Power Transmission Engineering

APRIL 2016

HIGH-TORQUE CAPACITY COUPLINGS

RECALLING 75 YEARS OF NASA GLENN RESEARCH

GETTING A GRIP ON YOUR LUBRICATION SYSTEM

TECHNICAL

[RATING OF ASYMMETRIC TOOTH GEARS]

[METALLURGICAL FAILURE ANALYSIS OF POWER TRANSMISSION COMPONENTS]

Power Transmission Engineering®

APRIL 2016

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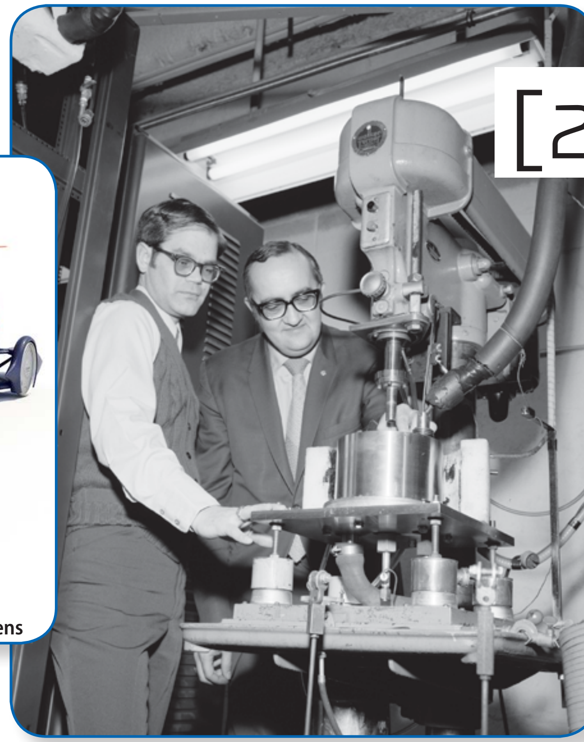

FEATURE ARTICLES

TECHNICAL ARTICLES

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Power Transmission Engineering

VOL. 10, NO. 3

Inset photo courtesy of Eaton

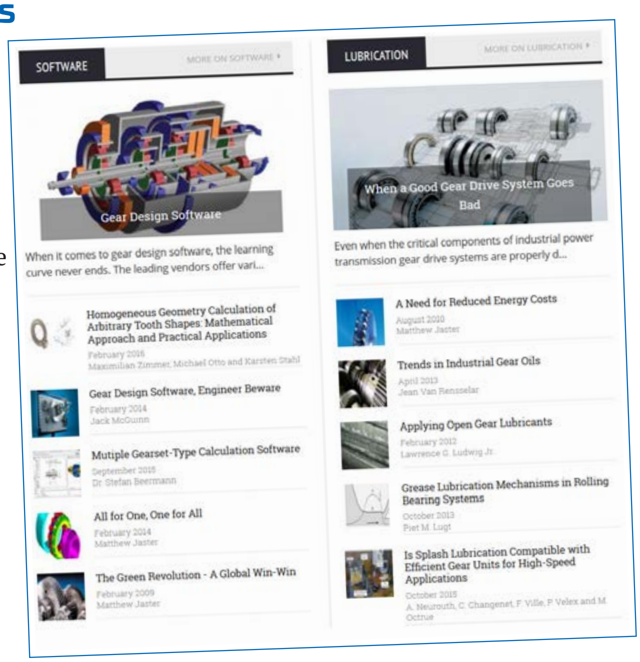
www.powertransmission.com

PTE Featured Topics

The *PTE* homepage (*www.powertransmission.com*) features an in-depth collection of mechanical component and motion control content. Articles are indexed by subject, so all you have to do is type what you're looking for in the search bar.

This Month's Highlighted Topics:

- **Software**
- **Lubrication**



Social Media

Have you browsed our Twitter page recently? We've added the latest PT news and product information from companies like Heidenhain, SICK, Regal Power Transmission and Intellidrives. Check out these and other PT manufacturing topics here: *https://twitter.com/PowerTransMag*

Facebook is another resource that features updates on product and industry news items, Ask the Expert resources and a quick and convenient way to renew your PTE magazine subscriptions: *https://www.facebook.com/Power-Transmission-Engineering-524202381060172*

Motor Matters with George Holling

George Holling, technical director at Rocky Mountain Technologies, Inc. will be regularly contributing blog material on the *PTE* website regarding motors, power quality, power factor, efficiency and other relevant PT topics. Visit *www.powertransmission.com* for more details.

Back to Basics

Our continuous push to get you the technical information you need regarding mechanical components just got easier at *www.powertransmission.com*. Our Back to Basics section delivers quick access to topics such as application guides, product selection and sizing, gear design and more. This section is perfect for anyone new to the industry or for those looking to refresh their skills.

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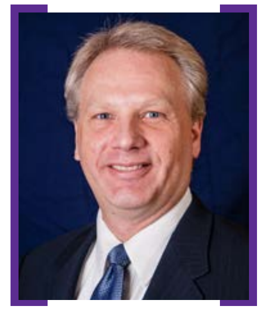


He Shoots, He Scores!

There's nothing quite as satisfying as scoring a goal. Here at *Power Transmission Engineering*, our goal is to provide you with as much relevant educational and technical material as possible, and every issue we strive to cover the subjects of power transmission and motion control from as many different angles as possible, so that no matter your job title, and no matter your industry, if gears, bearings, motors and related components are important to you, we've got you covered.

This issue is no exception, and we hope we've provided something for everyone, with articles on lubrication, couplings, bearings, gears and more. We have application examples from mining, energy production and rocket cars. We have articles aimed at design engineers, maintenance professionals and everyone in-between.

But if you read just one article this issue, I hope it's Erv Zaretsky's piece on the history of the NASA Glenn Research Center (page 20). It's a conversational, historical perspective on the research center's achievements in the fields of lubrication, bearings and gears. Nasa Glenn turns 75 this year, and much of what we know today about the lifetime and failure of mechanical components is based on the work done there over the years.

Unfortunately, there's never enough space in the magazine to include everything we want, so we rely heavily on the Internet to bring you even more content.

A great example of that is our new blog on *powertransmission.com*. It's called *Motor Matters*, and it's written by George Holling, who is the technical director of Rocky Mountain Technologies, a company specializing in the technology of switched reluctance motors. He'll be writing for us periodically on the subject of motors in general, and he's begun with a simple guide to choosing the right type of motor for your application. If motors are among the products you design, specify or buy, we're confident that *Motor Matters* will be a valuable resource for you.

But it's not just our content we'd like to share with you. Lots of others out there share our vision and mission of education, and they produce relevant articles and information we think you'd be interested in. I'd like to point out a couple of those that we've come across lately.

The first is *www.bearings.com*, a new website launched by Motion Industries. The site includes articles, videos, white papers, training materials and more. "*Bearings.com* is a unique, intelligent online tool that provides loads of great information and resources," says Randy Breaux, Motion Industries' senior vice president of marketing. "People know us for our large inventory, but there is a lot of knowledge behind the inventory."

Bearings.com includes articles like "Selecting the Right Bearing," "Prevent Premature Mounted Bearing Failure," "An Overview of Bearing Lubrication," "Bearing Corrosion and its Causes," and many more. Videos include how-to and hands-on demonstrations of bearing failure analysis, bearing lubrication, and bearing installation, for example. The content is geared to both OEM and MRO users. If you buy, specify, maintain or replace bearings, it's definitely worth a look.

Another good resource is the Martin Sprocket blog. There you can find articles like "Gear Drive Troubleshooting – 11 Common Problems & Solutions." We'll be keeping an eye on this blog, and we hope you will, too. Go to *www.martinsprocket.com/blog/* to read that article and more.

Of course, don't forget to stop by and visit "Gear Talk with Chuck," which is the twice-weekly blog written by Chuck Schultz over at *www.geartechnology.com*/blog/. Chuck covers all things gear-related, and he offers hints, tips and insights from a lifetime in the gear industry.

I've tried to point out some new and noteworthy online resources here. But as much as I appreciate you reading my column, you don't really need me. That's because every issue, we run a column on page 4 called *PTExtras*, which includes a quick run-down of some of the online resources we think are worth your time (both on our own site and around the Internet).

If you find something interesting, useful or practical, either here in print, or in the links we've provided, then we've accomplished our goal.

As always, thanks for reading.

Randy Stott

Eaton Airflex Torque Limiting Couplings

DECREASES MAINTENANCE COSTS AND DOWNTIME FOR MINERAL PROCESSING APPLICATIONS

Eaton has been well-versed in clutches for mineral processing applications for decades. "I was visiting a Canadian mining operation and looking over drawings from an Eaton air clutch from the 1960s," said Mike Williams, product line manager for Airflex at Eaton. "It was pretty amazing to see the decades of design and application experience that Eaton has maintained in this industry. We've taken this knowledge and applied it to our new generation of torque limiting couplings."

Eaton has been providing coupling technology in mineral processing since the early 1990s, according to Williams. "We're now just beginning to commercialize these products as we're seeing a significant shift from clutch-based drivelines to variable frequency drive (VFD) systems in grinding mills."

The Airflex TLCs are available in a wide range of sizes, from 51 to 76 inches, with a torque range capacity of 2.5 to 12.1 million inch-pounds on grinding mill applications of 4,000 hp and above. These couplings protect equipment from damage during torque overloads. They are designed to reset and restart automatically and instantaneously, allowing maximum uptime for mill operators.

"The Airflex TLC is electromechanical to a point," Williams said. "There's an automatic control system built in so when a torque overload or slip is detected it will automatically disengage the coupling between the motor and pinion. By varying the applied air pressure, the coupling automatically resets."

An operator doesn't have to enter the driveline area to reset the component. "You simply have to reset the external control panel and hit the go button," Williams added. "This leads to significant time and cost savings. Additionally, the torque settings remain constant through service life, requiring no periodic adjustments, lubrication, calibration or other preventative maintenance."

Eaton took decades of mill operational field data to come up with this technology. The company has utilized both its clutches and couplings to upgrade mining operations in Canada, Chile and Mexico, and are actively pursuing other opportunities globally. As is the case with most industrial applications, the trend is to develop components with a smaller footprint by offering weight and size reductions. "Shrinking the size of the clutches and couplings will have a positive effect on the longevity of the equipment," Williams said. "We recently worked with a mining operation in Mexico, for example, where we offered the option of downsizing from a 76-in. TLC to a 66-in. version. A lot of these components are interchangeable and, despite being a newer product, they were willing to trust Eaton's capabilities without previous experience in their application."

As this technology becomes more popular, Eaton will continue to target opportunities in mineral processing. "We have to make sure we're adapting our components to help solve the problems associated with torque spikes and overloads," Williams said.

Additionally, Eaton is paying close attention to the Industrial Internet of Things (IIoT). "We have a lot of resources as a power management company, particularly in electronics and hydraulics to really look into feedback control. As safety requirements become more restricted in this industry, it would be beneficial to give our operators the ability to remote-in utilizing a tablet, for example," Williams said. "There are plenty of opportunities in this area that we're currently looking into."

In the near future, Williams would like to meet with Eaton engineers to see how products like *Pro-FX* software

or the AxisPro line can be adapted to the company's Airflex couplings, (*Ed's note: See sidebar right*).

"I think we're going to start seeing a lot of this technology in our coupling, clutch and brake products," Williams added. "The ability to get metrics on everything we're doing in real-time will be extremely helpful to our customers moving forward."

For more information:
Eaton
Phone: (800) 386-1991
www.eaton.com

Adapting to the Industrial Internet of Things (IIoT)

Mike Williams, product line manager for Airflex at Eaton, believes the next step in the evolution of the Airflex product line is to incorporate some of the technologies Eaton is already offering in areas like electronics and hydraulics. "We'd like to take some of the technologies found in our AxisPro products or *Pro-FX* controls and software and see how they can be used in our torque limiting couplings," Williams said.

Eaton's AxisPro product helps simplify machine control for demanding applications including injection and blow molding machines, large press applications, die casting, primary metals, test and simulation and wood processing applications. These valves offer on-board motion control, enabling closed loop drive control without the need for expensive motion control cards. Together with the ability to configure the valve using *Pro-FX Configure* software, an AxisPro valve simplifies machine control for distributors and end users alike. The valve also features built-in diagnostic light-emitting diodes (LEDs) and a CANopen bus that makes system commissioning and debugging easier.

With *Pro-FX* electronic controls and software, Eaton has the ability to simplify electric control integration without sacrificing customization options. The software comes with six programming languages, including graphical and textual, as well as an extensive set of function block libraries. The libraries contain pre-configured software objects to help customers rapidly develop their applications.

Eaton's ability to combine knowledge from electrical, hydraulic and mechanical solutions will be pivotal in the company's drive toward improving productivity, machine efficiency and operator safety," Williams said.

To learn more about these Eaton products please visit *www.eaton.com/axis-pro* or *www.eaton.com/pro-fx.com.*

Suhner

MANUFACTURES LOW-BACKLASH, LOW-NOISE SPIRAL BEVEL GEARS

Suhner Manufacturing Inc. offers low-backlash and low-noise spiral bevel gears within its diverse range of power transmission products utilizing the Palloid and Zyklo-Palloid hobbing processes which the company began using in the late 1950s.

Palloid-toothed gears are based on a technical development from straight-toothed to spiral-toothed bevel gears. Thereby the teeth are hobbed in a continuous procedure with a conical hob. The combination of this continuous process on a single thread tool leads to a very accurate pitch of the teeth.

Since the Zyklo-Palloid gear hobbing meets and exceeds all high-quality manufacturing prerequisites, one-off, small and large lot size production can be applied equally. In the Palloid-System, since the teeth are hobbed in a continuous process, the Module

(Mn) can be freely selected. Therefore, a very high flexibility for the gear dimensioning and bevel gear calculation is provided.

While both tooth systems have similar insensitivity characteristics for bearings, a high contact ratio as well as a very accurate pitch, the cost efficiency and the high load root radius of the Palloid-System should be specially mentioned.

A further development on the proven Zyklo-Palloid-Toothing (soft-cut) is named “HPG-S hard cut”. The thermal deformation, caused from heat treatment, will be eliminated with boron nitride coated knifes. Therefore, the surface quality on the tooth flanks will reach grinding quality, according to DIN 3965, Part 3 (Quality 4 – 6 is available). “Better quality, approaching grinding quality (*without grinding*) is the key to our process,” said Todd Newsom, product manager at Suhner.

In combination with the material, the surface treatment and the adjustment of the required lubrication, spiral bevel gears are a suitable solution when it comes to redirecting the maximum torque. All these can be achieved with small space and high mechanical efficiency. “The difference using HPG and HPG-S spiral bevel gears is the tooth flank surfaces – HPG is Rt < or = 4 μm/20 micro-inch and HPG-S is Rt < or = 2 μm/10 micro-inch, even

smoother. The result is getting up to 30 percent greater load carrying capacity due to desired tooth contact pattern without heat treatment allowances. There is a longer tooth contact pattern with HPG and HPG-S than with cut and lapped gears," Newsom said.

Engineering Considerations

Because of the sophisticated combination of the different spiral bevel gear angles, the circumferential force is divided in several components that can lead to significant axial forces. Therefore, gear design depends a lot on the bearings. The bearings have to absorb all the axial forces so the bevel gears do not move under load.

Any movement would affect the contact pattern of the teeth, which would result in edge wear that could destroy the entire gear. Just as important as the bearing, is the stiffness and the geometrical accuracy of the case. The advantages of spiral bevel gears can be obtained when gears are optimally positioned and perfect tooth contact is maintained. When dimensioning the gear geometry, several criteria must be considered: required ratio, number of teeth and space/conditions. The criteria must be decided at the start of the engineering process.

"In order to prevent teeth from breaking, all spiral gear teeth have a slight amount of "flex" under a load. However, these deflections are very small in comparison to the flexibility of the gear support shaft and bearings. Proper engineering considerations must be made at the beginning of designing any application requiring spiral bevel gears. If the elastic motions on the gear and pinion supporting shafts and bearing are 'too much,' no spiral bevel gear set is going to survive very long," Newsom said.

For more information:
Suhner Manufacturing, Inc.
Phone: (706) 235-8046
www.suhner.com

Regal Power Transmission

LAUNCHES TORQUE-AMPLIFICATION ANALYSIS PROGRAM

Regal Power Transmission Solutions (PTS) has launched a torque-amplification measurement and analysis program for precisely measuring the true torque loads and vibration frequencies experienced by rolling mill drives, as part of a program to help mills process tougher alloys, increase output with thicker slabs or higher speeds, protect against cold-end slabs, or mitigate torsional vibration. Developed under Regal's Kop-Flex brand, the Perceptive Technologies TqM torque amplification analysis program combines computer modeling of complex drives with true torque measurements to determine the actual torque amplification factor (TAF) on the drive, instead of inferring it from motor current readings. Kop-Flex then engineers solutions that reduce TAF and torsional vibration using alterations of coupling stiffness, improved overload protection, resilient couplings and other strategies.

"TAF can be defined as the peak torque divided by the rolling torque," explained Chris Carrigan, director of application engineering and lifecycle services at Regal PTS. "It's a unit-less factor that illustrates the severity of a torque spike in terms of magnitude. It is affected by system dynamics or how the inertias and stiffnesses are distributed across a complex drivetrain. Entry conditions, such as slab temperature, speed, angular clearances and backlash in gear components all play a role. The old rule of thumb for mill drives was to keep the TAF under 2.5, but with motor sizes increasing, slab thickness increasing and new alloys being processed, the old rules don't apply. As rolling torque increases, so will peak torque, degrading overload protection devices, bearings, couplings, work rolls, etc. Often the first sign of a torsional problem is equipment failure."

TAF analysis applies measured torque readings to 3D mode shape analysis to visualize how a drive train twists at various locations to determine where to alter stiffness or increase damping. "We use torque monitoring hardware developed by Regal Kop-Flex for high-speed turbomachinery drives, so it is already mill-hardened, accurate and capable of high-rate data sampling," said Carrigan. "High-rate sampling using strain gages allows the system to capture momentary torque spikes that would normally be unseen on motor current readings because of the high-inertia in these drives. At lower sampling rates, peak torque measurements are often truncated because the system cannot capture them. High-rate sampling is a must to capture these events in a complex, high-inertia drive."

According to Carrigan, Kop-Flex has used the technology to engineer TAF reductions as high as 50 percent. TAF data capture and analysis can be a temporary service or it can be integrated with a mill's condition monitoring system as an ongoing service. Regal PTS offers Perceptive Technologies condition monitoring equipment and diagnostics for the steel industry to track bearing vibration, temperature and other data. Additional data on torque loads allows the mill to correlate the measured torque with slab temperature, force on the work rolls, speed, gap, etc., so engineers can better understand the root cause and make needed changes on scheduled downtime, before cumulative damage leads to an unscheduled outage.

For more information:
Regal Power Transmission
Phone: (410) 787-8430
www.regalbeloit.com

Force Control

HAZARDOUS BRAKES PROVIDE LONGER SERVICE LIFE

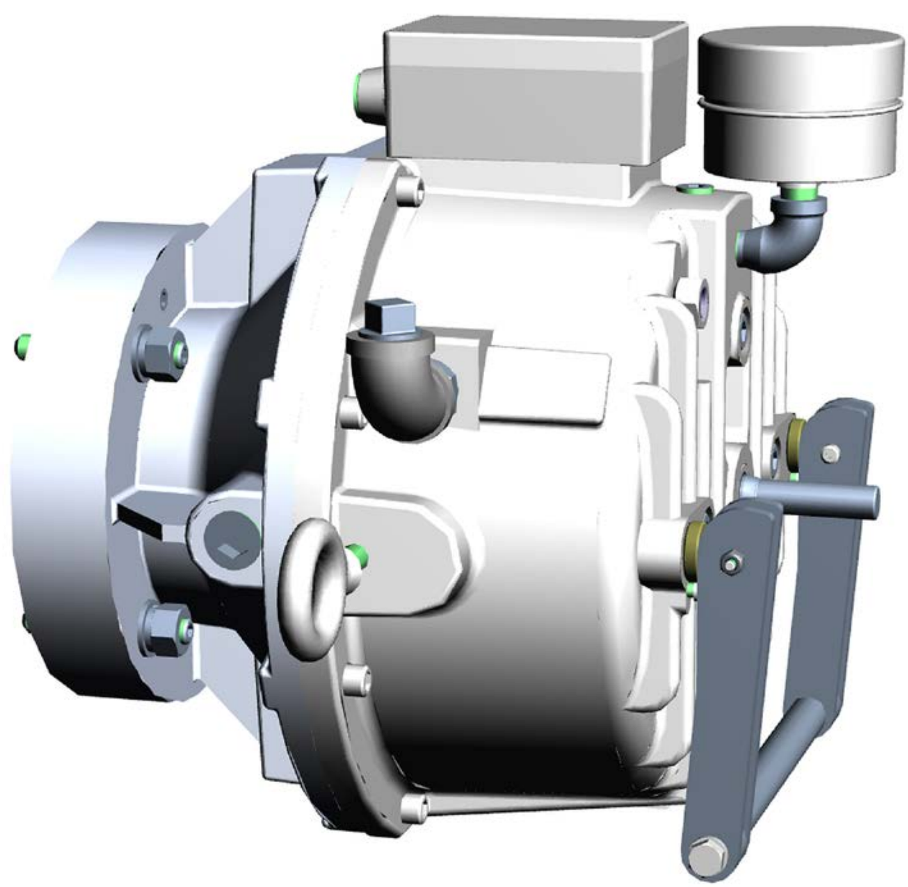
Force Control MagnaShearT hazardous duty brakes, which employ oil shear technology, now meet Class I and Class II Div 2 specifications (Div 1 in process with approval forthcoming). With spring set torque ratings from three to 900 foot-pounds available, MagnaShearT motor brakes can be sized to the correct torque independent of the motor frame size or horsepower. They also feature "quick mount" features for quick and easy mounting to drive motors in NEMA frame sizes 56 to 405.

These proven motor brakes are totally enclosed from outside contaminants, with seal integrity for harsh and washdown environments. A modular design /assembly allows for ease of servicing and maintenance. MagnaShearT motor brakes are suitable for applications where the motor is reversed each cycle such as cranes, winches, and hoists as well as ship and railcar loader/unloader conveyors, tippers, sweep samplers and more.

Proven oil shear technology transmits torque between lubricated surfaces - thereby eliminating wear on friction surfaces, providing longer service life with no maintenance or adjustment. A patented fluid recirculation system dissipates heat - eliminating heat build-up which is the most common problem in dry braking systems.

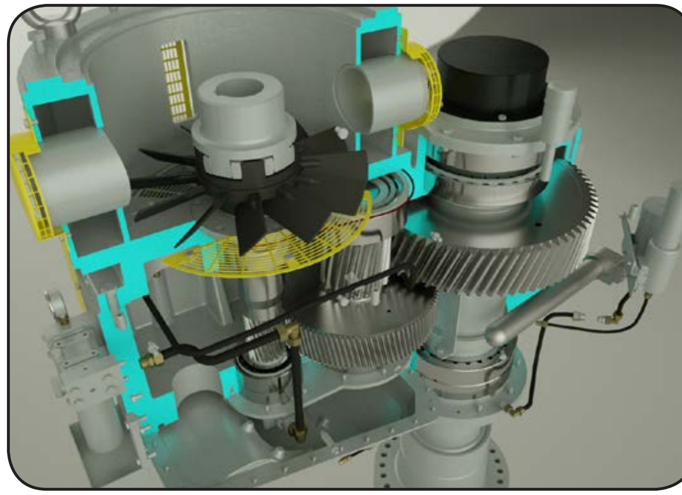
The oil shear technology also provides a smooth "cushioned" stop which reduces shock to the drive system, further extending service life of downstream components. The totally enclosed MagnaShearT brakes are impervious to moisture, dirt and dust that is common in coal prep plants as well as the bulk handling of coal, aggregates and more.

For more information:
Force Control Industries
Phone: (800) 829-3244
www.forcecontrol.com



Santasalo

LAUNCHES VERTICAL MOUNTED GEAR UNITS



Santasalo is pleased to announce the launch of the AMF vertical mounted gear unit series. The AMF is purpose-built for the most demanding vertical applications with high external forces without the need for external cooling. By incorporating a bidirectional axial fan, optimized housing design and additional new features, Santasalo's AMF vertical gear unit provides high thermal capacity and eliminates the need for external cooling in extreme ambient conditions.

The AMF gear units feature Santasalo's proven drive technology, in operation in thousands of vertical mixing applications around the world. Direct drive construction with electrical motor and flexible HSS coupling ensures high efficiency, while the highly optimized gear unit layout results in cost savings and a smaller footprint. More on the AMF design can be seen on the product animation at the website below.

These two or three-stage vertically mounted helical gear units feature a power range of up to 750 kW and nominal output torque of up to 200 kNm, as well as a reversible operational direction. Their robust design ensures they're easy to transport and install without risk of damages.

Santasalo already delivered the first order for the AMF gear unit series in Kazakhstan (five units) and two additional projects are currently being delivered for fine grinding applications in the United States (six units), and Australia (three units).

"We are very pleased to introduce this completely new product for very demanding process industry mixing applications. It reflects our deep understanding of the tough requirements within process industries which we have gained over the decades," said Pasi Jokela, senior vice president of global capital sales at Santasalo.

"Our R&D team has made high performance gear units suitable for the most demanding agitating and mixing applications. Some of our key customers have already selected products from this new AMF line which tell us the real story of the AMF gear unit's superior features to meet demanding customer's needs."

For more information:

Santasalo Gears Inc.
Phone: (864) 627-1700
www.santasalo.com/products/flotation-drive

Preventing Downtime for Hanger Bearings

Certified Bearing Specialist (CBS) Takes on Screw Conveyor Application

Dale Renner, CBS and sales representative at Bearing Headquarters Co., explains how his bearing expertise helped solve a customer's problem and saved significant downtime and cost.

"One of my customers in the ethanol industry was experiencing high failure rate with bronze hanger bushings. The application was on a screw conveyor in a highly caustic area of the plant. The screw conveyor was conveying wet corn mash which in itself is very abrasive and acidic. Due to the nature of the conveyed material, the hanger bearings were caking up and breaking down the lubrication process of the bearing. Thus premature failure of the bearings occurred. This particular plant runs 24 hour a day, seven days a week, 365 days a year, except for scheduled maintenance shutdowns. Downtime due to equipment failure is not only a fear but one of the company's greater expenses. Downtime expense prevention is a matter the company takes very seriously. Weekly maintenance teleconferences are held among the maintenance managers where problems are shared and resolutions sought. This company has multi-plant locations and the equipment used throughout their infrastructure is similar in nature. Thus the teleconferences are a good way to share critical information in hopes of preventing equipment failure and lost profits due to downtime.

"As a solution to their bearing problem I suggested that they replace their oil impregnated bushings with graphite bushings. Graphite bushings are self lubricating and do not require a scheduled PM program for lubrication. They offer many advantages over conventional bushings such as they operate at extremely high temperatures where oil based lubricants burn off or oxidize, they will not gum or seize, they will not congeal or solidify at low temperatures or cryogenic conditions, survives run dry applications, eliminates galling or seizing in hot dry applications, will not attract dust, they will not swell or wash out and will withstand a wide variety of hostile fluids. They are insoluble in most industrial fluids, works in acids, alkalis, hydro carbons, water and liquid gases and have a very low coefficient of friction. They are non-current conducting and are FDA-approved.

"Thus the problem of the bushings caking up due to breakdown of the lubrication process was significantly reduced. The life expectancy increased from three to 24 months saving the customer over $4,553.00 in product and material alone, which is a minute figure compared to downtime cost savings. This information was shared with the maintenance managers and has become and approved product application endorsed by the company's corporate engineer."

For more information:

Bearing Specialists Association (BSA)
Phone: (630) 790-3095
info@bsahome.org
www.bsahome.org

Certified Bearing Specialist

BSA's Certified Bearing Specialist (CBS) program is the only bearing industry-specific program that identifies and quantifies the specific skill sets to certify an industry professional as a bearing specialist. The CBS program is all about developing the expertise to help customers and end users make the best bearing decisions. Take advantage of this complimentary access to a Certified Bearing Specialist. Please email your question to *info@bsahome.org*. An expert CBS will respond to your inquiry and it may appear in this article.

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bearings
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Dale Renner has been working for Bearing Headquarters Company for almost 11 plus years and has been in the industry for 27 years. He is known for strong product knowledge and a hands-on approach with customers. Renner is a graduate of Elmhurst College, in Elmhurst Illinois and holds a B.S. in business administration. He is married and has two children and two grandchildren.

Nasa Glenn Research Center — A Look Back

Excerpted from *Tribology for Aerospace Applications*

Erwin V. Zaretsky

NASA GLENN RESEARCH CENTER IS 75 THIS YEAR

In 1941, the federal Aircraft Engine Research Laboratory set up shop in Cleveland, Ohio. This year, and several name changes later, what is now the NASA Glenn Research Center celebrates its 75th anniversary. As part of the year-long festivities, Glenn's adjunct Lewis Field main campus will be open to the public May 21 and 22, and Plum Brook Station in Sandusky, Ohio will hold its open house June 11 and 12. There will be tours, and families can meet astronauts and talk with the center's scientists, engineers and technicians working on the nation's space and aeronautics programs. Admission is free, and space-themed souvenirs and NASA merchandise will be available for purchase. Watch for more details on the center's website (*www.nasa.gov/centers/glenn/events/tours*).

In an effort to recognize NASA Glenn's 75 years of invaluable research, *PTE* thought readers might find the following of particular interest. It is the preface from the 1997 book, *Tribology for Aerospace Applications*, co-authored and edited by Erwin V. Zaretsky of the Glenn Research Center, and in collaboration with his then-NASA Glenn contemporaries as well as with Society of Tribologists and Lubrication Engineers contributors. *Tribology for Aerospace Applications* is a textbook and reference source for designers of rotating machinery; users and designers of such mechanical components as bearings, gears, and seals; tribologists; university and industrial researchers; and students of machine design. The book incorporates information from more than 900 references, spanning over 50 years of technological advances. Copies of the book can be ordered from the Society of Tribologists and Lubrication Engineers (*www.stle.org*); Phone: (847) 825-5536.

But what makes the preface of this book of particular interest is that it serves as a concise but richly informative history of the center's early days—beginning with when winning a war was its vital, top priority. Once the peace was won, the real fun started. And when you see how much of the (largely unnoticed) U.S. space program R&D done by these men and women over the decades that has been successfully applied to commercial applications, you'll see it is one place where our tax dollars truly are "at work." **PTE**

Reprinted with permission from the Society of Tribologists and Lubrication Engineers, a not-for-profit professional society headquartered in Park Ridge, IL, *www.stle.org*.

October 10, 1989. During dinner at the monthly meeting of the Cleveland contingent of the Society of Tribologists and Lubrication Engineers (STLE), Ed (Edmond E.) Bisson, a 1973 NASA retiree who decades previously had introduced tribology research at the National Advisory Committee for Aeronautics (today's NASA), turns to Bill (William I.) Anderson and in his best reminiscing voice begins recalling his years of tribology research at the Lewis Research Center. There, until 1984, more than 35 research scientists and engineers were dedicated to identifying and advancing the state-of-the-art in lubrication, bearings, gears, friction, and wear.

Don (Donald H.) Buckley stops Bisson to interject: "The decision to cut back this research came from NASA headquarters, but tribology research is still being conducted at Lewis in the Surface Science Branch of the Materials Division," referring to the re-named group he had headed prior to his own retirement from the agency.

Anderson, joining the conversation, remarks to Buckley, "That's true, but areas of technology that might have been previously addressed are not now being adequately covered as a result of those 1984 cutbacks."

Bisson asks (declaring, really), "Like work on space mechanisms for long-term space missions, dynamic and static sealing, highly reliable, long-term cryogenic turbo machinery bearings, and bearings for advanced aircraft?"

"Precisely," Anderson responds. "In fact, the bearing technology that is operating in the space shuttle turbopumps today is what we developed at Lewis in the early-to-mid-1960s."

Until this point I sat listening, eating my meal. The conversation sounded

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THE COUPLING.

like many we had over the years at Lewis when Bisson, Anderson, and Bob (Robert L.) Johnson managed all of tribology research at the Center.

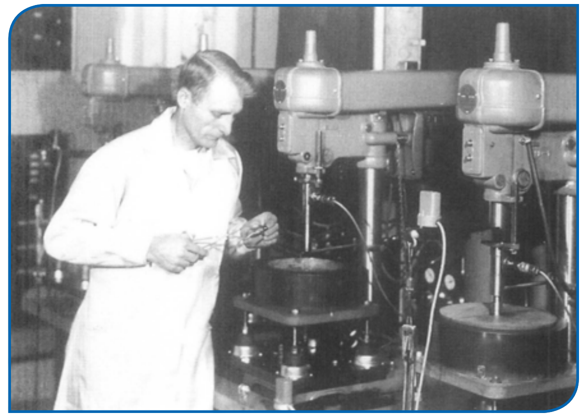
So I turn to Bisson, "You know, Ed, you never told me just how you got started in tribology."

Bisson sits back and jokingly answers, "I'm glad you asked," with a detectable 'What took you so long?' tone in his voice.

"The group's origin was actually in 1939, at the NACA (National Advisory Committee for Aeronautics) Langley Field Laboratory in Virginia in the Power Plants Division," he says. "At that time and during World War II our primary concern was the lubrication and wear of piston rings and cylinder barrels in reciprocating engines. In 1943 we moved from Langley Field to the NACA Aircraft Engine Research Laboratory in Cleveland, Ohio.

"(At that time) the U.S. Army Air Corps (now USAF) was flying aircraft from unimproved air fields. In North Africa particularly, aircraft were taking off in a virtual sandstorm. Ingestion of sand played havoc with rings and cylinders, wearing them badly. Overhauling these engines could be simplified appreciably if the overhaul shops could stock standard-size pistons and rings, rather than several different sizes (over-sizes) of pistons and rings.

"Such stock simplification necessitated that the cylinder barrels be of standard size. Experiments were conducted to establish whether worn cylinders could be electroplated with chromium — back to standard size — without adversely affecting their lubrication and wear properties. There are two types of chromium plate: dense and interrupted. Dense chromium plate did not have good friction and wear properties, but interrupted chromium plate did. The interrupted surface plating was obtained by reversing polarity as the plating process was coming to an end.

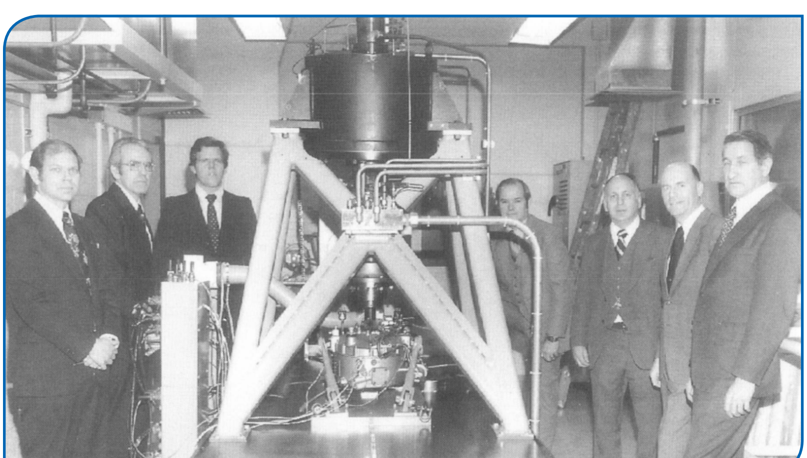


Eldred Johnson, chief technician for bearing research at NASA Lewis, with NASA five-ball fatigue testers on January 20, 1960. The fatigue tester was conceived by William Anderson, designed by Thomas Carter and Erwin Zaretsky, and assembled and operated by Johnson. The first tester began operation in March 1959. Eight testers were built by NASA. Over one-half-million test hours had been accumulated and reported before NASA terminated the research in October 1964. (All historical photos courtesy STLE.)

"Research was also conducted on nitrided-steel piston rings in an attempt to extend the wear life of the rings. Although extremely difficult, design and construction of nitrided piston rings were accomplished and research toward incorporating steel piston rings was continuing as the war ended in 1945. Single-cylinder engine tests at NACA Langley were used to check friction and wear of chromium-plated cylinders, as well as of nitrided-steel piston rings. Full-scale engine tests were conducted by other U.S. agencies under NACA direction."

Buckley queries Bisson: "Who were the key people performing this work?"

"Myself and Bob Johnson," Bissson replies. "At the end of World War II, NACA's interests shifted to the turbine engine with its accompanying problems of high-speed, rolling-element bearings, high-speed seals, and higher-temperature synthetic lubricants. It became evident that scientific research was necessary on the fundamentals of friction, lubrication and wear. We carried out basic tribology studies on 'mechanically clean' surfaces of various materials. Because turbine engines needed lubricants with high-temperature capabilities, we studied synthetic liquid lubricants and solid lubricants with higher temperature capabilities than the mineral oil lubricants then available."



Visit by staff members of Bell Helicopter in 1979 to recently inaugurated NASA Lewis 500-hp helicopter transmission test stand. Left to right: Dr. John Coy (NASA), Charles Braddock (Bell), Stuart Loewenthal (NASA), B.J. Hampton (Bell), Erwin Zaretsky (NASA), Walter Sonneborn (Bell), and Dennis Townsend (NASA). The work by NASA on the Bell OH-58 transmission improved life and reliability and increased power-to-weight ratio by approximately 50 percent.

Buckley adds, "The solid lubrication studies were interesting in that the group began to examine the fundamental lubricating properties of what was then a new lubricating material — molybdenum disulfide (MoS_2). Considerable research on the other then-principal inorganic solid lubricant — graphite — was well under way by this group and elsewhere.

"There was little difficulty in justifying the study of solid lubricants because early in (the war) a very serious problem developed in military aircraft. When they (would fly) at high altitudes to minimize detection and assault vulnerability, the carbon brushes of the

Left to right: Erwin Zaretsky (NASA), Dr. Romaldus Kasuba (Northern Illinois University), and John Coy (NASA). A visit to NASA Lewis in January 1995 by Kasuba, Dean of Engineering at Northern Illinois University and an internationally known gear expert.

aircraft generators began to exhibit a severe wear problem that came to be known as 'dusting.' The carbon brush manufacturers, NACA, and others undertook to find a solution to the dusting problem. As is so often the case, this critical need was the impetus for beginning fundamental solid lubrication studies in earnest. The role of graphite content in carbons and the effect of environment on graphite behavior were extensively studied, as was the role of adjuvants (materials added to carbon bodies to blunt their environmental sensitivity). Much of this work was published in NACA technical notes shortly after the war and was nicely summarized some years later by Bisson and Anderson (in their 1964 book, *Advanced Bearing Technology*). This latter summary was particularly significant because at the time it was prepared, NASA was in a race to develop lubricants for space applications and much of the fundamental understanding gained during the war served as the guiding light."

"Molybdenum disulfide during World War II was pretty much still a laboratory curiosity," Buckley continues. "Some of the first attempts to use it as a solid-film lubricant were made at NACA. I vividly recall seeing vials of corn syrup in the laboratory and upon inquiry being advised that this was the mechanism for achieving adhesion of molybdenum disulfide to substrates to be lubricated. Since those early beginnings, hundreds of papers have been written by authors the world over on the solid lubricant molybdenum disulfide and how to achieve its adhesion to surfaces."

Anderson offers, "Actually, the jet engine probably was the greatest technology driver in the field of tribology. I remember that when I began working at Lewis in 1951, rolling-element bearing life in jet engines was approximately 300 hours. The bearings were probably the single greatest inhibitor of jet engine reliability and maintainability. Major advances in rolling-element bearing technology were needed so that engine designers could fully utilize advances in engine aerodynamics and thermodynamics. Engine designers were projecting needs for bearings capable of highly reliable, long-life performance at *DN* values exceeding 2 million and operating temperatures exceeding 400°F. Among the perceived research needs were improvements in bearing design, lubrication techniques, lubricant-limiting temperatures and materials."

Bisson adds that "If I remember, the bearing group besides you initially included Fred Macks and Zoltan Nemeth, to be joined later by Bob (Robert) Butler, Tom (Thomas L.) Carter, Fred (Frederick) Schuller, Bob (Robert) Cunningham and Erv (Erwin V.) Zaretsky. In 1958, (NASA) was organized with former NACA installations such as the Lewis Flight Propulsion Laboratory (renamed in 1948), serving as the core facilities of the new agency. The NASA Lewis Research Center was born and quickly assigned primary responsibility for air-breathing and space propulsion systems and space auxiliary power systems. These broadened responsibilities required a significant increase in the scope of research. It became impossible to do all of the required work in-house — even with a rapidly expanding staff. University grants and contracts with aerospace companies became a prominent segment of the total R&D activity at Lewis. Organizational units with primary responsibility for contract management were formed. Members of in-house research groups served as technical advisors and monitors on contractual R&D. The original bearings group became, successively, the Bearing Section (as part of the Lubrication and Wear Branch), the Bearing Branch, and finally, the Mechanical Components Branch. The last name reflected the broad expansion of research efforts that grew to include fluid film bearings (organic liquid, gas, and liquid metal lubricated), rotor dynamics, gears, and transmissions.

Visitors to NASA Lewis in 1974 to discuss NASA gear research results. Seated, left to right): Dr. Hillel Poritsky (General Electric), Dr. Harmon Blok (Delft University, Holland), and Dr. Lee Akin (GE). Standing, (left-to-right): Dr. John Coy (NASA), Erwin Zaretsky (NASA), and Dennis Townsend (NASA). Poritsky, during his career at GE, was a pioneer in fluid film lubrication and contact mechanics. Sick, who performed gear-related pioneering lubrication research, is famous for his "flash temperature" theory. Akin had a long, cooperative relationship with NASA Lewis, performing pioneering gear lubrication studies with Townsend.

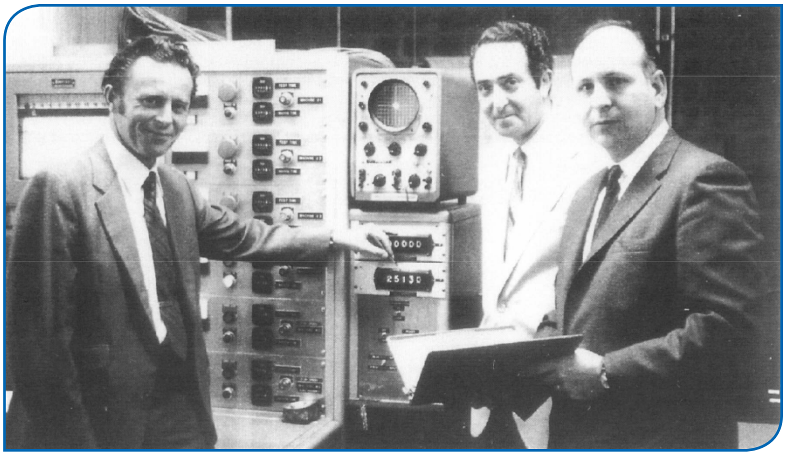
"Using sophisticated surface analytic equipment," Bisson continues, "much basic information was obtained by Bob Johnson's group on the effectiveness of various contaminants (such as absorbed gases and hydrocarbons) in reducing adhesion and friction of clean surfaces. As I remember, the results showed that even partial coverage of the surfaces by gaseous oxygen, hydrogen sulfide, or various hydrocarbons can be beneficial. In fact, as little as one-quarter or one-third of a monolayer coverage can reduce adhesion and friction appreciably."

Buckley is nodding in agreement as I ask him, "Who besides you and Bob Johnson were involved in that effort?"

"K. (Kazuhisa) Miyoshi and 'Tally' (Talivaldis) Spalvins on lubrication fundamentals, and Hal (Harold E.) Sliney on high-temperature lubrication."

Anderson offers that "The broadened scope of research was accompanied by a significant growth in personnel complement. New staff members included Neil Anderson, Dave (David E.) Brewe, Harold H. Coe, John Coy, Marshall W. Dietrich, George K. Fisher, Dave (David P.) Fleming, Bernie (Bernard H.) Harnmick, Al (Albert F.) Kascak, Stu (Stuart H.) Linewentlaal, Andy (Andrew) Mitchell, Dick (Richard I.) Parker, Dave (David W.) Reichard, Doug (Douglas A.) Rohn, and Dennis P. Townsend. The unique talents and dedication of this group made possible a broad array of advances in the state of the art in bearings, gears, lubrication, transmissions, and supercritical shafting."

"As an organization," I respond, "we probably did more research on rolling-element fatigue than any other single group worldwide. The NACA spin rig, which was conceived by (Macks) in 1953 and put online by Tom (Thomas L.) Carter in 1955, produced the first large quantity of data on rolling-ele-



Left to right: Hans Signer (ITO, Eric Bamberger (GE), and Erwin Zaretsky (NASA). Working together as a team under NASA sponsorship, these three designed and operated the first successful 3-million-DN bearings at Industrial Tectonics, Inc., Rancho Dominguez, California, on June 29, 1973. The photograph was taken in the control room after the two specially designed 120-mm-bore ball bearings had reached a speed of 25 130 rpm and 425 F. After 2,500 test hours, the bearings were removed undamaged.

ment fatigue used to evaluate materials, lubricants, temperature, and stress effects on bearing life and reliability. Limitations of the spin rig as a test vehicle for conducting fatigue tests at elevated temperature resulted in Anderson conceiving the NASA five-ball fatigue tester in 1958."

Anderson breaks in to graciously add, "Of course, if you and (Carter) had not designed and built the five-ball rig, it would have never been a reality. The spin rig and the five-ball fatigue tester produced a great deal of valuable data on rolling-element fatigue. Much of what we know today regarding the parameters that influence rolling-element fatigue evolved from tests conducted in these two invaluable testers. They greatly reduced the need for much more costly and time-consuming, full-scale bearing tests."

I remind that "From 1959 to 1985, as a result of these test rigs, we were able to increase rolling-element fatigue life by nearly 40 times what was benchmarked in 1958."

"This was quite an accomplishment," says Bisson. "In practical terms, rolling-element reliability in jet engines today can exceed 60,000 hours, with a potential of over 100,000 hours before replacement. Sure beats the 300 hours of the early 1950s!"

Buckley points out that the work on dynamic seal technology paralleled the accomplishments in rolling-element fatigue and bearing technology. "Seal speed capability went up approximately 50 percent as a result of our research, with a significant reduction in gas leakage." To which Bisson adds, "I don't want to brag — but I will anyway. As a result of our improved seal technology, the engine companies achieved greater engine efficiency and reduced fuel consumption for the airline industry."

"(I believe)," says Buckley, "that the researchers in the seal group were Larry (Lawrence) Ludwig, Gordy (Gordon) Allen, Bill (William) Hady and John Zak."

"We also made a significant impact on gear and mechanical power transmission technology," I say. "We were late starters in 1969, but we filled a much needed gap in technology. I remember starting to advocate this program in 1965; it took me nearly four years to get approval. With the addition of Dennis Townsend, John Coy, Stu Loewenthal, and Neil Anderson, we were able to make significant contributions in gear fatigue, life prediction, and reliability. The first practical gear rig to study tooth pitting and gear lubrication was designed and built by Townsend. Loewenthal and Anderson did pioneering work on gear and transmission efficiency, as well as on traction drives. Much of our lubrication and bearing work carried over to our gear research."

To which Anderson adds, "The impact of this work was on both U.S. Army and civilian helicopters, as well as on turboprop aircraft and wind turbines. You and the group were able not only to create a significant database and design analysis, but also to demonstrate increased helicopter transmission survivability with oil out. The application of the NASA/Lewis technology in the Helicopter Transmission System Technology Program from 1977 to 1984 demonstrated a 50 percent increase in power-to-weight ratio, with no reduction in transmission life, reliability or efficiency."

Bisson: "Since I started all of this, as well as this conversation, I should be able to summarize our other significant accomplishments. Bill, take notes, I may not be able to remember this again."

Bisson turns to Buckley and me and with a smile says, "Help me and Bill out" (*see sidebar*).

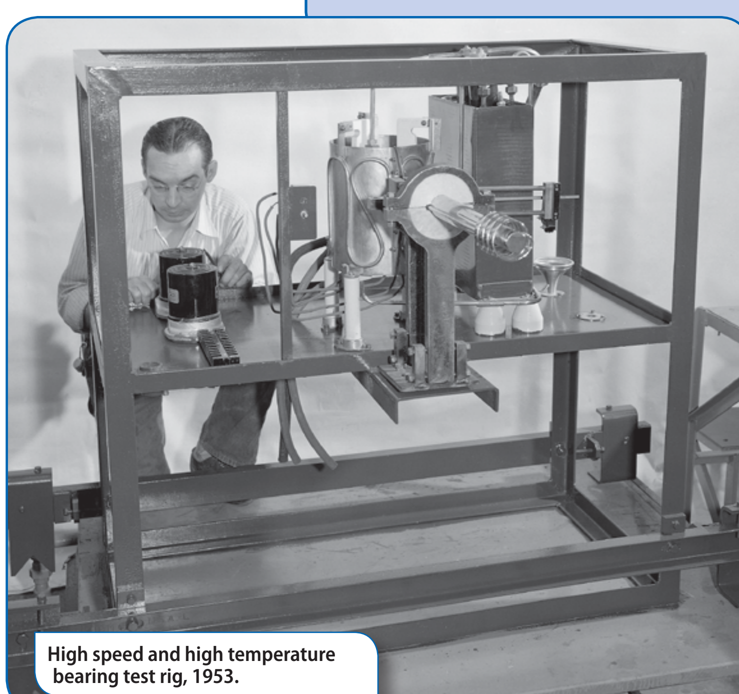
Bill, looking over the list says, "Do you realize that this list represents nearly 50 years of tribology research at Lewis? Someone should put all this material into a book."

"Sure," I jokingly — I thought — say — "*Tribology in Aerospace Applications* would be a good title." **PTE**

50 YEARS of TRIBOLOGY RESEARCH AT NASA GLENN

Aircraft Turbine Engine Rolling-Element Bearings

- First test of turbine engine main-shaft bearing made of high-temperature tool steels
- First successful 3-million-*DN* ball bearings
- First data showing the relationship of elastohydrodynamic (EHD) film thickness, lubricant type, and rolling-element fatigue
- First analytical formulation and experimental verification of residual and hoop stresses on bearing life
- Analytical formulation of EHD lubrication film thickness
- Improved rolling-element bearing cage designs
- Improved rolling-element bearing lubrication techniques
- Improved rolling-element bearing materials
- Improved analyses for rolling-element bearing life, power loss, and temperature rise
- Increase in bearing operating temperature to 425° F in air and 600° F in low-oxygen environment



High speed and high temperature bearing test rig, 1953.

High-Energy Rocket Engine Turbo-Pump Bearings

- Successful operation of ball bearings with self-lubrication cages at high *DN* values in both liquid oxygen and liquid hydrogen

Rankine-Cycle Space Electric Power System Bearings

- Successful operation in sodium potassium (NaK) of anti-whirl journal bearing designs with definition of stability limits

Brayton-Cycle Space Electric Power System Bearings

- Analytical formulations for design of gas-lubricated tilting pad, Rayleigh step, and spiral-groove journal and thrust bearings
- Super-Critical Shafting
- Analytical formulations of both influence coefficient and modal balancing
- Analytical formulations for determining resonant speeds and mode shapes for both undamped and damped shafting
- Improved dampers for high-speed shafting

Gears

- Improved materials
- Improved high-speed lubrication techniques
- Modified tooth forms for improved life and lower noise
- Analytical formulations for life and power loss prediction

Seals

- Analytical formulations of Rayleigh step and spiral-groove life pad seal characteristics
- Pressure-balanced seal design
- Zero-leakage seal designs

Transmissions

- Design and experimental verification of fixed-ratio multi-roller planetary traction drive
- Higher power-to-weight-ratio hybrid (gear/traction roller) transmissions for helicopters
- Higher power-to-weight-ratio multipath gear transmissions for helicopters
- Higher power-to-weight-ratio standard geared helicopter transmissions through advanced bearing, gear, and lubrication technology **PTE**

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What Lubrication Method Should I Use?

Analyzing Oil Versus Grease in Bearing Applications

Keith Bartley, Custom Orders Engineer, Baldor Electric Company

Lubricants are a critical factor in the performance and life of a rolling element bearing. Less than 10 percent of bearings reach their theoretical L10 life, and poor lubrication can be attributed to 80 percent of those that fall short. Ideally, a lubricant forms a film layer between moving components in a bearing, separating moving parts, minimizing friction and preventing wear between balls or rollers, raceways and retainers. Lubricants also protect metal surfaces from corrosion and moisture, dissipate heat and can even prevent the ingress of contaminants.

There are two common ways to lubricate rolling bearings. Grease is the most common method and is used in most bearing applications. Another option is oil, which is typically used in more demanding applications.

Grease is comprised of a base oil and a thickener. The ratio is approximately 85 percent oil to 15 percent thickener. The thickener acts as a sponge and contains the base oil. It can also have other additives used for anticorroision and extreme pressure agents for high loads. The oil can be a conventional mineral oil or a synthetic. It is important that the oil component has the appropriate viscosity for the application. Viscosity is the thickness of the oil. As oil heats up, it gets thinner. If it gets too thin at operating temperature, it will not provide the needed lubrication. The thickener is usually a metal soap (lithium, sodium, aluminum or calcium). The stiffness of the thickener is graded using a National Lubricating Grease Institute (NLGI) class with 0 being very soft to 6 being very thick. Rolling bearings typically use a NLGI class from 1 to 2.

Poor lubrication is attributed to a large percentage of bearing failures in a wide range of manufacturing applications.

Grease is commonly used for several reasons. It is easy to lubricate a bearing with grease. Grease can be easily added by manually pumping it through a zerk fitting located on the bearing housing. The grease fitting is positioned so that an appropriate amount can be pumped directly into the space between the internal rollers of the bearing. Automatic greasers may also be used to deliver a specific grease charge at specific time intervals. Where bearings are operating at low speeds, the bearing and the internal cavity of the housing can be completely filled with grease, where the grease acts a barrier to prevent the ingress of contaminants into the bearing. For higher speeds, bearing housings are typically filled to ⅓ capacity.

Grease also simplifies the housing design. Standard bearing housings bought off the shelf do not require any special modifications for grease lubrication. Grease can even be used to create a housing seal. Labyrinth seals can be designed where grease is pumped into the labyrinth passages of the seal, providing a barrier against contamination. These types of seals are made so that they fit loosely with the housing, which allows for misalignment, and they can be made where they do not wear or damage the shaft. Some manufacturers produce sealed bearing designs where the grease purges through the bearing and fills the complex labyrinth passages of the seals. Grease becomes a critical element of the seal. These factors make grease inexpensive, and convenient for customers to use.

A disadvantage of using grease is

> **"A disadvantage of using grease is ensuring the correct amount is being added to the bearing assembly. You cannot see how much is being pumped through a grease gun. Too much or too little can cause heating and premature failure."**

ensuring the correct amount is being added to the bearing assembly. You cannot see how much is being pumped through a grease gun. Too much or too little can cause heating and premature failure.

When the lubrication requirements exceed the capabilities of grease, oil is used. Oil lubrication provides more oil directly to the bearing than grease, which can help dissipate heat. Oils used for lubrication can be mineral or synthetic. Mineral oils are extracted from crude oil and contain natural occurring molecules. Synthetic oils are manmade, where all of the molecules are the same size and shape. This can provide better lubrication properties and more stability at higher temperatures. There are various types of oil lubrication, including oil bath, oil mist and oil circulation.

An oil bath is a system where oil is added to a bearing housing so that the oil level comes to the center of the lowest roller or ball. As the bearing rotates, the oil is picked by the rollers and distributed throughout the internal components of the bearings. In this system the volume of oil is significantly greater than when grease is used. The oil washes through the bearing and falls back into the sump. This type of system provides a significant volume of oil, reducing friction and operating temperatures.

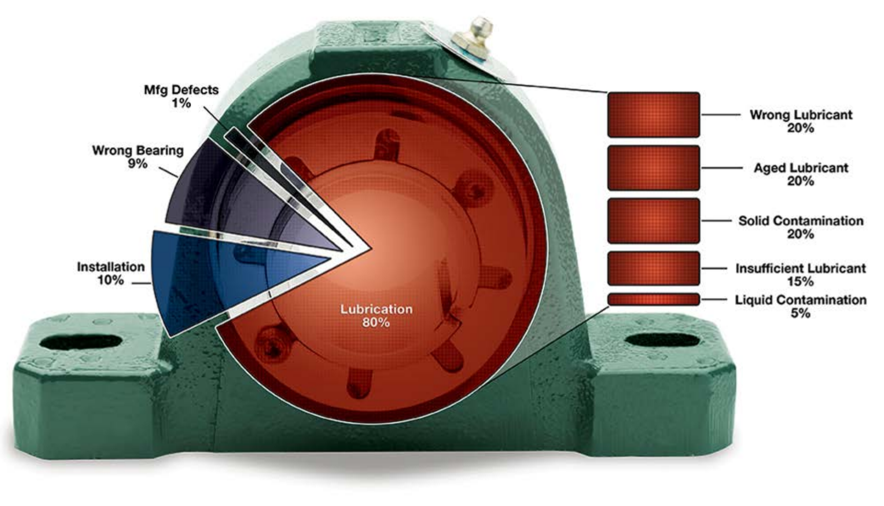
Another way to provide oil is by injecting it under pressure. This is called an oil mist system. Oil is injected directly into the center of bearing, coating the moving elements. It requires a pump, but it uses very little oil compared to static oil where the entire lower sump is filled to a prescribed level. With static oil, the oil is churned by the rotating bearing and may froth and cause heat due to fluid friction. These issues do not exist with oil misting.

For severe applications where external heat may be present, an oil circulation system may be needed. In this type of system, a stream of oil is pumped into the housing, preferably through the center of the bearing, and flows out of the bearing housing through large drains. The oil may also pass through filters and heat exchangers to cool the oil before being returned to the bearing housing.

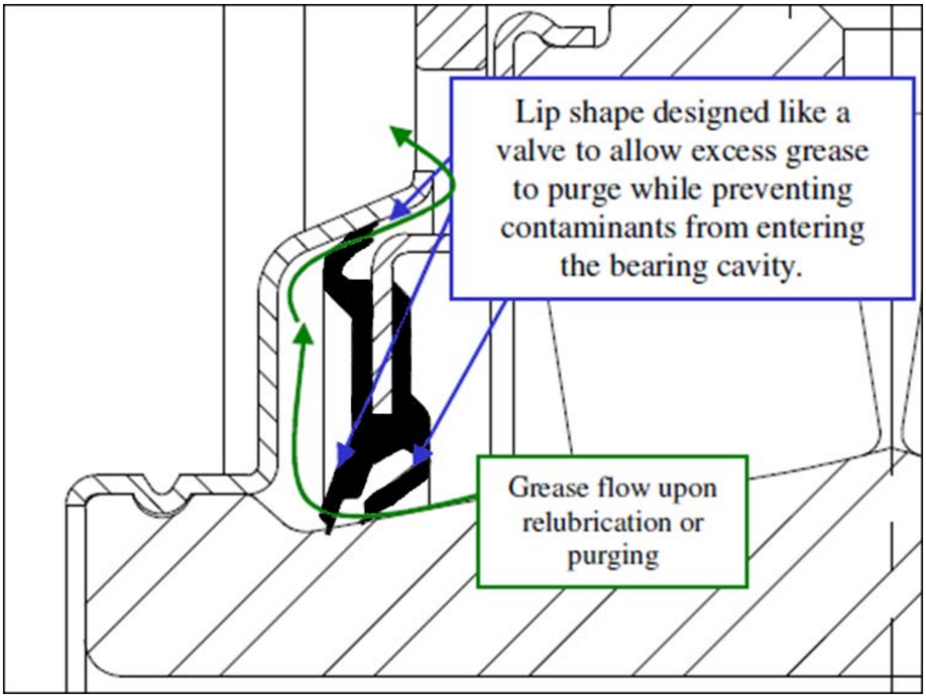
Oil is used when grease cannot handle the demands created by heat and high shaft speeds. There are, however, additional costs and challenges when using oil. To use oil, the bearing housing will have to accommodate the liquid lubricant. Seals used for grease may not be sufficient for oil lubrication. A more intricate seal will have to be used. Often contact seals are used. These type of seals are less forgiving regarding misalignment, and in time, will wear the shaft. For static oil, in addition to improved sealing, a sight gage will also be needed. Circulating systems require additional components such as pumps, heat exchangers, and filters. Housings will have to be modified for large inlets and drains, crossover holes and thermal sensor devices. Maintenance of static and oil circulating systems may require sampling and testing of the oil. Oil temperatures can be continually monitored so that equipment can be shut down in the event of an equipment failure, saving valuable machinery and repair costs.

Grease and oil can be used for different reasons. In the following paragraphs, several examples are given, detailing the lubrication system used, and the reasons why those systems were chosen.

Large hammer mills used on car shredders typically use large radial bearings turning several hundred rpm. One customer was operating successfully using grease, but later changed to a circulating oil system, which allowed the rotor bearings to operate at higher speeds, increasing output from the shredder. The circulating system not only accommodated higher speeds, but the operating temperature of the shredder was reduced.



Common modes of mounted bearing failure.



The benefits of properly designed grease paths and purgeable seals .

Large facilities such as mines or cement pants that use long stretches of conveying equipment usually choose to use grease. The bearings used for this type of equipment are operating at slow speeds and work well with grease. It is more economical to individually grease each unit than it would be to provide the necessary equipment required for oil systems where many bearings are used over a very large area.

Another application requiring oil circulation are bearings used dryer sections of a paper mill. Superheated steam at 400°F is blown through hollow shafts, creating extremely high temperatures for bearings. Circulating oil allows bearings to survive in this type of environment, by constantly removing the oil and cooling it before it is pumped back into the bearing.

Fans run at extremely high speeds. Grease is used in many of these applications, but sometimes the fans turn faster than a grease lubricated bearing can handle. On one such application, a $4\frac{7}{16}$ spherical roller bearing on a fan was turning 2,000 rpm using grease lubrication. Bearing temperatures exceeded 200°F. The customer switched to an oil circulating system and the operating temperatures came down to 145°F.

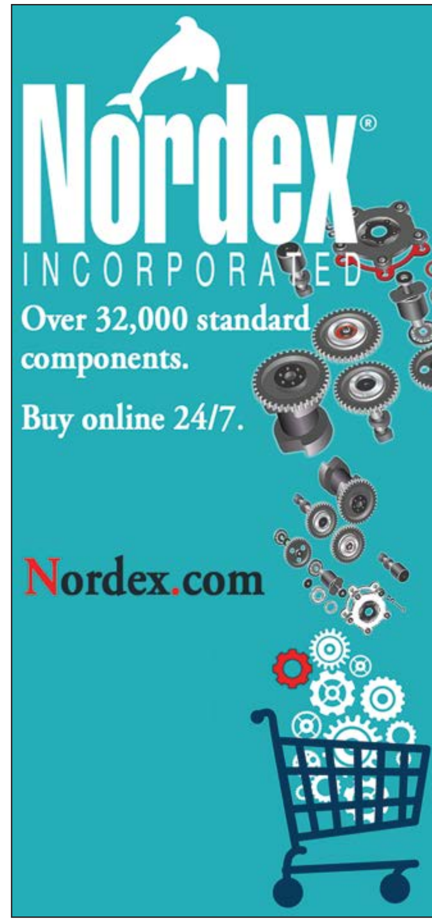
Another scenario where a circulation system could be used is where the bearing housing is inaccessible. The housing could be buried in a machine or located on top of a high structure. Oil lines could be plumbed to the housing, and the oil system could be located externally, easily accessible by maintenance personnel.

Deciding on which lubrication method to use can be based on several factors. It can be driven by cost, ease of maintenance, improved bearing life or higher performance of equipment. When choosing a lubrication method, several factors need to be examined. Using application data such as loading and speeds, bearing manufacturers provide data for their product that enables customers to determine if grease or oil should be used. Bearing and lubrication manufacturers can also provide critical information regarding viscosity and lubrication intervals required for a specific application. Poor lubrication is attributed to a large percentage of bearing failures. Choosing an appropriate method will maximize the life of a bearing. **PTE**

"Less than 10 percent of bearings reach their theoretical L10 life, and poor lubrication can be attributed to 80 percent of those that fall short."

For more information
Baldor Electric Company (A Member of the ABB Group)
Phone: (479) 646-4711
www.baldor.com

Keith Bartley is currently a customer order engineer for Baldor Electric. He has 26 years of experience building and designing custom made bearing housings and related components.



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The To-Do List

Eight Steps to Selecting and Managing Your Lubrication System

Matthew Jaster, Senior Editor

Lubrication management should be standard operating procedure at any manufacturing facility. Vital to both operational and maintenance personnel, a strong, coherent and specific lubrication program will have lasting results in machine efficiency and maintenance. Of course, even those with the best intentions can't always keep up with the challenges presented day-to-day on the manufacturing floor. Thankfully, *PTE* is here to help with eight steps to selecting, storing, analyzing and managing your lubrication requirements.

#1 Get it Right the First Time

Enhancing equipment reliability starts with simply applying the right product at the right time and in the right amount and then monitoring it regularly, according to Bill Watson, director of marketing and engineering, Klüber Lubrication NA LP. "For example, taking a gear oil sample for analysis. It is also very important to follow the equipment manufacturer's recommendations," Watson said. This simple step will pay off immediately, potentially saving hours of downtime while extending the lifespan of the machine. Cindy Shearer Galloway, marketing director, Syn-Tech Ltd., says that paying strict attention to the correct amount of lubrication and applying it only when needed should be a top priority.

#2 Consistency Pays Off

Galloway also stresses the importance of compatibility. "It is important that replacement or maintenance lubricants are compatible with previous lubricant formulas. Incomplete lubricants can cause machine and lubrication failures," Galloway added.

Kluber offers a variety of lubricant management tools and resources for manufacturers today including KluberEnergy.

Klüber identifies lubrication issues early, particularly in the food and beverage industry, to avoid catastrophic failures.

#3 Do Your Research

Klüber provides onsite training, equipment mapping (a more detailed plant lubrication survey, labeling of equipment, applicators, and recommendations for lube rooms, plus lubrication analysis of both oils and greases. "First and foremost, we will ensure that the correct product is in use by examining all of the tribological conditions," Watson said.

Galloway believes several factors play a part in choosing the correct lubricant. "The lubricant must have the correct base fluid viscosity. If it's a grease, you need the correct National Lubricating Grease Institute (NLGI) number for the application. You also want the lubricant to provide the correct corrosion control. It should perform over the machinery's various temperature ranges. In addition, it's important to have the correct load capacity of the lubricant and evaluate the plastics and elastomers that the lubricant may come in contact with," Galloway said.

#4 Stay on Schedule

Following your maintenance schedule is the easiest, most efficient way to ensure your equipment stays in peak operating condition, according to Galloway. "Syn-Tech Ltd. lubricants offer increased life, extending maintenance intervals, increasing efficiency by reducing maintenance and downtime, ultimately saving money, time and equipment."

"In order to maintain equipment reliability, it's extremely important to not just have a maintenance plan in place, but ensure that it's followed on a consistent basis. Having a well-documented procedure understood by all operators ensures that even if roles change, the equipment receives the same high level of regular attention prescribed. Best practice would go even further and have the OEM lube chart available as well," Watson added.

#5 The Importance of Proper Storage

Galloway said that environmental and storage conditions have a great influence on the rate at which a lubricant degrades, affecting the lubricant's useful life once applied to a component. Adhering to some simple recommended practices for the storage and handling of lubricants will greatly improve the chances of a lubricant maintaining critical characteristics.

"Oil will naturally separate from most grease. Temperatures in excess of 110°F can greatly accelerate oil separation. The grease in storage containers should be checked periodically. If puddles of oil are found, do not pour or siphon off. Instead, thoroughly disperse the oil back into the grease with a clean spatula, paddle or mixing apparatus. When grease is removed from a drum or pail, the grease surface should be smoothed to prevent oil separation into the cavity," Galloway said.

Other simple steps that can help your cause, include wiping off the tops and edges of containers before opening to avoid contamination from debris. If drums must be stored outside, use plastic covers to direct water and contamination away from the bungs.

"If the customer is not sure about shelf life, our policy is generally four years from the date of manufacture," Galloway added. "Syn-tech Ltd. lubricants with an expired shelf life can be requalified at Syn-Tech Ltd. at no charge. Testing is conducted using our product manufacturing specifications. If no deficiencies are found, the lubricant is recertified for an additional four years. This eliminates the need for disposal and purchasing – an excellent cost savings for our customers."

"Cleanliness is paramount and the organization of products so that it is clear which applications the lubricant is used for," Watson said. "Making sure that containers are properly sealed, and contamination is not possible. If bulk storage is being used, ensure that even the transfer containers are then cared for in the same way; things like dedicated grease guns, hoses, etc. ensure that lubricants aren't being mixed, even when being moved from one area to another."

Syn-Tech manufactures lines of lubricants with varying viscosities.

Syn-Tech Ltd., based in Addison, Illinois, develops lubricants for automotive, aerospace, defense, industrial, medical and commercial industries.

#6 Education and Training

Toby Porter, food market manager, Klüber Lubrication NA LP, believes training is imperative in lubrication management. "Lubrication is a science, and very detailed at times – and it takes time to become knowledgeable in all of the pertinent facets. Yes, we emphasize training and its benefits regularly to our customers. The front line for predictive maintenance is the user of the equipment (the customer), we train so that if and when problems arise, they're likely caught early enough to avoid catastrophic failures leading to significant downtime," Porter said.

There are a few simple and steadfast rules to consider, according to Galloway. For example, here are some specific in-plant suggestions for grease applications:

Release pressure from a pumping apparatus during downtimes, shift changes or overnight. This will reduce the amount of oil separation from the grease.

For application equipment it is important to avoid sharp transitions in supply lines, keep pumping pressures down, below 100 psi if possible and keep supply lines as short as possible. This will allow lower pumping pressures.

When changing over to a new lubricant on a line, it is very important to ensure that all old lubricant has been removed. When assembling new lines, plan for additional couplings, valves, etc., that will make purging the system easier. Develop a specification for changeover procedures.

Check brushes and sponges used to apply grease regularly for deterioration.

Keep grease storage containers in a dry, cool area when not in use. Keep the tops clean and free of dirt and debris.

#7 Stay Up on Market Trends

It might be an overstatement to say that some technologies and methods work and some don't. This isn't just an issue in lubrication, but an ongoing struggle in the world we live in today.

On occasion, tried and true methods remain reliable and consistent, but there's always new ideas that may or may not pan out. The secret is to be aware of everything that is happening in your particular area of expertise, stay up on trends and follow the organizations that seem to be doing it right.

"For example, there has been a movement towards equipment operators or production line supervisors taking on regular lubrication tasks, so that maintenance can focus more on equipment reliability- as an efficiency gain," Porter said.

Many customers have begun implementing what's known as Total Productive Maintenance (TPM). The strategy and implementation can vary, but one common theme is the transfer of lubrication practices to the operators and line workers of the machinery. "This can have benefits in multiple ways, but one is that the staff working on the equipment has a closer connection to the typical operating conditions and can more easily recognize anything out of the ordinary. This can improve the predictive maintenance and decrease the sometimes lengthy downtime that comes from problems going unnoticed," he added.

Syn-Tech's goal is to extend the length of lubrication intervals and machinery, according to Galloway. "We want our customers to consider lube for life lubricants, zero migration lubricants when oil leakage is a problem," she added. "Our customers should consider the lubricant early in the machine design and consider one lubricant for various pieces of equipment to reduce purchasing and stock, eliminating confusion and redundancy, and in some instances cost."

#8 Experience Never Hurts

Have questions or need advice on how to manage your lubrication system? There are plenty of resources available at (*www.powertransmission.com/Lubrication.htm*). Our online Buyer's Guide features companies that provide greases, oils, lubricants and lubricating equipment. The companies that provided information for this article are also a valuable resource for lubrication methods and best practices:

Syn-Tech Ltd. was founded in 1968. The company, based in Addison, Illinois, develops lubricants for the automotive, aerospace, defense, industrial, medical and commercial industries. Syn-Tech not only formulates lubricants for individual applications, but they manufacture lines of lubricants with varying viscosities, thickeners and base fluids including H-1 and H-2 food grade lubricants.

Klüber Lubrication is a full subsidiary of Freudenberg Chemical Specialities and is a company of the Freudenberg Group since 1966, headquartered in Weinheim, Germany. Klüber Lubrication offers approximately 2,000 different speciality lubricants, many of them developed and manufactured to specific customer requirements. **PTE**

For more information:

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Syn-Tech Ltd.
Phone: (630) 628-7290
www.syn-techlube.com

Stay the Course

Noria's Reliable Plant 2016 took place April 5-7 in Louisville, Kentucky. If you missed the opportunity to attend this conference, the company provides a variety of education and training sessions on lubrication throughout the year. These include public courses, onsite training and online training resources. Here is a brief rundown of what they offer through the year.

Industrial Lubrication Fundamentals

Industrial Lubrication Fundamentals is an introduction to optimal lubrication practices, which covers the common activities of a lubrication technician. This training is considered to be a key component to support a lubrication excellence program. This interactive course uses a variety of activities and media to provide the lube technician with the technical knowledge and methodologies of lubrication excellence, which enhance their competencies to execute qualified lubrication duties.

Machinery Lubrication Level I

Attendees will learn proven industry methods for selecting, storing, filtering and testing lubricants to boost reliability and generate lasting results in machine efficiency/maintenance. They will also gain better understanding of oil analysis, so they can align their efforts with those of maintenance professionals or oil analysis experts.

Machinery Lubrication Level II

If you have already scratched the surface of the amazing improvement and resource-saving potential in good lubrication practices, ML II will round out your perspective with excellent preventive maintenance techniques. Attendees will learn how to identify wear patterns, degraded lubricants and those small but significant leaks that can spell disaster over a period of time.

Oil Analysis Level II

Lubricants can serve as a wellspring of information for preventive maintenance. If you find yourself wanting to bring the valuable benefits of on-site fluid testing to your workplace, Oil Analysis II will equip you with everything you need. Attendees will learn what to look for when sampling and performing their own on-site oil tests – detecting harmful particle and thermal stressors that degrade lubricants before they do serious damage.

Oil Analysis Level III

Attendees will learn the more detailed aspects of fluid analysis, technologies associated with it, and even how to go a step further from simply performing on-site tests to launch a strong oil analysis program at your workplace. **PTE**

For more information:

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Surface Refinement with Nanotechnology

REWITEC OFFERS SURFACE TREATMENT SOLUTION FOR WIND APPLICATIONS

Rewitec's innovative surface refinement technology with nano- and micro-particle-based bonding components can be utilized in wind, industrial, shipping and automotive applications.

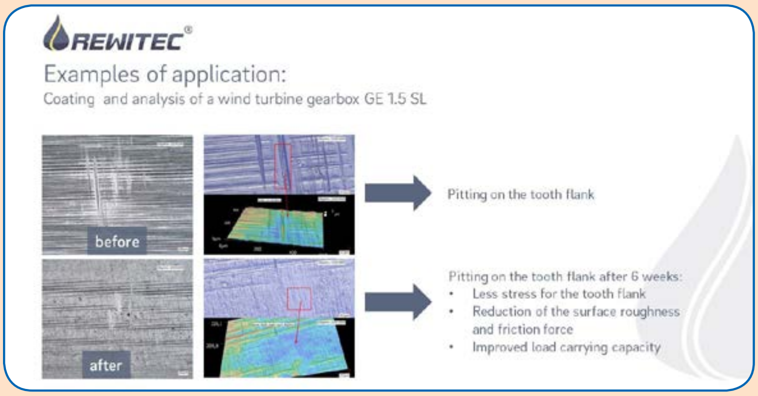
While applying the products, lubricants are used as a carrier for the active components. This allows the treatment of metal surfaces (gearboxes, bearings and internal combustion engines) to run with greater reliability and durability due to reduced friction, temperature and wear.

"Rewitec is a longtime supplier to the wind power industry specializing in surface wear protection and refinement of metal surfaces in tribologic systems," said Torsten Trute, technical sales at Rewitec. "Our products are applied to reduce friction and wear and to extend the life and energy efficiency in the main, pitch, and azimuth gearboxes, as well as the main, generator and pitch bearings."

How it works

Rewitec will get added to each lubricant and then the chemical is applied during operation on the treated metal surfaces. The lubricant in this case acts as a means of transportation and carries the silicon coating onto loaded metal surfaces. By using friction energy and crystalline temperatures that arise in the so-called mixed friction range, the products passivate the surface and reduce the roughness. This affects the service life and safety of the systems.

"This innovative technology ensures that life and machine performance are enhanced over the long term and the wear in the tribological systems is reduced. Once added to the lubricant, the Rewitec products, specifically developed for each respective purpose, provide our clients with protection over many hours of operation," Trute said. "The concentrated active agents are generally supplied pre-mixed in a neutral oil, which is compatible with practically all standard lubricants. For special lubricants, such as polyglycol oils, we are able to provide appropriate special products. It is also possible to apply our active agents to special lubricants supplied by the client as well."



Testing Results

The Competence Center for Tribology of Mannheim University of Applied Sciences examined with a rolling wear tester the effect of Rewitec in gear oils under rolling-sliding motion. The experiment was carried out on a modern two-disc test assembly which makes it possible to simulate tooth flank operating conditions. The evaluation showed the extent of change in friction behavior and in temperature after adding Rewitec.

Tests were carried out with two gear oils. A conventional mineral oil (Agip Blasia 150) and a high-performance PAO based oil (Agip Blasia SX320). Each performed with and without the addition of Rewitec. The results were compared. Two tests were performed including a short-term tests for 20 hours and 20 minutes and long-term tests for 61 hours with higher stress.

Compared to a standard mineral oil, Rewitec lowered the friction by 23 percent and the temperature by eight percent in the first short-term test. Compared to a high performance PAO oil, Rewitec lowered the friction by 18 percent and the temperature by four percent in the second short-term test.

During the long-term test at a higher pressure, Rewitec compared to a high-performance PAO oil with a 33 percent friction reduction, 20 percent temperature reduction and the surface roughness reduced by approximately 50 percent.

Field Application

Availon s.r.l., located in Italy, partnered with Rewitec GmbH for the surface improvement of the gears and bearings in their wind turbine gearboxes. The company utilized Rewitec DuraGear W100 Gearbox Surface Protection to a gearbox after ten months of operation. Based on the evaluation, the application of the Rewitec product resulted in an improvement to the surface structure and roughness of the tooth flanks, a reduction in run through marks, micropitting and seizure and the electrical resistance from the gearbox improved significantly.

"In dealing with Rewitec products, experience has shown that the wear of our wind turbines is significantly delayed," said Jochen Holling, mechanical engineer, global technical support and engineering, Availon GmbH. "In most cases, the progressive damage in certain gearboxes and bearings with pre-mechanical damage was even eliminated." **PTE**

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Analyzing the Cement Process

Bearing Application and Production Considerations

Power Transmission Engineering is collaborating with the Bearing Specialists Association (BSA) on a special section within the magazine. *Bearing Briefs* will present updated reports on bearing topics for each issue in 2016. Complimentary access to all BSA Bearing and Industry Briefs is available on the BSA website at *www.bsahome.org/tools*.

BEARING SPECIALISTS ASSOCIATION ®

We build relationships

Quarry

The manufacturing process begins in a limestone quarry. Mining methods such as ripping, dozing, drilling and blasting are commonly employed. Limestone provides the first essential component, calcium, for the manufacture of cement. Materials are transported to the crushing plant for further size reduction. Common methods of transport are trucks, loaders and belt conveyors.

Bearing applications: Mounted spherical and tapered roller bearings, both set screw and adapter mount. Spherical roller, ball and cylindrical roller bearings are also used. Split housing cylindrical bearings and split to the bore cylindrical are often used in "trapped" applications.

Items to consider: Bearings are subjected to abrasive dust and fine dirt. Some bearings may need to withstand very wet conditions. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered. Bearing housings are often struck by heavy materials requiring cast iron or solid steel, pillow block construction. Many applications are relatively slow speed and may require additional lubricant.

Crushing

Quarried limestone is usually too large for effective use in the remaining steps of the production process. Impact and hammer crushers reduce the size of relatively soft material, while compression crushers are used for larger rock. Effective size reduction aids material transport, material blending and further size reduction through various grinding methods.

Bearing Applications: Mounted spherical roller bearings, spherical and tapered roller bearings.

Items to consider: This application is subjected to heavy shock loads which require all steel or cast iron pillow block construction. The area is heavily laden with abrasive dust and dirt, requiring robust bearing seals. Crusher related spherical bearings are specified with additional internal clearance and are constructed to withstand the heavy vibratory and shock loads (shaker screen).

Pre-blending

Crushed material is transported on belt conveyors to a stacker assembly. The stacker assembly builds a bed of material in either circular piles or long, linear rows. These "pre- blending beds" are built in layers and then reclaimed at right angles to the pile. This has a homogenizing effect on the material, providing a consistent product to the Raw Mill.

Bearing Applications: Mounted spherical and tapered roller bearings, both set screw and adapter mount. Ball bearings in idlers. Head and tail pulley contain spherical roller bearings.

Items to consider: Bearings are subjected to abrasive dust and fine dirt. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

Raw Mill

Blended limestone and clay are introduced to a grinding mill with sand, fly ash, and iron ore. Correct proportions are important to product quality, requiring a high level of automation and analysis. Raw materials are ground to a fine powder using vertical roller mills, rotary ball mills, or a roller press. Fineness is controlled with a material separator using airflow and rotating vanes to classify product. Coarse product is returned to the mill while fine product is conveyed to storage. Bucket elevators, screw conveyors, and air slides are utilized for material conveyance.

Bearing Applications: Pillow block and flange mounted spherical and tapered roller bearings are typically found on screw conveyors, belt conveyors and bucket elevators. Large fans may utilize babbitt lined, oil lubricated sleeve bearings. Smaller fans utilize mounted ball and spherical bearings. Some cylindrical but mainly spherical roller bearings (depending on design). Large mounted spherical roller bearings can also be found on vertical mill grinding wheel assemblies.

Items to consider: Bearings are subjected to fine, abrasive dust. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

Homogenization

Ground raw meal is stored in large silos that are air activated to promote blending of the raw meal, reducing chemical variation and promoting stable sintering in the kiln. Some systems utilize a series of mass flow silos: individual silos are sequentially filled, while product is withdrawn from all silos simultaneously. Dry material is conveyed pneumatically or by bucket elevator to the rotary kiln.

Bearing Applications: A variety of bearings are used. Mounted spherical and tapered roller bearings, are typically found on larger conveyors and bucket elevators, while smaller conveyors may utilize setscrew mount ball bearings. Fans may utilize mounted ball and spherical bearings. Agitator– sealed single row deep groove ball bearings on the fixed end and cylindrical roller bearings on the free end. Housed or mounted spherical and ball bearings for bucket elevators. Pneumatic Blowers, both regenerative and non-regenerative Ball bearings including thrust bearing sets.

Items to consider: Bearings are subjected to fine, abrasive dust. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

Preheater/Precalciner

Dry, homogenized raw meal is fed into a preheater/precalciner where it is dried, heated and partially calcined before introduction to the rotary kiln. Calcination occurs at around 900°C and involves the disassociation of carbon dioxide (CO_2) from calcium carbonate ($CaCO_3$).

The resulting calcium oxide is then free to combine with alumina, silica, and iron oxide to form new mineral crystals.

Bearing Applications: Large fans may utilize babbitt lined, oil lubricated sleeve bearings.

Smaller fans utilize mounted ball and spherical bearings. Mainly spherical roller bearings.

Items to consider: Bearings are subjected to fine, abrasive dust. These bearings are usually mounted in outdoor applications, so rain is a concern. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

Rotary Kiln

Partially calcined material flows to the kiln, where heat drives the reactions necessary to sinter the raw meal. Maximum temperatures, inside the kiln, will approach 2000°C. Cement clinker is formed when the raw meal components combine, under heat, to form clinker minerals. The resulting minerals have the ability to chemically react and harden when mixed with water. Fossil fuels, preferably coal, provide the thermal energy required to drive this process. Alternative fuels, with good heat value, are also utilized.

Bearing Applications: Large fans may utilize babbitt lined, oil lubricated sleeve bearings. Smaller fans utilize mounted ball and spherical bearings. Double row cylindrical roller, cylindrical roller, spherical roller, and tapered roller bearings.

Items to consider: Bearings are subjected to fine, abrasive dust, heat and rain. Bearings should be fitted with robust seals. Lubricant for high temperature applications should be used when applicable. Closed end housings and protective covers should be considered.

Clinker Cooler

Fully formed cement clinker falls from the rotary kiln, into a reciprocating grate cooler. Fans force ambient air through slotted grates, which transport the hot material while channeling cooling air to the clinker. The heated air is recovered for combustion, reducing the kiln's fuel requirement. Cooled clinker is conveyed by pan conveyors, bucket elevators, drag chains and belt conveyors to storage silos. Screw conveyors are used to transport dust from dust collectors.

Bearing Applications: Pillow block and flange mounted spherical and tapered roller bearings are typically found on screw conveyors, belt conveyors and bucket elevators. Large fans may utilize babbitt lined, oil lubricated sleeve bearings. Smaller fans utilize pillow block spherical bearings. Spherical roller bearings, spherical thrust bearings, and thrust ball bearings.

Items to consider: Bearings are subjected to fine, abrasive dust and high temperature. Bearings should be fitted with robust seals. Lubricant for high temperature applications should be used when applicable. Closed end housings and protective covers should be considered. Occasionally, auxiliary bearing coolers may be required.

Finish Grinding

Cement clinker is drawn from storage silos using apron weigh feeders and ground with gypsum. The product is a fine powder referred to as Portland Cement. Grinding takes place in the same way as in the Raw Mill. Common systems are rotary ball mills and vertical roller mills. Product is classified with a separator and transported around the mill circuit with air slides, screw conveyors and bucket elevators. The final product is pneumatically conveyed to cement storage silos for later distribution to customers.

Bearing Applications: Pillow block and flange mounted spherical and tapered roller bearings are typically found on screw conveyors, belt conveyors and bucket elevators. Fans utilize mounted ball and spherical bearings. Spherical roller bearings.

Items to consider: Bearings are subjected to fine, abrasive dust. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

Distribution

Cement stored in silos is withdrawn for bulk shipment by truck, rail or barge. Redi-mix plants combine the cement with aggregate and water to form concrete. Cement is also packaged in 50 to 100 pound bags and palletized for use by smaller customers or for sale in places like home improvement stores.

Bearing Applications: Pillow block and flange mounted ball, spherical and tapered roller bearings are typically found on screw conveyors, belt conveyors and bucket elevators. Fans utilize mounted ball and spherical bearings. Spherical and cylindrical roller bearings. Fans use thrust ball bearings and thrust spherical roller bearings.

Items to consider: Bearings are subjected to fine, abrasive dust. Bearings should be fitted with robust seals. Closed end housings and protective covers should be considered.

For more information:

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Case Study: JBJ Techniques and the BLOODHOUND SSC Project

Photo courtesy of Flock and Siemens

The Challenge

Specialist power transmission supplier JBJ Techniques Limited, of Redhill, Surrey, England were recently contacted by the staff of Bloodhound SSC R&D engineering team to solve a problem on the fuel pump test rig. JBJ Techniques had worked with various team members in the past and this previous experience made JBJ an easy choice to assist with this project. The scope of supply was to produce a suitable drive coupling with a maximum diameter of 160 mm, capable of transmitting 550 Nm @ 10,000 rpm, with as short an assembly as possible, and at the same time be able to accept misalignment within the drivetrain.

The Solution

JBJ proposed a Sier Bath coupling from their principles — RL Hydraulics, in Germany, a wholly owned subsidiary of U.S.-based Lovejoy Inc. The high-torque capacity of the coupling meant that, when assembled, it fit perfectly within the existing adaptor arrangement, and the crown tooth gear form on the coupling allows for relatively high misalignment without transferring loads between the shafts. JBJ had the blank parts in stock, having a comprehensive inventory of power transmission couplings of many types and designs, thus helping to keep customer downtime to an absolute minimum.

JBJ Techniques's proposed solution required a special driveshaft that, when connected to the output flange of an automotive gearbox, enabled easy assembly of the Sier Bath unit. 3D models were then supplied and approved by the Bloodhound team, and after manufacture, the complete assembly was dynamically balanced to ensure that the coupling operated without generating any additional forces.

The fuel pump is, in effect, the pump for the rocket; it's an end-suction centrifugal pump driven by a Jaguar 'F'- type V8 engine. Its role is to pump the oxidizing agent (hydrogen peroxide) into the rocket engine that contains the actual (solid) fuel (rubber). The other engine is a jet and does not require a separate pump.

The end-suction centrifugal pump (Fig. 1) is basically an impeller mounted within a volute housing; the impeller is mounted on a shaft supported on two bearings. One is mounted close behind the impeller with a pressurized, double-mechanical seal to prevent leakage. A bearing housing accommodates the length of the shaft and ensures a suitable gap between the bearings sufficient to support the rotating parts. The photo shows it standing on its suction inlet flange with the outlet (dis-

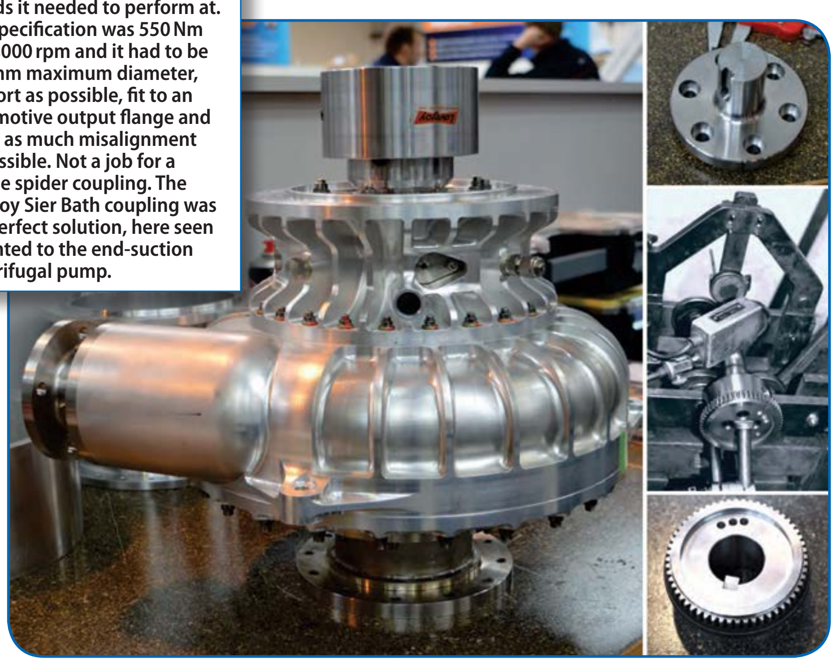

Figure 1 The coupling underwent dynamic balancing before delivery because of the high speeds it needed to perform at. The specification was 550 Nm at 10,000 rpm and it had to be 160 mm maximum diameter, as short as possible, fit to an automotive output flange and allow as much misalignment as possible. Not a job for a simple spider coupling. The Lovejoy Sier Bath coupling was the perfect solution, here seen mounted to the end-suction centrifugal pump.

charge) pointing left, and the coupling at top mounted on the end of the shaft.

The company takes pride in the fact that the coupling specified and supplied by JBJ Techniques performed exactly as designed. The research and development process has only added to the knowledge base needed to help Bloodhound SSC succeed in its mission of breaking the land speed record and, most importantly of all, to help inspire the young to be the future engineers that shape the world we all live in. We are all eager to see Bloodhound SSC "flying" across Hakskeen Pan in South Africa — driven by Wing Commander Andy D. Green — the British Royal Air Force fighter pilot and new World Land Speed Record holder. **PTE**

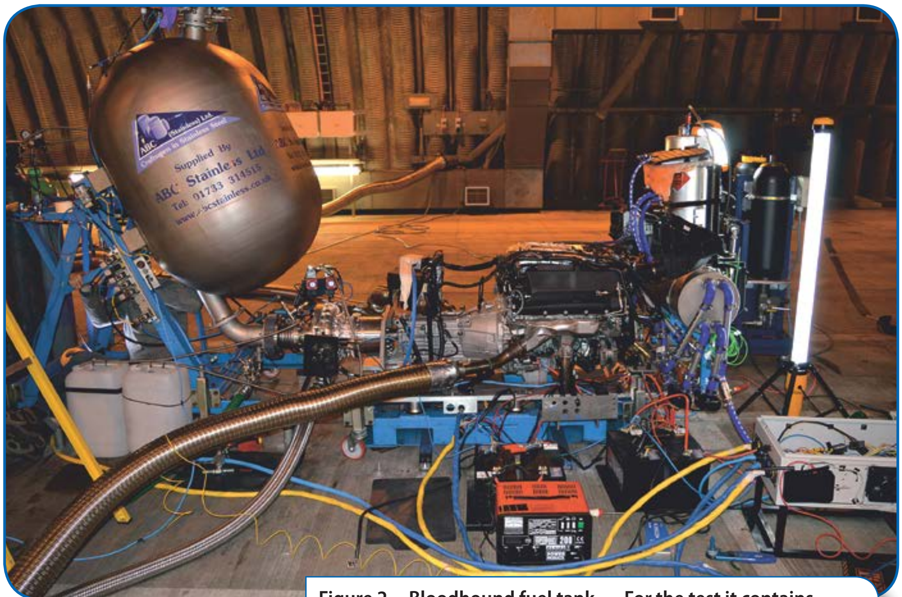

Figure 2 Bloodhound fuel tank — For the test it contains water to be pumped through at the same speed and pressure that fuel will be pumped during the actual land speed record attempt.

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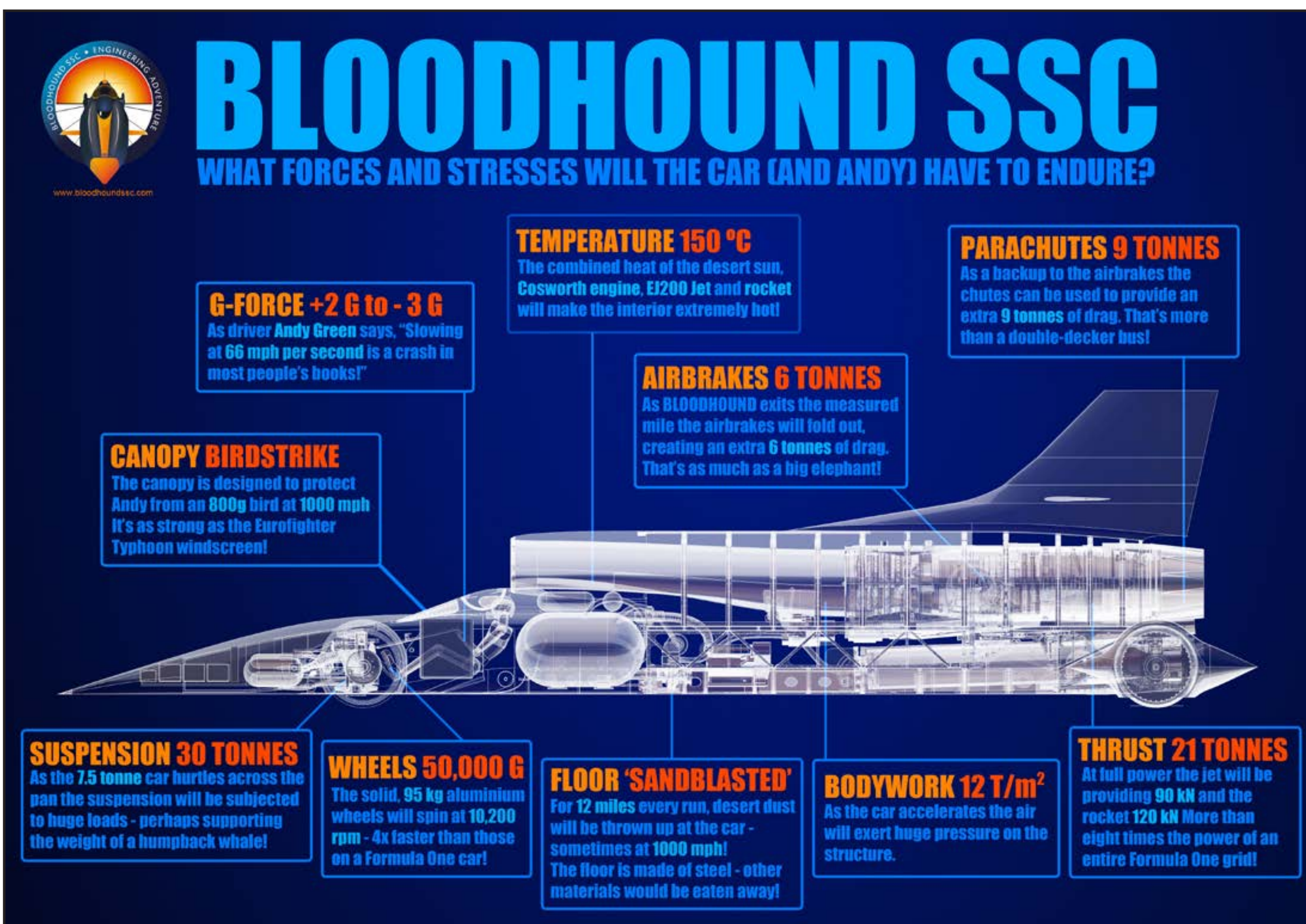


Rating of Asymmetric Tooth Gears

Alex L. Kapelevich and Yuriy V. Shekhtman

Asymmetric tooth gears and their rating are not described by existing gear design standards. Presented is a rating approach for asymmetric tooth gears by their bending and contact stress levels, in comparison with symmetric tooth gears, whose rating are defined by standards. This approach applies finite element analysis (FEA) for bending stress definition and the Hertzian equation for contact stress definition. It defines equivalency factors for practical asymmetric tooth gear design and rating. This paper illustrates the rating of asymmetric tooth gears with numerical examples.

Introduction

Although the gear geometry and design of asymmetric tooth gears (Fig. 1) are known and described in a number of technical articles and books, they are not covered by modern national and international gear design and rating standards. This limits their broad implementation for various gear applications, despite substantial performance advantages in comparison to symmetric tooth gears for mostly unidirectional drives. In some industries, like aerospace, which are accustomed to using gears with nonstandard tooth shapes, rating of these gears is established by comprehensive testing (Ref. 1). Unfortunately, such testing programs are not affordable for the many less demanding gear drives that could also benefit from asymmetric tooth gears. On the other side, asymmetric teeth, though nonstandard, have involute flanks like standard involute gears with symmetric teeth. Their drive and coast flank involutes unwind from two different base circles, and drive and coast pressure angles at a reference diameter are different. Typically (but not always), a drive tooth flank has a higher pressure angle than the coast flank. Although it leads to the drive flank contact ratio reduction, selection of the drive tooth flank with a higher pressure angle allows for reducing contact stress of the drive flanks and increasing gear transmission density of asymmetric tooth gears. An asymmetry factor that defines the difference between drive and coast pressure angles is a subject for optimization (Ref. 2).

The goal of this article is to bridge the gap between the stress evaluation methods of symmetric and asymmetric tooth gears and to allow for the application of existing rating standards to asymmetric tooth gears.

Design Methods of Asymmetric Tooth Gears

Traditional design of asymmetric tooth gears. Some researchers describe the geometry of asymmetric tooth gears by applying a traditional rack generating method (Refs. 3–8). This method defines asymmetric gear geometry by the preselected asymmetric generating gear rack parameters and addendum modifications (Fig. 2). Typically, an asymmetric generating rack is modified from the standard symmetric rack by increasing the pressure angle of one flank. The opposite flank and other rack tooth proportions remain unchanged.

Direct Design of asymmetric tooth gears. The alternative Direct Gear Design method (Ref. 9) does not limit gear parameter definition by a preselected generating rack, thus allowing comprehensive customization of asymmetric tooth geometry to maximize gear drive performance. This design method pres-

Figure 1 Asymmetric tooth gears.

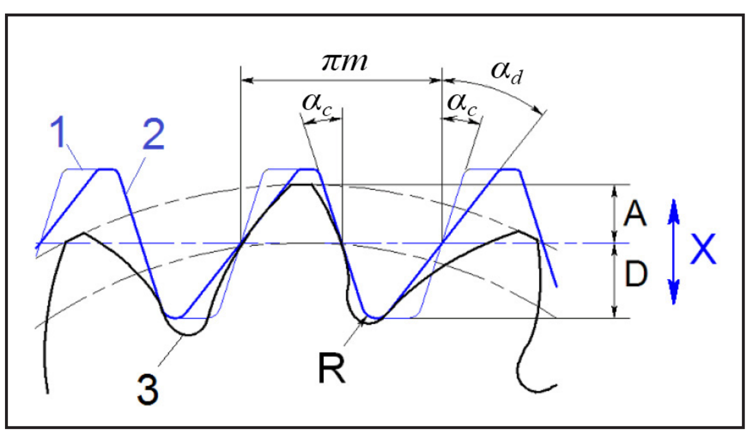


Figure 2 1) – initial standard symmetric generating rack; 2) – modified asymmetric generating rack; 3) – gear profile; *A* – gear addendum; *D* – dedendum; *X* – addendum modification (*X*-shift); *R* – rack tip radius; *m* – module; α_d – drive profile (pressure) rack angle; α_c – coast profile (pressure) rack angle.

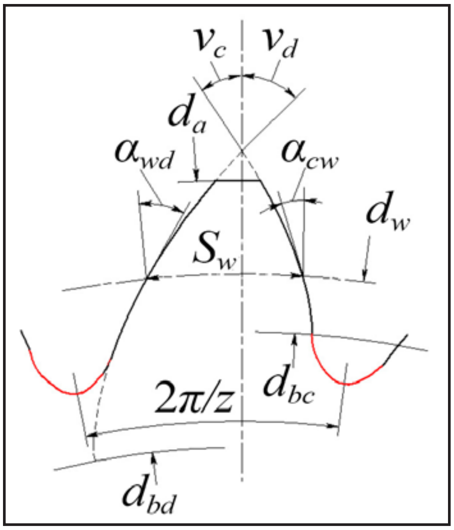


Figure 3 Tooth profile (root fillet profiles in red) z – number of teeth; d_{bd}, d_{bc} – base diameters; v_d, v_c – involute intersection profile angles; d_w – operating pitch diameter; α_{wd}, α_{wc} – profile (pressure) angles at diameter; d_w, Sw – circular tooth thickness at diameter; d_w, d_a – tooth tip circle diameter; symbols "*d*" and "*c*" are for drive and coast tooth flanks

ents an asymmetric tooth by two involutes of two different base circles (d_{bd} and d_{bc}) and a tooth tip circle d_a (Fig. 3).

Drive and coast profile (pressure) angles α_d and α_c at operating pitch diameter d_w:

$$\alpha_{wd} = \arccos\left(\frac{d_{bd}}{d_w}\right) \tag{1}$$

$$\alpha_{wc} = \arccos\left(\frac{d_{bc}}{d_w}\right) \tag{2}$$

Asymmetry factor K:

$$K = \frac{d_{bc}}{d_{bd}} = \frac{\cos(v_c)}{\cos(v_d)} = \frac{\cos(\alpha_{wc})}{\cos(\alpha_{wd})} \geq 1.0 \tag{3}$$

Circular tooth thickness S_w at operating pitch diameter d_w:

$$S_w = \frac{d_w}{2}[\mathrm{inv}(v_d) + \mathrm{inv}(v_c) - \mathrm{inv}(\alpha_{wd}) - \mathrm{inv}(\alpha_{wc})] \tag{4}$$

Equally spaced teeth form the gear. The root fillet between teeth is the area of maximum bending stress. Direct Gear Design optimizes the root fillet profile, providing minimum bending stress concentration and sufficient clearance with the mating gear tooth tips in mesh (Refs. 10–11).

Comparable Symmetric Tooth Gear Definition

In order to apply existing rating standards to asymmetric tooth gear rating, the asymmetric tooth gears must be replaced by comparable symmetric tooth gears. Tooth geometry of these symmetric tooth gears should be described by symmetric generating rack parameters and addendum modifications (or X-shift coefficients).

Transformation of asymmetric generating rack to symmetric rack for comparable symmetric tooth gear generation. Traditional gear design of asymmetric tooth gears uses an asymmetric generating rack and addendum modifications. In order to define the tooth geometry of comparable symmetric tooth gears, the asymmetric generating rack should be transformed to the symmetric generating rack. Parameters of this symmetric rack include (Fig. 4):

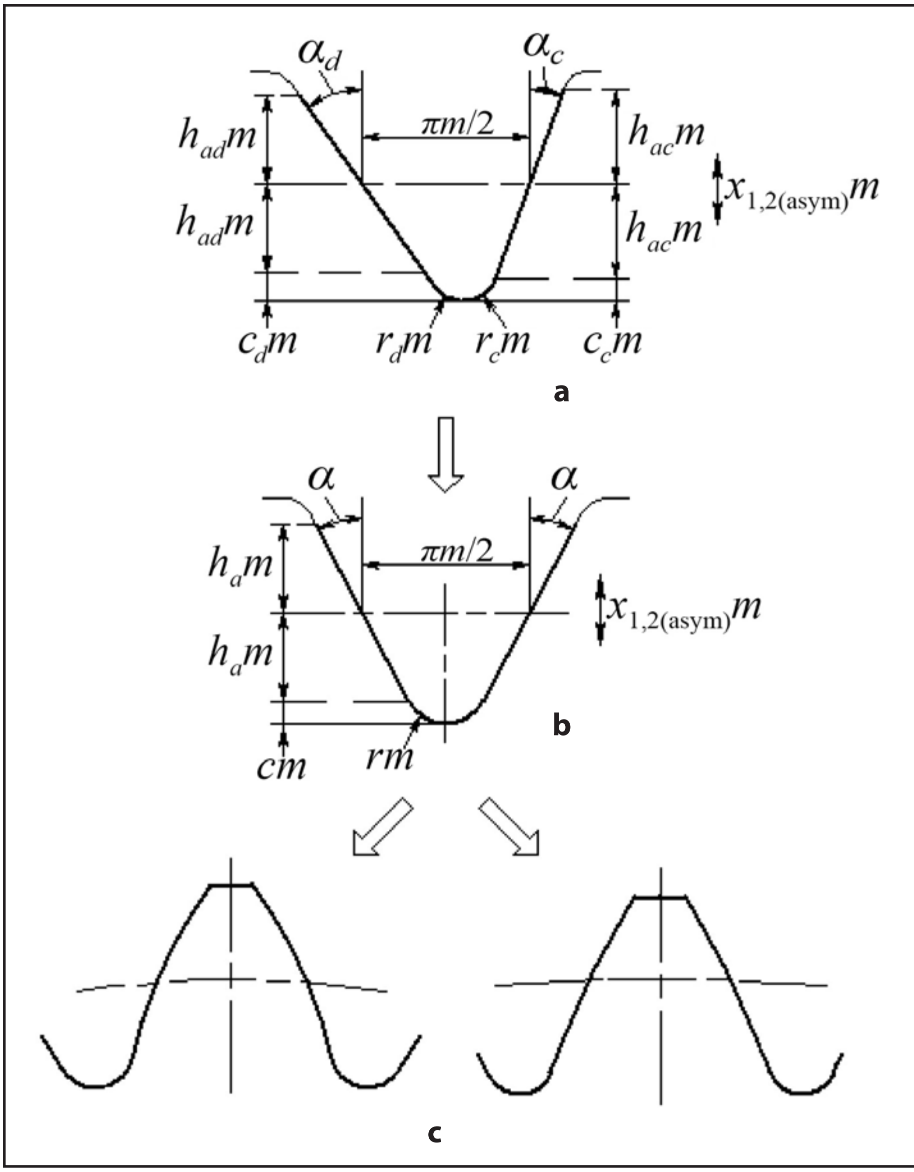


Figure 4 Transformation of asymmetric generating rack to symmetric rack for comparable symmetric tooth gear generation. a – asymmetric rack; b – symmetric rack; c – comparable symmetric tooth profiles.

Symmetric generating rack profile (pressure) angle:

$$\alpha = \frac{\alpha_d + \alpha_c}{2} \tag{5}$$

Rack addendum coefficient:

$$h_a = \frac{h_{ad} + h_{ac}}{2} \tag{6}$$

Full rack tip radius coefficient:

$$r = \frac{\pi/4 - h_a \tan\alpha}{\cos\alpha} \tag{7}$$

Clearance coefficient:

$$c = r(1 - \sin\alpha) \tag{8}$$

Addendum modification (X-shift) coefficients:

$$x_{1,2(sym)} = x_{1,2(asym)} \tag{9}$$

where index "1" and "2" are for the pinion and gear, respectively.

Definition of symmetric rack for comparable symmetric tooth gear generation based on direct gear design of asymmetric tooth gear pair. The Direct Gear Design method of asymmetric tooth gears does not utilize any racks to generate gear tooth geometry parameters. However, in order to define the tooth geometry of comparable symmetric tooth gears that would be used for asymmetric tooth gear rating, the symmetric generating rack should be defined by asymmetric gear parameters.

Parameters of this symmetric rack include (Fig. 5):

Symmetric generating rack module:

$$r = \frac{\pi/4 - h_a \tan\alpha}{\cos\alpha} \tag{10}$$

where z_1 *and* z_2 are numbers of teeth of the pinion and gear, respectively.

Profile (pressure) angle:

$$\alpha = \frac{\alpha_{wd} + \alpha_{wc}}{2} \tag{11}$$

Rack addendum coefficient:

$$h_a = \frac{d_{a1} - d_1 + d_{a2} - d_2}{4m} \tag{12}$$

Full rack tip radius coefficient:

$$r = \frac{\pi/4 - h_a \tan\alpha_w}{\cos\alpha_w} \tag{13}$$

Clearance coefficient:

$$c = r(1 - \sin\alpha_w) \tag{14}$$

Addendum modification (X-shift) coefficients:

$$x_1 = \frac{s_1 - s_2}{4m\tan\alpha} \text{ and } x_2 = -x_1 \tag{15}$$

Depending on whether the asymmetric gear design method utilized is traditional or direct, the symmetric generating rack parameters defined by Equations 5–9 or 10–15 are used to design the comparable symmetric gears and obtain their rating data for required gear drive operating conditions. A sample of the asymmetric and comparable symmetric tooth gear geometry data is presented in Table 1.

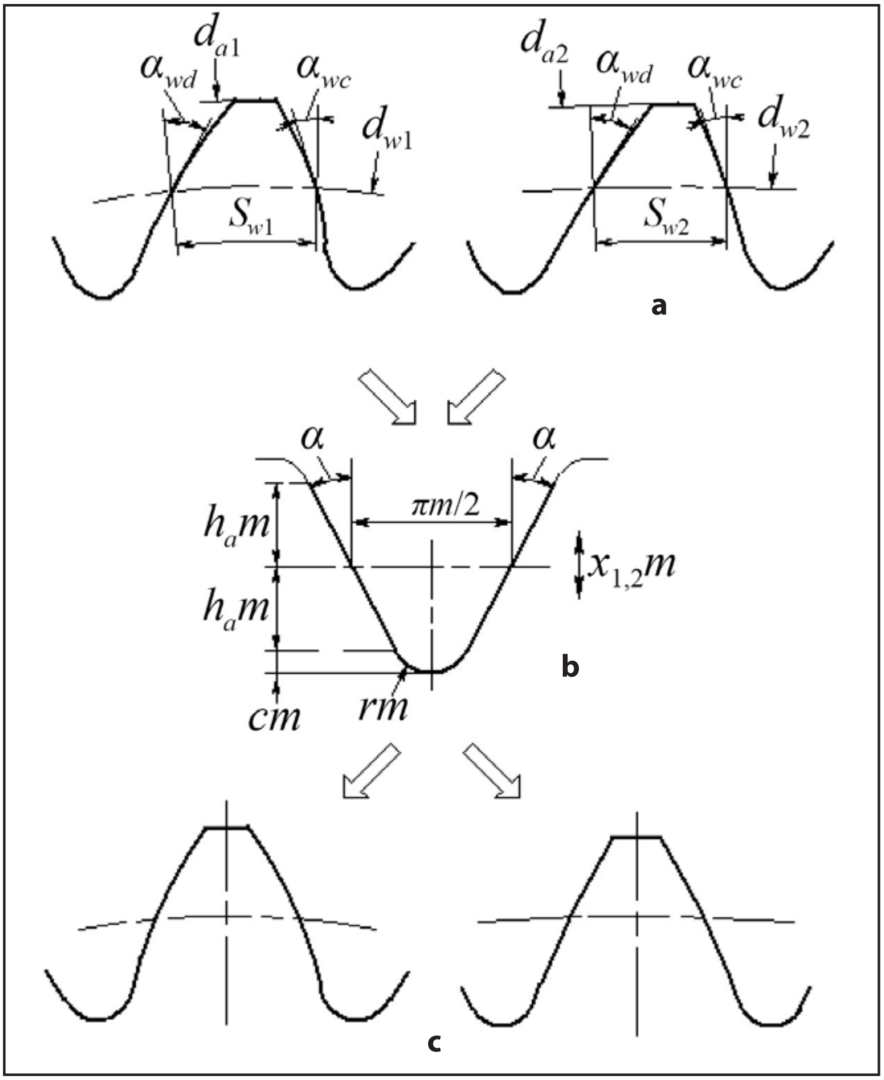
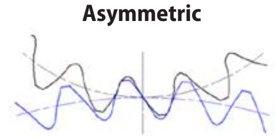
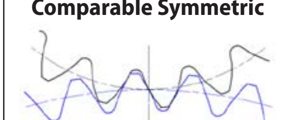


Figure 5 Definition of symmetric rack for comparable symmetric tooth gears generation based on Direct Gear Design of asymmetric tooth gear pair a – mating asymmetric tooth pinion and gear profiles; b – symmetric rack; c – comparable symmetric tooth profiles.

Table 1 Asymmetric and comparable symmetric tooth gear geometry data

Gear Pair	Asymmetric		Comparable Symmetric	
				
Number of teeth	20	49	20	49
Module	5.000		5.000	
Pressure Angle	35°/20°*		27.5°	
Asymmetry Factor	1.147		1.0	
Pitch Diameter (PD)	100.000	295.000	100.000	295.000
Base Diameter	81.915/ 93.969*	200.692/ 230.225*	88.701	217.318
Tooth Thickness at PD	8.168	7.540	8.168	7.540
Center Distance	172.500		172.500	
Generating Rack Angle			27.5°	
Addendum Coefficient			0.951	
Root Radius Coefficient			0.327	
Root Clearance Coefficient			0.176	
Profile Shift Coefficient			0.060	-0.060
Tip Diameter	109.802	254.214	110.110	253.910
Root Diameter	89.080**	233.597**	89.360	233.141
Root Fillet Profile	optimized	optimized	trochoidal	trochoidal
Face Width	30.00	27.00	30.00	27.00
Contact ratio	1.20/1.55*		1.31	

* drive/coast flanks, ** root fillet optimized

Stress Calculation of Asymmetric and Comparable Tooth Gears

Root bending stress and conversion coefficients. The standard procedure for bending stress calculation (based on the Lewis equation) cannot be used for asymmetric tooth gears because a symmetric Lewis parabola does not properly fit into an asymmetric tooth profile. Finite element analysis (FEA) is a more suitable analytical tool to calculate the maximum root stress in the asymmetric and comparable symmetric tooth gears in order to define bending stress conversion coefficients. The Direct Gear Design technique utilizes the FEA tooth root bending stress calculation for both symmetric and asymmetric tooth gears (Ref. 9). Correlations between standard and FEA root stress were explored by Vanyo Kirov (Ref. 12). Although there are differences in the standard and FEA root stress calculation results, FEA allows for defining conversion coefficients between asymmetric and comparable symmetric tooth maximum bending stresses. A 2-D or 3-D FEA program can be used for tooth root bending stress calculations; this article describes the 2-D FEA procedure developed by Yuriy Shekhtman. *ANSYS* software was used for the 3-D FEA; the 2-D and 3-D finite element meshes of the asymmetric and comparable symmetric gear teeth are shown in Table 2.

For the maximum root bending stress calculation, normal load F_n is applied to the highest point of single tooth contact (HPSTC) of the drive tooth flank.

$$F_n = \frac{2T_1}{d_{bd}} \tag{16}$$

where T_1 is the pinion driving torque, d_{b1} is the pinion base diameter.

The pinion and gear conversion coefficients are:

$$C_{F1,2} = \frac{\sigma_{Fmax\,(sym)1,2}}{\sigma_{Fmax(asym)1,2}} \tag{17}$$

where $\sigma_{Fmax(asym)1,2}$ and $\sigma_{Fmax\,(sym)1,2}$ are the maximum FEA root bending stresses of the asymmetric and comparable symmetric tooth pinion and gear.

Table 3 includes 2-D and 3-D finite element stress models of the asymmetric and comparable, symmetric gear teeth.

Table 2 2-D and 3-D finite element meshes of asymmetric and comparable symmetric teeth

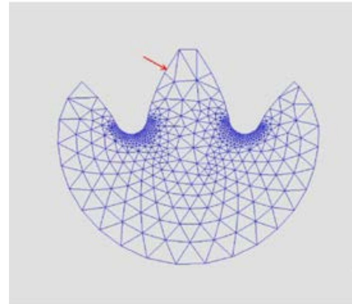
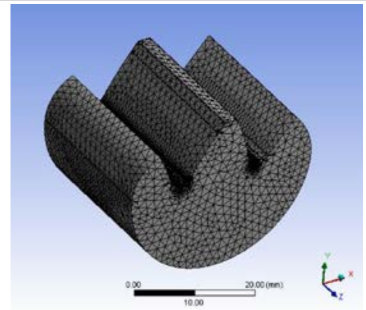
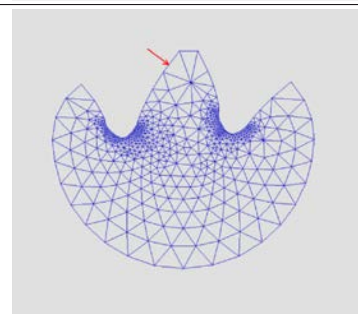
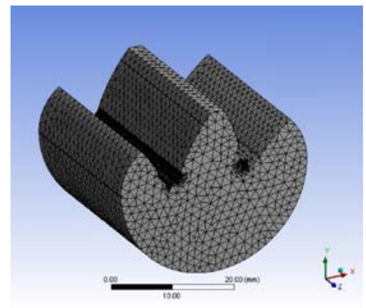
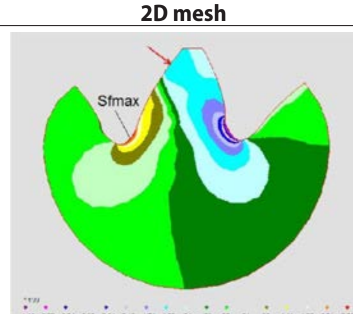
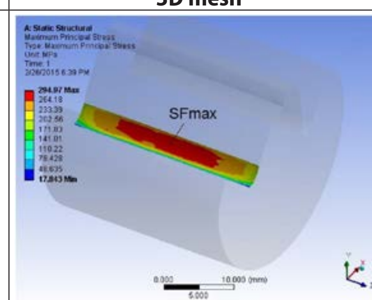
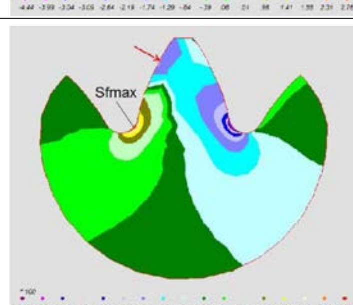
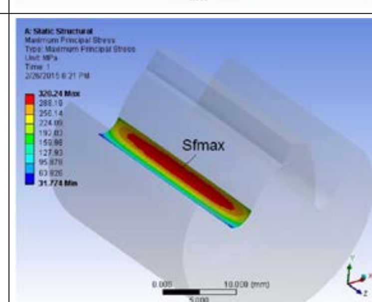
	2-D mesh	3-D mesh
Asymmetric tooth		
Comparable symmetric tooth		

Table 3 Root fillet stress of asymmetric and comparable symmetric teeth

	2D mesh	3D mesh
Asymmetric tooth		
Comparable symmetric tooth		

The standard tooth flank contact stress calculation procedure (based on the Hertzian equation) is suitable for both symmetric and asymmetric tooth gears.

The Hertzian equation allows for calculating the maximum contact stress in asymmetric and comparable symmetric tooth gears to define the contact stress conversion coefficients.

The Hertzian contact stress is:

$$\sigma_F = \sqrt{\left(\frac{F_n}{\pi b}\right)\left(\frac{E}{2\,(1-\upsilon^2)}\right)\left(\frac{1}{\rho_1}+\frac{1}{\rho_1}\right)} \tag{18}$$

where b is face width in contact, E and υ are modulus of elasticity and Poisson ratio, assuming mating pinion and gear materials are identical, ρ_1 and ρ_2 are pinion and gear curvature radii in contact.

For a spur pinion and gear with a contact ratio < 2.0, the maximum flank contact stress is localized near the lowest point of single tooth contact (LPSTC) of the drive tooth flank of the pinion. The pinion drive flank LPSTC point coincides with the gear drive flank HPSTC point (Fig. 6).

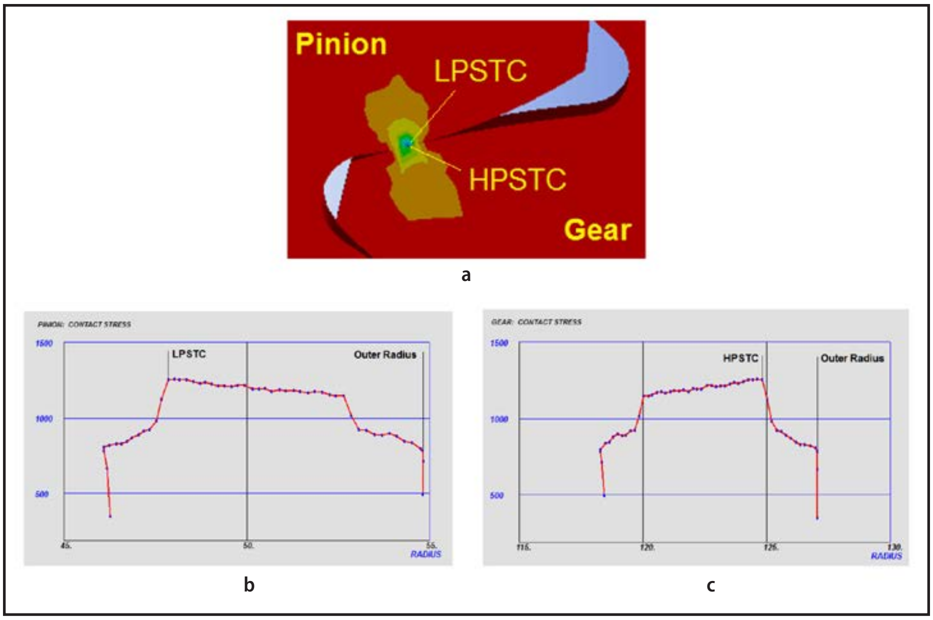


Figure 6 Contact stress point.

The contact stress conversion coefficient is

$$C_H = \frac{\sigma_{Hmax\,(sym)}}{\sigma_{Hmax(asym)}} \tag{19}$$

where $\sigma_{Hmax\,(asym)}$ and $\sigma_{Hmax\,(sym)}$ are the maximum Hertzian contact stresses of the asymmetric and comparable symmetric tooth gears pairs.

Standard Rating of Asymmetric Tooth Gears

The rating of involute gears with symmetric tooth gears is established in national and international standards (Refs. 13–14). In order to apply these rating standards to asymmetric tooth gears, the bending and contact safety factors defined for the comparable symmetric tooth gears should be multiplied by the contact and bending conversion coefficients accordingly. Then the rated bending safety factors of asymmetric tooth gears are:

$$S_{F(\mathrm{asym})1,2} = C_{F1,2}\, S_{F(sym)1,2} \tag{20}$$

where $_{SF(sym)1,2}$ are the root bending safety factor of comparable symmetric tooth gears defined by the rating standards.

The rated contact safety factor of asymmetric tooth gears is:

$$S_{H(\mathrm{asym})} = C_H\, S_{H(sym)} \tag{21}$$

where $S_{H\,(sym)}$ is the flank contact safety factor of comparable symmetric tooth gears defined by the rating standards.

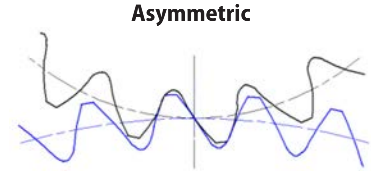
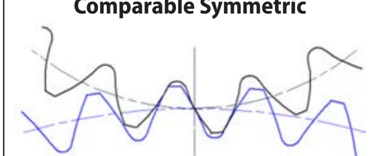
A sample of the asymmetric and comparable symmetric tooth gear stress analysis results is presented in Table 4; geometric data for these gears is in Table 3.

Summary

This article outlines a simple and effective approach to rating asymmetric tooth gears using existing, symmetric tooth gear rating standards that include:

- Conversion of the asymmetric tooth geometry to the comparable symmetric tooth geometry and definition of its generating rack
- Calculation of maximum bending stresses using 2-D or 3-D FEA to both asymmetric and comparable symmetric gear teeth
- Calculation of maximum contact stresses for both asymmetric and comparable symmetric gear teeth using the Hertzian equation
- Definition of the bending and contact stress conversion coefficients
- Standard stress analysis for the

Table 4 Asymmetric and comparable symmetric tooth gear stress analysis results

Gear Pair	Asymmetric		Comparable Symmetric	
				
Number of teeth	20	49	20	49
Module	5.000		5.000	
Pressure Angle	350/200*		27.5°	
Torque, Nm	900	2205	900	2205
RPM	1000	408	1000	408
Service Life, hours	2000		2000	
Material type	Carburized, case harden steel, like AISI 8620			
Bending Stress (2D FEA), MPa	276	277	309	334
Bending Stress (3D FEA), MPa	295(+7%)	284(+2.5%)	320(+3.5%)	350(+5%)
Bending Stress, MPa			448*	480*
Contact Stress, MPa			1507*	1407*
Maximum Contact Stress, MPa	1257		1349	
Bending Stress Conversion Coefficients (2D FEA), $C_{F1,2}$	1.120	1.206		
Bending Stress Conversion Coefficients (3D FEA), $C_{F1,2}$	1.085	1.232		
Contact Stress Conversion Coefficients (Hertz), C_H	1.073			
Bending Safety Factors	1.90/1.84**	1.95/2.00**	1.70*	1.62*
Contact Safety Factors	1.02	1.12	0.95*	1.04*

*Calculation method: per ISO 6336 standard, **2D/3D FEA comparable symmetric gear tooth and definition of the contact and bending safety factors

- Definition of the contact and bending safety factors for asymmetric tooth gears using the symmetric tooth gear safety factors and the bending and contact stress conversion coefficients
- The presented asymmetric tooth gear rating approach allows expanding implementation of these types of gears in many primarily unidirectional gear drives, thus maximizing their performance. **PTE**

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Dr. Alex Kapelevich operates the gear design consulting firm AKGears, LLC. He is a developer of modern Direct Gear Design methodology and software. He has over 30 years of experience in custom gear drive development, with particular expertise in gear transmission architecture, planetary systems, gear tooth profile optimization, asymmetric tooth gears, and gear drive performance maximization. Kapelevich is author of the book "Direct Gear Design" and many technical articles.

Dr. Yuriy Shekhtman is an expert in mathematical modeling and stress analysis. Drawing upon over 40 years' experience, he has created a number of computer programs based on FEA and other numerical methods. A software developer for AKGears, Dr. Shekhtman is also the author of many technical publications (*y.shekhtman@gmail.com*).

Metallurgical Failure Analysis of Power Transmission Components

Craig J. Schroeder

When a power transmission component fails, it can adversely affect the performance of the assembly, often making the machine inoperable. Such failures can not only harm the reputation of the manufacturer, but can lead to litigation, recalls and delays in delivery due to quality concerns. Some failures can even result in bodily injury or death. Understanding why a part failed is critical to preventing similar failures from reoccurring. In the study of a failed part, the analyst must consider a broad range of possibilities for the failure. Although some failures can be attributed to a single primary cause, it is common for multiple secondary factors to contribute. The failure analyst must evaluate all of the evidence available to prepare a hypothesis about the causes of failure.

The most common type of failure that is studied is the fracture of a component. Fractures often have the most serious consequences, especially when load-bearing members lose their ability to carry their intended load. Other types of failures that can occur may be related to distortion, wear, or corrosion. A well-equipped materials laboratory will have most of the tools to effectively analyze a component that has experienced these types of failures. These tools include a low power stereomicroscope, metallographic equipment, hardness testers, spectrometers and a scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDS) to name a few.

The process of analyzing a failed part starts with the collection of background information. It is important to know what the specified requirements for the part and the material are. That information is often available in the form of a part drawing and referenced material specifications. It is also important to know what the expected performance of the part is and how the failed part compared to that expectation. Any changes made to the manufacturing process should be reported to the failure analyst. Examples include vendor changes, design changes, material changes, thermal processing changes, etc.

The next step in the failure analysis process is the visual examination of the part. Features to be noted, recorded and photographed in the visual examination include fractures, fracture origin regions, damage to the part, the presence of residues, corrosion products, and corrosion pits to name a few. In some cases, non-destructive testing (NDT) may be warranted if cracks are not readily visible or if they may be present below the surface. Chemical and hardness testing is performed in most cases to verify whether the part met the specified requirements. If enough material is available, tensile testing and impact testing is desirable to help understand the inherent mechanical properties of the metal.

After gathering as much background information as possible, the next step in most investigations is visual inspection and low power light microscopy. This is where the analyst performs a general assessment of the damage and features present on the part. For example, a fractured shaft that was used in an industrial application is presented in Figures 1

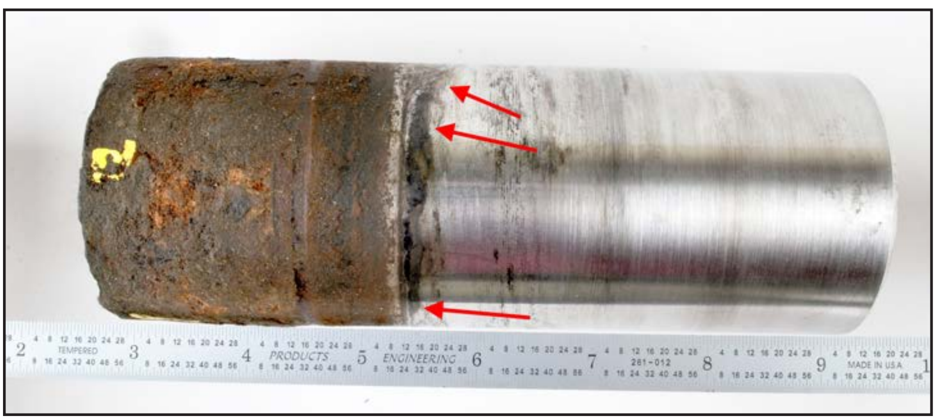


Figure 1 Fractured shaft, as received. Yellow marking indicates 12 o'clock position arbitrarily identified by Element New Berlin. Arrows indicate fretting damage.

Figure 2 Three o'clock position of shaft after rotating piece 90°. Arrows indicate pattern of fretting damage. Pattern of fretting damage suggested non-uniform contact on bearing. Pattern at 3 o'clock position indicated region of non-contact when bearing was present.

and 2. The yellow markings were made by Element to identify the 12 through 9 o'clock positions on the shaft. Markings such as these can prove invaluable in the course of an investigation to help orient the analyst and communicate the findings, especially after the part has been excised for further testing and analysis. It is obvious that the fractured end of the shaft, at the left portions of the images, was severely corroded. The arrows in the photographs indicate the presence of non-uniform fretting damage, suggesting that the fit with the bearing and the loads that were applied to the shaft were non-uniform. Although the fretting damage was located away from the fracture, it provided clues about the non-uniformity of the bearing fit and the loading on the part. This non-uniformity can lead to vibration and bending stresses on the shaft that can contribute to the failure of the part.

The fracture surface of the shaft is presented in Figure 3 after rotating the piece relative to Figures 1 and 2. The white arrows indicate the final fracture region. The final fracture region often consists of a rough texture or shear lip. The green arrows indicate the primary fracture origin region, which was judged to be approximately 180° away from the final fracture region. The blue arrows indicate ratchet marks. Ratchet marks are linear features, indicative of intersecting crack planes and are commonly present on fatigue-related fractures with multiple origins. As the blue arrows indicate, there were many fracture origins present around the circumference of the shaft. Ratchet marks are also associated with high stress concentration. The red arrows indicate the locations selected for further analysis via SEM-EDS. Section M was selected for metallographic analysis. It's critical for the analyst to carefully document, record and identify the features of the failed part and the damage present on the failed part in its as-received condition. The failed part will be handled, excised and examined in the laboratory. It can be critical to know the condition of the part, as-received, as the part can be damaged and sectioned during the investigative process.

Closer inspection of the fractures by low-power stereomicroscopy reveals a relatively rough texture with a notable amount of corrosion deposits and post-fracture mechanical rubbing damage, as shown in Figure 4. Inspection of the fracture and other features via electron microscopy is often the next step in the failure analysis process. Scanning electron microscopy is often utilized by the analyst to verify the fracture mode as features visible with a low power binocular microscope are not always resolvable, can be inconclusive and can sometimes be misleading. The scanning electron microscope can typically resolve features of interest up to 5,000×. In rare cases, magnifications up to 100,000× can be achieved. The light binocular microscopy is typically useful up to 50×. A scanning electron micrograph of the deposits present in the fracture origin region is presented in Figure 5.

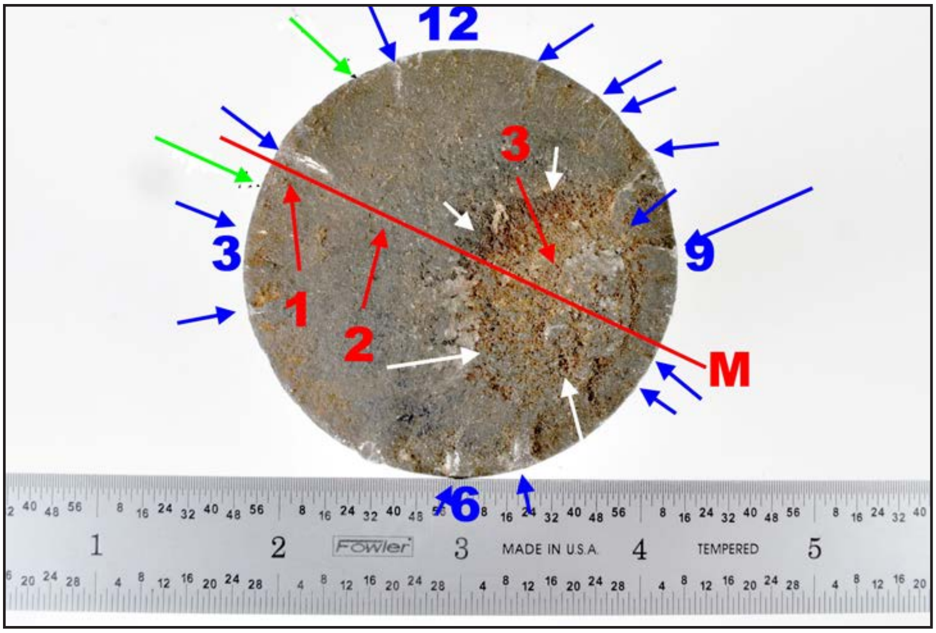


Figure 3 Fracture surface (Fig. 2, left). White arrows indicate final fracture region. Blue arrows indicate ratchet marks. Green arrows indicate fracture origin region. Red arrows indicate locations selected for further analysis. Section M selected for metallography.

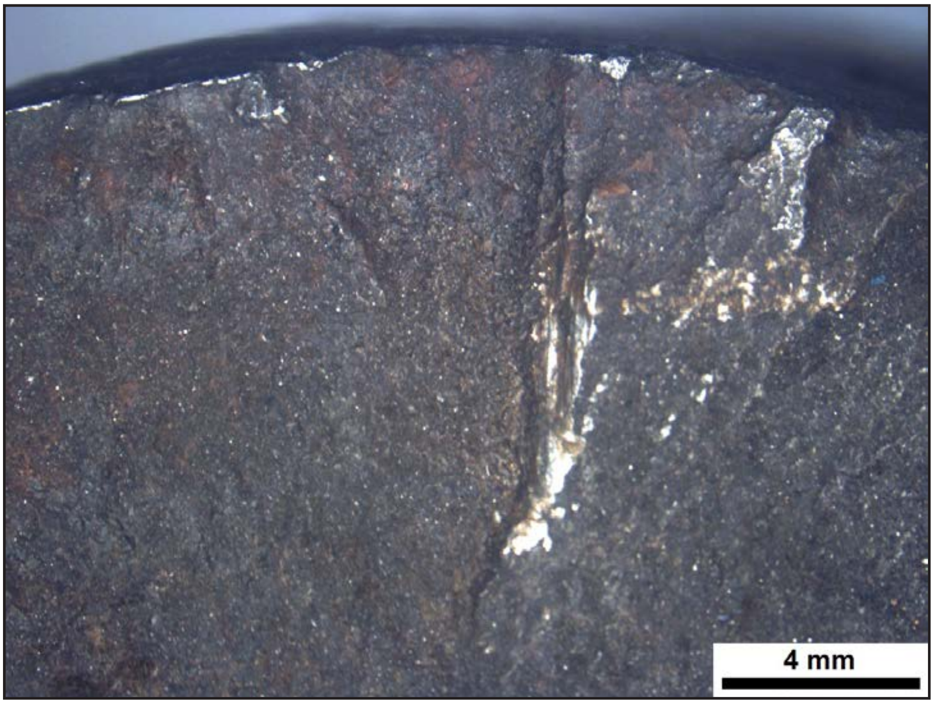


Figure 4 Magnified view of origin region (Fig. 3, top left), Location 1. Post-fracture mechanical rubbing damage, along with black and orange corrosion deposits, are evident in this view (original magnification (OM) 6×).

Table 1 EDS Results (Relative Weight Percent)

Element	Base Metal	5 minute Clean	30 Minute Clean		
		Location 1	Location 1	Location 2	Location 3
Iron	99.6	30.9	65.3	4.6	49.0
Manganese	—	—	0.6	—	1.2
Chromium	0.3	—	0.2	—	—
Silicon	0.1	0.2	0.4	21.6	0.5
Aluminum	—	0.1	0.5	7.0	0.2
Sodium	—	1.4	3.5	0.1	1.2
Magnesium	—	—	—	0.3	0.9
Calcium	—	5.2	0.4	17.2	1.6
Titanium	—	—	—	0.5	—
Zirconium	—	—	—	0.3	—
Phosphorus	—	11.0	0.6	—	0.4
Sulfur	—	0.5	0.7	—	0.4
Carbon	—	16.5	18.8	12.2	20.8
Oxygen	—	34.2	9.0	36.0	23.8

— = Not Detected

Analysis completed using Energy Dispersive X-ray Spectroscopy (MA-15).

EDS analysis can detect and quantify elements from atomic no. 5 (boron) and greater on the Periodic Table. Relative percentages of the detected elements can be determined and are normalized to total 100%. Therefore, the results of these analyses are relative rather than absolute values.

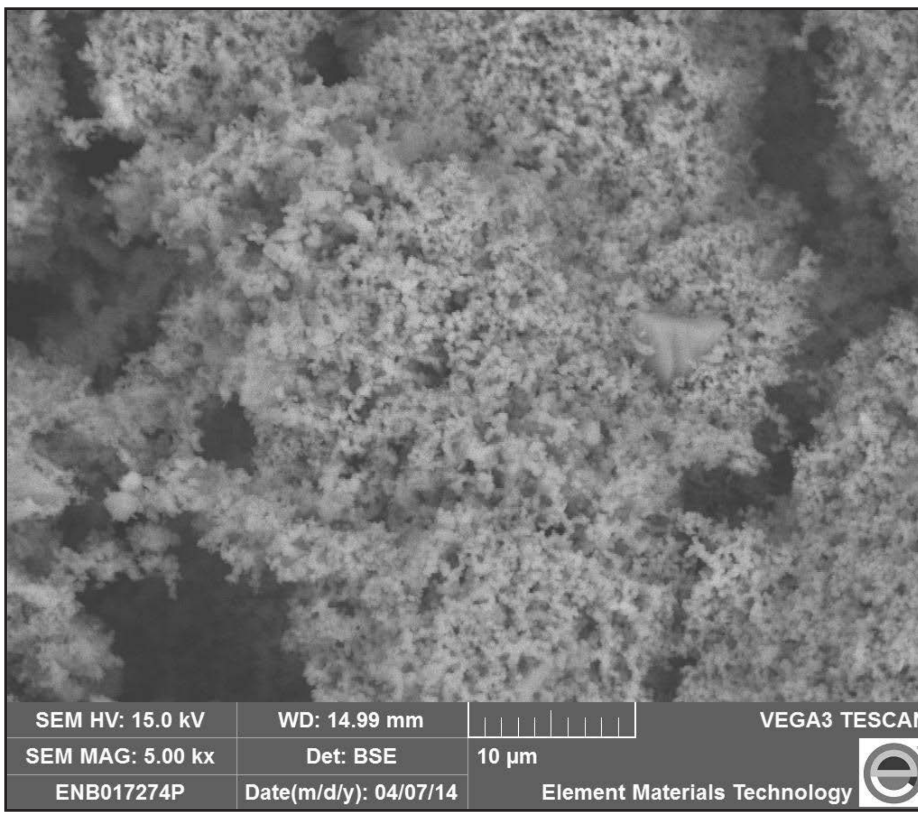


Figure 5 **Scanning electron micrograph of Location 1. Substantial amount of deposits were still present after preliminary cleaning of fracture surface. Features had oxidized appearance.**

The corrosion deposits obscured the original fracture features, even after the piece had been gently cleaned. Location 1 is presented in Figure 6 after additional cleaning. The features detected beneath the corrosion deposits had the appearance of corrosive etching, indicating the shaft was present in a severely corrosive environment. The features in Figure 6 had a texture similar in comparison to pearlite lamellae, indicating the location shown had been etched.

Although the original fracture features were obscured by the corrosion deposits and mechanical rubbing damage, an evaluation of the corrosion deposits can still prove valuable via SEM. The EDS attachment to the SEM can provide a semi-quantitative assessment of the contaminants that are present of the part. This is often useful in a case where corrosion deposits are evident on the part. The results of the EDS analysis of various locations on the fracture surface are presented in Table 1. It is good practice to determine the elements present in the base metal first, so it can be determined which elements detected are present as contaminant material, and which elements detected are from the base material. The analysis of the base material is not intended to verify the composition of the steel as the EDS is only accurate up to approximately 0.1 weight percent. Often, the presence of trace elements in the steel with a composition of less than 0.1 weight percent, such as carbon, phosphorus and sulfur, are not detected in the base metal via EDS. Verification of the base metal composition is better suited to other techniques such as optical emission spectroscopy (OES).

In addition to the base metal elements, the EDS detected manganese, aluminum, sodium, magnesium, calcium, titanium, zirconium, phosphorus, sulfur, carbon and oxygen. The manganese may have been from the base metal. The aluminum, sodium, magnesium, calcium, titanium and zirconium were judged to be present as mineral deposits. The source of the phosphorus was not known, but the presence of phosphorus is often associated with detergents. The source of the sulfur was not known. The carbon was judged to be present as organic or carbonaceous deposits. The detection of oxygen indicated the presence of oxides or corrosion deposits on the steel. In general, the EDS detected foreign material present as mineral deposits, dirt, and oxidation products. Often, chlorine will be detected on corroded components. Chlorine, in the form of chlorides, is corrosive to steel in a moist, acidic environment. In this case, chlorine was not detected on the part.

Metallography is a particularly important step in the metallurgical failure analysis process. Examination of the microstructure can help verify whether proper thermal processes were applied to the part. Metallography can also identify whether material anomalies were present in the material that could have had a deleterious effect on

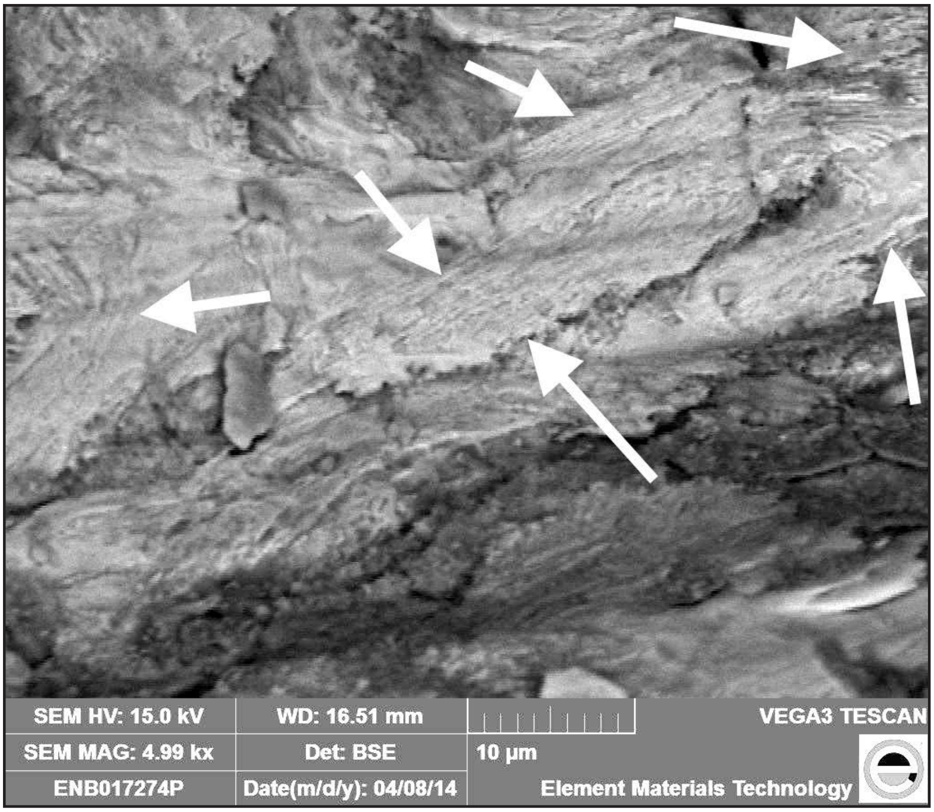


Figure 6 Scanning electron micrograph of Location 1 after additional cleaning. Arrows indicate features with appearance of corrosive etching into the pearlite lamellae on the steel.

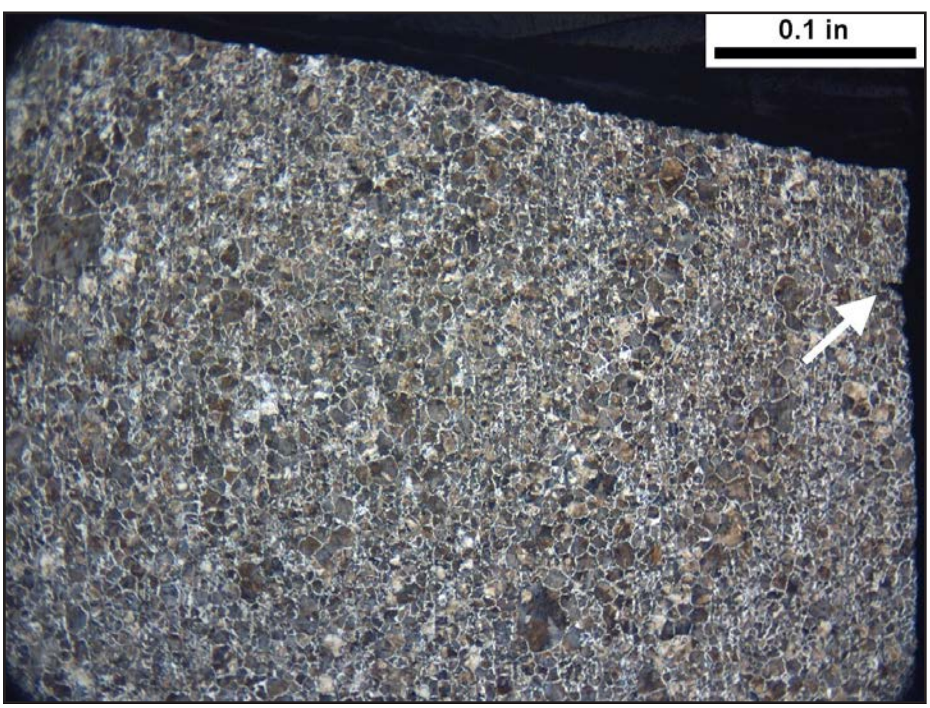


Figure 7 Section M — after etching. The fracture surface is at top portion of image. The microstructure consisted of pearlite and ferrite. The arrow indicates location of feature selected for closer inspection; 2% nital (OM 10×).

the part's performance. In this case the microstructure was judged to be normal for the material of manufacture, as shown in Figures 7 through 9. Some variation in the grain size was evident in the view. The grain structure was judged not to be a contributing factor in the failure of the part. A higher magnification view of the top right portion of Figure 7 is presented in Figure 8. A secondary crack, indicated by the white arrow, is at the right center portion of the image. The image was overexposed to show the gray scale that was present in the crack. A higher magnification view of the right center portion of Figure 8 is presented in Figure 9. The arrows indicate the presence of corrosion scale in the tip of the crack. The presence of corrosion scale in the tip of the crack is typical for corrosion fatigue related cracking. Corrosion fatigue can occur to a part due to a combination of cyclic stresses that exceed the fatigue strength of the part and corrosive attack that potentially initiates the cracking, but also accelerates the rate of cracking. Although some of the corrosion present on the part could have formed after the piece had failed, it was judged that corrosion fatigue was the mechanism of failure due to the presence of corrosion scale at the tip of the crack. The microstructure of the shaft otherwise consisted of pearlite and grain boundary ferrite, typical for plain carbon steel in the annealed or normalized condition.

After all the information is collected, a final conclusion can be made based on the evidence available. In this case, the following conclusions were determined:

- The fracture of the shaft was judged to be due to a combination of cyclic stresses that exceeded the fatigue strength of the part and corrosive attack that potentially initiated the cracking, but also accelerated the rate of cracking. This type of cracking is also known as corrosion fatigue. Although most of the original fracture features on the surface of the part were obliterated by corrosion damage, ratchet marks, indicative of intersecting crack planes and high stress concentration, were evident on the fracture surface. Ratchet marks are characteristic of fatigue-related cracking. Substantial corrosion products were present along the outer diameter of the shaft.
- Metallographic analysis of the shaft revealed the presence of a secondary crack near the fracture origin region. Corrosion scale was present at the tip of the crack. The presence of corrosion scale at the tip of a crack is commonly associated with corrosion fatigue. It was therefore judged that corrosion not only took place after the part fractured, but contributed to the progression of cracking. The microstructure otherwise consisted of pearlite and grain boundary ferrite, typical of plain carbon steel in the annealed or normalized condition.

Follow on activities, such as a stress analysis of the system, may be in order to help understand remedies to prevent failures from occurring again. Often, a stress analysis in the design of a system may not account for anomalous conditions such as corrosion pitting, non-uniform contact between the bearing and shaft, or mechanisms such as corrosion fatigue. In this case, a stress analysis was beyond the scope of the project. Sometimes, an investigation such as this may be performed in stages, or, budgetary restraints may prohibit certain types of testes and analyses from being performed.

The metallurgical failure analysis of a part can help determine conditions that contributed to failure that the design engineer might not have thought of in the design stages of the assembly. The failure analysis investigation or process can be thought of as a forensic puzzle. The more pieces of the puzzle are in place, the more conclusive the investigation will be. It is often tempting to ask the analyst to minimize the amount of testing performed to save time and money. It may also be tempting to withhold background information about the part for fear of biasing the analyst's final conclusion. It should be understood, however, that restricting the amount of testing and withholding important information will effectively take away pieces of the forensic puzzle that can prove critical to achieving the correct final conclusion. If the reasons for failure are not properly understood, corrective actions to prevent future failures may be ineffective. When the investigation is complete, it is often up to the parties involved to collectively determine the best course of corrective action to prevent similar events from occurring again. **PTE**

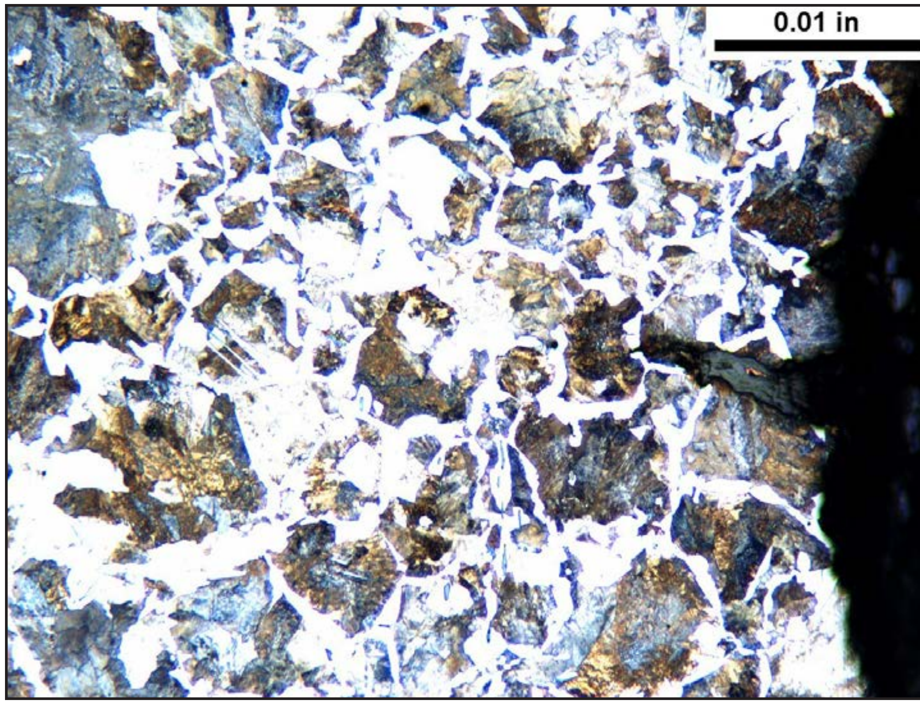


Figure 8 **Higher magnification view of the right-center portion of Figure 7, as indicated by the arrow in Figure 7. Secondary crack is evident at right portion of image. Image was overexposed to show crack, indicated by arrow; 2% nital (OM 100×).**

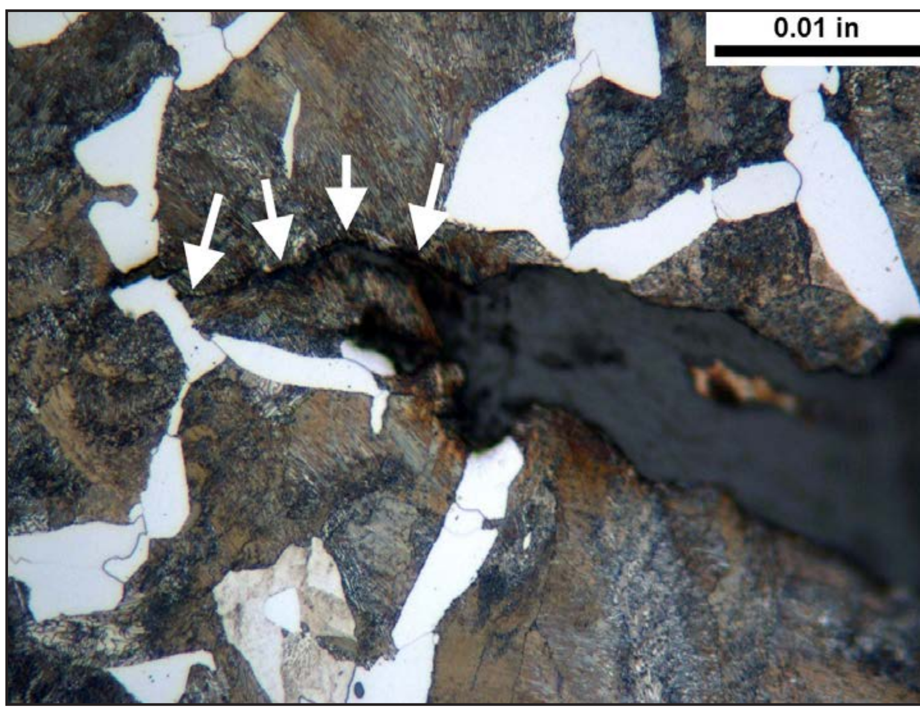


Figure 9 **A higher magnification view of the right-center portion of Figure 8. Arrows indicate the presence of corrosion scale in tip of crack; 2% nital (OM 500×)**

Craig J. Schroeder, P.E. is a senior metallurgist at Element Materials Technology in New Berlin, WI. He has a Masters of Science degree from the University of Wisconsin-Milwaukee, as well as extensive experience in the industrial and manufacturing sectors—including over fifteen years as a failure analyst. Through his failure investigations Schroeder has "CSId" a variety of components—gears, shafts and bearings among them.

Timken

MAKES VP APPOINTMENTS

The Timken Company has named **Andreas Roellgen** and **Brian J. Ruel** to the positions of vice president of sales. Ruel leads the company's selling team across the Americas, and Roellgen will oversee the Timken sales organization for the rest of the world. In addition, **Michael J. Connors** will lead the company's marketing organization as newly appointed vice president of global marketing.

Andreas Roellgen

Brian J. Ruel

"These appointments are part of the new organization we've put in place to increase speed to market and streamline decision making," said Christopher Coughlin, group president and executive vice president for Timken. "We expect to leverage the collective experience now captured with these bearing leadership appointments to improve both our focus and accountability with regards to driving profitable growth."

Michael J. Connors

Connors joined the company in 1983 as a manufacturing engineer and later assumed a series of management positions in manufacturing, product management, marketing and business development, including director of large-bore bearing manufacturing and vice president of manufacturing. In 2004, Connors was named vice president of industrial equipment and then president of Process Industries, focused on serving customers in heavy industry, power transmission and wind energy markets. Most recently, Connors was vice president of distribution. He received a bachelor's degree in mechanical engineering from Worcester Polytechnic Institute and a master's degree in business administration from the University of Hartford.

Roellgen joined the company in 1997 as a business development manager in the company's European headquarters in Colmar, France. In 2000, he transferred to the new business development team in Canton, Ohio. He returned to Europe in 2003 and held various positions including general manager of warehousing, logistics, replenishment and customer service, and was named director of supply chain Europe in 2007. In 2010, Roellgen was named managing director of Europe and, most recently, served as vice president of Process Industries and managing director of Europe. Roellgen earned master's degrees in mechanical engineering from Technical University of Munich, Germany, and in business administration from INSEAD in France.

Ruel joined the company in 1984 as a sales engineer, later assuming a series of automotive business leadership roles, including director of sales, director of new business development for the Asia Pacific region and director of quality and customer satisfaction. In 2010, Ruel was promoted to vice president of light vehicle systems and also served as vice president of rail. Most recently, he served as vice president of the company's Mobile Industries business. Ruel holds a bachelor's degree in mechanical engineering from the University of New Hampshire.

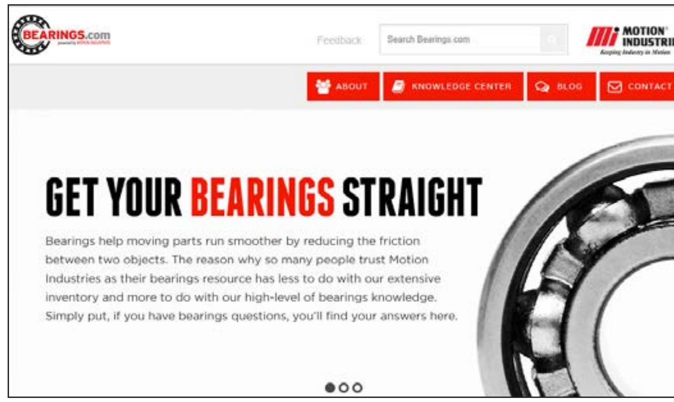
TB Wood's

PRODUCES COUPLING VIDEO SERIES

A series of informative TB Wood's coupling videos has been produced to clearly show the proper installation steps and maintenance tips for various coupling models such as TB Wood's Sure-Flex and Dura-Flex couplings. The short how-to videos can be viewed on the TB Wood's website at tbwoods.com or on Altra's YouTube channel at www.youtube.com/AltraMotion. TB Wood's, Inc. is a global leader in the design and manufacture of industrial couplings and belted drive solutions. Highly-engineered TB Wood's coupling products, including Sure-Flex and Dura-Flex elastomeric couplings, Form-Flex disc couplings, G-Flex grid couplings, Jaw couplings and bushings, represent the latest in coupling technology, featuring superior design and exceptional quality to ensure long-lasting performance. Reliable TB Wood's couplings are utilized in many key markets including food & beverage, energy, wastewater, concrete, metals, pulp & paper and material handling on applications such as conveyor systems, rolling mills, pumps, compressors, palletizers, debarkers, printing equipment, fans & blowers, machine tools and mixers.

Motion Industries

LAUNCHES BEARING KNOWLEDGE WEBSITE



Motion Industries recently announced the launch of its new knowledge website: *www.Bearings.com*. Designed as an information hub, *Bearings.com* offers valuable resources to professionals about the latest bearings-related news and applications. Site visitors have access to a wide array of content on the subject – including articles, videos, white papers, training materials and more.

"*Bearings.com* is a unique, intelligent online tool that provides loads of great information and resources," said Randy Breaux, Motion Industries' senior vice president of marketing, distribution and purchasing. "People know us for our large inventory, but there is a lot of knowledge behind the inventory. We wanted to bring this up front, and *Bearings.com* is one way to share useful information with those who can benefit from it."

Geared toward MRO and OEM professionals, the Bearings knowledge site houses content that can be beneficial to any operation such as how to recognize a counterfeit bearing and useful bearing how-to's with videos such as: "Bearing Mate" (large bearing installation), "Bearing Protection Rings" (ring installation) and "Speedi Sleeve" (avoiding unplanned downtime).In addition to being both desktop- and mobile-friendly, the website allows users to share articles that interest them with others across Facebook, Twitter and Pinterest.

AGMA

NAMES CROSON PRESIDENT

AGMA has named **Matthew E. Croson** as its next president. Croson has more than two decades of leadership and communications experience in manufacturing trade associations and most recently served as president and CEO of the Adhesive and Sealant Council. He will replace Joe T. Franklin, Jr., who is retiring in June after leading AGMA for 25 years.

AGMA was founded in 1916 by 19 manufacturers with a goal of helping improve the emerging gear market by developing technical standardization. Franklin stated, "Under Matthew Croson's leadership, the association will continue that same mission, helping nearly 500 members compete more effectively in today's global marketplace."

Prior to leading the Adhesive and Sealant Council, Croson held communications leadership positions at the Packaging Machinery Manufacturers Institute. He also worked at InteliData Technologies Corp. and Burson-Marsteller, where he specialized in relationship management and corporate communications.

"Matthew Croson's communications background and his experience bringing individuals, manufacturers and customers together will help AGMA meet the diverse needs of our members," said Dean Burrows, chairman of the AGMA board of directors. "We are confident he will lead the organization's wide range of high-quality programs and services, and will continue to grow membership and participation."

"I'm honored to help AGMA continue to grow and support its members and the gear industry as a whole," said Croson. "I will be working closely with Joe Franklin and the team in the coming months to ensure that the transition of leadership is as seamless as possible."

Croson is an elected member of the board of directors at the National Association of Manufacturers' Council of Manufacturing Associations and is a member of the American Society of Association Executives and the U.S. Chamber of Commerce. He has a bachelor's degree in English from George Mason University in Fairfax, Virginia.

The Search for AGMA's new president was conducted by Association Strategies, Inc., a nonprofit and association executive search firm, located in Alexandria, Virginia.

William Jandeska

RECOGNIZED FOR LIFETIME ACHIEVEMENTS IN POWDER METALLURGY

William F. Jandeska, Jr., FAPMI, president, Midwest Metallurgical, Ltd., and project manager for the Center for Powder Metallurgy Technology, has been selected to receive the Kempton H. Roll PM Lifetime Achievement Award by the Metal Powder Industries Federation. The award will be presented during the Industry Luncheon on Monday, June 6, during Powdermet 2016—the International Conference on Powder Metallurgy & Particulate Materials in Boston, Massachusetts, June 5–7, 2016.

Jandeska has distinguished himself as an expert in the field of powder metallurgy (PM) through developing innovative components and relationships between suppliers and vendors. He has promoted the continued growth of PM for more than 44 years through the joint involvement of part fabricators and the end-user community, which is evident by his support and leadership activity in MPIF, APMI, SAE, and ASM.

Beginning his career as an intern at U.S. Steel and Caterpillar Tractor, Jandeska worked while completing his BS, MS and Ph.D. from the University of Illinois. After completing his degrees in 1971, Jandeska joined General Motors Research Labs for a 20-year tenure, which included an appointment to assist the DoD National Technology Leader for GM with responsibility for high-performance magnetics, P/F connecting rods, main bearing caps and development of advanced gearing materials. In 1991, he joined GM Global Powertrain Group as manager for PM technology and lead subject matter expert for the PM creativity team, positions he held until his retirement in 2006.

Jandeska has received numerous awards, including the MPIF Distinguished Service to Powder Metallurgy Award and the MPIF Automotive Achievement Award. He also co-chaired both the 1989 Powder Metallurgy Conference & Exhibition and the 2002 World Congress on Powder Metallurgy & Particulate Materials, in addition to chairing the MPIF Technical Board from 1989 to 2003. Jandeska has conducted APMI International chapter presentations on technology, needs, and the direction of the automotive industry; authored numerous technical papers and presentations at MPIF/APMI annual conferences; and has held numerous seminars educating hundreds of GM personnel worldwide. Jandeska is an APMI International Fellow, ASM International Fellow, and received the SAE McFarland Award and the ASM Outstanding Young Member Award.

The Lifetime Achievement Award, named in honor of Kempton H. Roll, founding executive director of MPIF, was established in 2007 to recognize individuals who have devoted their careers and a lifetime of involvement in the field of PM. This will only be the third time the award has been given since its inception.

Baldor Electric's Becker

RECOGNIZED FOR EXCELLENCE IN MANUFACTURING

The Manufacturing Institute has announced they will present **Chelsea Becker** with the Women in Manufacturing STEP (Science, Technology, Engineering and Production) Ahead Award at an April 21 reception in Washington, D.C. The STEP Ahead Awards honor women who have demonstrated excellence and leadership in their careers and represent all levels of the manufacturing industry. Becker is a strategic project manager for Baldor Electric Company, a member of the ABB Group.

Becker is being recognized by the Manufacturing Institute as an emerging leader, women under the age of 30 who are currently employed in the manufacturing industry and have already made significant contributions early in their career. She joined Baldor in 2007 as a mechanical engineering intern while attending the University of Arkansas at Fort Smith (UAFS). During her career with Baldor, she has held positions of increasing responsibility including designer/drafter, packaging engineer and product engineering cost reduction project manager. Becker has a bachelor's degree in mechanical engineering from UAFS and a master's degree from Webster University.

"I am very thankful to be nominated for this award," said Becker. "I firmly believe that no matter the age or sex of a person, manufacturing is a very viable career choice, and I share my experiences with local students frequently to help them understand the variety of job options that are available. I appreciate the opportunities Baldor offers women in manufacturing, and I hope I can encourage more girls to enter the field."

Amy Lakin, executive vice president of supply chain, said, "I've really enjoyed watching Chelsea develop as she moved from a student to a full-time employee. She isn't afraid of hard work or new projects, and she balances them well with her home life. She has also been very active in our student outreach program, organizing plant tours and speaking at career fairs about the benefits of engineering and manufacturing careers."

Jennifer McNelly, executive director of the Manufacturing Institute, commented on this year's honorees. "These women are the faces of exciting careers in manufacturing. We chose to honor these women because they each made significant achievements in manufacturing through positive impact on their company and the industry as a whole."

Timken

AWARDS SCHOLARSHIPS TO 17 CHILDREN OF EMPLOYEES AROUND THE WORLD

The Timken Company recently awarded college scholarships to 17 sons and daughters of Timken associates in 12 locations around the world. Valued at up to $540,000 over four years, these scholarships are funded by The Timken Company Charitable and Educational Fund, Inc. The program has awarded more than $22 million in scholarships since its founding in 1958.

Chairman John M. Timken, Jr. hosted a recognition event at Timken World Headquarters in North Canton, Ohio, for students and their parents. Local scholarship finalists attended the event in person, while other finalists and their parents joined a global webcast.

"Each of these scholars has achieved significant academic success, participated in school and community activities, and demonstrated leadership ability," said Timken. "The Timken Scholarship program enables these accomplished young people to explore new opportunities and gain the knowledge they need to make a powerful and positive difference in the world."

John M. Timken Jr., chairman of the Timken board of directors, with scholarship winners from Ohio. Other winners are from U.S. locations (3), India (3), China (2), France (1), Romania (1), Canada (1) and Poland (1).

The $35,000 Henry Timken Scholar Award recognizes the top-ranked applicant and is renewable for up to three additional years for a total of $140,000. This year's Henry Timken Scholar is Sidney Long, the daughter of Michael Long, a machine operator in cone manufacturing at the Bucyrus Bearing Plant in Ohio. Sidney, a senior at Buckeye Central High School in New Washington, Ohio, plans to study pre-veterinary medicine at The Ohio State University.

The $25,000 Jack Timken Scholar Award was presented to Simona Prasad, the daughter of Ram Narayan Prasad, lead production operator technician in the company's bearing plant in Jamshedpur, India. The award is renewable for up to three additional years for a total of $100,000. After graduating from Loyola School in Jamshedpur, India, Simona plans to study design and architecture at the Indian Institute of Technology Bombay in Mumbai.

Five students received $10,000 scholarships, renewable for up to three additional years, for a total value of $40,000 each including Sayan Das, Sean Gu, Victoria Mangano, Indranil Pal and Mihnea Vladimir Savu.

In addition, 10 individuals received $10,000 scholarships including Joanne Ash, Jenna Berg, Bryndalyn Corey, Willis Elkins, Yuchen Huang, Nicole Johnson, Victoria Johnson, Laura LaPlant, Larissa Waldorff and Ziyang Wang.

Ametek

PROMOTES MALONE TO REGIONAL SALES MANAGER

Ametek Solidstate Controls (SCI), a leader in highly customized uninterruptible power supplies (UPS), has promoted **Daryl Malone,** a 20-year industrial electronics industry veteran, to regional sales manager. Malone now oversees activity in the western region of the United States, including new equipment sales, representative recruiting and client account development, according to John Ely, marketing manager for SCI. Malone has spent this entire career with Ametek and held various positions over the years; he most recently was in applications engineering, prior to his promotion being promoted to regional sales manager.

Gear Motions

NAMES NEW VICE PRESIDENT

Gear Motions, a leading precision gear manufacturer, has named **Paul Andruszko** vice president of its Buffalo, New York, operations, which includes its Oliver/Pro-Gear and Niagara Gear divisions. Andruszko has more than three decades of experience in the gear industry and most recently served as general manager of the company's Niagara Gear division. He replaces Michael Barron, who retired in December after leading Oliver/Pro-Gear for more than 20 years. Oliver/Pro-Gear creates custom gears for all types of equipment, including elevators, ski lifts and petroleum exploration, production and refining equipment, in low to moderate volumes. Niagara Gear manufactures precision ground spur, helical and pump gears for a large and diverse global customer base.

"Gear Motions is committed to delivering products that meet world-class specifications for quality, safety and efficiency, and exceeding our customers' expectations," said Barron. "I'm confident our customers can expect the same level of quality and attention to detail will continue and flourish under Paul Andruszko's leadership. He has the talent, knowledge and hands-on experience in gear design to lead Oliver/Pro-Gear and Niagara Gear into the future."

"Mike Barron and I worked closely together so that the transition of leadership is as smooth and seamless as possible," Andruszko said. "Our Buffalo divisions will continue to provide extraordinary service to our existing customers while helping new clients design gears that will make their operations smoother and more efficient."

Andruszko joined Gear Motions in 1988 as a manufacturing engineer in the company's Niagara Gear division. He has since held numerous positions within the company, including operations and engineering manager. Prior to joining Gear Motions, he gained engineering experience at Pratt and Whitney Aircraft, a division of United Technologies that designs, manufactures and services aircraft engines and auxiliary power units. He has a bachelor's degree in mechanical engineering from the University of Hartford in West Hartford, Connecticut.

Hydraulic Institute

PRESENTS LIFETIME ACHIEVEMENT AWARD

The Hydraulic Institute (HI) recognized and honored Jack Claxton, vice president, engineering, Patterson Pump Company, as its Lifetime Achievement Award recipient. The award was recently presented to Claxton during HI's 2016 Annual conference in Tucson, Arizona.

Claxton has more than 40 years of service in the pump industry and has been an instrumental HI member for more than 30 years. He is one of HI's most well respected members and has previously received HI's "Member of the Year" award. He has been a pioneer within HI technical affairs, lending countless hours to the betterment of the industry by chairing the inaugural versions of several very important American National Standards.

Committees that have benefitted from Claxton's leadership and active involvement include the Standards Committee, Technical Affairs Steering Committee, Rotodynamic Pump Group, HI International Standards Technical Liaison, Delegate of the International Pumps Standardization Committee, ANSI/HI 9.8 Pump Intake Design (Chairman 1994 - Present), ANSI/HI 9.6.4 Vibration Allowable Levels (Chairman 1995 - 2012) and ANSI/HI 9.6.8 Dynamics of pumping machinery (Chairman 2005 - Present).

Claxton is also very active in the international standards community. He served as a member of the U.S. Technical Advisory Group to ISO Technical Committee 115 for 19 years and chaired the committee for 11 years, and has served as the U.S. expert to JWG 9 for ISO 10816-7 Pump Vibration, U.S. expert to ISO TC 115 WG 7 for ISO 14414 Pump System Energy Assessment, U.S. expert to ISO TC115 SC 2 WG 4 for ISO 19688 Model Testing of Pumps and is currently the Chairman of Sub-committee 3 of ISO Technical Committee 115.

McInnes Rolled Rings

COMPLETES HEAT TREAT EXPANSION

McInnes Rolled Rings has completed an $8 million, 25,000-square-foot expansion to its current manufacturing facility. The addition expands its present heat treat size capabilities by providing the ability to quench and temper forgings up to 144 inches in diameter. With separate high agitation water and polymer quench tanks, this new state-of-the-art bay will significantly expand the daily tonnage capacity to ensure the fastest delivery times available in the industry.

McInnes contracted with Can-Eng Furnaces Intl. Ltd. to design and install the most advanced technology to process large diameter product. The furnace and quench tank designs are augmented by a customized material handling system by Dango and Dienthal Hollerbach GmbH capable of processing loads up to 25 tons. The system's fast transfer from furnace to quench tank provides optimal and repeatable process controls.

"This new bay nearly doubles our quenched and tempered offerings to the power transmission industry and adds the ability to solution anneal large diameter stainless steel rings. Also, the addition of water quenching improves our ability to meet the high property demands of the custom flange markets," said Shawn O'Brien, vice president, sales and marketing. The expanded heat treat operation officially began service on March 1, 2016.

Plan Accordingly

Three upcoming shows cater to different areas of power transmission components and motion control technologies, including Windpower 2016, Powdermet 2016 and the Sensors Expo & Conference. All three exhibitions will offer the latest products, solutions and latest real world applications dedicated to wind energy, powder metal technologies and sensors. Here's a quick rundown:

Windpower 2016 takes place May 23-26 in New Orleans.

Windpower 2016

General Information: Windpower 2016 takes place May 23-26 in New Orleans, Louisiana at the Ernest N. Morial Convention Center. This exhibition brings together innovators, thought leaders and policy makers to chart wind energy's course for the future.

Schedule at a Glance: Technical sessions include "Wind 201: Wind Development for Pros," "U.S. Offshore Wind Energy," "U.S. Wind Energy Market Forecasts," "Slipping Down the Cost Curve," "Advances and Innovations in Interconnection Strategies for Wind Farms" and more.

Don't Miss: More than 100 presentations and sessions are categorized into five main groups in order to easily identify the areas of wind power attendees are most interested in. These groups include:

Power Station

Gain a better understanding of how leading wind energy experts are pushing global wind development into the future as they explain new commercial opportunities, market expansion, and what lessons may be learned and applied.

Tech Station

Hear from the very best minds in business, academia, and government to advance innovations in wind technologies that could fundamentally change the industry.

Operations Station

Analyze the right management strategies to address the operational life-cycle issues that challenge owners and operators, now and down the line.

Project Development Station

Discover an exchange of ideas and insights, and cover every key topic on developing a wind project from siting, wildlife to transmission, integration, and forecasting.

Thought Leader Theater

Defining the future of wind with more than 14 hours of forward-looking, thought-provoking content.

Social Events: AWEA Opening Recption takes place Monday, May 23 and is open to all registrants. This will take place at Generations Hall, a few blocks away from the conventional center, and allows attendees to connect with colleagues and friends and meet new contacts while enjoying local musicians.

The Wind Energy Foundation (WEF) fundraiser takes place Wednesday May 25 and allows attendees to experience a taste of Creole and funky New Orleans jazz on an authentic steamboat on the Mississippi River. A ticket for this event includes a one hour private cruise, steam engine room visitation, great live music and local food and beverages.

Added Value: Keynote Speaker Steve Farber, author of *The Radical Leap*, will share deeply thought-provoking and eminently practical leadership techniques and tips. Whatever the audience, his voice is always humorous, poignant and original. No matter what is challenging an organization—improving customer service, coping with change, inspiring transformation, improving corporate culture, recruiting and retaining great talent, building teamwork, fostering innovation—it all comes down to leadership.

For more information:
AWEA
Phone: (202) 383-2500
www.windpowerexpo.org

Powdermet 2016

General Information: The 2016 International Conference on Powder Metallurgy and Particulate Materials takes place at the Sheraton Boston June 5-8 in Boston, Massachusetts.

Schedule at a Glance: Technical sessions include "Advancements in Component Forming and Characterization," "Powder Production," "Ceramics," "Lightweight Materials," "Sintering" and more. In addition to the regular technical sessions, several special interest programs are offered, including "Lean Alloys," "Tungsten-Based Materials" and "Atomization for Powder Production and Spray Deposition."

Don't Miss: The PM Design Excellence Awards Luncheon is scheduled for Tuesday, June 7. This annual luncheon will highlight winners from the 2016 PM Design Excellence Awards Competition sponsored by MPIF. (Please note that attendance is restricted to full-conference delegates and other registration requirements). Winners in 2015 included Advanced Materials Technologies, FMS Corporation, Keystone Powdered Metal Company, Allied Sinterings, Inc. and others.

Social Events: The John F. Kennedy Presidential Library and Museum is one of 13 presidential libraries administered by the National Archives and Records Administration. The museum will open for attendees to discover the life, leadership and legacy of one of the most famous presidents. After exploring the museum, attendees will enjoy a traditional Boston dinner overlooking the Boston Harbor.

The 11th Annual APMI International Golf Tournament takes place June 5 at Pinecrest Golf Club, opened in 1955 in Holliston, Massachusetts. The course measures over 4,900 yards and is a playable track for golfers of all abilities.

Added Value: Powdermet 2016 is being held in conjunction with the Additive Manufacturing with Powder Metallurgy (AMPM2016) Conference. All of the technical sessions, special events and exhibition will be open to all Powdermet 2016 delegates.

For more information:
Powdermet 2016
Phone: (609) 452-7700 Ext: 114
www.powdermet2016.org

Sensors Expo & Conference 2016

General Information: Sensors Expo 2016 takes place June 22-23 at the McEnery Convention Center in San Jose, California.

Schedule at a Glance: Technical sessions include "Embedded Vision: The Ultimate Software-Defined Sensor," "Building Success in the Internet of Things," "Sensor Subsystems for Vital Parameter Monitoring," "3D Robots," "Trends in Telematics," "Cloud-Based Data Analytics Using Next-Generation Medical Sensors," "Printed, Flexible Stretchable Sensors for Wearables, IoT and Other High Volume Applications" and more.

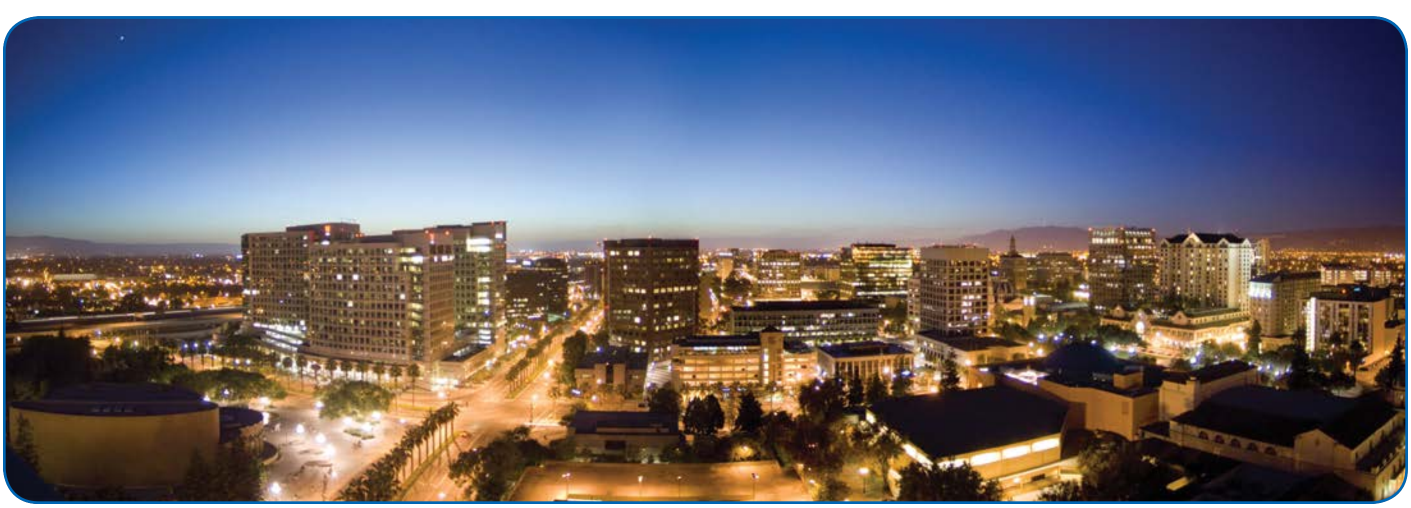
Don't Miss: New this year, the Expo will feature an expanded two-day IoT track, expanded flexibles and wearables track, sensors and embedded systems design track, embedded security pre-conference symposia, flexible and wearables pre-conference symposia, hands-on workshops, university and non-profit program and a startup venture forum and pavilion.

Social Events: The Engineering Excellence Awards Ceremony and the Best of Sensors Expo Awards Ceremony.

Added Value: Can't make the Expo in June? Sensors Midwest will be co-located with SMTA International, the industry's top conference on electronics assembly and advanced packaging for a two-day sensors event featuring education, networking and the latest sensor technologies. Sensors Midwest takes place September 27-28 at the Donald E. Stephens Convention Center in Rosemont, Illinois.

For more information:
Questex LLC
Phone: (617) 219-8300
www.sensorsexpo.com

Have an event our *PTE* readers might be interested in? Our Events section includes basic information about upcoming seminars, trade shows and conferences. Please send information and high-res photos (300 dpi) to Matthew Jaster, senior editor, at *mjaster@powertransmission.com*. **PTE**



May 2-5–2016 Offshore Technology Conference Houston, Texas. OTC gives attendees access to leading-edge technical information, the industry's largest equipment exhibition and valuable new professional contacts from around the world. Its large international participation provides excellent opportunities for global sharing of technology, expertise, products, and best practices. OTC brings together industry leaders, investors, buyers, and entrepreneurs to develop markets and business partnerships. The event includes a technical program, R&D topics, OTC training courses and an awards luncheon. For more information, visit *2016.otcnet.org*.

May 3-5–Gearbox System Design: The Rest of the Story Sheraton Sand Key Resort, Clearwater Beach, Florida. This course focuses on the supporting elements of a gearbox that allow gears and bearings to do their jobs most efficiently. Learn about seals, lubrication, lubricants, housings, breathers and other details that go into designing gearbox systems. Sponsored by AGMA, this course is taught by Raymond J. Drago, chief engineer, and Steve Cymbala, senior drives engineer, at Drive Systems Technology, Inc. This seminar will start with the basics and then focus on the pros and cons of types of housing construction, housing elements, bearing mounting, selection and role of gearbox accessories, appropriate lubricant selection and more. AGMA members ($1,895) and non-members ($2,395). For additional information, visit *www.agma.org*.

May 12-14–2016 AGMA & ABMA Annual Meeting Omni Amelia Island Plantation Resort, Amelia Island, Florida. Highlights for the 2016 AGMA & ABMA Annual Meeting include a diverse lineup of speakers and presenters, the return of the popular AGMA/ABMA golf tournament (a scramble at the Amelia Island Omni Ocean Links Golf Course that winds along the coastal Atlantic Ocean), a formal Centennial Dinner, First Timer's Luncheon and special AGMA and ABMA dinners for its members. The whole meeting community will group together for a historic photo on Thursday afternoon. Additionally, retired members are welcome back to the meeting, so please contact the AGMA or ABMA if you know any fully retired gear or bearing executives that need an invitation. Resort service fee includes complimentary self-parking, unlimited deluxe internet access, on-property resort transportation services, unlimited use of health and fitness center, in-room coffee service, local and toll free phone access, and resort beach access. For more information, visit *www.agma.org*.

May 16-19–AISTech 2016 David L. Lawrence Convention Center, Pittsburgh, Pennsylvania. The Association for Iron and Steel Technology (AIST) exhibition and conference will feature technologies from all over the world that help steel producers compete more effectively in today's global market. The event will provide perspective on the technology and engineering expertise necessary to power a sustainable steel industry. Technical sessions will include safety, ironmaking, hot sheet rolling, specialty alloy and foundry, electric steelmaking, galvanizing, rod and bar rolling and more. In addition to the 550+ technical presentations, conference registrants are encouraged to attend the AIST Foundation Golf Classic on Sunday as well as the opening plenary sessions, the President's Award Breakfast and the Industry Leader Town Hall Forum. For more information, visit *www.aist.org*.

May 17-19–Advanced Gear Design and Theory University of Wisconsin-Milwaukee, School of Continuing Education. Explore manufacturing methods and considerations, inspection and quality control, materials and heat treatment, drawing data requirements, specifications, basics of load capacity rating and lubrication types and methods. With a strong emphasis on the proper selection, design application and use, rather than fabrication, designers, users and beginning gear technologists can all benefit from the curriculum. Fee is $1,095 by Thursday March 17th and $1,195 after March 17th. The class is taught by Raymond Drago, chief engineer for Drive Systems Technology, Inc. Enrollment is limited, please visit the website below for additional information. For more information, visit *http://uwm.edu/sce/courses/advanced-gear-design-and-theory*.

May 30-June 3–IFAT 2016 Munich, Germany. The international trade fair for environmental technology offers a global innovation platform and meeting place for those involved in water, sewage, waste and raw materials management. In 50 years, visitor numbers have increased from a starting figure of 7,000 to over 135,000 today. More than 3,000 exhibitors from across the globe cover the full range of professions under the heading: Resources, Innovations and Solutions. Key topics include sustainability, recycling and water and sewage technologies. IFAT's mission to offer companies a profitable, international and global network is also reflected in the continuous growth in the number of events taking place abroad, such as IE Expo, IFAT India, IFAT Eurasia, and IFAT Environmental Technology Forum Africa. For more information, visit *www.ifat.de*.

June 9-10–PTDA 2016 Canadian Conference Westin, Ottawa, Ontario. For the 15 year, key decision makers of the Canadian power transmission/motion control (PT/MC) industry gather for business networking, education, a manufacturer industry showcase and more. The PTDA Canadian Conference starts with an optional golf outing and an Industry Showcase Welcome Reception featuring tabletop exhibits from every registered PTDA manufacturer member company. For the second year, meeting rooms can be reserved for one-on-one meetings. Participants will hear information targeted to solve the most vexing needs of the industry, including information on corporate culture, hiring, knowledge transfer and an update on the Canadian mining industry. For more information, visit *www.ptda.org*.

June 13-17–Turbo Expo 2016 COEX Convention & Exhibition Center, Seoul, South Korea. This international expo for turbomachinery professionals brings together the best and brightest experts from around the world to share the latest in turbine technology, research, development and application in the following topic areas: industrial gas turbines and aircraft engines, steam power plants, wind turbines, fans and blowers, organic Rankine cycle and supercritical CO_2 cycle power systems. Turbo Expo offers networking opportunities with a dedicated and diverse trade show floor. The three-day exhibition (June 14-16) attracts the industry's leading professionals and key decision makers, whose innovation and expertise are helping to shape the future of the turbomachinery industry and will feature a student poster session. For more information, visit *www.asme.org*.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Automatic for the People

Matthew Jaster, Senior Editor

The world is full-on automated. From our factories to our vehicles to our leisurely activities, the future is now and it's nothing but algorithms, robotics and hands-free operation. It comes as no surprise that a 2016 Google search brings a fair amount of technology gone awry. The following examples don't scare us (they're actually quite fascinating) but they probably should worry us a little bit…

Pavement power

Former U.S. Army Captain Jeremy McCool finished his graduate degree in urban policy and sustainability at Columbia University and hasn't looked back. He formed his company Hybrid & Electric Vehicle Optimization (HEVO) Inc. in November 2011 to create a wireless charging network for electric vehicles (EVs). This charging method could potentially provide a safe, fast and cost effective method of charging EVs that eliminates the hazards and inconveniences associated with plug-in charging. The mission is to create a charging network embedded in the road that can power vehicles while they're driving.

Imagine a soft drink delivery truck making frequent stops to grocery stores in New York or San Francisco. What if every time the driver stopped to make a delivery, a sensor in the road could recharge the vehicle using a principle called resonant magnetic induction? HEVO is rumored to be working on these concepts with some of the higher profile EV manufacturers. If everything goes according to plan, we may someday live in a world where smaller, lighter batteries for EVs can be powered during a routine traffic stop (*www.hevo.com*)

Getting a grip

It's amazing enough the tasks that robots today can complete with simple programming. The four fingers of the LearningGripper from Festo Robotics are driven by 12 pneumatic bellows acutators. Based on a trial and error principle, the gripper assigns itself the task of gripping an object and carrying out a variety of complex tasks. The idea is that the system will be able to execute these tasks independently without time-consuming programming. It's a robot that essentially behaves like a newborn baby, gradually getting better and better in order to perform intricate motion sequences.

The factory of the future, for example, can incorporate self-learning systems into future production lines and optimize their own performance characteristics autonomously. Recent trade fair demonstrations as well as a Robotics Exhibition at the Museum of Science and Industry in Chicago highlighted the Festo LearningGripper demonstrating how the robot can learn a complicated mechanical motion strategy in less than an hour (*www.festo.com*).

But can you send it back if the order is wrong?

Is this the future of casual dining? Here at the Rollercoaster Restaurant in Vienna, Austria, (tentatively opening April 2016) patrons will witness two robots sending food and beverages along an intricate track system toward guests. These robots, located under the ceiling at a dispatch area, can mix and shake cocktails for patrons or perform a variety of other intricate programmable tasks. Is it fun? Is it necessary? Is it slightly gimmicky? Who cares when you're watching your alcoholic beverage of choice zip around a track system before being dropped off right at your table! Heinemack GmbH, creator of the rollercoaster system, has similar restaurants in Germany, Kuwait, Sochi, Abu Dhabi and more to come in the foreseeable future (*www.rollercoasterrestaurant.com*).

Have any stories or anecdotes about automation, motion control and robotics? It could potentially be featured in an upcoming issue, contact Matthew Jaster at *mjaster@powertransmission.com* with all the details. **PTE**

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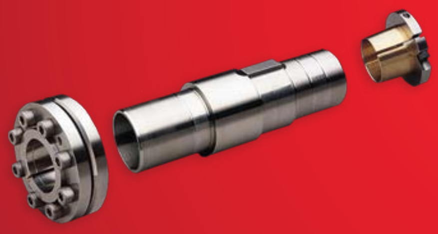
Disassembly



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