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FEBRUARY
2025

BEARINGS
DRIVE SELECTION
SEALING NEEDS FOR ELECTRIC MOTORS

TECHNICAL

Statistical Analysis of Planet Pin Tolerances in Planetary Gearboxes

Gearboxes in Robotics and Heavy-Duty Machines

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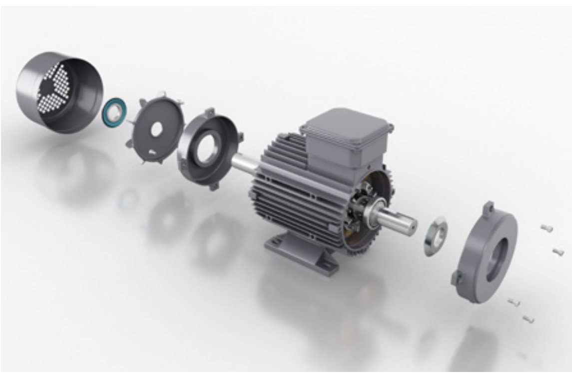
FEATURE ARTICLES



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TECHNICAL ARTICLES

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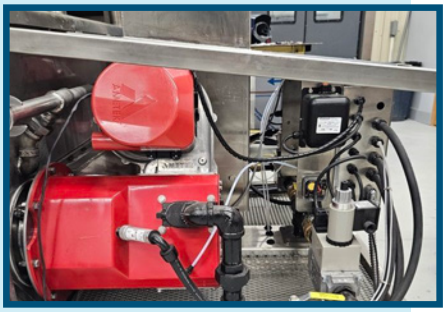
PTE™
VOL. 19, NO. 1

PTE REVOLUTIONS

Power Density Progress



Productivity and efficiency are paramount in the highly competitive snack food production industry. JD Manufacturing, Inc (JDM) in Pine Bluffs, WY, stands out as a leader with its high-performance automatic batch fryers, which are engineered specifically for kettle chip production. The batch frying process imparts kettle chips, whether made from potatoes, sweet potatoes, parsnips, carrots, or beets, with their distinctive premium texture and taste. JDM enhanced its systems with the Nautilair 12.3" High Energy Blower by Bison.

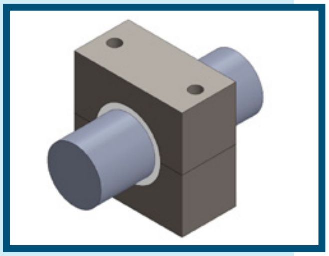
`powertransmission.com/blogs/1-revolutions/post/10132-system-support`

Electromechanical vs. Hydraulic: A Linear Motion Case Study

There's a delicate balance in the constant evolution of today's assembly line. Once dominated by hydraulics, manufacturing floors are incorporating a growing number of electromechanical solutions to supplement legacy hydraulic components, particularly in lower force, linear motion applications. Manufacturers that recognize this trend and harness the benefits of both hydraulic and electromechanical solutions position themselves to optimize future operations, regardless of market trend demands.

`powertransmission.com/blogs/1-revolutions/post/10138-electromechanical-vs-hydraulic-a-linear-motion-case-study`

Vesconite Anticipates Movie Prop Platform Orders in 2025



A provider of engineering services in the hydraulic and pneumatic industry anticipates new orders in 2025 for movie prop platforms that use low-coefficient-of-friction Vesconite bushings. It hopes to produce several platforms in 2025, which will add to the number of platforms that it has produced since its first foray into the movie industry in May 2005.

`powertransmission.com/blogs/1-revolutions/post/10123-vesconite-anticipates-movie-prop-platform-orders-in-2025`

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New Year, New Look, Same Great Content

PTE™

You might have noticed a few changes around here, starting with our new logo and new look, starting with the front cover and running throughout the magazine. *PTE*'s distinctive new logo is crisp and recognizable, while conveying a sense of motion.

After all, motion is what we're all about. And THAT's not changing.

What ELSE is not changing is our commitment to the technical professionals and engineers who are our readers. Many trade publications seem like nothing more than vehicles to push advertisers' messaging onto an audience. But that has never been our approach.

Don't get me wrong. We love our advertisers. But we serve them best by serving you with the best possible technical information on mechanical power transmission and motion control.

This issue is no exception.

Don Congdon's no-nonsense explanation of the components of a gearmotor system and how to choose them is a great example. Congdon explains everything from the electronic drive to the output shaft and how to configure the components for your application. See his article on page 14.

The experts at Trelleborg sealing solutions have presented an interesting Q&A (p. 18) that covers the unique considerations for shaft seals in electric motor applications.

Our long-time contributor, Norm Parker has given us an interesting analysis of the global and domestic market for roller bearings, touching on the uncertainties related to EV manufacturing and pending tariff actions, design and engineering trends, and more (p.20).

We also have Senior Editor Matt Jaster's preview (p. 22) of the upcoming Bearing Show North America, colocated with Lubricant Expo North America, along with his profile of Atlantic Bearing Services (p. 26).

Benjamin Abert of FVA and Tim Erlewein from Wittenstein have presented a terrific technical article on the positional tolerances of pins in a planetary gearbox system (p. 32).

I also highly recommend Pablo López García's article (p. 40) on gearboxes as the unsung heroes in a variety of applications—from humanoid robots to off-road machinery.

It's a really full issue. We've got articles on bearings, motors, gearboxes and more, with expert insights and important discussions about the technologies and trends shaping the modern power transmission industry.

We hope you like the new look. Even more, we hope you continue to like our commitment to quality content. Please send feedback to *stott@agma.org*. We'd love to hear from you.

PTE

Randy Stott
Publisher & Editor-in-Chief


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ZF
Produces sMOTION Active Chassis Dampers

A new era of damping technology has begun as sMOTION from ZF is now bringing stability and dynamics together for improved comfort and driving performance. This system adapts damping force exactly to the corresponding driving situation while also initiating very fast vertical movements for each individual wheel, thus actively lifting the vehicle to ensure optimal roadholding performance while enhancing a more pleasurable driving experience. This capability from sMOTION creates a unique driving experience. The system's damper technology is now being used in two new models of a German premium manufacturer.

In the case of automotive chassis, it has often been challenging to combine excellent dynamic properties with high-level comfort. That has been made easier for automakers with sMOTION as the pitching and rolling maneuvers inevitable in dynamic steering, braking and acceleration have been virtually eliminated.

"Our fully active sMOTION chassis system can almost completely prevent vehicle body movements in certain driving situations," explains Dr. Peter Holdmann, member of the board of management at ZF and head of the chassis solutions division. "At the same time, the comfort characteristics of vehicles equipped with sMOTION increase significantly."

Two new Porsche models already make use of part of ZF's sMOTION active suspension system—the Panamera and Taycan. Each features Porsche's "Active Ride" air suspension which uses sMOTION's damper and valve technology.

sMOTION Sets Standards for Driving Comfort, Dynamics and Safety

The sMOTION active chassis system is based on the well-known, adaptive ZF damping system CDC (Continuous Damping Control) with two external valves, each of which independently regulates the compression and rebound direction of the damper. In this way, damping pressure is optimally adapted to the respective driving situation, an important quality for driving comfort and dynamics. sMOTION goes a step further using a high-performance oil pump to actively move the wheel suspension via the piston rod. In this way, the electronic control system can neutralize the effect of road unevenness on individual wheels. It is also able to compensate or even counteract the wheel height when cornering—for example, when accelerating and braking.

Active Vertical Movement of the Wheels

sMOTION is particularly powerful during dynamic driving maneuvers: A sharp steering movement to the right would normally cause a conventionally damped vehicle to "tilt" to the left. Passenger cars equipped with sMOTION, automatically adjust the cornering inclination to the speed and generate a "helicopter mode." Thus, the vehicle's driving behavior is almost light-footed.

For example, a vehicle equipped with sMOTION can use the active damper system, to elevate a vehicle by eight centimeters within half a second. This means the control electronics, also developed by ZF, can hold a passenger car weighing three tons almost horizontally on the road up to a cornering force of 1 *g*.

Motion Sickness: Minimize Causes

This wheel-specific active body control, which does not use stabilizers, has significant potential in terms of comfort. If vertical movements of the vehicle body are prevented, so-called "motion sickness" can be potentially eliminated.

"Our system virtually eliminates motion sickness, which today primarily affects passengers reading or watching films while traveling," explains Thomas Kutsche, vice president engineering productline suspension at ZF. The calming of the vehicle body can be increased even further, for example if information on road conditions, such as bumps or potholes are known, which the system can compensate for in a targeted manner. If automated and autonomous driving continues to increase in practice, this chassis characteristic becomes increasingly valuable for all vehicle occupants.

Expansion of ZF's System Portfolio—25 Years of CDC

With sMOTION, ZF is adding to its portfolio for passenger car steering, braking and chassis. With these electronically controlled actuators, ZF can influence the complete longitudinal, transverse and vertical dynamics of vehicles as a software-controlled overall system. In the future, the combination of these technologies will lead to networked chassis systems that can be coordinated holistically with the *ZF cubiX* software: "We can support manufacturers not only with the components, but also with software driving functions for the overall system," says Holdmann.

ZF is among the top technology suppliers when it comes to semi-active and active damping systems. The first CDC system came onto the market 25 years ago and sMOTION uses the latest generation of CDC technology, which is CDCrci with two valves on each damper—one for the rebound stage, the other for the compression stage.

zf.com

ZERO-MAX
Offers H-TLC Overload Safety Devices with new Customization Options

Zero-Max H-TLC torque limiters are designed to disengage in the event of a torque overload, protecting both

the machine and the products being processed. The H-TLC features a consistent, reliable, repeatable, and adjustable disengagement torque setting, and is designed to withstand corrosive environments. An available actuating disc can be added for triggering alarms or providing automatic system shutdown the instant an overload condition occurs.

The Zero-Max H-TLC is an economical detent-type torque limiter that automatically resets itself after a torque overload has subsided or has been corrected. The H-TLC is operational in both directions of rotation, and both directions of disengagement, and has a -40°F to +180°F operating temperature range. The H-TLC is configurable for shaft-to-shaft mounting where it serves as a torque-limiting coupling, or with an internal bushing added for support on belt or chain drives that transfer power to a secondary shaft, while offering torque limiting overload protection.

The H-TLC design offers multiple reset positions within a single revolution as standard. A single reset per revolution is also available as a customization. They are an excellent alternative to friction type torque limiters, which generate heat and wear during operation, which can degrade accuracy and performance. The mechanical design and overload protection also offers a compliment to electronic overload protection in many applications, providing additional protection to downstream machine components.

The special composite and polymer materials and the construction of the H-TLC make it ideal for use in corrosive environments. These torque limiters can also be customized to meet the needs of individual applications. Typical custom features may include: special bore sizes and tolerances; special keyways, hex bores, or splines; upgrades from plated hardware to all stainless steel hardware for added corrosion protection; food grade grease; single-position reset (only one reset position per shaft revolution); a synchronous actuating disc that offers only a single reset location per revolution (to coincide with the special single-position reset), among other features. A low-profile torque adjustment screw that features smaller built-in dimensions is also available.

The H-TLC is a natural complement to Zero-Max's Torq-Tender Overload Safety family of products. The H-TLC is fully adjustable to handle a range of torque settings should changes be needed in the system. The external adjustment allows the torque setting to be fine-tuned to the needs of the application. Simply adjust the unit's external torque adjusting screws to achieve the desired torque setting.

The H-TLC is available in two model sizes, with multiple spring options, offering a torque range from 4 in-lbs. up to 500 in-lbs., or 0.5 Nm to 56.5 Nm. Bore sizes range from 0.250" through 1.125" in imperial sizes, or 8 mm through 28 mm in metric sizes.

zero-max.com

SKF
Introduces Bearings Designed for Circular Performance

SKF has unveiled a new series of bearings designed for circular use enabled by new advanced Laser Metal Deposition (LMD) technology. The innovative SKF Infinium bearings mean that, for the first time, bearings can be reclad and reused repeatedly, marking a significant advancement in circularity and additive manufacturing. Using LMD technology, SKF has created bearings that offer better performance and durability compared to standard bearings, customized for targeted applications.

The multi-material bearing can be remanufactured repeatedly, with no limit to the number of times. Damaged areas can be fully removed and fresh material added to the ring. As a result, the bearing can reduce the costs of ownership, extend life and reduce waste.

The bearings are designed to withstand the most demanding applications depending on the material it is reclad with. For example, applying a stainless-steel alloy means a normal bearing can be transformed into a corrosion resistant one, with the performance of a full solid stainless-steel bearing, at a comparatively lower cost.

"For the next generation of bearings, SKF Infinium, we needed to reimagine our product design. Our goal was to keep bearings in use for as long as possible, achieving a more circular business model. This is the first time a bearing solution has been designed for circularity, and it has huge potential to revolutionize how bearings are used," says Thomas Fröst, president, independent and emerging business.

"Our new technology exemplifies our clean and intelligent strategy, enabling both us and our customers to minimize the scrapping of used bearings. Each bearing cycle may be extended due to superior performance, maximizing output for every ton of bearing steel produced," Fröst continues.

The bearings have already proven their durability in some of the toughest industries, where testing is still ongoing. Results so far have been promising, with the SKF Infinium bearings already outperforming standard bearings and showing reduced corrosion.

skf.com

MAXON
Unveils High Efficiency Joint Drive for Dynamic Robotics

Maxon proudly announces the launch of the High Efficiency Joint (HEJ) Drive 70-48-50, the newest addition to its High Efficiency Robotic Joints portfolio. This advanced actuator sets new standards in torque density and efficiency, catering specifically to autonomous mobile robots operating in unstructured environments such as humanoids, quadrupeds, exoskeletons, or mobile manipulators.

The HEJ 70-48-50 delivers a peak torque of 50 Nm and reaches speeds up to 28 rad/s, all while maintaining a mass just above 1 kg. Its compact design and high torque density make it ideal for mobile manipulation tasks, offering roboticists a powerful yet lightweight solution.

“The HEJ 70 represents a significant leap forward in actuator technology for dynamic robotics,” said Stefan Müller, chief technology officer at Maxon. “By combining unmatched efficiency and systems integration with a lightweight and compact design, we’re enabling our customers to push the boundaries of what’s possible in autonomous mobile robots.”

Maxon’s High Efficiency Joints combine torque-dense electric motors, planetary gears, electronics, sensing and support structures into highly compact, IP67-rated and EtherCAT-controlled robotic actuators. Integrated heat sinks and cross-roller bearings facilitate deep systems integration. The control system can be configured flexibly and supports various topologies for impedance control of the joint. While the newly launched HEJ 70-48-50 is well-suited for mobile manipulation or smaller robots, its larger version, the HEJ 90-48-140, targets locomotion or propulsion systems. Key actuator features for autonomous mobile robots are high robustness, low mechanical inertia, good back-driveability, and high efficiency, all of which are addressed by maxon’s High Efficiency Joints platform.

These systems enable roboticists to quickly create high-performing and reliable robots, following modern design principles dictated by deep reinforcement learning and related simulation approaches. Maxon firmly believes that fast-moving robotics companies should focus on their core robotics value drivers and challenges, while maxon handles key complexities typically associated with robotics actuators, such as high performance, reliability, supply chains, integration, and testing. Modern robotics demands highly scalable manufacturing of complex and high-performance robotics actuators, and this is a key competence of Maxon.

robotics.maxongroup.com

ORBEX GROUP
Introduces Compact Wheel Drives for Advanced Mobile Robots

Orbex Group, a U.S.-based supplier of slip rings and electric motors, introduces a new family of compact wheel drives (CWD), increasing its offering of precision motion solutions. The CWD-500 and CWD-1000 are integrated motor, gearbox, encoder and wheel combination units, designed to facilitate easy application in compact robotic applications like autonomous mobile robots (AMR) and automated guided vehicles (AGV).

Both the 600-watt CWD-500 and 1,200-watt CWD-1000 are compact enough to fit into tight installation spaces and are designed to have the minimum axial length. Each wheel drive features a 160-millimeter wheel diameter, with larger diameter wheels as an option. Their innovative design also offers excellent power and torque density and high axial and radial load capacities, while quality construction provides smooth, precise and reliable motion for up to 30,000 hours.

The defining feature of the CWD-500 and CWD-1000 is an integrated gearbox that ensures efficient operation with 90 percent reducer efficiency and a 15:1 gear ratio. For precise positioning, both wheel drives feature a 16,384-count encoder and are designed to minimize backlash to less than 30 arc-minutes. These compact wheel drives also operate with low noise, while an IP54 protection rating ensures each wheel drive is protected from dust and moisture contamination.

orbexgroup.com

LIEBHERR
Supplies Slewing Bearing for Europe's Largest Lifting Swing Bridge

Liebherr's components product segment supplies the heart of the rotating pillar for the bridge Friesenbrücke, which is being erected for Deutsche Bahn in Weener. It comprises a 5 m, 12.5-ton combined roller and ball bearing along with eight matching pinions. This rotating pillar and the associated mechanical systems by Hermann GmbH Maschinenbautechnologie support the 145 m long, 1,800-ton central section of Europe's largest lifting swing bridge to date.

The Friesenbrücke is the key part of the 173 km rail route between Groningen and Bremen. "With its total length of 335 m, it is the largest lifting swing bridge in Europe, carrying not only rail traffic, but also footpaths and cycle lanes," says Alexander Volgmann from Deutsche Bahn. "The bridge spans the river Ems and opens the way for ships by rotating up to 90 degrees. This is where Liebherr's slewing bearing and pinions come into play."

The combined roller and ball bearing along with eight matching pinions ensure that the bridge can rotate on its central pillar. "The technology used here is a lift-and-rotate mechanism. First, the rotating section of the bridge is unlocked. The central section is then lifted by the rotating pillar, releasing it. Finally, the hydraulic drive and the slewing bearing swivel the bridge," explains Karl Völkl from Hermann GmbH Maschinenbautechnologie, the supplier of the rotating pillar for the Friesenbrücke.

The bridge section will be rotated around 1,850 times a year. To support optimum operating times, Liebherr has designed the slewing bearing for a service life of 100 years and verified it by a finite element (FE) analysis. Moreover, the bearing has been coated with a C5 anti-corrosion layer, specifically designed for use in or near water.

"Additionally, our intelligent bearing clearance monitoring system measures wear on the axial raceway, allowing efficient monitoring and maintenance of the bearing," explains Michael Sander, technical sales engineer for slewing bearings at Liebherr-Components in Biberach (Germany).

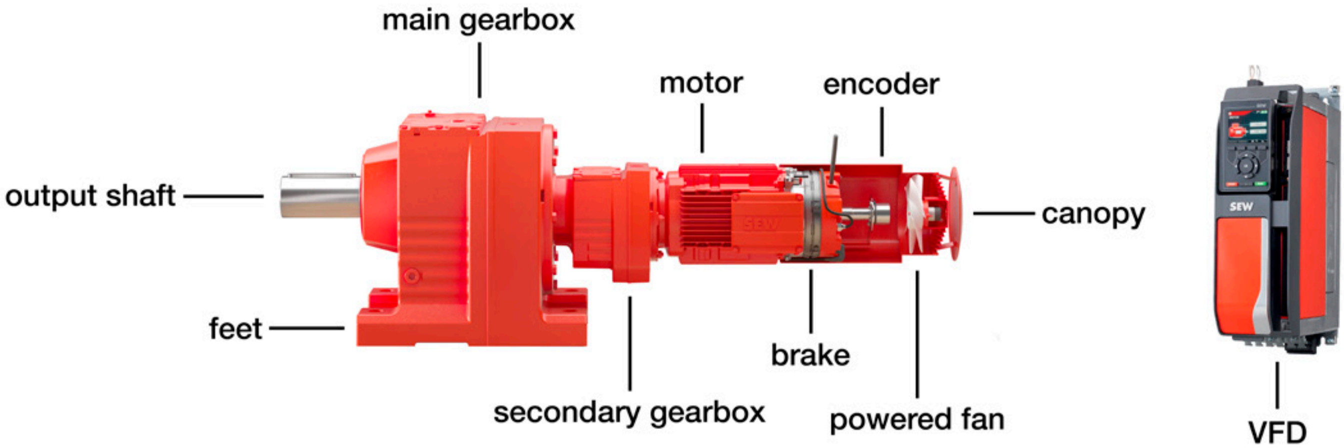
This solution integrates sensors directly into the bearing, with the measurement results fed directly into the customer's system. "The seamless integration into the customer's control system is a key innovation. We provide a specially developed and protected code, allowing the customer to integrate the data into their own system, using their own logics and interface," adds Sander. No additional gateway is required, reducing system complexity thanks to the software-integrated bearing clearance monitoring system.

liebherr.com

To Pick the Right Drive, Ask the Right Questions

SEW-Eurodrive addresses application requirements to select components

Don Congdon, Corporate Trainer, SEW-Eurodrive



A drive and some of its optional accessories. All photos courtesy SEW-Eurodrive.

Selecting a drive, whether for a new application or to replace an existing one, doesn't have to be a traumatic experience. The key to success lies in asking a logical sequence of thoughtful questions.

Learning Objectives

1. Recognize the core components and optional accessories making up a drivetrain.
2. Identify an application's key electromechanical requirements.
3. Identify an application's key electronics requirements.

If an electrically powered industrial machine moves, chances are that a *drive*—an electronically controlled gearmotor—orchestrates that motion. While ordinary gearmotors have moved industry for over a century, inexpensive electronic drives have been mainstream technology for just a few decades. Consequently, plant engineers and maintenance personnel may feel uncomfortable about selecting a drive. Traditionally, drive manufacturers guided this process through their sales engineers, but many now offer online selection tools or smartphone apps as an alternative. While these certainly make the selection process more convenient, they can be daunting to use correctly.

Happily, there's a simple solution to this problem: ask the right questions before sitting down to the selection tool. Thoughtfully defining the problem and organizing the application's requirements paves the way to a smooth and successful selection experience. This article outlines the questions you should ask yourself as you prepare to use a drive manufacturer's selection tool.

The Drivetrain

The drivetrain contains everything that powers the application, including the drive itself. The drive (pictured above) has three core components: a gearbox, an electric motor, and a variable frequency drive (VFD). It may connect directly to the application, or it may deliver power through additional transmission elements, such as a belt, chain, or spindle. In either case, the drive must have appropriate coupling and mounting devices. These include flexible couplings, flanges, feet, or torque arms.

The motor may require a brake, either to stop the load or hold it in place. If the application requires precise speed control or accurate positioning, a motor encoder will be necessary. When a PLC or other industrial controller manages the application, the VFD will probably need a suitable fieldbus interface or some extra inputs and outputs.

The questions you'll be asking will define the drive. They flesh out the main components and tease out the specialized accessories required. The questions broadly divide the drive into its electromechanical and electronic components.

Core Electromechanical Questions

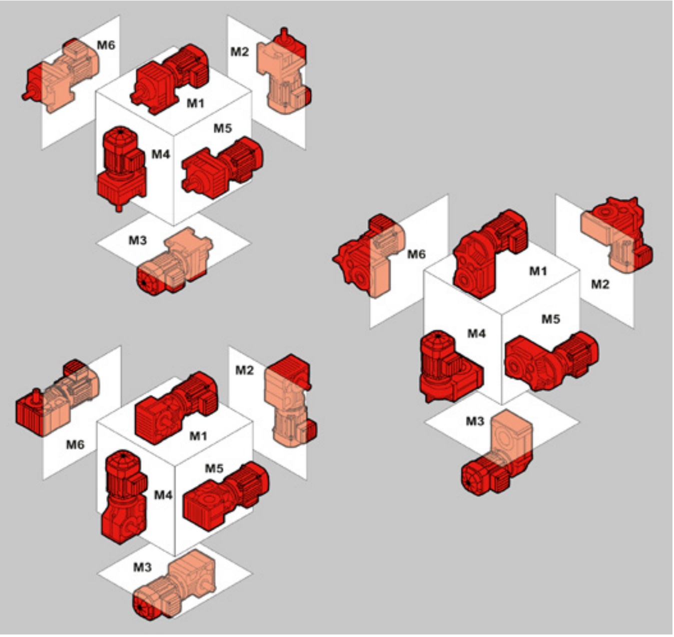
Begin by identifying the application's *motion*. Is it rotary or linear? With linear motion, is it horizontal, vertical, or angled? Vertical and angled applications usually require a brake, while horizontal ones may or may not. Be sure to identify the motion's *duty cycle* too. Continuous duty applications, like simple conveyors or a blower, can work well with an ordinary AC induction motor. Cyclic applications performing repetitive sequences, such as packaging machines, may benefit from a more dynamic permanent magnet synchronous motor.

While you're thinking about the application's motion, identify the expected *loads*. Besides their magnitude, also determine whether they're predominantly static or dynamic. Sizing a drive for an application with relatively static loads is simple. If the load varies widely or can change abruptly, the drive will need a larger service factor. Be sure to identify the application's acceleration requirements too. In cycling applications, the motor must deliver sufficient torque to accelerate the load within the time constraints. PM synchronous motors can handle aggressive acceleration better than ordinary induction motors.

Determine the application's *speed, torque,* and *horsepower* requirements. These help size the motor and gearbox. The speed and torque requirements also determine the appropriate gearbox ratio. Be sure to identify how the drive will connect to the application. List appropriate details like *shaft diameter, flange and feet requirements,* and *coupling type*. Finally, if the application needs a brake, identify the required braking torque.

Application efficiency has progressively become more important in recent years due to rising energy costs and legislation mandating efficient motors. Questions that you've already answered may steer the selection tool towards a particular motor efficiency rating. For example, a continuous duty application requires a premium efficiency (IE3) motor. You can improve efficiency even further by requesting a particular *gearbox style* and *mounting position*. Gearboxes based on helical or bevel gears tend to be much more efficient than those containing worm gears, so they're preferable when efficiency is paramount.

Similarly, the gearbox mounting position influences efficiency since position determines how much oil the housing must contain to keep the gear stages lubricated. Vertical mounting positions often require more lubricant, which leads to higher churning losses as the gears plow through the oil. Whenever possible, select a mounting position that requires the least lubricant. Every manufacturer has its own mounting position identification scheme (pictured above right). Be sure that you understand it, so you can correctly specify the gearbox mounting position.



Gearbox mounting position identifiers vary among manufacturers. This is SEW-Eurodrive's system.

Environmental Electromechanical Questions

You're past the most difficult electromechanical questions. Those that remain help identify additional factors needed to ensure a good match between the drive and the application. Begin by describing the application's *operating environment*. Is it indoors or outdoors? Clean or dirty? Wet or dry? Are there harsh or corrosive chemicals involved? Will the drive require regular washdown?

The answers to these questions determine the drive's materials, protective coatings, seals, and cabling. A drive operating in a poultry processing plant, for example, requires multiple washdowns per day with hot water and caustic cleaning agents. Ordinary protective coatings won't survive these conditions for very long. A stainless-steel drive with potted motor windings and conduit box connections is a much better choice.

On the other hand, the environment can be dry but still very harsh. Drives powering ore or rock crushing machines must endure heavy dust and abrasive grit. These will probably require multiple shaft seals or ones specifically designed to keep abrasives out. The drive may also need bearing re-lubrication fittings to make regular grease changes simpler.

Identify the application's expected *temperature range*. Is it unusually hot or cold? Temperature affects lubricant choices. Mineral oils and greases perform well at everyday temperatures, whereas specialized synthetics are better choices for hot and cold extremes. The gearbox and motor may require auxiliary heat in a cold environment or more aggressive cooling in a hot one. While you're thinking about lubricants, remember that food processing and pharmaceutical machines often need food-grade lubricants.

Core Electronics Questions

At this point, you've asked enough questions to specify the motor and gearbox. The remaining questions help select the VFD and its accessories. These may be unfamiliar territory if you've not worked with VFDs before. While all VFDs do much the same thing—control the motor—they vary widely in their features and intended applications. Again, asking the right questions will help you decide which one is right for you.

You've already answered an electromechanical question that is equally important for selecting the VFD—the application's *horsepower* requirement. Additionally, determine the available power supply *voltage* and *phase* (single- or three-phase). These answers size the VFD and identify possible models. In most cases, a drive manufacturer will offer several VFDs that will satisfy your application's basic electrical requirements. Listing additional application requirements will help you choose from among these.

Begin by identifying the application's *operating mode*—whether it's speed-, position-, or torque-based. Speed-based applications are the simplest, so almost any VFD can handle them capably. Do determine the *accuracy* required, however. Entry-level VFDs can handle applications with modest requirements—fans, pumps, and blowers, for example. Applications requiring higher accuracy must use a VFD that supports closed-loop control via a motor encoder. While many VFDs can operate in closed-loop mode, not all come with built-in encoder interfaces. Those that don't will require an add-on interface board. This must match the motor encoder's communications standard.

By their very nature, positioning applications require a more advanced VFD. It must run the motor at a specific speed while monitoring one or more encoders to determine the application's position. Upon reaching the specified position, it must stop the motor cleanly and accurately. If your application requires positioning, determine its *type* (linear or angular) and the required *accuracy*. These answers will also influence the encoder selection. Precise positioning will require an expensive, high-resolution encoder, while basic positioning can get by with a more economical choice.

Applications requiring torque-based control are the least common, so not all VFDs support this mode. They require the VFD to maintain a specific tension on the load by adjusting the driving torque. A wire winder is an example, as is the paper feed system in a web printing press. In each case, the VFD monitors the tension on the wire or paper with a sensor, such as a dancer potentiometer. The VFD uses this feedback to generate the torque required to maintain the target tension. If your application is torque-based, be sure the VFD supports this mode and can interface with the required sensors.

For the final core electronics question, determine how the VFD will integrate into the application. Many VFD manufacturers offer their products in two styles: *control cabinet* and *decentralized* (pictured above right). A control cabinet VFD, as its name implies, lives in an electronics cabinet. Wires enter and exit the cabinet, connecting power, the motor, and any sensors to the VFD. The cabinet protects the VFD from the environment, especially important when operating under harsh conditions.

Control cabinet (left) and decentralized (right) VFDs perform the same task but in completely different ways.

Decentralized VFDs approach control differently. They mount either on the motor itself or very close to it. Since they're exposed to the application's operating environment, decentralized VFDs usually have relatively high IP (ingress protection) ratings, such as IP66 or higher. A decentralized VFD integrates more seamlessly into the application and typically requires less wiring since it mounts very close to the motor. Decentralized VFDs are becoming increasingly popular in many industries. Some drive manufacturers even offer "electronic gearmotors"—an all-in-one gearbox, motor, and VFD (pictured below). These offer an especially elegant solution to many drive challenges. As a bonus, some are exceptionally efficient because they combine a super premium efficiency (IE4) motor with an efficient gearbox and VFD.

A highly efficient electronic gearmotor integrating a motor, a helical-bevel gearbox, and a VFD.

Secondary Electronics Questions

Once you've identified the core electronics requirements, ask questions that will reveal *special features* affecting the VFD. For example, many applications include controls or sensors that the VFD must monitor. These may be digital devices like toggle switches, pushbuttons, limit switches or a referencing cam. Alternatively, they may be analog devices, like temperature sensors, a speed-control potentiometer, or a voltage that represents a process variable. Most VFDs include at least a few digital inputs and outputs, but not all support analog signals. In some cases, the VFD may require an expansion card to augment its built-in I/O.

Finally, consider the *control method* that the application will use to manage the VFD. Simple applications like fans and pumps may rely on the VFD's front panel for control and status display. More-sophisticated applications might operate the VFD in terminal control (binary) mode via switches, a potentiometer, and digital indicators.

The most sophisticated applications use a PLC or similar industrial controller to manage the VFD. These usually communicate with the VFD over a fieldbus—a robust industrial network. Fieldbus control provides maximum flexibility and sophistication but adds an extra layer of complexity. If the application requires fieldbus control, you'll need to identify the controller brand and model, as well as the fieldbus standard it uses. Newer controllers use Ethernet-based fieldbuses such as EtherNet/IP, Modbus TCP, or PROFINET. Older controllers use legacy standards such as PROFIBUS or DeviceNet. Most VFD manufacturers support multiple fieldbus standards. The VFD may have a built-in fieldbus interface or may require an add-in card.

Selecting the Drive

At this point, you've gathered everything necessary to use the drive manufacturer's selection tool. Fire it up and answer its questions, supplying the information that you've gathered. You'll discover that thinking things through in advance will give you confidence as you work your way through the selection process, as well as afterwards when the tool generates its recommendations. Far from being a worrisome experience, drive selection will become a routine task that gives plenty of satisfaction.

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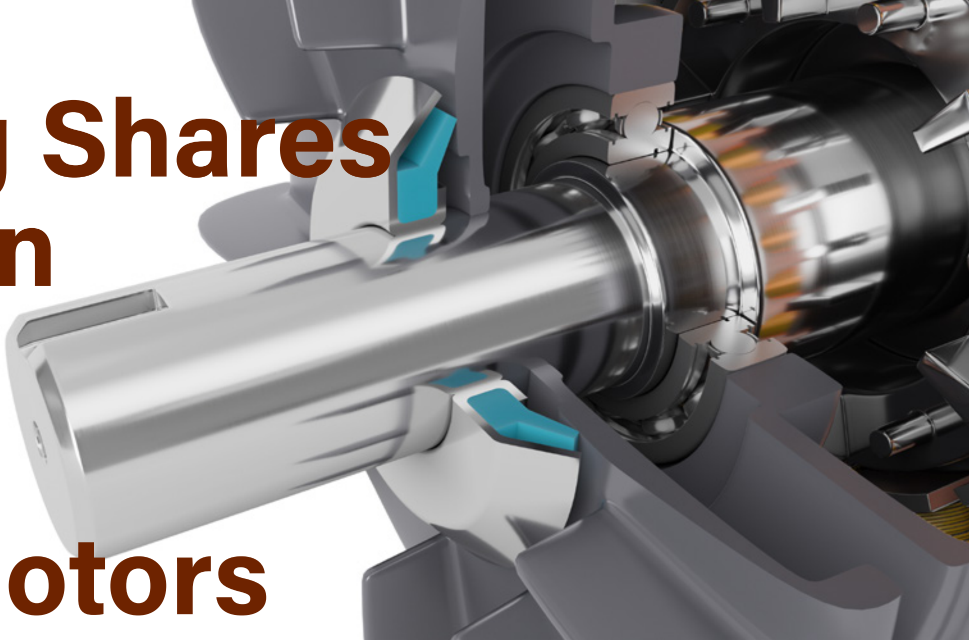
Trelleborg Shares Insights on Sealing Needs for Electric Motors



As dry running systems, electric motors operate on reduced lubrication versus their gas-powered wet-running counterparts, requiring specific sealing solutions to manage friction and heat generation.

Discussion includes radial shaft seals as well as PTFE-based seals

Trelleborg

From electric motors and linear actuators to robots and gearboxes, the range of equipment and machinery used to create automation in industrial applications is diverse. Each has its own set of sealing requirements and understanding these critical components requires many years of experience. In this article David Kaley, Trelleborg's global segment manager for industrial automation, shares his insights on sealing needs for electric motors. Standard, elastomer-based radial shaft seals as well as high-performing PTFE-based seals are discussed.

Q: What is an electric motor?

An electric motor is a device that converts electrical energy to mechanical energy. Most operate using the interaction of the motor's magnetic field and electrical current in a wound wire to produce torque-supplied force on the motor shaft.

Q: Tell us about the different kinds of electric motors.

There are many different types of electric motors. However, in its simplest form, an electric motor may be driven by direct current (DC) supplies, like in rectifiers or batteries, or by alternating current (AC) supplies like in power grids, electrical generators or inverters. Electric motors are categorized by their power supply type, application use, construction and type of movement output.

Standardized motors offer appropriate mechanical energy for industrial use. Applications include blowers and pumps, industrial fans, conveyors, machine tools, power tools, processing equipment, packaging machines, vehicles and more. If it moves it probably has a motor connected to it.

Electric motors are categorized by their power supply type, application use, construction and type of movement output.

Q: Can you explain more about the differences between AC and DC motors?

Alternating current motor (AC motors): Consist of a stator with a coil that is supplied with alternating current to convert electric current into mechanical power. The stator is the stationary part of the motor while the rotor is the rotating part. AC motors are a power source for a wide variety of applications due to their flexibility, efficiency and noiseless operation.

Direct current motor (DC motors): Transform electrical energy into mechanical energy by creating a magnetic field in its stator powered by direct current. The field attracts and repels magnets on the rotor making it rotate.

One of the main differences between AC and DC motors is speed control. An AC motor runs at the frequency of the AC supply and resists changes to speed even when the load changes. To change the speed of the motor, a variable frequency drive (VFD) is used to convert the AC supply to DC and back again at a different frequency. This means that AC motors are ideal for situations where the motor speed is slow to medium and remains constant while the load on the motor varies. This is why AC motors are used in heavy-duty, continuous-speed industrial applications.

DC motors can easily be speed-controlled by modifying the voltage supply. They provide a consistent amount of torque over their entire speed range but are sensitive to changes in the load. This makes them ideal for situations where fine speed control is necessary and the load does not vary significantly, such as in domestic appliances or robotics. DC motors generally cost significantly more than AC motors due to higher manufacturing costs. Also, because AC motors have such widespread use, economies of scale contribute to their relatively lower price.

Q: What are some of the key considerations when it comes to electric motors?

All types of electric motors share operating priorities at some level. The main concerns for electric motor original equipment manufacturers are as follows:

- **Stator protection:** Critical for preventing damage to the stator windings which are the most vulnerable part of the motor. Stator protection helps ensure the longevity and reliability of electric motors by preventing overheating, overcurrent and other potential faults.
- **Rotor lubrication:** Rotor lubrication primarily involves the lubrication of the bearings that support the rotor. Proper lubrication is essential for reducing friction, preventing wear and ensuring smooth operation.
- **Particle and liquid ingression:** Particle and/or liquid ingression in electric motors refers to the entry of liquids, dust, dirt and other solid particles into the motor. This can significantly impact the motor's performance and longevity.
- **Shaft vibration:** Shaft vibration in electric motors refers to the oscillatory motion of the motor's shaft, which can lead to various operational issues if not properly managed.
- **Friction/heat generation:** Friction creates heat which can lead to issues impacting performance of the motor and its longevity.
- **Precision:** Precision in electric motors is crucial for applications that require high accuracy, reliability and efficiency. Achieving precision involves having high-quality components, tight tolerances, advanced control systems and feedback mechanisms like encoders and resolvers.

Q: What kind of critical sealing components are needed to address these challenges in electric motors?

As dry running systems, electric motors operate on reduced lubrication versus their gas-powered wet-running counterparts, requiring specific sealing solutions to manage friction and heat generation. Electric systems have fewer sealing components but still require long-lasting sealing products. The seals must protect the motor by keeping oil and grease on the rotating shaft and preventing the ingress of dust and dirt. Static seals such as O-Rings, gaskets, bonded seals and molded parts are used as sealing elements for lids, flange joints, threads and covers.

The type of rotary seal used for high-speed low-friction industrial motors depends on the complexity of the application.

Reducing power loss across the system is another function of the seal, so less energy is required to power equipment or convert into performance. Friction from the bearings and the sealing arrangement both affect power loss, so balancing sealing capabilities with the need for minimal friction is a challenge. A nitrile butadiene rubber (NBR) or fluoroelastomer (FKM) seal usually offers the best solution for reducing friction and power loss depending on the application's temperature and speed of rotation.

Elastomer radial oil seals are traditionally a primary rotary seal in standard wet-lubricated systems because they have excellent sealing performance and easy installation. However, elastomer radial oil seals struggle to stand up to the conditions of electric motors, such as increased rotary speeds, reduced lubrication or dry running conditions. Elastomer seals also create greater friction resulting in higher power loss.

Polytetrafluoroethylene (PTFE) rotary seals are an excellent alternative, featuring benefits that suit the demands of electric motors and high-speed, critical environments, including:

- Ability to withstand high speeds of up to 224 miles per hour
- Extremely low friction performance
- A wide operating temperature range (-148°F to +500°F)
- Ability to run dry
- Compatibility with most lubricants
- Inertness to most chemicals
- Low break-out force and no stick slip
- High wear resistance

Q: What unique sealing solutions can Trelleborg offer for electric motors?

Trelleborg's Varilip PDR radial oil seal is designed specifically to offer superior performance for electric motors operating at higher speeds. It is constructed from one or multiple Turcon PTFE-based sealing elements which are mechanically retained in a precision-machined metal body. The metal body gives a robust static seal against the housing, preventing changes in operating temperature caused by repeated oscillation. Meanwhile, the Turcon sealing element effectively prevents leakage while allowing for motion between the rotating and stationary parts of the motor, leading to excellent performance at high speeds. Characterized by low friction and stick-slip-free running, the seal reduces temperature generation, permits higher speeds at the outer edge of the rotor and lowers power consumption. This results in a long-service life, maximizing the time between maintenance and greater productivity.

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Roller Bearing Outlook 2025

Examining the domestic and global markets

Norm Parker

Understanding the overall economy as it relates to the global bearing market is critical because it will ultimately determine how companies spend their money. In a down economy, companies go into protective mode, reducing inventories, headcount, R&D expenses and less willing to spend money on products on projects that have not turned into real purchase contracts. In a healthy economy, we see more R&D in heat treatment, lubrication, steel quality, etc. with headcount and resources willing to support long-term (and unpaid) projects.

The 2025 outlook for the global and local bearing markets appears moderately positive overall with projected growth in global and domestic automotives sales, which are key indicators for global bearing sales. US vehicle sales are projected to hit 16.3M units, up from 16M in 2024. Additionally used vehicle sales are expected to hit the highest volume since 2021 at 20.1 million units. The driver of the growth is a general ease in affordability as auto loan rates decline, credit approval rates rise along with increased inventory spurring buyer incentives.

This year EVs are expected to hit 25 percent of new vehicle sales; 10 percent of that being full EVs (no fuel engine)—up from 7.5 percent in 2024. The remaining 15 percent is spread among the various types of hybrids (this can include a simple 48v engine-mounted motor-generator unit). All of this is backed by a presumed strong economy with a GDP growth of 2.6 percent. The remaining 75 percent of sales will remain with internal combustion engines—the lowest percentage on record to date. (Ref. 5)

Globally, the automotive forecast also remains strong, up 1.7 percent to 89.6M units in 2025. Slowing electric vehicle adoption rates somewhat moderates an otherwise cautious recovery growth. "The forecast outlook incorporates several factors, including improved supply, tariff impacts, still-high interest rates, affordability challenges, elevated new vehicle prices, uneven consumer confidence, energy price and supply concerns, risks in auto lending and the challenges of electrification. In the U.S., President-elect Donald Trump is expected to hit the ground running in 2025 with a range of policy priorities, including universal tariffs, deregulation, and wavering BEV support." (Ref. 4)

The global GDP growth projections are mostly unchanged from 2024 at 2.8 percent; still slow from the pre-COVID average of 3.2 percent. All this works into an anticipated bearing market growth of around 1 percent. (Ref. 6)

Figure 1—Courtesy - Precedence Research

From the bearing manufacturers perspective, anticipated deregulation of the MPG standards, carbon credits and further potential steel tariffs are somewhat balanced by the already slowing EV transition. "GM CEO Mary Barra said this summer that the EV transition will take decades, Cadillac changed course on its plan to be all-electric by 2030, Audi said it's "flexible" on an EV transition in July, Ford canceled plans for electric 3-row crossovers in August, Toyota scaled back its EV production target in September, and similar headlines keep coming." (Ref. 9)

The bearing and larger automotive market are already under strict anti-dumping legislation along with the full "75 percent" USMCA rules since 2023; additional tariff rules would not make a substantial impact on these markets as they are already highly regulated industries. "On July 10, 2024, the Biden Administration issued two proclamations Proclamation No. 10783, 89 Fed. Reg. 57347 (July 10, 2024) and Proclamation No. 10782, 89 Fed. Reg. 57339 (July 10, 2024) concerning imports of steel and aluminum products from Mexico and imports of aluminum products from Russia, China, Belarus, and Iran. The proclamations allow additional import duties of 25 percent for steel and 10 percent for aluminum to be levied on these categories of merchandise under the Trade Expansion Act of 1962." (Refs. 1,2,3)

Bearing Manufacturers Perspective

I had the opportunity to discuss the 12-month outlook with several bearing manufacturers and while market and product strategies are different, everyone shared the same concerns about the uncertainty of the EV markets and tariffs.

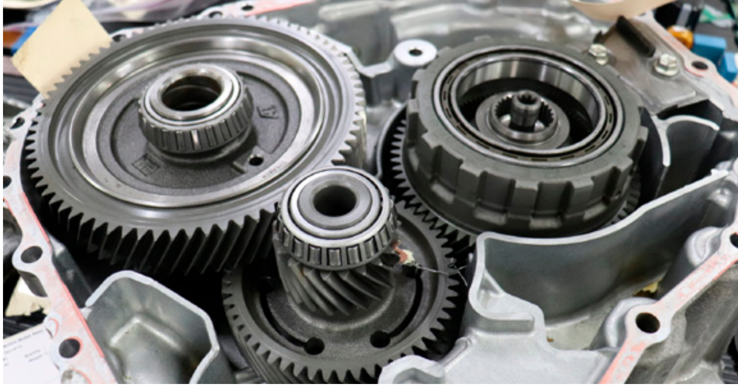
Many companies have created new departments dedicated to electrification with the idea that the ICE market would slow down as the EV side picked up. With the current MPG standards, the automotive companies were forced to attempt to create an EV market which did not exist and does not exist at a very high financial loss. Making products for customers that do not exist is not sustainable for most companies. The bearing manufacturers are likewise forced to keep up with the artificial demand. Projections of millions of EVs that were already supposed to be here simply has not materialized. Again, we are seeing numerous program delays, cancellations, unfinished factories sitting idle while ICE demand remains strong. Manufacturers have no choice but to support the products that are in demand and allocate only the resources needed to support what now appears to be a slow growth, secondary EV market.

In the design space, electrified gearboxes continue to mature in design while designers continue to experiment with new architectures in attempts to further improve efficiency, performance, noise, and cost. It is a strange place we are in. The EV market was forced onto the industry through regulation in the name of efficiency. To entice new customers, the outrageous torque and power that multi-motor EVs can produce has been one of the largest selling points. If your EV isn't a sub 4 second 60 mph, you can hang your head in shame.

On the engineering side, there is strong continued development in ULV (ultra-low viscosity) oils. It seems we are seeing a challenge area around 4cSt at 100°C. To maintain enough film to protect the bearings and gears, more aggressive additives are needed. The issue is, the additives are corrosive to copper if the oil is used to cool the motor. The obvious 3 options for these issues are: 1. Develop additives that are less corrosive to copper—not easy, cheap, or fast. 2. Use different lubricants for the gear and motor side. Mixing of fluids is always a concern, but not so different from the current motor oil, motor coolant and transmission fluid combination that we deal with every day with ICE architecture. 3. Dry motor housing with sealed bearings. The primary issue here is heat. The older style small motors can manage the smaller amount of heat generated in the dry motor sump but higher power 200 kW ++ motors can generate a motor-deteriorating amount of heat which is why wet sumps have taken over as the design preference in higher power applications.

Bearing damaging levels of stray electric current in motors continues to be a regular conversation. We know how to fix it; throw a ceramic ball bearing on the resolver side and a conductive ring on the gear side and forget about it. The problem is—that can be a $25 solution (add "million" to end to see how executives view that number). Hard rubber or plastic-coated outer diameters in lieu of ceramic are not new, but still not regularly found in high volume. On the grounding side, some companies are working on integrated the grounding into the bearing, but this is not an easy or cheap solution either. There is also talk of being able to limit the current on the motor side. All these solutions are still in discussion.

Regionalization is a big topic of conversation right now. This started before COVID, which would be a logical guess to when this started. Prior to COVID, we were seeing USMCA, anti-dumping, discussion of tariffs, fair trading practices, concerns about reliance on China, etc. We were seeing bearing manufacturers starting to talk about setting up factories in N. America for N. America. We are not the only place, we are seeing India, Europe, S. America all bringing products closer to the end user. COVID simply reinforced a trend that had already begun. Providing the legislation remains favorable, we expect this trend to continue.



Conclusion

A strong economy can fix just about anything. There is an old Wall Street saying that everyone looks like a genius in a bull market. We have discussed these large expenditures that are not seeing a return. A strong current product market can maintain these costs, to an extent, while secondary markets develop. The risk that everyone is very aware of is the high level of debt capital which will turn into a real problem if the economy softens. For this reason, companies are quickly pulling back expenses in the EV market and realigning with the ICE market where the current volume is. A potential silver lining—though at a cost much higher than silver—is when the EV market does develop, everyone is ready for it in the engineering and manufacturing worlds.

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Inside the PT Ecosystem

Bearings and lubricants front and center in Detroit this March

Matthew Jaster, Senior Editor

The Bearing Show North America 2025, colocated with Lubricant Expo North America 2025 takes place March 18–20 at Huntington Place in Detroit. The Bearing Show connects the evolving needs of bearings end-users with the latest technologies serving OEM development, maintenance professionals and R&D engineers.

In just its second year, The Bearing Show has firmly established itself as a key event on the North American industry calendar. This dynamic platform brings together a diverse range of stakeholders, including bearing manufacturers, OEMs, end users, and lubrication experts. Attendees have the unique opportunity to network, explore the latest solutions, and learn strategies to optimize bearing performance and mitigate failures.

"The show's growth trajectory is remarkable," said Tom Harris, event director. "The 2025 edition will feature twice as many bearing-related exhibitors compared to 2024, showcasing its rising prominence and industry appeal. Additionally, this year's conference will host senior representatives from leading companies such as Nexteer Automotive, FEV, HF Sinclair, Ford, GM, NES, NSK, North America Bearing Company, Silverthin Bearing, Vibrac, and WD Bearings. Exhibitors and attendees are traveling from across the globe, including key markets like Turkey and China, further emphasizing the event's international significance. Their participation underscores the show's importance for both the bearing sector and the industries that rely on these critical components."

The bearing market in 2025 faces several critical challenges as it adapts to evolving industry demands and global dynamics. Electrified drivetrains, for example, are reshaping mobility by operating at higher speeds and generating unique thermal and electrical conditions. Bearings in these systems must handle greater loads, faster speeds, and the risk of electrical discharge damage from stray currents.

Sustainability and energy efficiency also present opportunities and pressures, with manufacturers needing to create eco-friendly solutions that minimize friction and energy consumption while complying with stricter regulations.

Additionally, global supply chain disruptions and rising raw material costs are straining production and pricing, pushing companies to innovate and streamline operations to stay competitive.

This year, The Bearing Show will look at the latest developments in OEM bearing requirements, particularly with regards to future fuels and electrified drivetrains. On day one, companies including, Nexteer Automotive, FEV and HF Sinclair, Ford and GM will be presenting on evaluations of bearings within high-speed drivetrains and modern bearing challenges in automotive motion control. Ford and GM will be presenting on preferred OEM architectures and mechanical engineering challenges for hybrid vehicles. Meanwhile, on Day 3, leaders from bearing companies including, NES, NSK, North America Bearing Company, Silverthin Bearing, Vibrac and WD Bearings will present on a range of topics including:

- Bearings for High Performance Applications
- Bearings for Space and Low Orbit Applications
- The Role of AI in Optimizing Bearing Performance
- Preventing Bearing Failure
- Misconceptions of Rolling Element Bearing Performance
- Comparison of Lubricant Selection for NTN, Timken and SKF Bearings

Lubricant Expo

The Lubricant Expo is connecting lubricant solution providers with the full range of end-user buyers, as well as the entire chemical and equipment supply chain with thousands of engineers and executives in attendance. This year's program will include expert-led conference sessions on topics such as:

Lubricant Analysis: Learn the ins and outs of lubricant analysis, a vital element for predicting equipment health and maximizing machine uptime.

Sustainability: Discover how the latest advancements in lubricants can improve equipment performance and longevity with sustainability.

Led by seasoned industry experts, these conference sessions will provide attendees with actionable insights they can immediately apply in their own work environments.

Every year, the event features keynote presentations from industry pioneers who provide insights on the latest trends, technologies, and challenges shaping the lubrication industry.

The Bearing Show highlights current component trends.

Booth Previews

Boca Bearing Company Booth #234

The reduction of rolling resistance and conservation of energy has been our company s hallmark since 1987. Boca Bearing Company stocks a full range of ceramic balls, full ceramic and ceramic hybrid replacement bearings for all industrial, medical, and specialty applications.

Ceramic balls are rolling, spherical elements that are used in check and ball valves, bearings, and other mechanical devices that provide rotary or linear motion. They are made from inorganic, nonmetallic materials that are processed at high temperatures. Many ceramic balls can achieve an extremely smooth surface finish to a high degree of tolerance. As a result Ceramic Balls have an extremely low coefficient of friction as compared to Metal Balls. Grinding removes cuts, scratches, scuffs, and other irregularities. Many ceramic balls exhibit much greater hardness than steel balls, resulting in longer life and improved reliability. Ceramic balls can also provide high stiffness, low thermal expansion, light weight, increased corrosion resistance, and electrical resistance. Boca Bearings has expanded their assortment of Silicon Nitride Ceramic Balls, Alumina Oxide Ceramic Balls and Zirconia Ceramic Balls.

Boca Bearings offers a line of ceramic balls, the C-HIP series. The C-HIP Ceramic Balls are made of the same material as the Si3N4 Ceramic Ball series, but these C-HIP balls are made by Hot Isostatic Pressing (HIP). Because of the greater temperature and pressure that is used in the making of these C-HIP balls they have an even greater density and hardness than a standard ceramic ball. Ceramic balls are suitable for applications where high loads, high speeds and extreme temperatures are factors.

bocabearings.com

Klüber Lubrication Booth #613

Klüber Lubrication offers expert tribological solutions by supplying high-performance specialty lubricants directly to customers in almost all branches of industry and regional markets. Our customers include producers of components, modules, machines and systems as well as companies using this equipment for their own production or processing activities.

Klüber Lubrication offers tried-and-tested specialty lubricants and bearing greases for specific applications. An important way to optimize the efficiency of a lubricant is to adapt the base oil to the respective application. Customized base oil technologies for the specific application ensure that the lubricity is maintained over a wide temperature range and at variable speeds and vibrations.

In addition to efficiency, optimized ageing behavior and increased safety also play a decisive role in the development of next-generation lubricants, especially in highly stressed, safety-relevant areas. This is achieved through improved wear behavior, excellent shear stability and high load-carrying capacity.

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Lubrizol Booth #405

Lubrizol, a Berkshire Hathaway company, is a specialty chemical company whose science delivers sustainable solutions to advance mobility, improve wellbeing and enhance modern life. Founded in 1928, Lubrizol owns and operates more than 100 manufacturing facilities, sales and technical offices around the world and has more than 8,000 employees.

Lubrizol CV9660 is engineered to meet the increasing demand for low-sulphated ash, phosphorous, and sulphur (SAPS) heavy duty lubricants whilst setting a new standard in the industry. With simplified formulation logistics and technology which exceeds the performance requirements in many key engine tests, such as the OM471, the latest Daimler durability test, Lubrizol CV9660 delivers top performance and meets exacting industry requirements.

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Napoleon Engineering Services Booth #730

Napoleon Engineering Services (NES) is in Olean, NY, seventy miles south of Buffalo in the heart of the Allegany Mountains. Founded in 1997, NES is a one-stop shop for engineered bearing products and specializes in Custom Bearing Manufacturing, Bearing Testing, and Bearing Inspection, providing valuable products and services to many industries including aerospace, drivetrain, agriculture, oil and gas, electric motor, automotive and heavy equipment, to name a few.

nesbearings.com

SKF Booth #531

SKF's lubrication division excels in both automatic and manual lubrication systems and equipment. They offer comprehensive solutions to reduce friction, which leads to improved performance, reduced downtime, better sustainability, and a safer workplace. The main challenge in the industry, according to is educating end users on the necessity of clean lubrication for optimal machine performance. The concept of delivering the proper lubricant to the right place, in the correct amount, at the proper interval is critical. Lack of proper lubrication leads to machine breakdowns resulting in downtime, expensive repairs, and reduced productivity.

The sector will increasingly depend on automation and wireless technology. Monitoring the performance of your machines through a mobile phone will become standard practice. The Internet of Things (IoT) will be integral to daily operations.

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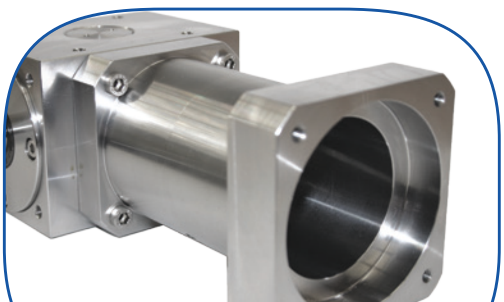

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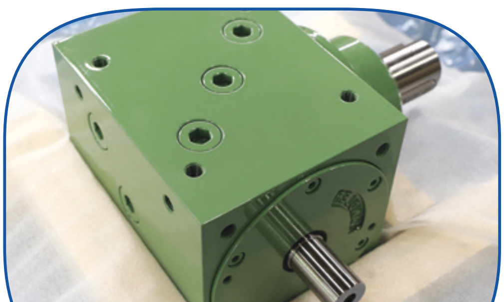

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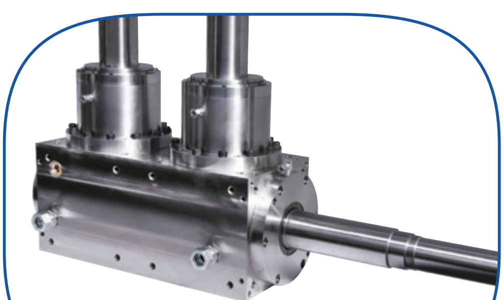

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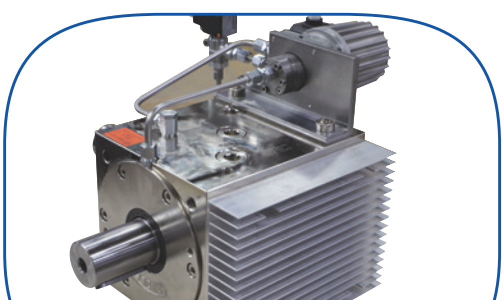

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The Reliability Game

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Matthew Jaster, Senior Editor

The test bench for wind turbine gearboxes at the ABS Wind Brazil workshop is the largest capacity in LATAM dedicated exclusively to supporting the wind industry.

Call it destiny, divine intervention or good ole-fashioned fate, speaking with Alejandro Pardiñas, CEO of Atlantic Bearing Services (ABS) and ABS Wind, one gets the impression he had no choice other than to become a mechanical engineer. This was evident way back when his great-grandfather became a mining engineer for Rio Tinto.

"He was assigned to a copper mine in Cuba in the 1850s. And as a mining engineer that was when the saga of mechanical engineer in my family started. After that, I don't know, there was probably a traditional song, genetics, whatever the case may be, nearly everyone in my family before me; my wife and now, my two my kids, have been involved in mechanical engineering," Pardiñas said.

It's no surprise the industry recently celebrated Pardiñas—and his engineering legacy—by presenting him with The Ponce de León Executive of the Year Award. Under Pardiñas' leadership, ABS has transformed into one of the fastest-growing startups in the U.S. becoming a global leader in engineering solutions for heavy industry and the renewable energy sector.

ABS has expanded its portfolio with brands such as MGS Gears, ACB Custom Bearings, AEC Engineering Chains, and ABS Wind, a division specializing in services for the wind industry that has become a global reference in spare parts supply, repair and maintenance for major turbine manufacturers and wind farm operators.

A History in Manufacturing

ABS, strategically based in Miami, specializes in the design and manufacturing of custom-made industrial bearings, gearboxes, engineering chains, and special mechanical parts. These solutions are tailored to meet the specific needs of clients and crafted with a strong focus on precision engineering to support high-performance applications across various industries.

Since 1999, ABS has established itself as a trusted partner in industries like steel, cement, mining, sugar, renewable energy and more.

In Cuba, Pardiñas was responsible for taking care of industries such as mining, jewelry, steel mills and other local industries as a sales engineer. He then escaped the country and pursued a career in bearings and power transmission here in the United States.

"I started my career here in 1998 as a sales engineer in bearing and power transmission business. We opened ABS in 1999. This was a unique opportunity given that most bearing and power transmission distributors relied on the engineers from the OEM to support the end users. It was clear to me that ABS could be successful in the bearing and power transmission markets," Pardiñas said.

A Proactive Member of the Engineering Community

Pardiñas used AGMA and ABMA documents and standards for his career project during school and later joined both associations through ABS. MGS Gears, one of the first three companies in Italy to join AGMA, further solidified this connection. As a board member of ABMA, Pardiñas actively supports the growth and competitiveness of the North American industry. His role on the National Industrial Advisory Board at Florida International University's College of Engineering and Computing further underscores his dedication to educational excellence and fostering the next generation of engineering talent.

He has a unique origin story about being introduced to AGMA in college when two of his college professors in Cuba were allowed to access AGMA standards without a membership.

"My professors were the only instructors in the country that had a connection with AGMA and access to all aspects of gear design and gear science. It was a spectacular opportunity for us," Pardiñas said. "In fact, one of my college professors, José Martínez Escanaverino from Cuba, has been working 14+ years at ABS as a scientific director."

Escanaverino was recently honored with AGMA's prestigious annual publication award for his contributions to the ANSI/AGMA 6008-B24 standard, "Specifications for Powder Metallurgy Gears." He became an Academic Member of AGMA in 1993 and actively participated in the Helical Gear Rating Committee (HGRC), earning recognition as an Associate Member for his work on the ANSI/AGMA 2001-D04 Standard, published in 2004. One of his most notable contributions was a paper presented at the 1999 FTM in Denver, titled "Failures of Bevel-Helical Gear Units on Traveling Bridge Cranes (99FTM13)." The paper addressed a longstanding debate between crane and gear manufacturers regarding service factors for gear unit selection and provided clear recommendations to both manufacturers and end-users, resolving the controversy. Due to restrictions imposed by the Cuban government, he was unable to attend the event. However, AGMA executives arranged for a designated presenter, and the paper's significance led to its full publication in the November/December 2000 issue of *Gear Technology*, where it was praised as highly relevant and impactful for its audience.

Reliability Focused

This magazine has frequently covered gearbox and bearing reliability. It remains one of the most challenging aspects of mechanical power transmission to date and an area in which Pardiñas has invested heavily at ABS.

"Everybody's struggling on the reliability side. And we've invested heavily in it since the very beginning," Pardiñas said. "We are designing gears, gearboxes and bearings every month, because 80 percent of our revenue is a custom-made power transmission component, designed by us and produced internally."

ABS acquired a gearbox repair facility for the wind industry in Costa Rica nearly 15 years ago, followed by a second facility in Mexico in 2017. This expansion continued with the establishment of ABS Wind Mexico, with locations in Puebla and Oaxaca; ABS Wind Brazil; the ABS Wind US workshop in Big Spring, TX; MGS Gears in Milan, Italy; and a facility in Dalian, China. These strategically located facilities have enabled ABS to localize its services. Today, ABS provides engineering, reverse engineering, repair, field services, and more, serving clients across the USA and in over 20 countries worldwide.

The company prides itself on adapting to the changing dynamics of the mechanical power transmission markets and analyzing the impact they may have on the industry.

"We typically compete with major industry-leading organizations in our field. Our flexibility and ingenuity are areas that allow us to adapt to our customer's requests," Pardiñas added.

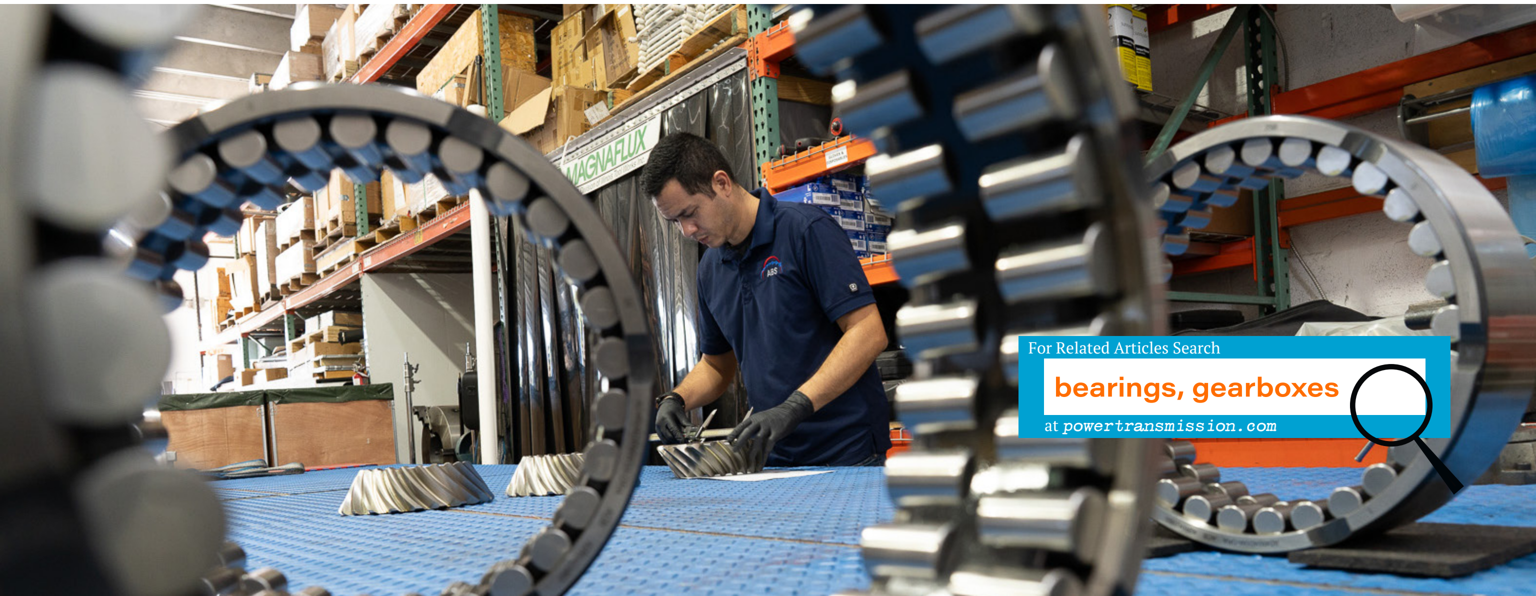
MGS Gears, led by Maurizio Stucchi and backed by a team with 30+ years' experience is synonymous with precision and Italian design. ABS Wind, a global company specialized in multi-brand maintenance and repair solutions for wind turbines, and ZF Wind Power, a world leader in the manufacturing of wind turbine announced a strategic collaboration at the Cleanpower congress for the repair of their gearboxes in the North American market in early 2024.

This partnership designates ABS Wind as the authorized and exclusive partner for the repair of gearboxes and components from ZF Wind Power in America. It also enables Thrive, ZF Wind Power's service concept, to strengthen the efficiency to regional partners.

The hub of this operation will be located at ABS Wind's expansive facilities in Big Spring, TX, a strategic location equipped with qualified personnel and the necessary technology, including an advanced test bench for wind turbine gearboxes. This setup ensures compliance with the stringent quality standards demanded by the technological giant.

"This partnership with ZF shows our global customers that we are key players in gearbox repair and reflects our growth as their exclusive partner in the United States," Pardiñas said.

Marco Partidas, ABS Quality Engineer, working on ACB bevel gears, which are key components in gearboxes.



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Award-Winning Leadership

At the Chamber's 44th Anniversary Gala in 2024, the Spain-US Chamber of Commerce in Florida honored Pardiñas with the 'Executive of the Year' award and recognized Avangrid-Iberdrola, a leading energy and technology giant, as 'Company of the Year' for their remarkable contributions to the energy sector.

Monica Vázquez, president of the Spain-U.S. Chamber of Commerce, presents the Ponce de León Award to Alejandro Pardiñas, CEO of ABS.

Reflecting on the award, Pardiñas commented: "For an American entrepreneur, born in Cuba, who maintains strong personal and business ties with Spain and whose business extends and creates value across various Ibero-American countries, receiving this recognition from the Spain-U.S. Chamber of Commerce as a testament to my professional journey is both an honor and a source of deep pride. I share this achievement with my founding partners, who believed in this venture, as well as with all the members of the ABS and ABS Wind teams."

The award surprised Pardiñas in a good way. "It was great just to be nominated by the Spain-US Chamber of Commerce in Florida and I was humbled to receive the award. We rarely get the opportunity to stop and look back at what we're capable of achieving. It means a lot to our organization as well as the Cuban American community. We are successful in music and banking, but rarely do we get recognition in the engineering sciences," Pardiñas said.

Future Insights

ABS is planning to establish its first roller bearing factory by the end of 2025. "We are doing everything on our own and will be operational by September. This will give us an advantage in the market because we are going to be a local manufacturing facility," Pardiñas stated.

The company also aims to consolidate its presence in certain niche market segments, including areas affected by upcoming tariffs. Furthermore, ABS is gaining recognition as a strong player in the U.S. steel and renewable energy sectors, which now constitute a significant portion of its business activity.

To further enhance its expertise in renewable energy, ABS is launching ABS Power Conversion, focusing on systems for wind, solar, electric vehicles (EV), and battery energy storage systems (BESS). These initiatives underscore ABS's dedication to advancing the energy transition with innovative and sustainable solutions.

ABS is also investing heavily in research, exploring advanced repair techniques, bearing housings, and solutions for heavy load challenges, among other areas. 'There's no large research venture in the repair and replace business—not in gears, but more on the big components,' Pardiñas added.

Finding and retaining top-tier engineering talent remains another challenge the company fully embraces.

"When you're lucky enough to find the level of skill you need in our business, you need to be a magician to keep it inside the organization. Every single member of my team has plenty of opportunities outside of ABS. We need to be aware of this and we need to make ABS the best place to work for everyone and keep them invested in our organization," Pardiñas added.

The main challenge on the human resource side is trying to find the right engineers in the right location to grow the business while keeping sustainability and energy efficiency in mind.

Pardiñas said meeting the needs of the local industrial markets will be key to ABS now and in the future—a future that will certainly involve other members of the Pardiñas family joining the ranks of mechanical engineers—fate will certainly play a role in this.

For Pardiñas, he appreciates the chance to work side-by-side with his family.

"This is important for me, because you can imagine working 70 hours a week for 25 years, traveling +120 days/year you have compromised your time with your family, so at least you try to have quality time with them. I'm extremely grateful for the work/family balance this company has provided."

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Statistical Analysis of the Position Tolerances of Planet Pins in Planetary Gearboxes

Benjamin Abert and Tim Erlewein

Manufacturing processes are not perfect and are subject to deviations. These deviations occur in all forms and are limited by tolerances. Tolerances are described in standards such as ISO 1101 (Ref. 1) or ASME Y 14.5 (Ref. 2). Tolerance ranges are standardized for various manufacturing processes, such as shaft tolerances in DIN ISO 286 (Ref. 3) or center distances in DIN 3964 (Ref. 4).

In most cases, the deviations follow a normal distribution, as described by Equation 1, where σ is the standard deviation and μ is the nominal value. The standard deviation is a measure of the scatter of the values around the mean.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{1}$$

The positions of the planet pins in the planet carrier are also subject to tolerances. It is known that uneven distribution of the planets around the circumference leads to uneven load distribution. According to ISO 6336 (Ref. 5), uneven load distribution due to deviations can affect the load capacity of the planetary stage. In addition to deliberately implemented asymmetries, it can also be assumed that tolerances lead to a change in the load sharing between the planets.

The tolerances are mostly defined as geometric deviations from an ideal position. The definition for the tolerance is mostly done per part. In the context of catalogue gearboxes, the application and the requirements for torque density can change quite drastically. This means that a tight tolerance is not needed for every application.

If the geometric tolerances are not met, the parts are released using a simulation in a special release process. Both the customer's requirements and the measured production deviations play a role in this process. The simulations are very reliable but generate a comparatively large amount of work.

This study uses a Monte Carlo simulation to investigate the influence of tolerances on the load capacity. This simulation analyzes the safety of the planetary stage with variable planet pin positions and discusses the results, including the possibility of load-dependent tolerances for catalog gearboxes. The resulting surrogate model should facilitate a determination during the measurement process as to whether the part can be utilized for the order, whether it will be incorporated into another order, or whether it necessitates disposal.

Simulation Model

The simulation model and the theoretical approach used are explained below.

System Simulation

The simulation model is based on a quasi-static gearbox simulation with the *FVA-Workbench 9.0.2*. In this method, analytical models are used to simulate the behavior of gearbox components under load. Shafts are approximated as Timoshenko beams, rolling bearings as Hertzian contacts, and gear teeth as mechanical plates. The planet carriers are too complex to be meaningfully modeled using analytical equations, so they are modeled as reduced stiffness matrices according to Guyan (Ref. 6).

To obtain the displacements in the gear system, and thus the load distribution on the tooth flank, the stiffness is solved iteratively in a system of linear equations. The procedure is based on the *RIKOR* method (Ref. 7).

The overall system simulation determines the deformation of all components under load. The face load factor $K_{H\beta}$ and the load sharing factor K_γ for the calculation are derived from the stiffness characteristics of the mechanical system.

Conservative calculations are used for the design of the models presented in the Results and Discussion section. It is assumed that the largest face load factor and the largest load sharing factor in the planetary gear stage occur on the same planet. The load capacity is determined for this planet in accordance with ISO 6336. This study is carried out exclusively on one-sided planetary carriers. Errors caused by the assembly of two parts with tolerances are therefore not considered.

Tolerance Simulation

In the mechanical model, the planetary pins are connected to the side plates via coupling elements, which can be displaced in the radial and tangential directions. This changes the position of the pin and the planet. The influence on the gearing is considered, in particular on the center distance, backlash, and tip clearance. This reduces the amount of effort required for the meshing and the static condensation of the planet carrier. The carrier must only be prepared once in a pre-processing step before the simulation, enabling very fast simulations. In this paper, only one-sided planet carriers are investigated. For two-sided planet carriers, additional static misalignments would occur.

It is assumed that a standard deviation for the position of σ = 6 µm can be achieved in the production process. Figure 1 shows the resulting Gaussian distribution.

To keep the evaluation of the results manageable, it is assumed in this study that no angular errors occur in the manufacturing process.

Statistical Methodology

To determine the influence of the pin positions, 10,000 positions are simulated in a Monte Carlo simulation. In each simulation run, all planetary pins receive a new deviation, which is determined randomly. These deviations are determined in both the radial and tangential directions according to the assumed distribution from Figure 1, resulting in a superposition of two distribution functions.

The acting torques, load distributions, and deformations are determined for each deviation. A load capacity analysis is then performed in accordance with ISO 6336. However, the load capacity of each planet is used with the resulting force factors.

The convergence of the Monte Carlo simulation is assessed visually. Figure 2 shows an example of the tangential deviations for the first planet, variant 1 from the Results and Discussion section, in a histogram. The x-axis shows how far the planet deviates from its nominal position, while the bars show how often each of these deviations appears in the calculation. The mean value and the estimated standard deviation are also shown as vertical lines. A comparison of the histogram with the specified standard deviation shows that both the mean and the standard deviation of the two curves match. The mean value of the data set results in μ = - 0.041 µm and the standard deviation is estimated as σ = 5.941. Thus, we can assume that the results of the Monte Carlo simulation are reliable.

Results and Discussion

Load differences between the planets can be compensated by a centering movement of the sun, especially in gearboxes with three planets. The centering movement is made possible by the bending of the shaft. To consider this effect, two variants are examined in this paper. The first variant is characterized by small planets and a large, immobile sun. Thus, there is very little compensation by the sun shaft. The second variant is designed with a very high gear ratio and therefore includes comparatively large planets with a smaller sun. This reduces the bending stiffness, which makes it possible for the sun to compensate for deviations effectively. The gearbox models examined are based on classic industrial gearboxes, as offered by many manufacturers. The same balancing effect could also be achieved using a floating ring gear. This variant should not be considered in the following.

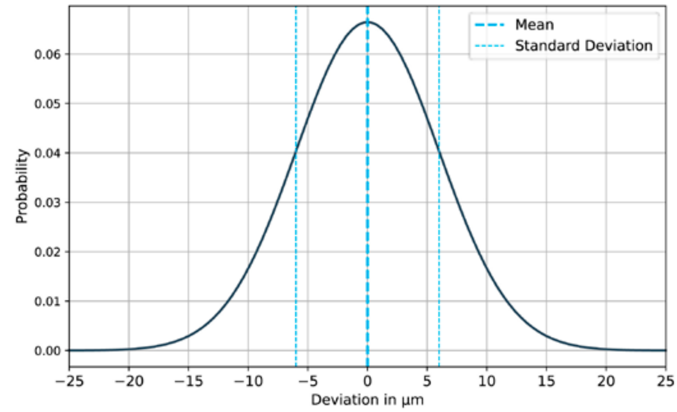


Figure 1—Gaussian distribution showing the probable deviations of the planet pin.

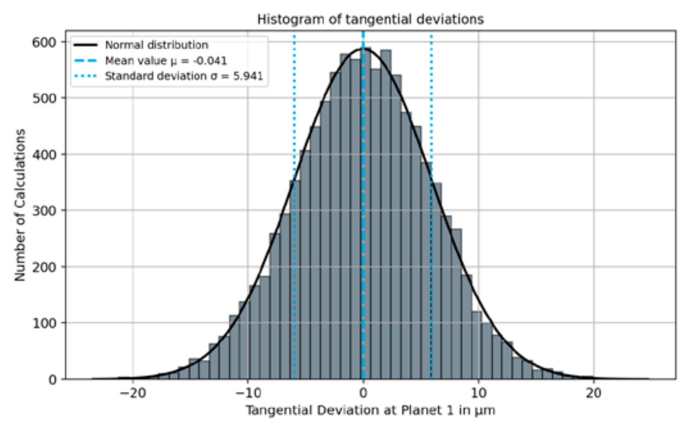


Figure 2—Histogram of the displacement variables for planet 1 of variant 1.

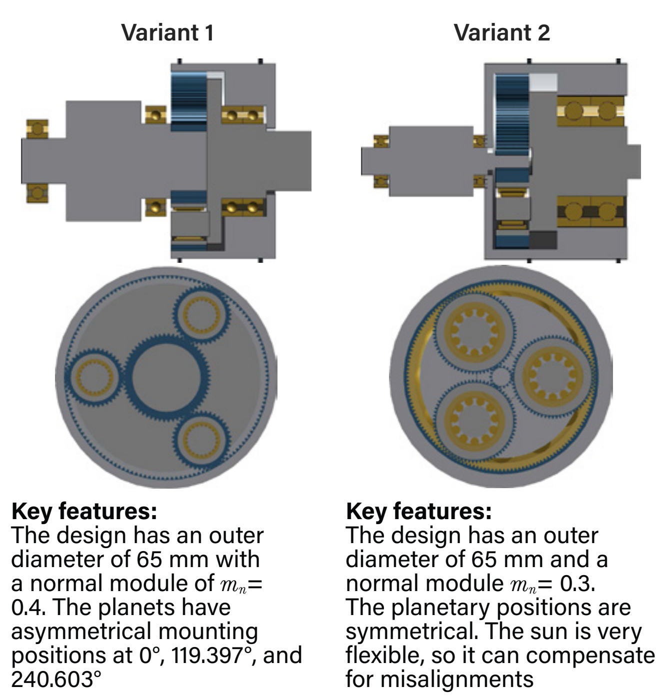


Figure 3—Visualization of the variants discussed.

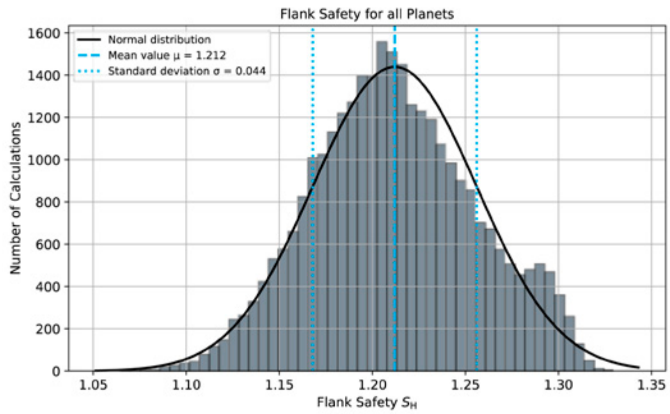


Figure 4—Histogram representation of the flank safety factors.

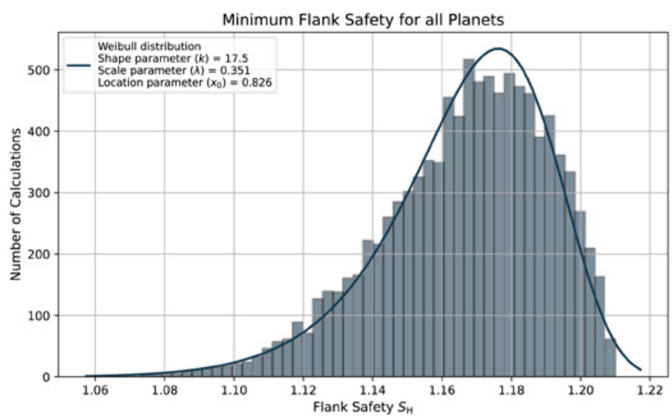


Figure 5—Histogram representation of the minimum flank safety factors.

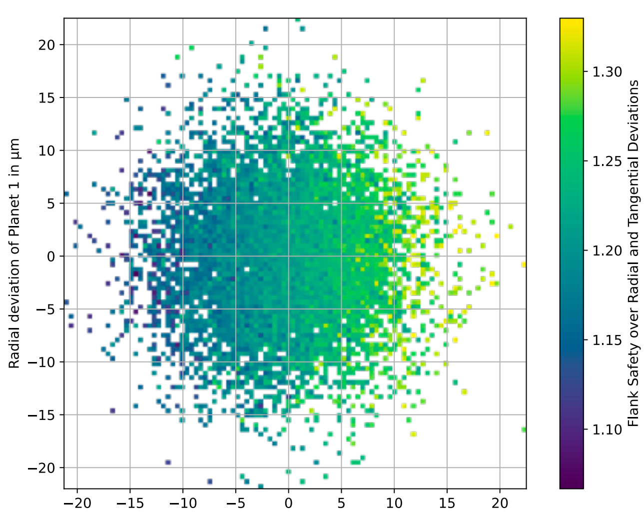


Figure 6—Flank safety factor over the radial and tangential displacements.

Results for Variant 1

Variant 1 is driven by the sun with 20 Nm at 5000 rpm, with a transmission ratio of i=3.3. This results in a pitting safety of S_H = 1.22 and a tooth root safety of S_F= 1.77 for the sun-planet mesh according to ISO 6336. These safety factors have been determined using the highest face load factor $K_{H\beta}$ and the worst load-sharing factor K_γ. The planet-ring gear mesh has a flank safety of S_H= 2.4; however, this is not critical and is not considered further below.

The safety factors for all Monte Carlo simulation calculations are shown in Figure 4 and Figure 5.

Figure 4 shows all the calculated safety factors. On average, the nominal safety factor is achieved. The fit with the normal distribution is not perfect. This might indicate that it could be a superposition of multiple distribution functions.

The minimum safety factors in Figure 5 are generally lower, with an average of S_H = 1.17. Furthermore, the distribution function has changed from a normal distribution to a Weibull distribution. This is reasonable, as the deviation-free safety factors limit the minimum upper safety factors. Larger deviations can also lead to lower safety factors.

To better understand the effects of the displacements, the displacements relative to a planet are examined in more detail below. Figure 6 shows the safety factors for the sun-planet mesh of planet 1 over the radial and tangential displacements. The flank safety increases as the tangential displacement increases. The highest safety is observed at the right edge, i.e., with a counterclockwise displacement. Radial displacements have no significant effect on the flank safety.

What is notable in Figure 6 and all the following diagrams is that there is no continuous color gradient, meaning that individual fields of low safety can appear in areas with higher safety factors. This is because all of the planets were varied, and the safety is determined based on the position of all planets and the resulting load sharing. This effect was reduced by averaging the values in fields with more than one calculation.

To better characterize the system, the next step is to plot the safety factors over the angles. Since this design has three planets, all distances can be represented by two angles. The left side of Figure 7 shows the safety of planet 1 over the angles to planet 2 and planet 3. It can be observed that high levels of safety are achieved when planet 2 and planet 3 are shifted into the load. Safety always increases when the other planets carry more of the load. However, these observations are not appropriate for optimizations.

The minimum safety factors are shown on the right-hand side. Here, it can be seen that the safety factors reach their maximum closest to the deviation-free nominal design case. The high safety factors are also arranged along an angle bisector, which represents the case where the positions are rotated in the same direction.

The next step is to make a determination on the load-bearing capacity of the overall system based on the data. To do so, the determined safety factors are divided

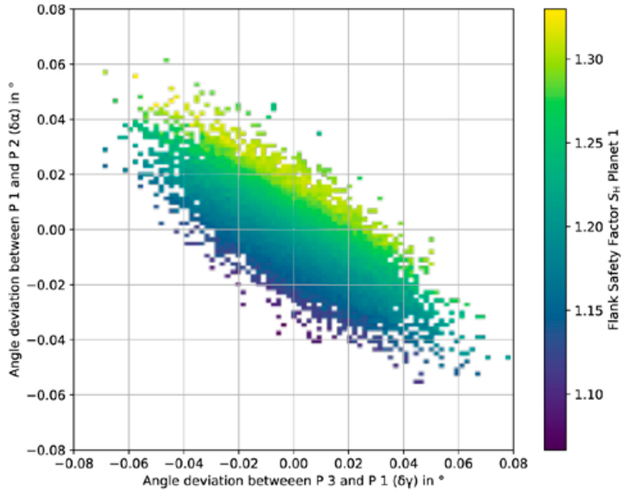
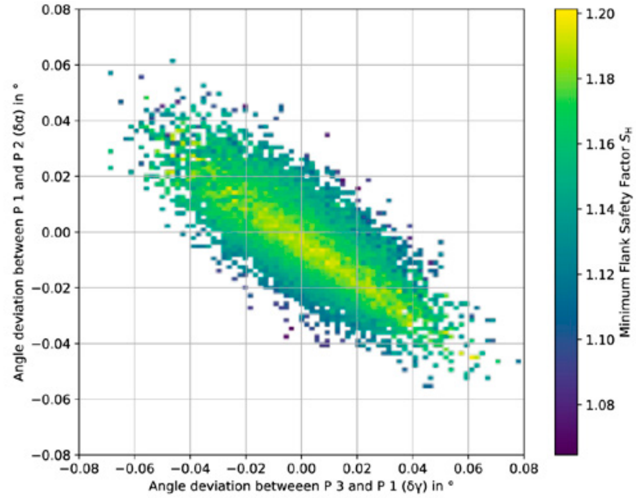



Figure 7—Pitting safety of planet 1 over the angles to the neighboring planets (left), minimum pitting safety of all planets over the angles to the neighboring planets (right).

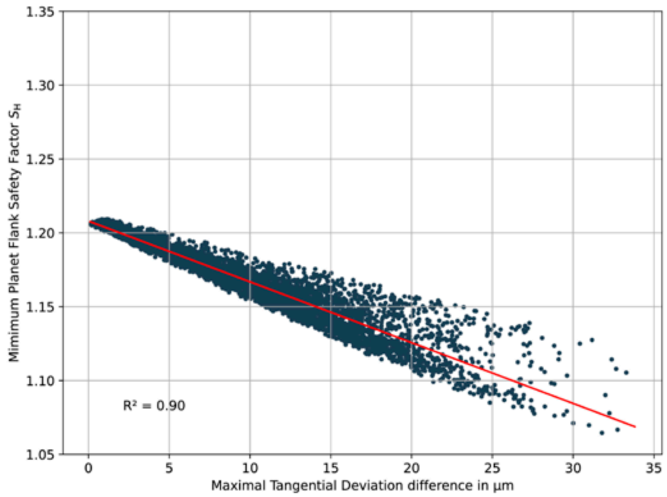


Figure 8—Regression of the maximum tangential deviation over the minimum pitting safety factor.

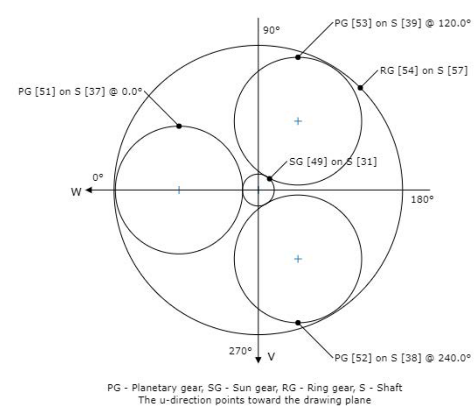


Figure 9—Representation and numbering of the planet positions.

into classes and the largest difference to the tangential deviation between two planets and the classes is determined. This results in a linear relationship between the deviation and the minimum safety factor, as shown in Figure 8.

The coefficient of determination R^2 is 0.9, which indicates that there is a good correlation between the safety factors and the deviations. The deviations primarily occur on the upward side toward the safety factor. The data points are very close to the regression line on the lower side with less safety. Therefore, this regression can be used as a surrogate model, i.e., as a simplified model approach. However, the coefficient of determination of $R^2 = 0.9$ indicates that not all influences are fully represented. This is logical, as a radial displacement can also lead to an additional misalignment as well as the increasing loads on the planet.

Results for Variant 2

10,000 calculations were also performed for variant 2. The mean value of the calculations is -0.082 µm with a standard deviation of $\sigma = 6.045$ µm. Concerning these values in Figure 9, we can assume a convergence of the simulation.

The sun is very mobile in this design, and the thin design makes it possible for the sun gear to compensate for planetary displacements. The mobility is due to the arrangement of the planets being symmetrical. The designation of the planets and the angular arrangement are shown in Figure 9.

As in the previous model, this gearbox was designed for flank safety in the sun-planet mesh with a nominal safety of 1.2. Figure 10 shows the histograms of the calculations, with the minimum safety factors on the right and all planetary safety factors on the left. Overall, the safety factors for this

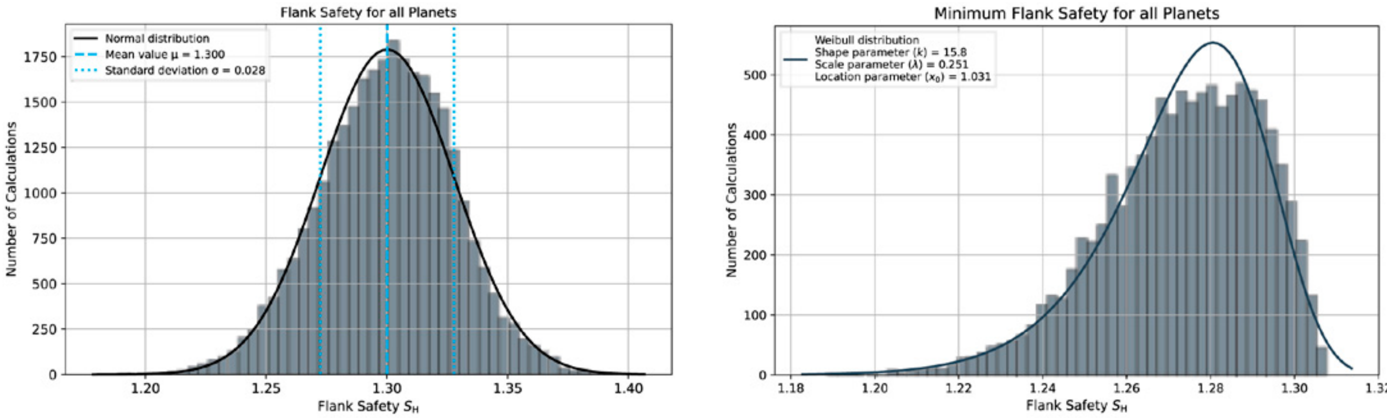


Figure 10—Histograms of the flank safety for all planets (left) and the minimum flank safety for all planets (right).

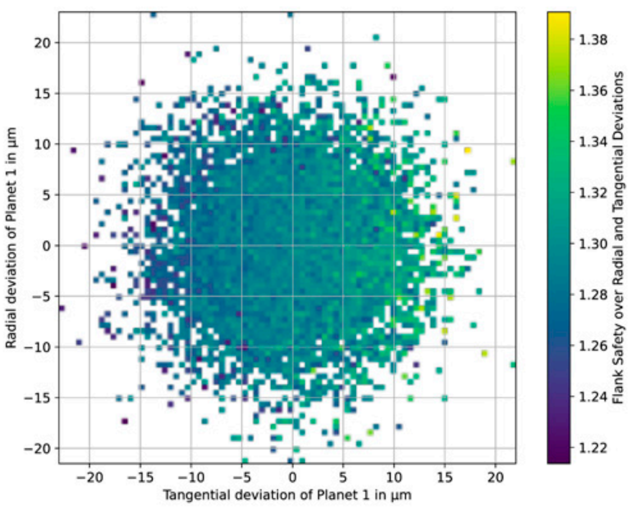


Figure 11—Flank Safety over radial and tangential deviations(left) and influence of the sun gear stiffness on the pitting safety factor.

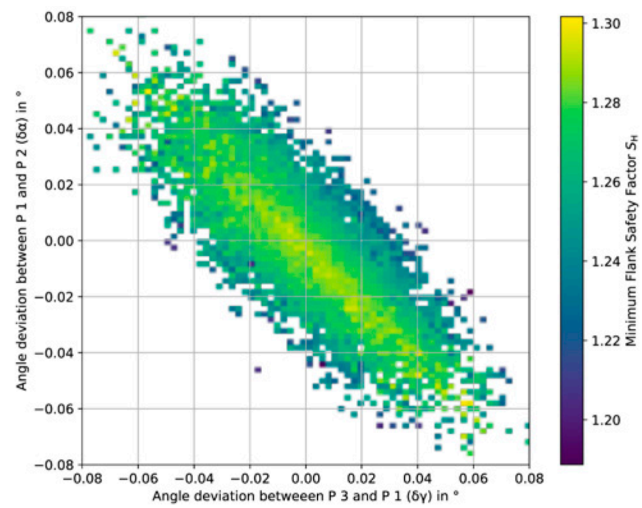


Figure 12—Minimal flank safety over the angles between planet 1-2 and planet 1-3.

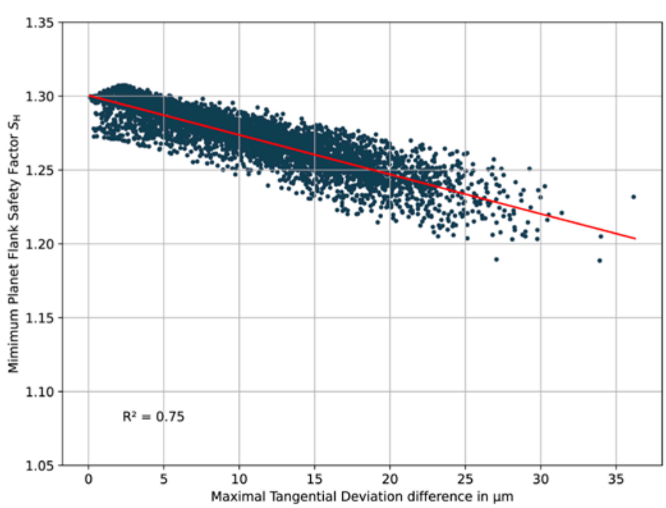


Figure 13—Regression of the maximum tangential deviation over the safety factor.

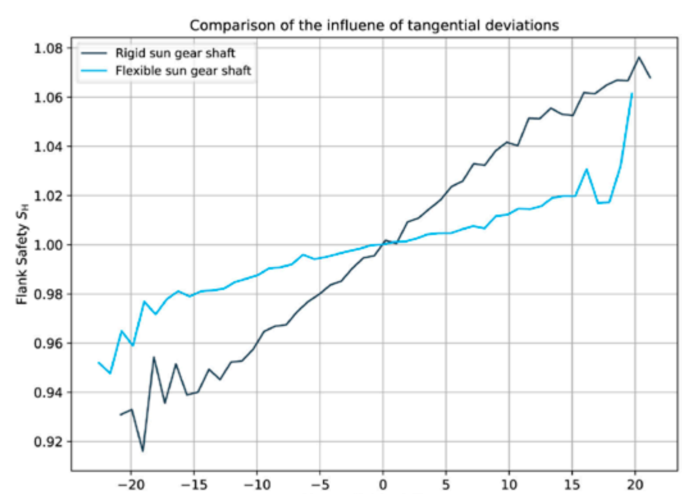
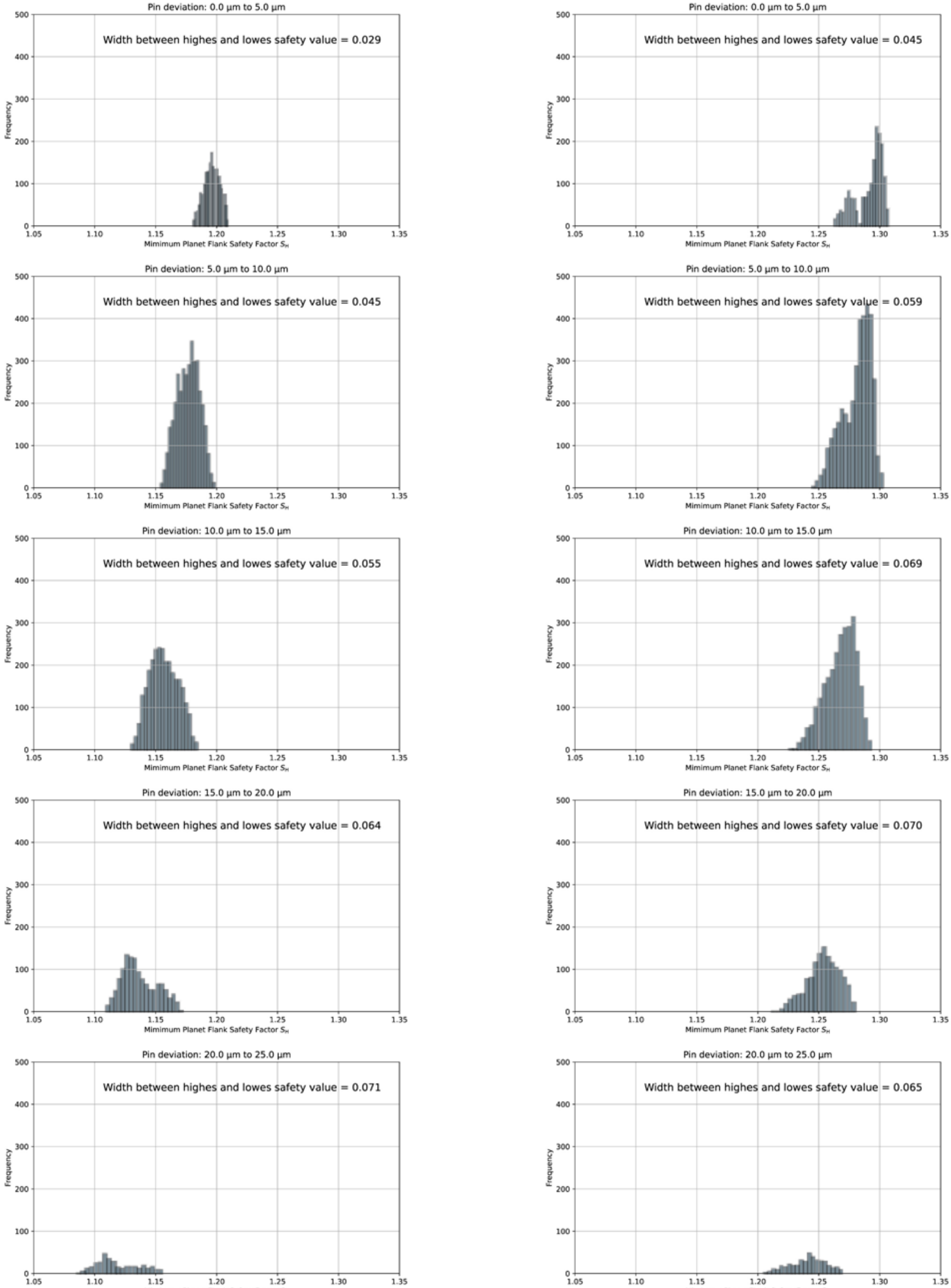


Figure 14—Comparison of the influence of tangential deviations.

Variant 1

Variant 2



Key features:
The design has an outer diameter of 65 mm with a normal module of mn= 0.4. The planets have asymmetrical mounting positions at 0°, 119.397°, and 240.603°

Key features:
The design has an outer diameter of 65 mm and a normal module m_n= 0.3. The planetary positions are symmetrical. The sun is very flexible, so it can compensate for misalignments

Figure 15—Comparison of safety factor histograms for different maximum displacements.

model are slightly higher than in the previous model. This is because the design calculation is based on the conservative assumption that the highest load-sharing factor K_γ and the highest width load factor $K_{H\beta}$ occur on one planet.

In comparison with the previous gearbox, the Gaussian curve fits very well here as a distribution function. The minimum safety factors are also represented by the Weibull distribution. However, the fit towards the maximum of the Weibull distribution is lacking, which suggests that it is not one single distribution but a superposition of distribution functions.

The flank safety of planet 1 over the radial and tangential displacements of the planet is shown in Figure 11. On the left side, the displacements are shown in a scatter plot. This plot shows a more uniform safety factor over the entire displacement field (left), compared with variant 1. This suggests that the additional mobility of the sun gear shaft means that displacements have less of an impact on the safety factor.

Figure 12 shows the minimum flank safety over the angular deviations between planet 3 and planet 1 (γ) and planet 1 and planet 2 (α). Here a clear difference in the safety factors can be observed. The line of high safety factors that runs diagonally through the diagram is particularly noticeable. Particularly interesting is the comparison with variant 1, where the line of maximum safety factors runs perpendicular to it.

The regression of the results is shown in Figure 13. Unlike in the previous example, the coefficient of determination is given with R^2=0.75. Even if the coefficient of determination is worse than in the previous example, this can still be rated as a usable regression considering the initially described specific use case. The wider scatter indicates that the unconsidered influences play a more important role in this case.

Comparison

Despite their apparent similarity, the variants exhibit markedly different behaviors in the evaluations, which will be discussed in detail below.

Upon examination of the tangential displacement of the two variants, it becomes evident that tangential displacements exert a comparatively minimal influence on variant 2 displacements This can be demonstrated by comparison of the mean flank safety factor with the tangential displacement as shown in Figure 14. Looking at smaller tangential displacements (<± 15 µm) a linear correlation between the displacement and the safety factor can be observed. For higher tangential displacements less calculation points are available and the noise in the line increases. Moreover, it is evident that the slope of the first variant, which features a stiffer sun shaft, is steeper than that of the variant with a flexible sun shaft.

The next step is to compare the minimum safety factors. It is noticeable that the calculations around the regression scatter significantly. To quantify this observation, the distributions of the safety factors for different maximum displacements are analyzed and compared. For this purpose, the maximum tangential deviation is separated into bins of 5µm. For each bin, a histogram is calculated and displayed in Figure 15. As no distribution function is apparent, a range is defined and output as the distance between the bins with the highest and lowest safety factor.

If the distribution range for the different bins of maximum tangential displacement is plotted in a bar chart, the scatter varies significantly across the bins. The scatter also increases significantly for high displacements in both examples. The scatter of the rigid sun gear shaft is lower here than the scatter with a flexible sun gear shaft.

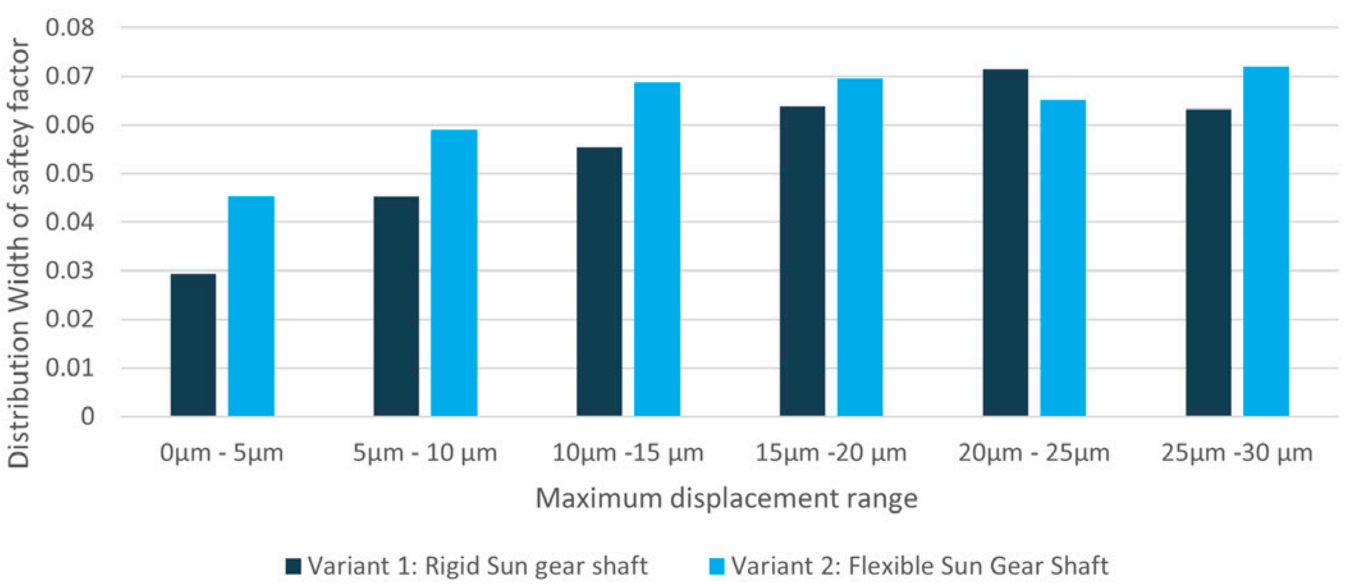


Figure 16—Distribution width for different displacement ranges.

The diagram is displayed in Figure 16. In general, the deviations do not exceed seven percent from the mean safety per bin.

Summary and Future Work

This study presents a method for evaluating systems with tolerances, using an example of a planet carrier to illustrate and statistically evaluate the influence of manufacturing tolerances on the load capacity of planetary gears.

A normal distribution is assumed for the position tolerances at the planet carrier, and the standard deviation of the position tolerance is assumed to be 6 µm. A Monte Carlo simulation with 10,000 calculations is used to analyze the influence of the deviation. For this purpose, the number of simulations was deemed sufficient.

The results show that meaningful conclusions can only be made in an aggregated form. To do so, the minimum flank safeties of the planetary stage are plotted over the angle deviations. The results clearly show that optimal utilization is possible for gearboxes with small deviations. However, planet carriers with significantly larger manufacturing deviations can also be used if the backlash allows. These can be mounted and are functional, albeit with lower maximum torque.

With this realization, a geometric position tolerance can be reformulated as follows: Are the customer's torque requirements such that the part can still be used despite greater deviations? Or can I find another customer with lower power density requirements in the near future? Based on this approach, large deviations should only be considered as rejects if the storage costs are greater than the profit on the component.

This is a proof-of-concept study in which the positional tolerance of the planet pins on the planet carrier is the only parameter that is varied. The simple study shows how the tolerances can be evaluated. Scaling to larger tolerance systems is possible in principle, but there are still some open questions:

- In the abscissa of the regression, all influencing parameters must be represented in such a way that a sufficiently good regression is achieved.
- Definition of these parameters may make up the majority of the work.
- Since all calculations are independent, adding an additional tolerance should not result in additional simulations. This would provide a very time-efficient method of assessing the tolerances.

Acknowledgment

All results were generated using the scripting module of the *FVA-Workbench* gear simulation tool and exported to *Excel*.

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First presented at the 2024 Fall Technical Meeting (FTM), October 7–9, 2024, Rosemont, IL. Printed with permission of the author(s). Statements presented in this paper are those of the author(s) and may not represent the position or opinion of the American Gear Manufacturers Association.

Beyond Motors: Gearboxes as the Unsung Heroes in Robotics and Heavy-Duty Machines

Pablo López García

Robotic devices—such as cobots, exoskeletons, prostheses, and humanoids—are designed to operate in environments that are shared with humans. These settings are often unpredictable, making human-centric movement a crucial requirement.

As the trend towards electrification and the establishment of modern robotics technology continue to advance at an unprecedented pace, a new paradigm is emerging in the world of machinery. Modern robots and machines are no longer just tools; they are becoming intelligent, efficient, and adaptive systems that redefine how we interact with machines in our daily lives. This shift is not only changing industries from manufacturing to construction but is also paving the way for smarter, more sustainable, and useful mechanical solutions.

Movement is pivotal to any machine, as it is the primary means by which a machine interacts with and influences the physical world, enabling it to perform useful work. This movement is driven by actuators, which convert energy into mechanical motion, serving as the critical components that determine the machine's overall performance. Whether it's precision, speed, or power, the ability to control and optimize movement is what defines a machine's effectiveness and its ability to accomplish complex tasks.

Central to this paradigm shift in modern machinery is the actuator—a critical component that powers these machines, ensuring their reliability, torque, and precision. In this era of electrified machinery and autonomous robotics, the actuator choice plays a pivotal role in reshaping the future of how machines operate.

Modern Robotics: Machine Versus Human Movement

In recent years, the development of advanced, human-centric robotic systems—such as collaborative robotic manipulators, bionic prostheses that restore limb functionality, injury-preventing exoskeletons, and humanoid robots used in industrial and service sectors—has substantially accelerated. These innovations hold great potential to revolutionize multiple industries by augmenting human abilities and taking over monotonous, hazardous, or physically demanding tasks. Yet, despite these advancements, robotics still faces significant hurdles in realizing its full potential for societal impact.

While progress in cognitive systems and AI is a critical bottleneck, the field also grapples with a fundamental hardware challenge, as highlighted by Tesla's development of its first humanoid robot, Optimus. The issue is straightforward: as engineers incorporate all the necessary components for a robot's functionality, the resulting system becomes excessively heavy. This high mass limits speed and reduces productivity, and it increases the energy required for movement. A key contributor to this weight problem is the actuators—typically around 30 in a humanoid robot—comprising an electric motor, gearbox, and control circuit with sensors.

As an engineer with a background in the automotive industry, I was intrigued by this issue when I transitioned into robotics a decade ago. My previous experience had shown me the sophistication of actuation technologies in other fields, which made this challenge in robotics surprising. However, working with the highly experienced Brubotics team of the Vrije Universiteit Brussel, I quickly realized the unique demands of robotic actuation and became passionate about finding innovative solutions to overcome these limitations.

Robotic devices—such as cobots, exoskeletons, prostheses, and humanoids—are designed to operate in environments that are shared with humans. These settings are often unpredictable, making human-centric movement a crucial requirement. At Brubotics, our research during over three decades has shown that robots safely interacting with humans must move in a compliant and predictable manner that should be quite close to human motion. This distinguishes modern robots from traditional machines, which generally follow more rigid movement patterns, conditioned by the extreme position accuracy requirements of these devices.

However, replicating human movement in a machine is a complex engineering challenge. While humans may initially not be considered top performers in movement compared to some animals or to modern machinery like helicopters or CNC machines, engineering human-like movement is incredibly difficult. One major challenge is replicating the high specific torque that the human body produces. For instance, when jumping, each ankle generates torques over 400 Nm (Ref. 1)—comparable to a Formula 1 engine at each foot! Our joints, such as hips, shoulders, and elbows, deliver impressive torque relative to their size.

Beyond torque, speed is also a factor. Human joints typically move at under 100 rpm, whereas electric motors and engines can easily exceed 15,000 rpm. This contrast highlights that the challenge in replicating human movement isn't about moving fast—it's about creating lightweight systems capable of high torque.

This concept, known as torque density (or more precisely, torque-over-weight), is central to what is currently known as the hardware problem of modern robotics. Even with cutting-edge technology, electric motors are still about ten times heavier than human joints with comparable torque output. This weight problem makes building robots that move like humans extremely challenging. Interestingly, most videos showing collaborative robots at work are sped up by 5 to 10 times; otherwise, their slow movements would be tedious to watch for more than a couple of seconds.

Heavy-Duty Machines

A machine that moves surprisingly close to humans, albeit at a different scale, are excavators and other off-road, heavy-duty machinery. These machines can achieve extremely high torque densities while moving at moderate speeds. At a certain point, I began using this example to visually explain the hardware problem in modern robotics: humans move more like excavators than electric motors.

To build these off-road machines capable of delivering very high torque densities at moderate speeds, a combustion engine is often combined with a hydraulic actuation system. In the past, cable and pulley systems were used to actuate these machines, but due to reliability and cost issues, they were largely replaced by hydraulics over 70 years ago.

It should thus come as no surprise that hydraulics and cable-pulley systems have been intensively explored as well in modern robotics over the last few decades to achieve the high torque densities required. The amazing (former) ATLAS robot from Boston Dynamics, a pinnacle of human-like movement performance in modern robotics, uses hydraulic actuators. The use of cable-pulley actuation systems, often termed 'remote actuation' in modern robotics (Ref. 2), involves locating the actual prime mover remotely from the actuated joint and using a cable or flexible shaft to transfer the movement. Many exoskeletons, robotic hands, and lightweight robotic manipulators developed in recent decades have employed these solutions (Refs. 3,4,5).

Interestingly, Boston Dynamics' largest commercial success is not ATLAS but SPOT, a highly versatile, four-legged robot that can also incorporate a robotic arm on its back. SPOT's joints use electric motors and gearboxes instead of hydraulic actuators. Additionally, the new ATLAS generation recently presented by Boston Dynamics has transitioned from hydraulic actuation to using electric motors and gearboxes, like other prominent humanoid robots such as Tesla's OPTIMUS, Figure's 01, or Apptronik's APOLLO. These

Human-centric robots vs. excavators.

robots achieve acceptable torque density using electric motors by means of employing an actuation strategy fine-tuned by collaborative robots (cobots) over the past decade: the use of high-ratio gearboxes.

On a larger scale, in off-road machinery, there is a noticeable and increasing parallel trend towards electrification. The shift in this case is primarily driven by efficiency gains and maintenance advantages of electric actuation compared to the combination of combustion engines and hydraulics traditionally used in this industry. The off-road industry is heavily investing in finding solutions to replace engines and hydraulics with electric motors and gearboxes. However, the high torque-densities required in this sector make the transition to electrification extremely challenging. Currently, although some battery-driven electric systems can be found already in the market, powering smaller off-road machines (Ref. 6), combustion engines and hydraulics remain the predominant choice for larger machines (Ref. 7). As a result, the electrification of off-road machines significantly lags behind other sectors such as passenger cars.

Gearboxes in Robotics

As noted by the famous MIT's Robotics Professor Sangbae Kim, the father of a Cheetah robot that can run faster than its animal equivalent, *"gearboxes are where the problem starts..."* in modern robotics.

High-ratio gearboxes add complexity, weight, losses, non-linearities, backlash, and other challenges to robotic systems. Nevertheless, they are essential for compensating for the low torque densities of electric motors. High-ratio gearboxes (typically over 100:1) allow small, lightweight motors to deliver high torques by trading speed for torque. The strain-wave gearbox, known for low backlash and high-ratio capabilities, has a clear advantage from the control perspective that makes it today the dominant gearbox technology in modern robotics.

Despite their advantages, strain-wave gearboxes have their own problems. This explains on the one side Prof. Sangbae's view of gearboxes at the core of the hardware problem of modern robotics, and on the other side the extensive and active research on high-ratio gearboxes during the few last years, that contrasts with decades of relative calm in this domain. Innovative gearbox technologies are continually being developed at the present, to try to address the challenges in modern robotics.

Cycloidal gearboxes, another promising technology, offer high torque density and robustness. They are particularly suitable for industrial robots and heavy-duty machinery. Cycloidal gearboxes can handle high shock loads, making them ideal for applications in rough conditions where minimizing machine downtime is vital.

Planetary gearboxes, commonly used in automotive and industrial applications, are also being adapted for robotics. These gearboxes provide high efficiency, compactness, and the ability to handle high torques. Advanced manufacturing techniques and materials have further enhanced their performance, making them a viable option for robotic applications where positioning accuracy is not pivotal.

Other disruptive gearbox technologies have also been recently developed and are discussed in more detail in our publication (Ref. 8).

Gearboxes in Off-Road Machinery Electrification

Comparing the challenges of off-road machinery electrification and modern robotics reveals striking similarities. Excavators and collaborative robotic manipulators provide a representative example: both are basically self-carrying manipulators that

- have an own weight that is an order of magnitude larger than their payload
- need to operate in highly unstructured environments
- require actuators with extremely large torque densities
- are often subject to unexpected impacts
- have duty cycles involving large uptimes and variable operating conditions that make particularly challenging achieve energy efficiencies compatible with battery power
- have non-linear torque-angle movement characteristics
- require moderate position accuracies
- require moderate power densities
- are (or will be, in the case of robotic manipulators) highly mobile
- show a high value potential related to the exploitation of energy regeneration

From this analysis, it becomes apparent that gearboxes are predetermined to play a pivotal role in the electrification of heavy-duty machinery, just like for human-centric, modern actuation. Suitable gearboxes for off-road vehicles need large gear ratios, compact designs, good efficiency, and the ability to handle higher power densities. Cooling and lubrication solutions are essential here, due to the higher powers involved.

Conclusion

Our analysis suggests a promising role for high-ratio gearboxes along the path towards electric actuation in off-road machinery and modern robotics. In heavy-duty machines, high-voltage, high-speed electric motors achieving power densities beyond 2.5 kW/kg can be combined with high-ratio planetary and cycloidal gearboxes. These gearboxes incorporate two degrees of freedom that can be used to combine the input from two different electric motors (Dual-Motor actuation) [9] that is like the split principle used by some hybrid vehicles.

This provides a versatile solution that can cope with operating conditions both in robotics and heavy-duty machines, involving frequent, maintained operation at substantially different torque and speed ranges. Gearbox backdrivability will also play a crucial role in enabling energy recuperation, reducing battery size requirements, while the optimization of cooling and lubrication systems will be fundamental in making these solutions viable alternatives to hydraulic-based actuation for achieving large torque densities.

The future of heavy-duty machinery and modern robotics lies in the successful integration of advanced gearbox technologies and electric motors. By addressing the challenges of torque density, efficiency, and power management, these innovations will drive the transition to more efficient and sustainable machines.

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. He completed a doctorate with the Brubotics research institute of the Vrije Universiteit Brussel (Belgium) on the potential of planetary gear transmissions in human-robot interaction, in 2022.

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ZF
Receives CLEPA Innovation Award for Electric Motor Without Rare Earths

The automotive supplier association CLEPA honors ZF as a top innovator in the "Green" category. The award-winning technology, an electric motor without rare earths, sets new standards in electromobility by dispensing with magnets and improving sustainability with the same performance.

"This award is a recognition of our continuous efforts to develop innovative and environmentally friendly solutions for electromobility," says Dr. Otmar Scharrer, head of engineering electrified powertrain technology at ZF. "With our electric motor, we are demonstrating a more sustainable alternative to conventional solutions that does not require the use of rare earths and at the same time offers maximum performance."

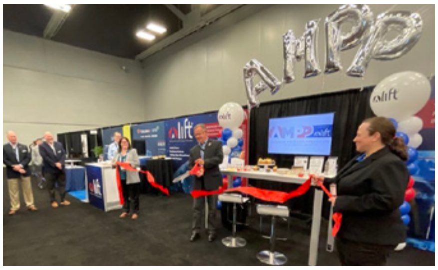
Rare earth metals are often difficult to extract, and their mining has a significant environmental impact. Nevertheless, they are still a necessary component of electromobility, as they are used in batteries and magnets. The I^2SM (In-Rotor Inductive-Excited Synchronous Machine) from ZF completely dispenses with these metals by using an inductively excited, magnet-free system in the rotor. This reduces dependence on critical raw materials and significantly improves sustainability and efficiency. Dispensing with rare earths saves valuable resources in production and reduces dependencies in the supply chains. In addition, compared to the permanent magnet synchronous machines (PSM) currently used, there are no drag losses due to permanent magnets, which leads to better efficiency during long highway journeys at high speeds.

ZF previously received the CLEPA Innovation Award in 2022 for its autonomous shuttle and in 2020 for an environmentally friendly eTrailer, a prototype truck trailer with an integrated electric drive. In 2017, WABCO and ZF won the innovation award for their jointly developed Evasive Maneuver Assist system for commercial vehicles.

Every year, the European association CLEPA recognizes outstanding innovative achievements in the supplier industry. In the Digital and Green categories, an international jury of experts' awards prizes to particularly progressive, sustainable and digital projects.

zf.com

LIFT
Announces Advanced Metallic Production and Processing Center



LIFT, the Department-of-Defense–supported national advanced materials manufacturing innovation institute, operated by the American Lightweight Materials Manufacturing Innovation Institute (ALMMII), today announced that it will introduce its new state-of-the-art Advanced Metallic Production and Processing Center (AMPP) in the new year solving a critical gap in addressing advanced materials challenges across the U.S. industrial base.

The announcement was made at the Defense Manufacturing Conference in Austin, TX.

Located at LIFT's Detroit headquarters and advanced manufacturing facility, the new center will deliver high quality metal powder, wire and rod feedstocks across all alloy classes at a development scale to support the diverse breadth of additive manufacturing processes on the market today, curated by LIFT's team of materials scientists.

AMPP will bring new synergies and collaborations to LIFT's 385-member ecosystem, defense collaborators and the broader national manufacturing industrial base including: Original Equipment Manufacturers, Systems Manufacturers, Materials Producers, Materials Developers, Application Developers, Part Manufacturers, Academia and Start Ups.

"LIFT's new capability exemplifies a core mission of the Department of Defense manufacturing innovation institutes to bridge gaps in the U.S. defense industrial base," said Keith DeVries, director of manufacturing technology (ManTech) under the Office of the Under Secretary of Defense for Research and Engineering.

"Today's world of advanced manufacturing, particularly the advancements in manufacturing processes, require the development of new, novel materials enabling manufacturers to bridge the gap between concept, prototype testing, product feasibility and production," said Nigel Francis, CEO and executive director, LIFT. "This new capability will efficiently and effectively drive the acceleration of new materials and processes to market, from the United States, for the warfighter and cross-sector manufacturers. This is especially relevant to many forms of additive manufacturing."

LIFT, celebrating its 10th year as a Department of Defense national manufacturing innovation institute, is a Detroit-based nonprofit public-private partnership that is focused on Driving American Advanced Manufacturing into the Future by connecting advanced materials, manufacturing processes, systems engineering, and talent development in support of our national economy and national security. The institute is also continuing to develop its national mandate, recently opening a facility in Puerto Rico while exploring other expansion opportunities across the country, including in Florida.

lift.technology

February 18–20

MDSM 2025

Motor, Drive Systems and Magnetics (MDSM), Tallahassee, FL., features the latest technical advancements in motor, drive systems, motion control, magnetic applications, technology, and rare earth materials. This is an opportunity for professionals to hear content in design, efficiency, and application advancements in automation, robotics, manufacturing, utilities, automotive, medical, consumer, aerospace & defense industries. Motor & Drive Systems is focused on the latest technical advancements impacting the design, integration, and efficiency of motor, drive systems, and motion control.

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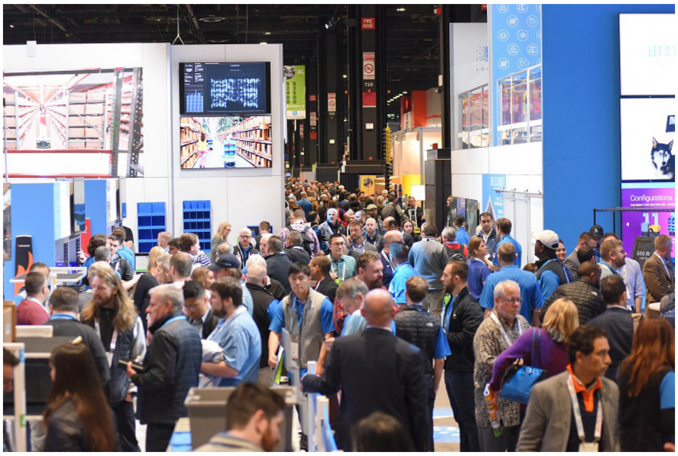
March 17–20

ProMat 2025



ProMat (Chicago) addresses the changing workforce, latest manufacturing equipment and technologies as well as distribution and supply chain issues. ProMat is the place where manufacturing and supply chain professionals help build the future. ProMat will offer the latest innovations from more than 1,100 solution providers. The show includes four keynotes and more than 100 seminars covering trends, best practices and cutting-edge equipment and technology solutions for improving productivity and profits throughout the supply chain.

powertransmission.com/events/213-promat-2025

March 17–20

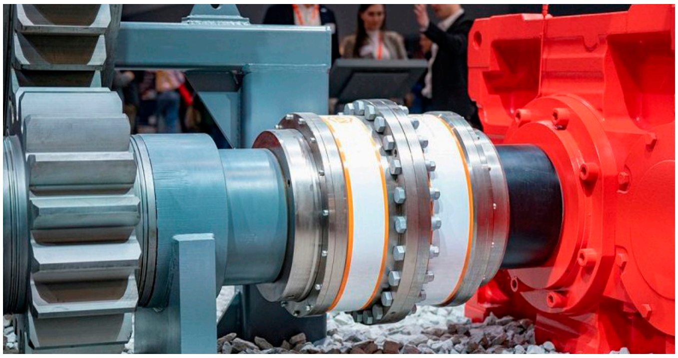
The Bearing Show 2025

The Bearing Show (Detroit) connects the evolving needs of bearings end-users with the latest technologies serving, OEM development, maintenance professionals and R&D engineers. Meet visitors from OEM's, machine manufacturers, industrial plants, global distributors, and more. Matching the needs of end-users with the innovation and opportunities occurring throughout the supply-chain is essential. The Bearing Show features exhibitors from the entire ecosystem, including finished bearings, condition monitoring, tools & equipment, components, materials, testing, and machinery used in the processes of bearing production and application. *See extended coverage of the event on page 22.*

powertransmission.com/events/971-the-bearing-show-north-america-lubricant-expo-north-america

March 31–April 4

Hannover Messe 2025



From drive and fluid technology to digital platforms and IT security to industrial internet and robotics, Hannover Messe (Hannover, Germany) reflects the manufacturing industry's broad scope and provides important economic and social impulses every year. Additional 2025 topics include 5G technology, additive manufacturing, automation, sensors, e-mobility, material handling and more. Traditionally, drive technology and fluid power has been represented at Hannover Messe by many companies from Germany and abroad, especially in odd-numbered years. This will also be the case in 2025 when manufacturers will present their latest applications and components for intelligent and sustainable production.

powertransmission.com/events/978-hannover-messe-2025

April 7–13

Bauma 2025

From the digital construction site to alternative drives and tomorrow's construction methods, the most important topics will be discussed, and innovative solutions will be presented during Bauma 2025 (Munich). Topics include climate neutrality, drive concepts, digital construction, sustainability, and mining challenges. In view of the high-quality standards of innovation and relevance, it is not surprising that nearly 70 percent of Bauma visitors are top decision-makers in their companies. Bauma offers attendees the ideal opportunity to establish lucrative business relationships and to profitably network with the industry.

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A Transmission from 2050

Aaron Fagan, Senior Editor

In the not-so-distant future, the world of power transmission has undergone a transformation so profound that today's engineers would scarcely recognize it. Welcome to the year 2050, where gears, drives, and motion systems have evolved into technological marvels beyond imagination. Let's take a whimsical yet insightful journey through the advancements shaping tomorrow's motion technology.

Self-Healing Gears

Picture this: a gearbox in the depths of an Arctic wind turbine begins to wear under extreme stress. In 2025, this would spell disaster. But in 2050, embedded microbots swarm into action. Made of shape-memory materials and guided by AI, these bots repair microscopic cracks and restore damaged surfaces in real-time. This self-healing technology, inspired by biological systems, ensures near-perpetual uptime for critical machinery, slashing maintenance costs and eliminating unexpected failures.

AI-Driven Transmissions

Gone are the days of static, one-size-fits-all transmissions. The power systems of 2050 come equipped with AI-driven optimization modules. These systems monitor performance in real-time, adjusting gear ratios, torque distribution, and energy usage to match dynamic conditions. Imagine a robotic arm in a factory shifting effortlessly from high-speed assembly to delicate, precise adjustments—all without human intervention.

This intelligence extends to predictive maintenance. AI-driven gears not only report potential issues but also propose solutions. A humorous side effect? Some engineers complain that overly chatty transmissions request unnecessary downtime for "data meditation."

Biomimetic Designs

The engineers of 2050 have finally admitted what nature has known all along: fractals and Fibonacci sequences hold the secrets to efficiency. Enter biomimetic gears, whose tooth patterns mimic organic structures like seashells and honeycombs. These designs minimize friction, reduce wear, and enhance load distribution, making them ideal for everything from micro-robots to massive industrial machinery.

Interestingly, this technology has led to a trend among manufacturers to boast about their "biologically inspired" designs. One fictional advertising campaign even claimed its gears were "evolved in the wild," prompting regulatory boards to demand a clarification that no bees were harmed in the process.

Quantum Drives

While still in the experimental phase, quantum drives promise efficiencies that border on the miraculous. By harnessing quantum entanglement, these systems transmit torque without mechanical connections, opening doors to possibilities like frictionless energy transfer. Though skeptics argue this technology will remain more theoretical than practical, early prototypes have already captured imaginations (and hefty R&D budgets).

A Nostalgic Twist

Despite these advancements, 2050 has also seen a surprising resurgence of 20th-century bevel gears as luxury collector's items. Enthusiasts argue that no AI or quantum mechanism can replicate the tactile satisfaction of manually adjusting a classic gearbox. It's a quirky nod to the past in a world racing toward the future.

The Journey Ahead

As fantastical as these innovations sound, many are rooted in research already underway today. Engineers and scientists are laying the groundwork for tomorrow's breakthroughs, experimenting with materials, refining AI algorithms, and exploring the boundaries of physics. Who knows? Perhaps the self-healing gears or biomimetic drives of 2050 are already emerging in your lab or factory floor. One thing is certain: the future of motion technology will mesh imagination with engineering in ways that both inspire and entertain. And while some of these predictions may remain firmly in the realm of science fiction, they serve as a reminder that today's innovators are tomorrow's pioneers. Here's to a future where anything—even an autonomous-repair gearbox—is possible.

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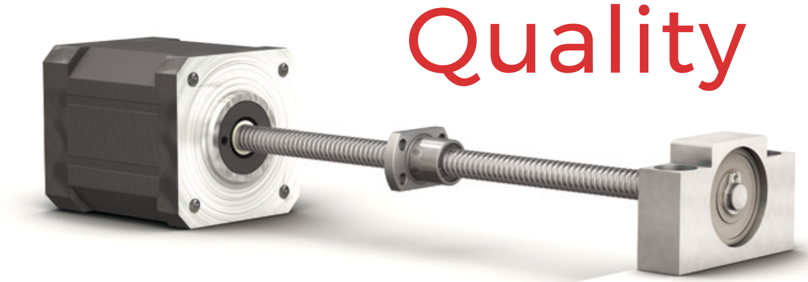

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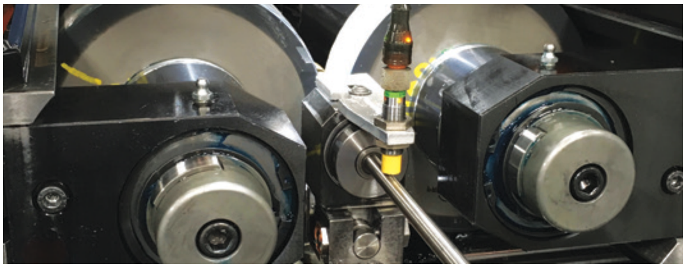

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