

Power Transmission Engineering®

A wide-angle photograph of a large industrial factory. The scene is filled with complex machinery, including conveyor belts, metal frames, and various mechanical components. The lighting is bright, and the overall atmosphere is one of a busy manufacturing environment. The background shows a high ceiling with industrial lighting fixtures.

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FEBRUARY 2018



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Power Transmission Engineering

VOL. 12, NO. 1

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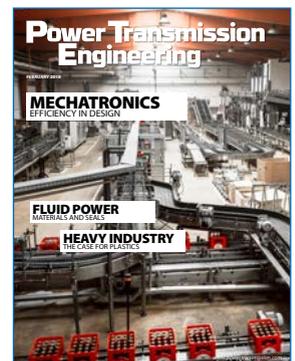
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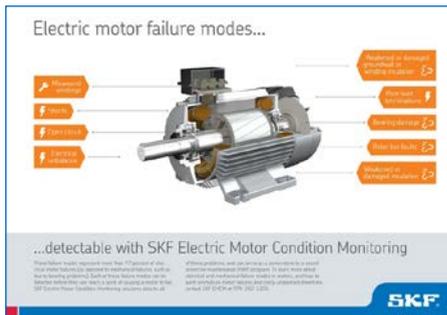
PTE Videos Groschopp

Even when the motor matches the application on paper, you can still run into new variables while testing. Groschopp offers six common checks to help determine why your motor may be overheating in this Tech Tip video (www.powertransmission.com/videos/Groschopp-Tech-Tip:-Troubleshooting-an-Overheated-Motor/)



PTE Videos SKF

SKF dynamic motor monitors capture data from a motor while it is in operation, allowing the user to analyze power quality, motor condition, load torque and motor efficiency. This video introduces SKF's line-up of dynamic testers. (www.powertransmission.com/videos/SKF-Dynamic-Electric-Motor-Monitoring/)



Gilman Examines Machine Tool and Spindle Service

Overall equipment performance is a measurement of performance comprised of three factors: asset availability, production, and quality level. The following article examines the different types of procedures used when a spindle goes down. These range from the most basic plan of action to a highly advanced plan.

(www.powertransmission.com/blog/gilman-examines-an-effective-machine-tool-and-spindle-service/)



Power Transmission Engineering TV

Recent interviews on the **Power Transmission Engineering TV** page focus on mechanical power transmission discussions from Napoleon Engineering Services, Cincinnati Gearing Systems and more: (www.powertransmission.com/tv/)

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Waiting for the Boom



I've always been a big fan of thunderstorms. I especially enjoy that quiet moment of anticipation right after you see a flash of lightning.

There's a tension in the air, a sense of excitement. You know what's coming, and you wait for it...

I feel like we're in that moment, right now. We're waiting for the boom.

The manufacturing economy has enjoyed solid growth over the past few years. Most every prognosticator says the fundamentals are good, and confidence is high that we should see another year of steady, sustainable growth in the 2-3% range. Overall, business is good, and it looks like it will stay that way for a while.

At the same time, there also seems to be a sense of anticipation, especially among manufacturers. The Trump Administration has dangled some tantalizing ideas in front of America, not the least of which are tax reform and the proposed \$1.5 trillion in infrastructure investment. There's a giddy, hopeful excitement in the air. No one's really sure about the long-term effects of the Administration's plans. No one knows for sure if there will actually be a boom, but they sure are excited by the idea.

Theoretically, lowering the corporate tax rate should free up a lot of dollars for capital investment, which means more machinery, which means more bearings, motors and gearboxes. The same is true for infrastructure investment. Building roads, bridges and railways would significantly increase demand for construction equipment, compressors, locomotives and lots of other power transmission-consuming machinery.

However, booms are awfully hard to predict, whether you're talking about thunderstorms or the economy. Sometimes the brightest, most impressive flash turns out to be just a flash. You wait and wait, but in the end you get nothing more than faint rumblings.

Maybe there's a boom coming, maybe not. Only time will tell.

But you have to admit that—politics aside—it's an exciting time to be involved in manufacturing. Technology continues to change at an ever-increasing pace, and it's evident everywhere you look. Our cars can now drive themselves. Our homes talk to us. Our mobile devices connect us to everyone on the planet, and soon they'll connect us to every *thing*. Oh, yes, the Internet of Things is real, alright. It's unstoppable, and it's not going away.

You can see it even in something as mundane as a gear drive or actuator. Just flip through the pages of this magazine and you'll see that components are getting smarter, systems are becoming more efficient, and Big Data is being put in the hands of every decision-maker.

The world is changing, and clearly, manufacturing is at the heart of that change.

So in the end, it doesn't really matter if there's going to be a manufacturing boom, just like it doesn't really matter if there's thunder after the lightning. What really matters is the rain. The rain is like that slow and steady economy. It may not be as exciting, but it provides the fuel for growth.

And when you look beyond all the flash and thunder, you'll notice there's a manufacturing renaissance going on. That's what's important, and that's what's fun to be a part of.

A handwritten signature in black ink that reads "Randy Stott". The signature is fluid and cursive, with the first letters of "Randy" and "Stott" being significantly larger and more stylized than the rest of the letters.

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Nord Drivesystems

ADDS INVERTER SIZE TO CONVEYOR DRIVE SERIES

The new Nordac Link series of field distribution systems is designed for networked intralogistics facilities with many drive axes. These frequency inverters and motor starters enable flexible configuration of features and functions to suit application requirements. Coded plug-in connectors for power, communications and sensors enable swift and safe commissioning. Integrated maintenance switches and direction switches facilitate servicing these systems later on. Size 2 Nordac Link frequency inverters premiered at the 2017 SPS IPC Drives show in Nuremberg, Germany. These latest field distribution systems are suitable for motor ratings up to 7.5 kW. The various models in this series now offer solutions for all typical tasks in postal hubs, airport baggage handling systems and warehouses. The AC vector drives are suitable for horizontal conveyors as well as inclined and vertical conveyors. They integrate hoist functions and the safety functions STO and SS1 according to EN 61800-5-2.

The drive manufacturer offers to implement project-related variant reduction, drawing on extensive experience in a wide range of industry sectors. Plant manufacturers and operators can reap significant cost savings through streamlined processes in

purchasing and engineering as well as during commissioning and maintenance. The Nordac drive electronics range comprises several frequency inverter series for motor outputs up to 160 kW. Featuring an integrated PLC, these AC vector drives can carry out logical sequences and provide autonomous process control. Nord has enabled drives for connection to a cloud using only standard components.

The company is also preparing a fully operational software solution for predictive maintenance, based on Nord inverters, which, due to their onboard PLC, are fully capable of processing status data (such as power consumption, speed, voltage, and status word) as well as data from externally connected sensors (e.g. light curtains, vibration sensors). Offering such solutions, Nord enables machine manufacturers and system integrators to develop advanced maintenance concepts or new service models in the world of digitization and IoT/Industry 4.0.

For more information:

Nord Drivesystems
Phone: (608) 849-7300
www.nord.com



Gearing Solutions

OFFERS 5 HP FLEXFRAME SPEED REDUCER

Gearing Solutions introduces its Flex-Frame 5HP face mounted speed reducer with patented adaptors, which allow them to be used with either IEC or NEMA motors. This allows users to quickly switch or replace motors, interchange IEC and NEMA motors for export applications, add face, flange or foot mounts, and use GS convertible shaft adaptors to match virtually any motor to any gearbox.



Consisting of a face mounted speed reducer with a hollow shaft input, these new designs function as gearheads. Built on the Nu-Lobe gear design, they are available in standard ratios of 3:1, 4:1 and 5:1, making them ideal for a wide range of industrial and commercial applications, including use on mixers, parking lot gates, wind turbine yaw drives, conveyors, hoists and other material handling equipment, food processing equipment, robotic drives and more.

With aluminum housings, FlexFrame units are up to 50 percent lighter than other units with similar torque ratings, creating a premium weight to torque ratio (power density). This allows them to be used in cantilevered and over-center designs where heavier gearheads are not feasible. Gearing Solutions gearheads are shock load resistant, cost-effective, and easily mounted.

For more information:

Gearing Solutions
Phone: (440) 498-9538
www.gearingsolutions.com

Ogura Industrial

RELEASES MS SERIES CLUTCHES AND BRAKES TO NORTH AMERICAN MARKET

Ogura Industrial is pleased to announce a new addition to their product line. Although this product is not new to Ogura, it is new to North America. The MS series is finding new opportunities for machinery manufacturers in North America because of some of its unique features. The MS series is a complete line of clutches, brakes and combination clutch-brake units. There are eight sizes available ranging in torque from 9-738 lb ft. The key advantage with the MS series is that it can automatically adjust for wear. Once a clutch or brake is set in an application, the armature maintains the proper airgap so that time to speed or time to stop remains constant through the life of the unit. In addition to individual clutches and brakes, there is also a foot mounted version which is enclosed in a foot mounted housing with both double bearing input and output shafts, providing excellent overhung load capability.



For more information:

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

Stafford

SHAFT COLLARS SET UP RAPIDLY WITHOUT TOOLS

A line of quick release shaft collars with a mounting flat for securely attaching cameras, counters, optics, sensors and many other devices is available from Stafford Manufacturing Corp. of Wilmington, Massachusetts.

The Staff-Lok Shaft Collar features an integral hinge with a conformal cam lever and a knurled screw that provides fully adjustable clamping by hand

without tools. Featuring a mounting flat with a countersunk drilled and tapped hole and two mounting holes on the face, it permits the attachment of optics, sensors and other devices along with rapid setup and positioning.

Machined from steel with a non-glare black oxide finish, Staff-Lok Shaft Collars are ideal for use as clamps, stops



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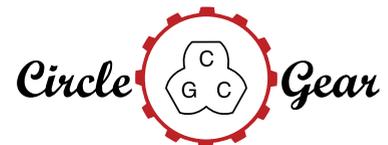
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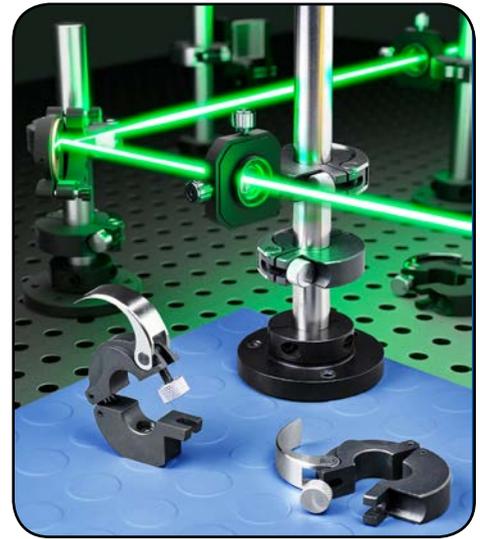
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For more information:
Stafford Manufacturing Corp.
Phone: (800) 695-5551
www.staffordmfg.com



Rexnord

BROADENS ITS IIOT SMART TAG SOLUTION OFFERING

Rexnord is pleased to introduce the Smart Coupling, part of its growing portfolio of connected products featuring the IIoT Smart Tag Solution. Its Coupling & Shaft Solutions products, including Elastomeric, Disc, Grid, and Gear Coupling products as well as Torque Limiters, are used in a variety of applications across numerous industries in the Energy, Industrial Equipment and Material Handling Sectors. These products provide excellent torque transmitting, vibration dampening, and high misalignment capacity, while enabling extended life to installed equipment such as industrial fans, boiler feed pumps, gas turbines, on/off-shore centrifugal compressors, automotive test benches, bulkhandling and paper mill drives, among others. Rexnord's offering of Smart Coupling products, as well as the recently launched line of Thomas 4-Bolt XT SR and XT SRLS products, were featured at the 2017 Turbomachinery & Pump Symposia in Houston TX, Dec 12-14. During this show attendees were able to discover the strengths of these new products while immersing in the user ex-

perience and capabilities deployed using the IIoT Smart Tag solution. Rexnord provides a range of connected products that offer a means to monitor critical parameters of your equipment, providing operational analytics that anticipate the failure of key components, increasing the performance of your system, prolonging the useful life of your equipment and avoiding catastrophic failures that result in costly production downtime. "Rexnord's portfolio of Smart Coupling and shaft management products with the IIoT Smart Tag Solution is bringing an increased level of connectivity to our customers and end-users," says Chino Imediegwu, Director Global Product Management. "As part of our strategic DiRXN initiative, this new capability enables us to deliver value to our customers throughout the product's lifecycle in totally new ways while increasing the ease of doing business and positioning Rexnord as the OEM of choice for their coupling and PT drive component solutions."

For more information:
Rexnord
Phone: (866) 739-6673
www.rexnord.com/couplings



Portescap

OFFERS LINEAR ACTUATOR WITH HIGH DEGREE OF ACCURACY AND REPEATABILITY

Portescap introduces the new 35DBM high power Stepper Can Stack Linear Actuator.

This 35mm linear stepper motor offers an enhanced design ideal for applications demanding high linear force. The new 35DBM features an optimized magnetic circuit powered by high energy neodymium magnets. The 7.5 degree step angle provides finer incremental movement with a high degree of accuracy and repeatability.



With a holding force of 112N, the 35DBM stepper linear actuator is suited for use in applications such as auto injectors, laboratory automation, medical pipettes and valve actuation. Portescap's 35DBM high-force actuators are fully customizable for adaptor tips, stroke lengths, windings, flanges and end of motion detection sensors.

The 35DBM is available in captive and non-captive versions with various leadscrew pitch and winding options on Portescap's online motor selection tool, *MotionCompass*. They are manufactured in an ISO certified facility and are RoHS compliant.

For more information:

Portescap
Phone: (610) 235-5499
www.portescap.com

Steinmeyer

OFFERS A SELECTION OF MINIATURE BALL SCREWS

Steinmeyer recently announced a new program to stock a selection of miniature ball screws. The samples are available now for immediate shipment. The program involves stocking a selection of catalog designs that are mainly intended for use as prototypes for new customers. It is ideal for engineers needing miniature ball screws for early-stage development of precision



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machines, instruments and devices. Stock consists of diameter selections of 3 mm, 6 mm, 8 mm, and 12 mm, with a variety of pitches and lengths. Nut designs include threaded or cylindrical.

The miniature ball screw program includes the option to pay by credit card to enable engineers to purchase the samples with minimal effort.

“We want to make it as easy as possible for engineers to get their hands

on a Steinmeyer miniature ball screw,” said Bruce Gretz, executive vice president at Steinmeyer. “Once they feel the quality and workmanship, we are confident that they will be customers for a long time.”

For more information:

Steinmeyer, Inc.
Phone: (781) 273-6220
www.steinmeyer.com

Intellidrives

ULTRA-THIN DIRECT DRIVE ROTARY TABLES
OFFER DYNAMIC SPEED RANGE

The Intellidrives ACR-335UT precision rotation stage is a low profile rotary table with high-speed direct-drive rotary servo motor. The large 335UT mm center aperture and light-weight construction makes this rotary stage a suitable option for handling 300 mm silicon wafers for semiconductor processing.

ACR-335UT has very wide dynamic speed range and can move at sub-rpm speed with low velocity ripple and accelerate quickly to 300 rpm. This stage can be easily installed into IntelliDrives low profile open frame XY tables with a minimal stack-up height to minimize Abbe error.



These features make the ACR-335UTUT outperform the stability, acceleration and settling speed of traditional servo motor gear-driven mechanisms. IntelliDrives offers a wide range of servo amplifiers and advanced controllers to provide a complete, integrated package.

For more information:

Intellidrives, Inc.
Phone: (215) 728-6804
www.intellidrives.com

JW Winco

FLAT KNURLED THUMB SCREWS OFFER NUMBER OF ASSEMBLY OPTIONS

JW Winco, Inc. recently announced the offering of GN 653.2 Steel & Stainless Steel Flat Knurled Thumb Screws with Recessed Stud for Loss Protection.

The thumb screws, which are RoHS compliant, can be used to prevent loss of the thumb screw, due to the recessed portion of the stud. When using, instead of a typical tapped and bored hole, it is necessary to provide tapped bores with a thread on each of the two elements to be assembled. Additionally, a clearance bore on one or both sides is required.

Depending on the design and required clamping length of the component being attached, there are a number of assembly options. The steel knurled thumb screw body with a black oxide finish has tensile strength of class 5 and the visible face is fine turned. The stainless steel version is made of 303 stainless steel and comes with a matte, shot-blasted finish.

For more information:

JW Winco
Phone: (800) 877-8351
www.jwwinco.com



Zero-Max

ETP POWER SHAFT LOCKING BUSHING ENSURES FAST MOUNTING OF COMPONENTS

Zero-Max's ETP Power keyless connections can be used as the locking device in laminated floor manufacturing systems. They are also useful for locking into position gears, pulleys, sprockets and other components in automated machinery.

Handling torque ranges from 531 to 10,620 inch lbs. (60-1200Nm), these ETP Power shaft locking bushings from Zero-Max provide the highest radial load performance within the single screw ETP product line.

The ETP Power single radial screw design ensures fast mounting, repositioning and phasing of the components to the shafts. ETP Power positions in seconds and can be readjusted hundreds of times just as quickly and without any axial movement of the bushing or component along the keyless shaft. An Allen wrench is all that is required to mount and lock these bushings into place. They have sealed, clean lines that resist debris collection and clean easily without any special maintenance.

The ETP Power's single radial tightening screw provides a solid and precise connection between shaft and hub, unlike conventional shaft

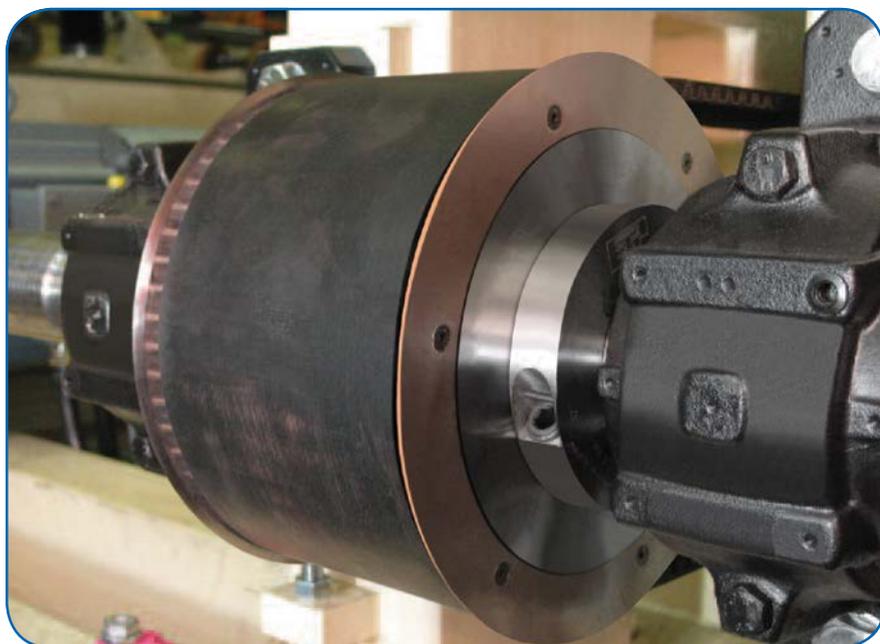
locking bushings. It incorporates a double-walled sleeve filled with a pressure medium. When the actuation screw is tightened, the hydraulic pressure medium in the sleeve expands the double walled sleeve, forming a very tight, continuous connection between the shaft and mounted component. The bushing aligns precisely without axial movement as it is tightened.

The unique, single adjusting screw design makes the ETP Power superior to conventional mechanical locking bushings where numerous adjusting screws are needed. Tightening numerous screws creates axial movement of the bushing and is less precise.

Available in 15, 19, 20, 22, 24, 25, 28, 30, 32, 35, 38, 40 mm and 3/4", 1", 1 1/4" 1 1/2" and 1 3/4" shaft sizes. ETP Power bushings are applicable in new and retrofit applications, particularly in automated machinery applications.

For more information:

Zero-Max
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www.zero-max.com



Efficiency of Design

Energy efficiency is for more than just motors. Here are some mechatronics companies making sure you get more bang for your buck when it comes to your power bill.

Alex Cannella, Associate Editor

Energy efficiency is a buzzword that most commonly gets tossed around when talking about motors. Companies regularly (and rightly) tout how much their new IE5 motors are going to save you on your electricity bill while regulations have repeatedly raised the floor on the bare minimum efficiency required in commercial motors.

Energy efficiency isn't just for motors, though! The DOE has also been taking looks at full systems efficiency, such as with pumps, for example. And making sure every part in both your products and your manufacturing equipment is as energy efficient as possible goes a long way to making your own manufacturing efforts lean and efficient.

Have you considered, for example, the energy efficiency of your product's actuators? They're not exactly what you'd consider your primary source of energy consumption in most cases, but they're still a vital part of a lot of applications from the medical industry to fully automated manufacturing lines.

Today, we're going to be looking at the full automation side of that coin, or more specifically, at how SKF is expanding in the industry with its line of CASM (Component Actuator Servo Modular) electromechanical cylinders.

Cylinders are used regularly in automated assembly line machines, but they've predominantly been hydraulic- or pneumatic-based. SKF has expanded its line of electromechanical actuators, which have been designed to handle the constant wear of a 100% duty cycle, with the introduction of the CASM actuators to complement their existing assortment. The primary difference between the CASM actuators and SKF's other high performance actuators are the sizes,

which lend themselves to pneumatic replacements.

According to Cynthia Daneker, application engineering manager at SKF, many of the company's customers had started asking for actuators capable of handling full duty cycles, heavy loads or rapid movements. These applications were typically using pneumatics and hydraulics. By creating the CASM line, SKF was able to offer the market drop-in replacement products which met the basic envelope of the pneumatic actuators found in the market.

SKF's most recent electromechanical cylinder line, the CASM, was designed specifically to handle higher speeds and loads while running at up to a 100% duty cycle.

To compare CASM with other conventional cylinders is to compare the benefits of electromechanical cylinders themselves. Without the restriction on duty cycles holding them back anymore, electromechanical cylinders have a number of advantages over competing technologies, primary amongst them being energy efficiency.

According to SKF, an electromechanical cylinder will actually consume 90% less power than a pneumatic one. A majority of the savings are due to the nature of the cylinder—a pneumatic cylinder requires significantly more power to compress air than an electromechanical cylinder needs to just feed electricity through—but an electromechanical cylinder is also more efficient and loses fewer watts received from the motor.

Just replacing a cylinder won't automatically drop your energy bill by 90%. After all, you've still got all the other parts in the system drawing electricity as well. But it's still enough to



SEW Eurodrive's MOVIGEAR drive system has seen adoption outside its intended food and beverage market.

see a difference in your overall energy expenditure, and when coupled with other similarly energy efficient parts, the change spells savings in your daily operations.

The CASM line also gives manufacturers a wide amount of flexibility. SKF's actuators are designed to work with a manufacturer's existing setup, and can even be custom-made to accommodate specific customer requirements.

"[Customers] can use their own motors. They can use their own controls. The interface to the customer is highly customizable," Daneker said.

They're also programmable. According to Randy Hams, senior application engineer at SKF, several of SKF's actuator lines are fully programmable. Product lines such as the CASM cylinders can be programmed with almost any routine a manufacturer might require, no matter how complex. According to Hams, the sky is virtually the limit.

"If the time and money are available, there is practically no limits to what can be done with the current electronics available on the market for

closed-loop systems,” Hams said.

And thanks to their flexibility, SKF’s electromechanical cylinders can be reprogrammed more easily than other actuators. Often, reprogramming a pneumatic or hydraulic cylinder could potentially require a technician to physically adjust the cylinder during setup, as well, but an electromechanical cylinder has no such requirements, making reprogramming a simpler matter.

In their current form, CASM cylinders outstrip their pneumatic and hydraulic cousins, accomplishing the same tasks while using only a fraction of the energy. And with this product under their belt, SKF has been spending the past few years specifically taking aim at automated applications that were formerly not inside their reach. In particular, they’ve been making inroads with the automotive manufacturing industry, one of the strongest markets for automation.

SKF’s actuators aren’t the only product becoming more popular in the automotive industry. SEW Eurodrive’s MOVIGEAR mechatronic drive system has also been seeing adoption amongst automotive manufacturers.

Much like SKF’s actuators, MOVIGEAR’s main selling point is energy efficiency—and the savings that come with it. SEW’s studies have found that in some cases, MOVIGEAR uses up to 40-60% less energy than existing drive systems. According to Rainer Neufeld, corporate electronics manager at SEW Eurodrive, it’s the mechatronics ideology of studying electronics and mechanics side by side that has led to breakthroughs that have made the MOVIGEAR so efficient.

“Because of that mechatronics approach, a lot of our products reached the highest efficiency because the motor, gear, electronics, and communications are all designed to work together,” Neufeld said. “And that’s where you gain the highest amount of efficiency.”

SEW’s Electronics Product Manager, Brian Lambert, also cited the drives’ high breakaway torque as a primary reason behind their efficiency.

“You don’t have to oversize the motor because of the high breakaway torque,” Lambert said. “You can

right-size it and that’s where a lot of the energy savings come in at the end of the month when you’re looking at your electric bill.”

MOVIGEAR was originally designed with the food and beverage industry in mind, with an ergonomic design that washes easily and has no corners for food or bacteria to get caught in, but many of the MOVIGEAR’s selling points are appealing to more than just the food and beverage manufacturers.

“It was actually designed for the food and beverage market, but soon we found out that this was a very high-efficient product line, and very compact compared to other gearmotor lines we have,” Neufeld said.

MOVIGEAR drives have found applications in conveyor lines in the automotive, airport, and packaging industries, as well. In particular, SEW experienced a breakthrough with an



SKF’s CASM electromechanical cylinders are designed to operate in applications where a 100% duty cycle is required.

airport in California that was overhauling its entire conveyor system — 650 conveyors in all.

MOVIGEAR’s primary selling point was savings via energy efficiency, but according to Neufeld, the drives also offered up-front cost advantages. Because they drew less electricity, SEW’s drive systems could also run with smaller transformers, which the airport had been considering upsizing during the overhaul, saving the airport even more money compared to competitors.

The drives were also more efficient when it came to managing spare parts. The airport had originally been planning on maintaining an inventory of over 100 spare parts, but with SEW’s



system, they only had to keep 15 on hand for the entire system.

And the MOVIGEAR line will only become more maintenance-efficient as time goes on. Like many other IIoT-savvy companies, they're working on rolling out a preventative maintenance software upgrade. The upgrade would allow manufacturers to maintain a close eye on their drives, which will constantly track everything from how much current the motor draws to fault histories, and predict future maintenance needs before they happen based on that information. In addition, manufacturers can use the software to trigger warnings when a drive begins exceeding its limits, such as if a drive begins to run hotter than a certain pre-defined threshold, for example.

not, absolutely true, doubly so in a manufacturing line or conveyor system that is constantly running. When your automated line is running non-stop around the clock, the hours of use add up quickly, and across thousands of hours of runtime accumulated over multiple years, those incremental improvements in energy efficiency add up. It may take a few years to see, but a more efficient part will almost always be cheaper in the end.

The issue for companies like SKF and SEW is convincing potential customers. They can put together graphs and cite test results, but at the end of the day, the kind of savings they tout can sound unbelievable. Being able to energy costs by 90% sounds too good to be true, like a mysteriously conflated

it's been proven with drive systems, it's been proven with actuators. Your mileage will definitely vary depending on how often your machines are active and how stark the difference in efficiency is, but energy savings are something that can be calculated before you make a final decision to purchase. Hams noted that with actuators, in particular, also having a high-efficiency motor will also matter when calculating your savings.

"In electric actuation, it is the energy in that determines the energy out," Hams said. "This energy comes from a motor. In commercial actuators, the motors are primarily low cost brushed DC and single phase AC. In the CASM, we use servo, BLDC and three-phase AC that have the ability [to] accept high-end control systems with closed loop technology."

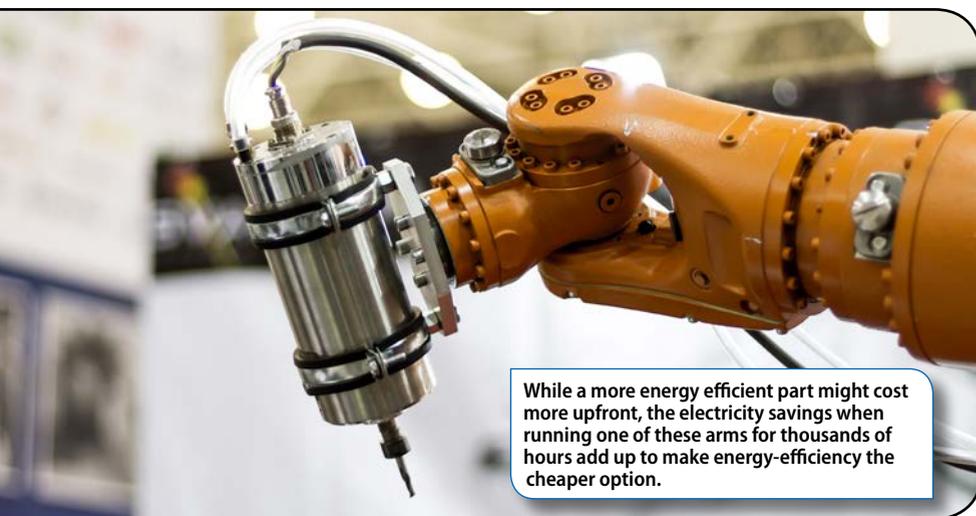
Daneker also noted that sometimes the pressure to switch to more eco-friendly products can come from then next rung on the manufacturing ladder. For every company that's balked at the additional cost of purchasing an electromechanical actuator from SKF, there's been a new lead that's been pressured by their own customer base to find more energy efficient or green options.

Customer pressure shouldn't be what ultimately convinces you, however. The savings with energy efficient products speak for themselves, no matter the field you operate in. It might not ultimately be an SKF actuator or SEW drive that you buy. But high-efficiency parts do make a difference to your bottom line, and when manufacturers are trying to find any way possible to make their manufacturing efforts leaner and more efficient than ever, that should be getting your attention. **PTE**

For more information:

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SKF Motion Technologies, Inc.
Phone: (800) 313-4753
www.skf.com



While a more energy efficient part might cost more upfront, the electricity savings when running one of these arms for thousands of hours add up to make energy-efficiency the cheaper option.

Both companies have run into an unexpected issue, however: convincing customers that their product will save them money in the long run. According to Daneker, some customers tend to balk at the extra cost of SKF's electromechanical cylinder that they spend upfront compared to pneumatic or hydraulic competitors.

But the argument for SKF's cylinders goes the same as for any other product with a higher energy efficiency: Once you calculate how much you can save on your energy bill, the extra you'll spend up front is pocket change compared to the costs you would otherwise accumulate over the next five or ten years of using a less efficient competitor.

It's a claim that is, more often than

number that the marketing department marked up by taking advantage of very carefully curated facts.

In SEW's case, the airport that eventually installed MOVIGEAR drives outright didn't believe the energy savings SEW advertised, and it took a lot of sitting down and talking

"A lot of times, customers have a hard time believing the efficiency savings and they start second guessing," Lambert of SEW said. "But no, these are the numbers that we've got. Seeing is believing, though, and we've more than once sent a unit out to a customer to run on the line and see on a power meter for themselves."

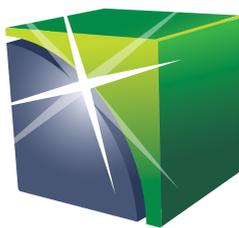
But the fact of the matter is that energy efficient products do save money. It's been proven with motors,



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Flexibility in Fluid Power

Latest Sealing Technologies Offer Optimum Wear and Frictional Characteristics.

Matthew Jaster, Senior Editor

The selection of seal materials greatly depends on factors such as operating temperature, pressure rating, fluid type and the chemical compatibility of fluid. While the most common seals are manufactured with materials like PTFE, rubber or polyurethane, the fluid power industry is always looking for unique sealing solutions that work hand-in-hand with the most difficult applications.

With manufacturing capabilities changing rapidly, organizations like SKF and Freudenberg Sealing Technologies need to create dependable products for fluid power applications—and a little flexibility and creativity goes a long way in meeting customer's increased demands.

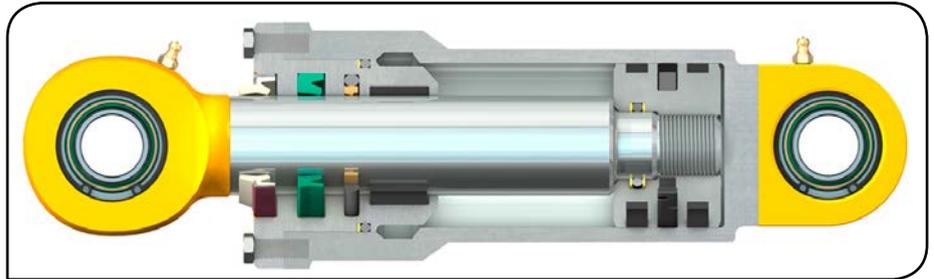
"Customers are seeking increased power density, along with changes in hydraulic fluids, rod surface coatings, and longer equipment life expectancy," said Scott Barth, business development manager for hydraulic seals at SKF. "Developing new materials, seal designs and sealing systems is necessary to meet these increasing market demands."

"We are seeing trends toward much higher pressures, higher loading, wider temperature ranges (higher and lower), more use of biodegradable & synthetic-based oils, and longer life. These lead to the need for more durable & robust sealing technologies," said Norbert Frank, global segment director, fluid technologies at Freudenberg Sealing Technologies.

SKF Focuses on Expanding Material and Seal Capabilities

How do you meet the sealing requirements of a several different fluid power applications? It starts with broadening your product portfolio. SKF has several new and innovative sealing technologies including:

Hydrolysis-resistant urethanes for



This photo shows a hydraulic cylinder integrating seals between various components in the hydraulic cylinder (photo courtesy of SKF).

use in high temperature water applications or hot and high humidity ambient environments; internally lubricated urethanes for lower friction and improved wear resistance on ceramic coated shafts; bonding urethane to PTFE and other rigid plastics for improved performance at high pressures, temperatures and speeds; bonding thermoset materials to PTFE and other plastics for improved sealing and longer service life and more.

"Creating seal assemblies with materials from multiple manufacturing capabilities allows SKF to offer unique sealing products that address some of the most difficult fluid power sealing applications," Barth said. Additionally, creating seal packages that promote effective fluid sealing and improve the device efficiency by reducing losses due to seal friction."

Harsh and demanding applications really force these companies to find new and innovative ways to produce seals. For example, OEs are using more biodegradable fluids today which are more susceptible to entrained water. Most seal-grade urethanes fail from hydrolysis when exposed to high temperature, water or humidity. These hydrolysis-resistant urethanes offer a solution and performance upgrade to OE's using biodegradable or even some water-based fluids.

"As OE's move away from Chrome plated shafts to other options, such as

Nitride or ceramic coatings, seal wear and service life become a concern. SKF is developing new urethanes with better wear and frictional characteristics to extend seal life on these new and more aggressive surface coatings," Barth added.

There are also some unique fluid power applications with high speed (rotary or reciprocating) and high pressures, which lead to high friction and increased wear which tends to reduce seal life. Incorporating PTFE or Nylon in to their seal design in critical locations, allows SKF seals to operate at lower temperatures, which can reduce seal wear and prolong service life.

Premium urethane, PTFE, PEEK, Nylon, Hytrel, NBR, HNBR, FKM... There are several material combinations SKF uses to enhance seal performance to meet a customer's application requirements. And the company will continue to look for new materials that will enhance their product offerings in the future.

Another area that is often addressed is how to make fluid power components more energy efficient. Utilizing materials with improved frictional properties in seal designs—that also reduce operating friction—can improve the efficiency of the fluid power being converted into a force for doing work.

"Also, designing sealing systems that reduce the pressure loading of

individual seals can lead to a reduced overall friction loss from the seal package, which also improves the efficiency of the fluid power being converted into a force for doing work,” Barth said.

The end result hopefully is creating a product that both improves reliability and reduces environmental impact. Using more capable seal materials and optimized seal designs, as well as sealing components designed to work together as a sealing system, result in a more reliable sealing package, with longer service life and less likelihood that a fluid leak could occur and result in a spill into the environment.

Fluid power OE's are seeking to increase the power density on their equipment, which can lead to higher temperatures, pressures and dynamic velocities. From a seal perspective these increased system parameters can lead to noise, increased friction and heat generation that accelerate seal wear and material performance decay.

How will these sealing technologies evolve in the future?

Barth said they will need to keep up with increases in operating pressures, wider temperature ranges, more aggressive system fluids, and longer expected service life. This will be accomplished through the development of more capable seal materials, and improved seal geometries. R&D at SKF is actively working on expanding material and seal capabilities to meet these increasing customer demands.

Freudenberg Touts Latest Fluid Power Technology

Freudenberg Sealing Technologies has supported the fluid power industry for decades with highly innovative products that help customers tackle challenges such as rising demands for longevity, leak tightness and friction control. Four recent innovations illustrate the company's success.

One of its newest materials, polyurethane 94 AU 30000, is setting new standards that meet fluid power

requirements while ensuring a broader range of use. This innovation is complemented by the hydraulic wiper DMRW2, which is made of 94 AU 30000 and sheet metal. It features an integrated pressure relief function, a wiper lip and an additional sealing lip, which improves the sealing effect.

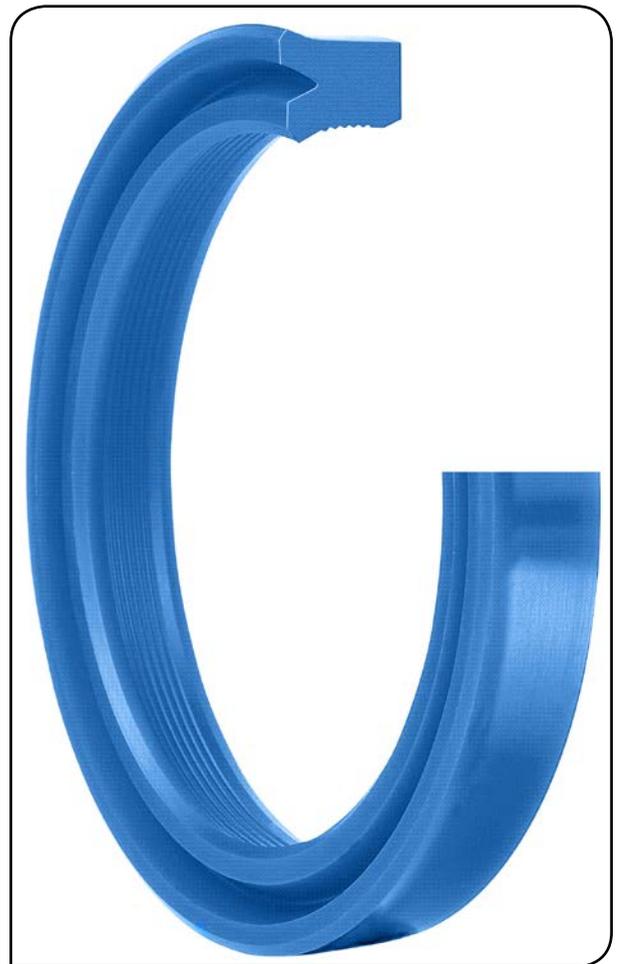
Another product Freudenberg is offering to the fluid power market is the BlueSeal, a patented Simmerring shaft seal that offers a weight savings of 40 percent compared to a conventional seal and requires only half as much installation space. This technology features a low-friction polytetrafluoroethylene power-optimized (POP) lip design that was developed to mechanically resist high pressures and stand up to aggressive substances.

Finally, the company's HDP330 High Pressure Piston Seals allow for optimum sealing performance in fluid power applications while enabling customers to save on mating component machining costs. HDP330 piston seals consist of a step cut polyamide sealing cap and an elastomer energizer. The step cut cap is molded with unique molding processes to allow for a very flat sealing surface to prevent cylinder drift in the applications. The step cut design allows for easy assembly into the piston gland.

Until recently, manufacturers often had to keep different hydraulic cylinder seals in reserve, depending on the region of the world where the machine would be used and the medium that the hydraulic system would employ. But construction machinery today is

developed for worldwide use and seals must be able to do their job reliably for years in the arctic or in the desert.

“The new generation of polyurethane (PU) seals delivers on this by extending maintenance intervals, increasing uptime and reducing costs, making them especially well-suited for construction and agricultural machinery, as well as materials handling technology. 94 AU 30000, for example, is more resistant to water and synthetic hydraulic fluids and withstands major temperature fluctuations better than other existing polyurethane materials. The material offers excellent performance in heat and cold and can be used in mineral hydraulic fluids at temperatures ranging from -31°F (-35°C)



Besides seal design, friction reduction can also be achieved by special Reduced Friction Nanotechnology (RFN) coatings or by grooving sealing surfaces (photo courtesy of Freudenberg).

up to 248°F (120°C),” Frank said.

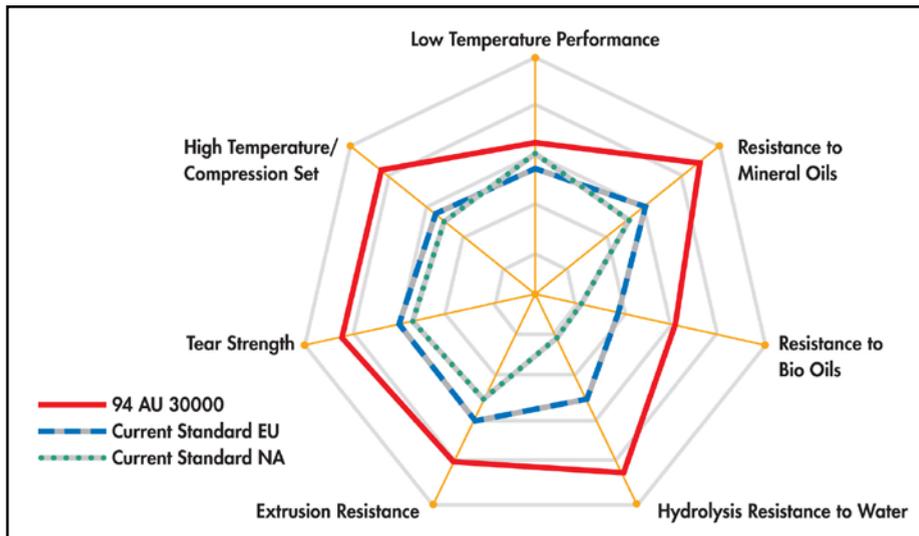
The main materials at Freudenberg Sealing Technologies are polyurethane, polyamide and polytetrafluoroethylene (PTFE). The requirements for materials in this market include high values for tensile strength and elongation at break, resistance to oils and ozone, high elasticity and abrasion resistance. “We develop and manufacture our own materials which allows us to custom tailor the blend or additives to give very specific advantages based upon the application,” Frank added.

For example, while polyurethane meets basic industry requirements very well they are also subject to severe wear and manufacturers are increasingly looking for universal solutions to cover broader ranges of applications. Materials like 94 AU 30000 are being developed to provide such universal solutions.

“At the same time, we continue to work on development of new elastomers that offer even better performance and longevity, which will lengthen maintenance cycles and reduce downtime,” Frank said.

These include products like BlueSeal that help reduce friction and strongly

Freudenberg Sealing Technologies step cut design allows for easy assembly into the piston gland and the robust design and material allow for the use of DOM (drawn-over-mandrel) cylinder tuning rather than honed. This can vastly reduce the cost of the cylinder assembly.



Materials like 94 AU 30000 are being developed to provide universal sealing solutions.

improve the energy efficiency of a system. Besides seal design friction reduction can also be achieved by special Reduced Friction Nanotechnology (RFN) coatings or by grooving sealing surfaces. Freudenberg can also use FEA simulations as physical testing to customize the sealing-tightness-to-friction ratio.

Reduced friction means reduced temperatures and reduced wear in the seal. If a seal causes less friction it will perform longer and thus prevent

oil and other fluid leakage. Hydraulic fluid leaks are an unmistakable sign of imminent seal demise. But the early effects of material failure are not directly visible in most cases.

There is an increase in a vehicle’s CO₂ emissions if slight disturbances in the frictional torque of a crankshaft seal occur. The triggers are often aggressive media and extreme loads.

Additionally, fluid leaks in some industries can have dire consequences. Fluid leaks in agricultural equipment could lead to soil, water and crop contamination.

“Increasing longevity, leak tightness and friction demands on seals have led to new applications for both existing and new Freudenberg products such as certain Simmerring shaft seals and hydraulic cylinder seals. Our expertise allows us to choose specific material and design combinations that best address the challenges at hand,” Frank said.

Agriculture machinery is becoming smaller and lighter to achieve cost reductions and to meet CO₂ emission restrictions. The installation of additional components like filters into this machinery helps achieve CO₂ reductions, but also leaves less installation space for other components.

“Therefore, our products need to become smaller which in turn increases physical influences like power density. This means our products have to withstand higher pressure and temperatures,” Frank added.

The seals in a hydraulic cylinder also have so-called guide elements in the form of rod and piston seals that are designed to prevent contact with the cylinder housing. The challenge here is a trade-off between absorbing high transverse forces and keeping frictional losses as low as possible. This is a complex issue especially for long-stroke cylinders, due to the insufficient lubrication during short strokes and the sagging of the long piston rod.

Freudenberg introduced high-performance guides, the patented piston and rod guides Guivex KBK and SBK, more than 10 years ago. The company's patented profiling of the guide rings from a fabric-based laminate greatly facilitates the entry of the lubricant into the area between the guide and the

products from proven and certified partners," Frank said.

Another trend is increasing demand for energy efficiency, according to Frank. "Given rising prices for energy and strict legal requirements that govern the use of energy, our customers are demanding more energy efficient components, especially for pumps and motors or for cylinder coatings (like ceramics). Energy efficiency is also an important factor for air compressors for pneumatics."

And with green efforts across the globe, sustainability remains an important focal point. Seal design can play a significant role in making sure green manufacturing initiatives are being met.

"There is a rising demand to reduce

Freudenberg's HDP330 High Pressure Piston Seals allow for optimum sealing performance in fluid power applications while enabling customers to save on mating component machining costs.



counter-surface. Shear forces that occur are evenly distributed.

The need to do more work within a given space typically means higher pressures for hydraulic systems. In addition to high-performance guides, Guivex KBK and SBK, Freudenberg's material offerings like 94 Au 30000 and HDP330 piston seals help address these challenges.

"We are seeing some major trends that influence fluid power applications, including strong commoditization of sealing solutions and an increased demand in mid-level quality products. Customers are no longer willing to pay high prices if there are 'good enough' products on the markets, even if these products lack longevity or reliability. Freudenberg is well prepared to handle this trend thanks to our special sourcing teams that can provide such

environmental impact of products and recyclability. The use of ecological lubricants or biodegradable oils has a certain impact on sealing materials. And we have norms and regulations like REACH that are banning materials like chromium plating," Frank said. **PTE**

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Emerging Motor Technologies

Copper's Continuing Role in Energy-Efficient Motor Development

Copper Development Association

When it comes to developing new motor technologies, copper continues to be integral to constant improvements in motor efficiency.

The standard induction motor achieved significant gains in efficiency through more copper in the windings, a higher-grade steel core, improved bearings and insulation, and improved cooling fan design.

As the search for ever-increasing efficiency brings the advent of new motor technologies and designs beyond the induction motor, copper will continue to be integral to the efficiency and longevity of these new technologies: from switched reluctance motors, permanent magnet motors and copper motor rotors.

According to E.F. 'Ned' Brush, Ph.D. of BFF Associates and expert in the area of motor technology, "The traditional major motor technology has been the induction motor. More recently, there is the permanent magnet motor, which has higher efficiency ratings and the switched reluctance motor with improved efficiency for specific application. Each has its place. The induction motor has been the workhorse in the industry for over 100 years. Although the induction motor has been around for that long, there are exciting developments in the motor design itself, achieving improved efficiency. One of those innovations is the development of the *copper rotor motor*, which can reduce motor losses by as much as 12 to 15%."

This report focuses on copper's role in energy efficiency improvements in new motor technologies. Industry experts share their first-hand knowledge as they discuss the applications, advantages, and disadvantages of each type of motor. Each has a special place—or niche—in the marketplace. Having a better working knowledge of new types of motors will be of value to the plant engineer, facility manager, and anyone working with or purchasing motors for industrial applications.

Permanent Magnet Motors

Technology. Long used in servo motor applications, permanent magnet (PM) synchronous motors are gaining increased use in industrial motor-driven systems. PM motor technology replaces the aluminum bars in the rotor with powerful permanent magnets created using rare earth elements; these are either surface-mounted (SPM) or internally mounted (IPM). According to John Malinowski, senior product manager, Baldor Electric Company, Ft. Smith, Arkansas, "The basic stator in a permanent magnet motor is very similar to that of a traditional copper-wound induction motor; only the rotor in these motors is unique, using permanent



Figure 1 A significant motor innovation is the development of the copper rotor motor, which can reduce motor losses by as much as 12 to 15%. (Graphic courtesy of Baldor Motors, a member of the ABB Group).

magnets either glued to the surface of the rotor or bar magnets embedded in the rotor laminations."

Motor manufacturers have demonstrated that PM designs offer efficiency gains as much as three NEMA bands higher (1.5–2%) than a Premium Efficient AC induction motor. However, in most cases these gains cannot be achieved without pairing the PM motor with a variable speed drive (VSD). Despite the fact that there is less copper in the permanent magnet motor than in a similarly rated AC induction motor, it still relies on copper in its operation to make it more efficient.

As Malinowski points out, "The permanent magnet motor is very power dense; that is, how much horsepower, how much torque the motor can produce compared to its physical size. Thus, frame adapters are now required to compensate for the change in shaft height." Manufacturers meet this challenge by making permanent magnet motors in the same NEMA and IEC AC induction motor frame sizes to enable easier retrofits.

In common use today, permanent magnet motors drive both hybrid and full electric vehicles, such as the Toyota Prius and the Chevy Volt. And compressor manufacturers are starting to incorporate PM motors because they can operate at very high speeds without the use of speed-increasing gearing, which is inefficient."

Permanent Magnet Motor Advantages:

- Excellent torque-speed curve
- Excellent dynamic response
- High efficiency and reliability
- Low maintenance
- Longer lifetime

- Low acoustical noise
- High-speed capability
- High torque/volume ratio or high power density

Permanent Magnet Motor Disadvantages:

- High cost
- Need for a variable speed drive (VSD)
- Rare-earth material availability

Permanent Magnet Motor Applications:

- Cordless tools
- Maglev trains
- Wind turbines
- Hybrid vehicles
- Air conditioning units
- Washing machines
- Medical equipment (MRI)
- Industrial motors

Switched Reluctance Motors

Technology. A switched reluctance motor (SRM) is a brushless DC electric motor that provides continuous torque. The SRM electronic drive is characterized (paired) to the motor; together, they form a very capable, closely matched system. The SRM is a viable replacement and improvement to induction motors in variable speed applications. Rob Boteler, manager of government relations, NIDEC Motor Corporation, St. Louis Missouri,

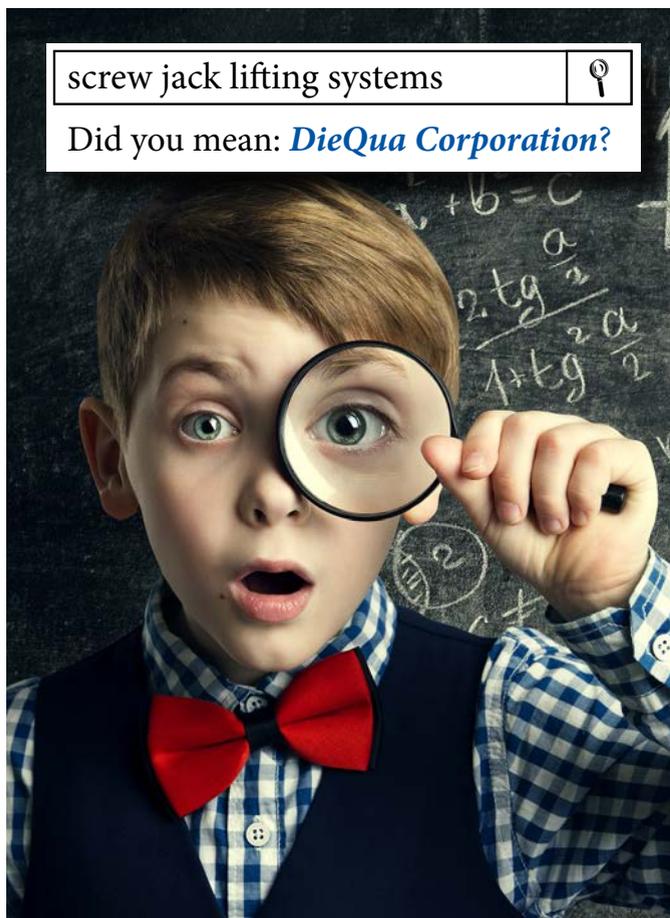
notes that “The switched reluctance technology has been around since the 1800s. What has occurred to bring this technology into the forefront of today’s advanced motors is the advent of power electronics and computing capability that allows commercially viable implementation.” Along with permanent magnet technology, NEMA’s Motor Generator (MG-1) section expects to develop a standard for switched reluctance motor technology in the future.

Helmuth Glatt, VP of engineering, NIDEC Motor Corporation, believes that the SRM has some distinct advantages over conventional motors. “One of the biggest differences that we have for a SR system is that it can operate with one of its phases missing or shorted out — an instantaneous stop mode for a permanent magnet or induction motor system.”

The quantity and type of copper wire are very important in the design of a switched reluctance motor. Each turn of the coil nests together to help fill the large stator slot allowed by the SRM design. As Glatt explains, “Copper is a key component to our coils. We usually use 100% copper to wind our electric motors because it has much lower electrical resistance than

“Exciting developments in motor design led to higher energy efficiency ratings.”

E.F. ‘Ned’ Brush, Ph.D. of BFF Associates



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alternative materials such as aluminum. Low winding resistance translates directly to less heat waste — thus improving energy efficiency and advantageously reducing the motors operating temperature.” When necessary the SRM uses a coil made of roped copper wire or ‘Litz wire’; the wire is made out of many smaller strands of copper wire twisted into the shape of a rope that is formed into a rectangular geometry. Using this type of wire transposes the conductor’s reducing skin effect — a phenomenon that results in the current migrating to the outside of that conductor, effectively increasing its (conductor’s) resistance.”

SR systems manufactured today are well suited for industrial application and are viable alternatives to other variable speed systems.

Switched Reluctance Motor Advantages:

- High efficiency, especially over a wide load range
- High torque and speed
- Exceptional constant-power speed range capability
- High reliability and long lifetime
- Simple and robust construction
- High power density
- Presently a standard product in NEMA specifications from 15 hp to 525 hp

Switched Reluctance Motor Disadvantages:

- Ripple torque
- High vibration level
- VSD necessary
- Acoustical noise (*The acoustical noise can be an issue with SR products, but minimization of noise is possible through careful design of the motor and its control algorithms, together with careful mechanical integration in the target application. Understanding the application in general and especially the motor’s duty cycle and load characteristics is important in SR applications.*)
- Slightly less peak efficiency than PM motor

Switched Reluctance Motor Applications:

- Washing machines
- Centrifugal machines; compressors and pumps
- Vacuum cleaners
- HVAC
- VSD systems
- Automation
- Machine tools
- Traction
- Rock crushers

Copper Rotor Motors

Technology. The innovation of the copper rotor motor technology was born out of the need to meet the low voltage motor market demands for greater energy efficiency — a demand not met by the traditional die cast aluminum rotor design. John Caroff, marketing manager, low-voltage motors, Siemens Industry, Inc., Norwood, Ohio, stated that “The goal was to gain efficiency using new copper rotor technology but retain the same footprint as the traditional aluminum rotor design. This is important, not only for new applications, but also for retro-

fit applications. Commercial high-temperature rotor casting machines were non-existent. To develop this new technology, we worked with the Copper Development Association (CDA) to design the rotor, and even more important — to design and develop the complicated rotor casting process.”

The significant investment in design and development of the CRM was justified by the efficiency gains over the conventional aluminum rotor designs. According to Caroff, “The initial purchase price of a copper rotor motor is slightly higher than the aluminum rotor motor, making the payback justification a factor. However, payback is relatively short and generally not an issue, given the typical 20-year design life of the motor. The die casting of a solid copper rotor yielded greater efficiency in the same size motor as a traditional energy-efficient motor, utilizing die cast aluminum technology.”

Designed in the U.S. to exceed the stringent NEMA efficiency table standards (MG1 Table 12-12), and exceeding the efficiency compliance with the 2010 EISA legislation, the CRM also gained the performance advantage in the European 50 Hz IEC motor. The use of copper rotor motors

“After a customer purchases their first CRM, they are returning to buy additional copper rotor motors again and again – for their efficiency and reliability.”

J. Balcerzak, in plant sales and motor product manager, KJ Electric, Syracuse, NY

as replacement motors for European equipment in the U.S. is a great opportunity for end-users to increase revenue while meeting legislation compliance. Copper is an amazing material. By using the copper rotor in our IEC motors we not only achieved the new efficiency requirements in Europe (IE 2, IE3) and USA (MG1 Table 12-12), but we were also able to reduce, in many cases, the length of the motor, making it more compact, and in others, achieving higher horsepower, both in the same footprint.”

Motor distributors in the U.S. are seeing an increase in sales of the copper rotor motor, especially with the intensified focus on energy efficiency, according to Jake Balcerzak, in-plant sales and motor product manager for KJ Electric in Syracuse, New York. Balcerzak says that CRMs are a significant part of their motor sales, and growing year-over-year.

In addition to standard induction motor applications, the CRM drives electric vehicles — from sport cars to military vehicles such as the 300-horsepower, 100-pound engine in the Tesla Roadster, to the multiple CRMs used in the design of the U.S. Army’s HEMITT A3 heavy expanded mobility tactical truck.

JB Straubel, chief technical officer for Tesla Motors, sees the CRM as an excellent choice for electric motor-driven vehicles because of their horsepower-to-weight ratio. “To us, it is a huge advantage to have a basic material structure for the motor that we can procure locally, and not be dependent on other regions or other countries that might limit or curtail supplies of these materials. We can actually spin that

copper rotor up to 14,000 RPM, so we get a lot of horsepower in a very tight package by spinning those high RPMs with (extreme) precision balance; it's quite a machine."

Rich Schafer, marketing manager at Baldor Electric Company, a member of the ABB Group, Greenville, SC, echoes this same enthusiasm for the copper rotor motor. "Copper rotor motors are unique from the standpoint that they allow us to make motors that are very efficient, and a motor that is more efficient runs cooler. You're going to be able to spin that rotor faster, so you can get a lot more horsepower into a smaller package and then gear it down accordingly."

Copper Rotor Motor Advantages

- Efficiencies higher than NEMA MG1 Table 12-12, and EISA 2007 requirements
- Inverter duty-capable
- High reliability
- Constant torque capability
- Cool running
- Lower maintenance cost
- Lower cost of ownership (power costs)
- Lower vibration with precise and better-balanced rotor
- Mostly the same product lines as the standard induction motor

Copper Rotor Motor Disadvantages:

- Higher initial purchase price
- High volume; stocked motors are limited to 20 hp or below for cast rotor
- Limited availability of casting machinery
- Cost of copper somewhat higher than other materials
- More complex processing procedure

Copper Rotor Motor Applications:

- All standard induction motor applications: light to severe duty
- Consumer and military electric vehicles
- Petrochemical, paper processing, refining

Summary

Each of these motor technologies—permanent magnet, switched reluctance and copper rotor induction motor—rely in their own unique way on copper in their design to produce motors that are more efficient and more reliable. The PM motor—with powerful permanent magnets in its rotor, the SRM with power electronic switching and its copper dense stator and rotor, and the CRM with the current-resistance-reducing cool running rotor—all provide options to accomplish energy reduction objectives and improve performance. Through the innovative use of copper, switching technologies and permanent magnets, customers today have more choices to achieve their efficiency and application-specific requirements. **PTE**



Figure 2 Three-phase SR Drive stator and rotor (Graphic courtesy of NIDEC Motors).

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Metal-to-Plastic Conversion Parts Help Drive Heavy Industry

Jack McGuinn, Senior Editor

While metal-to-plastic parts conversion actually began way back in the Fabulous Fifties, think toys, household products, etc., it is only in more recent years that plastic conversion has gained a firm foothold in the more strength- and lifetime-demanding applications such as aerospace, under-the-hood automotive, motors, valves, bearings and, as they say, much more. This was made possible by ongoing technical advances in both highly engineered polymers and injection molding machinery.

Some history, from Mark Fiorina, technical director of International Plastics LLC. “At the end of World War II there were a handful of commercially available plastics. By 1980 that number had grown to 4,500, and by 2000 there were more than 50,000 commercially available formulations.”

What about gears? Plastic, in some cases highly complex, gears are everywhere (see above)—just don’t expect to see them supplanting, for example, AGMA 12 gears any time soon. It is not until you get down to commercial AGMA 8 or less that plastic conversion can be considered. For more detail on this subject, Fiorina says “The best reference manual I have found for qualifying a plastic gear design was published by Plastic Gear Technology Inc., titled ‘Plastics Gearing.’”

Ron Brookhart, program manager/project engineer, Engineered Plastic Components, Inc. (EPC), suggests “contacting a custom-compounder for suggestions on a specific application. Custom-compounders are capable of engineering a plastic to work for a specific application and may have already done something similar.”

As reported in the opening, the takeaway here is that there still exists an almost limitless array of heavy industry-type applications in which plastic is reliably used. You may be interested (as were we) in knowing what determines whether an existing metal part can be plastic-converted. Fiorina walks us through a typical scenario.

“OK, I have a metal part and I think it can be plastic (what it is and the metal are irrelevant at this point). The first question



Figure 1 Zinc gear International Plastics prototyped, followed by first production gear (All photos courtesy International Plastics LLC).



Figure 2 A family of three steel-to-plastic thermostat covers.

you need to ask yourself is why do I want to change material? What are the problems the metal part is having and how would a plastic part solve those problems? Metal parts often have corrosion issues that require plating and/or painting, which is environmentally unfriendly; and sometimes there is a lot of machining of the metal, which is slow and costly. Many times multiple setups and multiple machines are required. Sometimes there are lubrication problems with a metal part, which results in premature failure of the product. Metals are conductive and you need insulating properties. This list can go on and on, and is different for every industry and every application. Then, you really have to look hard at the application and determine if plastics can handle the temperatures and mechanical loads that will be applied. This is the step that gets people into trouble.”

Trouble? What trouble?

Fiorina explains: “While you will usually find a range of materials that can solve the types of problems mentioned above, it is the temperatures and loads that often limit your material selection or prove to be outside of the capability of plastics—even with clever redesigning. This is when reality steps in and either tells you that you had a good idea or a bad one.”

Leaving that aside, there is another critical component to consider when looking to convert a metal part to what is known as engineering (higher-end) grade polymer, i.e. — the required injection molding.

Fiorina says that, “When moving to plastic from metal, especially if the metal part is a machined part, the 800-pound gorilla in the room is the plastic injection mold. This is an expensive piece of capital equipment that the end user frequently never sees or touches.” Why so expensive? “Unless you are talking about an inexpensive, aluminum prototype mold, they are typically made from hardened tool steel. Even though a mold builder has made hundreds or thousands of them, each one is a unique, one-off mechanical device. A mold has a highly engineered filling system to get the plastic into the cavity which will produce the part; a complex three-dimensional cooling system that must remove the heat from the cavity uniformly to control shrinkage and warping; an ejection system to push the part out of the mold without damaging it; a structural housing to support all of this that

is capable of taking very high compressive loads for millions of cycles without mechanical failure; an alignment system that will keep both halves of the mold in proper location when the mold is closed and plastic is injected at 300° F to 720° F under pressures of 5,000 psi to 40,000 psi. Lastly, it has to hold the precision cavity(s) that will actually produce the part. Frequently parts require under-

cuts, or threads or windows in the side of the part, (adding) substantial cost to the mold. The ins-and-outs of mold construction is a topic that could take up a couple of semesters, in senior level engineering.” Also required is expertise in grinding, EDM, wire EDM, CNC programming in 3,4 and sometimes 5 axes, CAD/CAM, solid modeling, CNC machining, heat treating, CNC Turning, and mechanical assembly.

Aside from the complexity and cost, what eases the pain according to Brookhart is that “The higher the volume, the more cost effective injection molding is.”

Indeed, what makes the above investment work is that the payback for metal-to-plastic can be considerable. For Fiorina, injection molding is a beautiful thing.

“The beauty of injection molding is that the process is fast relative to machining,” he enthuses. “Small, thin wall parts can cycle in 5 or 10 seconds; medium-sized parts can be molded in 20 to 40 seconds; big parts might take a minute or two. Also, one machine running a multi-cavity mold can produce several parts at one time.” Continuing, “The economic power of injection molding is unbelievable. Molding a part with it’s finished color in the material and eliminating 2,3,4,5 machining steps or assembly operations gives this process a unique advantage over machining.”

And what is the strongest poly-based (often with additives) material available? According to Brookhart, “The strongest materials are long-glass materials; polypropylene and nylon are the most common.” Combinations of the above are considered custom compounds. Explaining further, Brookhart says, “A custom compound is a plastic that has specific additives (glass fiber, UV, minerals, lubricants, etc.) to give it the properties required for a specific application. A custom compound is needed when off-the-shelf commodity plastics do not meet the requirements for the application.”

For functioning in harsh environments, and at elevated temperatures (300° F to 400° F), sophisticated polymers such as PPS, PPSU and PEEK are state-of-the-art. Example: Fiorina says that PEEK, capable of operating at temperatures as high as 500° F; it is used, for example, in oil and gas down-hole applications; electronics; pumps; insulators; etc. “But,” says Fiorina, “PEEK comes with a hefty price tag of \$50-to-\$70/pound,” adding, “As you go up the food chain, the materials get progressively more difficult (to work with).”

Considering other definitive attributes of plastics over metals, Fiorina says “Plastics are often an upgrade from a metal in applications where lubricity is the primary property required. While there are lots of additives that can make a material slippery (reducing the static and dynamic coefficient of friction), several engineering-grade materials are

	lb/ft³	Tensile strength (psi)	Modulus (psi × 1,000,000)	Coefficient of friction
Steel	490	100,000	30.0	0.65
Aluminum	165	56,000	14.0	1.20
Bronze	510	33,000	12.0	0.22
Nylon (40%carbon fiber)	82	40,500	4.0	0.34
Nylon (30% Glass fiber)	86	29,500	1.5	0.27
Nylon (Neat)	71	12,500	0.5	0.11
Nylon (Lubricated)	73	10,500	0.3	0.06

naturally slippery without any additives (acetals and nylons). If you can eliminate lubrication you can eliminate one more point of failure.”

And did you know that, according to Fiorina, we can be thankful for the fact that “The introduction of PAI (torlon) washers and spacers into automotive transmissions (is what) got manufacturers to the 100,000-mile warranty.”(And) “The introduction of acetal piston rings in pneumatic cylinders got us to the longer-life, no-maintenance cylinder. Longer life and reduced or no maintenance, (are) primary benefits of lubricated plastic parts.”

As demonstrated, components/parts used in heavy industry are proliferating. But as for the day when outside plastic parts become reality, Fiorina points to two applications: gears in an automotive transmission (high power, high torque), and large ring gears that are several feet across and carry large loads in compressors, or big machinery. “I do not see either of these applications going to plastic any time soon; the latter application is just too big, volumes are low, the molding machine required and mold itself would be huge and a very large investment. And, the physical loading is outside the envelope that plastics can handle.”

He boldly predicts, however, that “If you want to know if automotive transmission gears can be made of plastic, keep an eye on Formula One. They are definitely the tip of the spear when it comes to applications like that. When you see that first plastic gear show up in F1, you will see it on the street in 5 years.”

Tying things up in a neat, if complex, package, Fiorina says that, “The only thing that is constant in this process is that it is one full of compromises. The part geometry, material, mold, molding machine, and process all interact with each other simultaneously. It is a process that sounds simple in concept but in practice is one of the most complex. Add in client expectations, misconceptions, and snake oil sold by some molders, I am amazed we have come as far as we have.”

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Understanding the Dynamic Influences of Gear Oils and Radial Shaft Seals

Matthias Adler, Joe Walker, Sascha Grasshoff, Craig Desrochers and Matthias Pfadt

Introduction

Sustainability is becoming one of the most important aspects within the power transmission business. Users demand low-maintenance drive systems with as little disruption as possible, and expect lifetimes of more than 10,000 hours. Approximately 40 percent of long-term gearbox leakages can be traced back to poor interaction between the radial shaft seal (RSS) and the lubricant. Thus, it becomes essential to analyze the tribological system as a whole, which includes the gear oil, seal grease (if required), elastomer material and design, and the shaft. This paper highlights the most critical interactions between the industry's most commonly used gear oil formulations, with emphasis on synthetic oils featuring nitrile- and fluoro-elastomers. Described here are wear modes for radial shaft seal (RSS), such as the change of dimension, seal lip wear, and shaft run-in.

This report also offers evidence of how polarity of the base oils and additives alters swelling and shrinking behavior, which will eventually impact upon the sealing function. Chemical and physical reactions between lubricant and elastomer were space-resolved with the help of image-scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) analysis, as well as nuclear magnetic resonance (NMR). Through the newest micromechanical measuring system developments, one was able to determine the difference of the mechanical properties in the sealing lip area within μm . It was proven that certain oil formulations

merely changed the mechanical properties on the surface of the RSS. Typical immersion testing would not show any significant differences regarding the mechanical properties, but under long-term dynamic testing those oil formulations show considerable wear, and eventually leakage, of the RSS. It was proven that with an ideal combination of base oil and additives, the latest demands of life expectancy on the radial shaft seals can be met.

Functional Principle of the Simmerring Seal (Radial Shaft Seal)

Radial shaft seals are generally used to provide a dynamic seal for rotating shafts (Fig. 1-a). The sealing mechanism is a complex, dynamic interaction (Fig. 1-b) — as opposed to a simplistic static closure of the gap between the shaft and bore (Ref. 1).

The dynamic sealing mechanism is influenced by shaft surface, design of the sealing lip, viscosity and the wetting behavior of the lubricant, as well as the macro- and micro-mechanical properties of the elastomer. The sealing mechanism is based on the pumping effect of the lubricant in the sealing gap. The seal fulfills its function when the lubricant between shaft and sealing edge is completely extracted back (Ref. 2).

A sufficient supply of lubricant to the seal is crucial for the service life and reliability of the seal. The more intensive the lubrication, the lower the wear. Even when stationary, the medium to be sealed, which at the same time is used for lubrication, penetrates the uneven areas of the shaft and

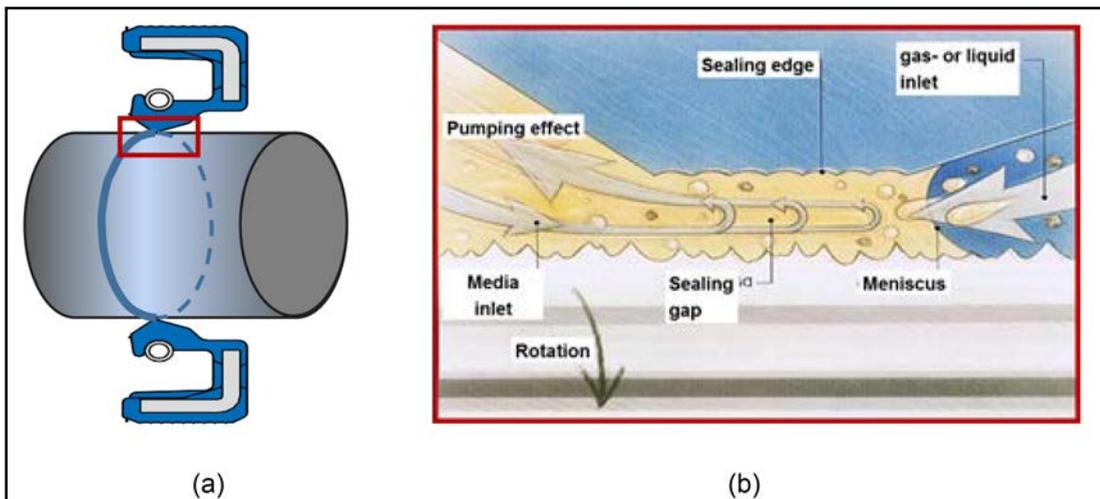


Figure 1 Radial shaft seal tribological system.

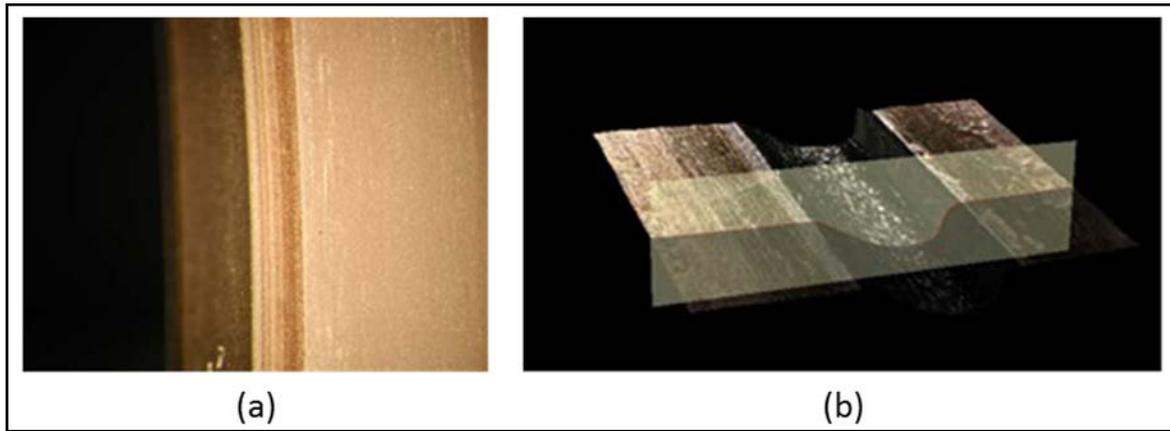


Figure 2 (a) View after 1,000 hours dynamic testing of the sealing edge (sealing edge wear with grooving); (b) magnified view of a shaft, showing shaft wear in the seal lip area.

sealing lip due to capillary forces. However, the direct contact of the sealing lip with the shaft predominates. Initial and then larger rotary movements produce a change, similar to a plain bearing, from a state of startup friction through mixed friction to predominantly hydro-dynamic friction. The seal must not run dry under any circumstances. Therefore when fitting the seal, lightly grease or oil the shaft and seal. The medium to be sealed is not only a lubricant, but also a coolant that draws off heat produced by friction.

The shaft, as part of the tribological system, influences the micro pumping action as well. Only a lead less surface finish can guarantee the leak free bidirectional operation. However, lead can assist in a unidirectional setup, when the thread's direction coincides with the pumping movement.

Boundaries for the functionality of the seal are also set by the roughness and hardness of the shaft; industry standards are available from industry leading manufacturers. Roughness and film thickness, which are, among others, pressure-dependent, and velocity and viscosity, are set by the application and therefore are not discussed further in this paper.

The following discussion highlights the interaction between lubricant and elastomer under a hydrodynamic scenario.

As the shaft surface and sealing edge move against each other, wear is introduced in the contact zone. This wear can either occur on the sealing lip (Fig. 2-a), the shaft (Fig. 2-b), or both. Figure 2-a is a magnified view of the sealing edge after 1,000 hours of dynamic testing. This sealing edge is showing edge wear with grooving.

This wear will eventually lead to a leaking application. Thus, to reduce the wear it is beneficial when a lubricating film is established between the RSS and the shaft. Wear reduction is also a function of the pumping effect.

In the following paper, basic mechanisms of the lubricant—elastomer interaction as well as methods to characterize those—will be described. There will be a principal distinction between physical and chemical interactions (Ref. 3).

Physical Interaction

Physical interactions between lubrication and sealing materials focus on diffusion/exchange interactions, as well as the wetting behavior between the elastomer and the lubricant.

Diffusion processes. Elastomers and lubricants are blends of different chemical compounds that are designed to meet a specific task in their respective system. The elastomer consists of a basic polymer; fillers; plasticizers; antioxidants; cross-linking additives; and processing aids. The lubricant consists of a base oil, additives, and for a grease, a thickener system. These additives could include a combination of extreme pressure (EP) additives, anti-wear (AW) additives, antioxidants, viscosity improvers (VIs), and corrosion protection. These additives and base oils all differ in their molecular size and polarity as well.

Recognizable is the significant difference in the polarity within the elastomer types ACM, NBR, and FKM, as well as the differences within the lubricant types: mineral (Min), polyglycol (PG) oil, and polyalphaolefines (PAOs). The additives, used in both elastomer as well as lubricant, tend to be polar. The majority of synthetic industrial gear oils consist not only of a single base oil, but also a blend of base oil chemistries. In oils where additive solvency is difficult, esters or methacrylates can be used to keep the additives dissolved in the oil. The mixture of opposing base oils is also important to

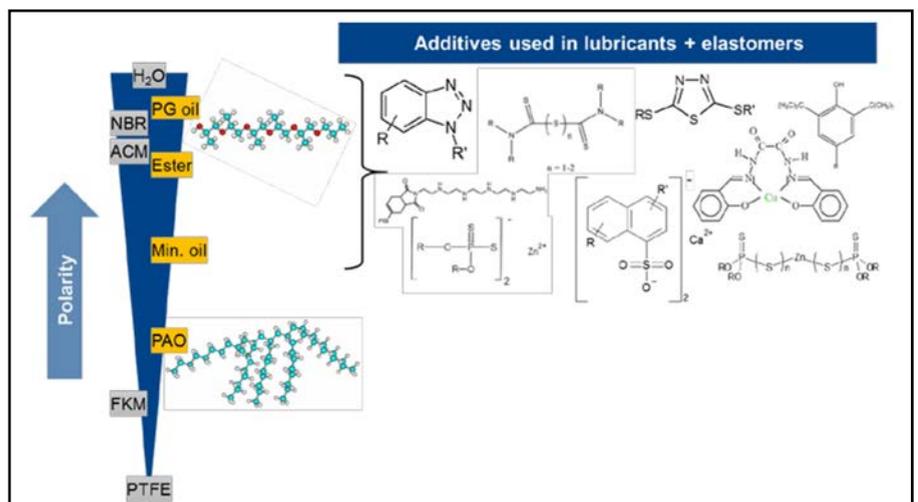


Figure 3 Qualitative comparison of polarity between lubricant and elastomer components.

the compatibility with elastomers. Pure PAO base oils tend to shrink most types of elastomer types; ester will swell those elastomers, for example. The combination of these two oils in the correct ratios can negate the end effect on the elastomer. This formulation is a careful process in mating the correct ratios of addition, base oil chemistries, and concentrations to develop a market-ready gear oil.

Polarity is the most important factor for the solubility of a chemical compound in a different chemical compound, such as the solubility of an antioxidant in a base polymer or in the base oil of a lubricant (Ref. 4).

When a multi-component system, such as the elastomer of the RSS, makes contact with another multi-component system, such as the lubricant, diffusion processes can take place that are driven by a concentration difference of the additives in the elastomer matrix and the lubricant. Compounds diffuse in the system, which has a similar polarity. Thus, non-polar elastomer components from the polar NBR can diffuse in a non-polar mineral or PAO lubricant. The result is a volume decrease of the elastomer. One can observe a volume swell when polar components of the lubricant, such as EP and AW additives, diffuse in the polar NBR. Another possibility is that the same number of molecules diffuse from the elastomer into the lubricant, and vice versa; in that case a volume change cannot be measured. However, the elastomer changed its chemical structure; the processes are displayed schematically (Fig. 4).

Temperature and molecular size can also influence the duration of the diffusion process. Test specimens and RSS of various NBR compounds were stored under 40°C at 500 hours in different PAO oils; the volume of oil bath was 80 times the volume of the rubber. Volume changes of the test specimen were measured according to DIN 53521. Additionally, the change of the inner diameter of the RSS, thus the interference with the shaft, was recorded. Observed were significant volume change differences of the tested PAO/NBR combinations.

Figure 5 displays the volume change measured on test specimens versus the corresponding change of the inner diameter of the radial shaft seal. This illustrates that there is a direct correlation between the volume increase of the test specimen and the inner diameter of the RSS, and vice versa. Therefore, it is possible that the interference and the radial

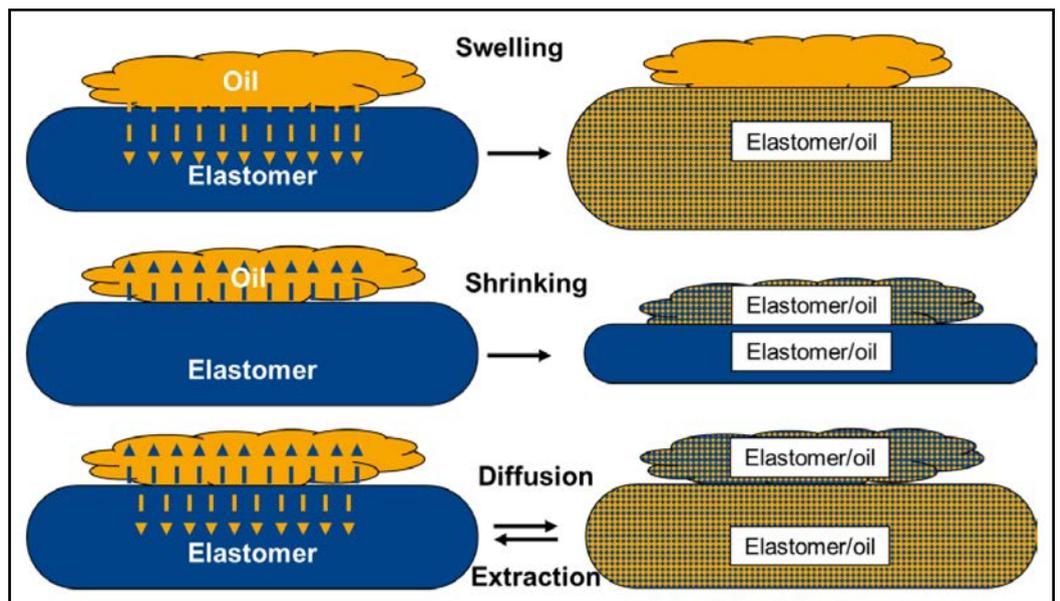


Figure 4 Schematic display of the three basic physical diffusion processes between lubricant and elastomer.

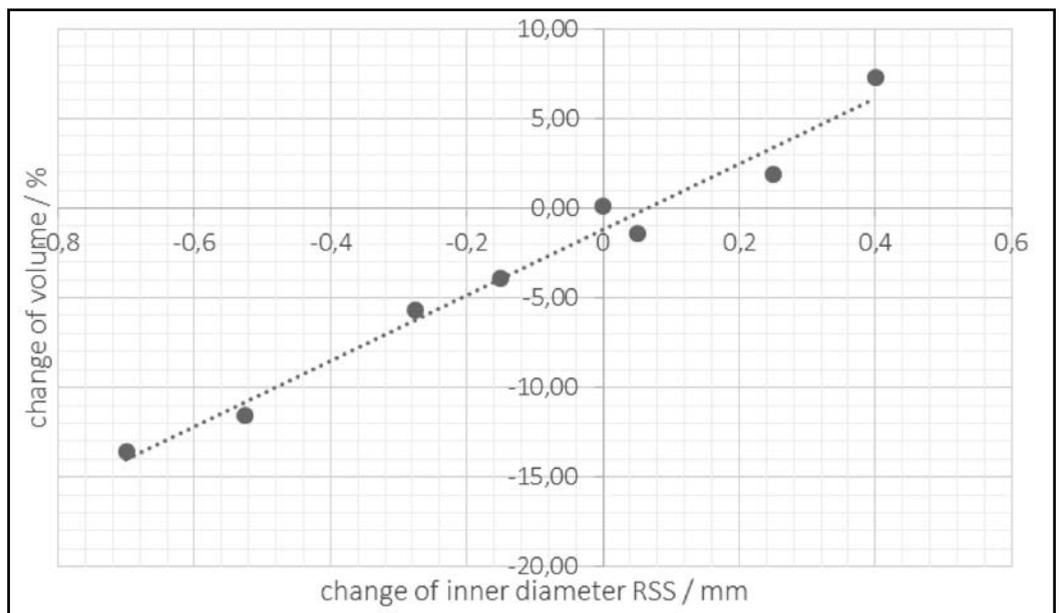


Figure 5 Correlation of the NBR RSS inner diameter change with the volume change after static tests in different PAO oils for 500 hours at 40°C.

force of the RSS significantly increases when shrinkage occurs. This could cause an increase of friction, which increases the thermal stress under the sealing lip, which results in higher wear. If swelling occurs, the RSS interference, thus radial force, decreases on shaft. If the swelling comes to a point where the inner diameter (ID) of the RSS is equal or greater than the shaft diameter, leakage occurs.

Diffusion processes not only change the dimensional parameters of the seal — they also change the chemical composition. This could be proven by examining the chemical composition of NBR RSS after static tests in different lubricants. Two-mm-thick NBR test panels were stored in various base oils and fully formulated oils for 1,000 hours at 90°C; the volume of the oil bath was 80 times the volume of the rubber. Afterwards, the NBR test panels were extracted under reflux with an acetone/n-hexane solution. The extract was analyzed through a gas chromatography-mass spectrometry (GS-MS) and the compounds qualitatively specified (Ref. 5). Figure 6-a displays a GC-MS spectrum of an extract of a NBR compound. Here, antioxidants (AO), plasticizer (Plast), and processing aids have been detected.

Figure 6-b displays the GS-MS spectrum of a PAO oil of an NBR compound after storage in a pure PAO base oil. One can recognize that most NBR additives are diffused in the oil.

Figure 6-c shows the GS-MS spectrum of an extract of an NBR compound after storage in an additive-enriched PAO oil. One can recognize that many oil components are diffused in the elastomer. To a point, those additives are capable of starting a chemical reaction with the elastomer.

The additives' diffusion behavior between lubricant and elastomer is not only determined by polarity, but mobility as well. Mobility is defined by the molecular size and the reactivity of an additive. A phosphor-rich AW additive might only react on the surface and not pass the outer layer of the seal; thus it would not change the elastomer matrix.

Figure 7 shows image scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) pictures of NBR specimens, stored for 1,000 hours at 90°C in two different, additive-rich PAO oils; the volume of the oil bath was 80 times the volume of the rubber. The yellow area indicates the phosphor-rich section of the elastomer.

The results above suggest that it is necessary to coordinate the elastomer formula with the lubricant composition to achieve the best possible interaction. Therefore, close cooperation in the development of lubricant and elastomer is crucial.

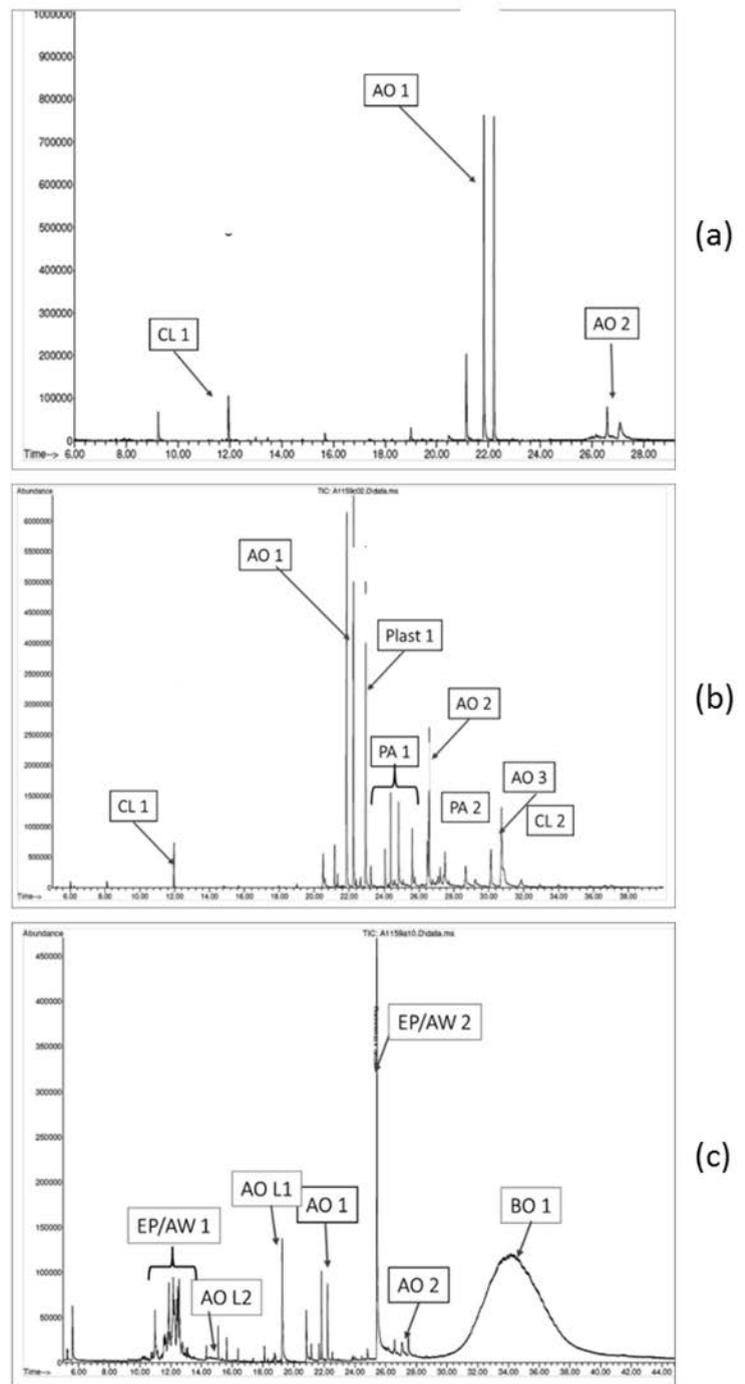


Figure 6 Characterization of elastomer extracts/oils with GC-MS of NBR compounds after static storage in different oils: (a) extracts of pure NBR; (b) NBR after storage with pure PAO oil; (c) NBR after storage in full additive PAO oil.

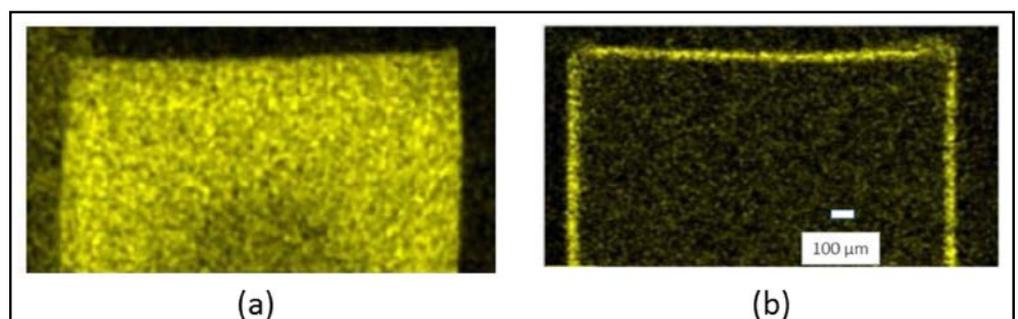


Figure 7 SEM-EDX analysis of a 2-mm NBR specimen cross-section in two different PAO oils, yellow highlighted are the phosphor concentrations.

Wetting behavior. The wetting behavior is another important physical interaction between the lubricant and the elastomer. It describes the ability of a lubricant to generate a joint surface with an elastomer or metal (Ref. 6).

One can define the wetting behavior through the measurement of the contact angle that a drop of lubricant creates with the elastomer surface Figure 8-a, according to DIN 55660-2 (Dec., 2011).

Where the lubricant has a poor wetting behavior, the contact angle will be large (Fig. 8-b); in the case of a good wetting behavior, the contact angle will be smaller.

When the lubricant has a poor wetting behavior with the elastomer, the lubricant will not penetrate well into the sealing gap (Fig. 9-a). Poor wetting of the sealing edge also suggests a higher probability of insufficient lubrication under the sealing lip — thus suggesting an increase of wear on the sealing edge and/or the shaft. The better the wetting behavior, the better the coverage will be in the sealing gap (Fig. 9-b).

One of the major factors that determine wetting behavior is the polarity difference between lubricant and elastomer. The combination of polyglycol gear oils and FKM seals is widely spread on the market for specialty and high-temperature applications, although it is challenging in terms of wetting the seal edge and a non-optimized system can lead to more wear on the sealing edge and/or shaft (Fig. 10).

The wear pattern of approximately 1 mm (Fig. 10) can be

minimized through additional features such as pre-greasing the seal with an appropriate grease and geometrical modification of the seal itself. Figure 11 shows three possibilities targeting the optimal wear characteristics.

In Figure 11-a a different FKM compound with a modified pumping effect was used to improve the wetting behavior of the system, thus reducing the wear.

Figure 11-b shows the original FKM, but pre-lubricated with a grease on the air side, which features good compatibility with PG oils and FKMs. The wetting behavior was improved by additional lubrication effect.

In Figure 11-c a modification of the wetting behavior of the FKM took place, emphasizing that oil can penetrate easily in the sealing gap, also reducing wear.

A seal lip grease is a simple method to improve the wetting behavior and will furthermore act as an assembly aid when the seal is installed on the shaft. The grease also protects the seal in conditions where lubrication supply is poor or in startup conditions. Proper selection of the grease is most important to consider the compatibility with the elastomer and with the gear oil. In some applications the grease can also act as an additional sealing mechanism. In most cases seals with dust lips are lubricated at assembly and re-lubrication is not possible. Generally, the quantity of grease required is approximately 40% of the volume between the sealing lip and the dust lip on the seal, distributed evenly around the

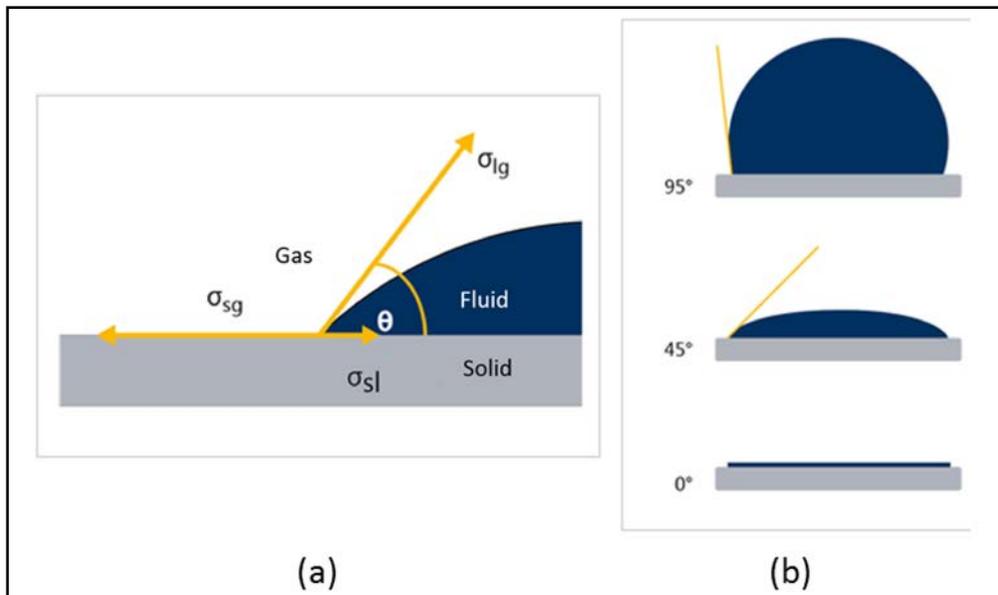


Figure 8 Basic schematic of how to measure the contact angle to evaluate the wetting behavior of elastomer and lubricant.

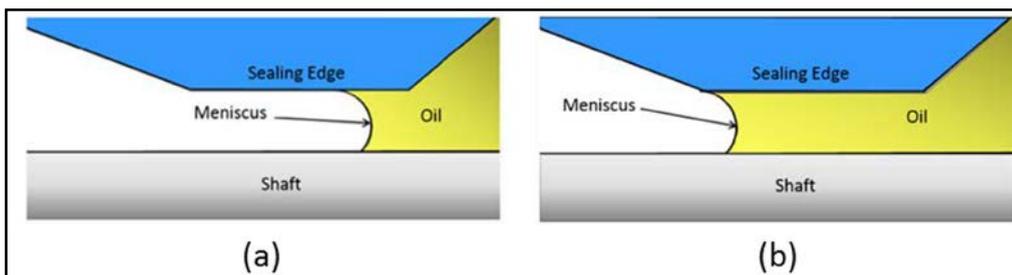


Figure 9 Schematic display of the lubricant penetration under the seal edge: (a) poor wetting behavior; (b) good wetting behavior.

inner circumference. By applying excess grease to the seal, it can falsely appear that the seal is leaking due to the excess oil bleed out of the sealing area.

Chemical interaction. Mechanical properties of elastomers are not only determined by the combination of polymer, filler, plasticizers, and additives, but also through the cross-linking density, which is formed in the vulcanization process. The cross-linking can be altered by chemical interactions.

Possible scenarios are either post-cross-linking, which causes an increase in stiffness/hardness, or a reduction of the cross-linkage through destruction of polymer chains, which results in a reduction of stiffness/hardness (Ref. 7).

The mechanical properties of the elastomer determine the function of the RSS. The sealing edge's ability to follow at excessive shaft eccentricity is defined by the macro mechanical behavior. A change of the mechanical properties of the elastomer, like hardening through a chemical attack, can lead to leakage or cracking within the sealing edge area.

Micro-mechanical properties of the elastomer, such as E modulus and loss modulus, affect the pumping ability and the wear characteristics under the sealing edge. An increase of wear, thus an increase of the sealing edge temperature, can be recognized when the elastomers soften due to chemical interactions with the lubricant. A result may be an acceleration of advanced aging processes. The pumping function can also be altered when the elastomer hardens in the sealing edge area, which may result in leakage or additional wear on the RSS and/or shaft.

Additives—or additive compounds of the lubricant and the temperature in the sealing edge area—define the magnitude of the chemical interaction between lubricant and elastomer.

Sulfur-cured elastomers such as NBR can be chemically altered through EP and AW additives. Typically, EP additives have high sulfur content and can create additional sulfur compounds within the elastomer. AW additives, based on phosphate or zinc compounds, can also alter the sulfur-cured matrix.

Typical FKM compounds, which are bisphenol-cured, can be post-cross-linked through amine compounds—the elastomer eventually hardening.

The speed of chemical reactions is extremely dependent on temperature, which suggests that the most immediate reactions will be close to the sealing edge. Friction—created in the dynamic operation

between RSS sealing edge and shaft—triggers a temperature increase in the sealing edge area. Temperatures up to 50°C are possible compared to the oil sump; thus chemical reactions along the sealing edge area can be accelerated.

A significant change of the mechanical properties in the sealing edge area can have a negative impact on the sealing mechanism, leading to leakage. It therefore becomes crucial to evaluate the changes in the sealing edge area with different lubricants.

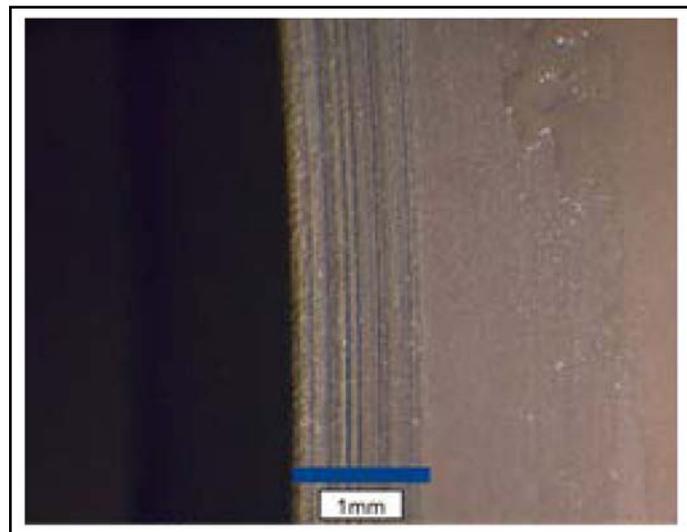


Figure 10 RSS FKM 1 with PG-oil (Viscosity 460) after 1,000h at 110°C (25× magnified) dynamic test.

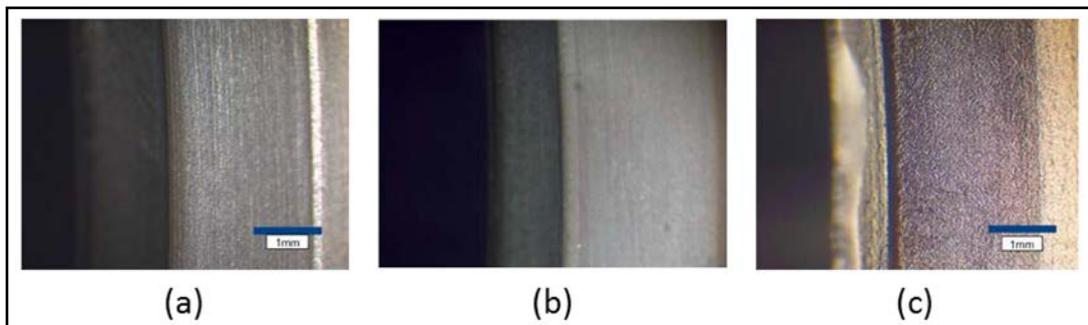


Figure 11 FKM RSS after dynamic long-term testing with PG lubricants: a) optimized FKM compound; b) optimized combination PG oil with additional sealing edge grease; c) FKM RSS with optimized wetting behavior (>1,000 hours).

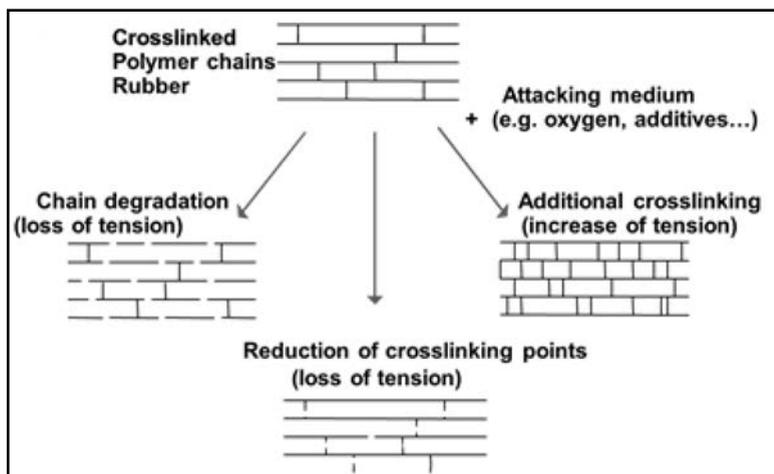


Figure 12 Schematic display of the change of the cross-linking density of elastomers through chemical interaction.

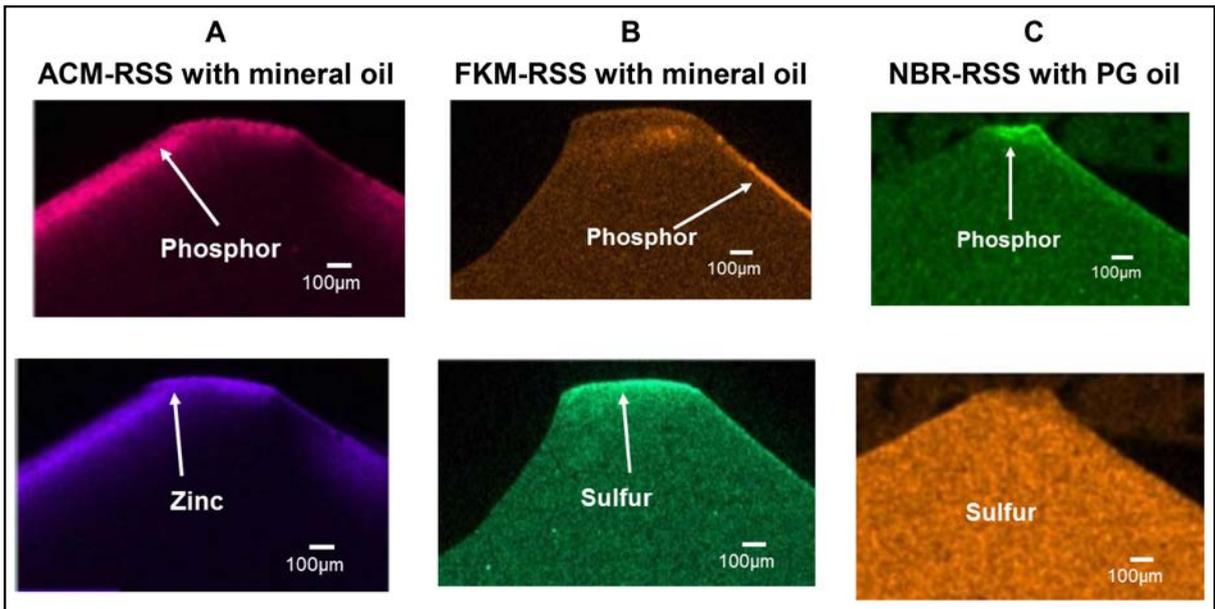


Figure 13 SEM-EDX analysis of an RSS sealing edge cross-section after dynamic long-term tests for different elastomer-lubricant combinations.

Figure 13 displays more intense chemical reactions of lubricants with phosphor, zinc, or sulfur compounds in the sealing edge area.

SEM-EDX analyses of FKM, ACM, and NBR RSS sealing edges are shown (Fig. 13) after thousands of hours of dynamic testing in different oils. One can recognize that different physical and chemical interactions took place in the sealing lip area. There are, dependent on oil composition and RSS compound, different chemical elements on the sealing lip edge. Note that the color of the image is not indicative of the element type; it is simply a color assigned by the software of the SEM-EDX.

Figure 13-a shows a SEM-EDX picture of an ACM RSS sealing edge after 1,000 hours of dynamic testing in mineral oil. One can see that the zinc- and phosphor-rich additives of the lubricant reacted within 200 µm of the elastomer. Axial cracks were visible due to the chemical attack.

Figure 13-b shows an SEM-EDX picture of an FKM RSS sealing edge after 1,000 hours of dynamic testing in mineral oil. One can see the sulfur-rich sealing edge and the phosphor richness in the elastomer matrix. A mechanical change of the sealing edge surface was noted.

Figure 13-c shows a SEM-EDX picture of an NBR RSS sealing edge, after 1,000 hours of dynamic testing in PG oil. This test revealed heavy phosphor enrichment in the sealing edge area. Additionally, sulfur was extracted from the sulfur-cured NBR, which also changes the mechanical properties of the seal.

The question arises—how much did the mechanical

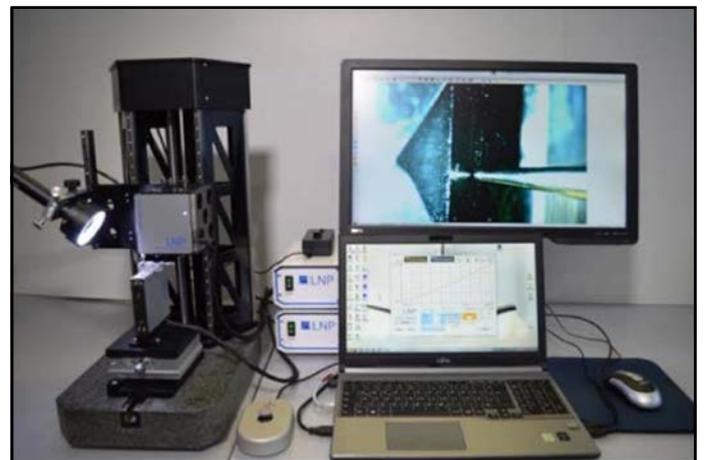


Figure 14 Display of a LNP nano-touch measuring device.

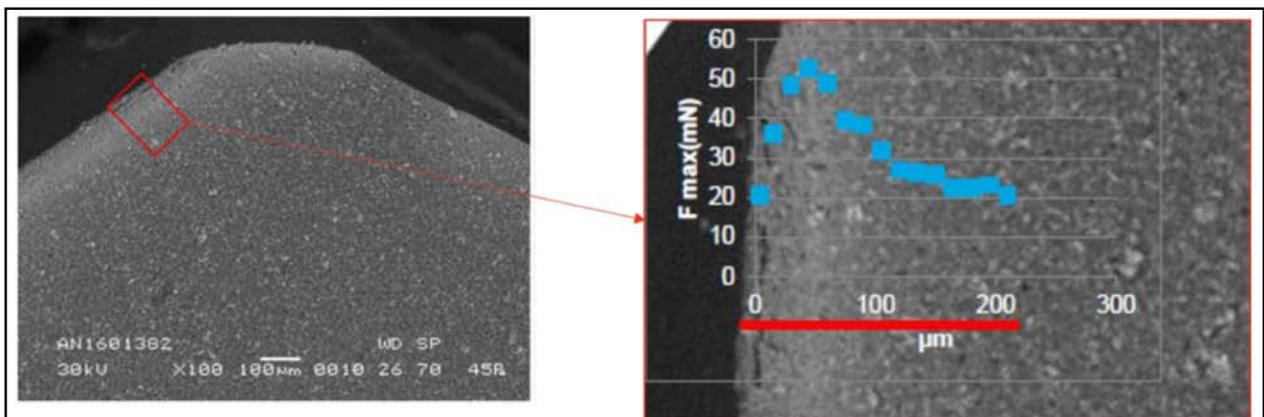


Figure 15 LNP nano-touch measurement.

properties change in the edge area (up to some 100 μm)? To conduct this test, the micro-stiffness of the cross-sections of the sealing edge of the ACM RSS from the edge was measured with an LNP nano-touch device. The LNP measures force with a needle-shaped indenter, which is necessary to enter the material. The measurement can be displayed in μm (Ref. 8).

Figure 15 shows a typical measurement of the macro-mechanical properties in the edge areas of an RSS after long-term dynamic tests. Force (F) is required to insert the nano-indenter through the cross-section.

The stiffness in the edge area has increased, and one can also recognize the concentration of zinc and phosphor in this area. Hence, not only did the micromechanics change, but the result is an altered sealing mechanism through the interaction between the elastomer with the lubricant.

Summary

The development of new test and measurement methods allows the characterization of the physical and chemical interactions between lubricants and RSS.

Shown are complex physical diffusion interactions that can contribute to geometrical changes of the RSS—thus to leakage. On the other hand, the exchange of chemical compounds can also create a chemical transformation within the elastomer, such as post-cross-linking, which will alter the sealing mechanism. Furthermore, the wetting behavior of the lubricant with the elastomer is an important factor for the wear behavior in dynamic applications. The wear resistance can be increased with correct selection of an RSS compound or optimized lubrication system.

The constant design requirements for less friction and reliable sealing function lead to continuous, further development of the tribological system consisting of seal materials, the sealing lip design, and lubricant. To achieve the best RSS-lubricant lifetime solution, both components must be adapted to the applicable application. Therefore, it is necessary to have a deep knowledge of the materials—on both the lubricant and elastomer side. An evaluation of the interactions is possible through the usage of various static and dynamic lab methods, as well as the usage of complex analysis methods. The gathered knowledge guarantees long-term sustainability for the application. **PTE**

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Sascha Grasshoff



The Development of Worm Drives

Joe J. Liou and Stefan Rakuff

Introduction

A worm drive is a geared power transmission device in which a worm meshes with a worm gear to transmit power between two non-intersecting shafts that are oriented at a right angle. The worm drive has been an active and challenging topic of technological study since Leonardo da Vinci (1452-1519). Significant breakthroughs achieved for high-speed applications in the last century can largely be attributed to the progress in tribology, which introduced dissimilar materials for the worm and worm gear, as well as closed housings to facilitate oil lubrication rather than grease lubrication in an open environment. The modern worm drive is a commonly used power transmission device to achieve high-speed reduction in a relatively small footprint, although with potentially limited load-carrying capacities and high wear rates. This paper provides a comprehensive compilation of state-of-the-art information on enveloping worm drives and future prospects.

In mechanical power drives of skewed axes, worm drives are commonly employed for speed reduction with high ratio (generally 20 to 300, higher ratio is also available) in a small footprint. Unlike other types of gear drives, characterized by rolling plus sliding between the meshing flanks, there is little rolling in the worm drive. The movement of a worm drive is purely caused by screw motion — sliding on the mated surfaces; therefore, the load capacity for worm drives is relatively limited and friction greatly affects the efficiency. The allowable transmitted power for worm drives is generally in several tens of kilowatts (less often for 100–1,000 kW) (Ref. 1). Worm drives present unique lubrication challenges, as the lubricant is continually scraped aside due to the abovementioned sliding motion. Consequently, the high temperature in many cases will be the limiting factor on the worm drive before the mechanical loading limitations are reached.

Worm drives have been widely used in various applications where 1) noise is a concern; 2) space is limited; 3) absorption of shock loading is required; and 4) no or minimum maintenance is required. In some literature the advantage of fast braking or emergency stopping was indicated; unfortunately, this concept of a self-locking worm drive has been disproved. In theory, worm drives in the static condition may have trouble driving the worms by the worm gears, depending on the lead angle of worm thread. If, however, the self-locking drive is subjected to shock or vibration, which is the typical case for many applications, the drive can no longer be self-locking and back-driving occurs (Ref. 2). Worm drives make up approximately 10 percent of all mechanical power transmissions (Fig. 1).

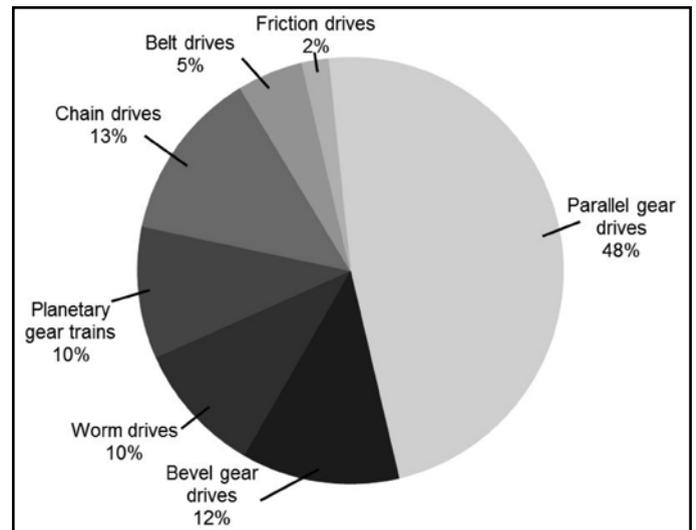


Figure 1 Global distribution of mechanical power drives in which worm drives make up approximately 10 percent of all drives (Ref. 1).

Worm Drives: State of the Art

The geometry of an enveloping worm drive is mainly based on the concept of involute profile. The 1937 British standard BS 721 rendered the involute profile as the standard thread form. The German standard DIN 3975 (Ref. 3) has classified the most common thread profiles of worm into five different forms, i.e. — ZA (straight-sided axial profile with a turning tool); ZN (straight-sided normal profile with a turning tool); ZK (grinding wheel or milling cutter); ZI (involute helicoid); and ZC (concave with grinding wheel). Technical report ISO/TR 10828 (Ref. 4) also has similar designations (A, C, I, K and N) for the worm geometry. The American standard — AGMA 6022-C93 — (Ref. 5) has no equivalent to the ZC form. The first four forms — ZA, ZN, ZK and ZI — vary in their radii of curvature. The differences in curvature are very slight for the smaller-size and higher-ratio worms, but are significant in the larger-size and lower-ratio worms. The actual profile used and the amount of curvatures obtained for the worm is not as significant as the accuracy with which the worm gear tooth profile matches the particular worm profile selected. Material pairs for worm drives can be metallic, metallic-plastic, and plastic depending on the operating requirements and conditions. In metallic pairs the selection of materials for the worm and worm gear is more limited than it is for other types of gears. The threads of the worm are subjected to fluctuating stresses and the number of stress cycles is fairly high. Therefore the surface endurance strength is an important criterion in the selection of worm material. The core of the worm should be kept ductile and tough to ensure maximum energy

absorption. The magnitude of contact stresses on the worm gear teeth is the same as that on the worm threads. However, the number of stress cycles is reduced by a factor equal to the speed reduction. Dissimilar or heterogeneous materials, especially steels-to-bronzes, are recommended for worms and worm gears for tribological advantages (Refs. 6–7). Steel-to-bronze results in much lower friction forces that do not exist in other metal combinations. It also results in sacrificial wear of the bronze and little to no wear of the steel, yielding improved contact over time.

The steels used for worms are: normalized carbon steels (40C8 and 55C8); case-hardened carbon steels (10C4 and 14C6); case-hardened alloy steels (16Ni80Cr60 and 20Ni2Mo25); and nickel-chromium steels (13Ni3Cr80 and 15Ni4Cr1). The case-hardened steels are typically with a surface hardness of 60 HRC and a case depth of 0.75 to 4.5 mm. The commonly used worm gear bronzes are tin bronzes, manganese bronzes, aluminum bronzes, and silicon bronzes.

Tin bronze gears are typically casted by centrifugal, continuous, investment, or sand cast methods (Refs. 8–9). Figure 2 shows the microstructure of the cast tin bronzes consisting of cored dendrites; they have a composition gradient of increasing tin as they grow. The last liquid to solidify is enriched with tin upon cooling, and forms alpha and delta phases. The alpha and delta phases fill in the areas between the dendrite arms. Cast or wrought manganese bronzes are the toughest materials in the bronze family, with good wear resistance, but do not possess the same degree of corrosion resistance, wearability, or bearing quality as the tin bronzes or aluminum bronzes. Aluminum bronzes are similar to the manganese bronzes in toughness, but are lighter in weight. They are available in both cast and wrought forms and can be heat treated to attain higher mechanical properties. Their bearing quality is better than manganese bronzes but inferior to tin bronzes (Ref. 9).

For lightly loaded applications, the British standard B721 (Ref. 10) and AGMA American standard 6022-C93 (Ref. 5) allow several alternative worm gear materials, such as gray

cast iron, ductile iron, or soft steel. The development of plastics for lightly loaded worm drives, e.g.—food processing machinery—began in the early 1970s (Ref. 11) and currently there is no standard dedicated to the specification of plastics for worm drives.

The manufacturing methods of steel worms are dictated by the tread profile selected. Worms now can be turned on a lathe by a knife tool with straight edge aligned with the base tangent in a plane tangential to the base cylinder. This is similar to cutting screw threads. Worms can be ground by a thread grinding machine, using a grinding wheel dressed with a double-conical form. Worms can be also milled in a thread miller or similar machine, using a double-conical milling cutter with an included angle equal to two times the pressure angle of the worm. After manufacturing, worms require a number of finishing operations, including heat treatment and final dimensional and surface finishing. Bronze worm gears are most commonly produced by hobbing. Two hobbing methods—radial in-feed and tangential feed—are available, depending upon the lead angle and required accuracy of tooth profiles. Either method can be used to produce throated worm gears. Fly cutting is another method used for the quick manufacture of limited quantities of worm gears, such as the breakdown situation (Ref. 12). Plastic worm drives can be manufactured with the same machining process, as are metallic drives, by hobbing or milling. The very low cutting forces permit high infeed rates. Large quantity and small size of worms and worm gears can also be produced by injection molding.

The tooth contact analysis reveals that the contact area between the worm threads and worm gear teeth tends to be a long, thin ellipse that is distorted into a banana shape by the nature of surfaces (Refs. 13–14). The surface entraining direction in the contact ellipse is effectively along the major axis of the contact ellipse. This entraining action causes unfavorable tribological behavior and leads to thinner oil film thickness. Previous works addressing the worm contact analysis are also available (Refs. 15–17).

The efficiency of a worm drive can be between 50 and 96 percent, depending on lubricant; speed; surface roughness; load; material pair; worm profile; worm gear size; worm thread number; and temperature (Refs. 18–21). With unfavorable entraining action and mostly sliding contact, most worm drives have far more friction in the gear mesh than those of parallel and bevel drives, which results in a significantly lower efficiency. A simple analysis reveals that supplying all the worm drives in the United States with a lubricant that allows a relative increase of 5 percent in the mechanical efficiency, compared to a conventional mineral oil, would result in savings of US\$ 0.6 billion per annum (Ref. 22). The efficiency calculations for worm drives are standardized in AGMA 6034-B92 (Ref. 23); BS 721 (Ref. 10); DIN 3996 (Ref. 7); and ISO/TR 14521 (Ref. 24).

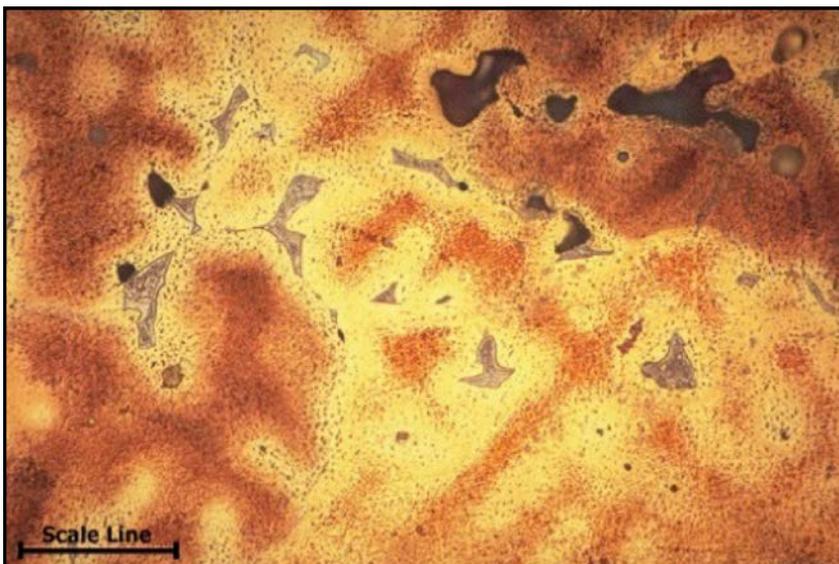


Figure 2 Microstructure of tin bronze as cast (scale line length ~50 microns) (Ref. 8).

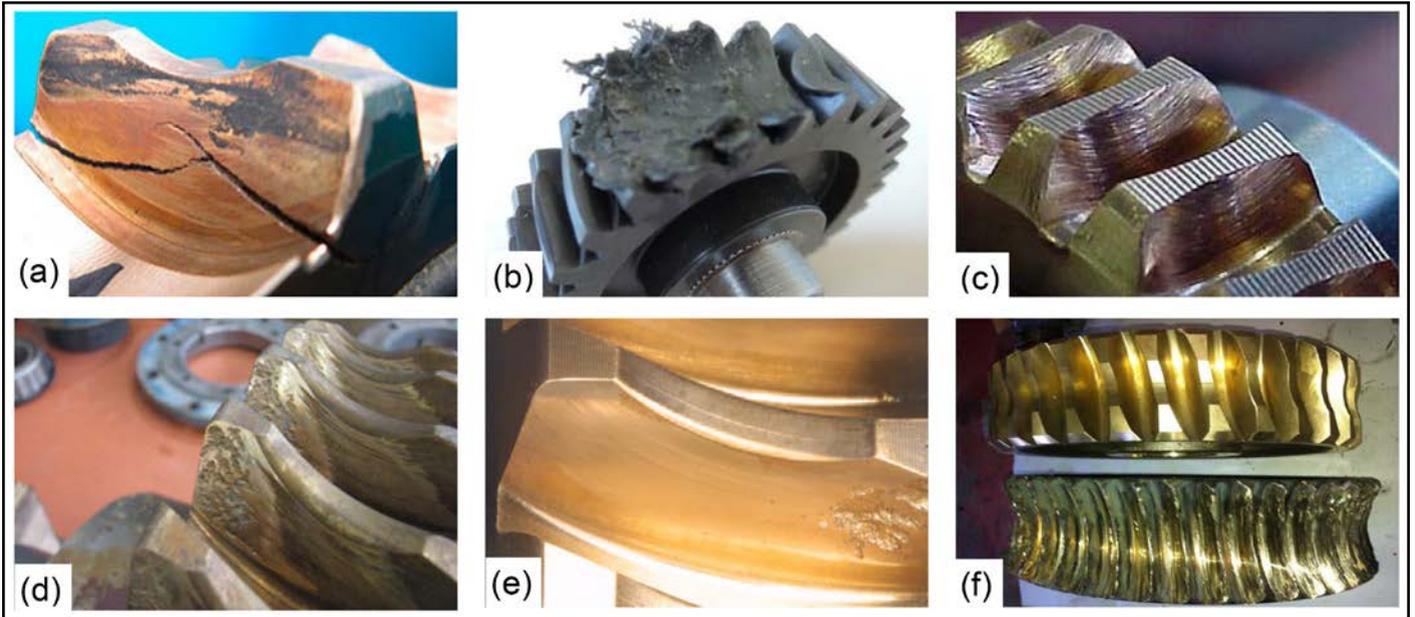


Figure 3 Wormgear failures: a) tooth breakage (Ref. 25); b) deformation and melting of plastic gear (Ref. 26); c) scuffing (Ref. 27); d) corrosion pitting (Ref. 28); e) pitting (Ref. 29), and f) wear — before (top gear) and after (bottom gear) usage.

In general, an increase in the noise level and vibration can be expected when worm drives fail. Different failures often leave characteristic clues on the worms and/or worm gears. Worm gear failures (Fig. 3) may be classified into two modes: 1) structural failure mode that includes tooth breakage due to impact or bending fatigue, tooth deformation and melting for plastic worm gear, and 2) surface failure mode that includes scuffing, case cranking, pitting and wear.

Future Outlook

It has been more than 80 years since the first standard for worm gearing was published, and worm drive development has progressed to maturity. Although the focus of gear research efforts has been dynamically changed, worm drives have constantly remained an active field. A brief review of the state of the art, such as the one presented here, may be helpful for better foreseeing future prospects. The following is the outlook for worm drives from the authors’ point of view.

Plastic worm drives. There is increasing demand from automotive, home/medical appliances, and food processing industries for worm drives that pair metallic and plastic, or plastic only materials. This demand is driven by the lower

cost, lighter weight and lower noise that can be achieved with plastics. Table 1 shows a list of metallic-plastic or plastic-plastic material pairs that have been developed specifically for worm drives. Plastics of interest include general-purpose plastics, general-purpose engineering plastics, quasi-super engineering plastics, super-engineering plastics, as well as glass fiber- and carbon fiber- reinforced plastic matrix composites. The latest development in worm material is the synthesis of carbon nano-tubes/polyacetal. The ongoing research direction of utilizing new developed plastics for worm drives focuses on wear resistance and surface temperature, since there is little rolling in the worm meshing. The plastic gear surface typically wears slowly, with a low specific wear rate if the gear is loaded below a critical value; however, the plastic gear wear rate will be increased dramatically when the load reaches a critical value for a specific geometry. The possible reason of the sudden increase in wear rate is due to the gear operating temperature reaching the material melting point under the critical load condition (Ref. 30).

A future challenge for the development of new plastics for worm drives is the cost of raw material and manufacturing processes. As an example (Ref. 36) for home appliance

Table 1 Metallic-plastic or plastic pair solutions		
Metallic or Plastic	Plastic	Remarks/References
JIS S45C steel, H _B = 210	Carbon fiber/Polyaminobismaleimide (PABM) resin matrix	Carbon fiber/Polyaminobismaleimide (PABM) show excellent wear re-sistance but the cost is expensive
	Glass fiber/Polyaminobismaleimide (PABM) resin matrix	
	MC polyamide (nylon)	
	PE polyamide (nylon)	
JIS S45C steel,	Mica filled polyamide (nylon)	The material is inexpensive with insufficient wear resistance
Steel	Polyetheretherketone (PEEK)	Good load-carrying capacity
	Polyamide PA 4.6	Inferior load-carrying capacity [33]
Steel	Reinforced glass fiber/Polyamide resin matrix	50 wt% glass fiber is relatively superior than 25% wt% glass fiber [34]
Synthesis of carbon nano- tubes (CNT)/ Polyacetal (polyoxymethylene POM) matrix	Synthesis of carbon nanotubes (CNT)/Polyacetal (polyoxymethylene POM) matrix	[35]

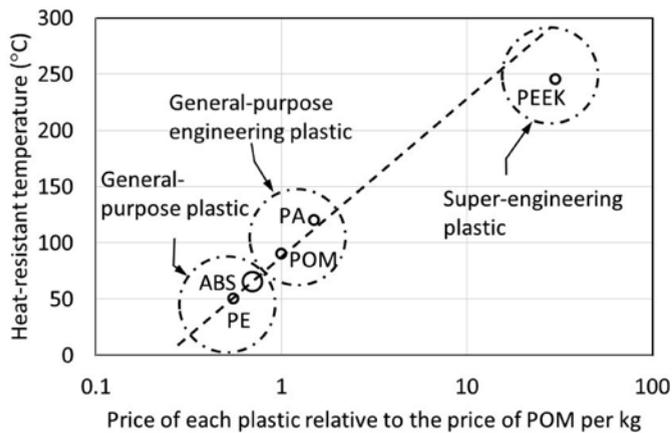


Figure 4 Heat-resistant temperature as a function of relative price to the price of POM per kg for plastics used for worm drives (Ref. 37).

industries, the molded fiberglass-reinforced POM gear cost is about a fifth of what the original machined metallic gear cost. Figure 4 shows an interesting indication that adopted from the study in (Ref. 37), addressing the heat-resistant temperature as a function of price of each plastic relative to the price of POM per kg. Even the price of super-engineering plastics can be more than one order higher than that of POM, so the future challenge in developing new plastics for worm applications will require low wear rate and high heat-resistance temperature while maintaining the cost similar to those of engineering plastic.

Integrated contact analysis for load capacity estimation.

In steel-bronze worm drives, the maximum load capacity is determined mainly by tooth breakage and pitting. Detailed geometry data of the worm drive is needed to perform the analysis. Many mathematical contact models have been developed to date to predict the tooth contact. However, the excessive wear of the softer worm gear and change in the tooth contact during the run-in period remains a modeling challenge. In addition, the abrasive wear on bronze worm gears may compete with the pitting during the normal operation. The material removed by the abrasive wear may in fact reduce the affected pitting area (Ref. 38).

An integrated contact analysis would be more accurate to estimate the load capacity. The integrated contact analysis should include the information of geometry (radii of curvature), kinematics (surface sliding velocity) and elasticity (gear tooth stiffness), coupling with material wear mechanism and material Woehler diagram to predict the stress distribution on the worm gear flank. This calculation has to be done iteratively. At any instance, the contact stress distribution can be established. Based on the contact stress distribution, the material removal and material life of flank surface can be predicted. A new surface on the worm gear flank is formed for the next instance of the calculation.

Enhancement of efficiency calculation. There are several standards available to calculate worm drive efficiency; however, many restrictions exist when applying these standards to the calculation of worm drive efficiency. For example, AGMA 6034-B92 and DIN 3996 do not consider the effect of lubricant type and surface roughness on efficiency. Lubricants influence the efficiency of worm drive mainly through reducing

power losses, which include churning losses and friction losses in hydrodynamic, elasto-hydrodynamic and boundary lubrication regimes. In conventional gear trains, synthetic oils can reduce power losses up to 8 percent for high-reduction worm drives (Ref. 39). In addition, the efficiency calculation in DIN 3996 is based on the empirical method from the worm drive with 20.5 of gear ratio. Applicability of worm drives with gear ratios other than 20.5 may be invalid (Ref. 40). Figure 5 shows the discrepancy among these standards — especially between AGMA and DIN/ISO standards. The efficiency of a worm gear pair calculated from the AGMA standard gradually increases with the rotational speed, while the efficiency from DIN/ISO standards seem to be insensitive to the rotational speed. To improve the efficiency calculation, local tooth friction and oil churning have to be obtained through the corresponding tribological behavior (lubricant, speed, surface roughness, load, temperature, and materials), gear size, worm profile, as well as thread number.

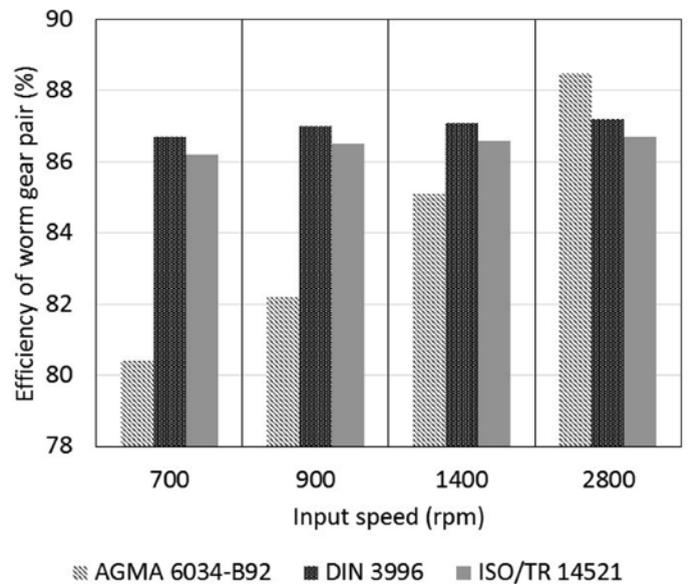


Figure 5 Efficiency of worm gear pair (gear ratio = 28, center distance = 150 mm) as a function of input speed based on the analytical calculation from AGMA, DIN and ISO standards.

Condition monitoring of worm drives. Condition monitoring is the process of monitoring a parameter of condition in machinery (vibration, temperature, particulates, etc.) in order to identify a significant change which indicates an ongoing fault in the machine. Condition monitoring has gained more attention as a result of maintenance operation of asset management. At one time, maintenance practices for gear drives were mostly reactive maintenance, i.e. — operate the geared drives until failure occurs. As the gear drives grew in capacity, preventive maintenance (PM) was then adopted to have periodic inspections of gear drive conditions. Such inspections are generally expensive and often require undesired scheduled downtime for the operation safety. As the condition monitoring techniques were developed during the 1970s and early 1980s to detect impending problems with obvious economic advantages in the aerospace and offshore oil structures (Ref. 41), predictive maintenance (PdM)

and condition-based maintenance (CBM) techniques have become increasingly adopted for many gear drives — especially with drives of large sizes or drives deployed in a remote area. The condition monitoring techniques that have been attempted for the gear drives are vibration analysis, oil debris analysis, acoustic emission, temperature, and power analysis (motor current/voltage/torque). Several condition monitoring techniques for parallel gear drives have been well established; however, the application of condition monitoring on the worm drives is currently limited. Research studies of condition monitoring and diagnosis on worm drives have been conducted since 21st century (Refs. 27; 42–44) to benefit worm drives in a remote area. The condition monitoring and diagnostic techniques may for worm drives differ from those for parallel drives. Taking the vibration analysis for example, compared to other gears types where defects manifest as periodic impacts in the form of side-bands around the gear mesh frequencies, such distinctive defect symptoms are not obvious for worm drives due to their continuous sliding interactions. Many challenges remain unclear such as, in the vibration analysis, which mathematical process has the most sensitive feature, at what frequency range is this mathematical process effective to the worm kinematics, and how these mathematical processes perform product-by-product in different application fields (Ref. 43); but progress has been made toward an integrated approach to condition monitoring and diagnosis using oil debris analysis, vibration analysis, and/or other techniques in parallel.

Conclusions

Worm drives have greatly advanced since the progress made in geometrical modeling, tribology and manufacturing processes. Further innovations in worm design, manufacturing, and operation could help develop a vast set of new opportunities for worm drives. The focus should be placed on designing gears that have higher load capacity and efficiency, less heat and noise, low cost and improved lifecycle. This paper presents a comprehensive compilation of state-of-the-art information on worm drives, highlights future outlook, and addresses important and challenging areas of research and development that should be explored for the industry to better cope with the innovations that are likely to occur in the worm drives. **PTE**

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Baldor Motor Basics — Part 10

How to Select Motors for Hazardous Locations

Edward Cowern, P.E.

A continuing series of articles, courtesy of the Baldor Electric Co., dedicated primarily to motor basics; e.g. — how to specify them; how to operate them; how — and when — to repair or replace them, and considerably more.

Failure to specify the proper motor for use in a hazardous location can have serious consequences — lost production, extensive property damage, and even loss of human life. Selection of the proper motor requires an understanding of Underwriters Laboratories' (UL) and National Electrical Code (NEC) class, group and division designations and the T code letters.

In some plant engineering departments there may be only a vague understanding of the selection criteria of motors for hazardous locations. In some cases the specifier passes the buck to another party in the hope that someone — perhaps the motor manufacturer — will fill in the missing specification data. In other cases, the same type of motor that had been used in the plant previously is specified, with the hope that this approach will certainly handle any situation. But this approach can greatly increase the cost of the project, and, in some cases, result in a motor inadequate for the application.

Hazardous locations are operating environments in which explosive or ignitable vapors or dust is present, or is likely to become present. Special motors are required to ensure that any internal fault in the motor will not ignite the vapor or dust. Requirements for electrical installations in hazardous locations are covered in Articles 500, 501, 502, 503, 510, 511, 513, 514, 515, and 516 of the *National Electrical Code*.

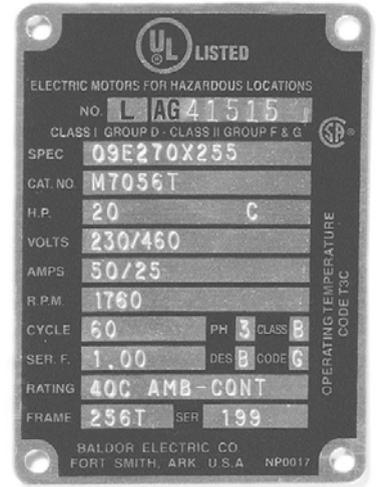
A relatively new Article 505 makes an abrupt change in traditional hazardous location requirements and brings the NEC closer to the somewhat less stringent European code requirements by classifying areas into three separate zones, i. e. — 0, 1 and 2. This section tends to involve wiring practices and components, rather than motors, so it will not be included in the discussion to follow.

At the present time, Article 505 sets forth some principles, but it will be some time before equipment suppliers will have products available to match the new requirements. We can also expect the “inertia of habit” to slow the change to the somewhat relaxed zone requirements. Perhaps the changes will be used first by multinational companies where engineers are more familiar with the zone system and matching hardware.

The term “explosion-proof” is often erroneously thought to apply to any hazardous-location motor.

Explosion-proof motors, however, are only those approved for Class I locations; that is, where potentially explosive gases or vapors are present. A Class I unit is constructed to contain an explosion within itself without rupturing. After the initial

Figure 1 An Underwriters Laboratory (UL) nameplate is used on all motors approved for use in Division 1 hazardous locations. In addition to the normal motor data such as horsepower, speed, voltage, amperage, NEMA code letter, etc. it also shows the specific class(es) and group(s) for which the motor is approved. In the example shown the motor is approved for Class I Group D and Class II Groups F and G. The T code is also indicated.



pressure buildup on ignition, the hot gas is forced to cool by passing through long, tight passageways (flame paths) before escaping from the motor. The temperature of gas escaping from the motor will then be below the minimum ignition temperature (MIT) of the gases of vapors in the atmosphere surrounding the motor.

Meaning of Motor “Class” Designations

Every motor approved for hazardous locations carries an Underwriters Laboratories (UL) nameplate that indicates the motor is approved for hazardous locations (see illustration). This nameplate identifies the motor as having been designed for operation in Class I or Class II locations’ some motors may be approved for *both* Class I and II locations.

Basically, the class identifies the physical characteristics of the hazardous materials present at the location where the motor will be used. Class I covers gases, vapors, or liquids that are explosive or else pose a threat as ignitable mixtures. A familiar example of a Class I material is gasoline. It is explosive as a vapor and ignitable as a liquid. Some of the most common Class I substances are listed in Table 1.

Class II covers dusts — specifically, dust in amounts sufficient to create explosive mixtures, and dusts that are electrically conductive. A prime example of a hazardous dust is wheat flour. As a compact mass, flour burns or smolders; but when it is finely distributed in air, it is highly explosive. Also included in Class II are electrically conductive metallic and nonmetallic dusts, such as powdered aluminum and magnesium, and pulverized coal. Aluminum and magnesium dusts can burn violently even when not suspended in air; but when airborne, they are explosive. Some common Class II substances are listed in Table 2.

Table 1 Class 1 substances and atmospheres	
Substance or Atmosphere	Minimum Ignition Temperature
Group A	
acetylene	305°C (581°F)
Group B	
butadiene	420°C (788°F)
ethylene oxide	570°C (1058°F)
hydrogen	500°C (932°F)
Group C	
acetaldehyde	175°C (347°F)
cyclopropane	498°C (928°F)
diethyl ether	180°C (356°F)
ethylene	450°C (842°F)
isoprene	395°C (743°F)
unsymmetrical dimethyl hydrazine (UDMH) 1, 1-dimethyl hydrazine	249°C (480°F)
Group D	
acetone	465°C (869°F)
acrylonitrile	481°C (898°F)
ammonia	651°C (1204°F)
benzene	498°C (928°F)
butane	287°C (550°F)
1-butanol (butyl alcohol)	343°C (650°F)
2-butanol (secondary butyl alcohol)	405°C (761°F)
n-butyl acetate	425°C (797°F)
isobutyl acetate	421°C (790°F)
ethane	472°C (882°F)
ethanol (ethyl alcohol)	363°C (685°F)
ethyl acetate	426°C (800°F)
ethylene dichloride	413°C (775°F)
gasoline	280°C (536°F)
heptane	204°C (399°F)
hexane	225°C (437°F)
methane (natural gas)	537°C (999°F)
methanol (methyl alcohol)	464°C (867°F)
3-methyl-1-butanol (isoamyl alcohol)	350°C (662°F)
methyl ethyl ketone	404°C (759°F)
methyl isobutyl ketone	448°C (840°F)
2-methyl-1-propanol (isobutyl alcohol)	415°C (780°F)
2-methyl-2-propanol (tertiary butyl alcohol)	478°C (892°F)
octane	206°C (403°F)
petroleum naphtha	288°C (550°F)
1-pentanol (amyl alcohol)	300°C (572°F)
propane	450°C (842°F)
1-propanol (propyl alcohol)	412°C (775°F)
2-propanol (isopropyl alcohol)	399°C (750°F)
propylene	455°C (851°F)
styrene	490°C (914°F)
vinyl acetate	402°C (756°F)
vinyl Chloride	472°C (882°F)
p-xylene	528°C (984°F)

Class III locations do not normally require hazardous-location motors. Specifying a hazardous location motor for Class III locations is a common error. Section 503-6 of the NEC permits a totally enclosed fan-cooled or non-ventilated motor to be used in Class III locations. A totally enclosed motor can be purchased at lower cost than a motor approved for hazardous locations. NEC Section 503-6 also allows the use of an open drip-proof motor in Class III locations, if the inspection authority is satisfied that proper housekeeping will be maintained. Class III locations are those where easily ignitable fibers and “flyings” are likely to be present. Such substances are commonly encountered in the textile, woodworking, and plastics industries. Class III materials are not normally airborne, because they are fairly heavy and settle rapidly. They are, however, quite flammable, and, therefore, create a potentially hazardous condition when near electrical equipment. Common Class III substances are listed in Table 3.

Meaning of “group” designations. Within Class I and Class II, Group designations are assigned to various combustible substances on the basis of their behavior after ignition. Group designations A through G are arranged in descending order according to the stringency of motor design requirements; Group A requirements would require the longest flame paths and tightest fits. Groups A through D fall within Class I, and Groups E, F, and G fall within Class II. Class III materials are not broken down by group.

Gasoline and acetylene provide an illustration of the group concept. Both are Class I substances. Acetylene is designated as a Group A substance, gasoline falls within Group D. MIT of automotive gasoline is 280°C (536°F), slightly below the 305°C (581°F) MIT of acetylene. An acetylene explosion, however, is more intense than a gasoline explosion, so acetylene is grouped well above gasoline.

Table 3 Class 3 substances (no groups assigned)

Ignitable Fibers or Flyings	
Rayon	Cotton
Sawdust	Sisal
Henequen	Istle
Jute	Hemp
Tow	Cocoa fiber
Oakum	Baled waste kapok
Spanish moss	Excelsior
(and other materials of similar nature)	

Table 2 Class II substances

Group	General definitions	Examples
E	Metallic dusts	Dusts of aluminum, magnesium, their commercial alloys and other metals of similarly hazardous characteristics
F	Electrically conducting non-metallic dusts	Coal dust Pulverized coal Pulverized coke Pulverized charcoal Carbon black and similar substances
G	Electrically non-conducting dusts	Grain dusts Grain product dusts Pulverized sugar Pulverized starch Dried powdered potato Pulverized cocoa Pulverized spices Dried egg and milk powder Wood flour Oilmeal from beans and seeds Dried hay and other products producing combustible dust when dried or handled and other similar substances

It is a common misconception that Class I transcends Class II and that a Class I motor will automatically satisfy any Class II requirement. But, a Class I motor is designed primarily to confine the effects of an internal motor explosion. Design is based on the assumption that, over a period of time, normal heating and cooling will cause the motor to breathe the surrounding atmosphere, and the atmosphere within the motor will, eventually, become the same as that of the operating environment. A subsequent internal fault can, therefore, cause an explosion within the motor.

A Class II motor, however, is designed to maintain the motor's surface temperature at a level such that Class II materials in the motor operating environment will not be heated to their MIT. If the operating environment contains both Class I and Class II substances, a dual-rated Class I/Class II motor must be specified.

Another common misconception is that because the Classes and Groups exist—then there should be suitable products (motors or other equipment) to operate in the defined environment. As it turns out, Classes and Groups are used for all types of equipment including enclosures, light fixtures, heating elements, operator devices, etc. But just because there is a definition it doesn't mean that a matching product is available. In the case of motors this is especially true for Class I Groups A and B. Apparently the market for motors to operate in these environments is so limited—and the designs so difficult—that most manufacturers do not make them.

The most common hazardous location motors are made for Class I Group D and Class II Groups F and G. Several manufacturers can build motors for Groups C and E but they are normally made on a special order basis.

Meaning of "division." Hazardous locations are further broken down into Division 1 and Division 2. The distinctions are defined in detail in Article 500 of the NEC. Simply stated, a Division 1 location is one in which ignitable substances are likely to be present continuously or intermittently in the course of normal operations. In a Division 2 location, ignitable materials are handled or stored in a manner that allows the combustible substance to escape in the event of spill, accident, or equipment failure.

For a complete list of Class I materials refer to NFPA 325—"Guide to Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids."

Division distinctions are concerned primarily with installation procedures required by the NEC. Class I and Class II motors for hazardous locations have no Division designation on the UL label. All Class I and Class II motors are designed to meet Division 1 requirements and are, therefore, suitable for installation in both Division 1 and Division 2 locations.

Hazardous-location motor T codes. All motors manufactured after February 1975 carry a T code designation (Table 4). The T code identifies the maximum absolute motor surface temperature that will be developed under all conditions of operation, including overload up to and including motor burnout. The T code designation of the motor must be correlated with the Minimum Ignition Temperature (MIT) of the substances in the motor's operating environment.

The presence of acetone or gasoline, for example, will affect motor selection. Acetone and gasoline are both Class I, Group D materials. Acetone has an MIT of 465°C (869°F) (Table IV) indicates that a motor with a T1 rating (450°C maximum surface temperature) would be acceptable for operation in an acetone environment.

Gasoline, however, has an MIT of 280°C (536°F). For operation in an environment containing gasoline, no less than a T2A motor, designed to develop a surface temperature no greater than 280°C, should be specified (Table 4). Although T codes and ignition temperatures are conservatively assigned and are based on "worst case" testing procedures, an extra margin of safety should be provided by specifying a T2B or higher T rated motor, designed to develop a maximum surface temperature of 260°C (500°F).

Meeting some of the lower temperature T Code requirements necessitates the use of automatic thermal overload devices (fractional horsepower motors) or normally closed (NC) winding thermostats in larger (integral horsepower) motors.

Winding thermostats are control devices with relatively low current capacity. They have to be connected to the motor's magnetic starter to cause it to interrupt power to the motor when the internal temperature gets too high. Failure to make the required "CONTROL CIRCUIT" connection will negate the motor nameplate T Code rating.

In a motor designed for Division 1 use, the winding thermostats are mounted inside the frame's flame path. On Division 2 motors, such a construction is not used, so thermostats and any other accessory must be intrinsically safe as discussed in IEEE 303. "Recommended practice for Auxiliary Devices for Rotating Electrical Machines in Class I, Division 2 and Zone 2 locations".

Use with inverter power supply. Unlike standard motors which can readily be used with Adjustable Speed Drives, motors used in Division 1 and 2 locations need specific certification and marking indicating suitability for the specific class and group, speed range and constant or variable torque. Most manufacturers have a specific family of Inverter Duty Explosion Proof motors suitable for Division 1 or 2 locations. Standard motors that are suitable for Division 2 use may be

Table 4 T codes and their associated temperatures

T Number	Maximum motor surface temperature	
	°C	°F
T1	450	842
T2	300	572
T2A	280	536
T2B	260	500
T2C	230	446
T2D	215	419
T3	200	392
T3A	180	356
T3B	165	329
T3C	160	320
T4	135	275
T4A	120	248
T5	100	212
T6	85	185

name plated with their speed capabilities. Intrinsically Safe Auxiliary devices must be used.

Additional sources of information. In addition to the NEC, three other publications of the National Fire Protection Association (NFPA) (*NFPA publications can be obtained from National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.*) will be helpful in selecting the proper motor. NFPA publication 325, mentioned previously, covers the properties of hazardous liquids, gases, and volatile solids, and provides a more comprehensive listing of hazardous substances than does Table 1. NFPA 497 — “Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas” will help classify installations and areas. NFPA 499 — “Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas” covers Class II substances. Each publication provides MIT’s for the substances covered in the respective publications.

The field service representative of the plant’s insurance underwriter can also provide advice when there is uncertainty as to what type of motor is required for a particular hazardous-location application. **PTE**

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Lenze

ENLARGES BOARD OF DIRECTORS

Lenze, a global leader and manufacturer of electrical and mechanical drives, motion control and automation technologies, is enlarging its board of directors by adding a fourth member to the current three. This decision firmly positions the company towards the implementation of its 2020+ growth strategy, which aims to fulfil Lenze's strategic priorities and goals until 2020 and beyond.

The newly created domain of directorial responsibility—operations—will be filled by **Jochen Heier**, who will be Chief Operating Officer (COO), effective January 1, 2018. Heier's most recent position was at Yanfeng Automotive Interiors, the world's biggest automotive supplier of interiors. As vice president and general manager for Europe and South Africa, he was responsible for the management, strategic development and expansion of the business. Before that, Heier held managerial positions in a variety of companies, including Johnson Controls, Exide Technologies and Frauenthal Holding AG.



"We are excited to continue fulfilling our 2020+ growth strategy," said Christian Wendler, CEO and chairman of the board of directors, Lenze. "Hiring Jochen means that Lenze has succeeded in appointing an internationally experienced manager with a wide range of competencies in production, supply chain, technology, internationalization and strategy implementation. In the newly created position, Jochen will be instrumental in continuing Lenze's positive development in the area of operations.

"By further expanding our board of directors, we believe we are excellently equipped to master the steadily growing challenges in the machine and plant manufacturing industry and to fully take advantage of the opportunities that are now emerging. Our goal is to keep growing, not only nationally but also internationally, in our three core areas—mechanics, automation systems and solutions, and digital services—and to set Lenze up in a sustainable way for the future," continued Wendler.

The directorial responsibilities of Christian Wendler as CEO and chairman of the board; Dr. Yorck Schmidt as Chief Financial Officer; and Frank Maier as Chief Technology Officer remain unchanged. (www.lenze.com)

Motion Industries

ANNOUNCES EXECUTIVE CHANGES

Motion Industries, Inc. recently announced three management changes, effective December 11, 2017. Tim Breen, Motion Industries president and CEO, announced the following promotions:

Randy Breaux was promoted to executive vice president of marketing, distribution, and purchasing. The increased cooperation among these disciplines allows the company to identify and plan for growing opportunities in the industry such as the industrial internet of things (IIoT) and automation. In 2016, Breaux was promoted to his most recent position of senior vice president of marketing, distribution, and purchasing. He joined Motion Industries in 2011 as senior vice president after 20+ successful years at Baldor Electric Co.



Kevin Storer was promoted to executive vice president of U.S. Operations and president of Mi Mexico, and will maintain responsibility for all field branch sales in the United States and Mexico. This change solidifies his position as the leader for field sales and allows the field to move in an agile, highly coordinated fashion with respect to operating efficiently, as well as seizing future opportunities in a decisive manner. Storer began his career with Motion Industries in the West Group in 1987, and held significant positions in the company before being promoted in 2016 to his most recent position as senior vice president of U.S. Operations and president of Mi Mexico.



Also, **Mark Stoneburner** was promoted to senior vice president of industry segments and business development. The addition of the business development function to Stoneburner's role enables Motion Industries to better leverage his deep industry experience, as well as his strong strategic approach to a growing portion of the company's overall business. He joined Motion Industries in 2016 as corporate account vice president—industry segments, bringing with him 33 years of industry experience. Stoneburner will continue to share responsibility for merger and acquisition (M&A) strategy.



“Our evolving industry offers us the opportunity to be proactive in how we partner with suppliers, how we interact with customers, and how we leverage our greatest asset—our people,” said Breen. “Each of these promotions allows Motion Industries to continue to ensure our leadership position and capitalize on opportunities going forward, which in turn will enhance our customer service even more.” (www.motionindustries.com)

AGMA

OFFICIALLY IACET ACCREDITED

The American Gear Manufacturers Association (AGMA) has been officially accredited by the International Association for Continuing Education and Training (IACET). Through a rigorous application process guided by the ANSI/IACET Standard, AGMA is now able to offer Continuing Education Units (CEUs) to students that take a course through them based on identified learning outcomes and delivery of those outcomes.



AGMA's education program has added two additional courses for the 2018 schedule and in addition to working on a Gear Manufacturing or Advance Gear Engineering Certificate, participants will have the opportunity to obtain CEU's based on qualified contact hours for a class. With an expanding program, AGMA is able to provide students a way to measure and quantify the continuing education they are investing in.

“We wanted to provide our students with a quality learning experience by adhering to adult education industry standards and the opportunity to use the education they receive with AGMA for professional development,” said Casandra Blassingame, director of education for AGMA. “Our students are working very hard on their professional goals and we are dedicated to making sure AGMA education counts. Having this accreditation just further proves why our gear classes are the best in the industry and we are excited to have been awarded this ‘Gold Seal’”.

According to IACET, “IACET Accredited Providers are an elite group of educators dedicated to quality in continuing education and training... and have been thoroughly assessed by a third party.” Some of the qualifications for AGMA include: Learning outcomes that are based on identified needs and clearly providing to learners, having established methods to award CEUs and a system to maintain, protect and provide training records, systematically evaluating all learning events and content to ensure they are providing the

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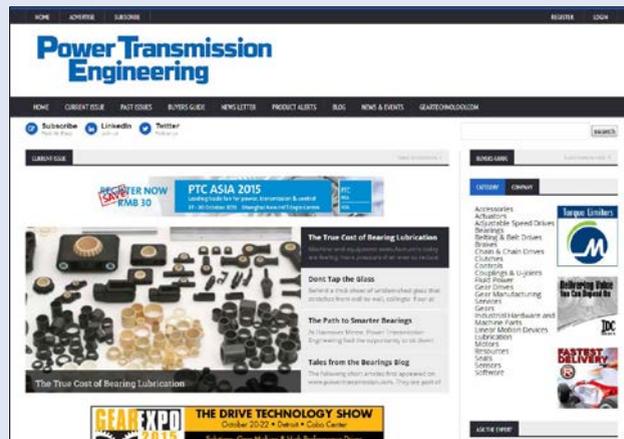
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best possible learning experience, and having qualified personnel planning and conducting their programs.

Students will need to check with their specific regulatory boards and agencies to confirm that the IACET CEUs will be accepted towards maintaining P.E. licensure. AGMA is now included in a list of approved providers on the IACET website. (www.agma.org)

Gear Motions

BEGINS PARTNERSHIP WITH SOUTHEAST INDUSTRIAL SOLUTIONS

Gear Motions has announced a new partnership with Southeast Industrial Solutions.

SEIS is a professional manufacturers' representative firm, servicing principals with engineering-level coverage for technical, custom products. With over 25 years of experience, SEIS specializes in consultative sales and developing innovative solutions to foster a long-term, collaborative partnership between the manufacturer and customer.

SEIS represents premier manufacturing companies as principals, bringing quality solutions to customers in the Southeast. Since its founding, SEIS already has an impressive list of principals it represents. SEIS services industries such as aerospace, automotive, construction, consumer electronics, industrial, medical, military and defense, mining, nuclear, oil and gas and telecommunications.

The emerging and agile firm strives to deliver personalized services to its principals and customers with engineering-level expertise and professional business practices. As a member of Manufacturers' Agents National Association (MANA), SEIS and its team are encouraged to continuously improve, be involved, and facilitate best practices.

Gear Motions welcomes SEIS and looks forward to introducing their precision gearing products and services to new customers and industries as a result of this partnership.

(www.gearmotions.com)



Continental

EXPANDS RUBBER MIXING OPERATIONS IN NEBRASKA

Technology company Continental has announced a \$9.3 million expansion of the rubber mixing operations at its industrial hose plant in Norfolk, Nebraska, to accommodate its North American manufacturing facilities by providing rubber for industrial hoses and whitewall tires for passenger cars.

"We have plans to add in excess of 19,000 square feet to expand our rubber mixing capabilities and better serve our internal and external customers," said Dan Granatowicz, plant manager. "We anticipate that the expansion will enable us to add in excess of 30 associates. The investment will also reaffirm our commitment as a good corporate citizen to the

Norfolk community and the region as we secure jobs and support the economies of each."



The Northeast Nebraska plant, less than 40 years old, currently employs slightly more than 360 associates. Granatowicz said that construction work will begin immediately and be completed by the end of the first quarter of 2019. The facility primarily manufactures industrial hose and supplies compound for a variety of applications such as general purpose air and water, garden, mining, petroleum, steam and welding hose. The new mixing operations also will enable the plant to supply compound for product-specific whitewall Continental passenger tires.

(www.contitech.us)

Forest City Gear

EARNs WOMEN'S BUSINESS ENTERPRISE CERTIFICATION

Forest City Gear has successfully met the Women's Business Enterprise National Council's standards for certification as a Women's Business Enterprise.

WBENC National WBE Certification validates that the business is owned, controlled, operated, and managed by a woman or women. To achieve WBE Certification, women owned businesses complete a rigorous documentation and site visit process. WBE Certification is an important accreditation recognized by hundreds of WBENC Corporate Members and government agencies, including most major US corporations and federal, state and local government entities.

"Supplier diversity is an increasingly important aspect of the procurement process that Forest City Gear is involved with in the industries we serve, and the WBE Certification gives us critical recognition," says Forest City Gear President and CEO **Wendy Young**. (www.forestcitygear.com)



Gilman Precision

ADDS RICH OLSON TO BUSINESS DEVELOPMENT TEAM

Gilman Precision, manufacturer of customized linear and rotary motion systems, is pleased to announce the addition of **Rich Olson** to their sales force as a business development specialist.



Olson will oversee the Midwest territory in the United States. Through a variety of means, he will play an important part in facilitating the connection between engineers and customers, creating smooth communication, and cultivating positive customer relations. Olson will aid clients by addressing their unique needs and assisting them towards the most efficient route of action to solve their linear or rotary motion challenge.

Doug Biggs, vice president of sales and marketing commented, "We are more than excited to add Rich to our Business Development team. Gilman is continuing to grow, and we believe Rich's skill set and experience will help expand our company even further by creating new opportunities as well as increasing value in customer interactions."

Olson has several years of experience working in the customer service and sales environment, specifically selling marketing and software solutions. Olson values customer care and a strong work ethic, making him a perfect fit for Gilman's team. He is thrilled to join the team in their pursuit to further expand the bands of excellence. (www.gilmanprecision.com)

Bison Gear

WELCOMES ILLINOIS GOVERNOR BRUCE RAUNER

As a follow-up to his visit to Bison Gear & Engineering for National Manufacturing Day in 2014, Governor Rauner took time on Thursday, November 30 to meet with members of the Bison management team. The governor received an up-

date on the state of global competition in the power transmission market and how that is impacting both Bison's operation and other manufacturing facilities in Illinois.

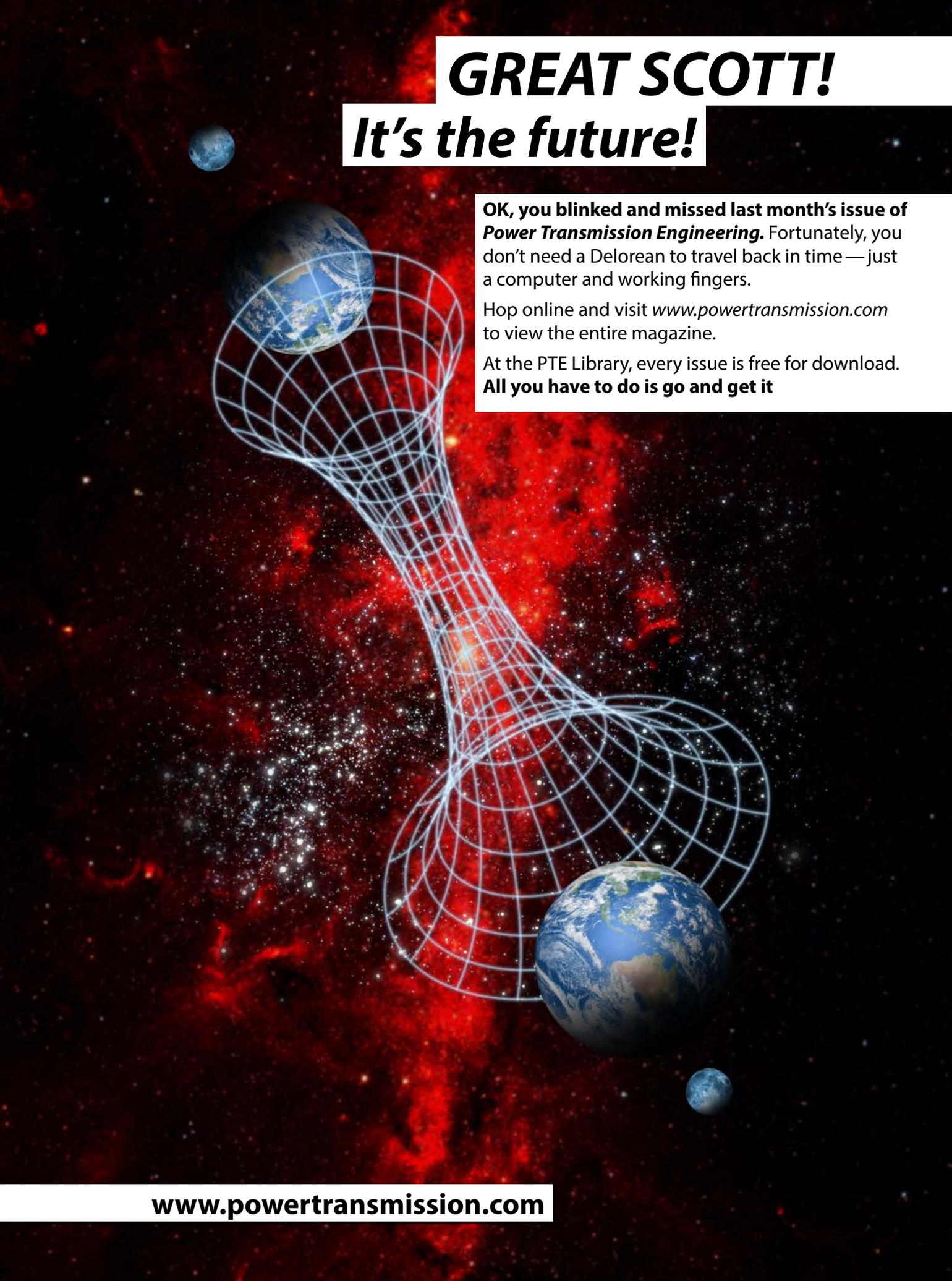
"Bison Gear & Engineering was honored to host Governor Rauner again. Manufacturing is the backbone to the US economy, so we are very pleased that Governor Rauner continues to visit local companies like Bison. Our team provided a first-hand look at the challenges we face and the opportunities that exist within the manufacturing sector in Illinois," said John E. Burch, CEO.

Bison showcased a significant investment made in capital equipment and staffing over the past five years. This investment has allowed the company to add a new product line that addresses shifting customer demand for more efficient gearmotors. "By introducing the PowerSTAR line of right angle gearmotors, Bison was able to develop a hypoid gear box that significantly improves motor efficiency vs. comparable models that operate at only around 40% efficiency. This advancement has allowed our customers to achieve a higher output measure of torque with reduced power demand," said Matt Hanson, vice president of product development.

Governor Rauner toured the plant floor at Bison with Executive Vice President of Operations, George Thomas. The tour highlighted many of the upgrades Bison has made to become more energy efficient and improve environmental impact. "A matching grant from the Illinois Department of Energy has allowed us to bring updated equipment online to address the increasing demand for our PowerSTAR gearmotors and newer lines of energy efficient DC motors," said Thomas.

The governor concluded his visit with a short town hall session for Bison employees. Several topics were covered relating to how his office is working with other branches of government to address the increasing tax burden on Illinois residents. Governor Rauner also spoke about multiple state sponsored programs which have been enacted to improve access for educational programs focusing on STEM (Science, Technology, Engineering and Math). (www.bisongear.com)



A wireframe wormhole structure is depicted in space, with a large Earth at the top and another large Earth at the bottom. Two smaller Earths are also visible in the background. The background is a dark space filled with stars and a prominent red nebula.

GREAT SCOTT!

It's the future!

OK, you blinked and missed last month's issue of *Power Transmission Engineering*. Fortunately, you don't need a DeLorean to travel back in time — just a computer and working fingers.

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March 7–10—The Manufacturing Meeting 2018

Miami, Florida. Hosted by two major manufacturing trade associations, AMT—The Association For Manufacturing Technology and National Tooling and Machining Association (NTMA), The MFG Meeting brings together the complete manufacturing chain for a unique conference experience. This event provides unparalleled opportunities to network with industry leaders and the agenda topics are designed to address key business challenges and provide actionable solutions. The event is intended for senior leadership, executives, vice presidents, senior sales directors, manufacturing technology's builders, distributors and end users. Learn about the future challenges and opportunities facing the American manufacturing industry, discover new ideas and participate in interactive discussions. For more information, visit mfgmeeting.org.

March 6–7—FVA Bearing World 2018

Kaiserslautern, Germany. FVA Bearing World 2018 will bring together experts from research and industry in the fields of design, calculation, and the practical use of bearings. More than 40+ high level presentations will detail the latest research projects as well as reports from field operation. Rolling bearings are still the main focus, but this year the event will also include an interesting look at plain bearings. The conference provides a comprehensive overview of the current state of technology, research, and development with leading national and international experts. Exhibitors include Schaeffler, SKF, FVA, Stresstech and more. With FVA Bearing World, the German Research Association for Drive Technology is initiating an international dialogue, an exchange of knowledge and experience in which researchers and developers from universities and bearing manufacturers come together with users and experts from the industry. For more information, visit bearingworld.org.

March 12–15—PCI Powder Coating 2018

Indianapolis, Indiana. This four-day event will kick off with the Technical Conference and Tabletop Exhibition on Monday & Tuesday, March 12 & 13, closing on the morning of March 14. Complete with general sessions and concurrent technical programs, attendees will have access to a variety of powder coating information as well as personal interaction with suppliers. The tabletop display area will feature powder coating manufacturers, powder coating application equipment, system houses, chemical suppliers and various services that support the powder coating industry. PCI's popular Powder Coating 101: Basic Essentials Hands-On Workshop will be offered on Wednesday afternoon, March 14 and Thursday, March 15. The workshop includes a comprehensive agenda that covers all the basics of powder coating operations. For more information, visit www.powdercoating.org.

March 14–15—Innovations in Bevel Gear Technology

Aachen, Germany. This WZL Aachen event will examine topics and trends in bevel gear technology that are presented and discussed in this special-interest seminar which is well established among the international technical community. Nowadays customers require high performance bevel gears. Within this seminar current developments of design and calculation processes are introduced. Furthermore the new inventions in bevel gear production and quality inspection will be presented.

The seminar gives an overview about the state of the art. Current problems in bevel gear production will be discussed in preparation for future research and developments. This conference will be offered with simultaneous translation into English. Instructors include Christian Brecher, Fritz Klocke and Christoph Lopenhaus. Contact WZLforum for additional information at <https://wzlforum.de>.

March 20–21—Fundamentals of Gear and Transmission Technology

Brookline, MA. This two-day course located at Franhofer USA CMI will examine the basic properties of gears as machine elements, gear manufacturing technologies, methods for quality control, as well as testing and analysis of load carrying capacity and running behavior. The course focuses on methods of interpretation, analysis and solving challenges in the design, manufacturing and application of gears. This course is "geared" towards designers and manufacturing engineers working in gear and transmission technologies, as well as for shop floor and department managers involved with the production and sale of gears and gearboxes. The \$1,495 fee includes all seminar materials, lunches and dinners. The U.S. Gear and Transmission Technologies Group brings together Fraunhofer CMI with German partners from Aachen, Fraunhofer IPT and WZL. For more information, visit www.cmi.fraunhofer.org.

March 20–22—Gearbox CSI

Concordville, PA. Gain a better understanding of various types of gears and bearings. Learn about the limitation and capabilities of rolling element bearings and the gears that they support. Grasp an understanding of how to properly apply the best gear-bearing combination to any gearbox from simple to complex. Gear design engineers, management involved with design, maintenance, customer service and sales should consider attending. Upon completion, attendees will be able to apply an understanding of forensic analysis of gearbox failures in future gearbox designs. Instructors scheduled include Raymond Drago and Joseph Lenski, Jr. For more information, visit www.agma.org.

March 22–23—PTDA Leadership Development Conference

San Antonio, Texas. PTDA 2018 Spring Meetings combine governance meetings and the Leadership Development Conference to offer networking opportunities along with powerful education for those looking to enhance their leadership skills and to achieve the goals set forth in the PTDA Strategic Plan. Step up your leadership game, while networking with your power transmission/motion control industry peers in an intimate and relaxed setting. Educational sessions are designed for emerging and seasoned executives who want to build executive leadership skills. Open to all employees of PTDA member companies. For more information, visit www.ptda.org.

CALL FOR PAPERS!

Are you sitting on an idea for a technical paper but wondering where to present it? Do you have one already written, sitting on your desk, gathering machine dust?

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Chances are you’ll be creating the paper under the auspices of the company for whom you work or own, or for one of the various industry-relevant associations. That means they as well will bask in the reflected glory that accrues with publication in *Power Transmission Engineering*.

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A Manufacturing Mix-Tape

Mechanical Motion Gives Sound Designers Creative Options in Film and Television Projects

Matthew Jaster, Senior Editor

I noticed it during my first assignment in a job shop. Maybe it was the gentle whir of a motor or the scratching sound of a grinding gear, but the factory floor boasted plenty of unique noises and sound effects. It reminded me of a popular story about how Sound Designer Ben Burtt created the iconic sound of the lightsaber for *Star Wars* back in 1977, still today one of the most iconic of Hollywood sound effects.

“I was still a graduate student working as a projectionist in a booth with some very, very old Simplex projectors,” said Burtt in the book *The Sounds of Star Wars*, by J.W. Rinzler. “The projectors had an electric interlock motor that connected them to the sound dubbers when used for mixing. When sitting idle, the motors made a wonderful humming sound. It would slowly change in pitch and form beats that created a soothing harmony. It would put you to sleep - it was either that or the fumes from the arc lighting in the room.”

Burtt recorded the sounds of that projector and the rest is motion picture history. The *Star Wars* sound design crew would continue to find small motors extremely useful for the original film. Additional motor effects came into play with the introduction of the droids R2-D2 and C-3PO.

On Tatooine, the audience heard more of the droids’ banter and could better hear their interior motors, which had been the responsibility of Sam Shaw [supervising sound editor]. The droid ‘engine’ sounds Shaw cut in came from the antenna and window motors of a Cadillac El Dorado.

“Making the motor sounds for the droids was a huge job,” Burtt said. “I had never gotten to that on my list, because they weren’t a priority.”

The antenna motor - a lower-pitched sound - was primarily used for R2 and the higher pitched window motor for C-3PO. But in their first scene in the desert, both Cadillac effects can be heard as part of R2’s audio movements.

“In that early scene, we didn’t have time to differentiate between whose sound was whose,” said Burtt. “Later on, the high-pitched motor became exclusive to Threepio and the lower-pitched one for Artoo.”

Star Wars wasn’t the only film franchise to seek out mechanical and electronic components for potential sci-fi sounds. The equally iconic Enterprise warp drive and transporter effects from *Star Trek* were achieved utilizing a test oscillator. The warp drive sound was produced with an oscillator going through a plate reverb chamber while a rising oscillator tone and a “singing” ethereal tone were combined to make the transport noise—essentially the beaming in the “Beam me up, Scotty.”

Mark Mangini, supervising sound editor for *Blade Runner 2049* created more than 2,600 new sound elements for the popular sequel last year including sticking a subwoofer in



his wife’s Honda Element to produce the noises of Officer K’s (Ryan Gosling’s) vehicle. Mangini also worked on *Mad Max: Fury Road* where he combined whale sounds with truck engines to exacerbate the howling noises of semi-trucks rolling across the desert.

And what about all those fancy, robotic noises when a Transformer transforms? One, in particular, known as “Reedman” was a tiny evil robot made up of a swarm of diabolical microns in the film *Transformers: Revenge of the Fallen*. The sound effect was simply recording the noise of rolling metal ball bearings and combining it with other everyday metal “clinks”.

The lesson here is simple. If you have a son or daughter heading to film school, they might consider stopping by the job shop down the street with some recording equipment. The audio options can be quite extraordinary.

Sources: www.empireonline.com, www.starwars.com, www.prosoundeffects.com and a special thanks to Lucasfilm Publicity for providing additional material. **PTE**



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