the limiting shear stress model creates a nonlinear abrupt change in the behavior of the film. The method for stabilizing the solution is to limit the initial pressure converge cycle to 1 loop and allow the thermal convergence to be reached. The pressure loop begins by assuming a Hertzian distribution of the pressure and adjusts it. Additionally, a limit of the maximum pressure that can be present at a grid point limits the effects of single point singularity occurring due to grid size. In cases with very high film thickness, the relaxation factor of the film height is reduced below 1E-2 even down to 1E-4. This increases the number of loops but significantly improves stability.

Results

The proposed methodology is developed to extract the parameters for the relationships and of a non-Newtonian lubricant. As a first application, the corresponding parameters of the FVA 4 reference oil are determined. The measurements were carried out on an MTM machine located of the tribology group of Imperial College in London, UK. Such ball-on-disc machines are commercially available, manufactured by PCS Instruments and sold under the name Mini Traction Machine 2 (Ref. 27). The friction coefficient vs. shear rate curves are shown in the semi-logarithmic plot (Fig. 3). The selected experimental conditions for are 0.5 m/s rolling speed, 0.7, 0.81, 0.9358 GPa maximum pressure and 60, 75, 90º C temperature. For the limiting shear stress , experimental conditions were 1 m/s rolling speed, maximum pressure 0.9358, 0.985 and 1.1 GPa at the same temperatures, resulting in a similar plot.

Since Equation 5 only has three parameters — a curve-fitting process is performed using the nine mentioned experiments. It can be said that parameters could be obtained with less experiments (namely 4), but since the data will be used for the limiting shear stress as well, nine experiments are required. The correlation factor is > 99%. The resulting parameters for FVA4 are the following:

Table 3 Eyring values for FVA4 oil

τ_{E0}	a_τ	β_τ	T_0	R^2
8.33 E5	2.82 E-9	1.647 E-2	273	0.993

Using the nine experiments, the same number of maximum friction coefficient values are obtained. Those are used to fit the proposed model of Equation 16. The correlation is over 96%. The resulting parameters for FVA4 are given below.

Table 4 Limiting shear stress equation parameters for FVA4 oil

c_1	c_2	$\beta_{\tau L}$	T_0	R^2
9.966 E-3	6.782 E-11	−0.002483	273	0.96

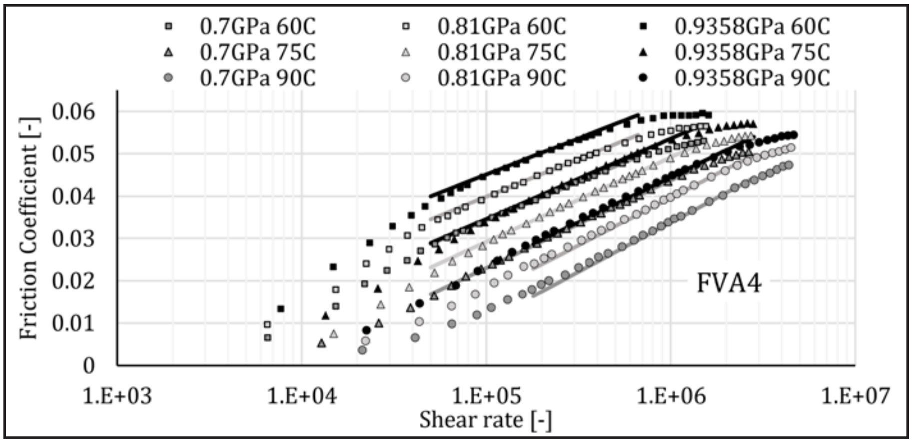

Figure 3 Friction coefficient vs log of shear rate. Data from the three different pressures along with fitting *sinh()* equation with the appropriate viscosity and Eyring stress for rolling speed 0.5 m/s.

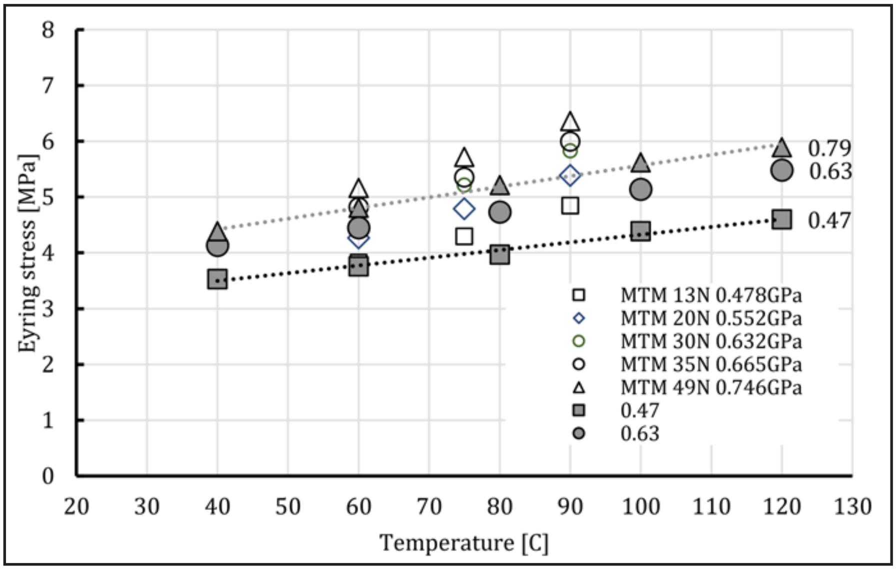

Figure 4 Calculated values from 15 experiments in an MTM (white markers) vs. values published (Ref. 1) for a similar viscosity oil at similar mean pressures (filled markers). Since not all tested temperatures are available an interpolation (dotted lines) for the in-between values is necessary.

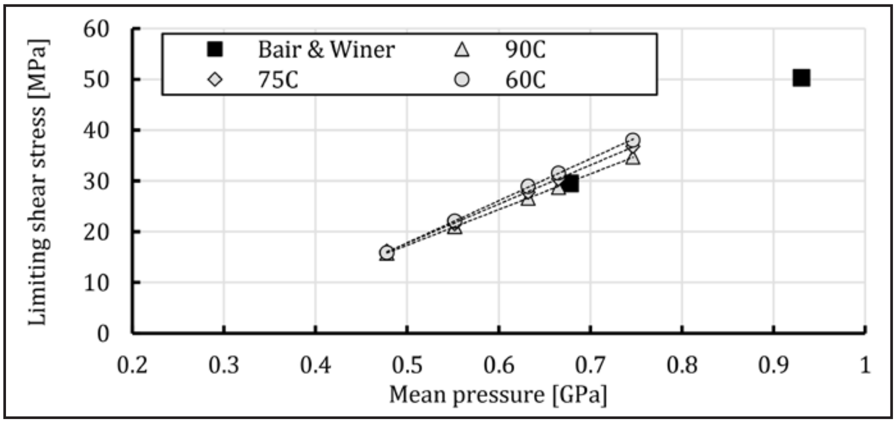

Figure 5 Comparison of calculated values of limiting shear stress for FVA4 vs. Bair and Winer for HVI650; Bair and Winer claimed that temperature does not influence the limiting shear stress, thus only one value is shown per pressure.

Preliminary Validation

In order to validate the results, three separate methods of comparison are performed.

- Comparison of the calculated Eyring stress was performed vs. published data for similar viscosity oils. The calculated Eyring stress values are acceptable since compared to the findings from Evans and Johnson (Ref. 1), they are within the same range (Fig. 4).
- Comparison of the limiting shear stress vs. published data from a ball-on-disc and two-disc machines. The method leads to values that are comparable for similar viscosity oils, as those reported by Bair and Winer (Fig. 5). Previous results by Evans and Johnson (Ref. 1) concluded that no significant effect of the temperature is observed for an ISO 460-HVI 650 (same viscosity as FVA4), but the present study found such a relation.
- Using a larger dataset of 90 test runs with FVA 4, and three repeats each at 5 different pressures, and temperatures from which conditions and experiments used in the methodology are excluded (speeds < 1m/s). For those experiments a simulation was set up in the thermo-EHL solver for calculating the friction force. The results are within a good accuracy ±–5% (Fig. 6).

For more information.

Questions or comments regarding this paper? Contact Emmanouil Athanasopoulos at *manos@feaqus.com*.

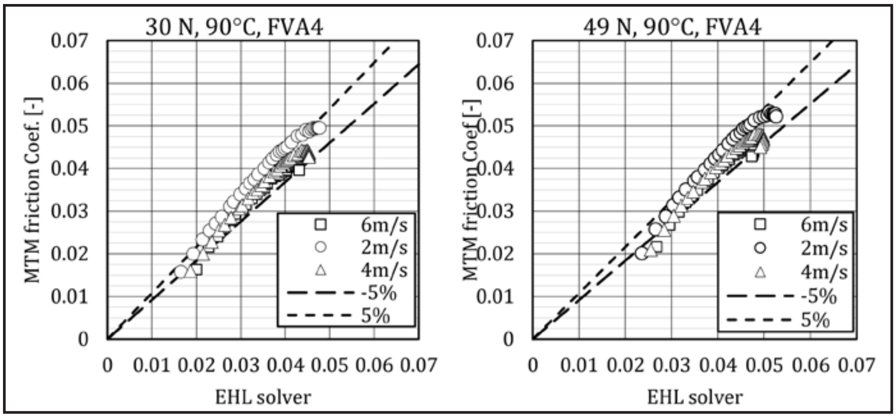

Figure 6 Comparison of the friction coef. measured in the MTM and the calculated values obtained using the Thermal-EHL solver.

Conclusions

The method, outlined in the present study, achieved to extract the rheological parameters needed to describe the oil behavior in elastohydrodynamic contacts. The Eyring and the limiting shear stress, as well as the factors considering the temperature and pressure influence, are obtained by evaluating the friction coefficient measurements conducted under nearly isothermal, fully-flooded EHL conditions.

Based on the friction coefficient over slide-to-roll ratio measurements, obtained from 18 test runs following the proposed procedure, the rheology parameters for the FVA4 reference oil were extracted. They can be used in advanced EHL models to calculate the friction coefficient.

As a preliminary validation of the method, these parameters were then fed in a thermo-EHL solver and the friction coefficient was calculated. The results showed very good agreement with measurements carried out under conditions outside the range of those used to extract the rheology parameters. A final validation incorporating experiments on a two-disk machine is on the way.

Summing up, the proposed method allows the use of a commercial, readily available test rig with automated process and minimum oil requirements to extract rheology parameters needed for advanced thermos-EHL simulation models and for conditions commonly observed in rolling element bearing and gears. **PTE**

References

1. Evans, C.R. and K.L. Johnson. *Proc. IMechE, Part C: Journal of Mechanical Engineering Science* 200(5), 313–324, 1986.
2. Johnson, K.L. and J.L. Tevaarwerk. *Proc. of the Royal Society of London. Series A, Mathematical and Physical Sciences* 356 (1685), 215–236, 1977.
3. Eyring, H. *The Journal of Chemical Physics* 4(4), 283–291, 1936.
4. Houpert, L., L. Flamand and D. Berthe. *Journal of Lubrication Technology* 103(4), 526–532, 1981.
5. Mihailidis, A. and K. Panagiotidis. *Lubrication Science* 15(4), 295–310, 2003.
6. Smith, F.W. *ASLE Transactions* 3(1) 18–25, 1960.
7. Petrusevich, A.I. *Izv. Akad. Nauk SSSR Otdel tekh. nauk.* 2, 209–223, 1951.
8. Johnson, K.L. and J.A. Greenwood. *Wear* 61(2), 353–374, 1980.
9. Bair, S. and W.O. Winer. *Journal of Lubrication Technology* 104(3), 357–364, 1982.
10. Bair, S. and W.O. Winer. *Journal of Lubrication Technology* 101(3), 251–257, 1979.
11. Guo, F., X.M Li and P.L. Wong. *Tribology International* 46 (1), 22–29, 2012.
12. Bair, S. *Tribology and Interface Engineering Series* 54, 193–205, 2007.
13. Wang, S.H. and H.H. Zhang. *ournal of Tribology* 109(4), 666–670, 1987.
14. Hsiao, H.-S.S. and B.J. Hamrock. *Journal of Tribology* 114(3), 540–551, 1992.
15. Wikström, V. and E. Höglund. *Journal of Tribology* 116(**3**), 612–620, 1994.
16. Kleemola, J. and A. Lehtovaara. *Proc. of IMechE Part J: Journal of Engineering Tribology*. 222(**7**), 797–806, 2008.
17. Roeland C.J.A. Doctoral Thesis in *Mining Engineering*., Delft, 495, 1966.
18. Rodermund, H. *Schmiertechnik+Tribologie*, 27(1), 3–5, 1980.
19. Doolittle, A.K. *Journal of Applied Physics* 22(**12**), 1471–1475, 1951.
20. Schilling, M. and Ege. *Forschungsvereinigung Antriebstechnik* 180, 1985.
21. Hamrock, B.J., S.R. Schmid and B.O. Jacobson. *Fundamentals of Fluid Film Lubrication,* 2004.
22. Chittenden, R.J., et al. *Proc. of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 397(1813), 271–294, 1985.
23. Moes, H. *Lubrication and Beyond*, Twente University Press, 2000.
24. Gupta, P.K., et al. *Tribology Transactions* 35(2), 269–274, 1992.
25. Mihailidis, A., et al. *International Journal of Surface Science and Engineering* 4, 337–359, 2010.
26. Kudish, I.I. *Elastohydrodynamic Lubrication for Line and Point Contacts,* CRC Press, 9781466583900, 2013.
27. Anghel, V., R.P. Glovnea and H.A. Spikes. *Journal of Synthetic Lubrication* 21, 13–32, 2004.

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A New Test Rig to Study Rolling Element Bearing Thermomechanical Behavior

D. Niel, C. Changenet, F. Ville and M. Octrue

Introduction

The rolling element bearing (REB) is an essential component in mechanical transmission to reduce friction between rotating parts. Now, with the development of the electrical motor in mechanical industry, REBs may work at very high-rotation speed. It leads to an increase of REB power losses and temperatures. In literature several approaches are used to estimate the REB thermomechanical behavior. Hence, for some applications, several divergent viewpoints can be found on thermal behavior modeling according to the dissipation sources taken into account. In order to overcome these discrepancies, a specific test rig was designed to obtain information on REB thermomechanical behavior. This test rig allows for obtaining REB power losses thanks to torque measurement. To study high-speed applications, the ($N._{dm}$) product expected volume is higher than one million.

Nomenclature

d_m	Bearing mean diameter [*m*]
F	Load [*N*]
f_0, f_1	Harris model factors [–]
G_{sl}, G_{rr}, K_z	SKF model factors[–]
M	Friction torque [*N. mm*]
M_1	Friction torque due to applied load [*N. mm*]
M_c	Viscous friction torque [*N. mm*]
M_{rr}	Rolling frictional moment [*N. mm*]
M_{sl}	Sliding frictional moment [*N. mm*]
M_{drag}	Drag frictional moment [*N. mm*]
N	Rotational speed [rpm]
R_s	SKF model factor [–]
T	Temperature [°C]
ϕ_{ish}	Inlet shear heating reduction factor [–]
ϕ_{rs}	Kinematic replenishment/starvation reduction factor [–]
μ_{sl}	SKF model factor [–]

Rolling element bearings are widely used in mechanical transmission to reduce friction between two rotating parts. With the further development of the electrical motor in mechanical industry, REBs operate more and more at high rotational speed. For these applications, REBs power losses can be predominant in mechanical transmissions. Several global models can estimate the REB resistive torque (Refs. 1–2). Hence, for some applications, several divergent viewpoints can be found between these models.

In order to overcome these discrepancies, some measurements are required. In the literature, several tests rigs are presented to measure REB torque loss.

A first set of test rigs measure torque loss on REB outer ring. In this case, the REB outer ring has to be mounted in the inner ring of a hydrostatic bearing. The torque is measured via a load sensor located on a beam between the REB outer ring and hydrostatic bearing housing (Ref. 3).

Brecher et al. (Ref. 4) used a hydrostatic bearing to measure the REB torque loss for high-speed application. In this test rig a telemetry system is used to measure the REB inner ring temperature.

Neurouth et al. (Ref. 5) have also used this design to measure the REB frictional torque for grease-lubricated thrust ball bearings.

However the hydrostatic bearing can be complex to use and modifies the outer ring thermal behavior.

REB torque loss can also be measured with strain gauges located on the housing. Hannon (Ref. 6) developed a test rig for four types of REBs within a similar size range. A slip ring allows measuring the REB inner ring temperature. In this test rig, four identical REBs are mounted on the main shaft. The global torque loss is divided by four in order to obtain the REB torque loss. The REBs' torque loss is measured thanks to a strain gauged torque table. This test rig has been developed for low-rotational speed and strong radial load conditions (up to 260 kN).

Pinel et al. (Refs. 7–8) developed a test rig for a 35 mm bore diameter angular-contact ball bearing under thrust load and for very high-speed application; the maximum rotational speed is equal to 72,000 rpm, which corresponds to a ($N._{dm}$) product equals to 3.4 million. The REB torque is measured with strain gauges located near the end of an arm that prevents the housing from rotation. However, this measurement can be complex to realize.

Finally, REB torque loss can be measured on the inner ring by using a torquemeter. In this case, the torquemeter measures the global torque of the shaft. However, some components can affect this measurement (seals, REBs mounting, etc.).

Takabi et al. (Ref. 9) designed an REB test rig to study the deep-groove thermal behavior in oil bath lubrication. The test rig is composed of two REB mountings and one test bearing. A torque sensor measures the torque loss of the system.

REB tests rigs with vertical shaft are also presented in the literature. These test rigs allow testing thrust ball bearings (Ref. 10) or cylindrical (Ref. 11) and tapered roller bearings (Refs. 12–13) under axial load. The torque measurement is realized with a torquemeter located on the vertical shaft.

To finish, some test rigs have been realized only for one application. Ke et al *(Ref.* 14) developed a specific REB test rig

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to study the thermal characteristics of double-row tapered roller bearings of a high-speed locomotive. Blake and Truman (Ref. 15) designed a test rig to measure the running torque of tapered roller bearings.

The abovementioned test rigs are dedicated to one operating condition or one size of REB. The new test rig developed in this study is dedicated to a wide range of REB dimensions and for different operating conditions.

In the first section of this paper a new REB test rig design is presented. The second part of this paper is dedicated to the first experimental results.

The New Test Rig Design

Specifications of this test rig. The new test rig has been designed to be able to study the thermomechanical behavior of several kinds of REBs and for different lubrication conditions (grease, oil bath and oil jet). This modularity has been a key point during the test rig design. The tested REB outer diameter is between 72 mm and 150 mm. A lot of REBs can be tested in this test rig: deep groove ball bearings, angular contact ball bearings, roller bearings, etc. Radial and axial load can be applied on the tested REB.

Test rig operation. Thus far, several tests rigs have been presented. For each test rig, a specific method is used to measure the REB torque loss. In this new test rig, REB torque loss measurement is divided into two steps:

- ***Calibration phase*:** Four identical REBs are mounted and work in the same operating condition (rotational speed, radial load, lubrication). These REBs are jet-lubricated with the same lubricant at a given oil injection temperature. The torque loss is divided by four in order to isolate the torque loss of one REB.
- ***Measure phase***: Two REBs (calibration block) are removed and replaced by the tested REB (Fig. 2). The torque loss of mounting blocks (determined in calibration phase) is subtracted to the global torque measurement in order to isolate the contribution of the tested REB.

This architecture requires a specific test rig design. The main challenge is to connect the blocks while maintaining a correct concentricity of the main shaft. Labyrinth seals are used to guarantee oil tightness and to limit power losses. Deep grove ball bearings are used in in the mounting blocks; their characteristics are presented in Table 1; they have been chosen in order to work at high-rotational speed.

Test rig components:

REB lubrication. The REB test rig is composed of two oil tanks. The first one is dedicated to the lubrication of calibration and mounting blocks. These REBs are always lubricated with the same oil at the same temperature (around 70°C). The lubricant properties are presented in Table 2.

The second reservoir is dedicated to the tested REB; it allows testing different lubricants. Gear pumps impose an oil flow between 0 and 1.5 L/min on the REB. Each oil tank is surrounded by hot plates to warm the lubricant. The oil pipes are thermally isolated to reduce heat exchange with the ambient air, allowing for an oil injection temperature even higher than 100°C. The electro spindle maximum rotational speed is equal to 18,000 rpm. A hydraulic jack allows applying a radial load on REB up to 20 kN.

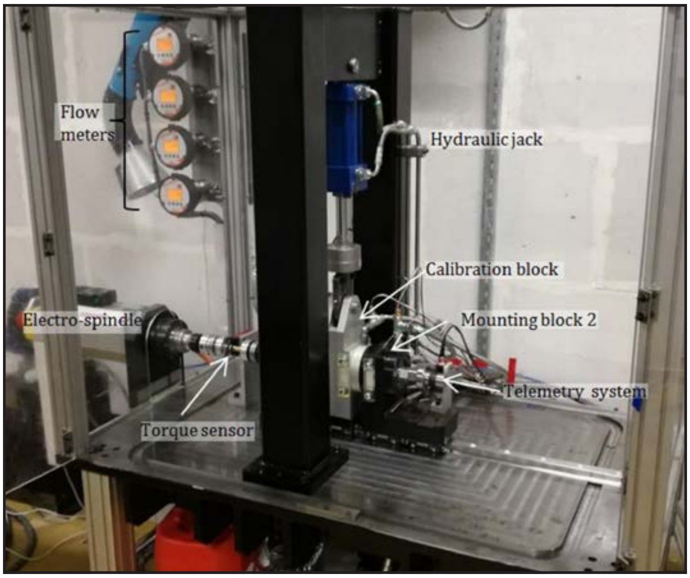

Figure 1 REB test rig.

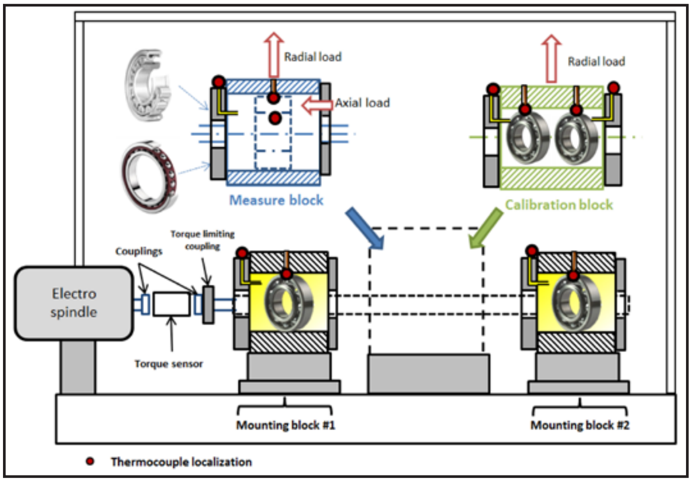

Figure 2 Test rig operation.

Table 1 Main features of the REB used in mounting blocks (SKF 61910)

Designation	Value
Bore dimeter [mm]	72
Outer diameter [mm]	50
Width [mm]	12
Static load [kN]	11.8
Number of balls [-]	16

Table 2 Oil properties

Temperature [°C]	Kinematic viscosity [mm2/s]	density [kg/m3]
20	83.58	864.6
40	36.61	851.6
80	11.67	825.6
100	7.787	[-]

Instrumentation. The test rig instrumentation is presented (Fig. 3). During a test, all the measures are monitored.

A torque sensor (manner 70234) is located on the main shaft between the motor and the mounting block #1. This sensor measures the global torque loss in a range from 0 up to 10 N.m. A torque limiter protects the sensor when the torque loss is up to the maximum value. Type-T thermocouples are located on the fixed and rotating parts of the blocks. For all REBs the outer ring temperature is measured to prevent unusual overheating. The oil inlet and outlet temperatures are measured to study oil heat transfer inside the REB. As ambient air has an influence on the test rig's thermal behavior, this temperature is also measured. On the tested REB, the inner ring and shaft temperatures are measured. A telemetry system located on the tip of the shaft allows transmitting temperatures to the data acquisition card. The force sensor (SCAIME K1427) is located on the extended piston rod of the hydraulic cylinder; this sensor measures the applied load. Flow sensors (Kobold ZOK-ExK/ZxK) are located upstream of each oil injection circuit.

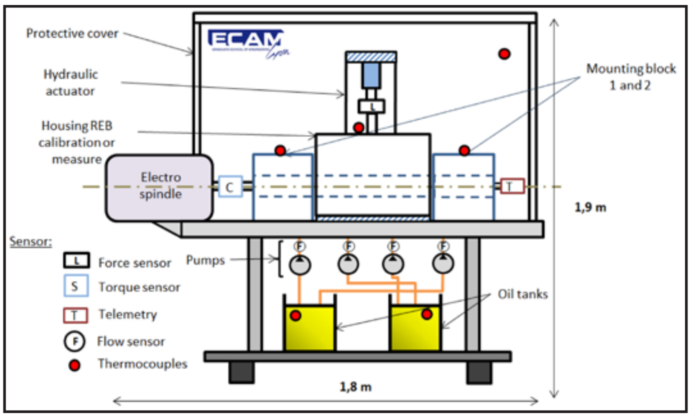

Figure 3 **Test rig instrumentation.**

Table 3 Mounting block REB operating condition

Designation	Value
Rotational speed	[0–12,300] rpm
Oil flow	12 L/h
Oil injection temperature	70°C
Radial load	400N or 1.2 kN
Axial load	0N

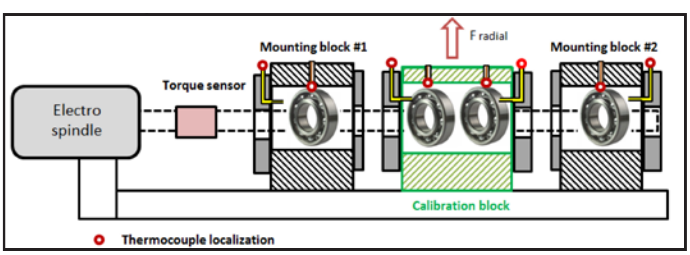

Figure 4 **Calibration phase.**

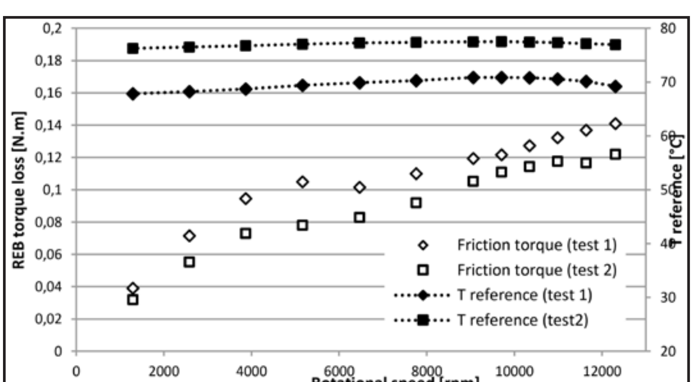

Figure 5 **Mounting block REB friction torque (radial load 400N).**

Mounting blocks characterization. The first test is dedicated to characterize the dissipation of the mounting blocks; to do that, the operating conditions are presented (Table 3). The oil flow in a REB is constant during the test for the entire rotational speed range. As presented previously, in the calibration phase four identical REBs are mounted on the main shaft. The global torque that is measured can be divided by four in order to isolate the torque loss of one REB.

In order to take into account the influence of REB thermal behavior on its frictional torque, a temperature of reference is defined in Equation 1.

$$T_{ref} = \frac{T_{outer\ ring} + T_{oil\ injection}}{2} \quad (1)$$

During testing, the bulk temperature of a REB can evolve with the test rig thermal behavior (ambient air temperature, oil inside the tank, etc.). In order to take this phenomenon into account, several tests have been carried out for different oil injection temperatures. Figure 5 shows the mounting block REB friction torque for two different temperatures. Figure 5 also underlines that reference temperature increase leads to a torque loss diminution. This experimental result is consistent with global power losses models. The same tests have been realized for a radial load equal to 1.2 kN. Thanks to this approach, the mounting blocks' torque loss can be estimated as a function of its thermal behavior.

Experimental Results and Discussion

This second part is dedicated to the first experimental results obtained on the new test rig. In order to analyze these results, the measured torque loss is compared with some calculated values.

REB torque loss global models. In the literature several models are used to estimate REB torque loss. Global models provide a torque loss value with limited numbers of input data.

Harris model. To estimate power loss dissipation in REB, Harris developed an empirical power loss model (Ref. 2). The torque loss for one REB (M_{harris}) is divided into two contributions — M_l is the friction torque due to the applied load and M_c the viscous friction torque.

Where M_l is defined by

$$M_l = f_1 F_{dm} \times 103 \quad (2)$$

And M_c is defined by

$$\upsilon \cdot N < 2000 \qquad M_c = 160 \times 10^{-7} \cdot f_o \cdot (d_m \times 10^3)^3 \quad (3)$$

$$2000 < \upsilon \cdot N \qquad M_c = 10^{-7} \cdot f_o \cdot (\upsilon N)^{2/3} \cdot (d_m \times 10^3)^3 \quad (4)$$

This model is developed for REB of mean diameter d_m under a static equivalent load F and at a rotational speed N. The factor f_1 depends on the bearing design and load, and f_o depends on the kind of REB and lubrication.

SKF model. To calculate REB power losses, SKF Company has also developed a global model (Ref. 1); this model is derived from computational models. The friction torque can be estimated by the following equation:

$$M_{SKF} = M_{rr} + M_{sl} + M_{drag} \quad (5)$$

The rolling frictional moment M_{rr} is defined by:

$$M_{rr} = \phi_{ish}\,\phi_{rs} G_{rr} (\upsilon N)^{0.6} \quad (6)$$

Where ϕ_{ish} is the inlet shear heating reduction factor and ϕ_{rs} is the kinematic replenishment/starvation reduction factor. The number G_{rr} depends on the kind of REB, its design and load.

The sliding frictional moment is determined by:

$$M_{sl} = G_{sl} \cdot \mu_{sl} \quad (7)$$

Where G_{sl} depends on the kind of REB, its design, and load. The sliding friction coefficient μ_{sl} depends on the lubricant shearing and for boundary lubrication on asperity contacts.

The frictional moment of drag losses for ball bearing is defined by:

$$M_{drag} = 0.4 \cdot V_m \cdot K_z \cdot (d_m \times 10^3)^5 \cdot N^2 + 1{,}093 \cdot 10^{-7} \cdot N^2 \cdot (d_m \times 10^3)^3 \left(\frac{N \cdot (d_m \times 10^3)^3 \cdot f_t}{\upsilon} \right)^{1.379} \cdot R_s \quad (8)$$

Where parameters V_m, K_z, f_t and R_s depend on the REB geometry.

Tested REB measurement. In the measure phase, two REBs located in the calibration block are replaced by the tested REB (Fig. 6).

The torque loss generated by mounting blocks can be estimated thanks to the experimental results obtained in the calibration phase (Fig. 5). During a test, oil inlet, oil outlet, inner and outer ring temperatures are measured. The first tested REB is a deep groove ball bearing. Its main features are presented in Table 4.

A test is divided into several steps. First of all, the test rig works at low rotational speed (about 5,000 rpm) to warm up the blocks. Hot plates located around the oil tanks warm up the lubricant until the oil injection temperature is around 70°C. The requested oil flow and radial load are applied on the tested REB. Progressively, the rotational speed is increased from 5,000 rpm to the maximum rotational speed range. When the measured torque loss value is stabilized, the test can begin.

First results and discussion. The results presented here are given for a radial load applied on the tested REB, which is equal to 400N. As far as the lubrication conditions are concerned, the oil flow is equal to 25 L/h and the oil injection temperature is around 70°C. These experimental results are compared with numerical results obtained through the abovementioned global models.

In Figure 7, torque loss calculated with Harris model is compared with experimental results. To perform this comparison, in Equation 4 the coefficient f_0 is set to 2 and the lubricant viscosity is calculated at outer ring temperature. Torque loss calculated thanks to global models are in the same order of magnitude as the measured torque loss. However, global models do not taken into account the REB torque loss variations.

Figure 7 underlines that torque loss evolution according to the rotational speed can be divided into 3 zones: from 0 to about 5,000 rpm the torque loss value increases with the rotational speed. In this zone, the resistive torque can be accurately estimated by using the Harris model. Then, from 5,000–10,000 rpm, the torque loss value appears to be almost constant; both models do not take into account this torque loss stabilization in their calculations. Last but not the least, from 10,000–12,300 rpm the torque loss evolution has a steep increase with the rotational speed. These increases begin when the ($N.{}_{dm}$) product is around 0.85 million. For both models, REB torque loss is not well estimated. The Harris model underestimates the REB torque loss. At the opposite, the SKF model overestimates the REB torque loss. This overestimation has already been observed in another study (Ref. 16). Finally, this increase for high-speed application is probably due to drag loss (Ref. 17).

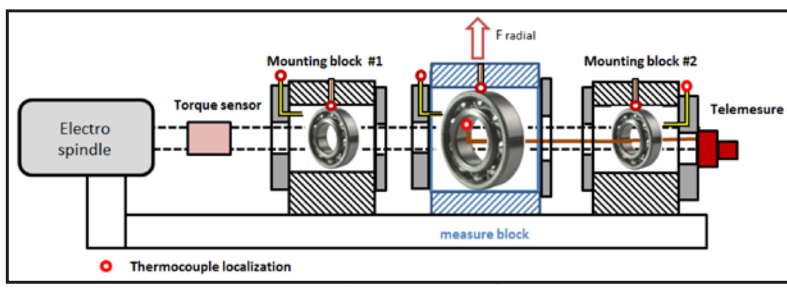

Figure 6 Measure phase.

Table 4 Main features of the tested REB (reference SKF 61815)	
Designation	**Value**
Bore diameter (mm)	75
Outer diameter (mm)	95
Width (mm)	12
Static load (kN)	14.3
Number of balls (-)	26

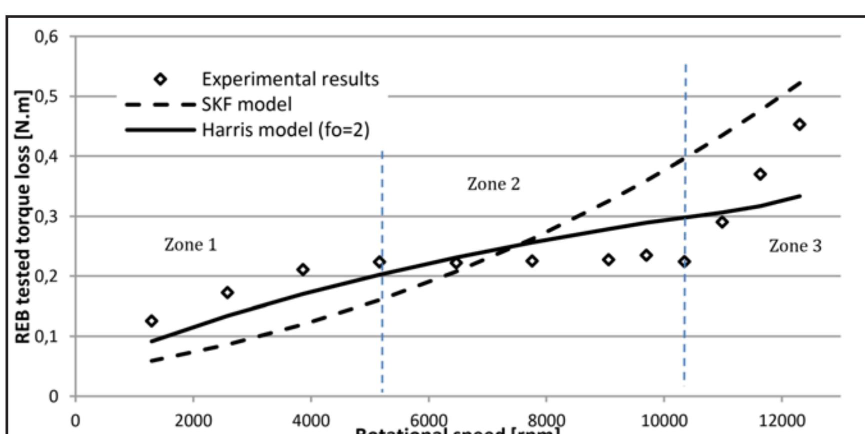

Figure 7 REB tested torque loss and global models (radial load 400N, oil injection temperature 70°C, oil flow 25 L/h).

For zone 1 and 2, it is interesting to note that the modified SKF model can provide good torque loss estimation. In this case radial and axial load have to be equal to 10 percent of the REB tested static load.

In Figure 8, torque loss calculated with SKF model, the load radial load is equal to 10 percent of the REB tested static load. The viscosity is also calculated at the outer ring temperature. Figure 8 underlines that REB torque is well estimated in zone 1 and 2 by using a SKF model without drag loss. But in zone 3, no model can correctly estimate the REB torque loss.

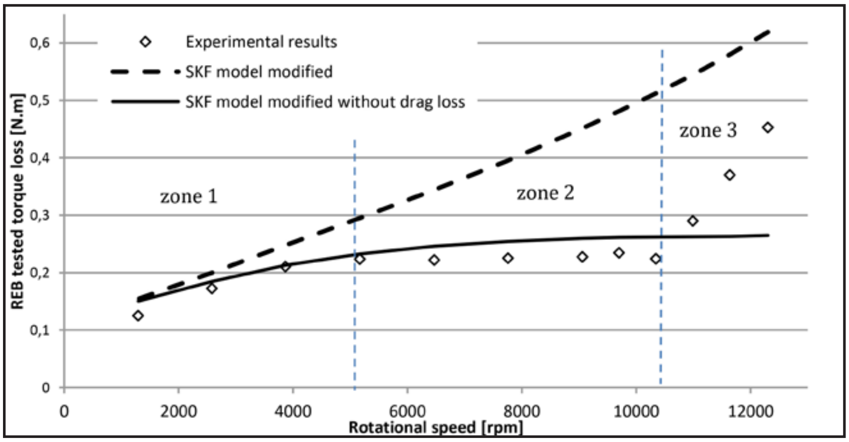

Figure 8 REB tested torque loss and SKF model modified (radial load 400N oil injection temperature 70°C oil flow 25 L/h).

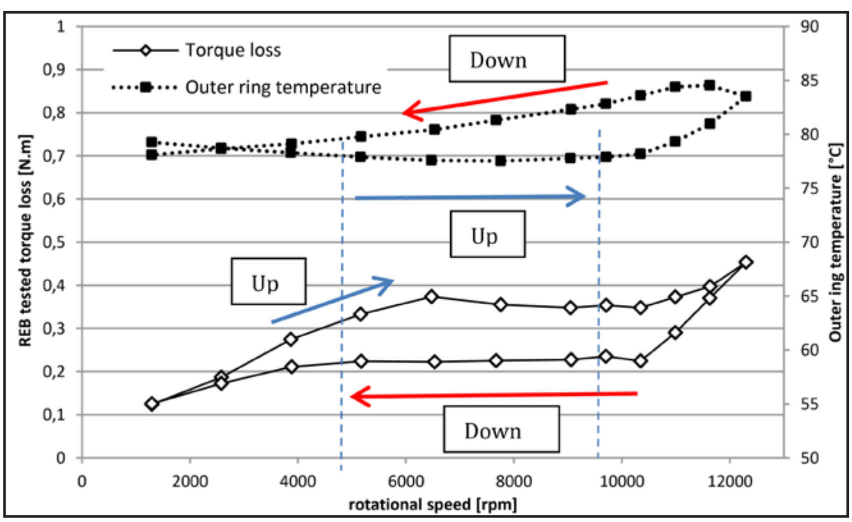

Figure 9 Influence of the rotational speed and REB outer ring temperature on the torque loss (test at 400N, oil injection temperature 70°C, oil flow 25 L/h).

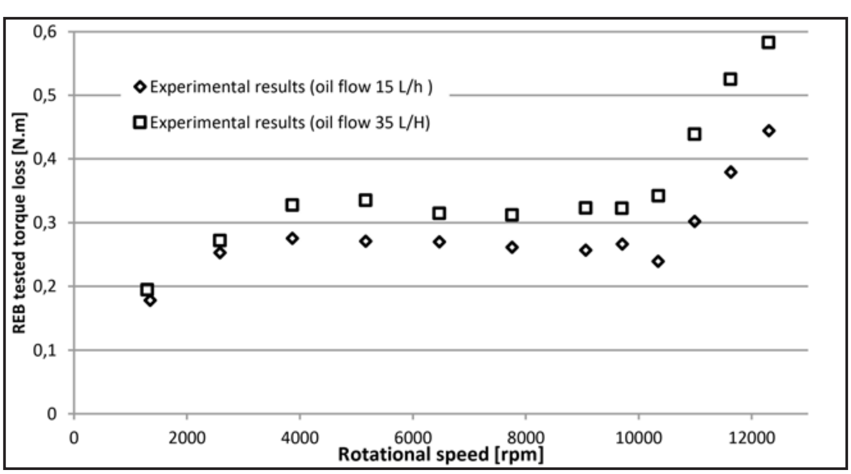

Figure 10 Influence of the oil flow on the torque loss (oil injection temperature 50°C, load 400N).

Influence of the operating condition on the REB torque loss. In this section the influence of the oil flow and REB thermal behavior on the torque loss are studied.

REB thermal behavior influence on the torque loss. Figure 9 shows the REB torque loss and its outer ring temperature according to the rotational speed. At the beginning of the test, the tested REB operates at a rotational speed equal to 1,300 rpm and under a radial load of 400N. The oil flow is equal to 25 L/h with an inlet temperature about 70°C. These operating conditions are constant during the entire test. The rotational speed is gradually increased from 1,230 rpm to 12,300 rpm. Then the rotational speed is gradually decreased. The torque loss evolution is similar to the one observed in the previous section. During the first phase (rotational speed increase), the outer ring temperature is constant in zones 1 and 2. In zone 3 the torque loss rise leads to a REB outer ring temperature increase.

During the down phase (rotational speed decrease), the torque loss evolution is similar to the one obtained during the first phase. But, as the REB is hotter, its torque loss is smaller — especially in zone 2.

To conclude, Figure 9 underlines that the REB thermal behavior has a huge impact on the REB torque loss.

Influence of oil flow. In order to study the impact of the oil flow on REB torque loss, several tests have been carried out for different oil flows at a given oil injection temperature (equal to 50°C), and under a radial load of 0.4 kN.

Figure 10 underlines that, for high-speed application, the oil flow has a predominant impact on the frictional torque. For instance, at 12,300 rpm an oil flow increase of 15 L/h leads to a rise of about 20% in REB frictional torque. Moreover, it can be noted that oil flow modifies the REB thermal behavior, and thus affects its frictional torque. This parameter is not taken into account in global models and it could be interesting to take it into account.

Conclusion

This research work aims to present a new REB test rig dedicated to the study of the thermomechanical behavior of this mechanical component.

In the first part of this paper, this new test rig is presented. It has been designed to study different kinds of REBs and for different operating conditions.

The second part is dedicated to the first results that have been obtained. An 85 mm pitch diameter deep groove ball bearing was tested under different operating conditions. Experimental results have been compared with global models of power losses. This part underlines that these models can estimate the REB torque loss for low-speed application. However, when the ($N_{\cdot dm}$) product tends toward a million, the REB torque loss increases suddenly; this increase is not correctly taken into account in the global models. Moreover, the influence of the REB thermal behavior and the oil flow rate on the REB torque loss were highlighted. **PTE**

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References

1. SKF Group. *Rolling bearings 6000 EN.* Göeteborg, Sweden: SKF Group 2013.
2. T. A. Harris, *Rolling Bearing Analysis*, 4th Ed., New York, United States of America: John Wiley& Sons, 2001.
3. A. Neurouth, C. Changenet, F. Ville, and A. Arnaudon, "Thermal modeling of a grease lubricated thrust ball bearing," vol. 228, no. 11, pp. 1266–1275, 2014.
4. B. W. WZLl, R. Aachen, O. S. Gmbh, and G. Corresponding, "High- Speed Rolling Bearing Test Rigs with Contactless Signal Transmission for Measuring the Inner Ring Temperature," *European Telemetry and Test Conference 2014*, pp. 116–121.
5. A. Neurouth, C. Changenet, F. Ville, and A. Arnaudon, "Thermal modeling of a grease lubricated thrust ball bearing," *STLE 2014 Orlando*, vol. 228, no. 11, pp. 1266–1275, 2014.
6. W. M. Hannon, T. A. Barr, and S. T. Froelich, "Rolling-Element Bearing Heat Transfer — Part III : Experimental Validation," *J. Tribol. ASME*, vol. 137, pp. 1–13, 2015.
7. I. Pinel, H. R. Signer, S. Technical, and V. Zaretsky, "Design and Operating Characteristics of High-Speed , Bearings."
8. S. H. R. Schuller F. T. , Pinel S.I., "Operating characteristics of a high speed, jet lubricated 35 millimeter bore ball bearing with a single outer land guided cage," *NASA Tech. Pap.* April, 1980.
9. J. Takabi and M. M. Khonsari, "On the thermally induced failure of rolling element bearings," *Tribol. Int.*, Vol. 94, pp. 661–674, 2016.
10. C. M. C. G. Fernandes, R. C. Martins, and J. H. O. Seabra, "Tribology International Friction torque of thrust ball bearings lubricated with wind turbine gear oils," *Tribiology Int.*, Vol. 58, pp. 47–54, 2013.
11. S. J. Fernandes CM, Amaro PM, Martins RC, "Torque loss in cylindrical roller thrust bearings lubricated with wind turbine gear oils at constant temperature," *Tribiology Int.*, Vol. 67, pp. 72–80, 2013.
12. J. Liebrecht, X. Si, B. Sauer, and H. Schwarze, "Investigation of Drag and Churning Losses on Tapered Roller Bearings," *J. Mech. Eng.*, Vol. 61, no. 6, pp. 399–408, 2015.
13. V. Paleu and D. Nelias, "On Kerosene lubrication of hybrid ball bearings," *Int. Conf. diagnosis Predict. Mech. Eng. Syst.*, Vol. 2007, No. Xiii, pp. 50–56, 2007.
14. Y. Ke, W. Ning, Z. Qiang, Zh. Yongsheng, Z. Jinhua, and N. Qingbo, "Theoretical and experimental investigation on the thermal characteristics of double-row tapered roller bearings of high speed locomotive," *Int. J. Heat Mass Transf.*, Vol. 84, pp. 1119–1130, 2015.
15. J. J. Blake and C. E. Truman, "Measurement of running torque of tapered roller bearings," *Pro. IMechE, Part J J. Eng. Tribol* vol. 218(4) pp. 239–249, 2004.
16. D. Niel, C. Changenet, F. Ville, and M. Octrue, "Thermomecanical study of high speed rolling element bearing : A simplified approach," *Pro. IMechE, Part J J. Eng. Tribol* vol. 0, no. 0, pp. 1–12, 2017.
17. F. Pouly, C. Changenet, F. Ville, P. Velex, B. Damiens, U. De Lyon, E. Lyon, and L. Energétique, "Investigations on the power losses and thermal behavior of rolling element bearings," *Pro. IMechE, Part J J. Eng. Tribo.*, Vol 224(9) pp. 925–933, 2009.

For more information.

Have questions or comments regarding this technical paper? Contact Dimitri Niel at *dimitri.niel@ecam.fr*.

Motion Industries (Genuine Parts Company)

ANNOUNCES 2018 GPC MANAGER OF THE YEAR AWARD

Motion Industries, Inc. has announced that its parent company, Genuine Parts Company (GPC), presented **Randy Breaux** (Motion Industries president — North America) and **Kevin Storer** (Motion Industries executive vice president U.S. operations and president of Motion Mexico) the 2018 GPC Manager of the Year honor. It is the single highest individual recognition in all of Genuine Parts Company.

"This is the 60th consecutive year that we have recognized one Manager of the Year out of all our associates worldwide," said Paul Donahue, president & CEO of Genuine Parts Company. "This year we decided to present the Manager of the Year Award to both Randy and Kevin to recognize the outstanding efforts of both leaders, resulting in a record year during a challenging time with the passing of Tim Breen, former president & CEO, in August. This award is the highest honor at GPC — a significant recognition of both Randy's and Kevin's exceptional leadership of the Motion Team in 2018."

Prior to being named Motion Industries president in December 2018, Breaux was executive vice president of marketing, distribution, purchasing and strategic planning for the company, and has nearly four decades of experience in the industrial manufacturing and distribution markets. He joined Motion Industries in May 2011, following 21 years of leadership roles with ABB/Baldor Electric Company.

Storer is responsible for all U.S. branch and field sales operations as well as Motion's Mexico operations. Storer began his career with Motion Industries in 1987, and was a branch manager and regional manager prior to becoming vice president/general manager of Motion's Los Angeles Division. In 2006, he was promoted to vice president/group executive before being named senior vice president, Western U.S. and president of Motion Mexico in 2014. He was promoted to his current position in 2017. (*motionindustries.com*)

Dana

COMPLETES ACQUISITION OF OERLIKON GROUP'S DRIVE SYSTEMS SEGMENT

Dana Incorporated has completed the acquisition of the Drive Systems segment of the Oerlikon Group, including the Graziano and Fairfield brands. This acquisition expands the company's capabilities in electrification and further optimizes its manufacturing presence in key growth markets.

The addition of the Drive Systems segment to Dana is immediately accretive to earnings and creates a number of opportunities for increased revenue and profitable growth, including:

- Extending Dana's current technology portfolio, especially in the area of high-precision helical gears for the light- and commercial-vehicle markets, as well as planetary hub drives for wheeled and tracked vehicles in the off-highway market.
- Growing Dana's electronic controls capability for transmissions and drivelines through the acquisition of VOCIS, a wholly owned business of Oerlikon Drive Systems, and further expanding its motors technologies through Ashwoods Electric Motors.
- Increasing Dana's product offerings that support vehicle electrification in each of Dana's end markets — light vehicle, commercial vehicle, and off-highway.
- Optimizing Dana's global manufacturing presence to be closer to customers in key growth markets such as China and India, as well as the United States.
- Adding four research and development facilities to Dana's extensive network of technology centers, as well as 12 facilities to the company's global manufacturing footprint.

DANA GRAZIANO Transmission Systems

DANA FAIRFIELD Custom Gears and Drives

"Dana's acquisition of the Drive Systems segment of Oerlikon enables us to support our customers' shift toward vehicle electrification across nearly every vehicle architecture in the light vehicle, commercial vehicle, and off-highway segments," said James Kamsickas, president and chief executive officer of Dana. "The Drive Systems business' highly talented team is also strategically positioned to give our customers access to critical manufacturing capabilities in key growth markets, such as India, China, and the United States."

The Drive Systems business serves a global roster of original-equipment manufacturers with a portfolio of high-tech products that can be found in a wide range of applications for operating machinery and equipment used in agriculture, construction, energy, mining, on-road transportation, and high-performance sports cars.

Selected customers include, but are not limited to AGCO, Ashok Leyland, Aston Martin, BMW, Caterpillar, CNH, Daimler, John Deere, Ferrari, Fiat Chrysler Automobiles, MAN, McLaren, Oshkosh, SANY, Scania, Terex, Volkswagen, and AB Volvo. (*www.dana.com*)

Forest City Gear

INTRODUCES QUALITY ASSURANCE MANAGER

Forest City Gear has hired **Bob McClain** as quality assurance manager to oversee the activities of the company's world-class quality lab and manage all its company-wide quality systems for aerospace, medical and other precision gearing applications.

McClain brings a wealth of quality program management experience and a deep familiarity with precision parts manufacturing for the aerospace, military, automation and other industrial markets. He will be instrumental in ensuring that Forest City Gear has the infrastructure, systems and supplier network in place to meet the very highest quality standards increasingly common to the precision gear projects that the company is renowned for, says Forest City Gear President and CEO Wendy Young.

"Our criteria for this position has never been more challenging: vast quality experience, familiarity with all the latest quality management systems and certifications as they relate to our core customers and, rarer still, someone that customers and quality staff alike would enjoy working with," said Young. "Fortunately, Bob is the perfect fit."

(*forestcitygear.com*)

Freudenberg Sealing Technologies

WELCOMES PRESIDENT OF SALE & MARKETING FOR AUTOMOTIVE BUSINESS

As of May 1, 2019, **Matthew Chapman** will take over as the new president of sales and marketing for the automotive business of Freudenberg Sealing Technologies. The company is part of the Freudenberg Group and the global market leader in sealing technology and a supplier to the automotive industry. Chapman succeeds Rainer Joest, who is retiring after more than 40 years of successful service to the company.

Chapman has detailed knowledge of the automotive industry. He has worked for Freudenberg Sealing Technologies in various sales positions in the automotive business for over 15 years. After successfully completing his mechanical engineering studies at Kettering University in Michigan (USA), Chapman joined the company's North America sales organization as an account manager in 2003. This was followed by other global management positions within automotive sales. Since 2018, he has been vice president of sales and marketing for new mobility, responsible for the worldwide business activities of Freudenberg Sealing Technologies in the field of electromobility.

His predecessor Joest is retiring after more than four decades with the company. Since 2016, he has been responsible for worldwide sales of the automotive business of Freudenberg Sealing Technologies. "We would like to thank Rainer Joest for his extraordinarily successful work. With his forward-looking decisions, he made a decisive contribution to ensuring that our company was able to master the necessary transformation regarding the emerging electro mobility also on the sales side," said Claus Möhlenkamp, CEO of Freudenberg Sealing Technologies. "With our innovations and product solutions for the new drives of the future, we are a partner at eye level for our customers in the automotive industry." (*www.freudenberg.com*)

Thomson Industries

EXPANDS ILLINOIS OPERATION

Thomson Industries, Inc., a manufacturer of mechanical motion control solutions, intends to consolidate operations from a Connecticut subsidiary to its Marengo, Illinois, facility, which could bring more than 50 new jobs to the region. Openings exist for people with a wide range of industrial production experience, including assembly, soldering, machine operation, buying and planning.

"The Marengo facility is the largest Thomson plant in the U.S., and we take great pride in the talented people who work here," said Thomson President Scott Benigni. "They have contributed significantly to our steady business growth and global reputation for impeccable product quality. We are excited about adding to their ranks."

The plant expansion is the result of moving the Thomson-affiliated Warner Linear product line from its current location of New Hartford, Connecticut. Both Thomson and Warner Linear rod-style electric linear actuators are used to control push/pull type motion in a wide range of products, from delicate surgical robots to large, off-highway agricultural and construction equipment.

"Thomson has been an important member of the general Marengo community for more than 50 years and is known locally for being a great place to work," said Marengo Mayor John Koziol. "The plant is already a significant contributor to the local and regional economy and we are pleased they continue to strengthen their commitment to the area. We congratulate them on their continued business success and welcome the new operations to Marengo."

(*www.altramotion.com/careers*)

Posi Lock Puller, Inc.

OPENS EUROPEAN WAREHOUSE AND SHOWROOM IN BRUSSELS

Posi Lock Puller, Inc., recently announced the opening of its European warehouse and showroom in Brussels, Belgium.

"Posi Lock has been a member of the EMEA Power Transmission Distributors' Association (EPTDA) since 2007 and has served several European and international companies successfully. Building on our strong brand awareness, international reputation, and a legacy of innovation, we want to invest more in our European network and get closer to our distributors," said Tamara Somerville, chief executive officer of Posi Lock Puller, Inc.

"Importing from the USA has been cited as an obstacle to trade by some of our trusted advisors and partners. We are removing that barrier immediately by starting a permanent European base. This expansion will provide our distributors and customer's shortened delivery times as well as the unique opportunity to be able to walk into the showroom

and view our entire product portfolio including the 100-ton hydraulic puller," added Somerville.

Posi Lock Puller produces mechanical pullers ranging from 1 to 40 ton capacity, hydraulic pullers from 5 to 200 ton capacity, and specialty tools and accessories. With its patented "Safety Cage" design, Posi Lock has set the standard for safety, durability, and simplicity of use. Designed for use in any industry where equipment and machinery pose tough maintenance challenges, Posi Lock enhances safety and efficiency while reducing downtime and cost.

Posi Lock is committed to increasing its global presence and supporting its customers around the world. Its European warehouse and showroom is the first step in providing the caliber of service Posi Lock's customers expect. The company is looking forward to expanding its presence in other global locations in the future. (*www.posilock.com*)

Brelie Gear Co, Inc.

ANNOUNCES NEW WISCONSIN PLANT

Brelie Gear Co, Inc. has announced plans to build a new 36,800 sq. ft. facility on a recently purchased 4.3 acre site in Waukesha, WI. Construction is planned to start in April 2019 and will be completed in November 2019. The announcement comes on the heels of an all-time annual sales record

in 2018. Upon completion Brelie will be moving from their current plant in Milwaukee to the new, larger plant.

"We're very excited to announce the building of our new facility," said Steve Janke, president of Brelie Gear Co, Inc. "Our current building has had numerous additions over the years, but we didn't have a good product flow or space to expand our staff."

The new larger space will continue to run as a full-service gear manufacturing facility that houses the latest in equipment technology and automation. Brelie continues to reinvest revenue into state-of-the-art technology and training to stay on top of efficiency and quality assurance.

"This new space will increase our production and ensure continued quality to best serve our customers," Janke added. "We will have room to expand our company for years to come."

Brelie Gear Co, Inc. is a leading manufacturer of fine and medium pitch spur and helical gears, worms, and worm gears. The company continually invests 20 to 30 percent of revenues back into the latest technology and employee training. (*www.breliegear.com*)

Sulzer and Tamturbo

COLLABORATE ON AIR COMPRESSION TECHNOLOGY

Sulzer and Tamturbo will together bring the benefits of high-speed technology in air compression to customers that need intrinsically safe oil-free air. The target is to replace existing technologies such as oil-free screw compressors in these applications. The global agreement between the companies covers sales to all industries, focusing on Sulzer's key industries such as pulp and paper, food, metals, mining and chemical processing.

Sulzer has used high-speed technology in its products for more than 20 years. The HST™ turbo compressor is the market leader in low-pressure compression e.g. in wastewater treatment applications. With this cooperation, Sulzer is tapping into a similar technological transformation in industrial air compression that happened in the low-pressure blower market from 1996 onwards.

Tamturbo as a company focuses on the industrial oil-free compressed air market. The high-efficiency turbo compressors developed and manufactured by Tamturbo produce oil-free air that does not contaminate the product. They typically supply 3–10 bar pressure to industrial compressed air networks — at the lowest possible total cost of ownership.

The core of the cooperation agreement is the high-speed technology with active magnetic bearings. The application of variable frequency electrical supply and advanced control technologies also plays an important role in the products. The flow mechanics are optimized by advanced calculation to make sure no energy is wasted. The HSR line of high-speed turbo compressors that Sulzer launched in December 2018 builds on this advanced technology.

Sulzer's long experience in product development, thorough customer application knowhow and extensive marketing and sales channels combined with Tamturbo's agility to develop innovative technologies and validate them in different applications are the cornerstones for bringing high-tech products for high-speed compression to the market.

"We are happy to provide the necessary backbone and muscle to our customers' effort to save energy, provide safe and clean air to the processes, and to make sure that unnecessary breakdowns and hefty maintenance bills are history in the field of oil-free compressed air," said Saku Vanhala, product portfolio manager at Sulzer.

"The cooperation with Sulzer to transform the industrial air compressor market by combining our accumulated capabilities will bring financial, environmental and reliability benefits to customers globally. We see strong potential in accelerating the technology disruption with Tamturbo's sustainable products also in the industrial medium-pressure compressor market," said Olli Kuismanen, director, partnerships at Tamturbo. (*www.sulzer.com*)

Nord

INTEGRATES TRAINEES INTO MANAGEMENT PROCESSES WITH NORDPRO INITIATIVE

Optimum customer satisfaction can only be achieved with optimally trained employees: This is the basic idea behind the NordPro initiative, which has operated a laboratory with the same name since 2011.

Here, employees receive training in the fundamentals of lean management and are given ideas for implementing these ideas in their daily work. The program is organized and managed by Nord trainees who use this opportunity to extend their organizational and representational skills. This "hands-on" experience is also an important part of the comprehensive Nord training program.

NordPro was founded in 2008 to sustainably ensure customer satisfaction in an age of increased expectations. The idea: To actively communicate lean management methods to employees in order to give them the tools with which company processes can be optimized for the benefit of customers. The program first started with the five tools Kaizen, Fluss, SMED, TPM, and Q-Groups, but since then has been continuously developed to include new methods.

In 2011, the initiators went a step further with the NordPro Lab. Specially equipped areas were created at the Bargteheide site, where various modularly structured training courses with a heavy practical emphasis are now held. Here, the theoretical knowledge of lean management which has been acquired is utilized and deepened using simulation games. By dealing with hypothetical problems, participants learn the effects of process improvements, in addition to which cross-departmental understanding of work processes is promoted.

The NordPro tools can be used for assembly, logistic and production processes, as well as at an administrative level, so that the training is used equally by all Nord employees across the various sites.

A further special feature of the NordPro Lab is that it is now organized and led by Nord trainees and dual-training students who take on the organization and implementation of the courses. However, their remit is also to continuously develop the laboratory and the content of the courses. This requires organizational expertise as well as a confident manner and specialist theoretical knowledge, which will be a great advantage in their further careers.

(*www.youtube.com/user/NORDDRIVESYSTEMS*)

Lafert North America

APPOINTS INSIDE SALES REPRESENTATIVE

Lafert NA has appointed **Lorri Fernandes** to the role of inside sales representative. Fernandes brings over 20 years of motor sales experience to Lafert NA, with a specialized focus in the power transmission and linear-motion components industry. Fernandes is technically skilled in directing multiple initiatives, while delivering results on primary objectives. With her educational background in communications from Ryerson University of Toronto, she's fulfilled a career in customer satisfaction roles targeted in the motor industry. Her training and knowledge will provide the leverage to problem solve and deliver the optimal solutions to meet our customers' application and industrial requirements. (*www.lafertna.com*)

Maxon Motors

OPENS NEW U.S. MANUFACTURING FACILITY

Maxon Precision Motors, a division of Maxon Motor of Sachsein, Switzerland, has announced the opening of a new manufacturing facility in Taunton, MA. The two-story, 59,000 sq. foot facility is located within the Myles Standish Business Park in Taunton at 125 Dever Drive.

Company officials led by Chris Blake, mpm president welcomed state/local officials and invited guests to a grand opening event at the facility this morning which included a ribbon cutting ceremony and tours of the building.

The new building will provide design engineering and production operations, significantly advancing Maxon Precision Motors presence and capabilities in North America. Its opening is an integral component in an ongoing global growth strategy underway by the privately owned Swiss company, in business since 1961.

Maxon Motor is the leading provider of precision DC motors and drive technology with distribution and sales in 40 countries worldwide. maxon's products include brushed and brushless DC motors, gearheads, sensors/encoders and customized drives. Its highly engineered products are used in a wide range of industries and applications including medical technology, industrial automation, robotics, security and communications, aerospace, automotive, and measurement/testing.

The new facility replaces a former sales/distribution and assembly operation at 101 Waldron Road in Fall River, MA, and will significantly expand maxon precision motors capabilities and employment. USA customers will benefit from closer collaboration that will provide value added opportunities with faster turnaround. Plus, a localized supply chain with domestic vendors will help build stronger customer relationships while reducing lead times.

"Our vision is to be an integral part of maxon's global growth strategy," explained Blake, who heads up the US management team. "With expanded engineering services in place, our customers will enjoy a closer collaboration on design and manufacturing and have a more direct line to our team during concept development, which will include rapid prototyping to better execute customer-specific products."

The new Taunton facility will include offices and conference areas, space for warehousing, and significant manufacturing space. PIt will integrate engineering with true high-volume manufacturing capabilities. (*www.maxonmotor.com*)

May 6–9—AISTech 2019 Pittsburgh, PA. This event will feature technologies from all over the world that help steel producers to compete more effectively in today's global market. AISTech is a can't-miss event for anyone involved at any level of today's steel marketplace, providing perspective on the technology and engineering expertise necessary to power a sustainable steel industry. More than 8,000 people are expected to attend AISTech 2019. Along with over 500 exhibiting companies, AISTech 2019 allows attendees to meet face-to-face with key individuals involved in the production and processing of iron and steel. The AIST Conference programs are developed by technology committee members representing iron and steel producers, their allied suppliers and related academia. Committees focus on ironmaking, steelmaking, finishing processes, and various engineering and equipment technologies. For more information, visit *www.aist.org*.

May 6–9—OTC 2019 Houston, Texas. The Offshore Technology Conference (OTC) is where energy professionals meet to exchange ideas and opinions to advance scientific and technical knowledge for offshore resources and environmental matters. Celebrating 50 years since 1969, OTC's flagship conference is held annually at NRG Park (formerly Reliant Park) in Houston. OTC has expanded technically and globally with the Arctic Technology Conference, OTC Brasil, and OTC Asia. OTC gives you access to leading-edge technical information, the industry's largest equipment exhibition, and valuable new professional contacts from around the world. Its large international participation provides excellent opportunities for global sharing of technology, expertise, products, and best practices. OTC brings together industry leaders, investors, buyers, and entrepreneurs to develop markets and business partnerships. For more information, visit *2019.otcnet.org*.

May 13–16—CTI Symposium USA Novi, Michigan. The CTI Symposium USA is the International Congress and Expo for Automotive Transmissions, HEV and EV Drives. The event features a two-day introductory seminar, a transmission expo, evening networking party and test drives for the latest development cars. Participants include automotive suppliers, transmission manufacturers, OEMs, metal processing, mechanical engineering and others from North America, Europe and Asia. Topics include powertrain technologies, hybrid transmissions, future considerations, commercial vehicles, starting devices, manufacturing and more. Autonomous driving, NVH, tools and performance forecasting will also be discussed. Speakers this year include Dave Filipe, vice president, global powertrain engineering, Ford, Mayank Agochiya, managing director at FEV Consulting, Inc., Mamatha Chamarthi, CDO at ZF, Stephan Tarnutzer, president, AVL Powertrain Engineering, Inc. and many more. ***Gear Technology*** and ***Power Transmission Engineering*** are co-sponsoring this event. For more information, visit *www.transmission-symposium.com/usa*.

May 13–15—SAE Fundamentals of Modern Vehicle Transmissions Seminar Jacksonville, Florida. Starting with a look at the transmission's primary function -- to couple the engine to the driveline and provide torque ratios between the two -- this updated and expanded seminar covers the latest transmission systems designed to achieve the most efficient engine operation. Current designs, the components and sub-systems used, their functional modes, how they operate, and the interrelationships will be discussed. This seminar is intended for anyone not familiar with the operational theories or functional principles of modern vehicle transmission systems. As the material covered is targeted at a number of design and engineering disciplines, attendees should have a minimum of two years design experience in the automotive powertrain field, or preferably a B.S. in engineering or related field. For more information, visit *www.sae.org/learn/content/99018/*.

May 14–16—Eastec 2019 West Springfield, Massachusetts. With more than 500 exhibitors, complimentary conference sessions, industry keynotes and much more, Eastec is an event dedicated to keeping northeast manufacturers competitive. It's where manufacturing ideas, processes and products that make an impact in the northeast region, are highlighted through exhibits, education and networking events. The event offers a unique chance to connect with resources that can solve your company's most pressing problems, improve productivity and increase profits. This year's show includes in-depth workshops that explore several management topics as well as information on additive manufacturing. The Smart Manufacturing Hub examines IIoT, 3D printing, and the latest automation technologies. Keynote speakers include Alan Beaulieu (ITR Economics), Denise Ball (Tooling-U-SME), Mary Ann Pacelli (MEP) and Michael Munday (Arwood Machine Corporation). For more information, visit *www.easteconline.com*.

May 20–23—AWEA Windpower 2019 Houston, Texas. Windpower 2019 is the wind industry's premier North American event with wind energy professionals from all over the world gathering in one place. It's the most effective way for attendees to expand their knowledge base and business network. With competitive pricing and stable policy in place, the wind industry is booming. Now the industry can focus on the future and the other drivers that will propel the industry forward through the 2020s. The program will feature speakers with "disruptive" and innovative ideas that will continue to strengthen wind energy's value proposition and challenge the current way we do business. Attendees will hear about how technology advances will continue to lower LCOE, and learn lessons from other industries that are more mature or have experienced similar rapid growth. They will also receive updates on: state policy support, transmission infrastructure efforts, and emerging and growing offtake trends. For more information, visit *www.awea.org*.

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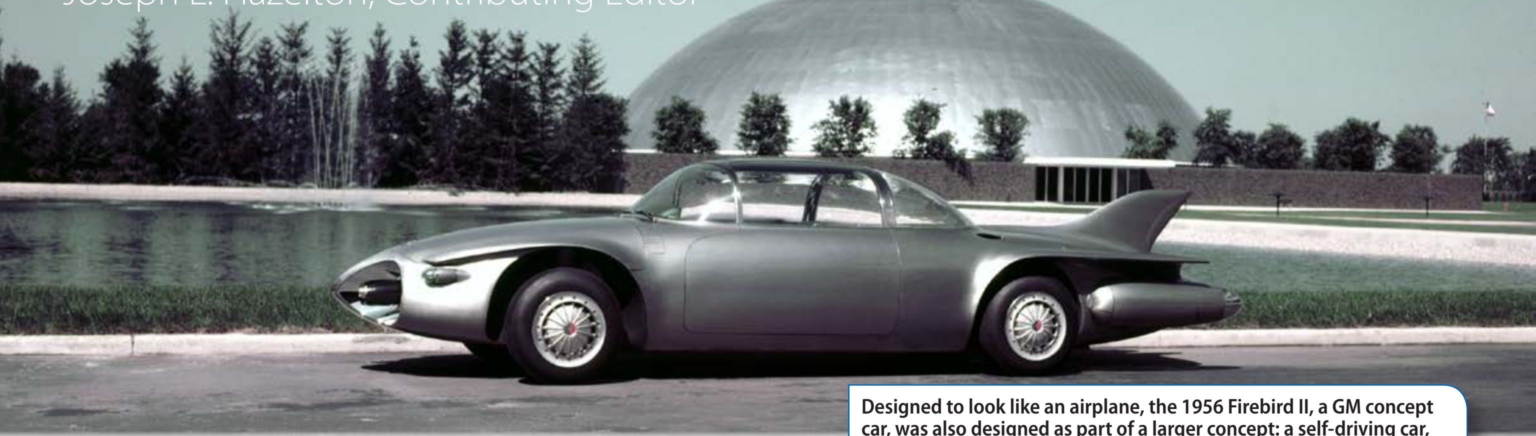
HANDS-FREE DRIVING IN THE 1950s

Joseph L. Hazelton, Contributing Editor



Designed to look like an airplane, the 1956 Firebird II, a GM concept car, was also designed as part of a larger concept: a self-driving car, an autonomous vehicle. (Photo courtesy of General Motors LLC)

Yes, the headline is correct: Autonomous vehicles are *not* a new idea. In fact, in the 1950s, hands-free driving so interested General Motors engineers that they designed a concept car for it.

And in 1956, at its own auto show, the GM Motorama, the automaker unveiled the car, the Firebird II.

The futuristic vehicle looked like an airplane; had two steering control handles, not a steering wheel; and had a dashboard TV screen. The Firebird II was successor to the Firebird XP-21, a one-seater car that also looked like an airplane. The Firebird II, though, was a four-seater, "a comfortable family car," according to its 1956 brochure.

Today, autonomous vehicles are being tested out on the road. In the 1950s, they were a dream of the future. The Firebird II showed how that dream could be a reality, how a car could become an autonomous vehicle — at least, autonomous as imagined in '56.

Now, the Firebird II brochure didn't use the phrase "autonomous vehicle," but it did describe in detail how 1950s technology could be used so drivers could stop steering, could put their hands on their laps, could take their eyes off the road.

However, they could stop steering *only* when they were on a "Safety Autoway." That was a special lane on highways. Or at least, it would've been, if highways were changed as needed.

One major change would've been a metallic strip down the center of a lane on the highway. The strip — GM called it a "conductor strip" — would've transmitted electronic signals to antennas on the Firebird II's front end. Once picked up, the signals would've been used by different motors in the car, motors that controlled steering, speed, and brakes. With the car "tuned in" — GM's words — the driver could stop steering and look elsewhere. The Firebird II would drive at a constant speed and a proper following distance.

However, to get tuned in, the car would have to be *in* the special lane, straddling the conductor strip. Also, once it was in the lane, there would be no passing.

In practice, the system would've worked like this. You're in your Firebird II, on the highway, in the right lane, the slow lane. You want to drive hands-free, so you use the onboard radio and television to contact the highway's nearest control tower, the other major change. The tower oversees your stretch of the highway. Other towers oversee other stretches. GM called each stretch an "Autoway Zone."

Once in contact, you tell the tower you want to switch to automatic driving. The tower tells you to move into the special lane. GM called it the "control lane." At this point, you look at your dashboard viewscreen, at its left panel. It shows a radar pattern when you want to steer into the control lane.

Once you're in the lane and getting signals from the conductor strip, then you can stop steering. You can slide the steering handles forward so they're out of the way and can turn your attention elsewhere. You're now part of a long train of cars moving at a constant speed and at a safe following distance from each other. And, in case of an emergency, all cars in the lane would brake automatically to slow down or would be automatically instructed to move into the highway's slower lanes.

Now, bear in mind, this vision of car and road working together wasn't pie in the sky in 1956. In its Firebird II brochure, GM said this highway could be built using "present-day knowledge and experience through electronic control and computation, radar and television — all now in operation." The Firebird II showed what a car would need to be self-driving on that highway. GM added, though, that the highway wouldn't become a reality until the "far, far future."

Admittedly, the hands-free driving imagined in '56 is different from the hands-free driving being tested today. Back then, hands-free driving would've happened only in a limited, controlled area, a special lane on highways. Today, it's being developed so cars can operate in less controlled, more dynamic areas, on highways *and* city streets.

Despite the difference, it is remarkable to think that hands-free driving was an idea as early as 1956, when Ronald Reagan was an actor and Dwight Eisenhower was president. **PTE**