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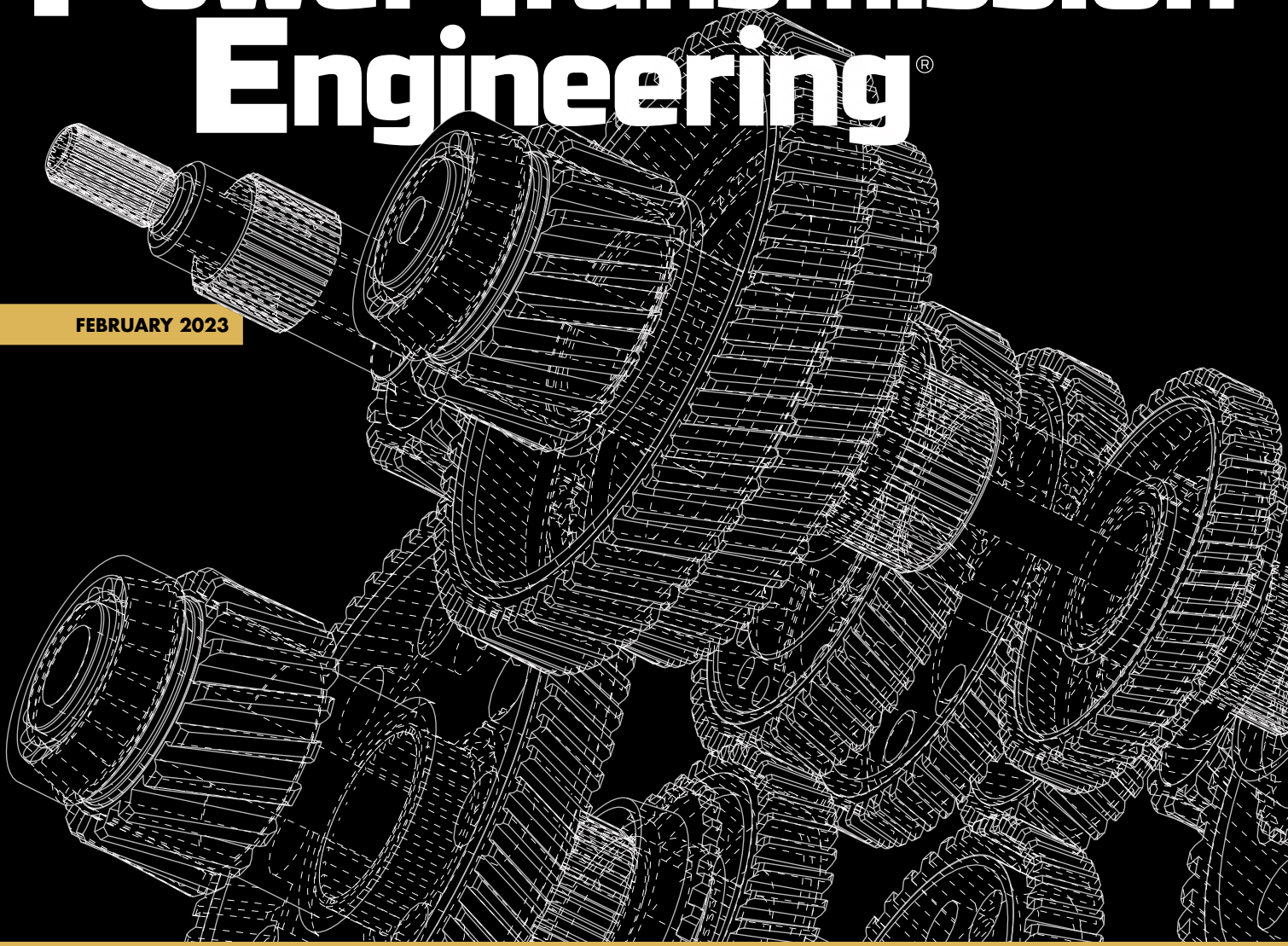

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RYAN MILLER,
Owner and Engineer Manager
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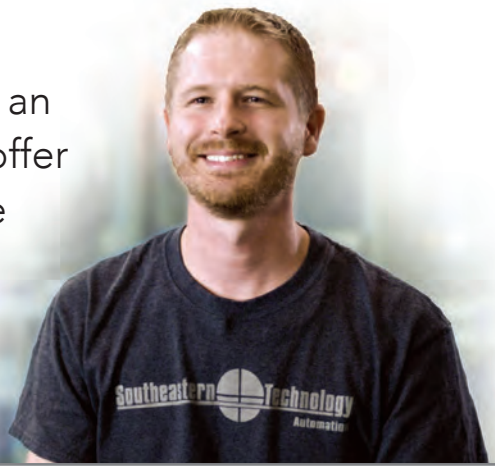
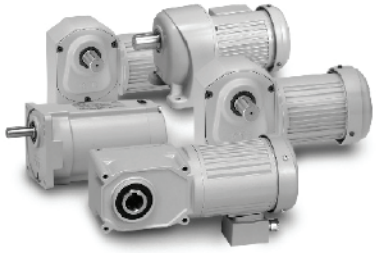


Brother leads the way, by shielding its entire line of standard gearmotors with the industry's best warranty. No matter how far the journey or how rough the path, rest assured you've got the protection you need right "at your side."



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TECHNICAL ARTICLES

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Vol. 17, No. 1. POWER TRANSMISSION ENGINEERING (ISSN 2331-2483) is published monthly except in January, May, July and November by The American Gear Manufacturers Association, 1840 Jarvis Ave., Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00. U.S. Periodicals Postage Paid at Elk Grove Village IL and at additional mailing offices.

Power Transmission Engineering

VOL. 17, NO. 1

DODGE

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Power Transmission Engineering

PTE Videos

Cam Roller Technology with PBC Linear

Learn about the full range of Cam Roller Technology solutions for linear motion applications available from PBC Linear. This video will introduce you to component solutions such as the hardened crown roller or V-Guide bearings ... to high precision guide rails and adjustable sliders such as the Redi-Rail family ... and finally to the heavy-duty, high load capacity Hevi-Rail series.

powertransmission.com/media/videos/play/231

FVA Simulation Hub

In today's transmission development, it is no longer sufficient to carry out a design only on the basis of a standardized load capacity calculation. In terms of competitiveness, but also in the context of environmental issues and climate change, highly efficient gears are in demand.

powertransmission.com/media/videos/play/229

PTE Revolutions

Bearing Reinvention with Schaeffler

Schaeffler has a rich history with bearings, according to Jitesh Modi, director of engineering. So much so that as transmission and e-mobility technology advances, the company evolves simultaneously. Today, development in battery electric vehicle (BEV) powertrains is focusing on increasing vehicle range and decreasing charging times.

powertransmission.com/blogs/1-revolutions/post/8994-bearing-reinvention-with-schaeffler

AGMA MEDIA
1840 Jarvis Avenue
Elk Grove Village, IL 60007
Phone: (847) 437-6604
Fax: (847) 437-6618

EDITORIAL
Publisher & Editor-in-Chief
Randy Stott
stott@agma.org

Senior Editor
Matthew Jaster
jaster@agma.org

Senior Editor
Aaron Fagan
fagan@agma.org

GRAPHIC DESIGN
Graphic Designer
Jess Oglesby
oglesby@agma.org

ADVERTISING
Advertising Sales Manager & Associate Publisher
Dave Friedman
friedman@agma.org

Materials Coordinator
Dorothy Fiandaca
fiandaca@agma.org

CIRCULATION
Circulation Manager
Carol Tratar
tratar@agma.org

MANAGEMENT
President
Matthew Croson
croson@agma.org

FOUNDER
Michael Goldstein founded *Gear Technology* in 1984 and *Power Transmission Engineering* in 2007, and he served as Publisher and Editor-in-Chief from 1984 through 2019. Michael continues working with both magazines in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

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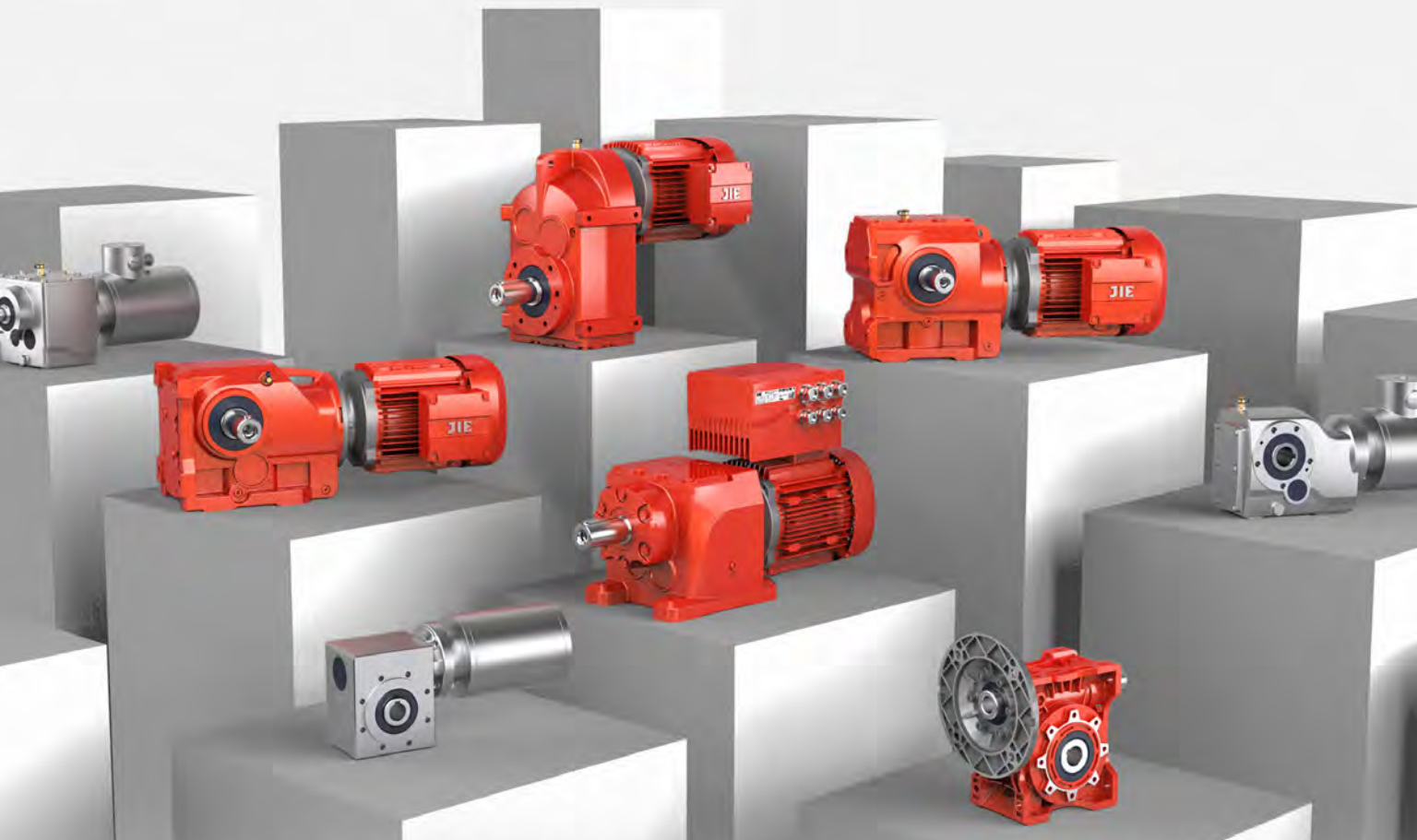

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Randy Stott
Publisher & Editor-in-Chief

THIS IS THE WAY

If you've watched any of the Star Wars/Disney+ series *The Mandalorian*, you've no doubt become familiar with the catchphrase "This is the Way," often uttered by the main character and others who come from his home planet.

In the series, the Mandalorians are the last of a dying breed, nearly wiped out by the evil Empire. They struggle to maintain their identity by keeping to the old ways, despite the fact that many of those ways seem archaic.

As the publisher of magazines that are printed and mailed to subscribers, sometimes I feel like a Mandalorian—struggling to maintain the old ways in times of overwhelming change.

People have been claiming that "Print is Dead" since long before I came into this business. That phrase has been part of the public lexicon since before the Internet became widely used. In fact, it was uttered quite famously by the character Egon Spengler, played by the late Harold Ramis, in the movie *Ghostbusters*, released way back in 1984. Janine, the secretary, is sitting at her desk reading a magazine and comments on how much she likes to read. Egon responds, completely deadpan, "Print is dead." But Egon had it wrong back then, and he'd still be wrong today.

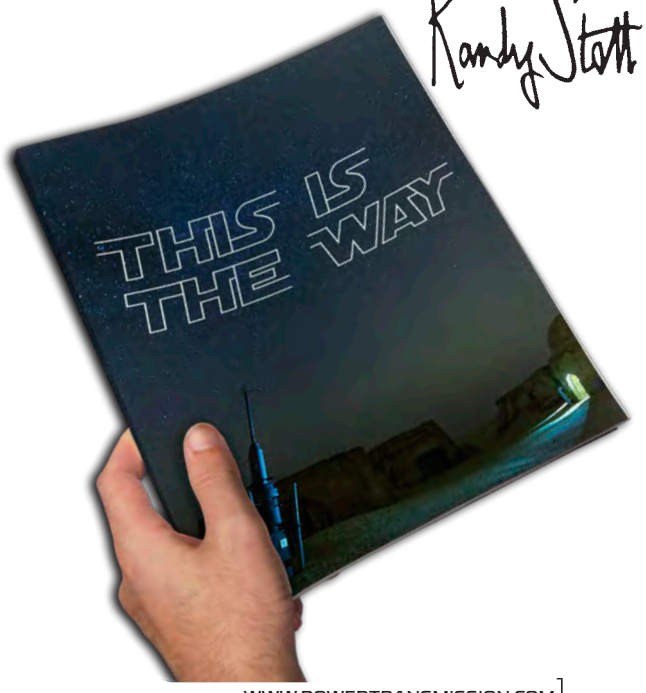
Sure, there's been a significant shift toward digital publishing. And make no mistake, we've embraced that change. We offer a wide variety of digital content—including the complete magazine, newsletters, videos, webinars, social media and so on. We strive to deliver quality content no matter the format. There are, after all, a lot of things you just can't do in print. Digital media, for example, are fantastic for engaging with people. But print, on the other hand, is fantastic for engaging with the content. With print, there's less distraction, better concentration and a physical and visual experience that's impossible with digital. A magazine in your hands provides a sense of quality, permanence and trustworthiness that you don't get when you're scrolling along on your phone.

Print is very much alive.

And it's not just me being some old dinosaur clinging to the old ways. You don't have to take my word for it. In fact, you can take your own. When you subscribe to the magazine, you, the readers have the option of choosing how you receive the magazine: print, digital or both. Our most recent data shows that two-thirds of you still request the printed version, and we're happy to keep delivering it.

So keep picking up your printed copy. Spend some undistracted time with it. Read the in-depth, comprehensive technical articles and think about their implications. Flip through the pages and notice the advertising. We're going to keep doing our best to make it the rich and rewarding experience you expect.

Randy Stott



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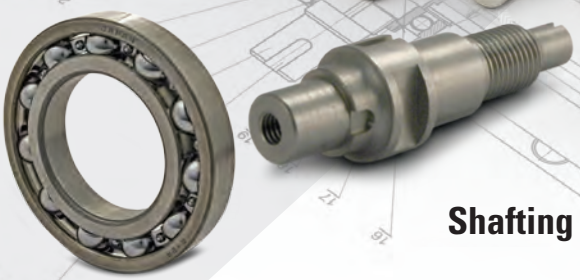

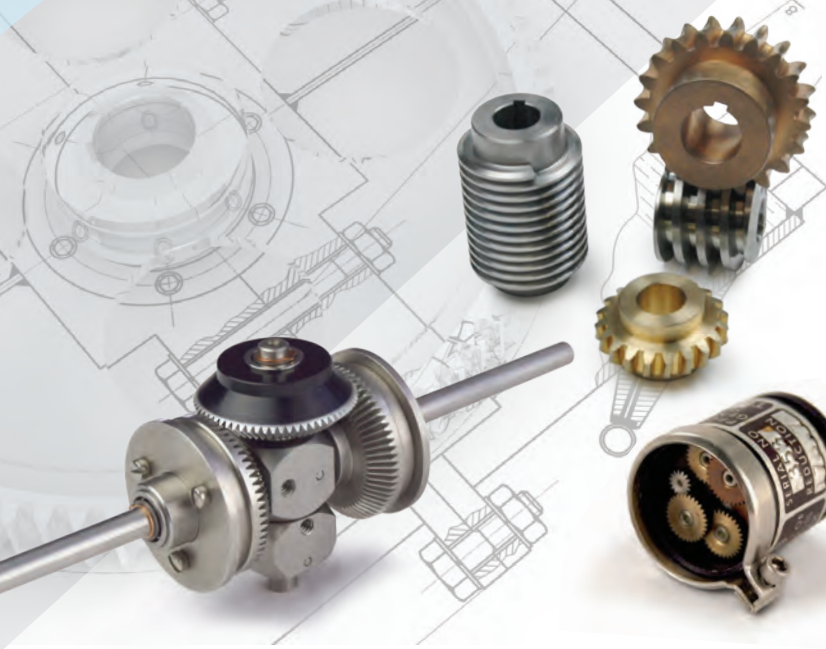

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ZF
DEVELOPS NEW E-DRIVE TECHNOLOGIES

ZF presents the latest generation of electric drives for passenger cars and light commercial vehicles. It sets standards through outstanding power density and energy efficiency. ZF achieves this thanks to numerous innovations at both the component and system level. These include the compact design of the drives, the "discrete approach" in power electronics, and a resource-saving use of materials, which also makes the production of the drives more sustainable. With their modular concept, the new ZF e-drives support automotive manufacturers in customizing the further electrification of their entire model range. For end customers, the new technologies offer higher efficiency, more power, and shorter charging times.

ZF develops and produces technologies for the mobility of the future. Two million e-motors produced and the high-voltage vehicle electric system with 800-volt technology show ZF is setting the pace in the dynamic electromobility market.

System approach anticipates market requirements

ZF is already developing its comprehensive product range for pure e-drives with a view to the functions desired by customers and end users. To better meet the highly diversified market demand, the Group is now presenting a new generation of electric drives based on a modular overall concept with electric motor, inverter, transmission, and software.

"We are focusing on three basic systems that meet our customers' main requirements, namely efficiency, performance and cost, even in the standard version," said Markus Schwabe, product line manager, electrified powertrain systems. "On this basis, we can optimally implement further individual customer requirements in e-vehicles of all segments."

"The great interest of manufacturers in our products in both the passenger car and commercial vehicle sectors is confirmed by our high order backlog in the high-voltage business. With the next generation of electric drives, we are consistently continuing our strategy of developing sustainable and efficient mobility for the future," said ZF Board of Management member Stephan von Schuckmann, who is responsible for e-mobility within the Group.

Innovative strength in the system as well as in the components

With the new generation of e-drives, ZF provides fully integrated electric drive systems. With its high level of interface expertise and unique know-how for driving strategies, ZF application engineers can meet customer requirements fully in the best possible way. However, the Group will also offer the innovative components individually, on which its own system solution is based. "Thanks to sophisticated internal interfaces, the new, extremely compact design allows system or component adaptations to be made with little effort. In addition, the design has very high structural rigidity, which enables superior noise behavior," said Dr. Otmar Scharrer, head of development for electric drive technologies.

The new generation of ZF e-drives will be available on the market as a complete system starting in 2025; ZF will bring individual components into series production earlier. The following innovations at component level make their contribution to the advanced overall system:

With "discrete package technology," power electronics manage the balancing act between a high degree of component uniformity and high adaptability. The individualization takes place at the chip level: A discretely structured ZF inverter is built with individual power semiconductor switches. This modularity offers better performance scalability than is possible with complex power modules. In addition, ZF's "discrete package technology" requires fewer types of components than using conventional power modules. "With our new approach to power electronics, we can serve different market requirements faster and more precisely," Scharrer said.

With a new, highly integrated e-motor, ZF once again increases the power density compared to the technology currently available in the market. A new cooling concept and a new winding technology play the decisive role here. Thanks to the new cooling concept, ZF allows oil to flow directly around the copper rods—exactly at the point where most heat is generated during operation. Such highly efficient cooling significantly increases performance with the same weight and installation space. The continuous power of the electric motor is increased to up to 85 percent of the peak power. In addition, the use of heavy rare earths can be largely dispensed with, and the e-motor can thus be produced more sustainably. The braided winding technology developed by ZF, a further development of the hairpin winding, enables a total of 10 percent less installation space. The winding head alone is around 50 percent smaller than with conventional approaches. This means that around 10 percent less raw material is processed.

With its new coaxial reduction gearbox, ZF transfers its know-how in planetary gearboxes to the next generation of electric drives. Two integrated planetary gears not only generate the desired axle ratio, but also include the fully integrated differential function. Compared to common offset concepts, the new solution reduces weight and installation space requirements without compromising efficiency, noise, and vibration.

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High-voltage converters (DC-DC converters) play a central role in fuel cell-powered electric drives. They compensate for the low output voltage and the strong voltage drop at high load of the fuel cells. The new high-voltage converter from the ZF power electronics platform, which was developed for passenger car and commercial vehicle applications, has a top value of 99.6 percent in terms of efficiency.

zf.com

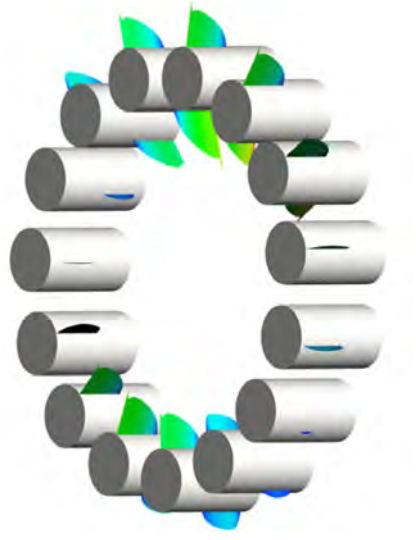
KISSsoft

APPLIES RACEWAY MODIFICATIONS FOR ROLLING BEARINGS

Rolling bearing life depends on the contact stresses that occur between the rolling elements and the raceways. Contact stresses are calculated from contact loads, which in turn depend on the external loads acting on the bearing and the precise internal geometry of the bearing.

In case of roller bearings, contact conditions highly depend on the distribution of the contact stresses along the length of the rollers, which is typically controlled via rolling element modifications. However, another possibility to control the distribution of the contact stresses is by applying modifications to the raceways.

The application of raceway modifications can be especially useful, when one must deal with manufacturing deviations or assembly misalignments found out during the final control or assembly. In such cases, it might be rather expensive to get a completely new bearing with properly modified rolling elements. Alternatively, the raceways can be ground to achieve better stress distribution. In this case, an engineer can use *KISSsoft* to design the best possible raceway modifications under the given circumstances and simulate the effect of these modifications.



Raceway modifications can be applied to cylindrical roller bearings as of the *KISSsoft Release 2022*. In the future, the possibility will also be added to the other types of rolling bearings.

kisssoft.com

Miki Pulley

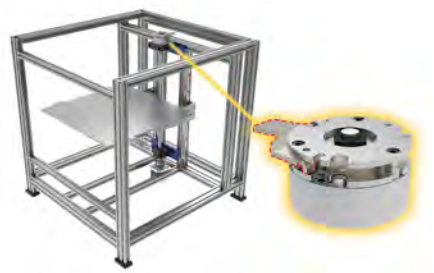
BXW BRAKES FEATURE MANUAL RELEASE LEVER FOR AUTOMATED PRODUCTION PROCESSES

Adjusting a stop and hold position in an automated system is made easy

using Miki Pulley BXW brakes with the manual release lever feature. It allows the operator to depress the lever and make a manual adjustment when the system is powered off. The lever also allows easy system indexing in the event of a power failure.

These new BXW brakes are Spring Actuated Electromagnetic Brakes. They provide reliable dynamic braking when a system's power is disengaged and excellent performance for longer-term holding requirements for staging, loading, and unloading system operations.

There are a wide variety of applications for the BXW brake with the manual release lever. These applications are ones that allow for free rotation without energizing the brake. This is ideal when a machine system must be manipulated during a power interruption – where the operator can easily depress the lever and release the brake allowing for rotation. Also, this model brake can be incorporated into a mechanical system design where a mechanical component engages the brake lever within the system to fine tune rotational placement.



BXW brakes utilize internal compression springs to provide power-off, fail-safe braking. The primary moving part in this robust but simple brake design is the armature plate. When actuated, the brake compression springs push the armature plate into the friction disc when power is disengaged. This feature provides fail-safe braking and allows the brake to maintain position over long periods of time, thus preventing an automated system from "coasting" when powered off.

Another important feature, Miki Pulley BXW Brakes function at full torque rating "right out of the box" so no startup run-in is needed. They are available in three different models for either single use braking, holding or both braking and holding. Depending on size selected, BXW Brakes are ideal for small and large applications including use with servo motors.

Additional features include quiet operation, high holding torque, space saving, long service life, stable, reliable braking power, and manual release mechanisms.

mikipulley-us.com

IKO

OFFERS U.S. AVAILABILITY OF MECH SERIES ACTUATORS

With AutomationWare's Mech Series E-actuators, engineers can obtain accurate, controllable movement for almost any performance and size requirement. The series features an advanced ball screw transmission system to handle a wide range of dynamic loads and speeds with exceptional thrust performance. The units come

with integrated brushless or high-speed stepper motors and an integrated feedback encoder.

In addition, the Mech Series delivers positioning accuracy to ±0.01 millimeter. Users can reduce space and cost by coupling the motors to the gearboxes or specify a sensorless version that uses motor control criteria to detect the correct position.

Versions and sizes include:

» Mech Value in sizes 16-25-32. These feature a high-quality ball screw.
» Mech Force in sizes 50-63-80-100-125-150. These deliver thrusts up to 190 kN force.
» Mech Plus in sizes 50-63-80-100-125-160. These combine high dynamic load and compact size.

Users can also monitor their Mech Series actuator using AutomationWare's AwareVu platform to ensure real-time control of temperature, vibrations, and other production process anomalies.

automationwareusa.com

Hexagon Manufacturing Intelligence

INTRODUCES ELEMENTS TO ASSIST WITH SYSTEM-LEVEL MODELING

Hexagon's Manufacturing Intelligence division has today introduced *Elements*, new simulation software that helps engineering teams understand the behavior of systems that are becoming increasingly complex in modern products. Using the software, teams can evaluate the performance and feasibility of new design concepts quickly to inform more efficient product development and reduce risk and cost.

Elements addresses the growing importance of integrated, multi-disciplinary system development and end-to-end workflows. Customers in every industry are demanding technologies that consider many physics domains and tackle mechatronics challenges in a robust way, fueling a growing trend towards system-level engineering. Achieving this requires the integration of all relevant engineering disciplines, control systems, and third-party supplier systems to understand how the domains interact, and how a design decision in one discipline impacts others.

Systems engineers can easily learn to use the *Elements* software, using its drag-and-drop environment to model any physics type or logic and analyze systems by intuitively connecting blocks—regardless of whether they represent electrical, hydraulic, mechanical components – to solve system-level engineering problems. It is based on the Modelica language, which is an open and widely used standard for building fast, flexible, and customizable models.

Systems modeling is indispensable in the early design phases because little information is required – often a CAD model, equation, or lookup table is sufficient and a 3D mesh is not required. *Elements* further speeds up engineering development because it also ensures that system-level models compute quickly and efficiently by optimizing equations and code for fast calculation, but with no loss of fidelity.

As the design develops, and components and subsystems are detailed in specialist simulation software, the components can be routinely integrated into a larger system through full compliance with the FMI standard and Hexagon's proprietary SmartFMU technology. SmartFMU unlocks the Functional Mock-up Unit (FMU) for supported Hexagon products so that changes can be made directly in the *Elements* system-level model without having to go back to the specialist *Computer Aided Engineering (CAE)* software and its expert user. This helps to avoid resource bottlenecks,

time-consuming switching between applications, and versioning problems.

Hexagon's roadmap will see its best-in-class *CAE* technologies readied for easy and productive use with *Elements*. At launch, the software provides SmartFMU connectivity with *Adams multibody dynamics* software and *Easy5*. Future plans are likely to include workflows with Cradle CFD thermal-fluid dynamics and Actran acoustic simulation products, among others.

Both standard FMI support and the novel SmartFMU plug-and-play capabilities offer immediate value and address challenges of system complexity, including those for transportation electrification; for example:

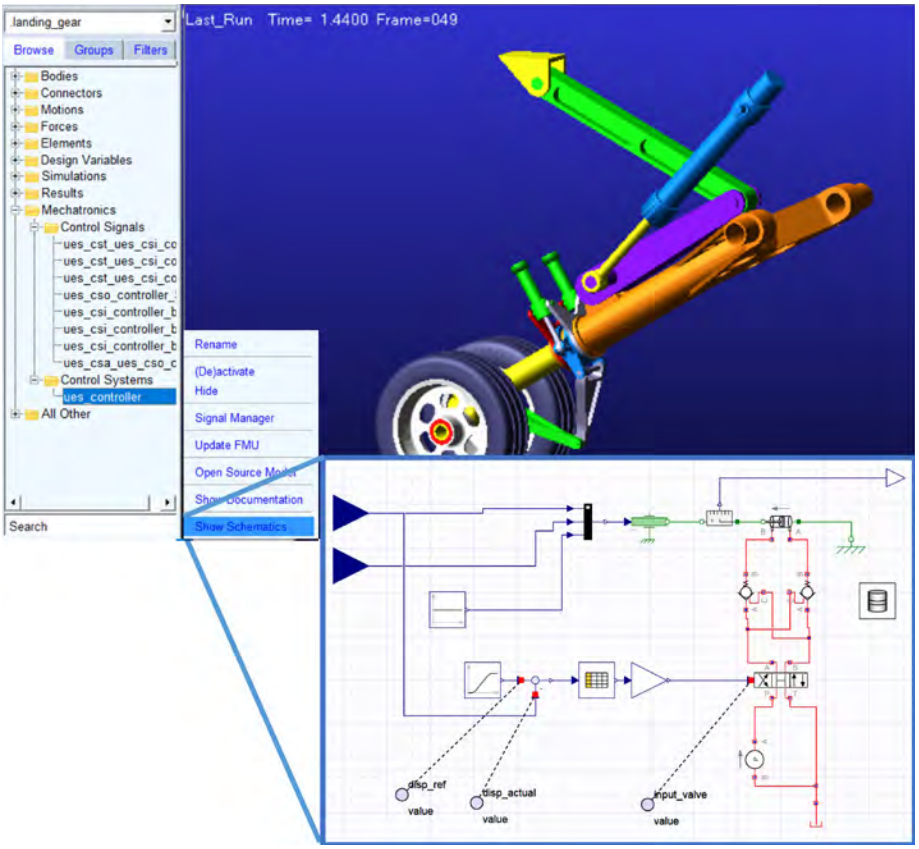
Helping automotive engineers to find optimal solutions to vehicle range optimization issues by considering a vehicle's energy use under different driving conditions, considering e-drive design, regenerative braking, climate control, ADAS safety requirements, and battery choice.

Improving the flexibility and accuracy of industrial robotics by designing control systems that take detailed mechanical system vibrations and interactions from multi-body dynamics simulation into account.

Right-sizing heavy battery systems in new eVTOL aircraft designs by helping engineers understand the power draw during take-off and landing, safety margins, and thermal management system controls.

Implementing safer, more sustainable long-life battery systems by using *Elements* to design control systems that balance the improved performance of lithium-ion batteries at elevated temperatures with the impact heating has on cell degradation.

Elements was developed in close cooperation with Maplesoft, building upon its powerful maths engine to optimize system equations and deliver fast efficient simulation to Hexagon's customers. Chris Harduwar, vice president of strategic solutions at Maplesoft, commented: "We are excited to begin this long-term collaboration with Hexagon, which has an impressive vision and track record of innovation. By combining the tried-and-tested Maplesoft system-level modeling technology with



the extensive Hexagon CAE portfolio, engineers in many industries benefit from new productivity-boosting solutions that significantly reduce simulation effort."

Mahesh Kailasam, general manager for design and engineering software at Hexagon, commented, "*Elements* offers engineers an easy way to explore behavior of systems quickly and find better solutions to problems using simulation, before committing designs to subsequent resource-intensive engineering processes. We look forward to a long-term collaboration with Maplesoft, using its powerful and open technology foundations to realize synergies with our extensive Hexagon *CAE* ecosystem portfolio and deliver valuable capabilities to our customers."

hexagon.com

SMAC

LAUNCHES LOW-PROFILE ACTUATOR FOR ROBOT END EFFECTORS

SMAC Moving Coil Actuators recently introduced its new LPL Series 125 low-profile electric linear actuator designed specifically for use on robot end effectors.

The LPL Series actuators utilize SMAC's moving coil linear servomotors for industry-leading precision control often needed for end effector applications, such as parts finishing, pick-and-place tasks, and assembly operations.

"With the use of robots becoming more prevalent, there is a demand for actuators with a short height/low center of gravity that can act as end effectors and perform a variety of tasks," said SMAC Founder and CEO Ed Neff. "We designed the LPL Series to fill that void, a low-profile actuator without compromising performance."

The LPL Series actuators offer programmable control of speeds, positioning down to microns, and forces from as low as 0.1 Newtons (N) up to 250 N. In addition, as LPL Series actuators complete their tasks they provide real-time feedback for tracking, performance, and quality control.

"Precision control and feedback is extremely critical in many robotic applications," Neff said. "Electric service actuators provide control and feedback

unmatched by any pneumatic actuator."

LPL Series actuators are unique in that they can be used on end effectors for a variety of applications, including testing buttons, switches, and levers; deburring and finishing parts; lifting fragile products; or clamping materials for welding or soldering.

LPL Series actuators also are cost-competitive, have high cycle rates, are energy-efficient, and have a lifespan of more than 100 million life cycles. The LPL's benefits are like SMAC's LDL and LBR Series actuators, which are also used for robot end effectors.

SMAC manufactures the LPL's moving coil linear servomotor, including its printed coil technology, and laser-machines the components and assembles the LPL Series actuators in its Carlsbad, Calif. facility. SMAC's vertical integration allows it to fill most orders within three weeks.

smac-mca.com

DENSO

INCREASES EFFICIENCIES, IMPROVES MORALE WITH FLEET OF MIR250 AUTONOMOUS MOBILE ROBOTS

DENSO has increased efficiencies, improved employee morale and ergonomics, and managed a tight labor market by deploying six MiR250 autonomous mobile robots to transport materials in its 800,000 square foot powertrain component production facility in Athens, Tennessee. According to a new case study from Mobile Industrial Robots (MiR), DENSO has successfully executed more than 500,000 missions since deploying its first MiR robot in 2020, recognizing a return on investment (ROI) in less than a year along with an ongoing need for more AMRs for additional logistics applications.

One of MiR's largest global customers,

DENSO has AMRs from MiR running in two other U.S. locations, as well as three facilities in Europe and two in Asia. According to Travis Olinger, a logistics and automation engineer at DENSO, the company chose AMRs over automated guided vehicles (AGVs) because AMRs can navigate on their own with quick mapping and quick changes without the need for a costly infrastructure built into the facilities' floor.

"Autonomous mobile robots were an obvious choice for our extremely dynamic environment, which we knew would require the robots to make regular route changes," Olinger said. "After testing AMRs from a few different vendors, we realized that MiR robots bring significant advantages in flexibility, safety, and user-friendliness. MiR stood out from the ability to use REST API calls to communicate with the robots; the intuitive nature of the MiR *Fleet* software; the ease of mapping; ease of mission creation, and ease of changing locations. MiR was just extremely intuitive compared to the other platforms we looked at."

Olinger said the MiR250 robots were particularly compelling because of their two-meters-per-second speed, the payload of 250 kilograms (550 pounds) to handle heavy metal parts, and the ability to navigate narrow spaces. Standardizing on the MiR250 shelf-lifter that pulls carts from MiR partner ROEQ allowed DENSO to expand quickly into other areas using the same cart base and customizing it for each use. As the engineering team receives additional requests for automated conveyance, they can easily design racks around the carts, helping to free up space, increase flexibility, and gain advantages more quickly.

AMRs improve employee morale, retention with transition to higher level tasks

DENSO employees were walking up to 12 miles per day moving material between production areas and the warehouse, spending about 60 percent of their time just pushing carts, Olinger said. The initial pilot program to automate this conveyance with AMRs eliminated this manual task, allowing six workers to transition to more value-added work. The project quickly expanded to bring components directly to line-side production for just-in-time efficiencies. Support for the robots has grown quickly among employees, with workers in other departments requesting robot support for transporting goods such as maintenance supplies and spare parts. DENSO recently purchased five MiR500 robots for future conveyance projects that require heavier payloads.

"Automating these repetitive and strenuous tasks with new technologies that make jobs easier helped us retain our existing labor force," Olinger said. "We had plenty of open jobs for value-added activities within the production environment. We wanted to pay people to make parts for us that makes us money, and not pay them to move parts that cost us money."

For more details on how DENSO has benefited from autonomous mobile robots and the company's future plans, see the full video and written case study at:

Asset Management in Manufacturing

Accessibility, transparency and digital transformation push condition monitoring technology toward a collaborative future

Matthew Jaster, Senior Editor

What's the secret behind a kinder, gentler shop floor where machine operators and condition monitoring experts partner up to solve manufacturing challenges? The common goal appears to be productivity, safety and accountability. PT products such as gears, motors, pumps, fans and bearings will—without a doubt—continue to run through rigorous and harsh environments for the foreseeable future, but software and hardware improvements aim to disrupt unplanned downtime and machine maintenance through a series of new condition monitoring assets.

Independent providers of digital technologies, such as ONYX Insight, are well placed to help renewable asset owners manage their assets effectively.

Why Condition Monitoring Will Be Pivotal to Making the Most of Wind Assets in 2023

2023 is set to be another big year for renewables, especially onshore and offshore wind generators, who are among the main beneficiaries of the Biden Administration's Inflation Reduction Act which will see significant investment by the federal government in renewable energy and associated technologies.

In the United States, nearly 70,000 wind turbines are in operation across the country, with their power capacity generating nearly 140 GW (*cleanpower.org/facts/windpower*). It is vital that the industrial sector maximizes the efficiency and longevity of the hardware which makes this energy production possible—the wind turbines. To do this we must leverage available data and digital

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technologies, ultimately improving return on investment in the infrastructure.

"This is something which ONYX Insight is driving forward with its innovation and expert analysis throughout 2023. For operators, effective case management is front and center of their operations. In 2020, 75 percent of wind industry professionals stated that they were under more pressure to run projects profitably, and moving forward into 2023, organizations will see the value of how data can empower condition monitoring to achieve this and ensure maintenance is carried out when needed," said Dr. Evgenia Golysheva, vice president strategy and operations at ONYX Insight.

Embracing digital transformation helps wind owners and operators navigate potential pitfalls. However, the way forward is not always straight forward. Challenges to be tackled as the industry progresses include better integration and interpretation of siloed data, increasingly complex and growing portfolios, and industry requirements for more holistic digital tools, Golysheva said.

Independent providers of digital technologies, such as ONYX Insight, are well placed to help renewable asset owners manage their assets effectively. Unbiased and multidisciplinary, they can offer a deeper understanding of hardware, software and engineering to all. There is space for everyone as the whole sector expands, but the industry must think hard about asset management to safeguard profitability.

"ONYX Insight's own research has found on average, a 100 MW wind farm can produce 200 false alerts per year, resulting in approximately $200,000 in technician labor costs, transport to turbines and lost revenue during downtime. However high-quality predictive maintenance using advanced analytics can reduce those false alerts by 93 percent," Golysheva said.

Data-driven condition monitoring is especially useful for organizations who operate offshore wind turbines, where organizing and carrying out maintenance is complex and costly.

Data-driven condition monitoring is especially useful in this regard for organizations who operate offshore wind turbines, where organizing and carrying out maintenance is complex and costly. By enabling better decision making in offshore O&M, advanced data sensing can optimize fleets and support effective asset management, and in turn boost profitability.

"We are seeing technology and data playing a role in profitable life extension of earlier models of wind turbines. For example, ONYX Insight' ecoCMS has transformed the economics of retrofitting condition monitoring on older, sub-2 MW turbines enabling their modernization, risk management and life extension through detailed analysis and asset integrity monitoring," Golysheva said.

Keeping assets running and maximizing power production has been the default strategy of many operators. Moving forward, they will seek to maximize revenue by optimizing energy sales. This will require flexible operating strategies, underpinned by market pricing, where turbines can be uprated or derated to maximize the value of energy sold.

"In the year ahead, ONYX Insight expects to see greater collaboration between operators and condition monitoring experts to push further reductions in operational expenditure by resolving practical problems, while increasing MWh (megawatt hours) through bespoke analytics engineering. ONYX is beginning the year with the start of its 'Get Ready for the Windy Season' campaign, which will see ONYX work with those in the industry to further supercharge this," Golysheva said. "With world leaders agreeing late last year that we must increase the pace with which we transition towards renewable energies, it will act as a powerful catalyst to further strengthen wind energy's infrastructure."

onyxinsight.com

Balluff Touts Standalone Condition Monitoring System

The retrofitting of manufacturing plants has often failed due to the high effort and the associated costs for the permanent monitoring of relevant machine and process parameters.

With the flexible Balluff Condition Monitoring Toolkit (CMTK) system, users quickly gain deeper insights into the actual condition of machines and can, therefore, detect deviations and problems at an early stage. All components are perfectly matched to each other.

The Balluff CMTK, a standalone system which contains everything needed to monitor the condition of processes and machines, including data acquisition and visualization, now has UL approval for use in the United States and Canada. It provides an easy-to-implement solution for adding condition monitoring to existing machines and processes. With the flexible condition monitoring toolkit, manufacturers can quickly gain deeper insights into the actual condition of their machines and systems, allowing them to detect problems early.

Each system includes the hardware and software and supports up to four IO-Link sensors.

The Balluff CMTK contains everything needed to monitor the condition of processes and machines, including data acquisition and visualization.

The CMTK runs independently, providing actionable data no matter what controls systems are in place. The base unit is a miniaturized computer which can be installed on a DIN rail in a control cabinet for easy deployment. Four IO-Link ports allow to the addition of sensors to measure factors like temperature, vibration, humidity and pressure. Built-in software stores this data, visualizes it on a dashboard, and can send alerts and export data. Built-in LAN ports connect the CMTK either directly to a computer or to an existing computer network. Depending on the sensors selected, the condition monitoring toolkit can be used for a variety monitoring tasks.

This flexible system provides a smart and low-cost way to retrofit plants with comprehensive machine monitoring. The condition data gained through the CMTK provides continuous status information on connected machines, enabling users to perform predictive maintenance. This greatly reduces unplanned downtime and the unnecessary costs associated with it. And it does all this completely independent of a cloud connection or machine control system.

During SPS in Nuremberg, Balluff's exhibition space took condition monitoring directly to its customer base by using a built-in condition monitoring sensor for an automatic coffee machine. The machine not only provided coffee enjoyment during the talks, but also became a real use case thanks to a built-in condition monitoring sensor and machine learning capabilities.

"In order to show visitors concretely how our networked solutions work together, we visualize the data of the exhibits via a central dashboard," said Alexander Schmidt, business strategy manager at Balluff.

Visitors could access a multitude of recorded data including the fact that espresso was the most ordered beverage for visitors to the Balluff booth. This representation of condition monitoring was supported by other exhibits at the booth including CMTK and the Balluff Engineering Tool (BET).

balluff.com

Higher Efficiency Through Transparency

As its latest achievement, SICK AG is now presenting a condition monitoring sensor for simultaneous vibration, shock and temperature monitoring.

The SICK AG Multi Physics Box detects vibrations, shocks, and temperature, providing important indications of faulty processes.

When operating machines with rotating components, i.e., electric motors, fans, turbines or ventilators, it is important to ensure smooth operation and to detect possible signs of machine failure at an early stage. This is where the Multi Physics Box condition monitoring sensor is set to help in the future.

The new Multi Physics Box mpb10 simultaneously detects vibrations, shocks and temperature, thus providing important indications of faulty processes that can lead to machine or plant failures. Based on the sensor data, malfunctions can be detected at an early stage and maintenance can be planned depending on the condition. The result: cost savings and efficiency gains due to less unscheduled downtime.

To be able to identify incipient faults, data interpretation must of course be as simple as possible. And the Multi Physics Box also helps with this. For example, the sensor records vibrations via a MEMS element and processes them directly according to the configurations. The final data output provides indication values in the time and frequency range that are much easier to interpret than pure raw data. If the measured values exceed individually definable limits, an alarm is also output. A multi-level alarm according to ISO 10816-3 can even be implemented for monitoring vibration limits. An optional trigger ensures precisely reproducible measurements. The sensor itself can be integrated into the machine or system via IO-Link or via a simple alarm-based switching signal and functions both on-site and in conjunction with a cloud service.

SICK sees virtually no limits to the range of applications for the Multi Physics Box. The sensor technology is well protected by a robust stainless-steel housing; even fine dust or water cannot harm it thanks to protection class IP68. At ambient temperatures between -40 degrees Celsius and +80 degrees Celsius, the sensors are said to deliver consistently reliable data. Thanks to flexible parameterization options, the sensor can also be used in a wide variety of applications. In other words, the Multi Physics Box is suitable for continuous condition monitoring in almost any industrial context and serves as a reliable data supplier even under harsh environmental conditions.

sick.com

Future Considerations in Real-Time Quality Monitoring

Anomalies and errors in the production process usually result in cost-intensive rework, elaborate final inspections and delivery delays, which in turn have a negative impact on productivity and sustainability.

The goal should therefore be to ensure quality directly at the time of process execution. This is precisely where the German-Czech research project AIQUAMA (AI-based Quality Management for Smart Factories) comes in, which has now been launched with a recent kick-off at the Forum Digitale Technologien in Berlin.

AIQUAMA lists the German Research Center for Artificial Intelligence, the Czech Institute of Informatics, Robotics and Cybernetics at the Czech Technical University in Prague, the Central European Institute of

The AIQUAMA project team at the kick-off in Berlin (courtesy idw/Germany).

Technology and the VSB Technical University of Ostrava as project partners along with Volkswagen AG as an application partner.

"The AIQUAMA project is an immediate and concrete extension of the RICAIP project. The topics not only monitor, but simultaneously formulate the key research trends in the field of Industry 4.0 in the next decade and push the vision of Industry 4.0 to new goals. Importantly, these are trends that our core industry welcomes and supports," said Professor Vladimir Marik, scientific director at the Czech Institute of Informatics.

For additional context, the RICAIP is an international distributed research center of excellence (CoE) that focuses on research in robotics and artificial intelligence (AI). RICAIP is based on the strategic partnership of leading Czech and German research institutions. With a maximum degree of autonomy, it is hosted at CIIRC CTU. The center addresses the current needs, gaps and demands across Europe in utilizing Industry 4.0 concepts in manufacturing.

In order to avoid quality-related errors in advance, an intelligent online planning component will be extended in such a way that quality-related parameters are also taken into account in the best possible way during plan generation and task assignment. Especially in manual assembly or machining processes or in work steps performed by hybrid teams of humans and collaborative robots, errors still happen. One such error is, for example, a worker reaching into the wrong material box or the wrong tool during a manual assembly task or a robot giving a hand at the wrong time.

However, suitable combinations of different sensor systems should now enable errors in the production process to be detected earlier than before and therefore eliminated more sustainably. Detected errors are explained transparently via suitable user interfaces so they can be avoided in the future.

The zero-defect production targeted by AIQUAMA is to be based on incremental quality monitoring in real time. For this purpose, multi-sensor data streams are evaluated using artificial intelligence methods. The evaluation itself is based on real, but also synthetic (training) data, which is analyzed using a combination of symbolic models and statistical machine learning. This research project will span from January 2022 to June 2025 and will no doubt create new advances in real time monitoring for industrial applications.

ricaip.eu

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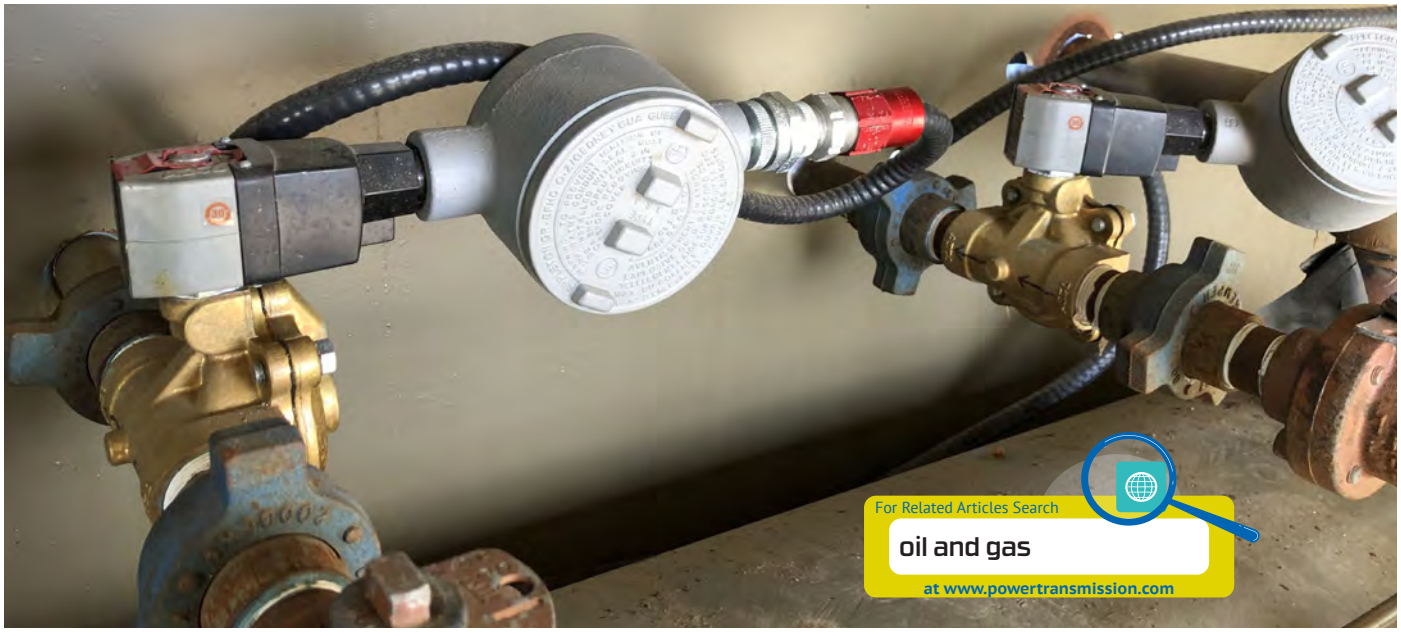
How New Solenoid Valve Technology Can Reduce Emissions in Field Wells

Electrification is key to decarbonize operations

Justin Valdez, Senior District Sales Manager of Fluid Control & Pneumatics, Emerson



Solenoid technology is a starting point for reducing greenhouse gas emissions. These valves can be used in addition to other technologies to reduce emissions. (Images courtesy of Emerson)

As the world seeks to curb the effects of climate change, the oil and gas industry has a big part to play. Whether driven by U.N. Sustainable Development Goals, government regulations or an investment community that's increasingly environmentally conscious, oil and gas companies are looking for new ways to decarbonize production and reduce their plants' emissions.

While recent strides have been made, the oil and gas industry still has room for improvement. Globally, oil and gas operations account for nine percent of all human-made greenhouse gases, according to data from the Organization for Economic Cooperation and Development (OECD). Reducing those emissions in a cost-effective manner will be essential for both the planet and the long-term viability of the industry.

As renewables become increasingly affordable and effective, electrification is a key area of opportunity for companies to decarbonize operations, especially in remote field wells where grid power is not an option. While some wells already rely on solar arrays or wind to help power production, they often still use gas-actuated pneumatic valves in their operations.

Gas-actuated valves come with several environmental drawbacks. Not only do they require carbon-based energy to operate, they're also responsible for a high volume of emissions. According to the EPA Greenhouse Gas Inventory, eliminating all gas-actuated pneumatic valves could result in a 25 percent reduction in all methane emissions related to oil and gas operations.

Replacing pneumatic valves with traditional electric valves has historically been an impractical solution, from both a financial and operational perspective. Electric valves struggled to meet pressure requirements, demanded too much energy, or weren't suited for class 1 hazardous conditions associated with well environments.

But with recent advances in solenoid technology, electronically enhanced solenoid valves can now meet the demands of field well conditions to effectively replace gas-actuated valves. Suitable for class 1, division 1 and 2 hazardous conditions, a new generation of valves offer a cost-effective way

Advancements in solenoid technology have allowed electronically enhanced solenoid valves to meet the demands of field well conditions to effectively replace gas-actuated valves.

to significantly reduce energy consumption and abate emissions in several applications, including separators, heater treaters and free water knockouts.

Game-Changing Advancements

The newest ASCO RedHat Next Generation valve can deliver enhanced pressure ratings at a dramatically lower wattage. Featuring a power management circuit, these new two-way valves can support pressure ratings of 750 psi while only consuming a maximum of 1.2 watts of power.

Compared to previous generations of electric valves that used more than 20 watts of power to deliver lower pressure ratings, this advancement opens a broad new range of possibilities. With low-wattage coils that can run on just two- or three-amp hours, they don't require large expansions to power capacity, whereas previous models could take more than six times the infrastructure to support their power consumption.

These solenoid valves also give operations uniquely versatile performance. The multi-voltage coil can support a wide range of voltages in both AC and DC. Available in a variety of ranges, such as 12-24V DC or 24-120 AC/DC, these valves deliver more flexibility and enable operations to streamline inventory of maintenance components.

For operations that rely on solar panels or other DC power sources, the direct current performance of these valves can offer a 150 to 500 percent improvement over industry standards, making DC characteristics equivalent to AC pressure and flow values. This simplifies control and eliminates the need for AC output cards and excessive wiring. It also allows remote well pads without access to grid power to electrify their valves without sacrificing performance or adding a lot of cost.

Eliminating Emission Events

Beyond the low power usage, replacing pneumatic valves also eliminates the associated emission events. Pneumatically piloted valves or actuated ball valves use system gas as their energy source, and when opening or closing, they vent that process gas.

To eliminate the emission event, many sites in the field today will use a hybrid solution to incorporate electric actuation. Three-way pilot valves use a generator to send instrumentation air to an actuator that opens and closes the valve. Although this solution eliminates the process gas from the emission event, there are still the costs associated with running the compressor.

With the low power requirements and increased pressure and flow capabilities of new solenoid technology, wells can eliminate the three-way pilot valve and actuate their open-close valves as a single assembly, thereby eliminating the emission event completely.

Fewer components in a valve assembly also means fewer opportunities for leaks. Streamlining components and eliminating valve packing wherever possible is an effective way to simplify maintenance and reduce fugitive emissions while also saving on costs of parts.

How Solenoid Valves Fit Into Sustainability Strategies

With upstream operations accounting for two-thirds of emissions in the oil and gas industry, well pads are a key area of focus in emission abatement strategies. Solutions companies choose to employ will vary greatly depending on production volume, geography, and other conditions, but in many cases, solenoid valves can have a part to play.

Pilot valves are an easy place to start for operators who want to begin electrifying their equipment. The low cost and high impact of these components can offer operations a significant return on investment, improving both energy efficiency and carbon footprint. And realizing those returns can help strengthen the business case for further electrification.

And for operations aiming to transition to renewable energy sources, these solenoid valves offer an extremely cost-effective solution. The low power requirements of these valves allow for more streamlined, less costly infrastructure for renewable energy production.

Overall, solenoid technology should be viewed as a starting point for reducing greenhouse gas emissions. It's just one tool in a much larger toolbox of potential solutions. These valves can be used in combination with a variety of other technologies to reduce emissions, such as level switch and detection units with built-in proof testing.

Whether an operation is taking the first step toward abating emissions or fine-tuning their sustainable production, they don't have to do it alone. Working with a partner who can offer a full portfolio of process and flow technologies and expert support will ensure the most effective solutions for efficient, safe and sustainable operation.

emerson.com
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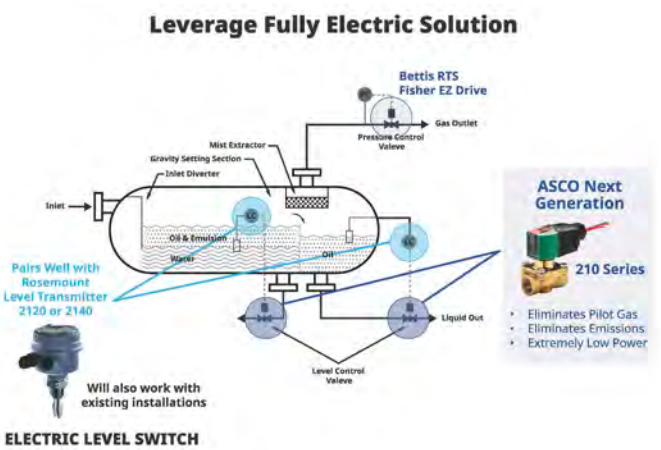

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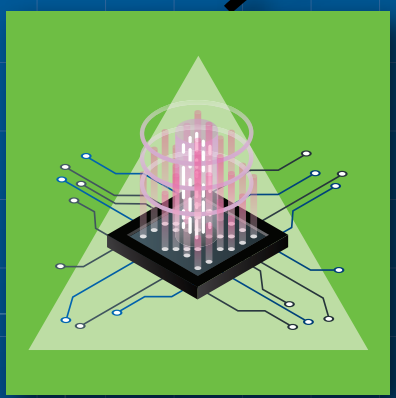

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Vesconite Marine Rudder Bearings

Vesconite contributes to a communication satellite launch

By Monique Potgieter and Deborah Spicer, Vesconite Bearings

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The Colibri (Image credit: 2021 ESA-CNES-Arianespace/Optique vidéo du CSG—JM Guillon).

Vesconite Bearings, through its supply of marine rudder bearings to the MN Colibri charter vessel in June, is proud to be associated with an exciting communication satellite launch that took place in September 2022. The MN Colibri has historically transported launcher components, including communications satellites, for various heavy-lift space launch vehicles, and outfitted with the Vesconite rudder bearings allowed it to transport the Eutelsat Konnect VHTS satellite, which is regarded as an important addition to global telecommunications infrastructure.

The MN Colibri transported the satellite to Pariacabo Harbour in French Guiana, near the Kourou-based Guiana Space Centre, the main spaceport of France and the European Space Agency. On arrival at the port, the Eutelsat was transported off the ride-on ride-off charter vessel. It then made its way to the launch site, where it was later successfully launched by an Ariane rocket. The Eutelsat Konnect VHTS is expected to deliver high-speed broadband and mobile connectivity throughout Europe, North Africa and the Middle East from the second half of 2023.

"Vesconite Bearings is pleased to have contributed to this momentous project," says Vesconite Bearings marine applications engineer Monique Potgieter of the development that plans to supply European users with 100 Mbps broadband as well as to eliminate broadband black spots. "Our marine bearings are used in many intriguing shipping projects that contribute to the technological advancement of our world," she notes.

Potgieter explains that, when the MN Colibri charter ship was undergoing planned inspection, it was found that the upper and lower flap bearings needed to be replaced on the flap-type rudders. The bearing supplier was then approached by a company that focuses on rudder new builds and servicing to supply the bearings. Vesconite Bearings had the right size bushing material in stock at its Netherlands warehouse and quickly delivered the stock to Hamburg, Germany, for further machining and installation.

Material for two bearings, measuring 170 mm outside diameter (OD) x 150 mm inside diameter (ID) x 157 mm length (L) and 180 mm OD x 150 mm ID x 190 mm L, were ordered at 5 pm on June 27, 2022, dispatched just after noon on June 28 and delivered to the dry dock that did the final machining shortly after 1 pm on June 29. Marine bearings are essential to the delivery of all manner of cargo, much of which is time sensitive.

"Our team of marine specialists is dedicated to attending to urgent enquiries and we engage with ship captains, ship servicing companies and vessel managers through WhatsApp, Skype, direct calls, email and the other platforms they prefer to ensure a high level of availability, quick responses to enquiries and fast processing of orders," says Potgieter.

The next step in Vesconite's ability to deliver rudder bearings and stern tubes quickly is its strategy to have a large number of bearings stocked in locations around the globe and, where necessary, to manufacture these quickly at the dedicated marine bearing facility for the production of extra-large bearings.

This dedicated facility can manufacture some of the largest marine bearings in the world in one to two days using its five large horizontal lathes and two large vertical lathes.

"In the case of the Colibri, we had bearings available close to the dry dock machine shop that was working on the ship," says Potgieter.

"We are proud that our marine-supply strategy makes us the supplier of choice for many shipyards and repair companies that trust us for fast deliveries, excellent customer service and quality products," she notes.

PTE

Editor's Note:

Benefits of Vesconite to Marine Applications

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- **Does not corrode.**
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- **Is resistant to oils and fuels.**
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- **Prolongs shaft life.**

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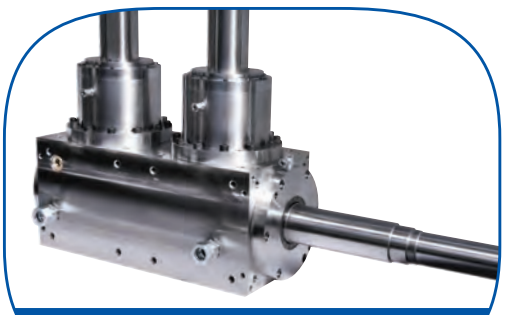

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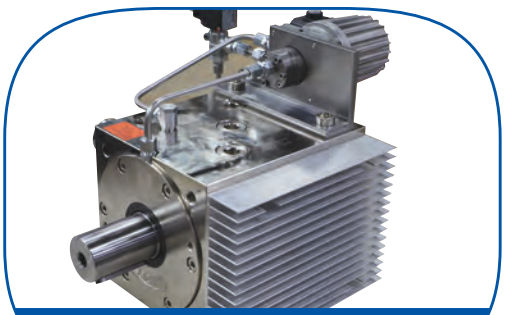

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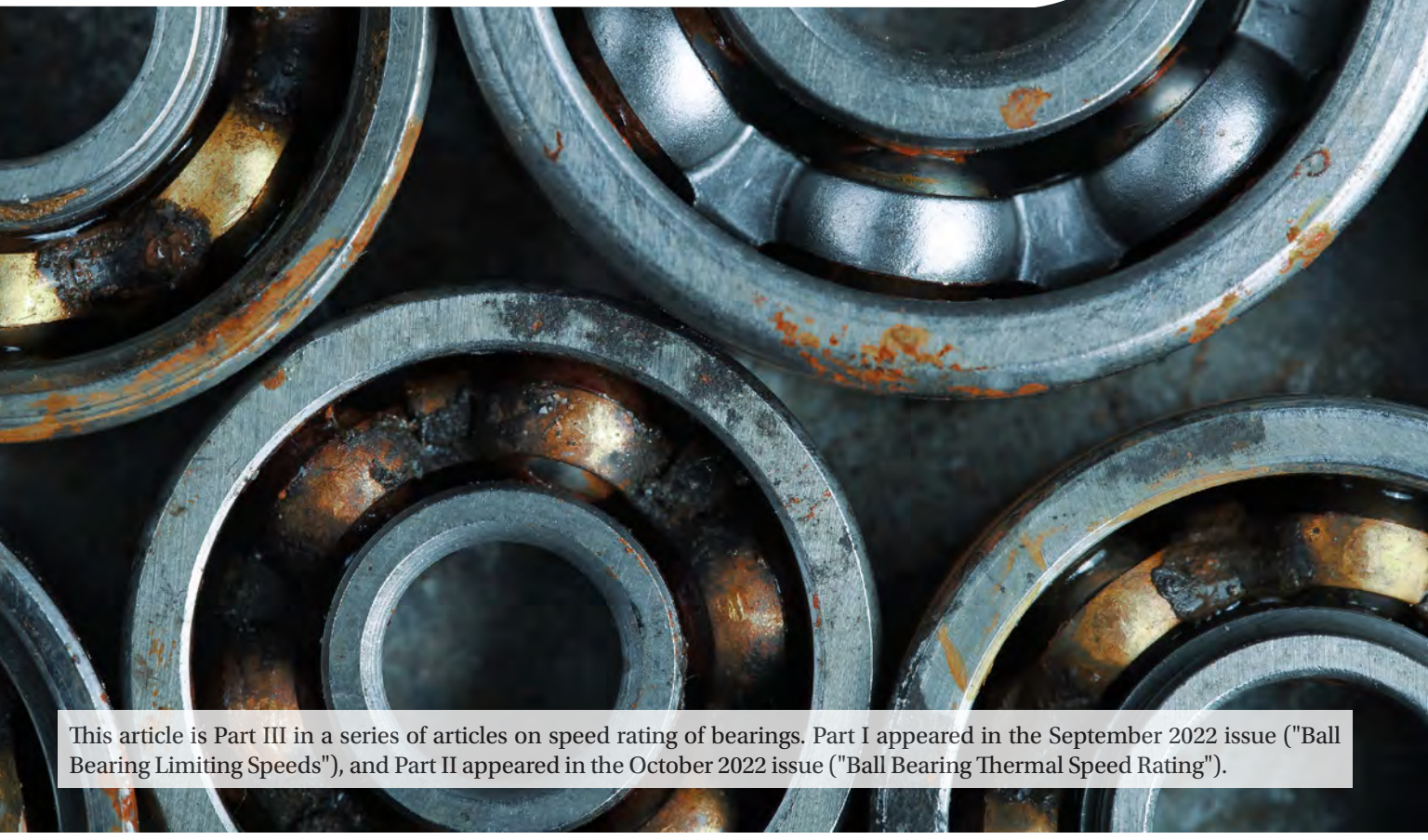


This article is Part III in a series of articles on speed rating of bearings. Part I appeared in the September 2022 issue ("Ball Bearing Limiting Speeds"), and Part II appeared in the October 2022 issue ("Ball Bearing Thermal Speed Rating").

Happy New Year! We are finally on to our 3rd and (maybe) final installment of speed ratings. For those playing along at home, DIN 732 is essentially the second part of ISO 15312. In ISO 15312, we solved the *Thermal Speed Rating*—which you could think of as a generic safe operating speed under normal conditions. DIN 732 defines a *Speed Ratio* which is a factor multiplied to the *Thermal Speed Rating* to calculate the *Thermally Safe Operating Speed*. This can be greater or less than 1 depending on conditions. Neither ISO 15312 or DIN 732 are stand-alone documents, they must be used together in order to calculate a meaningful result.

When we think about speed in terms of thermal limitations, the two primary drivers are load and lubrication. Lubrication is obvious, but perhaps not as obvious, are loads. Ball bearings can generate a lot of heat and become quite inefficient at high loads. It is a common notion that a ball bearing is always more efficient than a taper roller bearing. Intuitively, it makes sense. Tapers have a huge frictional sliding surface where the bottoms of the rollers and the rib meet. At first glance, it appears that a ball has almost no friction—a hardened steel ball on an equally hardened raceway. The difference comes in surface pressure and the losses come in the form of hysteresis (and a few other drivers); the small elastic yielding of the ball and raceway under load. Under heavy loads, it is no longer just near frictionless rolling on a hard surface. As loads increase, eventually the ball bearing losses will surpass tapers. Tapers are designed to take huge loads, spreading a load over the full length of the roller. As a result, hysteretic losses are much lower. Under continuous high loads, like you might find in some industrial applications, a roller bearing or sometimes even a larger ball bearing can be more efficient in terms of rolling losses. In automotive, we are always trying to find the right balance between highway efficiency and high load capability.

Now, please don't go out and buy bulldozer bearings for your EDM design because Norm said they were more efficient—but you get the idea. There are tradeoffs with every design that must be calculated and not just assumed.

SKF has a nice, expanded explanation on loss mechanisms here:

evolution.skf.com/using-a-friction-model-as-an-engineering-tool-3/

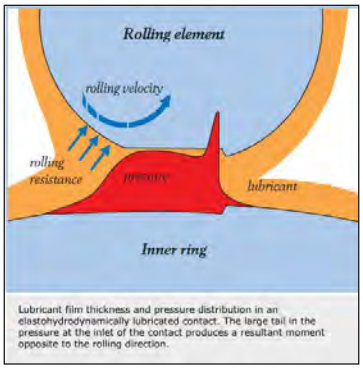


Figure 1—Courtesy SKF.

As a recap, we first covered the catalog speed rating, otherwise known as the limiting speed. This is the mechanical based speed limitation based on cage strength and friction assumptions. If the bearing is sealed, there is a lower speed rating also listed in most catalogs alongside the limiting speed. The second rating we discussed was the thermal speed rating $n_{\vartheta r}$ within the context of ISO 15312. This is the speed rating which has predefined conditions for load, ambient temperature and lubrication type that will maintain a bearing temperature of 70°C. This speed rating on its own is not incredibly useful, but is described as an ancillary value for the *Thermally Safe Operating Speed* n_ϑ as defined in DIN 732. As we go through this process, it becomes clear why the limiting speed and thermal speed ratings are set values—they are based on pre-defined conditions. The *Thermally Safe Operating Speed* is a dynamic value that includes variables for load, temperature, viscosity and oil flow. We will start with the definition:

Thermally safe operating speed

$$n_\vartheta = n_{\vartheta r} \cdot f_n$$

For the thermal speed rating $n_{\vartheta r}$, we will use the value that we calculated from ISO 15312 in our previous session. Recall $n_{\vartheta r}$ for a standard 6205 is 13,300 rpm. Now we just have the speed ratio to deal with, which is still a bit of a handful. When the Lubricant Parameter K_L is defined within the normal operating range of $0.01 \leqq K_L \leqq 10$ and likewise with the Load Parameter K_P $0.01 \leqq K_P \leqq 10$; the speed ratio f_n can be calculated as follows.

Speed ratio

$$f_n = \frac{490.77}{1 + 498.78 \cdot K_L^{0.599} + 852.88 \cdot K_P^{0.963} - 504.5 \cdot K_L^{0.055} \cdot K_P^{0.832}}$$

Where:

Lubricant factor

$$K_L = 10^{-6} \cdot \frac{\pi}{30} \cdot n_{\vartheta r} \cdot \frac{10^{-7} \cdot f_0 (\nu \cdot n_{\vartheta r})^{2/3} \cdot {d_M}^3}{\dot{Q}}$$

Load factor

$$K_P = 10^{-3} \cdot \frac{\pi}{30} \cdot n_{\vartheta r} \cdot \frac{f_1 \cdot P_1 \cdot d_M}{\dot{Q}}$$

Let's start by solving the total dissipated heat flow $\dot{Q}$:

$$\dot{Q} = \dot{Q}_S + \dot{Q}_L + \dot{Q}_E$$

Where:

$$\dot{Q}_S = k_q \cdot A_s \cdot \Delta\vartheta_A$$

In this case, the heat emitting bearing seating area, A_S, is the same as A_r used in ISO 15312. Again using our 6205 example:

$$A_S(6205) = \pi \cdot 15(52 + 25) = 3628.54 \text{ mm}^2$$

$\Delta_{\vartheta A}$ is the difference between operating temperature and ambient temperature. For ease of comparison, we will use the operating condition defined in ISO 15312 as 70°C. If we are operating at room temperature, $\Delta_{\vartheta A}$ = 47°C (23°C to 70°C).

Schaeffler provides the chart for the k_q value. Below, the 1 line is for axial bearings and 2 is for radial bearings which includes the 6205 ball bearing. This gives us about 0.32×10^{-6}. Our description states we should have a value between $0.2 - 1.0 \times 10^{-6}$ which seems reasonable. There are a lot of unspecified factors here depending on architecture which is characterized by the large gray area. The faster the system can self-cool, the larger this value is.

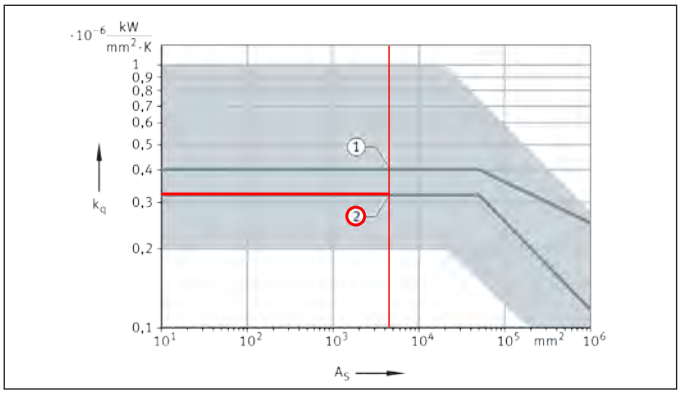


Figure 2— https://medias.schaeffler.us/en/speeds

$$K_L = 10^{-3} \cdot \frac{\pi}{30} \cdot 13{,}300 \cdot \frac{10^{-7} \cdot 2(12 \cdot 13{,}300)^{2/3} \cdot 38.5^3}{390}$$

$K_L = 0.12$ (Within the required range of 0.01 – 10)

Therefore:

$$\dot{Q}_S = 0.32 \cdot 10^{-6} \cdot 3628.54\ mm^2 \cdot 47\ °C$$

$$\dot{Q}_S = 0.054\ kW$$

Now on to heat flow dissipated by the lubricant.

$$\dot{Q}_L = 0.0286 \frac{kW}{l/min \cdot K} \cdot \dot{V}_L \cdot \Delta\vartheta_A$$

$\dot{V}_L$ is simply the oil flow. These numbers are always somewhat of a guess if you have a passive oil system. In these cases, you can just pick a reasonable middle of the road value ~ 0.25 l/min. There are published formulas that will give you estimates on needed oil flow rates based on speed, load and temperature.

Now we have:

$$\dot{Q}_L = 0.0286 \frac{kW}{l/min \cdot K} \cdot 0.25 \frac{l}{min} \cdot 47°C$$

$$\dot{Q}_L = 0.336\ kW$$

Now we can solve the total dissipated flow rate. For this exercise, we will just set the external heating / cooling factor $\dot{Q}_E$ to zero. If you have a heater or cooler, you will add that value here.

$$\dot{Q} = \dot{Q}_S + \dot{Q}_L$$

$$\dot{Q} = 0.058 + 0.358 = 0.39\ kW\ (390W)$$

Now we move to the lubricant factor:

$$K_L = 10^{-3} \cdot \frac{\pi}{30} \cdot n_{\vartheta r} \cdot \frac{10^{-7} \cdot f_0(\nu \cdot n_{\vartheta r})^{2/3} \cdot {d_M}^3}{\dot{Q}}$$

The bearing factor f_0 is a table value that can be found in ISO 15312 and DIN 732 and referenced in public literature. In our case, the 6205 ball bearing has $f_0 = 2.0$ (for oil bath or recirculation).

ν is the kinematic viscosity at operating temperature. For continuity, we will keep the value of 12 mm^2/s as defined in ISO 15312. Recall that we defined our operating temperature at 73°C. Regardless of where you set your operating temperature, just make sure it is consistent. Again, we revisit our ISO 15312 results for the thermal speed rating $n_{\vartheta r}$: 13,300 rpm. dm is the mean bearing diameter (6205): (52+25)/2 = 38.5 mm

Now on to the load factor K_P.

$$K_P = 10^{-3} \cdot \frac{\pi}{30} \cdot n_{\vartheta r} \cdot \frac{f_1 \cdot P_1 \cdot d_M}{\dot{Q}}$$

Most of these variables have now been defined—we just have f_1, the *other* bearing factor and P_1, the *decisive* load. f_1 is as a simple formula in DIN 732: $0.0009 \cdot (P_0/C_0)^{0.5}$ P_0 is the applied equivalent static load and C_0 is the static load rating. If axial loads are light, P_0 can be estimated as the applied radial load. For the 6205 C_0, we will use the SKF rating of 7.8kN. For P_1 we will continue using the ISO 15312 parameter for ease of comparison – which was 5% of Cor (7.8kN) or 390N. Now we have $f_1 = 0.0009(0.39/7.8)^{0.5} = 0.0002$.

Now we can solve K_P.

$$K_P = 10^{-3} \cdot \frac{\pi}{30} \cdot 13{,}300 \cdot \frac{0.00023 \cdot 390N \cdot 38.5}{390W}$$

$K_P = 0.0123$*

It is coincidental that P_1 and $\dot{Q}$ are the same value. Units are included for clarity.

*Schaeffler also provides a chart for basic configuration for reference. We can see here that for light load, the K_P factor can easily run off the chart > 1. If we use the ISO 15312 value of 390N, this would give us a Co/P (7.9/.39) of 20. Something doesn't seem to be lining up between the chart and the formula—the formula result seems too low. We will use our software to skip the guessing game, but for meantime, let's use the old college trick of setting the variable to 1 as a placeholder.

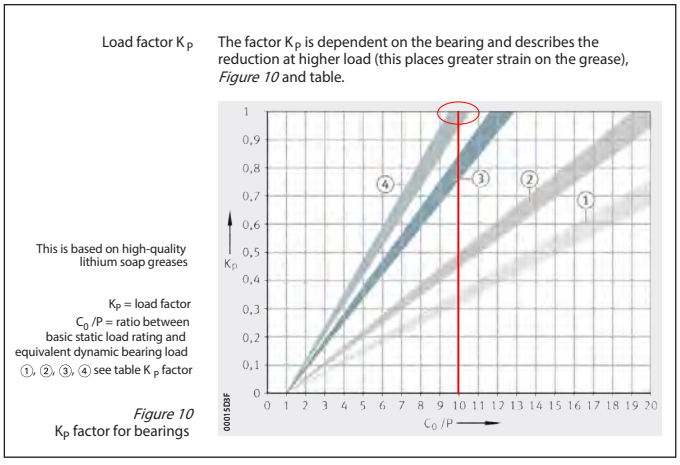


Figure 3—https://www.schaeffler.com/remotemedien/media/_shared_media/08_media_library/01_publications/schaeffler_2/catalogue_1/downloads_6/gl1_de_en.pdf

Let us try solving f_n with K_L: 0.12 and K_p: 1.

$$f_n = \frac{490.77}{1 + 498.78 \cdot K_L^{0.599} + 852.88 \cdot K_P^{0.963} - 504.5 \cdot K_L^{0.055} \cdot K_P^{0.832}}$$

$$f_n = \frac{490.77}{1 + 498.78 \cdot (0.12)^{0.599} + 852.88 \cdot (1)^{0.963} - 504.5 \cdot (0.12)^{0.055} \cdot (1)^{0.832}}$$

$$f_n = 1.26$$

This answer doesn't seem terrible. We can do a little reverse engineering in *Masta* to see if our Kp assumption holds any water. Using all of the same operating assumptions from ISO 15312:

$f_n = 24{,}535/16{,}558 = 1.48$

DIN 732 Speed Rating			
Inner Ring Angular Velocity (rev/min)		ω_i	2000
Outer Ring Angular Velocity (rev/min)		ω_e	0
Relative Angular Velocity (rev/min)			2000
Maximum Grease Speed (rev/min)		N_g	18000
Maximum Oil Speed (rev/min)		N_o	18000
Thermal Limiting Speed (rev/min)			24535.8008
Thermal Limiting Speed f0		f_0	1
Thermal Limiting Speed f1		f_1	0.000199
Thermal Reference Speed (rev/min)			16558.3839
Dynamic Equivalent Load (kN)			0.39
Lubricant Windage and Churning Temperature (°C)	ⓘ		70
Air Convection Heat Dissipation (kW)	ⓘ		0.07257

Working Schaeffler's f_n chart backwards, we see that the K_p value should have been around 0.69. I don't have a quick answer on how to get that number from the formula. This may need some clarification with our ISO folks.

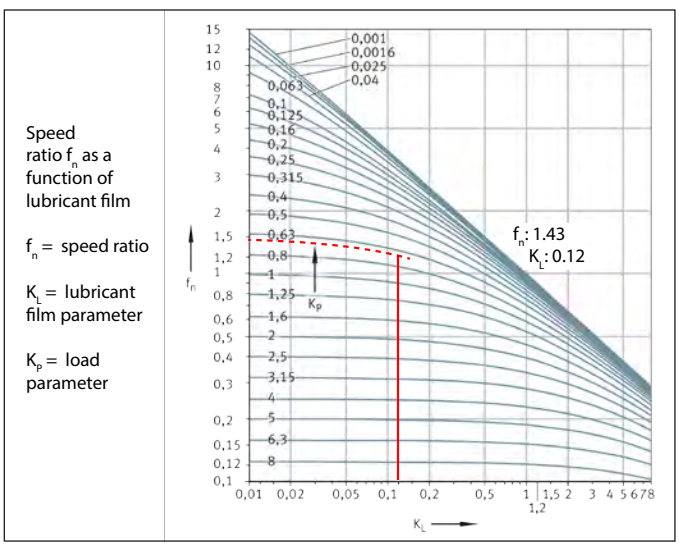
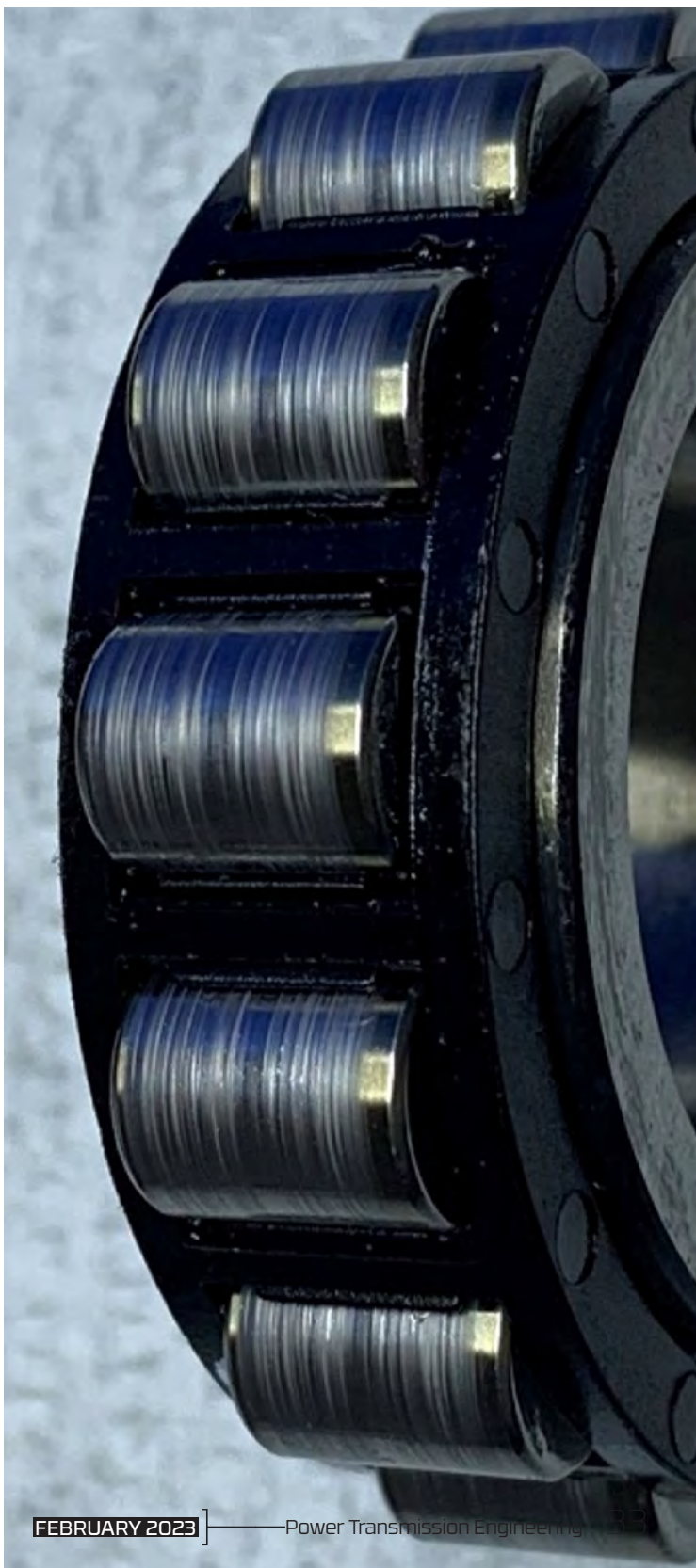
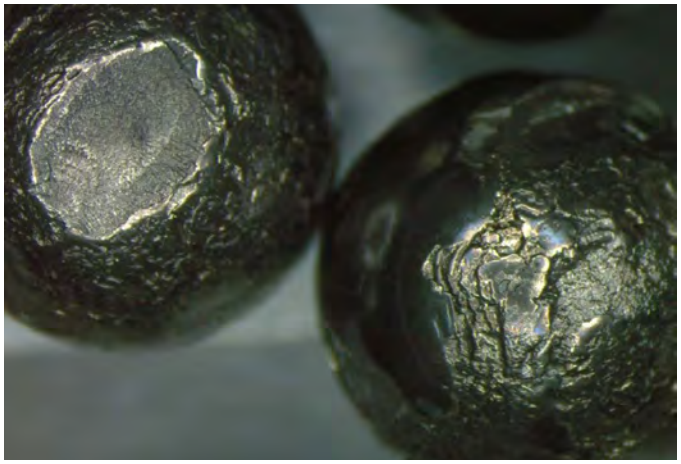


Figure 4—https://medias.schaeffler.us/en/speeds

We can solve that problem another day. Now let's solve our thermally safe operating speed with the software derived speed ratio:

$$n_\vartheta = n_{\vartheta r} \cdot f_n$$
$$n_\vartheta = 13{,}300 \cdot 1.48 = 19{,}684 \text{ rpm}$$





Alright, this is looking more promising. According to this standard, under the given conditions, we should be able to run this 6205 at 19,684 rpm continuously without overheating. *Continuously* is an important note because this means we can likely overshoot this value for brief periods. Of course we must always be cognizant of the mechanical limitations of the cage.

I thought it would be fun to compare some supplier's website results and *Masta* to see if our calculations come close. Many suppliers do not include thermal ratings—these are some of the few that do.

All results using standard 6205, 70°C, 390N Radial load, normal clearance, viscosity 12 mm^2/s	Our Results (using an SKF 6205 load ratings)	Masta	Schaeffler	NSK	SKF
Thermally safe operating speed n_ϑ	19,684	24,535	14,000	14,000	37,800
Thermal Speed Rating $n_{\vartheta r}$	13,300	16,558	14,400	14,000	28,000
Limiting Speed (catalog)	18,000	18,000	19,600	15,000	18,000
Comments	Used Masta to solve speed	SKF 6205	Most Conservative	Coincidence that n_ϑ = $n_\vartheta r$. Values diverge w/ changing variables	Likely need ceramic balls and custom cage to hit this n_ϑ

I am pretty satisfied with these results. Our hand calculated numbers are not as aggressive as *Masta*, but higher than the limiting speed—just what I would expect. Schaeffler and NSK are on the conservative side, but I strongly suspect you would receive better numbers with an application review. You should consult your SKF representative about their numbers.

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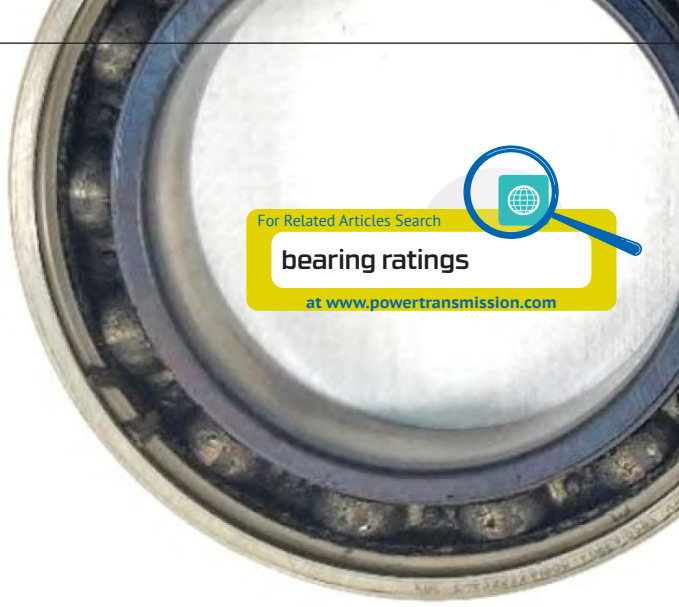

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Nomenclature

n_ϑ—Thermally safe operating speed RPM.
$n_{\vartheta r}$—Thermal speed rating.
f_n—Speed ratio.
N_R—Frictional power kW.
$\dot{Q}$—Total dissipated heat flow W.
M_R—Total frictional torque Nmm.
f_0—Bearing factor for frictional torque as a function of speed.
ν—Kinematic viscosity of the lubricant at operating temperature mm^2/s.
f_1—Bearing factor for frictional torque as a function of load.
P_1—Decisive load: radial load for radial bearings, axial load for axial bearings N.
$\dot{Q}_S$—Heat flow dissipated via the bearing seating surfaces kW.
$\dot{Q}_L$—Heat flow dissipated by the lubricant kW.
$\dot{Q}_E$—Heat flow. For heating by external source (+), for cooling by external source (–).
K_L—Lubricant parameter.
K_P—Load parameter.
K_q—Heat transfer coefficient 10^{-6} kW/(mm² · K) Heat transfer coefficient, as a function of the bearing seating surface. This is dependent on the housing design and size, the housing material and the installation position. For normal installation, the heat transfer coefficient for bearing seating surfaces up to 25,000 mm² is between $0.2 \cdot 10^{-6}$ kW/(mm² · K) and $1.0 \cdot 10^{-6}$ kW/(mm² · K).
A_S—Heat-dissipating bearing seating surface mm^2.
$\Delta\vartheta_A$—Difference between mean bearing temperature and ambient temperature K.
$\dot{V}_L$—Oil flow l/min.
$\Delta\vartheta_L$—Difference between oil inlet temperature and oil outlet temperature K.
B—Bearing width mm.
d—Bearing bore diameter mm.
d_M—Mean bearing diameter (D + d)/2 mm.
D—Bearing outside diameter mm.
d_1—Outside diameter of shaft locating washer mm.
D_1—Inside diameter of housing locating washer mm.
T—Total width of tapered roller bearing mm.

Norm Parker is currently the Sr. Specialist Roller Bearings—Propulsion Systems at Stellantis. He's been contributing to *PTE*'s "Bearings with Norm" blog since 2014.

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Reliable, User-Friendly Planetary Gear Unit Design

Stöber relies on *FVA-Workbench* for drive verification

FVA GmbH

Stöber Antriebstechnik GmbH + Co. KG rely on the *FVA-Workbench* for dimensioning and verification of their drives. The calculation and simulation software allows Stöber engineers to develop their innovative gear unit solutions more quickly and efficiently. The result: higher quality products.

Stöber uses the *FVA-Workbench* for dimensioning and verification of their standard gear units as well as customized applications and special gear units. A wide range of design objectives are considered, such as load capacity, excitation of vibrations, power loss, and efficiency. Designing modular planetary gear units involves the planetary gear unit stages of an entire series, consisting of different dimensions and gear ratios. With the *FVA-Workbench's* integrated scripting feature, these tasks can be implemented quickly and without special programming knowledge. Thus, countless calculations can be carried out, that would be very time-consuming without suitable software.

Scripting Makes it Easy to Perform Mass Calculations

For the design of planetary gears, Stöber's engineers first consider the macrogeometry taking various restrictions into account, such as installation space, manufacturing, and cost-effectiveness. Characteristics such as load capacity, power loss, or vibration are largely influenced by the gearing geometry. This development step is crucial for the excellent operating characteristics of Stöber drives. Customer-specific requirements can also easily be included in the design.

The possibility of performing mass calculations during gear unit

Figure 1—The* FVA-Workbench *makes mass calculations easy.

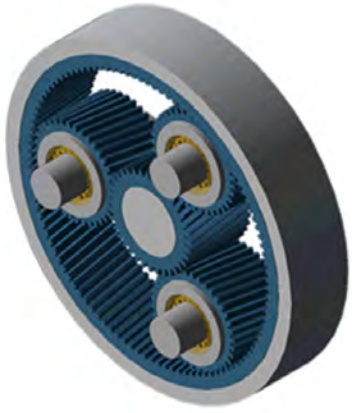

***Figure 2—Planetary gear unit design using the* FVA-Workbench.**

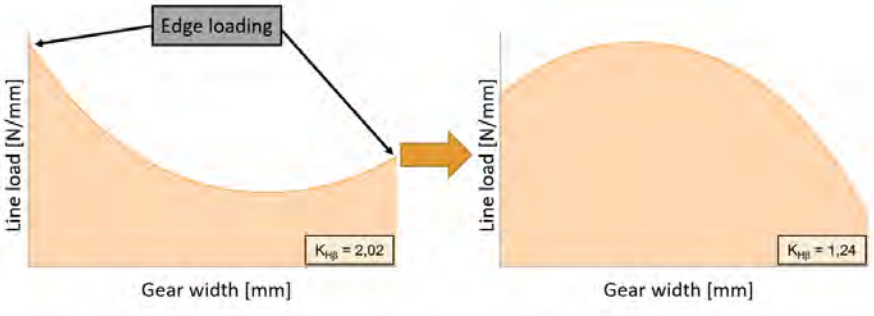

Figure 3—Calculation variants with and without flank modifications from the* FVA-Workbench *output report.

design helps engineers to determine perfect gear unit solutions. In the *FVA-Workbench*, the integrated scripting feature is used to perform mass calculations. In a preparatory step, the parameters to be varied (such as the helix angle, module, center distance, profile offset, and load information) are pre-defined in an *Excel* spreadsheet. The script then prepares a calculation plan and executes the mass calculations for each variant one-by-one. Scripting uses a pre-defined *FVA-Workbench* model, which is manipulated for each respective variant calculation. This way, several thousand variants can be calculated automatically within a very short time. The *FVA-Workbench's* excellent HTML-based reporting feature is used to evaluate the calculations. This format allows the engineer to select the results to be evaluated. The data can also be visualized and saved. Time-consuming searching through overflowing PDF files is no longer necessary. The scripting feature also makes it easy to export results to Excel for further evaluation.

The microgeometry is designed similar to the macrogeometry. Flank and profile modifications are varied, pre-defined in an Excel spreadsheet, read by the *FVA-Workbench*, and processed by the scripting tool. Figure 3 shows an example of two calculation variants from an *FVA-Workbench* report, with and without flank modification. Bearing and component stiffnesses can of course also be included in the calculations.

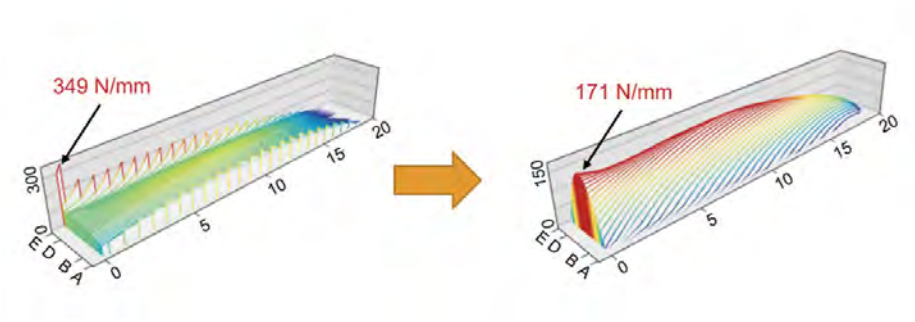

***Figure 4 — Visualization of the pressure distribution without (left) and with (right) profile modifications in the* FVA-Workbench.**

The *FVA-Workbench* includes several options for considering the planetary carrier stiffness. Early in the design phase, the approximate planetary carrier geometry can be predefined, exported via CAD interfaces, and configured by the engineer for production. Once the finished planetary carrier is available as a CAD component, it can be imported into the *FVA-Workbench* and meshed using internal tools. No specialist FE calculation knowledge is required, and comprehensive user guidance guarantees reliable results. The FE mesh can then be evaluated and optimized as necessary using FVA-validated methods. Alternatively, FE meshes of existing models can be loaded.

The *FVA-Workbench* can also be used to evaluate the local pressure distribution, with clear 3D visualization. Figure 4 shows an example of the comparison of two calculation variants, with and without profile modification. In addition to the local load distribution, several other characteristics can be calculated and used to make statements about the operational performance of individual components as well as the entire system.

A Solution for Reliable and Efficient Product Development

What used to require serial control of individual calculation cores with in-house developed software now takes place completely within the *FVA-Workbench*. This has greatly simplified integration and maintenance of Stöber's calculation landscape, allowing them to focus on their core business while also achieving a significant gain in performance in gear unit design. With its integrated scripting feature, the *FVA-Workbench* is perfect for designing entire modular systems. Powerful visualization and HTML-based reporting offer almost limitless possibilities for comparing individual calculation variants.

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Unconventional Gear Profiles in Planetary Gearboxes

Anand Varadharajan, Pablo Lopez Garcia, Stein Crispel, Bram Vanderborght, Dirk Lefeber and Tom Verstraten

Gear wheels have been used for transmitting motion since the third century BC (Ref. 1). Yet, the evolution of this transmission technology continues to date and finds its inevitable need in numerous applications. The multifaceted advancements in design, material, tribology and other areas collectively help the improvement of transmission efficiency, noise vibrational performance, durability and effective manufacturability of the gears (Ref. 2). Today, gearboxes are inevitable in numerous applications requiring high power density including wind turbines, electric vehicles, cranes, robotics, etc. A combination of high-ratio gearboxes with high-speed, low-torque motors is often used to achieve high power density (Ref. 3). Planetary gear trains (PGTs) help achieve a high gear ratio in a compact arrangement. Several configurations of planetary gears are widely studied in Refs. 4–8 where the gear profiles used in these studies are primarily involute.

From simple geometries like straight profiles to cycloids and then to the involutes, the evolution of gear profile geometry has taken centuries (Refs. 9 and 10). The concept of profile shifting and the CNC manufacturing process that began in the late 1970s marked an important revolution in transmission systems and helped the manufacturing of precise and mass quantities of standardized gears. To this day, involute gears have found their use in every possible application despite their continuous betterment. The strongly established standards and guidelines like AGMA have provoked the large commercialization of involute gears. Numerous computation and design software including *KISSsoft, ROMAX, Simcenter, MESYS,* etc. help in involute gear design and analysis. These softwares not only help to design simple gear trains but also enable us to optimize the design based on the contact/meshing performance and manufacturability. Although the advantages of involute gears like easy manufacturability, and insensitivity to center distance deviations are critical for its choice, the well-established standards in the previous decades and mass commercialization compels the use of involute gears. Because of this, the developments on other gear profiles (non-involutes) are very limited to this date despite the enormous advancement in high-precision manufacturing technologies (Ref. 11).

The downsides in involute gears like high-sliding velocities at the meshing extremes and low surface-load capability can be overcome with other gear geometries like cycloids and circular arcs (Ref. 12). Typically, the modifications are classified based on gear profile, flank and lead parameters (Ref. 13). The research works of Parsons (Ref. 14) show lead and flank modification of gears that help increase the load-carrying capacity of gears and better noise characteristics while Shen et. al. (Ref. 15) and Berlinger (Ref. 16) employ profile modification for achieving high efficiency and load-carrying capacity respectively. Yet, increased transmission error and sensitivity to manufacturing inaccuracies deter the usage of these unconventional gear profiles.

Through this paper, a review of unconventional gear profiles in planetary gear is presented and how future research in this direction benefits several applications. The analyses of different gear profiles show that some unconventional gear profiles have better meshing efficiency and load-bearing capacity than the involute gears. However, they are heavily constrained by their high transmission error and manufacturing inaccuracies.

"Overview of planetary gear trains and increasing the overall efficiency" provides an overview of planetary gear trains (PGTs) to understand the importance of high meshing efficiency in extreme gear ratios. In "Critical parameters to evaluate different gear profiles," a short description of the evaluation criteria of different gear profiles is briefed. "Unconventional gears in PGT" reviews planetary gearboxes with non-involute gear profiles from the literature and the potential gear profiles that can help to improve the efficiency of the high-ratio gearbox. Finally, a discussion on the confrontation of different gear profiles based on the evaluation criteria is provided in "Discussion" which is followed by conclusions and recommendations in "Conclusions."

Overview of Planetary Gear Trains and Increasing the Overall Efficiency

Planetary gears are compactly arranged gear trains that achieve high gear ratios with good efficiency. Traditionally, large gear ratios are achieved by coupling several planetary gear stages together which is known as a stacked arrangement—refer to Figure 1 (left). The efficiency of multistage PGTs (or stacked PGTs) is high (above 90%) even at gear ratios around 100:1 (Refs. 17, 18). However, the involvement of several stages is a severe downside of these gearboxes thereby becoming a bulky, heavy, and costlier solution.

On the other hand, an extremely compact arrangement of planetary gear trains known as the Wolfrom configuration (also called bi-coupled-PGT, differential-PGT or 3K-PGT) is an extremely power-dense transmission system that however comes at the cost of very low efficiency, refer to Figure 1 (right), (Refs. 4, 5, 8, 19, 20).

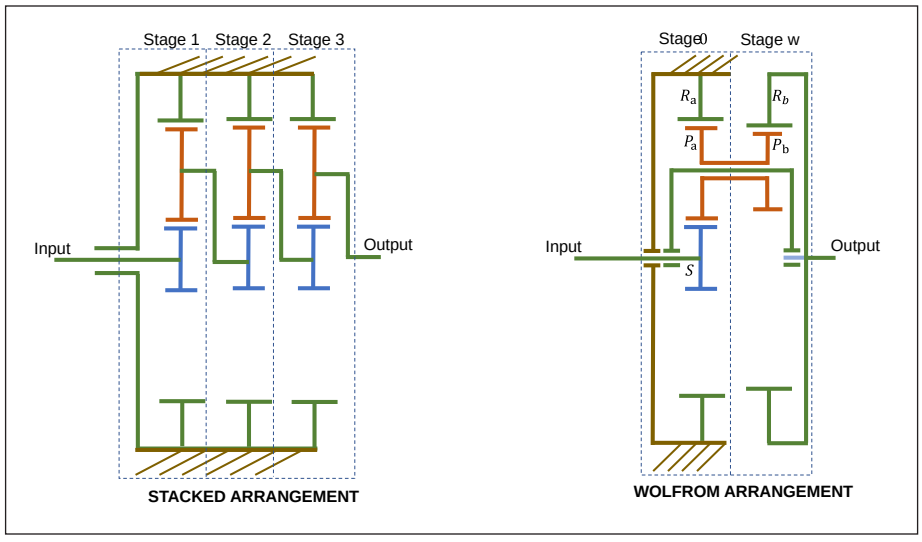

Figure 1—Planetary gear train configurations: (Left) stacked arrangement, (Right) Wolfrom-PGT.

This type of gearbox has the potential to bring a massive transformation in several applications due to its high-torque-density nature. Yet at this juncture, they are restricted to extremely poor efficiency at high reduction ratios due to latent power inherent to this configuration (Refs. 21, 22).

Wolfrom gearbox efficiency is characterized by the gear ratio and the meshing efficiency of involved gear pairs. From (Ref. 4), the Wolfrom gearbox efficiency is given as:

$$\eta_{Tot} = \frac{1 + \frac{H_i}{i_0} - H_e\left(1 - \frac{1}{i_0}\right)}{1 + H_i\, i_w + H_i(i_w - 1)} \quad (1)$$

$$H_i = 1 - \eta_i \;\; and \;\; H_e = 1 - \eta_e \quad (2)$$

$$i_0 = 1 + \frac{Z_{Ra}\, Z_{Ps}}{Z_{Pa}\, Z_S}\;;\; i_w = \frac{1}{1 - \frac{Z_{Ra}\, Z_{Pb}}{Z_{Rb}\, Z_{Pa}}} \;\; and \;\; i_{tot} = i_0 \cdot i_w \quad (3)$$

where

η_{Tot} is the total efficiency of the gearbox

i_0, i_w, i_{tot} are the gear ratios in stage-0, stage-w and total gearbox respectively

H_i, H_e are the gear loss factors in internal and external gear meshing respectively

η_i, η_e are the meshing efficiencies in internal and external gear meshing respectively

Z is the number of teeth in the respective gear wheels

This shows that in a Wolfrom planetary gear train (differential), the meshing efficiency of gears is extremely crucial as the gear ratio increases. Figure 2 is a representative example of a Wolfrom-PGT where the evolution of a gearbox efficiency is plotted in function of gearbox ratios for different meshing efficiencies (Ref. 23). For high gear ratios (e.g., 300:1), even a small increase of 0.5% in meshing efficiency will decrease the gearbox loss by more than one third of the initial loss.

High gearbox efficiency is of paramount importance not only to reduce energy losses but also to have better backdrivability. Backdriving is the principle of switching the natural input and output of the gearbox (Ref. 21). Hence the power flow from the input (motor) to the output (load) is reversed where a reducer gearbox becomes then a multiplier. This is one of the key characteristics deemed in several modern applications including collaborative robotics (Ref. 24). The gearbox in general is backdrivable when the overall efficiency is more than 50% in normal operation—forward driving—(Refs. 25, 26).

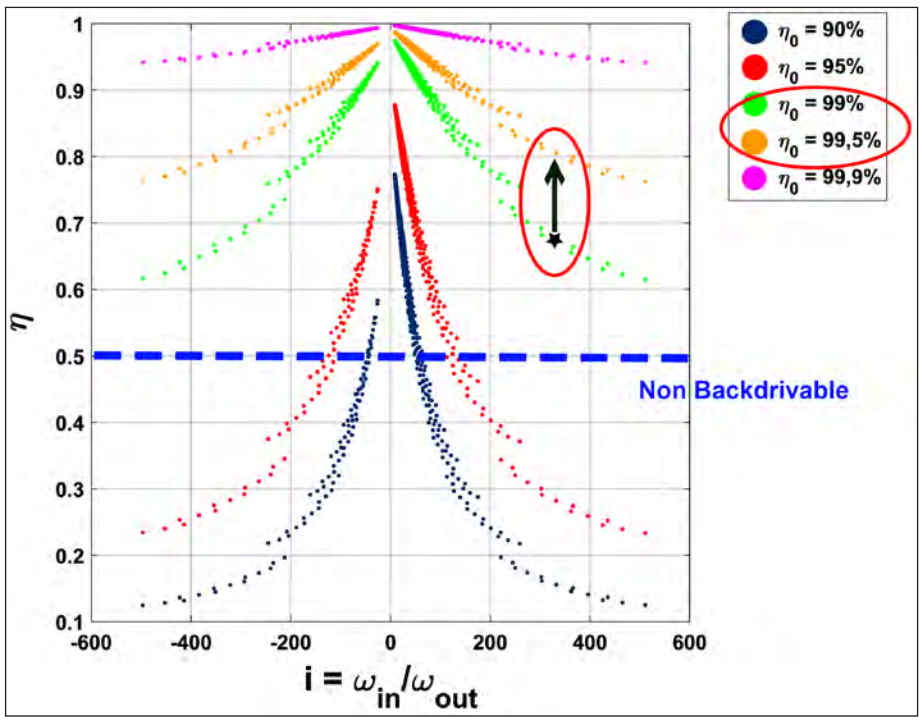

Figure 2—Evolution of gearbox efficiency for a three-stage PGT in the function of gear ratio for different meshing efficiency from (Ref. 23).

Critical Parameters to Evaluate Different Gear Profiles

The gear performance can be characterized based on several phenomena even if it is involute or non-involute gear. Namely the load-carrying capacity, meshing efficiency, manufacturability, vibrational behavior and lifetime, etc. The primary criteria to evaluate the different gear profile geometry are discussed further.

Meshing Efficiency

The power loss in gears is associated with both loaded and no-load conditions as described in (Ref. 27). The meshing losses can be calculated from:

$$\eta_{i,e} = \frac{[P_{IN} - \Sigma(P_{VZP} + P_R)]}{P_{IN}} \quad (4)$$

and

$$P_{VZP} = P_{IN} \cdot \int_0^b \int_A^E F_N \; v_s \; \mu \; d\theta \cdot db \quad (5)$$

where

$\eta_{i,e}$ is the meshing efficiency of gears

P_{IN} is the input power (kW)

P_{VZP} is the load-dependent power loss integrated along the path of action-AE and facewidth-b (kW)

P_R is the summation of all other losses due to gear no-load, bearings, lubrication, seals, etc. (kW)

μ is the coefficient of friction

F_N is the normal force acting on the gear tooth (N)

v_s is the sliding velocity of the gears in mesh (m/s)

d_θ,d_b are the integrating segments along the line of action (rotation) and the facewidth of the gears

Load Carrying Capacity

Gear wheels in action are characterized by the load transmitted and to what extent of efficiency. This is mainly dependent on the bending stress at the root and the contact stress at the surface of the teeth which influences their performance and lifetime. Considering the real operation, several factors depending on uniform/varying loads, lubrication conditions, and accuracy of manufacturing are derived from the standards and incorporated into the stress formulae.

Bending Stress

The gear tooth fillet or the root stress is responsible for the breakage or tooth rip-off failure in gears. It is calculated assuming the cantilever beam principle and given by Equation 6. AGMA standards use additional factors considering manufacturing deviations, uniformity of load, distribution pattern in the helical system, fatigue profiles etc. (Ref. 28).

$$\sigma_B = \frac{6\,hF_t}{l\,t^2} \quad (6)$$

where

h is the height of the load point from the tooth root (mm)

F_t is the tangential force of the tooth (N)

l is the facewidth (for spur gears) or effective length along facewidth (for helical gears) (mm)

t is the thickness of the tooth at pitch circle (mm)

Contact Stress

The contact stress in gears is responsible for the surface failure of the gear tooth. This failure leads to the pitting and scoring on the gear tooth affecting the lifecycles of the gears. The fatigue property of the material is critical to this stress. As a general approximation in involute gears, the contact stress is given by the Hertz formula (Ref. 28):

$$\sigma_c = \sqrt{\frac{F_N}{\pi\left(\frac{1-\nu_1^2}{E_1} - \frac{1-\nu_2^2}{E_2}\right)} \cdot \frac{1}{L\left(\frac{1}{\rho_1} \pm \frac{1}{\rho_2}\right)}} \quad (7)$$

where

F_N is the normal force (N)

ν_1,ν_2 are the Poisson ratios

E_1,E_2 are the Young's modulus

L is the facewidth (for spur gears) or minimum length of contact (for helical gears) (mm)

ρ_1,ρ_2 are the effective normal radii of curvatures of gears with + for external and for internal gears

The contact stress is calculated along the tooth surface at each point of contact. In general, the maximum load point corresponds to the single tooth of action where the entire load is concentrated to one pair of gear teeth.

Transmission Error

For a given gear ratio, the deviation in the rotation of the gear for an equivalent rotation of pinion is called the transmission error. Transmission error is responsible for the noise and vibration of gears. The transmission error is an effect of both the gear design aspect and manufacturing inaccuracies of gears. The design aspect comprises tooth deflections based on the load and the profile/lead modifications done to the gear profile for uniform wear patterns, etc. (Ref. 29).

The change in relative stiffness between gear teeth is kept to a minimum level for low vibration and noise conditions in gears which is handled by maximizing the gear contact ratio (Ref. 30). However, as the contact ratio increases along the transverse plane, the meshing extremes are far from the pitch point and thus the sliding velocities are high which is a trade-off in terms of meshing efficiency. On the other hand, it can be seen as an effective length of deformation during the meshing cycle; the more the gear teeth deform during meshing, the larger the area of the wear and thus the larger the friction and the power losses are. This can also be understood with the expressions given in "Meshing efficiency" where the necessity for keeping the sliding velocity low to reduce the power loss is evident.

Unconventional Gears in PGT

In recent years, non-involute gears have started finding their place in high ratio gearboxes to increase the efficiency and load-carrying capacity of gearboxes. The advancements in rapid prototyping and precision manufacturing methods further enable fabricating complex geometries in a relatively efficient manner that supports testing and advanced analyses of gears. In the following section, some planetary gear trains that exclusively use unconventional gears are reviewed and their characteristics are discussed.

PGT with Nonstandard Involute Teeth Geometry

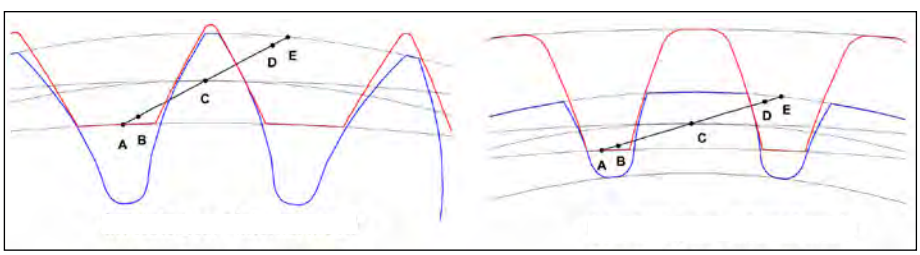

Figure 3—Internal meshing of low-loss gears (Ref. 6).

Low-loss gears described in Ref. 31 are optimized gears for high meshing efficiency. Although the fundamental tooth shape is involute, the low-loss gears involve unconventional profile modifications to a large extent as shown in Figure 3. The tooth has reduced addendum, large pressure angle, small module and large helix angle and facewidth which contributes to decreasing the transverse contact ratio in gears. Although the increase of the helix angle, in principle, leads to a larger power loss (Ref. 31), the effect is countered by the increase in pressure angle and reduction of the gear modulus. Since the transverse contact ratio (ε_α) is kept to a minimal value, the meshing region involves a shorter approach and recess lengths leading to lower sliding velocities. To maximize the load-carrying capacity, the total contact ratio ($\varepsilon_\alpha + \varepsilon_\beta$) is maintained by increasing the overlap ratio (ε_β) of helical gears.

Since low-loss gears have high meshing efficiency, this helps when used in a Wolfrom configuration to reach high gear ratios in a compact way and yet with good efficiency. Ref. 6 describes three different configurations of PGTs in which low-loss gears were tested initially. The results from Ref. 32 also prove that the weight of the Wolfrom gearbox is nearly reduced by 50% compared to the conventional planetary gear train of the same gear ratios although the overall efficiency deteriorates due to the configuration itself. Such a gearbox will be highly beneficial in high torque applications like wind turbines and automotive gearboxes if the efficiency could be further improved (Ref. 33).

As the involutes are the base geometry of the gear tooth profile, the manufacturability is said to be standard. Compared to the standard involute gears, the low loss gears exhibit large meshing stiffness and are more prone to manufacturing inaccuracies (Ref. 34). With the reduction in transverse contact ratio, the contact happens thus in a small domain consequently increasing the noise generated.

PGT with Cycloid Teeth Geometry

The convex-concave gears discussed in Ref. 35 share the basics of cycloidal gear teeth where the curve of action is an S-shape curve defined by two individual radii corresponding to the pinion and gear as shown in Figure 4.

The shape of the corresponding gear tooth following this curve of action is derived from differential geometry and gearing law (Ref. 36). The meshing efficiency of convex-concave reaches similar levels to that of involute gears for an ideal profile curvature. However, the loading condition significantly varies during the approach and recess cycle in the meshing.

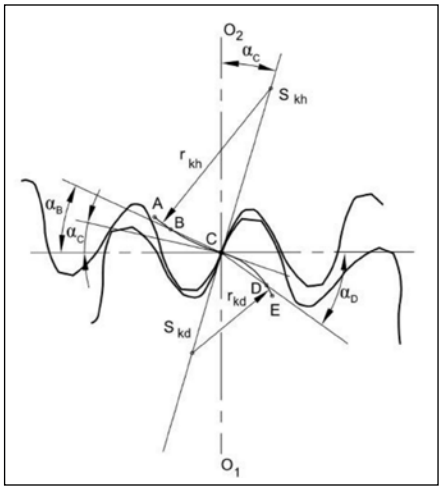

Figure 4—Meshing of convex-concave profile gears from (Ref. 35).

Compared to involutes, the convex-concave gears are gradually loaded and the peak load is taken by the tooth at the pitch point where the pressure angle is the least. Away from the pitch point, the pressure angle increases and therefore the load on the tooth is also lesser. The high sliding velocities at the start and end of meshing present in involute gears are eliminated with the convex-concave gears also due to the curved meshing action.

Brumercik et al. presented a reduced planetary gearbox with a convex-concave gear tooth profile (Ref. 37). The authors developed a small prototype to test this gear profile for a gear ratio of above 70:1 where Nylon 6.6 (PA66) gears were used. The results showed a favorable relative sliding between gears compared to the involute profile. Although the rapid prototyping method used is subject to manufacturing inaccuracies, such a small and lightweight gearbox could be used in applications such as a car's rear-view mirror.

PGT with Circular Arc Teeth Geometry

Double-circular arc gears were initially proposed by Litvin (Refs. 38, 39) which was derived based on the Wildhaber and Novikov circular arc gears (Refs. 40, 41). The double-circular arc gear proposed by Litvin is characterized by three circular arcs: one on the crown part, one on the base part and the other connecting the formers as shown in Figure 5 (top). Later, Wang (Ref. 42) adapted this profile to overcome the discontinuity in profile curves and proposed a new type of double-circular arc gears as shown in Figure 5 (bottom).

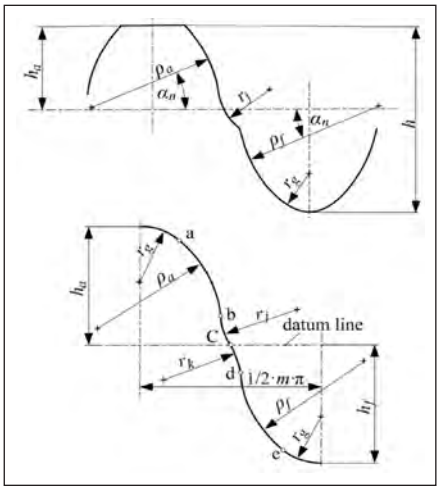

Figure 5—Double-circular arc gears proposed by Litvin (top) and Wang (bottom). Image adapted from (Ref. 52).

Due to the concavity and convexity nature of meshing and the resulting lower surface stress, this type of profile can handle much more torques and spans longer life compared to similar-size involute gears. Further, there is no limitation in the number of teeth, unlike involute gears. This type of gear is extremely sensitive to manufacturing inaccuracies and center distance deviations that reduce efficiency.

Wang analyzed the influence of these profiles by using them in a conventional planetary gear train (Ref. 42). The three-stage stacked planetary arrangement studied by the author had a gear ratio of 103:1 with the first two stages of 5.143:1 each and the last stage 3.9:1 gear ratio respectively. Due to its lower efficiency and high

load capacity, this kind of gearbox finds its better suitability in winch applications (Ref. 42).

Other Gear Profiles

Several other gear profiles exist apart from the ones mentioned above. A review of non-involute gear profiles by Okorn (Ref. 43) summarizes the design and capability of each profile. The unique profiles for which the meshing efficiency is deemed to be better than involute gears and can be of interest in using in Wolfrom gearboxes are discussed below:

S-gears

The S-gears developed by Hlebanja (Ref. 44) are generated by a specific rack design. The rack generates a specific concave-convex gear profile for which the meshing curve is in the shape of "S" as shown in Figure 6.

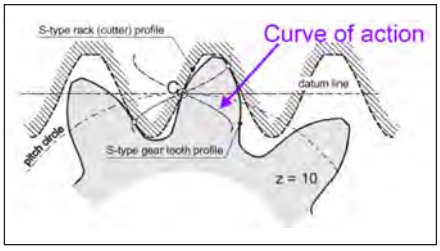

Figure 6—Rack cutting S-gears adapted from (Ref. 56).

S-gears show a good load-carrying capacity because of their broader tooth root and concave-convex meshing compared to involutes. Additionally, since the relative sliding velocities are reduced during the start and end of meshing, the power loss due to friction is lower. These gears initially used in rolling mills are now finding their use in several applications. The S-gears-based high ratio gear drives described in Ref. 45 are used mainly in marine, aircraft and robotic applications.

Pure Rolling Helical Gears

Pure rolling helical gears described by Chen et al. (Ref. 46) are based on a circular arc gear tooth geometry. The circle inscribed for the tooth geometry has the center in the tangent connecting the base cylinders of the gears in the mesh as shown in Figure 7. The radius of this circle is shorter than the length from the tangent point on the base circle to the pitch point. In other words, the radius of curvature about the pitch point is shorter compared to the equivalent involute gears. Additionally, these gears use the Hermite function to obtain the root fillet radius. A convex-convex meshing happens and as a result, the load transmission is restricted to a very small region increasing the contact stress and promoting more rolling action in gears. The local deformations in the gear tooth still exist and minimal sliding is expected to happen. The application of this gear profile to internal gears and high-ratio gear drives has not been analyzed yet. Additionally, their experimental performances are also not known yet.

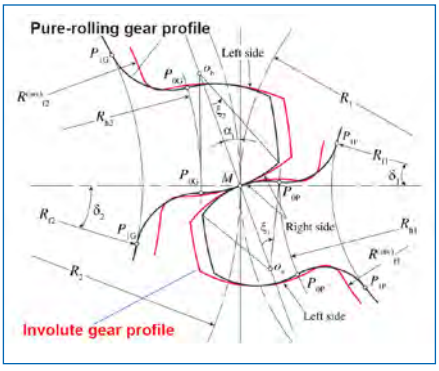

Figure 7—Pure rolling gear profiles in mesh adapted from (Ref. 46).

Involute-Cycloid Composite Gears

Cycloidal and involute gears have their own individual advantages and disadvantages. But the advantages of these two gears were combined in the involute-cycloid composite gears discussed in Ref. 47. As shown in Figure 8, the profile geometry is composed of epicycloid and hypocycloid for the addendum and dedendum extremes respectively and a portion of involute only around the pitch diameter region.

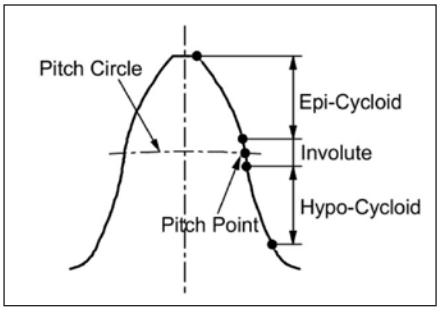

Figure 8—Involute-cycloid composite gear profile (Ref. 47).

Because of the involute profile around the pitch diameter, the action curve is linear to a limited extent about the pitch point of the meshing curve and making this gear less sensitive to the center distance deviations. The cycloid tooth profile increases the surface-load capacity and reduces the sliding velocities considerably at the meshing extremes. Therefore, the involute-cycloid composite gears have better meshing efficiency. Due to the involvement of cycloid for the dedendum part, undercutting is avoided, and small numbers of teeth could be realized. While the contact stress values are better compared to involutes because of the convex-concave contact, the root bending stress values see a significant increase due to reduced root thickness (Ref. 48).

Discussion

A comparison of high ratio planetary gear trains having different tooth profile geometries is provided in Table 1. Amongst the candidates, two variants of Planetary gear trains that were discussed initially are identified: namely the Stacked and Wolfrom arrangement. For the involute-profile PGTs, characteristic examples of commercial gear heads and novel gearboxes from the literature are also compiled. The transmission ratio of around 100:1 is observed for all the examples except one for which the gear ratio is 70:1.

Most of the planetary gearboxes with non-involute gears gathered from the literature use Wolfrom configuration to test their gear potential. This shows that the Wolfrom PGTs are a better way to study the significance of gear profile changes since the meshing losses are amplified due to internal latent power (Refs. 21, 22). The other parameters of these examples including dimensions, peak torque, and efficiency could not be directly evaluated against each other considering the difference in material and size range of every gearbox, which is also a strong limitation of this study. The meshing efficiency of unconventional gears (non-involute) presented in the table is below that of standard involutes and low loss gears. This shows there are still better non-involute gear profiles in terms of meshing efficiency other than the ones described here but their complete performance in the Wolfrom gear remains to be analyzed.

Parameters	Profile Shape / Units	Involute	Involute	Involute	Involute	Low loss gears	Cycloid teeth	Circular arc
Reference	-	Neugart PLE40 (18)	ZF (49)	R2Power (26)	BDG (25, 50)	(32)	(37)	(42)
PGT type	-	Stacked	Wolfrom	Wolfrom	Wolfrom	Wolfrom	Wolfrom	Stacked
Number of stages	-	3	2	3	2	2	2	3
Transmission ratio	-	100:1	107:1	125:1	97:1	125:1	70:1	103:1
Overall dimension (ØxL)	mm x mm	40x88	220 x 114	98x68	94x62	~170x55*	~30 x 20*	n/a
Material	-	Steel	Steel	Steel	Steel	Steel	Nylon 6.6 (PA66)	Steel
Weight	kg	0.5	16	1.56	1.1	~9.9*	n/a	n/a
Max. Output torque	Nm	14	700	120	90	n/a	0.052	3.34
Torque/weight	Nm/kg	28	43.75	76.92	81.8	-	-	-
Meshing efficiency	%	$\eta_{i,e}$~99*	$\eta_{i,e}$~99*	$\eta_{i,e}$ - 99	η_e - 97.7 η_i - 99.6	$\eta_{i,e}$~99.3*	η_i - 99 η_e - 98	$\eta_{i,e}$~97.5
Gearbox efficiency	%	98	79	69	93	97.43	73.76	77.87

* estimated, n/a: information not available

Table 1—Comparison of Planetary gear trains with non-involute profiles.

Table 2 gives a comparison of unconventional gear profiles discussed in the previous section and their performance levels. The analysis shows that although low-loss gears have very good efficiency, they suffer from increased bending and contact stresses and transmission error due to a limited contact ratio, which is a strong disadvantage. The cycloid gears, involute-cycloid composite and the double circular arc gears have nearly similar performance capabilities because of their similarity in convex-concave contact between meshing gears. However, their sensitivity to center distance deviations and manufacturing errors poses limitations. Pure rolling gears and the S-gears, on the other hand, perform better in terms of efficiency and bending stress but the surface stress limits of pure-rolling gears are critically lower due to the convex-convex contact nature. Both S-gears and pure rolling gears are subject to high transmission error because of the reduced contact ratios. Even though the sensitivity to center distance deviation is influential to a limited extent in S-gears because of the local line of action (instead of a curve), S-gears are prone to manufacturing inaccuracies. The non-involute gear profiles in general, can improve meshing efficiency and load-carrying capacity of gears compared to the standard involute gears. If their transmission error and manufacturability aspects are improved compared to standard involute, their usage in high ratio PGTs could be beneficial.

Property / Gear	References	Meshing efficiency	Bending stress	Contact stress	Transmission error	Manufacturability
Low loss gears	(6, 31, 32)	++	−	−	−−	++
Cycloid gear	(36, 37)	+	+	++	−	−
Double-Circular arc gears	(39, 51)	+	+	++	−	−−
S-gears	(52, 53)	+	++	++	−	+
Pure rolling gears	(54, 55)	++	+	−−	−−	−
Involute-cycloid composite	(47, 48)	++	+	++	−	−

Table 2—Comparison of unconventional gear profiles that are used in the Planetary gearbox or favorable to use to have a better efficiency. Based on the referred articles and simulations, the candidates are rated from poor (− −) to best (++).

Conclusion

The overall efficiency of high-ratio planetary gear trains with involute gears drops severely at reduction ratios of several hundred. Other unconventional gears could help solve this problem by achieving better meshing efficiencies than involute gears. A review of planetary gear with unconventional gears is presented in this paper. Several research groups already work individually on different non-involute gear profiles and the analyses show that the Wolfrom-gearbox—a compact type of planetary gear to achieve high ratios—is predominantly used to test the changes in gear profiles compared to the conventional stacked PGTs type.

A set of evaluation criteria that are fundamental to assessing gear profiles are briefed after which the design, performance and use of a few non-involute gear profiles are then discussed. The non-involute gear profiles like S-gears and pure rolling helical gears play a significant role in improving the meshing efficiency of the gears, while the convex-concave gears (cycloid) handle the contact loads in a better way. However, the real-time performance and absolute degree of improvement are little known yet due to the unavailability of all evidence in the literature. So, a relative comparison is done, and the profiles are confronted.

The non-involute gear profiles can improve meshing efficiency and load-carrying capacity of gears compared to the standard involute gears. But the reduced contact ratio and nonstandard manufacturing techniques have a negative influence on their accuracy, noise and vibration characteristics making them less preferred. Moreover, the dominance of involute gears which are backed by well-established standards undermines the potential of other gear profiles. Leveraging the advancements in present-day manufacturing technology, future research will be focused on improving the key characteristics of gears with high meshing efficiency so that when used in a high-ratio gearbox like Wolfrom, the power loss could be reduced drastically.

PTE

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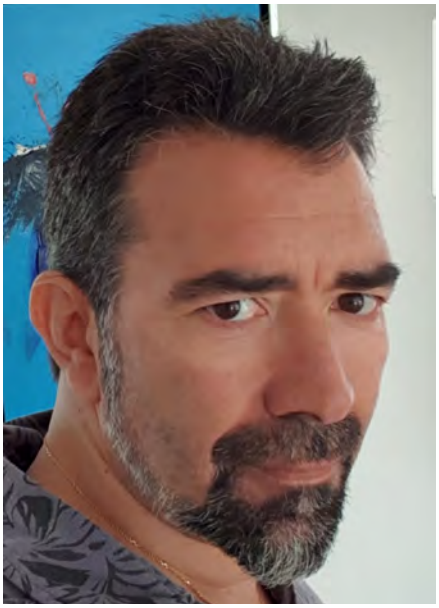
Anand Varadharajan received a bachelor's degree in mechanical engineering from Anna University, Chennai, India, in 2014, and a master's degree in electromechanical engineering from Vrije Universiteit Brussel (VUB), Brussels, Belgium, and the Université libre de Bruxelles, Brussels (under a Bruface joint program), in 2020. Prior to his master's he worked with the KONE elevators as a design engineer for three years. Since 2020, he has been working as a researcher with the Robotics and Multibody Mechanics Group, VUB and his research interests include optimization of gearbox efficiency based on tooth profile modifications.



Dr. Pablo López García was born in Asturias, Spain, in 1972. He obtained a master's degree in industrial engineering with the Escuela Técnica Superior de Ingeniería Industrial de Gijón, Spain, in 1998. After 20 years working in the European automotive industry, he completed a doctorate with the Vrije Universiteit Brussel, Belgium in 2022 on the potential of planetary gear transmissions in human-robot interaction. Since 2021, Pablo is an active member of the AGMA Committee on Robotics and Automation. His research interest are mechanical transmissions for modern robotic actuation.

Stein Crispel was born in Halle, Belgium, in 1994. He received a bachelor's degree in engineering from Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 2015, and a master's degree in electromechanical engineering from the Bruface Joint Master Program, VUB and the Université libre de Bruxelles, Brussels, in 2017. He is currently working toward a doctorate with the Multibody Mechanics and Robotics Research Group, VUB. Between September 2016 and January 2017, he participated in the Swiss–European Mobility Program for a study abroad with the École polytechnique fédérale de Lausanne (EPFL). He received a fellowship from the Research Foundation—Flanders for his doctoral research. His research interests include the study and development of redundant and energy-efficient actuators for applications with varying loads and speeds. His research also focuses on gear transmissions capable of achieving very high gear ratios suitable to be used in combination with electrical actuators for robotics applications.

Prof. dr. ir. Bram Vanderborght obtained his doctorate from Vrije Universiteit Brussel (VUB) in 2007. He performed research at JRL lab in AIST, Tsukuba (Japan) and did postdoctoral research at the Italian Institute of Technology. Since 2009, he has been a professor at VUB. He had an ERC starting grant and is currently coordinating three EU projects on smart and self-healing materials for soft robots. His research interests are human-robot collaboration for applications for health and manufacturing like exoskeletons, prostheses, social robots, drones and cobots. He is affiliated to the Interuniversity Microelectronics Institute (IMEC), Belgium, as scientific collaborator.

Prof. dr. ir. Dirk Lefeber was born in 1956. He received a degree in civil engineering and a doctorate degree in applied sciences in 1986 from Vrije Universiteit Brussel (VUB). He is currently an emeritus Professor with the Department of Mechanical Engineering and the former head of Robotics and Multibody Mechanics Research Group, VUB. His research interests include new actuators with adaptable compliance, dynamically balanced robots, robot assistants, rehabilitation robotics, and multibody dynamics.

Prof. dr. ir. Tom Verstraten received a master's degree in electromechanical engineering and a doctorate from Vrije Universiteit Brussel (VUB), in 2012 and 2018 respectively. In 2020, he became an assistant professor with the Robotics and Multibody Mechanics Research Group, VUB. He was awarded fellowships of the Research Foundation—Flanders for both his doctoral and postdoctoral research, as well as a Fulbright grant for visiting scholars for a research stay at the University of Tulsa from 2018–2019. He also worked in industry as an R&D Engineer with Aquasystems International, Halle, Belgium, from 2012–2013, and as a visiting researcher with Technische Universität Darmstadt, Darmstadt, Germany, in 2017. His main research interests include study and development of energy-efficient actuation systems for robotic prostheses, exoskeletons, and collaborative robots, and elastic actuators and redundant actuation.

Low-Voltage AC Motor Market Grew by 21.2 percent in 2022

With over 200 years of combined experience, Interact Analysis is the market intelligence authority for global supply chain automation. Our research covers the entire automation value chain—from the technology used to automate factory production, through inventory storage and distribution channels, to the transportation of the finished goods. The world's leading companies trust us to surface robust insights and opportunities for technology-driven growth.

Interact Analysis has established itself as the leading market intelligence provider to the motor & drive markets. Our research has guided companies as they benchmark against their competition and plan for future trends.

We have produced an interim update to our 2022 Low-Voltage AC Motor Market report. This report, published in October 2022, will aim to answer key questions being faced by market suppliers.

Updated research from Interact Analysis shows that the low-voltage (LV) AC motor market has fared well in terms of growth over the past few years, largely as a result of higher prices. In 2022 alone, the market grew to $17 billion with prices increasing by around 35 percent to 40 percent in the first half of the year.

As prices rose exponentially in 2022, this allowed for a 21.2 percent growth rate for the LV AC motor market this year. However, it is expected that a slight price decline in the second half of the year will have a knock-on effect on revenue and growth rates. Looking out to 2023, price declines will continue but the volume sold looks set to remain high, matching the 2022 rate. Overall, growth is expected to slow but not fall, as the current economic climate and high-interest rates are likely to influence demand for LV AC motors, particularly within the machinery sector.

The demand for motors tends to mirror the performance of the manufacturing sector. In 2023, LV motors market growth is projected to slow to around 0.29 percent in unit sale terms, with revenues falling by >10 percent due to reciprocal price decreases. The manufacturing sector is also likely to experience slow growth in 2023 because of high-interest rates and economic uncertainty caused by the Ukraine-Russia war. Many customers are thought to have overstocked in previous years and the motor market is emerging from this period of exponential demand. Taking a longer-term look at the market, it is anticipated that 2026 will see a year of economic decline affecting sales.

Low-Voltage AC Motor market experienced exponential growth in 2022 which is to decline significantly in 2023.

The adoption of IE4 motors has been well received by EMEA and legislation regulating the efficiency of motors in the EU continues to be a driving force for the market. While EMEA has tended to produce the highest-priced motors, IE4 legislation has pushed prices up further and has also forced other regions to increase the prices of their LV AC motors. By 2027, almost 30 percent of market revenues in EMEA regions will come from IE4 motors, in part because all 75kW and 200kW motors must be IE4 compliant in 2023. However, the situation in the Americas region is very different due to a lack of regulation concerning IE4, with average selling prices likely to remain stable out to 2027 as they currently sit just behind that of the EMEA region. The APAC region currently holds the lion's share of the LV motor market revenues but there is little in the way of regulation for IE4 motors. The majority of motors produced in the region are IE3 compliant and APAC looks set to be the largest market for lower-efficiency motors out to 2027.

Blake Griffin, Senior Analyst at Interact Analysis comments, "Perhaps the most prominent finding we have from this report is the impact that price volatility is having on market growth. In our previous report, we expected prices to rise to a certain level and stagnate for a few years before declining. We have seen the opposite. The motor market is currently experiencing extreme price volatility and changes in the global economy, making forecasting very difficult.

One of the biggest impacts of the Ukraine war has been the impact on the flow of materials from China to Europe. Historically, materials would flow through the trans-Siberian railway. With the war, this has basically stopped—leading to a significant increase in shipping expenses.

There are a lot of questions about which motor types will win out in the era of IE4 across Europe. With the new IE4 legislation in the EU, the next several years will be telling for where new motor technologies will find traction.

We can, however, confidently predict that prices will decline from 2023 onwards before they begin to stabilize in 2026/2027."

interactanalysis.com

Cummins

COMPLETES ACQUISITION OF SIEMENS COMMERCIAL VEHICLE BUSINESS

Cummins (CMI) recently announced that through its subsidiary Meritor, it has completed the acquisition of Siemens Commercial Vehicles business, a top supplier of high-performance electric drive systems for commercial vehicles. The acquired business will report through Cummins New Power business unit.

The acquisition contributes to Cummins' capabilities in direct drive and transmission-based remote mount electric motors, inverters, software, and related services, critical for the next generation of electric powertrains. The buyout will also add nearly 200 employees, primarily in Germany, China and the United States, which will expand its scope of offering global customers with a wider range of electrified product solutions across commercial vehicle applications.

Cummins is enthusiastic about the acquisition and looking forward to bringing its innovation in its key technologies. The buyout also reflects another key milestone as it bolsters Cummins' strategy to reach net-zero emissions by 2050.

Cummins acquired Meritor in August 2022. The buyout positions Cummins as a leading provider of integrated powertrain solutions across internal combustion and electric power applications. The acquisition adds products to Cummins' components business, offering attractive growth opportunities across the firm's range of power solutions and applications.

cummins.com

Jorgensen

PARTNERS WITH WILL-FILL ON COOLANT MANAGEMENT SYSTEM

Jorgensen Conveyor and Filtration Solutions has entered into a partnership with Will-Fill, a manufacturer of fully automatic coolant monitoring and managing systems. The strategic partnership allows Jorgensen to offer customers complete and worry-free coolant management systems, such as the company's recently launched PermaClean, that provide both filtering and measuring capabilities for an all-in-one solution.With the addition of the revolutionary Will-Fill add-on device, a coolant system can provide trouble-free care of metalworking emulsion by combining automatic measurement and analysis of fluid with faultless filling, permanent conditioning and timely reporting. The Will-Fill components are linked to a high-performance control unit, allowing the device to regulate and adjust the fluid level and the fluid condition automatically. Additionally, it can alert users when attention is necessary via wi-fi or lan network capability.

Will-Fill can be combined with Jorgensen's filtration options, such as PermaClean. Coolant tanks equipped with PermaClean eliminate tank sludge, significantly reducing the labor required for frequent tank cleaning. Plus, when combined with the cyclonic filtration option and a Will-Fill, the system is fully automated and nearly maintenance free.

Will-Fill units are field retrofittable and can be added to almost any machine tool coolant tank and is machine tool brand agnostic.

"At Jorgensen, our goal is to provide customers with systems that make coolant management an invisible process within their machining operations," said Karl Kleppek, president and COO at Jorgensen. "The combination of PermaClean and Will-Fill to our FlexFiltration systems portfolio uniquely positions us to deliver complete, fully automated, maintenance-free conveyor and filtration solutions-allowing users to return their focus to machining."

jorgensenconveyors.com

Clark Seals

HIRES JEFF THOMPSON AS SALES MANAGER

Clark Seals, a sealing technology company, recently announced that Jeff Thompson has joined the company as territory sales manager. In his new position, Thompson will manage sales operations in Texas, Oklahoma, Arkansas, Louisiana, Mississippi and Alabama.

Prior to joining Clark Seals, Thompson served as industrial manager at Parker Hannifin Rotary Seal Division where he successfully expanded sales and strengthened customer relationships. Prior to Parker Hannifin, Jeff served as territory sales manager at JM Clipper. In addition to his professional experience, Thompson holds a bachelor's degree in business administration from Letourneau University.

"Jeff brings a wealth of industry knowledge and professionalism to our organization and will play an important role in our company's sales initiatives," commented Scott Zahn, director of business development for Clark Seals. "With more than 20 years of experience in the sealing industry and uncompromising integrity, I believe Jeff will quickly become a valued resource for manufacturers looking to improve supply of rubber and sealing products."

clarkseals.com

Melior Motion

BECOMES SCHAEFFLER ULTRA PRECISION DRIVES GMBH

Schaeffler acquired Melior Motion GmbH in early 2022, an innovative

manufacturer of precision gearboxes for robotics and automation applications, among others. As of December 1, 2022, Melior Motion GmbH began operating under the name of Schaeffler Ultra Precision Drives GmbH. The aim of the acquisition is to continuously expand the Industrial division's portfolio of precision gearboxes and to secure a strategically strong position in the dynamically growing market for industrial automation.

Since the acquisition, Schaeffler has doubled the production capacities for PSC-series precision planetary gearboxes at Melior Motion's headquarters in Hameln, Germany. In addition, a production line was set up for the Chinese market at the Nanjing location in China. And the future focus is also clearly on growth at Schaeffler Ultra Precision Drives GmbH. Schaeffler is planning, for example, the construction of new assembly lines and investments in highly efficient production technologies to enhance the Hameln location. A further increase in personnel is also firmly planned.

As part of the Schaeffler Group's network of competence, Schaeffler Ultra Precision Drives GmbH is focusing on the development and production of high-performance, low-wear, and durable system components for individual requirements in industrial automation at the Hameln site.

Through the successful integration of Melior Motion, Schaeffler has systematically complemented its portfolio in the field of precision gearboxes by adding a second mainstay product. The existing series of high-precision strain wave gears for cobots (RT1 and RT2) are now complemented by precision planetary gearboxes for industrial robots. Schaeffler's Industrial division therefore has comprehensive development and technological expertise for precision gearbox applications across all sectors of industry.

schaeffler.com

Bosch Rexroth

OPENS NEW FACTORY AUTOMATION CUSTOMER INNOVATION CENTER

Bosch Rexroth has opened a new customer innovation center near Austin, Texas. The facility will provide a unique technology development experience for Bosch Rexroth factory automation customers from multiple industry segments, including electric vehicle manufacturing, battery production, consumer packaged goods and semiconductor manufacturing. The new innovation center is the latest in a series of expansions and investments Bosch Rexroth is making in North America, including a new plant in Queretaro, Mexico, and an expansion of its operations in Charlotte, N.C.

Located in Round Rock outside of Austin, the Rexroth Customer Innovation Center (CIC) is housed in a custom-outfitted, approximately 9,200-square-foot building with multiple exhibits and presentation areas where visitors can learn about Bosch Rexroth factory automation and industrial hydraulics products and technology.

The CIC features interactive technology demos that integrate multiple Rexroth factory automation systems, including the company's ctrlX AUTOMATION platform, Smart MechatroniX systems, TS assembly conveyors, autonomous mobile robot, linear motor-based Flexible Transport System (FTS), smart hydraulics and other technologies.

The demos allow visitors to see a scaled version of a complete factory automation production line. Bosch Rexroth is the only company that can provide this level of manufacturing technology all from one supplier.

Through the CIC, visitors will also have the opportunity to connect with other Rexroth innovation centers, including the company's flagship CU.BE center in Germany, in a growing network of similar facilities being established throughout the U.S. and globally. This network allows for more immersive digital experiences through virtual connections and digital twin capabilities. With this connection, customers and Rexroth partners can access other technology experts, along with an expanded range of factory automation technologies around the world.

The Austin CIC also has a state-of-the-art engineering lab, where manufacturing customers and other partners can join engineering teams from Bosch Rexroth globally to address specific factory automation challenges and applications.

The lab provides a collaborative setting to solve manufacturing system design, engineering and implementation challenges. Customers can engage with Bosch Rexroth experts to develop working prototypes and proof-of-concept systems that integrate multiple controls, drives, material transport, assembly, and linear motion products from the company's industry-leading portfolio.

"The new Customer Innovation Center gives our factory automation customers an opportunity for a unique, customer-focused experience, providing a space where they can interact with and learn about our current and future innovations to move their manufacturing operations forward," said Bosch Rexroth North America President and CEO Greg Gumbs.

"It will serve as a central point of contact for customers, users, partners and our own engineering and applications development teams, where we can explore ideas and develop solutions that focus on improving productivity, manufacturing flexibility and efficiency."

boschrexroth.com/en/us/company/trade-shows-and-events/events/austin-cic-round-rock-3072.html

February 21–23—Houstex 2023

SME's Manufacturing Technology Series in Houston, Texas brings together key decision makers, major tool and technology suppliers and thought leaders from across a broad spectrum of manufacturing disciplines. Hands-on equipment demonstrations, keynotes and panel discussions, emerging manufacturing technology showcases and networking activities offer attendees an opportunity to learn about the latest manufacturing trends. Regional industries include oil and gas, aerospace, automotive, transportation, energy, military, plastics, research and development and more. Houstex is an interactive experience, dedicated to showcasing advanced technologies and processes that help manufacturers innovate and create industry transformation. Houstex features hundreds of exhibits highlighting the latest products and services designed to help manufacturers develop their pathway to success.

powertransmission.com/events/927-houstex-2023

March 6–9—HAI Heli-Expo 2023

The Helicopter Association International (HAI) brings together hundreds of exhibitors in aircraft, avionics, and technology each year at Heli-Expo. The event features more than 50 free Rotor Safety Challenge education sessions, a career fair, a special workshop for military pilots as well as industry meetings, forums, and workshops. Topics include aeronautical decision-making, mountain flying, accident investigation, UAS, aviation safety, and many more. Helicopter airframe, engine, and component manufacturers and approved repair centers will also conduct technical briefings during the event.

powertransmission.com/events/934-hai-heli-expo-2023

March 10–11—EASA Fundamentals of DC Operation and Repair Tips

This EASA seminar will cover DC machine theory and operation, as well as repair tips. Topics will include testing and winding of armatures, fields, interpoles and compensating windings, machine work, balancing, assembly, and final testing. The theory portion is structured so that it can be grasped by entry-level personnel, while the overall material is in-depth enough that those with 30 years of experience or more will benefit.

powertransmission.com/events/929-fundamentals-of-dc-operation-and-repair-tips

March 14–18—IFPE 2023

IFPE, the International Fluid Power Exposition, is the leading North American exhibition bringing together the fluid power, power transmission and motion control industries. IFPE is co-located with CONEXPO-CON/AGG, held at the Las Vegas Convention Center. IFPE is where fluid power professionals meet to discover highly engineered solutions for improving mobile and industrial equipment's efficiency, performance, and sustainability. Attendees will also learn about the latest technology available to the industry and network to discuss and combat the most pressing industrial challenges. From sensor technology and data analytics to robotics, custom software development, and industrial automation, attendees will experience the latest innovations in fluid power.

powertransmission.com/events/906-ifpe-2023

April 17–21—Hannover Messe 2023

Hannover Messe picks up on the current trends and provides everyone involved with orientation in times of energy shortages, climate change and supply chain problems. How do you install intelligent energy management and thus create an environment for CO2-neutral production? What are the latest developments surrounding Industry 4.0 and artificial intelligence? And how about the mega-topic hydrogen? From drive and fluid technology to digital platforms and IT security to industrial internet and robotics, the huge variety reflects the manufacturing industry's broad scope and provides important economic and social impulses every year. Additional 2023 topics include 5G technology, additive manufacturing, automation, sensors, e-mobility, linear technology, material handling and more.

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Traveling in a Sea of Marvels

One-of-a-kind aquarium celebrates steampunk fiction

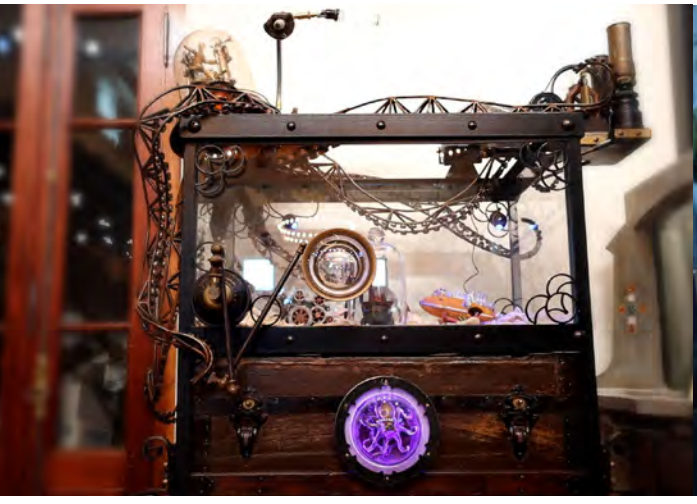
Matthew Jaster, Senior Editor

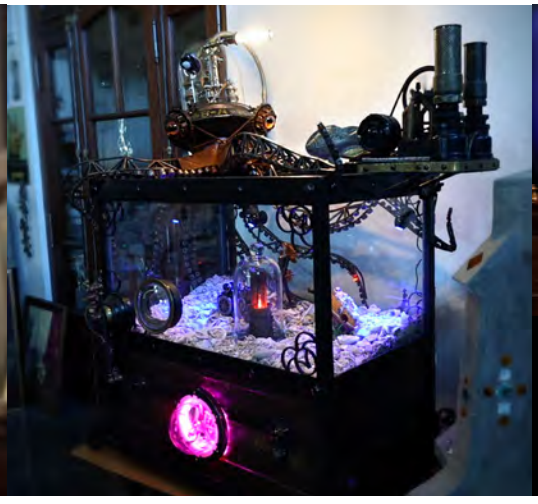
"So let me tell you that you will not regret the time spent on board my vessel. You are going to travel through a wonderland. Astonishment and stupefaction will probably be your normal state of mind. You will not easily become blasé about the sights continually offered to your eyes. I am going to embark on a new underwater tour of the world."

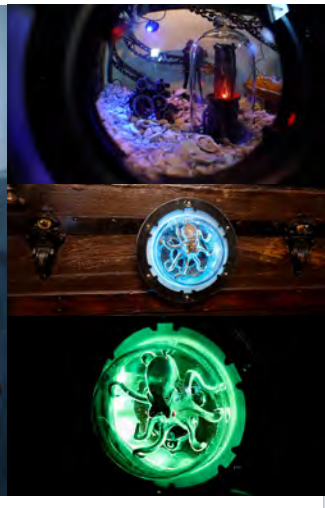
—Capt. Nemo, *20,000 Leagues Under the Sea*

In this classic science fiction tale, the protagonist has his futuristic electricity-powered submarine almost destroyed by a giant squid. What if Capt. Nemo created a mechanical "octopus" Kraken that he could pilot to attack and defeat his actual, biological nemesis?

This is the premise upon which Bruce Rosenbaum, Steampunk reimagineer, at Modvic—in collaboration with Jon Bander, a metal artist located in Franklin County, Mass.—ran with when they were commissioned by an Italian collector of aquarium antiquities for an original steampunk sculpture celebrating the novel.







Bander was responsible for creating the Kraken's body and aquarium structure and stand, while Rosenbaum collaborated with Gary Bagnall, executive director of the Museum of Aquarium & Pet History in San Luis Obispo, Calif. on the rest of the project.

"Gary is an expert in antique aquariums," Rosenbaum said. "It was fantastic to work with him creatively and have his guidance on the challenges of making it all come together." Collaboration is the key to every Steampunk project, according to Rosenbaum. "I know my limits and the need to also focus on marketing, branding and project management to keep the constant flow of projects moving forward so I can make a living as an artist and designer. Working with left/right brain artists, engineers, metal and woodworkers, lighting and electronics professionals gives me the ability to pull the talent together needed to do large, kinetic, performance-based art installations."

To create the Steampunk aesthetic, beautiful artifacts from the past such as period steam related objects, water tank components from vintage aquariums, antique chocolate molds, and additional repurposed period items were used in the design. The art piece also includes a working antique piston water pump that creates kinetic movement. The entire project took four months to design, engineer and fabricate.

For artistic flair, an underwater LED flame inside domed glass as well as other LED lighting were added to the submerged landscape. A magnifying glass for close-up viewing of fish and aquatic life was also incorporated into the tank's forward facing glass panel. "Understanding how the different elements would interact with the water in the aquarium and making sure anything we did would help the lives of the pet fish and not harm them was a challenging aspect to the project. Also creating an environment for easy cleaning, maintenance and repair if needed," Rosenbaum said.

For Rosenbaum it's a constant challenge to continually add complexity, interactivity and to integrate analog/mechanical pieces with digital elements as part of making "functional" and engaging Steampunk artwork.

"We can do anything—but the budget must reflect the mission. To create maximum flexibility—I present the project in modular parts (as in when buying a car and you can add the 'extras'), so the client can take the basic or the full bells and whistles model," Rosenbaum said.

Next up for Rosenbaum is a Time Machine-inspired interactive art installation that uses water—flow, direction and speed controlled by visitors—to run turbines and generators to produce electricity to power cell phone batteries, lighting, and electrical devices.

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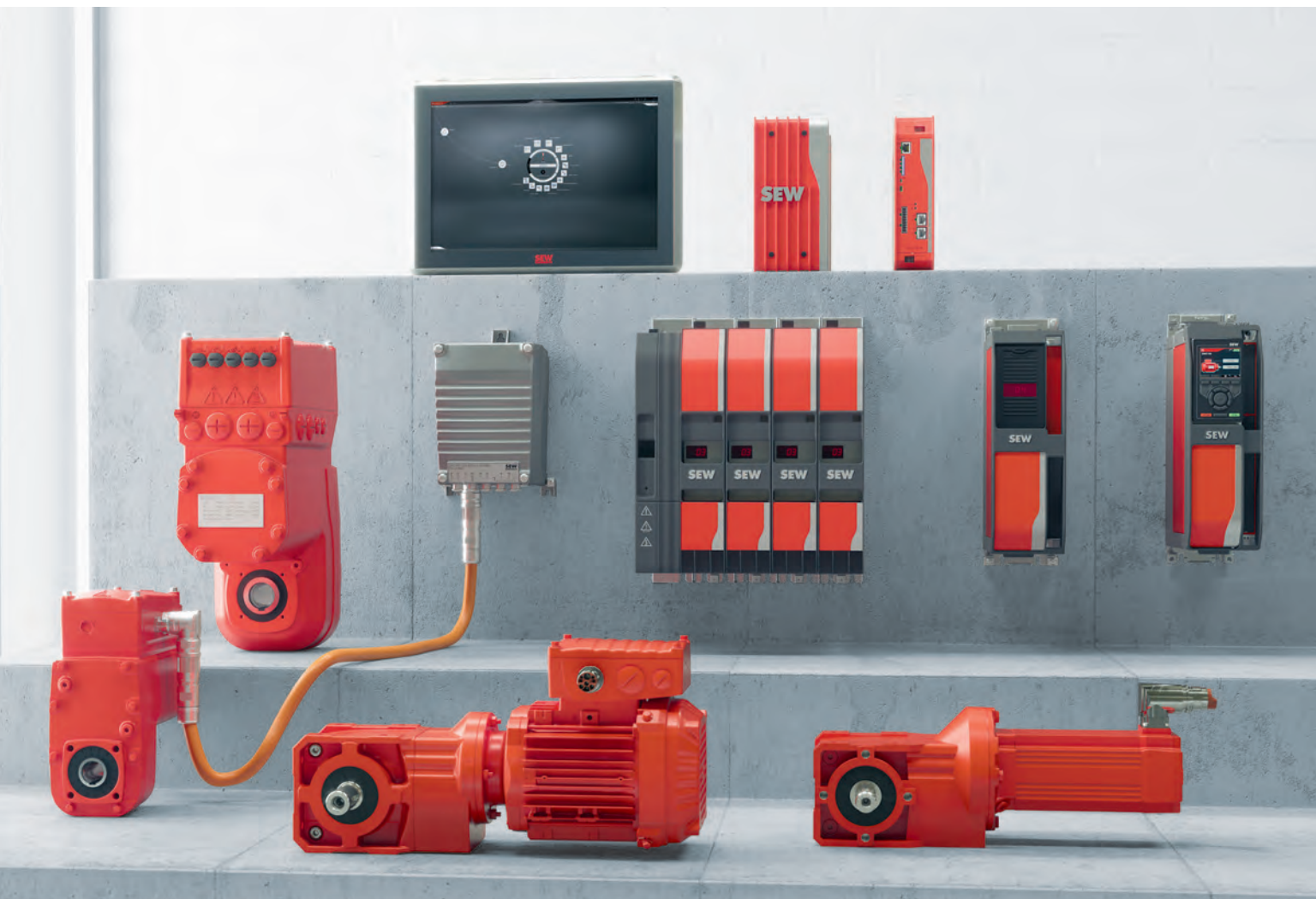

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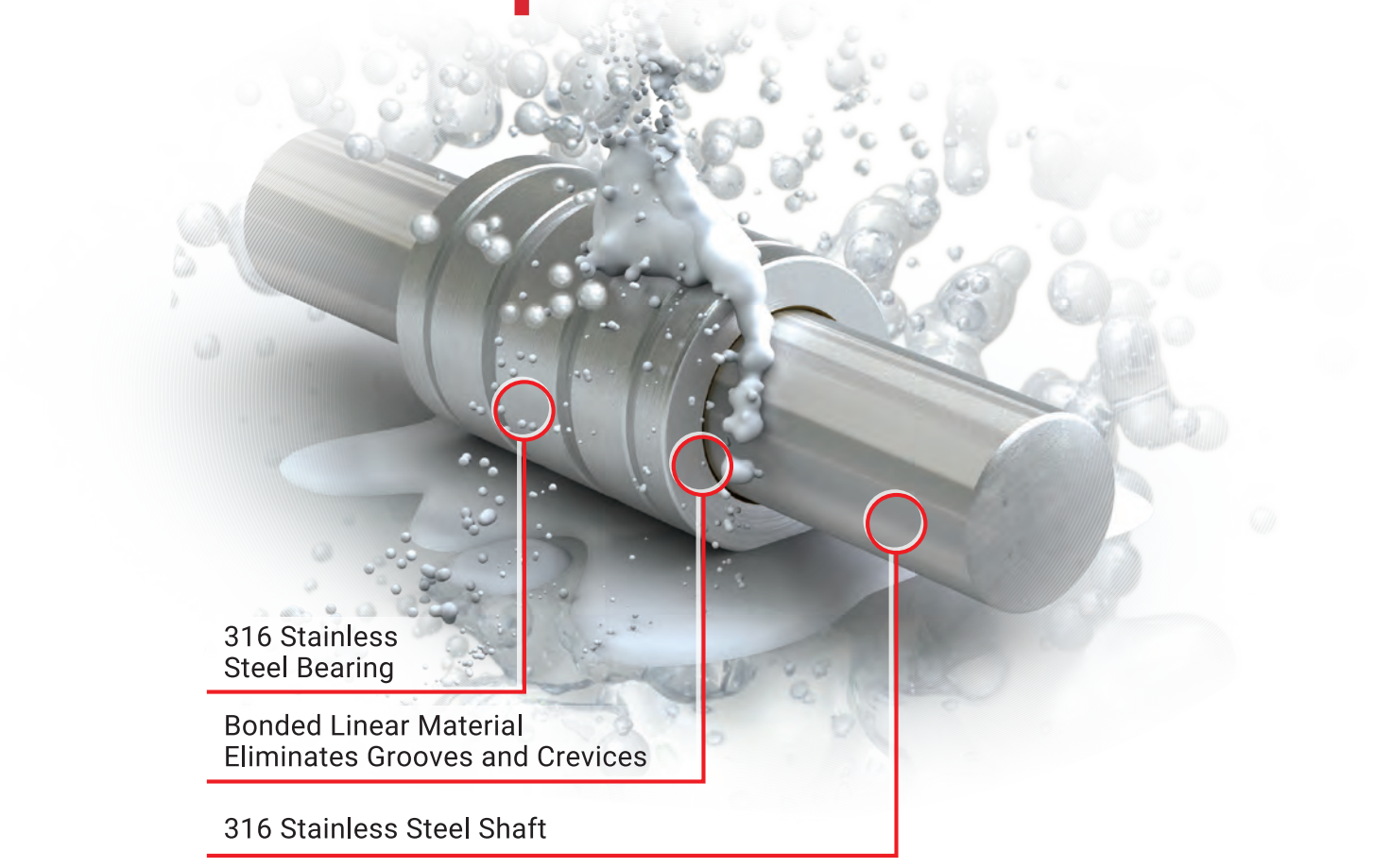

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