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FEBRUARY 2021

ENERGY

- Maintenance for Offshore Wind
- High Power Density Motors
- Gearboxes for e-mobility

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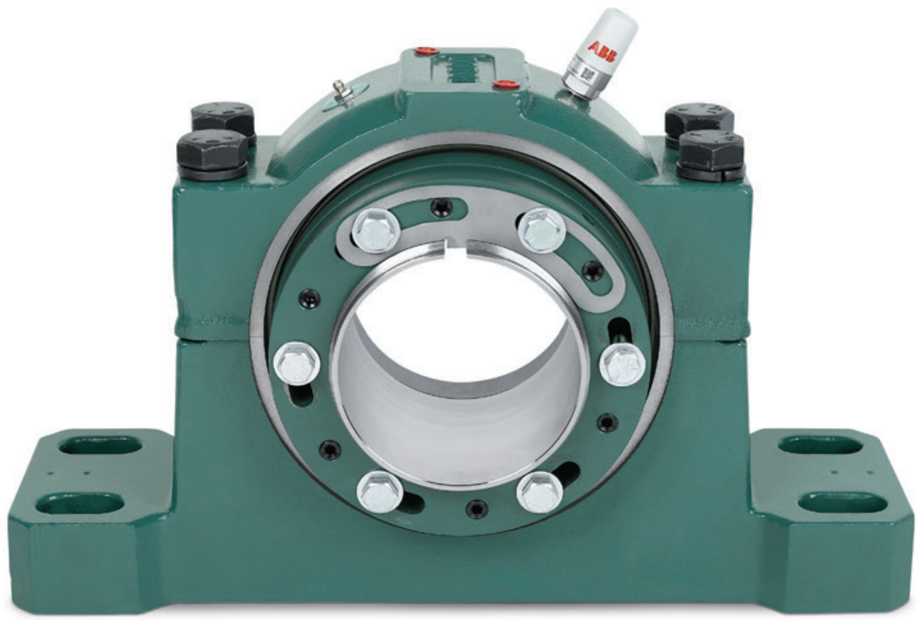

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PTE Videos
Schaeffler IT Security with OPTIME

As OPTIME allows for comprehensive wireless condition monitoring, IT security is crucial. Matti Seppä, Lead Solutions Architect at Schaeffler, explains how OPTIME ensures data security and makes it easy for the user to monitor thousands of machines. Learn more here:

Schaeffler IT Security with OPTIME (powertransmission.com) Expands-Electric-Mobility-Strategy-/)

R+W ST Series Industrial Torque Limiters

Industrial ball-detent torque limiter and safety coupling overview from R+W Coupling Technology, covering typical applications, basic construction and standard configuration options. Torque overload protection can be essential to maximizing uptime in industrial processes, including forestry and timber processing, scrap recycling and shredding, mining, crushing and milling, extrusion, and steel production.

Philadelphia Gear Portable Hardness Testing

One of Philadelphia Gear's technical experts reviews portable hardness testing capabilities as it relates to verifying and qualifying a variety of different part types during the gearbox repair process. Learn more here:

Philadelphia Gear Portable Hardness Testing (powertransmission.com)

Editor's Choice
Smart Moves with Bosch Rexroth

For hydraulically driven extrusion presses, the hydraulics components – pumps, spool valves and other elements – undergo significant wear and tear. One U.S. aluminum extrusion company, after assessing the performance of the drive and control of their aluminum extrusion press, undertook a carefully planned, phased process of upgrading key hydraulic and electronic control components. Learn more here:

Smart Moves with Bosch Rexroth | Power Transmission Blog

Power Transmission Engineering

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Randy Stott
Publisher & Editor-in-Chief

Renewed Energy

My daughter Renee is a serial appliance unplugger. She wants to reduce our carbon footprint, save energy and do the right thing. Sometimes this is frustrating, like when I flip the switch on the coffee maker, expecting that everything is good to go for my morning cup of brew—only to return a few minutes later to discover that nothing has happened. And while this is occasionally inconvenient, I can't really argue with what she's trying to do. Her heart is in the right place, and if she keeps at it, someday I'm sure she's going to save the planet.

Energy consumption isn't just an issue at home, though. It's one of today's key issues facing individuals, businesses and governments all over the world. And it's not just how much we use that's up for discussion, but also how we produce it and what effect it's going to have on our planet and our future .

Of course, that discussion is loaded with many diverse opinions about the best courses of action, and perhaps nowhere is that better illustrated than in the recent change in administration of the U.S. government. Clearly, the Biden administration has very different ideas about climate change and environmental policy than did the Trump administration. But no matter your political leanings, it's hard to ignore that there's a sea change going on. Even over the last four years, clean energy has grown, auto companies have continued to focus on reducing fuel consumption, businesses have committed to reducing their carbon footprints, and governments have continued to enact legislation aimed at change.

The energy discussion isn't going away. If anything, that discussion will be brought more to the forefront. That's why we've chosen "Energy" as the focus of this issue of *Power Transmission Engineering.* All those choices being made by consumers at the micro level and corporations and governments at the macro level are going to continue having a profound impact on mechanical devices and their design, manufacturing and use.

Wind Turbines are just one example. There's great interest in expanding the offshore wind turbine industry. But mechanical components running out at sea pose their own challenges. When the cost of replacing a single offshore wind turbine gearbox can be $1 million, predictive maintenance becomes a key issue—with challenges of its own. The article from ONYX Insight (p. 22) explores these concepts in detail.

Electrification of vehicles is another area where significant changes are in process. Every major auto manufacturer is working on developing vehicles for e-mobility, which means—among other things—that new gearboxes have to be designed, and they have to be adapted to the unique demands of being driven by an electric motor along with the increased requirements for reduction of NVH. We explore this in our technical article (p. 46) from the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University.

Lastly, efficiency of mechanical and electrical components will continue to be paramount in our industry. After all, the best way to prevent your energy consumption from harming the environment is to simply use less energy. Component efficiency is explored in depth in our articles on development trends in gearboxes (p. 30) and high power density motors (p. 40).

We've tried to tackle the subject of energy from as many different angles as possible this issue, because there's no one idea or solution that's going to solve all of our energy-related problems, and every little bit helps. Just ask Renee.

Sulzer

EXAMINES ELECTRIC MOTOR EFFICIENCY IN PUMP APPLICATIONS

Electric motors in industrial applications, including those used in pumping systems, consume 30 to 40 percent of the world's electricity. For the past two decades, equipment manufacturers, users and regulators have been tackling excessive energy consumption. This has led to the development of higher efficiency standards for motors and the adoption of variable speed drive (VSD) technologies to better match energy use and demand.

For motors designed for running in continuous duty applications (S1 operation), the International Electrotechnical Commission standard IEC-60034-30:2014 defines minimum energy efficiency specifications for four classes of motors: IE1, Standard Efficiency; IE2 High Efficiency, IE3 Premium Efficiency and IE4 Super Premium Efficiency. Each step up the IE efficiency ladder is associated with around a 20 percent reduction in motor losses, which translates directly into significant operating cost-savings.

The 2014 update also includes 8-pole motors and has widened the rated power band to include 0.12 kW up to 1'000 kW motors. US NEMA efficiency standards use an almost identical approach. In Europe, the IE3 standard has been mandatory for new industrial motors rated between 0.75 kW and 375 kW since 2017.

The European Commission estimates that the current efficiency regulations have reduced annual energy consumption by 57 TWh across the continent. The rules will be further extended in 2021 to cover both smaller and larger motors, a change that is expected to double the energy savings figure by 2030.[1]

Adjusting the focus of efficiency

So far, however, submersible pumps used in water and wastewater applications have been excluded from the efficiency regulations. In the main, that's because IEC-60034 standards require motors to be tested "bare" without seals, couplings or other system components. For machines with integrated motors and elaborate sealing systems, the calculations are a little more complicated as these losses need to be become part of the hydraulics.

Putting the regulations aside, commercial pressure to improve submersible pump efficiency has also been limited. The savings delivered by efficient motors are directly proportional to the duty-cycle of a motor. The biggest savings accrue from motors that operate continuously throughout the year. As a result, equipment owners have tended to focus their energy-efficiency investments on continuous-duty applications, rather than wastewater pumps which typically run for around 850–2000 hours, or approximately 10-25 percent of the time.

Sulzer believes that the case for premium motor efficiency in submersible wastewater pumps is stronger than either the regulators, or some users, currently recognize. That's why the company offers IE3 Premium Efficiency motor designs as the first choice in its complete range of submersible wastewater pumps.

Reducing operation and maintenance costs

Looking at the overall life cycle costs (LCC) for a pump over a 15-year period, energy costs represent the largest proportion at around 65%, with operation and maintenance accounting for 15%. The initial cost of the pump itself is only around 10% of the total, highlighting the importance of energy efficiency when it comes to long-term expenditure. The remaining 10% includes installation and decommissioning costs as well as downtime and environmental expenses.

In the case of wastewater pumps, there is an additional factor that needs to be considered. The pump needs to be designed to minimize the number of blockages that are experienced. A study by Water UK found that wipes made up around 93% of the material causing sewer blockages.

Assuming a pump becomes blocked every second month, operational costs to clear the system and expenses for any repairs, consumables and replacement parts, including labor, will represent 15% of the LCC; this can be reduced to less than 5% if the latest design of wastewater impeller is implemented, keeping blockages to a minimum.

Pump operators should therefore focus on two important points. Firstly, selecting new pumps that offer the latest design principles and have been tested for hydraulic performance under real-world conditions. Secondly, they need to focus on overall pump efficiency, which is a combination of motor design and hydraulic efficiency.

The impact of IE3 motors on energy costs

Selecting an IE3 motor and an impeller designed using computational fluid dynamics (CFD), can reduce LCC by EUR 12'000 compared to a low efficiency pump (assuming 15 years of operation of a typical 37 kW pump).

A second, and equally important benefit of higher efficiency, is greater reliability and a longer operating life. Energy is wasted by motors as heat, and in an enclosed submersible pump application, excess heat can dramatically shorten the life of key components such as wiring, bearings and seals. The improved efficiency of an IE3 motor equates to a lower operating temperature, which translates directly to a longer lifetime for all pump components, reducing the need for maintenance interventions.

In addition, motor wiring insulation is specified to give a minimum operating lifetime of 20'000 hours at a given temperature. As a rule of thumb, the lifetime of the insulation doubles for every 10°C (18°F) drop in operating temperature. The Class H insulation used in Sulzer motors is designed for a maximum winding temperature of 180°C (356°F). With actual operating temperatures of these high efficiency motors much closer to 105°C (220°F), the wiring has an expected lifetime of 320'000 hours. In lab conditions, some Sulzer pumps are reaching a theoretical life of a million hours before the motor windings fail.

For all these reasons, efficient motors are just one part of a holistic approach to pump performance and reliability improvement at Sulzer. Other key components of that approach include the use of advanced CFD to optimize performance and the innovative Contrablock Plus impeller design that resists clogging and allows easy wear compensation. Together, these changes can cut the lifecycle costs of an installation by more than half compared to less sophisticated designs.

www.sulzer.com

Regal Beloit

INTRODUCES QR CODES ON MOUNTING BEARING PRODUCTS

Regal Beloit Corporation has announced it is now putting QR codes on Sealmaster and Browning mounted bearings products and bearing boxes including Browining, McGill, Rollway, Sealmaster and System Plast.

Regal customers can use any smartphone to scan this simple, yet effective QR code to gain access to the landing page on regalbeloit.com, which provides:

- Information on how to register Regal bearing products
- Access to product specifications, including all critical dimensions and features, and the Regal 2D and 3D CAD libraries
- Installation and maintenance instructions
- Information on where to buy Regal products Instructions on how to download the Regal Power Transmission mobile app

"This is a natural progression of our goal to leverage digital technology to make it easier for Regal customers to quickly find information and improve transactions with our company," said Ian Rubin, director of marketing — customer experience, Regal. "The Regal Power Transmission Solutions group will expand this effort beyond bearings, working to deploy QR codes on other products. More information on that is to come."

www.regalbeloit.com

U.S. Tsubaki

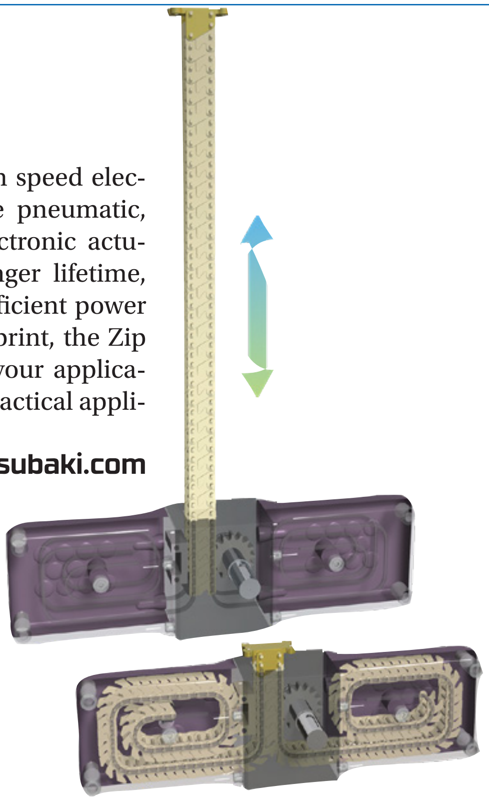
INTRODUCES ZIP CHAIN ACTUATOR

U.S. Tsubaki Power Transmission, LLC is pleased to announce the launch of the Zip Chain Actuator. The Tsubaki Zip Chain Actuator is an electric linear actuator that provides high speeds and multi-point stopping in a compact footprint.

The Tsubaki Zip Chain Actuator is a linear actuator that "zips" together specially segmented chain using a custom designed sprocket. This "zipping" action creates a rigid actuating arm for use in push-pull applications that require high speeds, long lifetimes, small footprints, and/or high precision.

Up to now, engineers have been limited to using pneumatic/hydraulic cylinders, or large, bulky screw-style electrical actuators. Tsubaki offers a compact, high speed electric actuator that can replace pneumatic, hydraulic, and traditional electronic actuators. With higher speed, longer lifetime, multi-stop positioning, and efficient power transfer, all in a compact footprint, the Zip Chain Actuator can upgrade your application and make previously impractical applications possible.

www.ustsubaki.com



Nexen

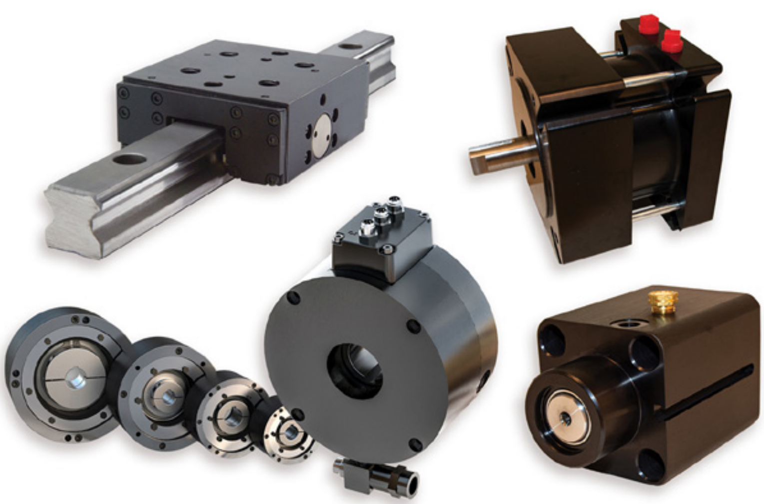
SENSOR OPTIONS ENHANCE CONNECTIVITY TO BRAKE FAMILIES

Nexen Group, Nexen Servo, Rail, and ZSE brake lines now have Industry 4.0 connectivity sensor options to enhance machine efficiency. Multiple sensors integrated into the brake families provide information about brake operation and health to the control system network.

The sensors used in the spring operated, air released ZSE brakes provide operation information such as brake engagement/disengagement and temperature. Information provided by the sensors is shared with the control network to aid in motor/drive programming, avoid brake overheating, and extend brake life. ZSE flange mounted, through bore, spring engaged brakes provide true zero backlash, low inertia, and high rigidity for precision holding applications. Rated for more than 2,000,000 holding cycles.

Nexen Rail brakes equipped with magneto-resistive sensors are used to sense brake engagement and disengagement. Industry 4.0 Connectivity to the control network aides in accurate linear positioning, predictive maintenance, and operational feedback. The engagement sensor is activated when the pistons and facing pair move out of the disengaged position and the facings transmit force to the rail. The disengagement sensor is activated when the rated air pressure is applied and the piston facing pair move to a disengaged position. Nexen's RB Series of linear profile guide rail brakes uses spring force to secure the load in holding applications. These profile rail brakes hold position accurately by reducing drive train backlash and elasticity.

Similarly, the Servomotor brake can be equipped with three inductive proximity sensors used to monitor disengagement, engagement, and wear. Using IO-Link v1.0 fieldbus connectivity, data can be shared within the control network to aid in motor/drive programming, predictive maintenance, and operational feedback. The disengagement and engagement sensors activate in a similar manner to the rail brake. The wear sensor activates when the brake is engaged and the facing is worn to a point that it needs to be replaced. Spring engaged, air released servo motor brakes mount to the shaft end of servo motors up to 20 horsepower. The brake acts as an adapter between dissimilar mounting features. The brake bore accepts the motor shaft that is fixed inside the brake with a split hub/shaft collar. This brake is a high-torque, zero backlash device.



www.nexengroup.com

Voith Turbo

INSTALLS FIRST VORECONNX VARIABLE SPEED DRIVE

Voith Turbo has successfully installed and commissioned the first VoreconNX variable speed drive for a U.S. customer, which began using it for its production needs on November 30, 2020. As a next-generation modular variable speed drive that combines a hydrodynamic power transmission with a planetary gear, the VoreconNX delivers low-range power up to 10 megawatts and is particularly well-suited to operate compressors in the power, oil & gas industries.

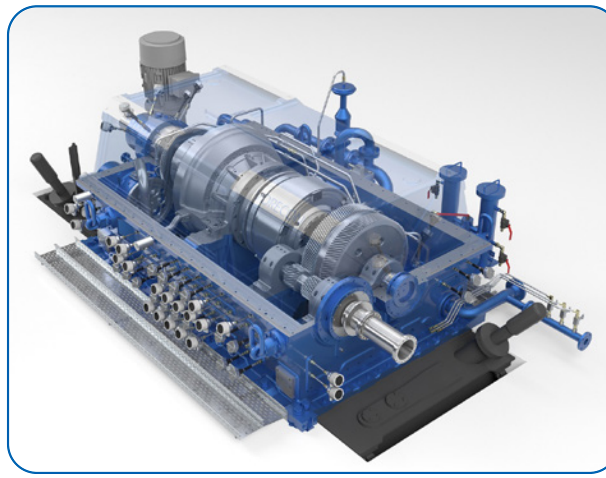
"The customer was very happy with the performance results from the unit's commissioning. They clearly see a lot of potential with VoreconNX, having ordered three units in total, due in part to their ease of maintenance that comes from a standardized design and allows part swapping between units," said Brinnet Paul, senior account manager, Voith Turbo North America.

Prior to delivery, installation and final commissioning at its new home in Louisiana, the VoreconNX unit was tested at Voith's Crailsheim, Germany, factory where it ran through a series of standardized performance tests including a speed ramping, overspeed protection and defined-load point tests. With the installation complete and the VoreconNX unit in operation, the owner expects to operate the unit for the next five years without shutdown. At that point, it will be taken offline for a routine inspection and maintenance.

"The entire installation and commissioning process went very smoothly despite the area being hit by three hurricanes this year," added Craig Aggen, senior field service technician, Voith Turbo North America, who also noted the drive not only passed a rigorous test on Voith's test stand but also an informal vibration test at the site. "We gave it the 'Coin Test.' This is where we balance a nickel on its edge on top of the VoreconNX and see if it stays or falls due to vibration. It stayed!"

Voith Turbo North America currently has several other VoreconNX units that have been ordered for use in the U.S. and Canada, with deliveries and commissioning activities coming up in the next two years.

"The units built for the North American market are going to be tested in a lot of varying conditions — from Canada to the Gulf of Mexico — and our customers are very excited to get this next-generation power transmission technology added into their production processes. Once installed, the VoreconNX will boost their operational efficiencies through adjustable pump guide vanes, which offer an improvement of up to eight percent at part load," said Peter Goretzki, product manager, Voith Turbo. "Beyond its efficiency improvements, ease of maintenance and small footprint, our testing also is showing another key value of the VoreconNX — we're predicting a mean time between failures of 48 years in long-term operation. That's a phenomenal number for an industry that values reliable operation."



voith.com/VoreconNX

NORD

OFFERS VERSATILE DRIVE SOLUTIONS FOR BAKING INDUSTRY

NORD DRIVESYSTEMS offers efficient and hygienic drive solutions for the baking industry, meeting their special requirements for hygiene, reliability, and robustness. This includes agitators, conveyor systems, weighing and filling plants, packaging machinery, and more. NORD's variable frequency drive technology guarantees high positioning accuracy and safe implementation of dynamic sequences. The drive units can also be controlled individually, for example, they can regulate kneading and conveyer speeds in order to prevent blockages or control the dough process. Due to their modular structure, NORD drive units are also service and maintenance friendly. For the baking industry, addition of the nsd tupH sealed surface conversion treatment provides an outstanding anti-corrosion treatment for gear units, smooth surface motors, variable frequency drives, and motor starters with cast aluminum housings for extra protection in washdown environments. The fan-less smooth surface motors do not spread germs and operate with very low noise.

CLINCHER Parallel Shaft Gear Units and the UNICASE Helical Bevel Gear Units are ideally suited for the demands of mixing and agitating applications. They boast torque capacities of 638,000 lb-in and 442,000 lb-in respectively along with extensive input designs and mounting options. They can also be supplied with food-grade mineral or synthetic oil and bearing lubricants as well as a variety of gearbox and motor washdown protection options. These products are extremely low maintenance with long service life. When combined with NORD drive electronics, you have a complete, reliable package from a single source.

NORD DRIVESYSTEMS offers application-specific equipment options that combine high performance and efficiency without the need for costly custom components. Each drive unit is specifically configured for the application it will be used for, such as agitators and mixers with high process-related radial and axial bearing loads. This includes an agitator version (VL2) with increased bearing distance and reinforced output shaft bearing, as well as a Drywell version (VL3) with additional oil slinger, dry cavity, and oil leak detection port.

Additionally, within NORD's paint portfolio, NSDF3 and NSDF3+ food duty paint is typically used for food production and packaging areas. This makes it the perfect solution for the bakery industry due to its compliance with environmental regulations and corrosion prevention. The paint systems used by NORD DRIVESYSTEMS are resistant to chemicals and have been tested for their resistance to all common substances which could have a negative effect on the environment. NORD paints are food-safe while being USDA and NSF compliant.

www.nord.com

NORD offers application-specific options for the baking industry.

Polygon

OFFERS DOUBLE INSULATION DIELECTRIC COMPOSITE TUBING FOR ELECTRIC MOTORS

Polygon Company highlights its Double Insulation Dielectric Composite Tubing for electric motor applications. Polygon Tube double insulation tubing is customizable to an individual application's needs, thus ensuring the highest possible quality and greatest safety benefit in each individual motor design.

Used as a sleeve within the armatures of electric motors, Polygon Tube double insulation tubing acts as a secondary layer of insulation and provides shock protection to the operators of electrical tools and appliances. The use of the additional layer of insulation allows the appliance to be rated "Double Insulated" and the need for grounding of the unit is eliminated.

Polygon's design and performance engineers use their extensive knowledge and experience in composites science to assist customers in determining the best fiber architecture and finishing to produce ideal secondary insulating sleeves for every application. This includes customizing sizes and machining holes and cutouts to fit numerous applications.

Composite materials are the ideal choice for insulative applications because they can be tailored to almost any engineering challenge. Polygon's design flexibility is unmatched and includes; fiber winding, finishing, and more according to customers precise needs. The outstanding dielectric and insulating properties of Polygon's industry-leading composite materials eliminate the risk of capacitance coupling, while their high torque strengths ensure durability.

Polygon Tube double insulation tubing holds an Underwriter's Laboratories (UL) certification AFW-G-10. Polygon's rigorous quality control standards ensure that every finished tube is tested at 5,000 volts minimum to guarantee its dielectric integrity.

Polygoncomposites.com

ACS

LAUNCHES LINE OF DRIVE MODULE PRODUCTS

ACS launches the first in a new line of high-performance Intelligent Drive Module products. The IDMsm is a 2- or 4-axis EtherCAT DS402 universal servo drive featuring unique control algorithms and processing technologies that enhance the performance of high-precision motion stages. Certified as EtherCAT Conformance Tested, the IDMsm provides up to 5A continuous and 10A peak per axis with 12–48 VDC drive supply.

"We're excited to offer our unique servo control and motion-to-process synchronization capabilities, backed by more than 35 years of high-performance motion control expertise, for demanding applications that utilize any brand of EtherCAT-based controller," says Jason Goerges, ACS Motion Control general manager North America and global vice president of marketing. "High-tech capital equipment manufacturers have a wide range of EtherCAT servo and stepper drive offerings to choose from. When OEM machines must outpace the competition in throughput, accuracy and time to market for sophisticated features, the IDMsm is the drive to win," Goerges added.

acsmotioncontrol.com

SKF Improves Bearing Predictability Through R&D Efforts

Matthew Jaster, Senior Editor

Guillermo Morales-Espejel, principal scientist at SKF Research and Technology Development, examines a bearing. (Photos courtesy of SKF)

The science of bearings continues to improve annually. Research on everything from fatigue behavior and misalignments to mounting errors and tribology has led bearing manufacturers to pinpoint key challenges in rotating machinery and make the necessary adjustments to provide the best possible solution. In turn, this research provides bearing designers with real-world data that is extremely valuable as new bearings are produced.

It is not efficient to put a bearing with a 20-year lifespan into a machine that's going to last 10 years. There has to be a happy medium, according to Guillermo Morales-Espejel, principal scientist at SKF Research and Technology Development.

"The goal is to provide a bearing for an application that will last the same lifespan as the machine," Morales-Espejel said. It's not a matter of improving the bearing itself, it's more a matter of improving the predictability of the bearing."

SKF has spent many years—particularly the Research and Technology Development department—solving the mysteries of bearing performance. This research has led to hundreds of custom machine designs for some of the world's most demanding applications.

A Closer Look at Bearing Research

First some design engineering facts presented during SKF's technical press event in late 2020:

- 90% of the bearings in the field outlive the machine when they are designed properly from the start and maintained.
- 9.5% of the bearings are replaced in the field as part of a preventive maintenance strategy. For so called critical assets (those machines, for example, that determine the bottle neck in a plant) such a preventive strategy could be more cost effective (even if the bearings are still ok) then accepting the risk of an unplanned failure.
- As SKF becomes better and better at predicting bearing failures and remaining life, this will enable customers to switch from a preventive maintenance strategy for these machines to a more predictive maintenance strategy, directly saving the cost of unnecessary maintenance and replacements.
- 0.5% of the bearings are replaced because of failures. From these, 33% fail because of fatigue which you could say is the 'correct failure mode' as it is simply cause by the number of load cycles that the bearing material was able to handle. 16% of these failures are caused by improper handling, which includes mounting errors, misalignment etc.

"We inform and educate many of our customers, end users and distributors each year to avoid these errors," said Bernie van Leeuwen, director at SKF Research and Technology Development. "51% however, is related to so called 'surface-initiated-failures', which on their turn can be caused by anything that can (start to) damage the raceway surface of the bearings, including contamination and lack of sufficient lubrication."

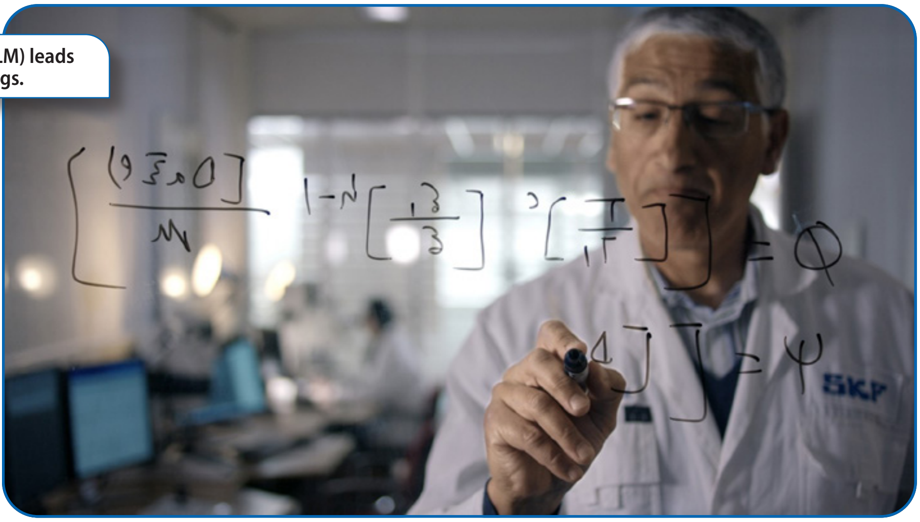
Historically a lot of research and eventually design engineering has been done on the understanding and calculation of the fatigue life. Through this research, it is clear that a greater understanding of surface-initiated-failures will lead to the increased reliability of rotating machinery, according to van Leeuwen.

GBLM Calculation Tools

SKF unveiled the Generalized Bearing Life Model (GBLM) in 2015 to ensure customers and distributors could select the right bearing for the right application, every time.

In the past it was difficult for engineers to predict whether a hybrid bearing could outperform a steel bearing in a given application.

"From 2015 to 2018, we tested hybrid bearings and began implementing and verifying the model," Morales-Espejel said. Through this research Morales-Espejel found great potential for hybrid bearings across many different applications. Hybrid bearings



The Generalized Bearing Life Model (GBLM) leads to better choices when selecting bearings.

use ceramic silicon nitride rolling elements and steel rings. They have been the preferred choice for high-speed, high-precision equipment such as machine tool spindles.

Today, the hybrid bearing's combination of low weight, good electrical resistance and good performance under demanding lubrication and contamination conditions is helping it find many new applications, from electric vehicle powertrains to industrial pumps and compressors.

"GBLM enables better choices to be made when selecting bearings for a wide variety of applications," he added. "We built curves in order to describe the behavior of bearings over a wide range of loads and surface conditions. Hundreds of these bearing tests compared steel and ceramic rolling elements and we were able to finalize a new GBLM for hybrid bearings."

When a bearing is heavily loaded, but able to run in a clean, well-lubricated environment, sub-surface fatigue is likely to be the ultimate failure mode, and a steel bearing may perform better than a hybrid. But a lot of bearings operate under lighter loads, but with a greater likelihood of poor lubrication or contamination. The SKF model shows if a hybrid solution would offer a longer life on those applications and will quantify the difference.

In a poorly lubricated pump bearing, for example, the rating life of a hybrid bearing can be up to eight times that of a steel equivalent. For a screw compressor bearing running with contaminated lubricant, meanwhile, the hybrid offers a rating lifetime a hundred times greater than a conventional steel bearing.

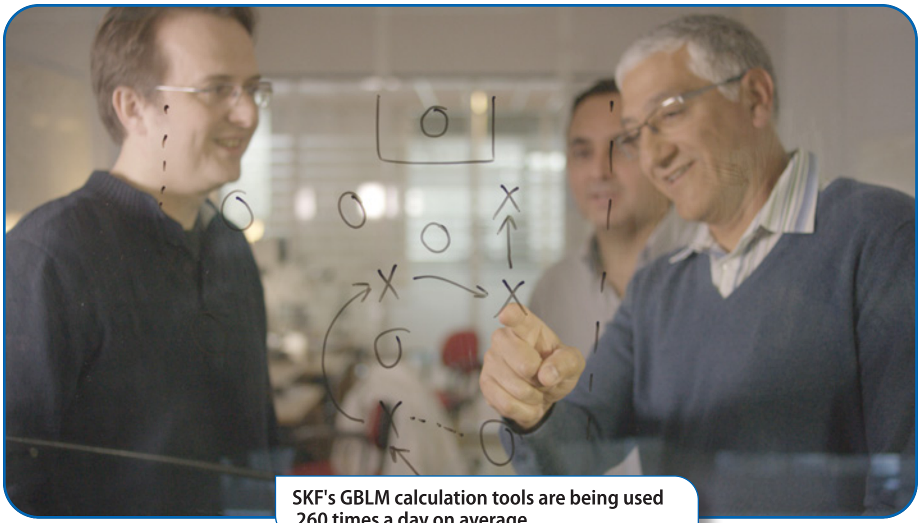
From railway and car engines to industrial pumps, hybrid bearings can provide the necessary combination of low energy consumption and high reliability. E-mobility is another area where bearings need to survive high speeds, accelerations, and temperatures with minimal lubrication. These bearings must resist stray electric currents, which can burn away lubricant films and damage rolling surfaces. Combined with their other benefits, the excellent electrical insulation properties of hybrid bearings make them the ideal solution for such applications.

"When you don't have tough tribological conditions, there is no need to have a hybrid bearing," Morales-Espejel said. "Hybrids will tend to introduce more subsurface fatigue that steel to steel bearings particularly with very high loads."

The challenge is comparing the two design types in a variety of different applications and circumstances and compare the results.

"Hybrid bearings don't always emerge as the winner in comparison with conventional designs. The idea is not to replace all steel-steel bearings with hybrid designs, but to do so when it makes economic sense. Our GBLM for hybrid bearings allows customers to make those decisions based on our data," Morales-Espejel said.

SKF's GBLM calculation tools are currently being used 260 times a day on average by the company's application engineers and customers.



SKF's GBLM calculation tools are being used 260 times a day on average.

From Preventative to Predictive

The move from preventative to predictive maintenance strategies will continue in the coming years. Tougher operating conditions will increase the need for more hybrid bearings in the future, according to Morales-Espejel. And with more effort on predictive maintenance, the bearing industry will see a significant increase in smart manufacturing technologies in the coming years.

"We'll see more sensors on bearings, more field data and intelligent software that will provide additional benefits," Morales-Espejel said. "The bearing industry will evolve as these tools are combined with good calculation methods, predictive measures and lots of sensors sending information to the models."

New steel bearings will also receive attention in the coming years.

We currently are using new steels in very extreme applications, but these steels are becoming more mainstream." Morales-Espejel said. "You cannot do some of the things with typical steel bearings in a corrosive environment, you need specialized steel in many of these unique applications. I believe we'll continue to see an increased demand for specialized steel bearings in the future."

Late last year it was announced that SKF—founded in 1907—and Imperial College London, were extending their R&D partnership. The SKF University Technology Centre (UTC) has been housed at Imperial College London since 2010 and has delivered research that helps bearings perform better and longer, whilst also contributing to lower energy consumption in the machines they operate in. This work will continue until 2025.

At the end of our conversation on bearing efficiency, I returned to the statement that 90 percent of the bearings in the field outlive the machines when they are properly maintained. Can this number reach 100 percent in the future?

"Manufacturing bearings that are engineered for specific operating conditions typically come with higher costs," Morales-Espejel said. "The pressure is mounting to provide as much real-time bearing data as possible to help our customers make informed decisions regarding their equipment. Our hope is to use this data to provide more efficient bearings in the future."

www.skf.com

Data collection continues to improve the overall efficiency of bearings, giving customers the ability to make well-informed decisions regarding their applications.

How Predictive Maintenance Can Unlock Offshore Wind Growth

A practical guide to adopting digital technology in wind energy applications

Dr. Evgenia Golysheva, ONYX Insight

Offshore wind capacity in 2030 is projected to reach 234 GW, according to the Global Wind Energy Council. This white paper looks at the key operations and maintenance (O&M) challenges that owners and operators of offshore wind assets face as a result of this expansion, and how digital tools can provide solutions, from day-to-day problem solving and quick wins to future-proofing operations and maintenance (O&M) strategies and long-term gains.

In a tough landscape where strike prices are low and margins are being squeezed, reductions in LCOE have been achieved by increasing turbine size and streamlining the supply chain. However, there is huge potential to achieve significant efficiencies without entering into a race for the biggest turbine or the lowest parts or service costs. This paper identifies short, mid and long-term opportunities for owners and operators to increase efficiencies, drive down O&M costs/time and boost profitability.

The offshore wind sector is thriving globally. Driven by innovations in turbine design and digital technology, the cost of producing energy from offshore wind is at record lows. Europe continues to set a benchmark, led by the UK, which has committed to power every home through offshore wind by 2030.

Offshore wind owners and operators can make significant savings by refocusing on minor repairs.

The European Union has added further momentum with a target of 60 GW installed capacity by 2030.

In the US, the American Wind Energy Association projects 9 GW installed capacity by 2026, up from just one 30 MW wind farm now. Asia-Pacific is also set for rapid offshore wind growth: China alone is expected to add 52 GW of capacity by 2030.

From the Baltic Sea to Brazil, offshore wind offers hope as the race to reach net-zero by 2050 gathers pace, requiring cleaner, cheaper and more plentiful electricity.

Offshore wind can deliver on all three requirements. But the sector must look ahead to potential stumbling blocks and take action to minimize them now.

Technical challenges

Owners and operators in the offshore wind sector have many challenges to grapple with and digital tools can help solve them. The goal is to provide a practical guide for the years and decades ahead, which will no doubt see new challenges — and new opportunities.

The offshore wind sector has already proven its resilience during the Covid-19 pandemic, providing a safe haven for investors as oil pricing continues to fluctuate. But the industry is not complacent. Increased budget pressures and a looming skills gap join ongoing challenges around grid integration, storage and port infrastructure.

Budget pressures are part of the industry due to competitive auctions and a drive to deliver affordable clean energy, but the pandemic has intensified this pressure. It has put a further financial strain on relationships throughout the supply chain and is eating into the budgets needed to ensure technicians are trained and skilled sufficiently to service a new, growing fleet.

Onyx Insight has set out a roadmap for how companies can navigate tricky conditions until 2030, and further establish offshore wind as vital to the fight against climate change.

Short-term: What companies can do now

There is no one easy solution to ensuring the continued resilience of offshore wind. There are, however, simple changes that owners and operators can adopt to drive further operational efficiencies and profitability.

Optimizing logistics

The distinctive costs and challenges of offshore wind result from the need to transport equipment and personnel to wind farms miles out to sea. Vessel hire, offshore cranes, and jack-up rigs present a high barrier to entry for new players, and a significant fixed cost for owners and operators. A single gearbox replacement can cost up to £1M.

Operators can tackle costs now by rationalizing vessel trips, particularly for crew transfer vessels, delivering significant savings in fuel costs while reducing transit times for technicians.

The key is planning — but with a cutting-edge twist. Operators can now tap into weather forecasts, advanced diagnostics, and available technical resource to complete the job and maximize vessel utilisation. Data gathering and sharing unlocks the holistic, supply-chain-wide view needed to release significant efficiency savings.

One powerful tool that can help owners and operators to achieve greater oversight and control of O&M schedules is predictive maintenance.

This delivers a detailed view of turbine health across large wind fleets, enabling owners and operators to prioritise and optimise maintenance work. Unplanned corrective work accounts for up to 40% of O&M costs, while working with a good predictive maintenance partner can deliver savings of 30% from O&M budgets.

Minor repairs are a major cost

Owners and operators can also make significant savings by refocusing on minor repairs. The most expensive tasks — gearbox, main bearing and blade replacements — are often front-of-mind. However, ONYX Insight estimates that work classed as minor correctives, such as pitch subsystem or yaw drives, accounts for approximately half of scheduled O&M.

Calendar-based instead of production-based scheduled maintenance causes inefficiency, incentivising maintenance teams to perform the same work on all assets regardless of need. This issue has been compounded by a reliance on often outdated manuals which fail to reflect modern diagnostic advances. Merging and prioritizing this work by moving to condition-based maintenance can deliver significant savings and improve reliability of assets.

Intelligence on asset health is crucial to enable this. What components across a fleet need replacement? Which assets only require monitoring in the short term? To benefit, wind farm owners and operators will need support from a predictive maintenance partner that can answer these mission-critical questions.

Independent assessments of the true cost of components and maintenance work can provide much needed reassurance to owners and operators.

The Next Technology Wave

The offshore wind sector is on the brink of a new technological revolution. A new data-focused era beckons, promising a future of intelligent, connected wind assets.

Advances will include instant insights at the touch of a button; remote inspection via drones; and autonomous robotic repairs. It sounds like science fiction — but the groundwork is being conducted today by forward-thinking owners and operators.

Life extension from day one

We must also remember that wind turbines being built today will be operational in 2050. Advanced predictive maintenance is already pushing the envelope on what is considered a useful turbine lifetime. By putting in place a data-driven life extension strategy as the turbine life cycle begins, not at the end of the warranty period, owners and operators stand to maximize the benefits.

Predictive maintenance for life extension can take many forms. Cross-channel data analysis combining insights from oil condition and vibration monitoring is already being rolled out. As more owners and operators become aware of the benefits of multi-channel data analytics, the potential to extend turbine lifetimes will increase accordingly.

Predictive maintenance also maximizes the impact of low cost, simple actions, such as performing grease flushing to protect the main bearing and identifying high risk components in advance to replace them at the optimal time. A grease flushing can add years to the lifetime of a component but is only 1% of the replacement cost — crucial for managing annual budgets.

Maintaining assets in peak health for longer has wider benefits for the industry. It can increase the value of a wind farm by up to 12%, unlocking further investment. If the correct predictive maintenance and data management strategies are ingrained into the entire UK offshore and onshore wind market, for example, the savings could be £140 million over the next five years.

The sooner predictive maintenance is implemented, the longer the life of the asset, and the greater the returns. Every KWh of production after the asset cost is paid back is pure profit — and the right predictive maintenance program can extend useful asset life by 25%.

Embracing new technologies

A further revolution in offshore wind will be enabled by investment into automated and remote technologies such as drones, facilitating safe inspections at a lower cost. The most dangerous and costly tasks, such as blade inspections, will be done by automated robotic automotive platforms. This places technicians out of harm's way as well as reducing logistical costs.

This robotic future comes together with mobile technology. In today's connected world, inspection data need no longer be relegated to dusty storage cabinets. Visual inspections by technicians are a valuable source of information about asset health. The latest mobile applications such as fieldPRO digitize inspection data automatically and create clean data for analysis by expert engineers armed with machine learning algorithms.

Digital tools can also lessen the pressure of skills gaps, by standardizing best practice and supporting operational decision making. Additionally, streamlining data collection can empower experienced personnel to spend more time problem solving, and less time on administrative tasks.

Long term: Growing a healthy offshore wind sector

Promoting sustainable growth in the long-term comes from putting in place best practice now. Ultimately, the most impactful gains for offshore wind will come through large-scale collaboration — through supply-chain wide data sharing and knowledge transfer.

Designing for use

Take the design of wind turbines, the lifeblood of industry growth. Currently, wind turbine designers are tasked with delivering a turbine that can be easily produced and withstand both the environmental challenges and production expectations of offshore operations. Maintenance or serviceability of the asset is often a secondary issue during design stage, which creates bottlenecks for O&M due to access issues for teams on the ground.

However, by focusing more on the operational requirements of wind turbines during the design process, the industry could see significant efficiency gains throughout the wider asset life cycle. Considering the placement and accessibility of fluid intakes, or the location of access hatches, for example, could streamline processes significantly throughout a maintenance job significantly reducing the cost of owning a wind turbine throughout its life.

Key to unlocking a holistic approach to turbine design is open communication throughout the supply chain. The reality of the turbine experienced by maintenance teams needs to be shared with design engineers, to ensure that from installation, to maintenance, to decommissioning, the asset has efficiency built in.

Collaborative maintenance zones

A further step-change in offshore wind operations will be delivered through a cluster approach to O&M across large offshore sites.

Logistics is the defining challenge of offshore wind. Locational proximity is therefore a key opportunity for

Europe continues to set a benchmark, led by the UK, which has committed to power every home through offshore wind by 2030. (All photos the sector. As projects are built further out to sea around the world, there is a huge chance for owners and operators to pool resources and drive unprecedented economies of scale.

This can already be seen in giant projects such as the 3.6GW Dogger Bank, owned by Equinor and SSE Renewables and, as tenders involving clusters of assets become more common, operational practices must keep pace. Data sharing and joint maintenance tenders will help to keep unnecessary trips out to wind farms to a minimum — and advanced diagnostics to accurately estimate remaining useful life can support this.

There's a final market dynamic which threatens the efficiency of offshore wind. Competition drives innovation and helps to deliver continued reduction in price. In the onshore industry, the cost of O&M service contracts has halved in the last three years due to multiple offers on the market from OEMs, ISPs and O&M teams looking to self-perform. However, in offshore wind, high barriers to entry favor the larger players, which could stifle the natural inventive spirit of the wind O&M sector.

Fixed costs such as jack-up rigs will limit the extent of downward pressure in practice, but artificially low pricing strategies adopted by some companies are driving margins down and could result in an entrenched oligopoly within the O&M space, limiting the options available to owners and operators for service contracts.

Independent assessments of the true cost of components and maintenance work can provide much needed reassurance to owners and operators. During vital periods such as during major component replacement work, this can be a significant boost.

When owners and operators have been properly informed on the risks of activities and the true condition of their assets, extra knowledge gives them the confidence to choose the right partner to help them save money in the long run.

If the correct predictive maintenance and data management strategies are ingrained into the entire UK offshore and onshore wind market - the savings could be £140 million over the next 5 years.

Technology & Sustainable Growth

As an industry, there's much that offshore wind can collectively be proud of.

The sector is set to spearhead the green recovery, especially in countries such as the UK where offshore wind represents the best way and example of how to scale renewables.

Investors are confident in offshore wind as an asset class, providing the resources for further innovation and growth. This comes in tandem with increasing interest from oil majors, who are slowly recognizing that the future of energy lies in the sky, not the ground.

With the right people, and the right tools, there is huge potential for the industry to provide affordable and clean energy in the run up to 2050 and beyond.

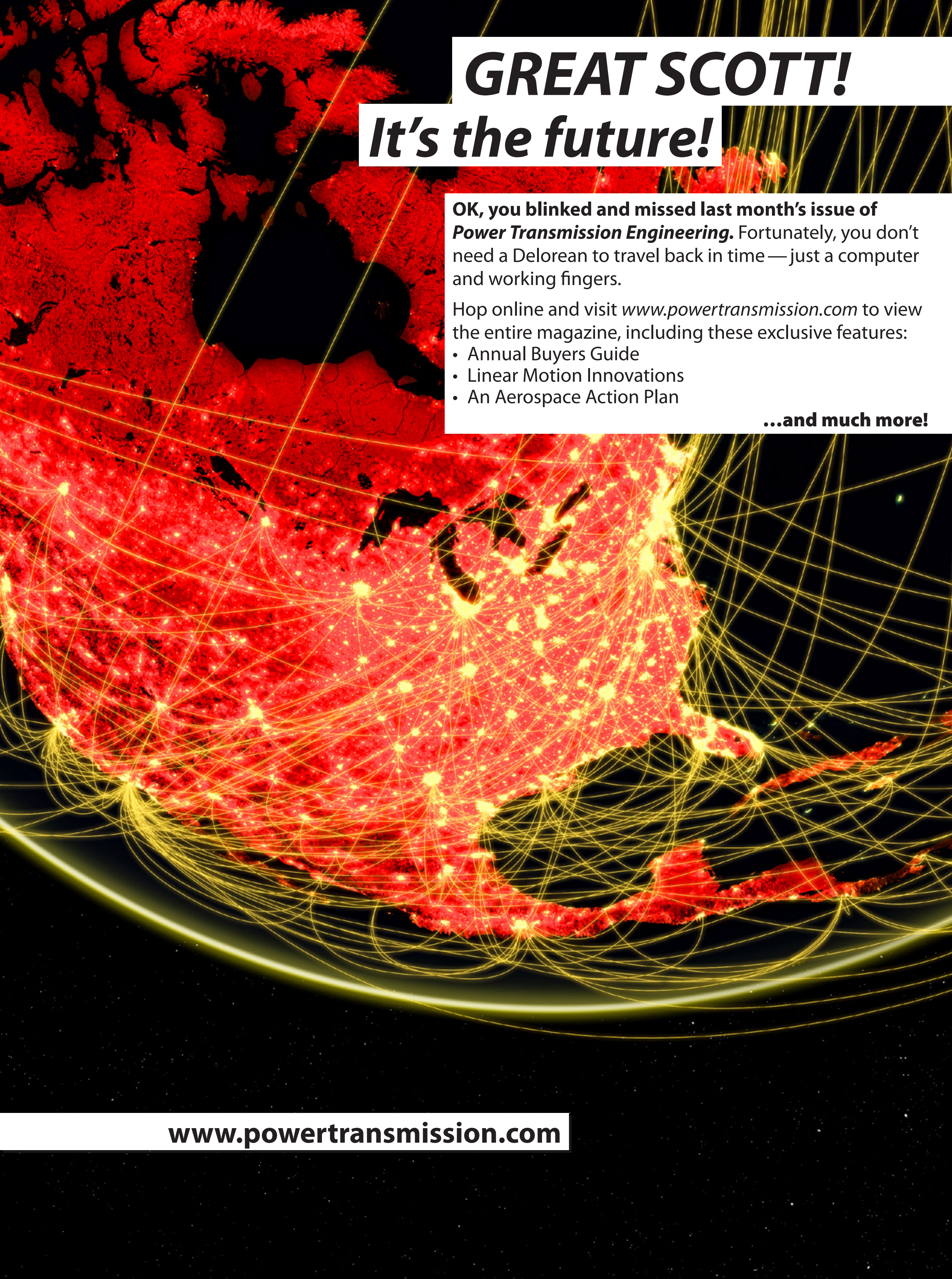
But to achieve this potential, owners and operators must future-proof operations by seizing on advances in digital tools that enable them to do more with less. Even now, turbine lifetimes of 40 years are within reach for assets installed in the next few years, with the right O&M strategies in place.

This is crucial as the industry tackles the exciting opportunity of floating wind, which will bring new logistical challenges that will lead to further evolution in O&M.

Ultimately, to ensure the continued success of the offshore wind sector, it is vital to optimize the production of current assets alongside building new infrastructure — and the best way to achieve this is through smart predictive maintenance strategies. **PTE**

onyxinsight.com

Dr. Evgenia Golysheva, head of engineering, has been working closely with a majority of UK offshore wind farms for many years providing owners (Centrica, SSE, RWE, E.ON, SPR) with data enabled engineering projects focussing on increasingly efficiency of offshore wind farm operation, improving turbine reliability and de-risking major maintenance operations. She is leading the UK engineering team at ONYX focusing on developing data driven methodologies for predictive maintenance: life models for the wind turbine components, advanced diagnostics using various condition monitoring systems, and operations and maintenance cost optimization models.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The Art of Manufacturing Design

SLM Corporation and NORD DRIVESYSTEMS Collaborate on Drive Technology Advancements

Oil and gas, grain and timber, iron ore and coal. These are just a few of the raw materials that keep the wheels of civilization turning each day. How they get delivered to the mills and refineries that convert them into usable products, however, is something to which few among us give much thought. Kent Phillips does. The president and CEO of the Superior Lidgerwood Mundy Corporation (SLM Corp.) spend their days manufacturing a host of advanced equipment that makes barge traffic and so much more possible. One of the primary contributors to these efforts is NORD.

"The marriage of flexible design practices, applied engineering, and passionate commitment to helping the industry as a whole — that's what separates us from our competition," said Phillips. "NORD plays an important role in this."

SLM, located in Superior, Wisconsin, got its start in the lumber industry, according to Sean Tenerelli, business development at SLM. The company's products were not only used to move lumber onto railcars in remote locations, but also to pull stranded or derailed trains back onto the track. The company has roots in cableway systems as well, where its hoisting innovations led to recognition in multiple World's Fairs and were incredibly important to the construction of historical landmarks such as the Panama Canal and the Hoover Dam. Some of these systems are still in operation today.

In addition, SLM has been involved in the design and implementation of winch, capstan, and hoist solutions for the U.S. government since the dawn of the war department, a partnership that continues to this day. "Look at any of the military vessels built over the last 150 years and the chances are excellent that you'll see our equipment," said Tenerelli.

Despite this proud history — or perhaps because of it — SLM has begun to transform itself over recent years. After the retirement of several key employees, the company began looking for ways to combine their unique experience in mechanical lifting devices with modern drive technology. This includes state-of-the-art control systems, hydraulically actuated leveling equipment, and automated solutions that make SLM products more cost-effective, reliable, and above all, safer.

"That's where our relationship with NORD started," said Kenneth Behrman, SLM's engineering and external affairs manager. "In order to accomplish our goals, we had to find the very best drive technology available and the application support necessary to integrate it with our winches and hoists. We soon found that NORD has both, with a broad product selection and excellent availability, as well as the price points we needed to be competitive."

One of the first examples of this collaboration was on a funicular hoist used to transport personnel to and from a hydroelectric dam located in the southeastern United States. SLM built the original system in 1912, and while it was still functional, the customer was asking that it be upgraded to modern operational standards. One of the challenges, however, was that the facility is protected by historic preservation laws, so the replacement equipment had to be minimally invasive.

"To design a hoist that would fit into the original space but meet today's much higher safety factors, SLM worked with NORD to design a CLINCHER gearbox paired with an open gearing set," says Behrman. "CLINCHERs are typically used for agitators and mixers or conveyors, but the unit they recommended possessed the required characteristics for in-line operation with an open gearing set as well as the capacity to transmit the required power generation, all in a small footprint."

In another example, SLM addressed the need for more efficient and standardized barge positioning systems. Behrman notes that legacy positioners are often unique to

SLM synthetic rope barge breasting winch with NORD gearmotor at an inland grain elevator.

SLM barge haul winch ready to safely and accurately position barges for loading grain.

each loading facility, based on decades-old technology that requires a high level of experience to operate. Given the current labor shortage and the fact that many dock workers are approaching retirement age, these skills are increasingly hard to find.

What's more, much of this work is manual—personnel must hoist heavy lines and walk along the sides of barges and docks, even in inclement weather. "It's a difficult and unsafe job," he said. "Because of this, it's tough to find people today that are willing to do it, and those who are willing are usually only familiar with whatever system they were trained on. We wanted to develop a standardized, largely automated system that someone can operate with minimal operator training."

Tenerelli said that the challenges in these systems is to balance operational needs with a cost-effective solution. "We found early on that facility owners were asking for better safety and efficiency, but usually balked at the price tag," Tenerelli said. "This led us to develop our S-Series of standard winches, which is NORD-based and offers a great ratio of cost, efficiency, and the desired safety improvements."

Engineering manager Behrman adds to this, stating that "In this and countless other examples, NORD's engineering team has provided sizing and application advice that keeps us on the forefront of design improvements. We are now able to apply gear motors in unique applications with the full support of the manufacturer's engineering team, allowing us to offer solutions that most cannot."

Similarly, operation of the tripper conveyors used at the tops of these grain, coal, and fertilizer facilities is not for the faint of heart. Here, a worker must manually engage a hydraulic clutch to activate a tripper device, dumping whatever material the belt is carrying into the elevator or railcar waiting below. When the tripper stops, the only thing holding it in place is a series of brakes that are notoriously unreliable given the extreme loads and extended service of such equipment.

Adding even more risk to this scenario is the fact that operators are often required to work hundreds of feet in the air, where any slip or equipment malfunction might send them toppling to a rapidly moving belt or the ground below. On top of this is the constant exposure to grain dust, which is not only hazardous to the workers' lungs, but explosive besides.

"For us here at SLM, this sort of working environment is intolerable," said Behrman. "But by using a pair of right angle, vertically-mounted winches equipped with NORD gearboxes and an advanced positioning control system, we've developed a system that gives operators full control from a remote station. This eliminates the need for personnel to work on or near the tripper, and provides much greater accuracy, avoiding the spillage that so often occurs with old-fashioned equipment."

There are many more examples, most of which utilize drive technology from NORD. In fact, Behrman and the SLM engineering team have created a ten-step development philosophy that they apply to all projects and which usually calls for NORD gearboxes. This methodology employs a "standardized products applied to customized solutions" approach in lieu of having to develop solutions from scratch every time.

"Safety and process improvements are fundamental to our success," said Behrman. "Whenever possible, we use completely enclosed gearing in our solutions. This decreases the possibility of human injury, drastically cuts maintenance and inspection time, and significantly extends equipment life. Because NORD products allow us to accomplish most of our solutions without open gears, chains, or belts, we're able to provide offerings that are safer and have higher ROI than our competitors."

"Around ten years ago, we made the decision to take all that we'd learned during our years working with the military and various government agencies and bring it to the commercial market," said Phillips. "We wanted to have customizable solutions that are built off a standardized platform, giving us the flexibility to arrange everything the way we wanted and deal with different levels of geometry and environmental constraints, but without the need for a fully customized package."

"NORD really helped us," Phillips added. "They became a committed partner, paying attention to our needs and showing a high level of interest in our success. The relationship has been very good for us." **PTE**

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www.nord.com

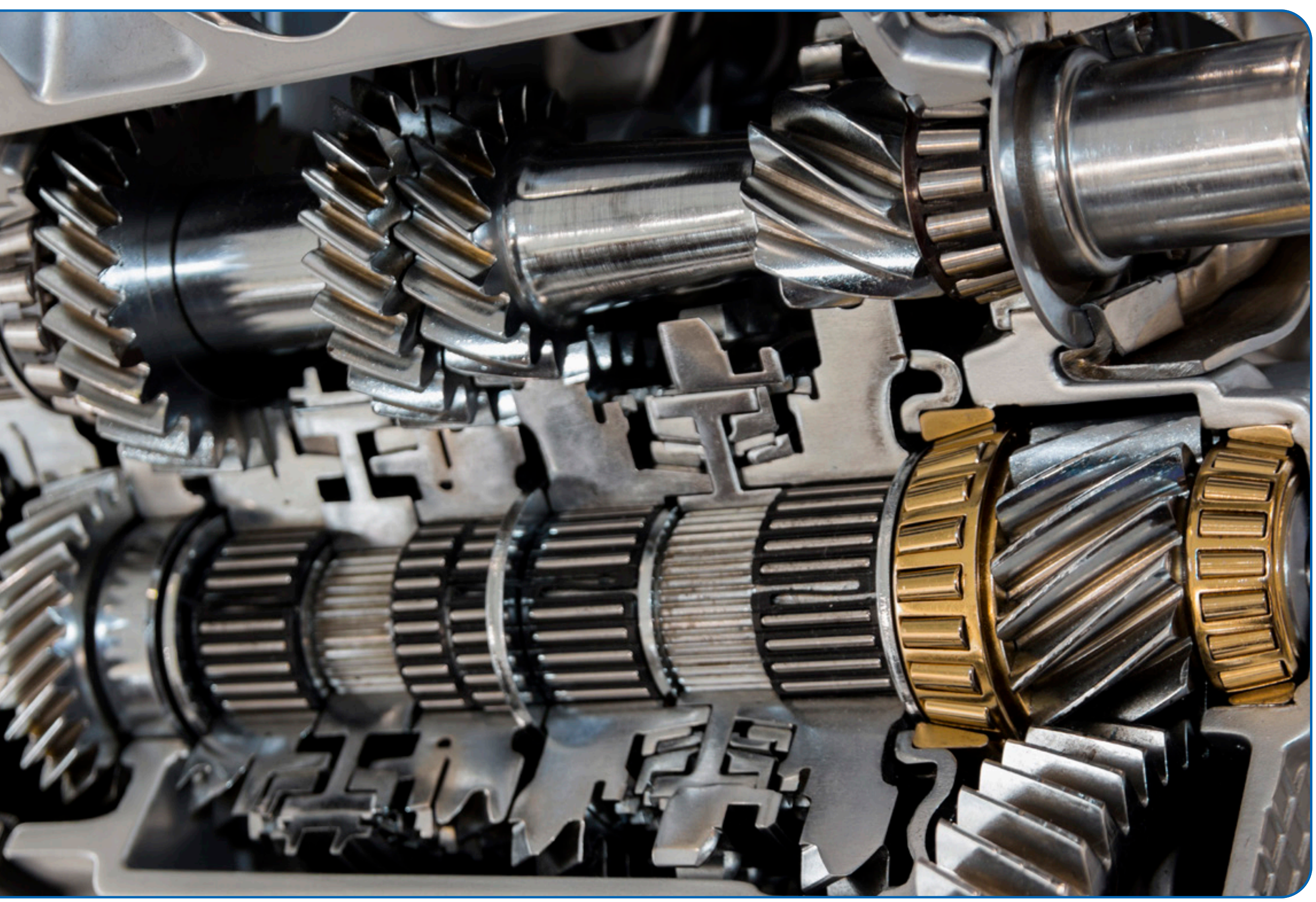
The Efficient, Evolving Technology of the Gearbox

Dr. Raj Shah, Nathan Aragon, Dr. Mathias Woydt

There is always some element of maintenance, replacement, and monitoring required when it comes to factory equipment; however, there are some components, which need much more than others. Gearboxes are one type of high-maintenance components. These are typically items, which face significant wear due to their unique job of converting high speed, low-torque power from electric motors into the low-speed, high-torque power necessary for machinery.

Despite the downside of being high-maintenance, gearboxes continue in their prevalence because, as the axiom in the power-transmission industry states, according to *Machine Design*, "Speed is cheap, torque is expensive." Furthermore, being dependent on motors to produce the torque demanded by many loads (known as direct-drive technology) is typically less economical than developing the torque via a motor/gear reducer duo. For this reason, most engineers cite gearboxes in their layouts. Gearboxes, also, can render other mechanical parts redundant, such as bearings, belts, pulleys, and chains. These omissions can streamline and contribute to the making of more cost-efficient motion-controlled operations.

Engineers must employ the most efficient gearbox, which suits their application's needs. Using an apposite gearbox is both economical and environmentally wholesome. Suitable gearboxes also need to generate less power losses, so designs can use cheaper, compact motors, which don't require as much space. A reduction of heat generation is also a byproduct of efficiency; this will extend the longevity of a gear reducer as well as the oil in it. A surplus of heat can make



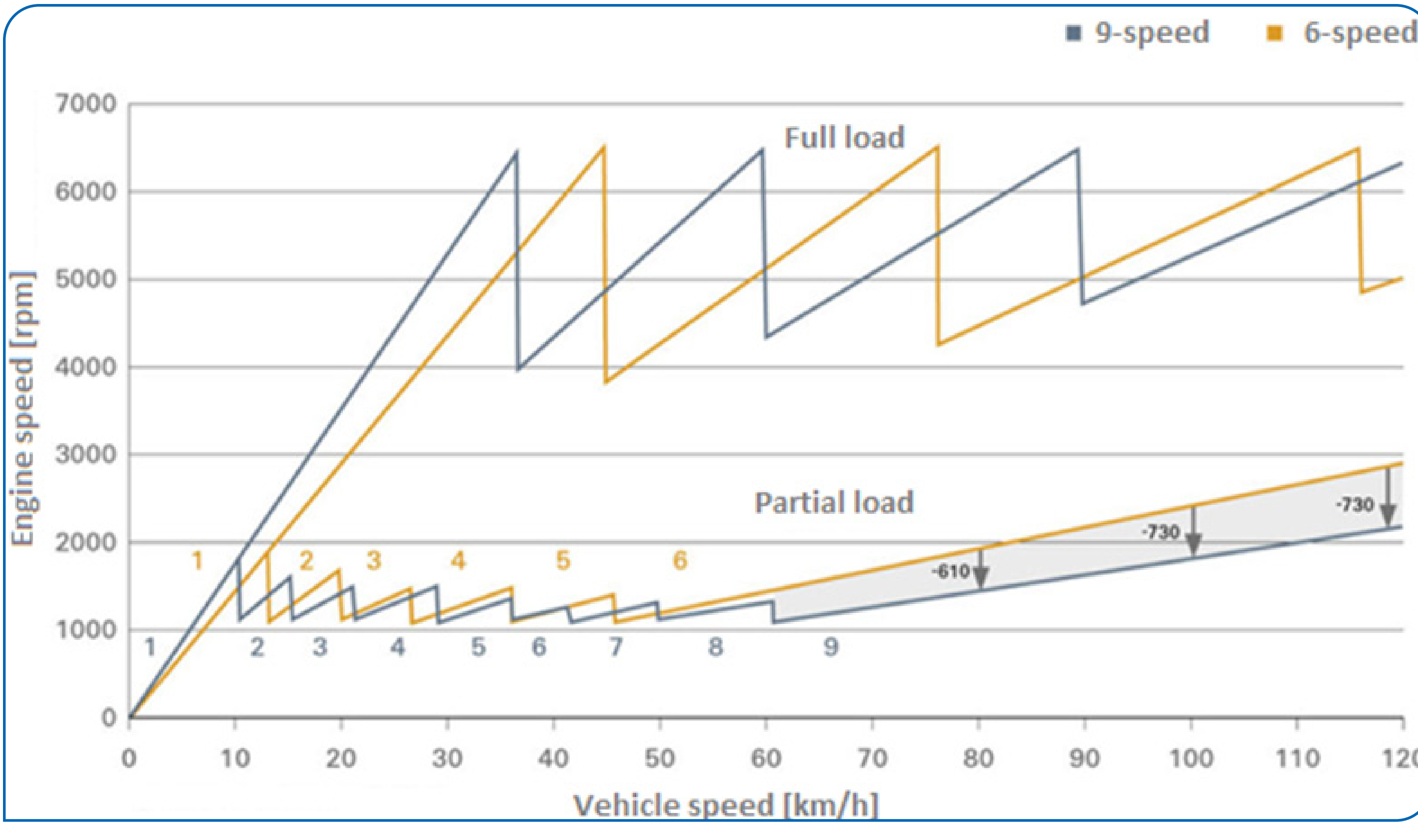


Figure 1 Comparison of six-speed and nine-speed automatic (The partial load line shows that at the same speed, the engine coupled with the 9-speed transmission runs at a lower speed. This saves friction and fuel. At full load, it can be seen that the narrower gradation of the gears allows the maximum power to be driven more often, which benefits the acceleration).

operations less safe since hot-running gear reducers are notorious for scorching distracted workers. In terms of reliability, gearbox designers tend to lubricants of higher viscosities, which contradicts efficiency.

There exists a variety of gearing, with every type having distinct positives and negatives, so it is worth considering each. Some examples of gears used commonly today include the following: There is worm gearing, which is exorbitantly priced, especially when it comes to right-angle applications. Self-locking, this type of gearing gets rid of the need for motor brakes in specific applications. On the plus side, it is hushed in tone and basically runs with relative smoothness when going in only one direction. Worm-gear efficacy goes as high as 65% to 80%. Sliding friction usually occurs, and this contributes to prodigality in terms of energy and the creation of heat as well as an increase in tooth wear. These are all contributing factors, which diminish the life of a gearbox. When the worm gears are used in applications in which the motor reverses, backlash breeds while the teeth deteriorate eventually.

Furthermore, within worm-gear reducers, so much heat is produced that designers must address pressure equalization between the inside of a reducer and the atmosphere. Installing a breather valve, which allows air in and out of the reducer is one means of pressure equalization. However, contaminants can also be let into the reducer, as can moisture, which results in oil breakdown and faster reducer failure. Including a bladder inside the reducer, to equalize pressure, is another method of pressure equalization. This can be problematic as well because bladders are likely to rupture and lead to reducer failure.

Another type of gearing is called spur gearing. It is less challenging and costly to machine as opposed to helical gearing, but more expensive than worm gearing. Basically efficient, spur gears have teeth with rolling, instead of sliding, friction, rendering heating a non-issue. Spur gears, on the other hand, have limited tooth engagement between mating gears. This places more force on individual teeth, decreasing the torque-carrying allotment of gearboxes. The teeth begin to be worn down by these factors, in addition to deforming or deflecting the teeth, which restricts the life of the gear. High torque ripple is also created by this limitation as the teeth meet and retreat, resulting in loud gearboxes.

New innovations in gearboxes are integral to a more environmentally friendly and sustainable future. The automotive industry increased over the years from 4–5 speeds to 8–10 speeds in order to close the gap between CVTs, toroidal gears, and electric vehicles (EVs). The new generation of gearboxes make it possible to reduce CO_2 emissions by up to five grams per kilometer by optimizing the roller bearings and minimizing the friction of seal lips. This new cutting-edge, green technology has been developed by Volkswagen. It is the manual gearbox, the MQ281 as it is called. This efficient gearbox was initially installed in the new Passat, with almost all other Volkswagen models to follow suit. Up until this time, manual gearboxes had receded into the background. It is now remarkably being noted that only modest alterations were necessary to boost efficiency and improve consumption, resulting in a significant effect on emissions and the environment. These often overlooked and underestimated; manual gearboxes make up a prominent allotment of the gearbox market globally owing to a high installation rate.

This new design is bolstered on a 2.5 shaft concept and touts a high gear spread capped at 7.89 and a torque spectrum of 200 to 340-newton meters. While this ensures a satisfactory driving performance, including for heavy vehicles with bulky wheels, it also enables "down speeding" which is (fuel-saving) driving in high gears with low engine speed. The main impetus for this latest gearbox is primarily to improve efficiency. In addition, a bearing concept was also adapted to the gearbox, in order to mitigate friction. This design employed friction-minimized bearings in tandem with low-contact seals. Furthermore, material use and its distribution for the gearbox casing was also ameliorated. A strength-optimized housing could also be designed with the assistance of a further virtual development tool. The new encasement upholds the noise requirements of today, such as avoidance of unwanted secondary sounds. It, thus, promises increased driving comfort by facilitating less audible and discernable vibrations in the vehicle.

Even with this advancement from Volkswagen, it still should be noted that manual (standard) transmission vehicles only make up around 3% of all vehicles sold in the US. They even have a loyal group of customers that can benefit from the usually smaller production costs as compared to automatics. However, manufacturers are even starting to phase them out. A significant reason for this is to cut out manufacturing costs in general by getting rid of a possible design choice. Also, standard transmissions used to be more attractive due to fuel efficiency, but after recent advancements in automatics, this fact is no longer always the case.

There have been shifts by automakers to go for automatic transmissions to have a higher number of gears, sometimes even going between 8 and 10 speeds. These higher numbers of gears allow for more smooth acceleration and can also improve efficiency. Mercedes Benz took these advancements seriously when they announced their 9G-TRONIC 9-speed automatic transmission in 2013. This transmission has a gear ratio spread of 9.15, which helps to reduce the engine speed and helped lead to an average fuel economy of 44 mpg. Also, the transmission offers up to 1,000 newton meters of transfer torque. They say that the 9G takes up the same volume of space as the 7-speed that came before, but the 9G is lighter than this previous transmission. In addition to Mercedes, Ford and General Motors paired up to create a 10-speed automatic transmission, and Ford alone made an 8-speed automatic, both of which will aim to increase efficiency. It has been reported that the Ford 8-speed will allow for adaptive cruise control, adjust gear shift timings based on inclines, declines, and curves, and will also adjust clutch pressure based on factors both outside and inside the vehicle.

Many manufacturers have also opted for different transmissions entirely, such as the continuously variable transmission (CVT). CVTs are known to give the same fuel efficiency as standard high-speed automatic transmissions and adds in even more smooth gear ratio transitions. This is because instead of having fixed gears and gear ratios, the CVT goes through a continuous range of gear ratios to get to the perfect one for the exact driving condition. This offers some advantage to standard automatic transmissions because, in standard gearboxes, the best gear ratio for a specific driving condition may be in between two fixed gear ratios. Nissan has developed a CVT known as XTRONIC that is designed for engines of 1.5L or 2L. They claim that it has a gear reduction ratio spread of 6 and that it shifts gears 30% quicker than its predecessor.

The topic of CVTs is important when considering purely EVs. Many people have been worried about the range of EVs being too short because batteries currently do not have enough energy density and storage capacity. A group of researchers from Australia and China carried out a study in 2018 about addressing the needs of EVs by using both CVTs and multi-speed dual-clutch transmissions (J. Ruan, et al, 2018). They determined that CVTs provide much potential for use in EVs based mostly on energy usage and fuel consumption. They showed that for a certain class of EVs, one through four-speed transmissions had consumed electricity ranging from 17.8 kWh to 15.1 kWh, respectively, while the CVT consumed electricity of 13.6 kWh, all in a city/highway combined cycle. The CVT also showed the lowest required battery capacity out of all the transmissions at 34 kWh for a range of 200 km. This is all very key information due to the inevitable advent of purely electric vehicles in the worldwide automotive market.

Another arena where the next-generation gearboxes success is critical is with the future of wind power. Although, many industry insiders are pondering if the pace of development is sustainable or if experts are biting off more than they can chew when it comes to technology. *Windpower Monthly*, in cooperation with wind turbine experts, Moventas, hosted an extended discussion on gearbox innovation at WindEurope 2019. It was attended by participants from prestigious companies such as GE, Acciona, Siemens Gamesa, Ingeteam, ABB, Innogy and Wood Mackenzie. The various segments in the supply chain were represented during the discourse.

Increasingly, wind turbines are being designed with low-wind conditions at the fore. Because of this factor, there is an increase in AEP expectations, rotor diameters, tower height and torque requirements. The question was posed to attendees at the event by *Windpower Monthly* editor, Shaun Campbell, inquiring as to whether the industry is nearing logistical and transport limits in terms of the installation, movement, and maintenance of very large components.

According to the aforementioned publication, at the conference, Jaco Nies, Chief Consulting Engineer for Systems Engineering at GE said, "If we practice for long enough and close enough to the logistical limits, companies will learn how to deal with larger components." Nies cited the Cypress platform, where they take the tip off the blade and transport separately, rendering the logistical problems, while not null and void, greatly simplified. He stated that 15 to 20 years ago, gearboxes were much thicker, and now they are smaller in diameter but a bit longer. "So yes, there are logistical constraints, but there are also developments on the way to deal with them. People are innovative, and we are constantly redefining these limitations," he concluded.

Moventas has a history which

enabled them to meet market requirements, while countering limitations, including torque and ratio demand, which have plagued gearboxes both yesterday and today. Moventas was the premier company in the industry to provide the high torque density Exceed gearbox solution in 2014. Its technological blueprint underpins both medium and high-speed platforms, maximizes energy output, CAPEX utilization, and the introduction of the next evolution of innovation to gearbox technologies.

The main challenge for gearbox design is that wind turbine gearboxes must be able to stand up to a wide variety of shocks and loads, which would not be found in most gearbox applications. In addition to the bending forces on the shaft, which are transmitted into the gearbox, there are also abrupt changes in torque instigated by gusting and even reverse torques under severe conditions. This means that the design of the drivetrain must be able to either insulate the gearbox from these shocks, or, alternately, the gearbox must be built to tolerate them. A study from the National Renewable Energy Laboratory (NREL) for the period 2009–2016 revealed that 76% of the gear failures were related to bearings and 17% to gear teeth [*www.energy.gov/eere/wind/articles/statistics-show-bearing-problems-cause-majority-wind-turbine-gearbox-failures; S. Sheng*].

White etching cracks (WEC) or white etching areas (WEA), known as "early bearing failures," affect the reliability of technical equipment, especially of wind turbines or azipods, and take many years off the lifespan of a gearbox. Premature failures and WEAs/WECs were observed in steel microstructures without any visible, metallographic default. A group of researchers from England have shown that WECs formed most frequently out of MnS inclusions, which were part of the subsurface of bearings. They attributed the crack formations to stress concentrations that appeared in certain parts of the bearings (Bruce, et al, 2015). Not much is known about the real root cause of flaking or "abnormal" flaking in the raceways originated by white etching areas/structures, but studies have shown that a variety of sources and parameters can lead to them. Researchers published a study in 2018 that focused on how lubricants, especially additives, affect the problem, and they confirmed that lubricants with metal additives usually lead to WEC formation. It was also suggested before that hydrogen originating from lubricants by arcing was a significant contribution to the formation of WECs. These researchers validated this by using TDS spectroscopy to observe oils that were heavily infused with water, which led them to conclude that water was a primary source of the hydrogen (Haque, et al, 2018). SKF tribochemistry studies (K. Stadler et al., 2013) confirmed the local generation of diffusible hydrogen under severe mixed friction contacts. Such conditions are seen in examples where a combination of lubricants and additives interact with fresh or nascent metallic surfaces.

Since many of the issues associated with gearbox wear and breakdown are related to the size of the forces with which they are inundated. One possible solution has been studied to decrease the torque by splitting the drivetrain into several smaller units, each equipped with its own gearbox and generator. Already, rotors driving eight or 16 separate gearboxes and generators have been tested to varying degrees of success. Ultimately, despite significant advances in gearbox design, the wind turbine gearbox remains a high maintenance unit. For instance, a wind turbine built with a lifespan of 20 years will likely possess a gearbox necessitating a major reworking every five-year interval.

Analogous to the human body, mechanical components such as gearboxes eventually need a check-up to ensure all is chugging along as it should be. The borescope is a highly useful tool for aiding mechanics to peer inside of complex mechanisms involved in all types of machines, such as automobiles and airplanes.

Recently, scientists have looked to more advancement regarding condition monitoring inside the wind turbine gearbox. By using new methods of process observation and control of the gears and bearings, damage can be anticipated, and this can reduce costs from unforeseen failures in the gearbox. There is a method known as an envelope spectrum that can be used as a diagnostic tool by monitoring harmonic frequencies of bearings. A group of researchers reported an improved envelope spectrum by integrating a cyclic spectral coherence along selected filtering bands. They report that this tool has been able to detect most failures under different load conditions, and the claim was verified by the National Renewable Energy Laboratory (NREL). They also saw that situations with a more significant load gave more detectability to damage, possibly due to the torque (Mauricio, et al, 2020).

The characteristics and compositions of lubricants used in wind turbines can play a significant role in the future for gearboxes. Aside from polyalphyolefins (PAO), esters and polylkyleneglycols (PAG) also entered this market. Researchers in Spain have done more studies into lubricants for wind turbine gearboxes. They investigated two ionic liquid additives into synthetic wind turbine gearbox oils for their potential in general friction and wear reductions. The two ionic liquids used were choline bis(trifluoromethylsulfonyl) imide ([choline][NTf$_2$]) and 1-Butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide ([BMP][NTf$_2$]). They did not prove to be very effective at reducing friction, but the wear was reduced in all the different testing conditions, with the BMP-NTf$_2$ solution showing larger improvements as compared to the choline-based formulation (Monge, et al, 2015). Ionic liquids can be applied in all types of base oils, but their corrosivenes must be checked.

Arguably, gears are the single most fundamental invention integral to the foundation of civilization, next to the wheel, of which they are a logical extension. What is not debatable is that a typical day in our lives is unfathomable without gears, a fact of life so accepted that the average person scarcely gives this reality a second thought. Spanning from the first prototypical gears comprised of wood and bronze and hailing from China, as far back as 800 B.C.E., up through the most complex gearboxes of today, found in everything from automobiles and airplanes to wind turbines, one fact is certain, the world as we know it would be impossible without the innovative and evolving technology of the versatile and indispensable gearbox. **PTE**

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High-Power Density Motors

George Holling, Rocky Mountain Technologies

Introduction

This paper will discuss the trade-offs between power density, efficiency and cost for high-performance electric motors in order to help designers choose the appropriate technology for their specific application.

There are many terms that designers use to convey a specific requirement for an application which is similar in their goals — yet different when one considers the underlying technology goals.

When it comes to the selection of an actuator, we are often faced with the terms "small," "light-weight," and "high-power" — all of which imply that a solution is sought which will fit a specific requirement; but the technical implications of these terms are significantly different.

First, one very common misclassification is "high power," which is often used when the designer is looking for high torque. It is important to remember that power (P) is the product of force (F) and motion (v); or for a rotating machine torque (T) and angular velocity (ω). Thus, an actuator with very high-force/torque output will deliver no power if there is no motion, and a very small force/torque will generate a lot of power when the velocity is very high.

Hydraulic actuators generally will yield the highest torque/volume if the underlying infrastructure to generate the hydraulic pressure is ignored, but the velocity at which the force is delivered is typically very low. Thus, the actuator has very high-torque density, but low power density.

It should also be noted that, for an electric motor, the physical size is directly related to its torque output, although there are some potential tradeoffs between volume and efficiency that will be discussed later.

A second key consideration is the efficiency (η), which is defined as the ratio of output power versus input power for a motor, and the inverse for a generator. Thus, a low-speed motor — even when it delivers a high-output force/torque — will always have low efficiency. Therefore actuators are often combined with a gear which allows the motor to operate at a higher speed and to operate at a higher efficiency, at which time the gear reduces the speed and increases the torque to match the application. Even though we lose some efficiency in the gear, this can significantly improve the overall performance of the actuator. A common example is the motor in a (gas-powered) car where we aim to operate the engine at maximum efficiency whenever possible.

The power and efficiency of a motor are directly related to the heat that is generated in the motor and which must be dissipated: the total heat losses (P_{loss}) are input power minus the output power:

$$P_{loss} = P_{in} - P_{out} = P_{in}\,(1-\eta)$$

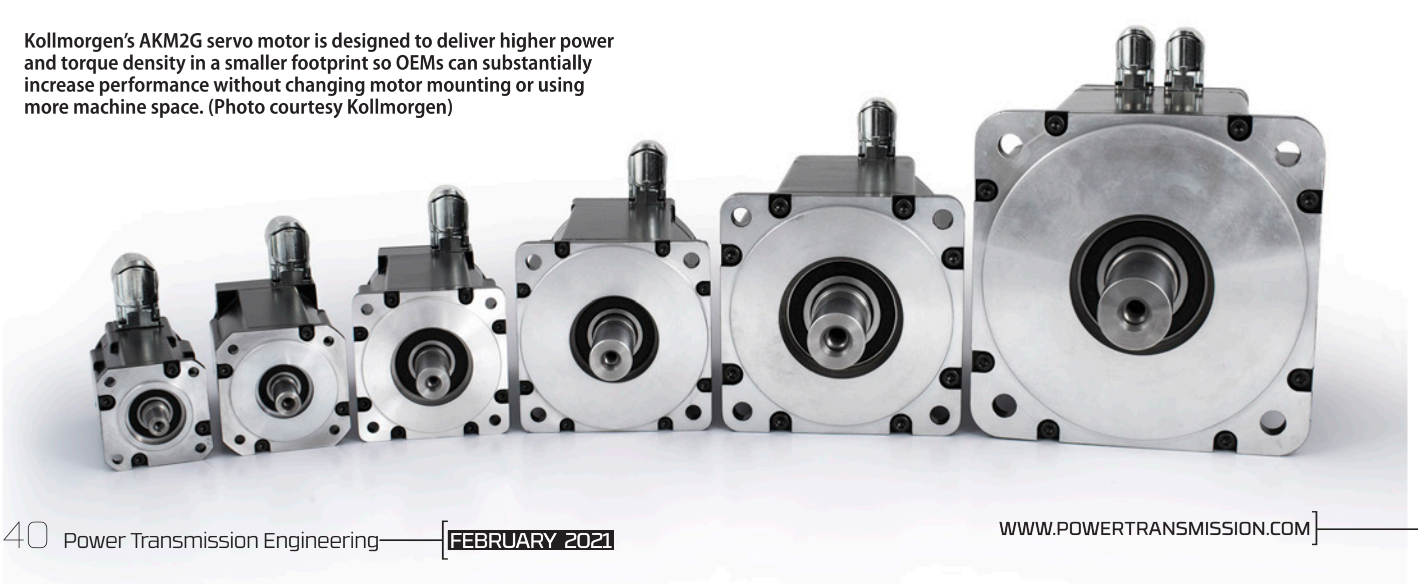
We can now discuss the implication of these physical relationships and how they can be used to properly select a motor that will yield the best fit for a specific application.

The Trade-Offs and How to Make Them Work for You

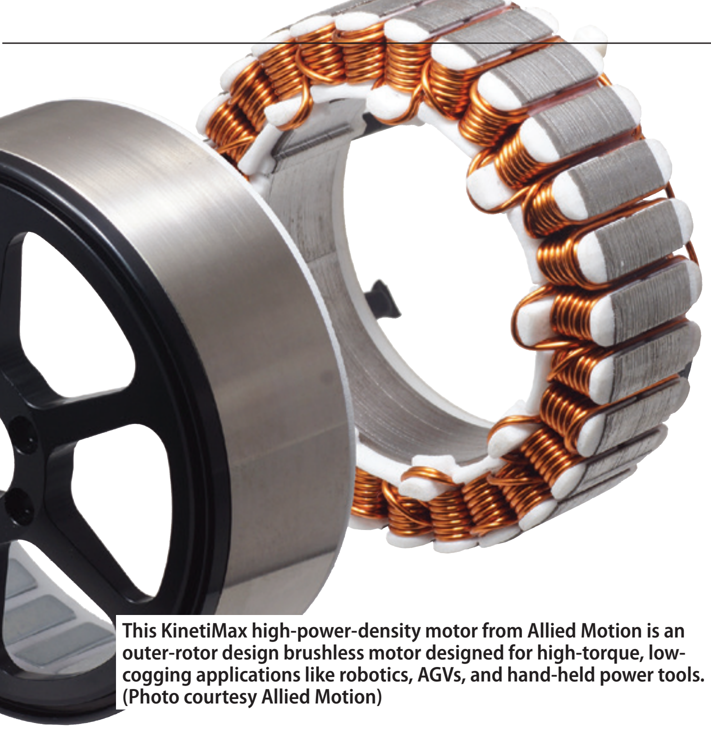
It is very common to have a customer call needing a motor or actuator, and when questioned about the detail they produce a complete set of machine drawings with a little black box space left open for the actuator, along with a set of specifications that cannot possibly be met, and all that at virtually no cost.

While there is no magic wand to fix this problem, there are some general avenues to explore in order to find a possible solution.

First, which motor technology to use? Brush DC motors, step motors and most AC induction motors are cost-effective, but they require more volume for a given torque and power than high-performance brushless PM motors; the latter



Kollmorgen's AKM2G servo motor is designed to deliver higher power and torque density in a smaller footprint so OEMs can substantially increase performance without changing motor mounting or using more machine space. (Photo courtesy Kollmorgen)



This KinetiMax high-power-density motor from Allied Motion is an outer-rotor design brushless motor designed for high-torque, low-cogging applications like robotics, AGVs, and hand-held power tools. (Photo courtesy Allied Motion)

are also significantly more efficient. Thus, we have less worry regarding what to do with the heat that these motors generate. The drawback is cost.

While brush DC and AC motors are often very cost-effective, a modern high-performance brushless motor with Neodymium magnets will be significantly more expensive. The high cost is partially offset by having less need for cooling infrastructure but typically, there will be a cost penalty for using brushless PM motors. One of the main cautions when using PM brushless motors with Neodymium magnets is that these magnets are typically very sensitive to temperature, and these motors can be easily damaged if they get too hot, which is especially true when lower-cost Neodymium magnet grades are used.

A trade-off solution is reluctance motors, which often offer better efficiency and smaller volume than brush and AC motors, but they may have lower efficiency and a larger footprint; although, at a significantly reduced cost — especially for high-volume OEM applications. Another advantage of reluctance motors is that they have no magnets and they typically operate at higher internal temperatures than PM brushless motors, but safety requirements may limit the allowable operating temperatures.

However, in many pump applications, where we have cooling via the load medium, i.e. — automotive water pumps — you may be able to operate at higher internal temperatures while still maintaining safe, external operating conditions.

An electric motor will change its operating efficiency with speed, but also with torque load. A lightly loaded motor is generally less-efficient than one operated at rated power, which is especially true for AC induction motors, shunt DC motors and reluctance motors. As load is increased, the motors will continue to produce the required torque, but their efficiency will generally drop.

Thus, the heat generated will increase disproportionately with the load. Sometimes we can use this to our advantage; e.g. — if we have an application that only occasionally requires high-torque/power output for a short time with sufficient cooling periods in between, and where torque/power performance is more important than efficiency. In such cases we can use a lower-rated, smaller and less-expensive motor to meet these high-load conditions for short, intermittent periods of time.

The ratio of peak torque versus crated torque varies greatly with motor technology. Some brush motors have little margin while modern brushless motors can often provide 5x or more peak versus rated torque. Reluctance motors are somewhere in between, with a practical ratio 3x or more peak versus rate torque.

If the motor needs to stay cool or operate very efficiently, you may want to chase a larger physical size that dissipates more heat since efficiency is also a function of the internal heat in the motor (windings and magnets).

We have already discussed the use of gearing, which can also be an effective way to reduce the size of an actuator package, i.e. — traction drives, conveyor belts etc. It must be remembered that the efficiency of the gear will be almost constant (hopefully, around 90+ %). Thus, if we boost our motor efficiency from, say 60% for a direct drive to 90% for a geared system, our overall efficiency increases from 60% to over 80%, which means less heat and often a much smaller system as well. It is beyond the scope of this discussion to address all the details that will be encountered — backlash, etc. That may be a paper all by itself.

The above has so far been only a discussion of motor technologies that excluded the drivers, where applicable. Different drive electronics, PWM switching frequencies, excitation waveforms etc., will further impact the motor efficiency, higher speed performance peak versus rated torque performance and, most importantly, the overall system cost which is, again, a subject worth a separate paper in itself.

As we can see from this discussion, the trade-offs are many and the specific decisions are complex. Most engineers that use actuators in their design are often ill-equipped to fully understand all of these factors.

Suppliers can be helpful, especially if you work with a good rep that offers many different product lines, while manufacturers have a tendency to steer you towards a specific equipment solution which may or may not be the best fit for your requirements.

Another suggestion is to consult with your peers and listen to their input, as they may have encountered similar challenges in their design. Sometimes you may simply want to retain an experienced consultant to assist you with sorting through this maze and help you find the best fit for your application while avoiding costly mistakes.

As always, when it comes to motor and actuators, there simply is no silver bullet solution and it is important to consider all aspects of the application that may lend itself to different solutions. **PTE**

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Complexity of Systems Number and Types of Interfaces and Unintended Consequences

Don Labriloa, Quicksilver Controls

When designing systems, most engineers notice that the development time and integration time usually very quickly grow as the size of the system grows. System engineering courses will note that the number of potential interactions between various interfaces within a system goes up by the factorial of the interfaces! When counting the interfaces, be sure to count each aspect of an interface, as this greatly expands the effective number of interfaces and resulting complications you will actually be dealing with when you try to integrate!

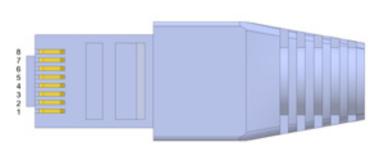
Fortunately some of the interfaces do not interact with ALL of the other interfaces, but often there are many more interactions, as well as understanding and follow through at the module engineering level, will greatly simplify the system and the resulting design and integration effort. Use of subsystems that have very few interactions can greatly speed the overall system. Note that each of the examples that follow I have seen in real life systems!

As an example, what many look at as a "simple" interface — consider a venerable RS-232 or RS-485 serial connection. For the RS 232, you must start with which revision to choose — RS-232 is actually a family of specifications. The variants have different voltage swings expected and allowed (±12V, ±5V, ±3V), as well as current drive capability (0.5A, 10mA, some less with micro power). The minimal RS-232 is called three-wire: Just Receive Data (RxD), Transmit Data (TxD), and signal ground. According to how much of the specification is implemented, you can add hand shake lines for Ready to Send (RTS) and Clear to Send (CTS), Data Set Ready (DTR) and Data Terminal Ready (DTR), and for modems to indicate a connection, Carrier Detect (CD), and a protective ground. The original 25 pin implementation included all of these signals for two separate channels, optional transmitter clock and receiver clocks, signal quality and a data rate indicators. The pinout for Data Equipment (modem) and Data Terminals are also swapped (to allow them to connect 1 to 1). If you need to connect between two data terminals, then you need a "Null Modem" to switch the wiring around. So connecting two "simple RS-232" signals together is not always so simple!

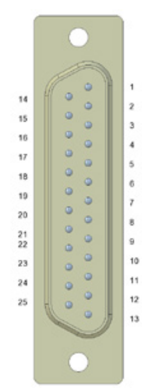
With RS-485 there are different equivalent loads which determines how many devices can be on one bus without loading down that bus — the default is 32 devices, but devices with lighter loading (1/8 loading) can allow up to 256 devices. Different devices can have significantly different common mode ranges allowed while transmitting data. The default is –5V to +12V, with newer devices significantly extending this. They also have different no-damage common mode ranges from the –5/+12 v of earlier devices to newer devices as high as 80v for non-isolated devices.

Some newer RS-485 transceivers will default to a "marking" or inter-character state when the bus is terminated but not driven, while the standard requires that there be a biased termination on the bus to prevent the receivers from receiving random characters or "break" characters as the voltage between ±200 mv is considered indeterminate by the RS-485 specification, and a simple termination would result in a near 0v signal if no device is driving the bus. Add the choice

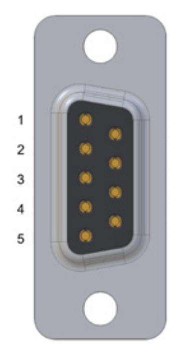
Pin	V.24 (25 pin)	EIA-561	9 pin
1	Shield	RI (DSR)	CD
2	TxD	CD	RxD
3	RxD	DTR	TxD
4	RTS	Sig Gnd	DTR
5	CTS	RxD	Sig Gnd
6	DSR	TxD	DSR
7	Sig Gnd	CTS	RTS
8	DCD	RTS	CTS
9	+Voltage		RI
10	-Voltage		
11	Not Used		
12	(2) DCD		
13	(2)CTS		
14	(2)TxD		
15	TxCLK		
16	(2)RxD		
17	RxCLK		
18	Local Loop Back		
19	(2)RTS		
20	(2)DTR		
21	Remote Loop Back		
22	RI		
23	Signal Rate Sel		
24	Ext Signal Timing		
25	Test Mode		
Input Output (Data Terminal Side)			



RJ-45 RS232 EIA-561



25 PIN DSUB



9 PIN DSUB

Figure 1 A few of the RS-232 Connector Variants.

Table 1 Comparison of reliability for different system types

Mechanical	Electronic	Software
Wear-out failures	Some Wear-out failures.	No Wear-out Failures.
Fatigue and over load faults can lead to failure.	Contacts (mechanical) wear-out; Electrolytic capacitor life time.	Failures not caused by repeated use, just discovered when faulty code is executed.
Mechanical parts can be inspected.	Electronic system commonly designed for automated test.	Inspection by customer difficult / impossible as source not normally accessible.
Unit to unit variation in every part. Failure modes may be introduced in some parts in manufacturing.	Analog typically more variable, Digital generally more repeatable.	Software may be perfectly copied for each unit. Any failure modes present are present in all units.
Preventative maintenance can help locate and repair/replace failing parts before full failure.	Some electronics self diagnostic to locate failures / redundant designs.	Tests often designed by those with a knowledge of how the system is supposed to work; easy to miss faults found by untrained ("no one would do that in that order!").
Access to parts can be more controlled.	Access to parts can be more controlled.	Software can be heavily battered from the outside if it has outward facing interfaces.
Accelerated life testing often used to locate marginal designs and to help prove reliability.	Accelerated lift testing applicable.	No wear-out so doing the same thing many times not as productive in accelerating.
Standard reliability calculations normally used.	Standard reliability calculations normally used.	Much harder to predict reliability.

of two-wire half-duplex communications and four-wire full-duplex communications to the mix, and selecting the ground connections for the 485 connection, which can provide unexpected sneak connections — especially if power is hot-plugged in a non-isolated system.

Connector pin-outs and network termination can add issues. Slew rate and balance of the drivers can generate EMI issues. Maximum baud rate will exclude certain drivers. Add to this that even the names of the signals are not consistent: D+/D- vs A/B. Even A/B are now consistent, with a split in the 485 world as to whether A represents Data+ or Data- (Really!).

Now that we have the right connector, properly terminated, possibly biased, with enough protection, and with the proper polarity, the fun has just begun. The RS-485 specification does not call out any protocols. As I have heard it said, we need standards — let's just make another one. A bit harsh maybe, but not completely inaccurate.

Assuming we are using serial communications, we can have 8-bit or 9-bit, 1- or 2-stop bits, parity or no parity. We can use special characters to indicate packet framing, or use the intercharacter spacing (such as Modbus) to denote a new packet or frame (even if the prior packet did not properly complete). The whole protocol must be selected, which includes not only how a successful packet is sent, but also how to recover after a bad packet was detected or a timeout occurs. The protocol must specify how to determine if a packet received is a resend of a bad packet or is a fresh packet. The protocol must handle timeouts, and bus handoffs — especially with half-duplex busses — and data overflow (prevention or recovery) if the receiving device cannot keep up with the data.

Finally everybody on the bus must agree what the packets mean and which optional features are available from which devices.

When we jump up to a couple of interfaces on one processor, the complexities multiply. The processor, itself, is a shared resource, as often is available buffer space. Other peripherals are often shared. Now the tasks handling the different interfaces must be carefully designed to control how they obtain and release resources, especially when multiple resources are needed — a failure in this design can result in what is called a "deadlock" or "deadly embrace." A simple example is when a task needs more than one resource, and additional tasks also need any combination of these same resources. The first resource will lock one resource first and then try to lock the additional resource(s). If another task has obtained any of them first, the first task is unable to get all the resources it needs, and must release all the resources it has already collected and then try again. Failure to use this approach can leave each (or multiple) tasks holding some of the resources needed, but not having enough to complete their task and forever waiting to get the resources needed. This is like playing certain card games where more than one of the players are seeking the same suit and all are stubborn!

There are other issues I have seen in projects where the various interrupt priorities were assigned more by the seniority of the programmer in the organization than on the requirement of the latency of the code. The higher priority interrupts are easier to code as there are fewer tasks that can interrupt to slow the completion; if not well managed, the clout of the senior programmers would give them the easier task, while what remains goes to the less senior programmers to try to complete the much harder task. Changes in the high-priority code can cause the lower-priority routines to cease being able to service their tasks in a timely manner. It is easy to end up with the code that is working properly (though taking more time or other resources than it should) actually being the cause of other good code failing. This results in all sorts of issues when unexpected events like a bad packet slows a normally sufficient task, and bugs "pop" up in other tested sections of code that are, in turn, robbed of resources (including CPU time). These are some of the hidden internal interfaces between code sections that account for the factorial growth in interactions and resulting hard to detect and recreate bugs. (The system did, eventually, have the resources reassigned properly, but this did not come without schedule impact!)

One of the areas where electronic and mechanical devices greatly diverge with software is in quality control and engineering margins. A mechanical device can be designed with tolerances and margins to withstand some degree of load beyond what is expected. An electronic device has voltage and timing specifications and can be designed to have margins for both so that it works with parts that can vary over time and temperature (and many other factors).

This includes derating components — using a 63v 105C capacitor in a 48 V system, 75C application will extend the useful life and reliability of the part. Knowing these interface margins allows a quality engineer to establish a degree of robustness, which can be selected or traded off (strength versus weight, for example). A quality engineer can use accelerated testing — testing the devices at high and low temperature, voltage levels, etc., to locate weak portions of a design and to get an estimated failure rate for the devices.

Software is harder to design with this type of "derating" and ability to do accelerated testing. You can leave growing room (processor time and memory space), but as to the code itself, how would you specify a safety margin? A single bit in error in a program — a loop that goes one count too many or few or a wrong jump condition and the code fails. Margin testing is much harder for code: a small change of code in a completely unrelated area can cause bugs in another properly coded section (think of pointers in C code running beyond their space as an easy example). Software typically assaulted with more sabotage attempts (hacks) than mechanical systems or electronic systems, and evidence of success can be harder to prove.

This does not mean that subtleties and interactions are not lurking for the mechanical engineer. The mechanical interfaces often extend outside the more determinate interfaces of hardware and electronics. Mechanical axes taken on their own can operate well within specification. Bolt them to a real life chassis, and the deflections of the chassis due to forces needed to accelerate the axis and its payload may cause other axes to miss their target. Mechanical resonances can be lurking just outside the normal excitation for an axis, until a heavier box is picked up with the wrong coupling/damping between the inertia inside the box and the platform moving it. Belts can change their length in response to temperature, humidity, and wear with the resulting shift in tightness changing their resonance. A similar effect can happen with gears with variable backlash from out-of-round molded plastic gears, for example. Add some wear and the load may intermittently decouple from the motor, causing excessive gain in the control loop while the motor is temporarily disconnected from the load inertia. Add in some flexing of the chassis caused by another axis twisting, and a nice, stable, well-behaved mechanism can suddenly have issues.

Implied Interfaces:

Now add another implied interface with non-level, non-flat floors that can flex the chassis and affect alignment or allow the chassis to rock. Move the machine and it can shift the area that straddles the concrete pours in the floor and you can suddenly get a few more unexpected interface interactions.

Electronics' "Achilles tendon" is often the shared power and ground systems. Noise can easily pollute other sections if care has not been taken to properly decouple and isolate. This is most apparent when trying to measure low level analog signals — special care is needed to reach full resolution and noise specification for fast and high-resolution systems. Noise from the digital or motion drive system can easily pollute the ground and reference voltages causing significant errors that may make a 16- or 18-bit system only give 10 or 12 bits of good data.

Sharing a power supply can cause complex interactions. One system shared a 12v power supply with an analog section while another subsystem used the same +12V supply to supply power to a small solenoid. The first analog signal showed intermittent noise spikes in its data. This resulted in multiple replacements of all of the cables and boards in the system. This was not able to fix the problem as the root problem was a broken catch diode which had been soldered directly to the solenoid. Many hours and dollars were spent locating the root cause of this issue. This is another example of a hidden interface and the resulting unexpected interaction.

Power systems interaction can be even more subtle. Something as simple as an LC filter in front of a local regulator can cause a handful of problems: When turned on, especially if rapidly switched on, the output of the LC filter (if not properly damped or clamped) will ring up twice the applied voltage before settling down. A local regulator rated at 35V will fail from overvoltage on a 24V supply due to the peak of the ringing hitting up to 48 V. If the regulator is a switched mode power supply an undamped LC filter can cause a significant impedance at its resonance frequency. Change the load current and the inductance in the LC filter can shift, resulting in a different resonance frequency. If this resonance is inside the loop frequency of any of the attached switched mode supplies, the switcher may become unstable and may oscillate or seriously ring.

When multiple switched mode converters are cascaded, (such as point of load regulators following a main higher voltage supply) the stability of the following stage is dependent upon the prior stages output impedance, including any filters in between the stages. Switch mode converters also present a negative impedance to the upstream devices. That is, for a given constant output power load, raising the input voltage causes the input current to fall. If sufficient negative impedance results (for any of the potential load power levels), either or both of the upstream and downstream converters can become unstable. The degree of negative impedance varies with load and input voltage. Care in the design of damping in any interstage filters, as well as the compensation of the power supplies can eliminate the instability issues, but they must be considered.

System Engineering:

A "joke" that is unfortunately often accurate is that the first 90 percent of a project takes 90 percent of the schedule. The last 10 percent of the project takes 90 percent of the schedule (and sometimes the last 1 percent can be 90 percent of the original schedule), thus projects are usually late. So what is an engineer to do?

First of all try to minimize the number of interfaces, both externally and internally. For electronics, this may mean using separate local power regulation rather than sharing, even if it adds some to the part count. Often eliminating low-voltage/high-current busses will pay for the now inexpensive local regulators.

Second, try to minimize the interactions. This needs to be done early in the design, and maintained throughout the design. An example of a good choice is in the design of ethernet systems: they use of line filters and transformers to isolate grounds so that the many devices connected within a building have much less chance of having electrical interaction.

For mechanical designs, the use of full 6 degree of freedom mounts on multiple subassemblies allow the easy removal and replacement of parts in both production and in the field. This significantly reduces interactions. Having adjustable mounting for subassemblies makes the position of each interacting module an uncontrolled interface to adjacent modules and can make the commissioning of a system quite complex and iterative.

For electronics, it is important to design how the system ground will connect between internal and external systems. The engineer must plan for how ESD discharges will not affect the rest of the system. Properly design filters to keep external noise out of a system and keep internal noise from radiating. Avoid thoughts like the chassis is ground (singular). Plan and test power supply stability early. Try to resist the urge to share supplies and sometimes even processor power across diverse systems, as digging out the resulting interactions has killed many a large project by missing market windows.

For software, this can include verification of interfaces for proper format and allowed usage. This should include buffer size checking and proper fragmented packet handling and rejection of improper signals from the interface (data, crc, functions, etc.)

Third is to drive the system design from the start through the final testing stage to allow isolated testing of as much of the system as possible at lower levels. Be sure to leave instrumentation in place that can diagnose without changing the system being tested. This is planning for troubleshooting and for validation. In a large system we designed the system so that ALL of the information used to calculate results was saved automatically for normal operations - not just in a diagnostic mode. Having the data always collected in the same manner allowed us to investigate a dubious result without trying to recreate it and wondering if we really recreated the issue. In that system, we ended up finding an unexpected root cause, and we were able to play our suggested correction against a couple years of collected data to test a couple of competing correction methods before implementation of the best resulting method into the system for a final validation. The availability of ALL the raw data saved a schedule slip of at least one or two years.

Fourth is (to try) to design in sufficient margins. This includes extra bandwidth into a system so that it does not choke on retries or on small variation in timing. Included in this should be an easy way to determine the reserve and to latch the worst case (minimum reserve, maximum memory used, etc.) so that the robustness of these internal interfaces can be easily verified. Similarly, reserve power in the supplies and for mechanical axes.

From the very beginning, plan on how to validate the parts and the whole system. Put in the "hooks" and design interfaces that are robust and can be properly validated. It is much easier to muster the cooperation for correction of issues when you have the tools to quickly locate the faulting interface or module. The result of clean, verifiable interfaces is a focus on how to fix the problem instead of the more common how to avoid the blame, which is common with poorly defined interfaces that may not work when integrated although each part appears to pass its own unit test.

This is a very light sampling of a significant science of system engineering and complexity management. It hopefully brings a few new concepts that are useful. **PTE**

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Consideration of Dynamic Excitation Effects in the Gear Design Process of Two-Stage Gearboxes for E-Mobility

Marius Schroers, Christian Brecher and Christoph Löpenhaus

Introduction and Motivation

At the beginning of a design process in transmission development, there is the definition of the requirement list. In addition to information on the input power provided (torque and speed) by the drive machine and the required output torque, all important requirements for safe use over the entire product life cycle are listed. The ratio of input torque to output torque or speed results in the total transmission ratio of the gearbox (Ref.1). In the course of hybridization and electrification of the drive train caused by electro-mobility (e-mobility), two-stage gearboxes are used due to the required total transmission ratios. Within the scope of this report, the investigations are limited to two-stage gearboxes. Due to the high speeds of the electric motor ($n_{in} > 10{,}000$ rpm) and the required output torques ($1.5\,\text{kNm} < M_{out,max} < 4\,\text{kNm}$), the total transmission ratio for e-mobility applications is usually between $8 \leq i_{total} \leq 13$, see Figure 1 on the left. A non-shiftable, two-stage gearbox with a total transmission ratio of $i_{total} = 12.5$, in which is used in a car with a hybrid drive train, is shown (Fig. 1). The gearbox can provide a maximum output torque of $M_{out} = 2$ kNm at a power of P = 70 kW (Ref. 2).

Due to the high speeds in e-mobility and the interactions between the stages, new challenges arise in the analysis and design of the dynamic excitation behavior of two-stage gearboxes. Thus, the gear mesh frequencies excite a wide frequency range. Depending on the number of teeth and the speed, the dominant first gear mesh order of both stages lies in the acoustically relevant frequency range over the entire speed run-up. If the excitation frequencies meet the natural frequencies of the drive train, resonance effects occur which lead to increased loads and should therefore be avoided (peaks, Fig. 1, top-right).

In addition, the average order spectrum of the difference velocity of the first gear stage shown in the lower part of the figure shows the interactions between the gear stages. Both the excitation orders of the first stage and the excitation orders of the second stage, which are transferred to the first stage, can be seen. By superimposing the gear mesh orders of both stages, the entire excitation and noise behavior can be

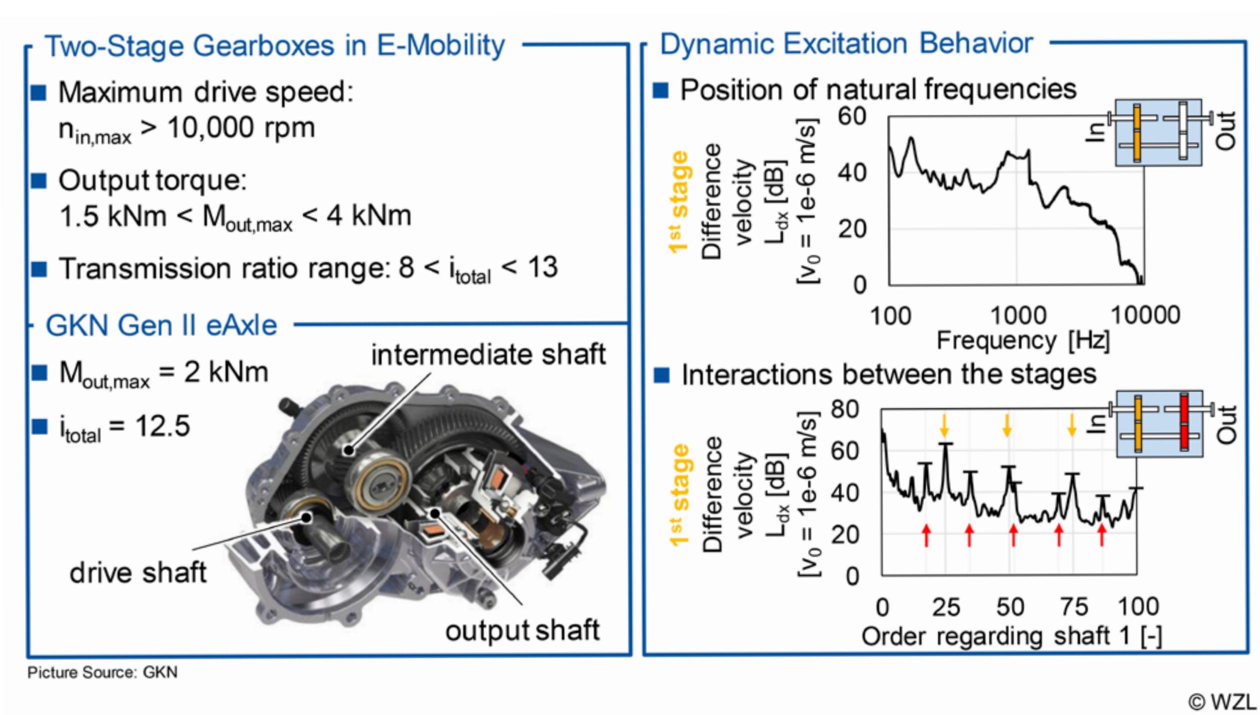


Figure 1 Two-stage gearboxes in E-mobility

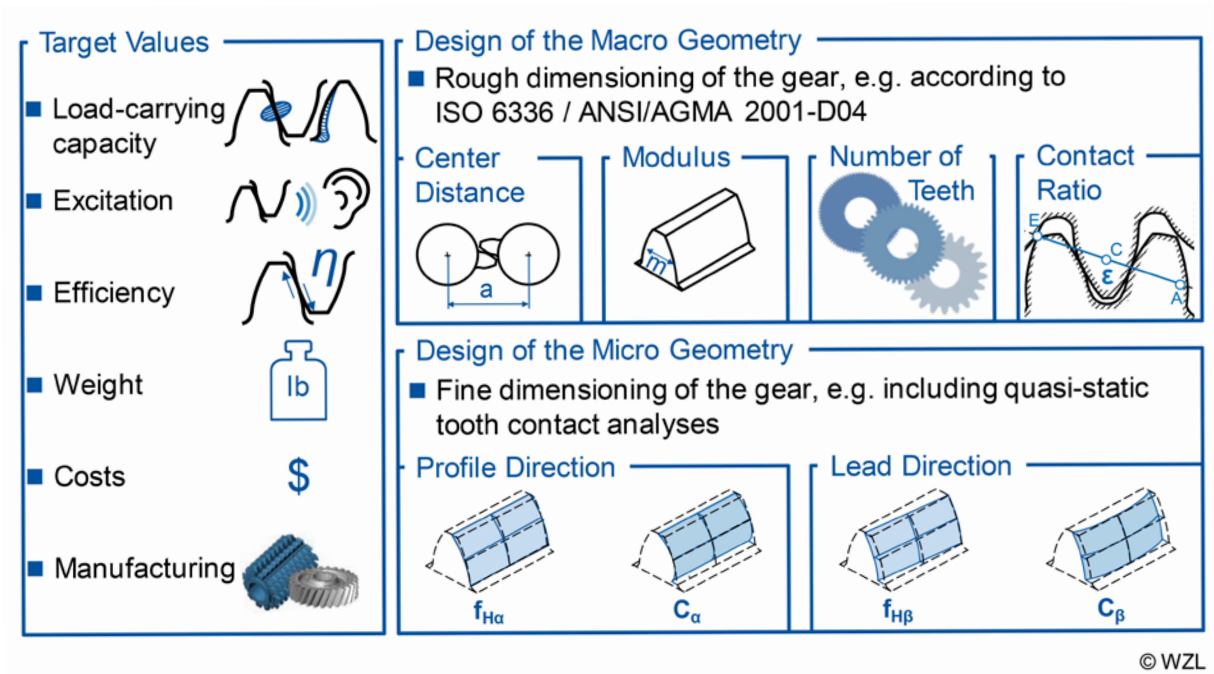


Figure 2 Target values and approach in gear design.

perceived tonal or less-tonal, according to DIN 45681 (Ref. 3).

The additional excitation effects must be taken into account in the gear design in order to meet the target values required in the requirement list (e.g. noise behavior). The objective of front-loading is to use valid mathematical models at the earliest possible stage of development, which can describe the operational behavior over the entire operating range. This allows later complex adaptations to be reduced and development costs to be kept low.

State of the Art

The objective in gear design is to define the gear parameters to meet the requirements specified in the requirement list. The gear parameters are determined step by step—sometimes iteratively. The gear mesh is then recalculated and analyzed with regard to the requirements. Possible target values in the design of gearboxes are listed in the left part of Figure 2 and include, in addition to the basic requirement for sufficient load-carrying capacity of the components, other quality features such as low excitation behavior and high efficiency.

Other important targets are the reduction of (manufacturing) costs and weight as well as general manufacturability. Often it is not only the fulfillment of one but several design objectives that are required—the separate achievement of which leads to improved or worsening effects in other target values when the gear geometry is varied (Ref. 1).

The determination of the gear parameters can be subdivided into macro- and microgeometric design. The design of the macrogeometry comprises the rough dimensioning of, for example, center distance, module and diameters (Fig. 2, above). On the other hand, the fine dimensioning is carried out in the design of the micro geometry. Using quasi-static tooth contact analyses, the occurring contact conditions can be analyzed and optimized by tooth flank modifications (Fig. 2, below). The investigations in this report focus on the rough dimensioning of two-stage gearboxes, which is why the following section focuses on this design part.

Design of the macrogeometry. For the fulfillment of sufficient load-carrying capacity, standardized calculation procedures are used, which enable an evaluation of damage types such as pitting and tooth root fracture (Refs. 4–6). The basis of the calculation is the comparison of the allowable and the occurring stress. The quotient of these parameters results in a safety factor. There are minimum values for these safety factors, which are usually listed in the requirement list. Experience-inspired knowledge is often used in pre-dimensioning. An experience-based approach according to Niemann/Winter calculates the gear geometry on the basis of two parameters for the occurring flank pressure and tooth root stress (Ref. 7). The method is carried out without iteration loops and can be applied without computer support; a disadvantage is the rough approximation.

Linke and Naunheimer suggest an approximate procedure for pre-dimensioning (Refs. 8–9). The basis for the determination of center distance, module and pinion diameter is the design against pitting and tooth root fracture according to DIN 3990 (Refs. 10–11), the contents of which can be found almost completely in ISO 6336 (Refs. 5–6). The required geometry-dependent flank and root factors are documented on the basis of previous knowledge or calculated and lead to deviations between pre-dimensioning and recalculation. Jaroš and Parlow extend the procedure according to Linke by iteratively recalculating the flank and root factors, and thus achieving good agreement between pre-dimensioning and re-calculation (Refs. 12–13).

Due to the large, possible variation space, iterative procedures are often applied which use different variation and optimization algorithms, and focus on different target variables. To reduce the gearbox mass, Savsani et al. compare results of Yokota et al. obtained with a genetic algorithm with results from a particle swarm algorithm and a simulated annealing algorithm (Refs. 14–15). The particle swarm algorithm has the highest potential. Bansemir and Parlow also apply iterative approaches based on different target values using the simulated annealing algorithm and a genetic algorithm (Refs. 16, 13).

For the evaluation of the variants, the target values described above are used. The reduction of the excitation behavior is particularly relevant in the automotive sector and its importance is further enhanced by the omission of the masking noise of the combustion engine in e-mobility (Ref. 8). There is no uniform characteristic value for the evaluation of the excitation behavior in the pre-dimensioning, since the entire speed range and the structure of the overall system must be included in the analysis for a realistic characterization. In contrast, today's design methods are based on quasi-static approaches or approximations. One example is the excitation level developed by Müller, which quantifies the excitation as a function of the contact ratios (Ref. 9).

Transmission ratio distribution for two-stage gearboxes. When distributing the transmission ratio between the two stages, different optimal results occur, depending on the selected target value(s). Taking the manufacturing costs into account, Ehrlenspiel determines the optimum distribution of the total transmission ratio to the two stages as a function of the lot size (Ref. 10). One design objective is to achieve the lowest possible total mass, so that various recommendations for the distribution of transmission ratios are available, but these show similar tendencies (Refs. 18, 19, 13). Möser has developed a similar approach for transmission ratio distribution based on a preferably low gear set volume (Ref. 20).

A recommendation for the transmission ratio distribution for two-stage gearboxes under acoustic target aspects does not exist so far. Possible approaches are the consideration of the technical consonance with which the occurrence of the excitation orders of both stages can be classified as pleasant or annoying. Existing work is limited to the interaction of an electric motor and a single-stage gearbox or several electric motors (Refs. 21–22).

Objective and Approach

As the state of the art shows, methods are frequently used in gear design that focus on single gear stages, and that the interaction between the stages is neglected when characterizing the excitation behavior. They also use quasi-static approaches or approximations based on macrogeometry. Due to the high drive speeds applied in e-mobility, the dynamic excitation behavior is dominated by the gear mesh frequencies in wide speed ranges. Possible load increases due to the coincidence of excitation frequencies and system resonance cannot be taken into account. Early and precise knowledge of the dynamic excitation behavior over the entire speed range should be sought in the sense of frontloading to reduce design and adjustment costs.

The objective of the present report is therefore to consider dynamic excitation effects in the gear design of two-stage gearboxes for e-mobility (Fig. 3). The objective is based on the research thesis that the design quality can be increased in an early development stage by considering dynamic excitation effects. This includes, on the one hand, the consideration of occurring system natural frequencies, as well as the interactions between the gear stages on the other.

At first, a design method is developed that combines the macrogeometric gear design with the simulation of the dynamic excitation behavior. For the evaluation of the dynamic excitation behavior, the simulation software *DynEx1D* is used, which considers the gear mesh with the force coupling element *GearForce1D* according to *Gacka* and the drive train as torsional vibration system (Ref. 13). The difference velocities of the two gear stages at a speed run up to $n_{in} = 12{,}000$ rpm

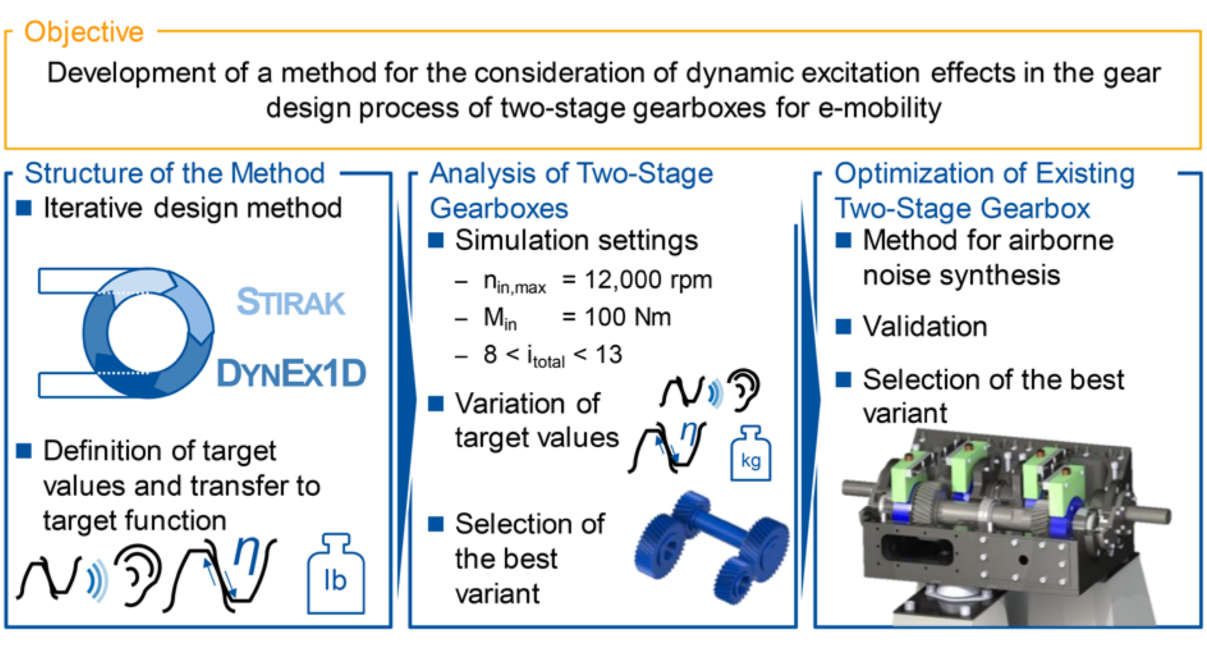


Figure 3 Objective and approach.

are selected as evaluation variables. A particle swarm algorithm based on the swarm behavior of birds is used to reduce the computing time (Ref. 24). In the design method, the variants are evaluated with regard to load-carrying capacity, dynamic excitation behavior, mass, tonality according to DIN 45681 and degree of loss (Ref. 3).

The method is then used to design new, two-stage gearboxes for e-mobility, to compare different target values and to identify the best variant. The total transmission ratio of the gearboxes is in the range according to e-mobility application between $8 \le i_{total} \le 13$. The dependency of the optimum transmission ratio distribution between the gear stages on the mass is also investigated and compared with recommended transmission ratio distributions from the literature. The last step is the application of the method to an existing two-stage gearbox whose acoustic behavior is to be improved (Ref. 25). The developed method will be extended by quantifying the transfer behavior between the excitation in the gear mesh and the resulting airborne noise on the basis of measurement results. The determined transfer function is applied to the simulation results and the resulting airborne noise is used to evaluate the variants.

Structure of the Design Method

The excitation and noise behavior of gearboxes is decisively determined by the interaction between excitation in gear mesh and the system behavior of the drive train (Ref. 26). Therefore, a design method is developed which combines the macrogeometric design of the gears with a dynamic simulation of the excitation behavior. The iterative procedure is shown (Fig. 4). The input torque M_{in}, the total transmission ratio and other variables, such as the maximum drive speed, are required as input parameters. The boundary conditions are also specified. These include in particular the parameter ranges of the variation parameters and the weighting factors for the evaluation. In the present design method, the pressure angle α_n, the contact ratios ε_α and ε_β, the width-diameter ratio b/d_1 and the transmission ratio distribution are specified for both stages. In addition, further parameters like the center distance can already be specified if they are not freely selectable due to an existing concept. Based on the input variables and boundary conditions, the gears are designed in the first step. For this purpose, center distance a and module m_n are determined according to ISO 6336 based on the Naunheimer procedure (Refs. 5, 10, 8). The safety against pitting and tooth root fracture is necessary criteria and are not used as quality criteria in the later evaluation. Variants that fall below the required minimum safety are sorted out in this step. This also includes variants which have undercut, too little tip clearance or too little tooth tip thickness and whose largest common divisor of the number of teeth is greater than one.

In the second step, the quasi-static characteristic maps required for further dynamic analyses are calculated for the possible variants with the aid of the FE-based tooth contact analysis FE *Stirnradkette* (*Stirak*). Due to the varying diameter in the profile and width direction of the gears, no fixed number of FE-elements is defined in the respective direction. Instead, the element size is determined dynamically as a function of the existing gear. With a view to reducing calculation time, an FE mesh that is as coarse as possible is selected. The third step is the dynamic calculation of the variants. For this purpose, the simulation program *DynEx1D*, which is described in detail in the next section, is used to calculate speed run-ups. For further evaluation, the difference velocity of the two gear stages corresponding to the temporal integration of the difference acceleration is selected, cf. equation 1.

$$\Delta\dot{x}_{1/2} = \int \Delta\ddot{x}_{1/2}\, dt = \int r_{b1/3} \cdot \ddot{\varphi}_{1/3} + r_{2/4} \cdot \ddot{\varphi}_{2/4}\, dt \qquad (1)$$

$\Delta\dot{x}_i$	[m/s]	Difference velocity	$\Delta\ddot{x}_{1/2}$	[m/s²]	Difference acceleration
r_{bi}	[m]	Base radius	$\ddot{\varphi}_i$	[rad/s²]	Torsional acceleration

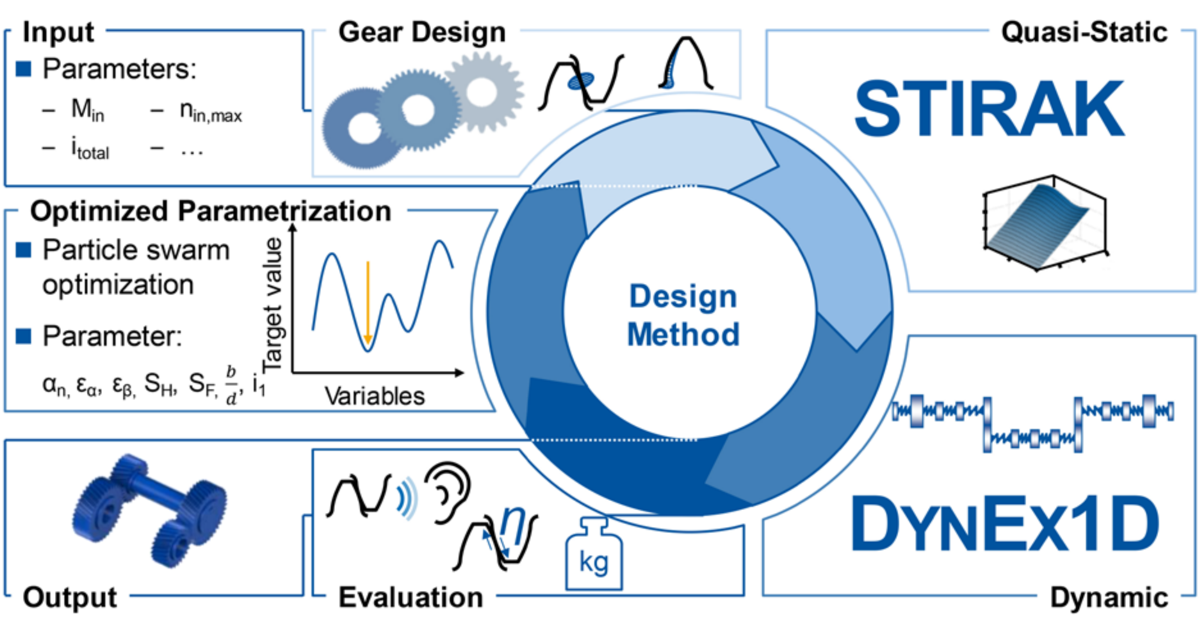


Figure 4 Procedure for the design method.

The evaluation and comparison of the variants are carried out on the basis of different target values. These include parameters for dynamic excitation behavior, tonality according to DIN 45681, mass and efficiency (Ref. 3). The description of the different target values and the combination of a target function are described later. New values are assigned to the variation parameters on the basis of the target function. For this purpose, the particle swarm analysis is used to assign new values to the parameters within the boundary conditions defined at the beginning. The algorithm of the particle swarm analysis originates from the class of the nature-analog algorithms and was derived from the swarm behavior of birds. The objective of the algorithm is to minimize a given fitness function, in this case, the target function. The variation of each particle depends on a cognitive, a social and a stochastic component. Thus, each particle strives to find the minimum in the spanned search space (Ref. 24). The iterative design method is performed up to a defined termination criterion that corresponds to the maximum number of iterations. The best variant can then be identified.

Dynamic simulation model. *DynEx1D* can be used to calculate the dynamic excitation behavior of multi-stage gearboxes. *DynEx1D* consists of two main components: The *GearForce1D* force coupling element according to *Gacka* developed at the WZL of the RWTH Aachen and the drive train regarded as a multi-body simulation model in the rotational degree of freedom (Ref. 22). The dynamic drive train behavior and the gear excitation can be calculated by the interaction of the two components. The input variables required are stiffness maps of the gears, the drive train structure and the operating conditions such as torque and rotational speed curves (Fig. 5). The stiffness maps can be determined with the FE-based tooth contact analysis *Stirak* (Ref. 26).

The drive train is mapped as a multi-body simulation model and considered as a torsional vibration system. For the determination of realistic natural frequencies and shapes, the complete test setup from the drive to the driven machine can be considered. The procedure for mapping the drive train in the MBS environment has the goal of providing the system matrices (mass inertia, stiffness, damping) for the simulation. The drive train is divided into a system of discrete mass inertias, which are connected by massless spring/damper systems. The numerical values of the parameters are then determined and used as input by the calculation core.

In order to avoid extended, costly calculation times and numerical inaccuracies, a modal reduction of the degrees of freedom according to Craig and Bampton is performed as a first step in the calculation core (Ref. 27). The force coupling element *GearForce1D* receives the kinematic conditions (angle of rotation and speed) from the dynamic drive train model as input variables in each time step and returns the excitation forces to it. The excitation forces consist of a variable tooth stiffness component and a damping component. The tooth stiffness is taken into account via the stiffness maps from *Stirak* mentioned above, of which the output values are the occurring forces and torques as a function of the current angular position and the load-caused transmission error of the gear. In contrast, the damping component is included via a speed proportional approach according to Gerber (Ref. 28).

The torque of the drive train and the rotation angles and speeds of input and output drives, gears and measurement systems can be selected as output values. However, the main focus of the software is on the gear mesh and the difference velocity and acceleration in the time and frequency domain. *DynEx1D* also enables variant calculations, taking into account the dynamic excitation behavior, to compare different gear stages and to identify the best variant on the basis of single-number values.

Target values. The evaluation of the variants can be carried out with regard to different target values. As mentioned at the

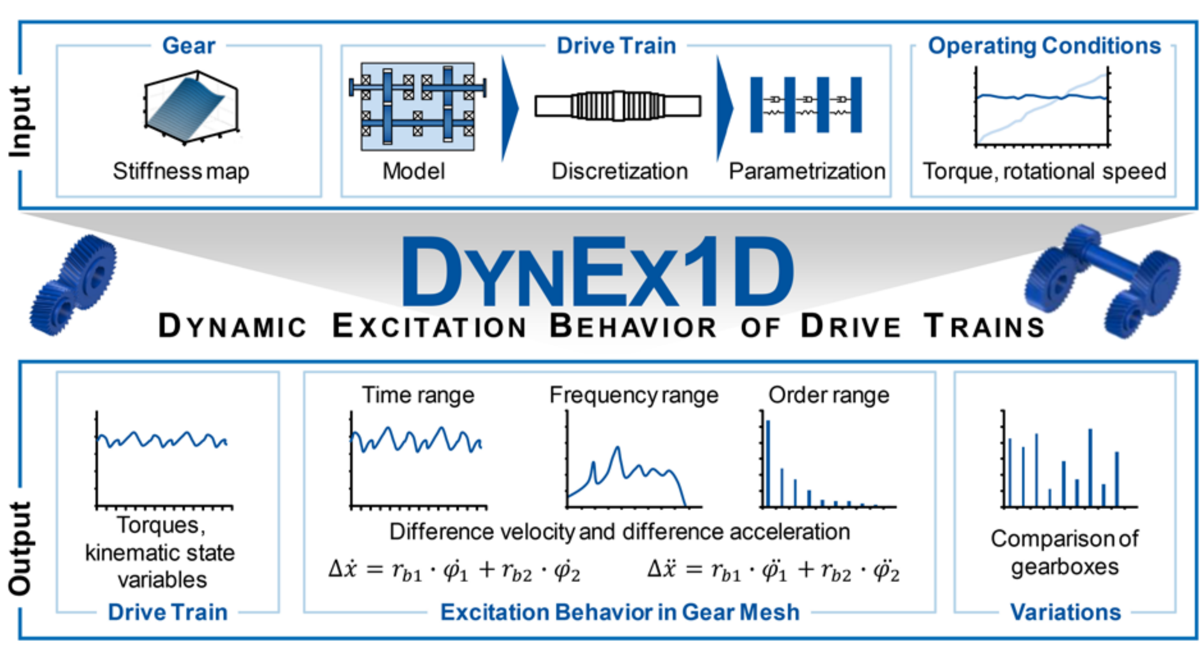


Figure 5 Performance scope of *DynEx1D*.

beginning, sufficient load-carrying capacity and the associated operational safety represent a necessary criterion, which is not included in the quality assessment but is included as a minimum requirement. Instead, the target values considered in the design method can be subdivided according to excitation, efficiency and weight (Fig. 6, bottom right).

The dynamic excitation can be evaluated both on the basis of the total excitation and on the basis of the tonality, according to DIN 45681 (Ref. 3). The total excitation is quantified on the basis of the dynamic simulation results of the difference velocity of the two gear stages.

For this purpose, the averaged order spectra of the speed run-up are determined for each gear stage. The energetically averaged excitation levels are then determined for the first four gear mesh orders of the first stage and the gear mesh orders of the second stage lying within this order range (Fig. 6). The total excitation level results from the energetic averaging of the two stages, so that this single-number value can be used for the evaluation of the total excitation.

The analysis of the tonality according to DIN 45681 allows a statement to be made about the occurrence of tones in the overall noise (Ref. 3). The metric was developed for airborne noise signals. To compare and classify different variants, however, it can also be applied to the difference velocity without comparing the absolute tonality values of the two different physical basic quantities. During the calculation, the total signal is divided into averaging intervals with a duration of $T_{average} = 3$ s and checked whether frequencies emerge and lead to psycho-acoustically perceptible tones.

Efficiency is used as the ratio of output power to input power. The complement to the efficiency is the loss ratio, which is better suited for evaluating and optimizing efficiency in a design method. The losses of a gearbox are dominated by the gear mesh losses (Ref. 29). Therefore, only the load-caused gear losses are taken into account to evaluate the degree of loss and the method of *Schlenk* is used, which is implemented in *Stirak* (Refs. 30, 31).

The last target value is the evaluation according to the gear mass. For the calculation, each gear is assumed to be a cylinder with the tooth width b and the mean diameter d_m, which represents the mean value between the root circle diameter and the tip circle diameter. Steel with a density of $\rho = 7{,}850$ kg/m^3 is assumed as the material. The calculated mass can thus be used as the first indicator for material costs.

In order to consider the various target values in a design method, these must be combined in a target function which can then be used for minimization (Fig. 6). Due to the different physical dimensions and the resulting different orders of magnitude of the individual target quantities, these are initially normalized. Based on preliminary studies, minimum and maximum values are determined for each target quantity and thus dimensionless, standardized target quantities are achieved. The combination of the target values in the target function takes place via weighting factors which are determined before each design process. The minimum of the target function represents the best variant.

Design of Two-Stage Gearboxes for E-Mobility

The method developed in the previous chapter is used in the following to design two-stage gearboxes. The focus is, on the one hand, on the mass, and on the other hand, on the dynamic excitation behavior. The range of the total transmission ratio investigated focuses on the usual transmission ratios in e-mobility and extends for both design objectives between $8 \le i_{total} \le 13$. The drive torque is $M_{in} = 100$ Nm. In each case, 50 iterations of the particle swarm algorithm are performed with a swarm size of 4 particles.

Verification of the model approach on the basis of the design focus mass. In the investigations on the design focus of the gear mass, only the weighting factor of the mass a_{mass}

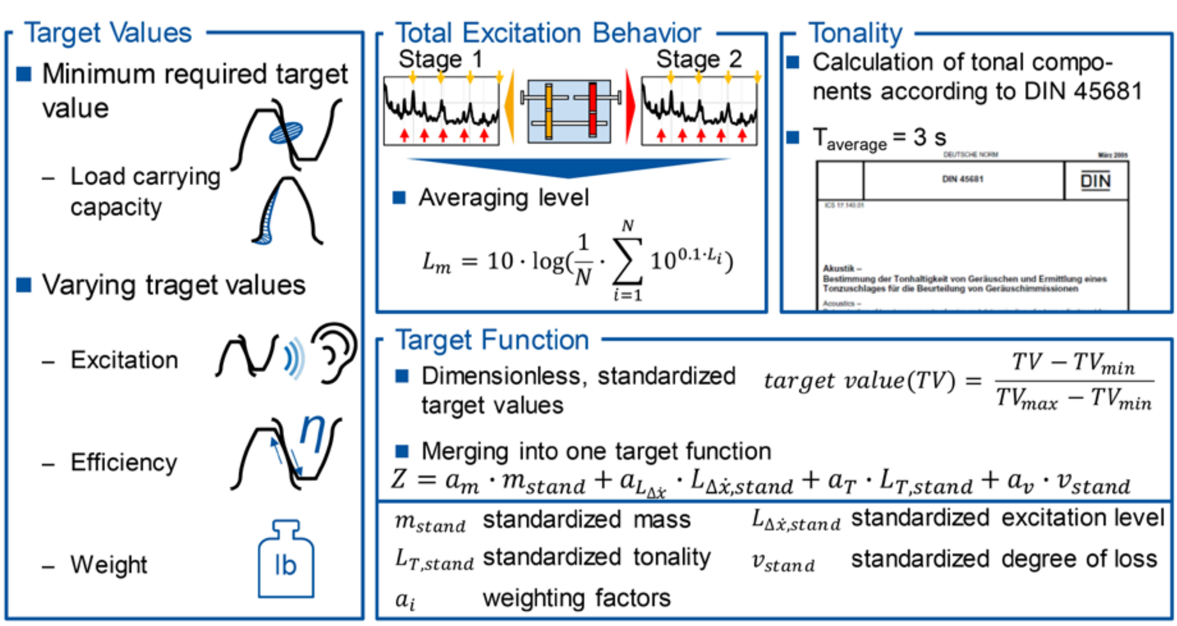


Figure 6 Definition of target values.

is taken into account and thus further target values are neglected. The course of the target value for the exemplary design of a gearbox with the total transmission ratio $i_{total} = 11$ is shown (Fig. 7, top left). The target value aims at the minimum of the target function of $Z = 0.116$. Up to the 12th iteration, strong improvements in the target value can be observed. From iteration 13 on, only slight reductions can be observed and the target function runs against the target value from iteration 34 on.

In the upper-right part of Figure 7, the resulting masses of the designed gearboxes are listed under consideration of the transmission ratio range. As the transmission ratio increases, the mass also increases from $m = 9.4$ kg ($i_{total} = 8$) to $m = 16.4$ kg ($i_{total} = 13$) due to the assembly space required for the larger gears. The resulting transmission ratio distributions are shown in the bottom part of the figure and are compared with the existing transmission ratio distributions according to *Römhild*, Bansemir and Parlow (Refs. 29, 19, 13). In general, all courses show similar tendencies with increasing overall transmission ratio, although there are differences due to different boundary conditions. The results of the method developed in this report are sorted between the curves according to *Römhild* und Bansemir.

Design focus on dynamic excitation behavior. The analysis of the influence of the dynamic excitation behavior in the design process takes place in a speed range between $n_{in} = 300$ rpm and $n_{in} = 12{,}000$ rpm, with a gradient of the speed ramp of $\Delta n_{in}/\Delta t = 390$ rpms^{-1}. Figure 8 shows the target values of gearbox variants with a total transmission ratio of $i_{total} = 11$ and different weighting of the target values; mass and efficiency are always weighted equally. The part of the dynamic excitation behavior is increased consecutively from an equal evaluation of all three target values (V1: $a_{excitation} = 33\%$) to an exclusive focus on the dynamic excitation behavior (V4: $a_{excitation} = 100\%$).

The results for the target variables mass and dynamic excitation level are shown in the upper row of Figure 8. With the increasing importance of excitation behavior, the mass increases continuously from V1 ($m = 20.2$ kg) to V4 ($m = 31.7$ kg). In contrast, the dynamic excitation behavior of both stages can be reduced by focusing on its reduction from V1 ($L = 43.2$ dB) to V4 ($L = 36.4$ dB).

The effect on the gear parameters of variants V1 and V4 is shown in the bottom row of Figure 8. Variant V1, with equally distributed weighting factors, has a transverse contact ratio of $\varepsilon_\alpha = 1.5$ and an integer face contact ratio of ε_β. Due to the lower torque and the high speed, the first stage has a smaller center distance and a smaller module than the output-side second stage. The pressure angle of $\alpha_n = 19°$ represents a compromise with regard to the further target values of efficiency and dynamic excitation behavior. This is also the reason for the ratio of the first stage $i_1 = 2.48$ below the ratio derived in Figure 7 for a minimum mass of $i_1 = 3.6$.

Variant V4 differs from variant V1 in terms of the contact ratios and the transmission ratio distribution. Due to the high acoustic weighting, the variant has a high overall contact ratio ($\varepsilon_{\gamma,1.stage} = 4.2$, $\varepsilon_{\gamma,2.stage} = 3.7$). The high contact ratio leads to reduced dynamic excitation behavior. In addition, the transmission ratio distribution results lead to a low ratio ($i_1 = 2$) of the first stage and to a maximum permissible ratio for one stage ($i_2 = 5.5$) for the second stage. The results confirm the tendencies from the work of *Brecher* et al., in which the annoyance of two-stage gearboxes could be reduced by a very low transmission ratio at the first stage (Ref. 18).

The increase of the mass and the decrease of the dynamic excitation level can mainly be explained by the safety factors. As the weighting of the excitation behavior increases, the safety factors against flank damage increase as well ($S_{H,V1} = 1.4$, $S_{H,V4} = 1.7$) and lead to higher center distances. In addition, a higher safety factor against tooth root fracture

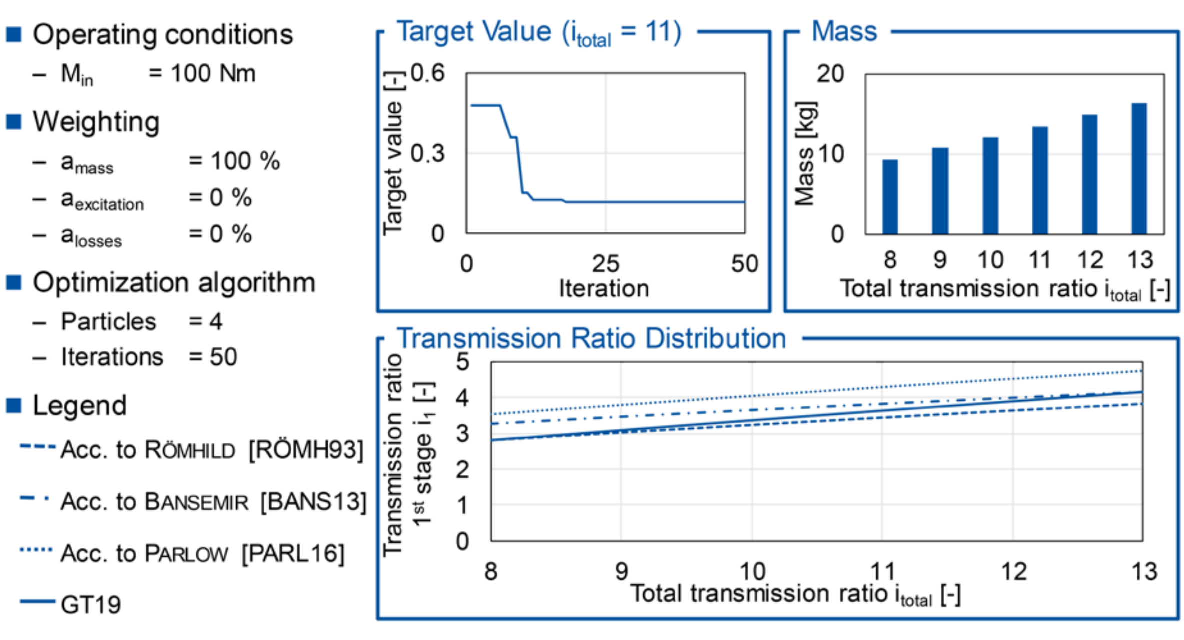
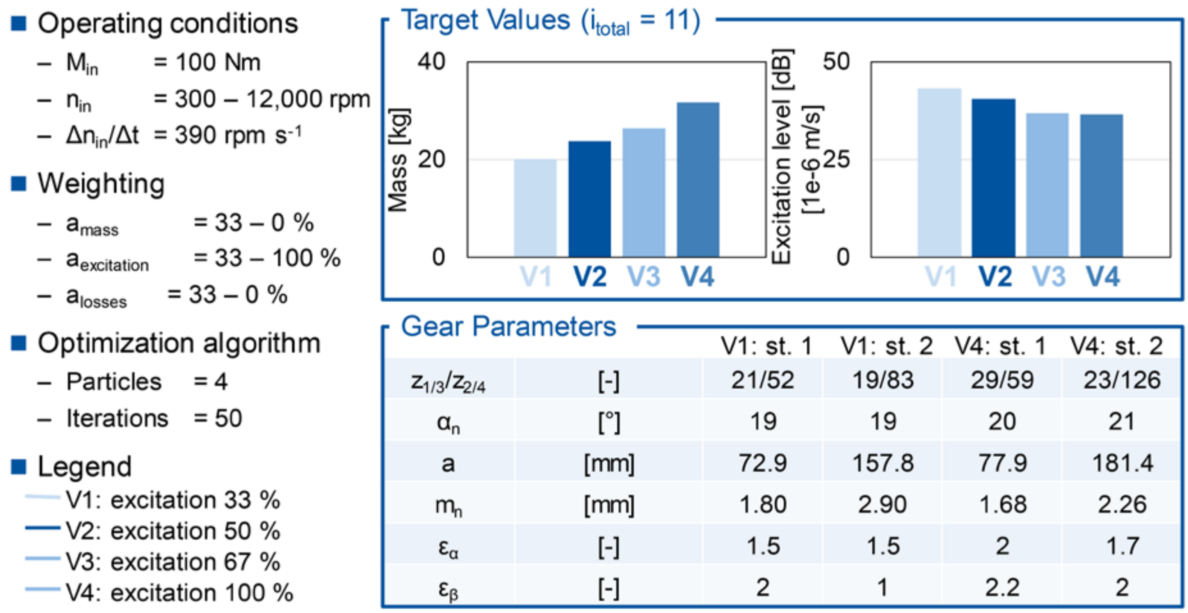


Figure 7 Mass and transmission ratio distribution with design focus mass.



		V1: st. 1	V1: st. 2	V4: st. 1	V4: st. 2
$z_{1/3}/z_{2/4}$	[-]	21/52	19/83	29/59	23/126
α_n	[°]	19	19	20	21
a	[mm]	72.9	157.8	77.9	181.4
m_n	[mm]	1.80	2.90	1.68	2.26
ε_α	[-]	1.5	1.5	2	1.7
ε_β	[-]	2	1	2.2	2

Figure 8 Comparison of target values with design focus dynamic excitation behavior.

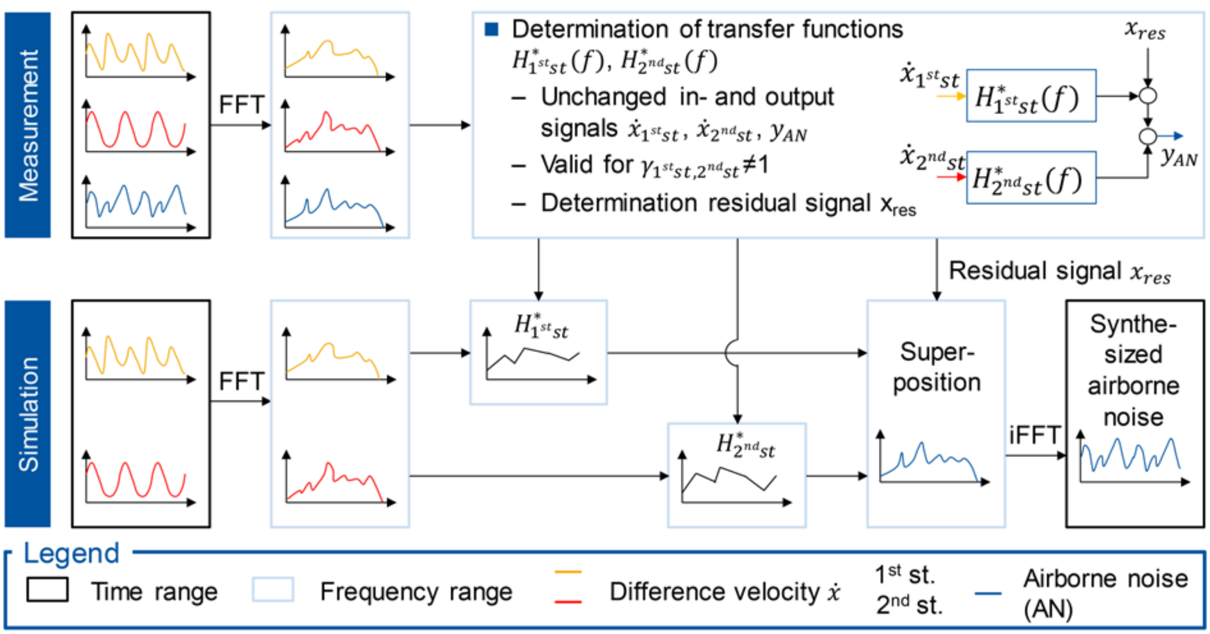


Figure 9 Airborne noise synthesis method.

($S_{FV1}=1.9$, $S_{FV4}=2.2$) leads to a higher module. Both factors lead to a higher gear mass and a reduced excitation level.

Application of the Method to an Existing Gearbox Design

Brecher et al. developed a two-stage prototype gearbox (Refs. 31, 18) for the investigation of the dynamic noise behavior of two-stage gearboxes. Gears designed for single-stage gearboxes were used and therefore did not take any interactions between the gear stages into account. Various measurement techniques were applied to the test setup to characterize the noise source and the receiver. The difference acceleration (custom-made tangential acceleration measurement systems from datatel Telemetry) was selected as the measurement variable for identifying the excitation source in the gear mesh; the signal was determined for each gear stage separately. The difference velocity corresponds to the integrated difference acceleration and was used for further evaluations due to the good agreement with airborne noise (Ref, 32). The characterization of the noise receiver is represented by the airborne noise recorded by microphones (free field microphones 4189A021 from Brüel Kjær).

In the following, a method for the synthesis of airborne noise signals based on calculated simulation results from *DynEx1D* will be developed and validated on the basis of measurement results. The airborne noise synthesis is then integrated into the design method which has been introduced previously. Based on this, optimized gears with regard to dynamic noise behavior and interactions between the gear stages are designed and compared with the initial variant.

Airborne noise synthesis method. For the analysis of the relationship between gear excitation and emitted airborne noise, a signal theoretical approach according to *Bendat* was used (Ref. 33). On the one hand, the objective is the mathematical description of the gearbox behavior, as well as the division of the total airborne noise into gear-independent and dependent noise components. With the separated signal components, synthetic airborne noise characteristics can be calculated on the basis of the difference in velocities determined with *DynEx1D*; the procedure is described in Figure 9.

First, the measured difference velocities of both stages and the recorded airborne noise at a microphone are transformed into the frequency domain. The transfer functions $H_{1.st}$ $H_{2.st}$ for a system with two inputs and one output can be determined using signal-theoretical equations. The residual noise x_{res} independent of the gear mesh can be determined by using the inputs and outputs and the determined transfer functions. Difference velocity signals also are the basis for the simulation side. After the transformation into the frequency domain, the transfer functions determined from the experiment are applied to the input signals. The components of the two gear stages are superposed with the remaining signal and transformed back into the time domain.

For a comparison between measurement and simulation, the excitation in gear mesh was evaluated using the difference velocity level of the two stages. The results of the calculated and experimental speed run-up are shown (Fig. 10). The left side of the figure shows the results of the drive-side first stage, the right side shows the second stage (output-side). In the psycho-acoustically relevant frequency range between $f = 500$ Hz and $f = 5{,}000$ Hz, high conformity between measurement and simulation can be determined. This is shown, for example, by the peak at $f = 1{,}250$ Hz, which dominates the spectrum. Comparing the difference velocities of the second stage measured at the output-side, the characteristic excitation curve is also depicted here by the simulation. Only in the frequency range between $f = 1$ kHz and $f = 1.7$ kHz is there a slightly increased excitation in the simulation.

The method for airborne noise synthesis described in Figure 9 was applied to the simulated difference velocity. The results of the synthesized airborne noise are shown in the lower part of Figure 10, as averaged frequency spectrum and averaged order spectrum. The comparison between simulation and experiment provides a high agreement over the entire frequency range. Only in the frequency range between $f = 1$–1.7 kHz is the synthesized airborne noise slightly overestimated. This can be explained by the deviations of the difference in velocity of the second stage in the same frequency range. With regard to the order spectrum, a high conformity between measurement and simulation can be determined. Due to the considered residual signal, which is not caused by the gear mesh, the areas between the gear mesh orders are also simulated with the correct level. Similar to the analyses of the difference velocity, the gear mesh orders are slightly overestimated in the simulation.

In summary, for the simulation chain consisting of a multibody simulation model and airborne noise synthesis, a high consistency for the depiction of excitation and noise behavior can be determined. In the following, the simulation chain can be used to improve the resulting noise behavior.

Improvement of an existing gearbox design. In the investigations on the dynamic operational behavior of two-stage gearboxes of *Brecher* et al., the same gear set was used on both stages (Refs. 30, 18). This reference gear set has a center distance of $a = 112.5$ mm and a transmission ratio of $i = 1.44$ ($z_{1/2} = 25/36$). Since this gear set was designed for quasi-static, acoustic investigations on single-stage gearboxes, no dynamic interactions between the gear stages were taken into

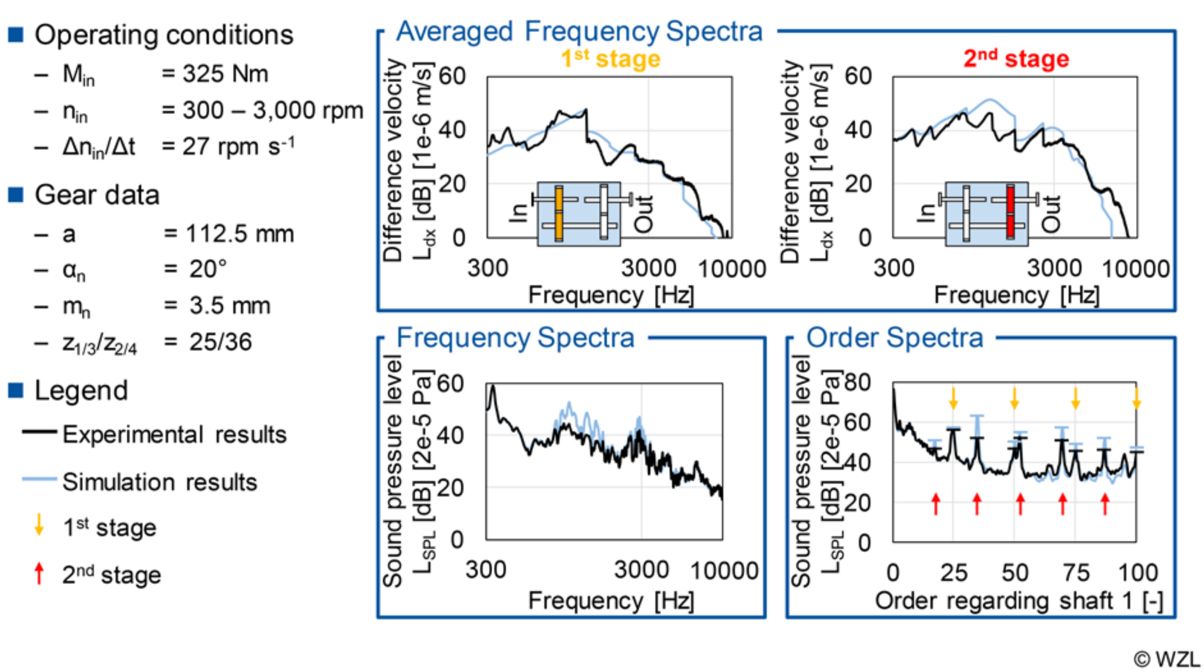


Figure 10 Validation of the method.

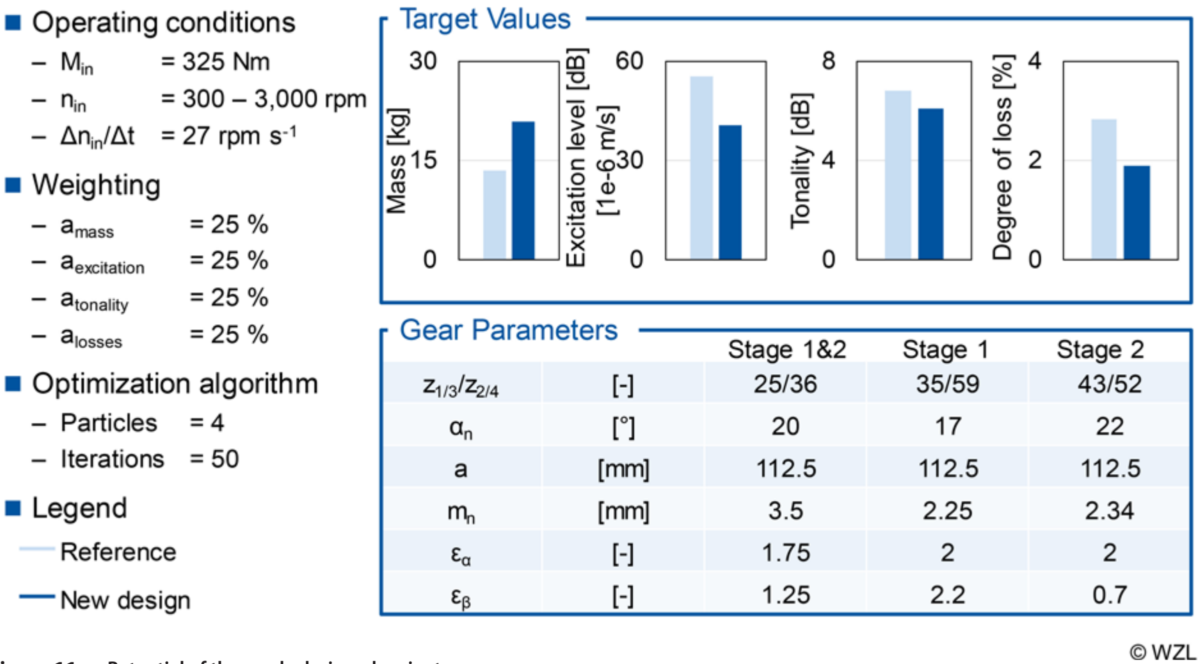


Figure 11 Potential of the newly designed variant.

account, thus a new design offers high potential for acoustic improvement.

In order to enable direct comparability with the reference gear set, the center distance $a = 112.5$ mm is specified as a boundary condition in both stages. Following the investigations of *Brecher* et al., the same operating conditions are selected ($M_{in} = 325$ Nm, $n_{in} = 300$–3,000 rpm, $\Delta n_{in}/\Delta t = 27$ rpms-1) (Refs. 30, 18). As target values the mass, the dynamic excitation behavior, the tonality based on the synthesized airborne noise and the degree of loss are considered — all of which are equally weighted.

The comparison between the reference and the newly designed gearbox is shown (Fig. 11, in the top line) in the top line. This shows that the newly designed variant is only for the target value mass worse than the reference. Considering the other three categories, an improvement can be achieved by the new design. This applies in particular to the target values of dynamic excitation levels and tonality, which include the interactions between the gear stages. The tonality of the new design can be reduced by the coordinated selection of the number of teeth.

Summary and Outlook

The hybridization and electrification of the drive train have increased the importance of the dynamic excitation and noise behavior of two-stage gearboxes. Consequently, the objective in gear design is to predict the excitation behavior of the gear mesh as accurately as possible at an early design phase by means of frontloading. Due to the high drive speeds present in e-mobility, the dynamic excitation behavior is dominated by the gear mesh frequencies in wide frequency ranges. In gear design, however, quasi-static methods are frequently used which focus on individual stages and neglect interactions between the stages. In addition, the dynamic operational behavior and thus, possible increased excitations by coincidence of excitation and system resonance cannot be considered.

Therefore, the objective of this report is to consider dynamic excitation effects in the gear design of two-stage gearboxes for e-mobility. The first step is to develop a method that combines macrogeometric gear design with the simulation of dynamic excitation behavior. The *DynEx1D* simulation software is used to evaluate the dynamic excitation behavior. A particle swarm algorithm is used to reduce the computing time. The evaluation of the variants is based on different target values with focus on the dynamic excitation level.

The method is then used to design gearboxes for e-mobility. For this purpose, a transmission ratio range between $8 \leq i_{total} \leq 13$ and a drive speed up to $n_{in} = 12{,}000$ rpm is investigated. With a focus on the target value mass, comparable recommendations known from the literature can be made for the transmission ratio distribution. With a focus on the dynamic excitation behavior, an improvement and thus a reduction of the gear excitation leads to an increase in the drive mass. Furthermore, the ratio of the first stage i_1 decreases with the increasing importance of excitation behavior. In order to consider the tonality of an existing gearbox, the method is extended by airborne noise synthesis using an experimentally determined transfer function. The newly designed variant shows the acoustic potential in which tonality and dynamic excitation level could be reduced.

In the future, further target values are to be considered in the design process that focus on the dynamic interactions between the stages. Axial force vibrations can be reduced by a targeted design of the axial forces at the intermediate shaft. Finally, the consonance and dissonance effects known from music theory can be transferred to two-stage gearboxes.

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Gear Research Circle for the development of the dynamic multi-body simulation software *DynEx1D*. **PTE**

For more information.

Questions or comments regarding this paper?
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Marius Schroers, M.Sc., studied mechanical engineering at RWTH Aachen University until 2015. Since then, he has been working as a research assistant, first in the group "Gear Design and Manufacturing Simulation," and since 2019 in the newly founded group "Gear Acoustics" in the Gear Department of the Laboratory of Machine Tools and Production Engineering (WZL). His research activities focus on the dynamic behavior of multi-stage gearboxes and the correlation between excitation, noise radiation and the perception-related evaluation of gearbox noise.

Prof. Dr.-Ing. Christian Brecher has since January 2004 been Ordinary Professor for Machine Tools at the Laboratory for Machine Tools and Production Engineering (WZL) of the RWTH Aachen, as well as Director of the Department for Production Machines at the Fraunhofer Institute for Production Technology IPT. Upon finishing his academic studies in mechanical engineering, Brecher started his professional career first as a research assistant and later as team leader in the department for machine investigation and evaluation at the WZL. From 1999 to April 2001, he was responsible for the department of machine tools in his capacity as a Senior Engineer. After a short spell as a consultant in the aviation industry, Professor Brecher was appointed in August 2001 as the Director for Development at the DS Technologie Werkzeugmaschinenbau GmbH, Mönchengladbach, where he was responsible for construction and development until December 2003. Brecher has received numerous honors and awards, including the Springorum Commemorative Coin; the Borchers Medal of the RWTH Aachen; the Scholarship Award of the Association of German Tool Manufacturers (Verein Deutscher Werkzeugmaschinenfabriken VDW); and the Otto Kienzle Memorial Coin of the Scientific Society for Production Technology (Wissenschaftliche Gesellschaft für Produktionstechnik WGP).

Dr.-Ing. Dipl.-Wirt.-Ing. Christoph Löpenhaus is working as Business Development Manager at Cerobear GmbH, Herzogenrath, Germany, since 2019. From 2014 to 2019, he served as Chief Engineer in the Gear Department of Laboratory for Machine Tools and Production Engineering WZL of RWTH Aachen.

Timken

LAUNCHES SOLAR AND WIND ENERGY INVESTMENTS

The Timken Company recently announced more than $75 million in capital investments through early 2022 to increase the company's renewable energy capabilities across its global footprint.

"This has been a breakout year for us in renewable energy markets," said Richard G. Kyle, Timken president and chief executive officer. "Through both innovation and acquisitions over the last several years, we've become a leading supplier and technology partner in wind and solar energy and it's resulting in record sales and a robust pipeline of opportunities. This latest round of investments represents our confidence in the future growth of our wind and solar business as the world continues to transition to renewable energy sources."

To serve Timken's global renewable energy customers, the company has developed an extensive network of engineering and innovation centers and manufacturing facilities located throughout the U.S., Europe and Asia. Timken will use the announced $75 million investment to:

- *Expand its state-of-the-art and LEED-certified manufacturing facility in Xiangtan, China, where it makes engineered bearings for wind turbines.*
- *Continue to scale-up its production capacity at sites in Wuxi, China, and Ploiesti, Romania, where Timken manufactures engineered bearings for wind turbines.*
- *Consolidate multiple sites into a new, larger campus in Jiangyin, China, to increase production capacity, broaden the product range and improve productivity for precision drives used in the solar energy market.*
- *All of the above investments will include advanced automation and manufacturing technologies.*
- *Timken's wind energy product portfolio includes engineered bearings, lubrication systems, couplings and more.*
- *Timken has been active in the wind market for more than 10 years and is now a critical design and manufacturing partner to many of the world's largest turbine and drive manufacturers.*

Timken's 2018 acquisition of Cone Drive launched the company's leading position in the solar energy sector. Timken develops and manufactures precision motion control products that provide solar-tracking system positioning for both photovoltaic (PV) and concentrated solar power (CSP) applications.

"Timken is known throughout the world for our ability to solve our customers' most difficult friction management and power transmission challenges, and that includes deploying our advanced engineering and manufacturing technologies to help produce the world's most efficient and reliable wind turbines and solar energy systems," Kyle said. "By continuing to invest and advance our technology, Timken will help the renewable energy industry improve efficiency, reduce cost and promote the growth of solar and wind energy sources."

www.timken.com

WBA

LEADS FIGHT AGAINST COUNTERFEIT BEARINGS WITH MOBILE APP

The World Bearing Association (WBA) a non-profit organization serving the public interest, announces the release of a new app, the WBA Bearing Authenticator, to help combat counterfeit bearings. The WBA, its member manufacturers and associations worked with oneIDentity+ to develop the WBA Bearing Authenticator, which is now available on the Google Play and Apple App Store for free download.

The WBA app allows bearing customers, distributors, and customs officials to scan a QR or DMC code on the bearing packaging to identify whether that code is correct and known in the manufacturer's database.

The WBA and its members have been fighting counterfeit products for years, working with customs officials worldwide to help identify and seize counterfeit products. The WBA is made up of three bearing manufacturing associations: JBIA representing Japanese manufacturers, FEBMA representing European manufacturers, and ABMA representing manufacturers in the United States.

ABMA American Bearing Manufacturers Association

"The app is a proactive approach to help customers and distributors to avoid selling and using counterfeit bearings. Counterfeit bearings pose a significant safety risk to bearing users and their operation, and the WBA is dedicated to making sure that customers are not cheated with counterfeit bearing products," said Alrik Danielson, president and chief executive officer of AB SKF, and president of the World Bearing Association.

The bearings industry alone loses billions of dollars to counterfeit goods every year. But what is most alarming, is that these counterfeit products can be detrimental to the safety of end users.

How Does it Work?

The WBA Bearing Authenticator app can be downloaded onto any mobile device via the Google Play or Apple App Store. Once downloaded, the WBA Bearing Authenticator app allows the user to scan a QR/DMC code on the bearings packaging. The app gives an indication of authenticity of a given bearing product by checking to see whether the QR/DMC is registered as a valid product code in a participating company's database and was not checked too many times.

The app then provides an indication of whether the code on the product is a correct code with one of three symbols:

- A green checkmark if the code is correct and is in the manufacturer's database;
- A yellow exclamation point if the code is correct but has been scanned too many times, which indicates that the user should contact the manufacturer to determine authenticity; or
- A red alarm symbol if the code is incorrect. The red symbol indicates the product is suspected fake and the user should contact the manufacturer for more information.

It is always recommended by the WBA and the manufacturers, that if there is no code, or the authenticity is in question, you should contact the manufacturer to be sure. Customers can easily reach out to the manufacturer directly to ask questions about the authenticity of the product directly through the app. The WBA Bearing Authenticator is currently supported by the leading international manufacturers -- JTEKT (Koyo), NACHI, NTN, NSK, Schaeffler, SKF, and Timken.

www.stopfakebearings.com

Bonfiglioli

LAUNCHES E-COMMERCE WEBSITE

In a major announcement that moves the industrial gearmotor manufacturing industry forward, international gearmotors/power transmission manufacturer Bonfiglioli recently launched its new Online Shop. The first of its kind in the power transmission industry, this e-commerce platform allows distributors OEMs and customers to research, configure, and order gearboxes and gearmotors with a variety of payment options and zero barriers to managing orders. Online chat provides live technical product assistance and support. The Shop's powerful, user-friendly interface allows users to quickly and efficiently:

- Research product specifications;
- Configure systems; easy-to-use platform

- Determine product availability;
- Updated, real-time shipping and delivery options;
- Connect with engineering resources;
- Schedule and manage deliveries;
- E-payment options
- Live chat

"The B2B digital commerce market is $12.2 trillion and growing," said Bonfiglioli North America CEO, Greg Schulte. "We are excited to introduce our new digital platform which is taking our company to the next level. Providing our customers with a true e-commerce experience, the Online Shop is a huge opportunity for our customers, providing accessibility and convenience, along with real-time support. Our product eliminates many supply chain and application engineering inefficiencies. Backed by major investment and facility expansion in the North American market, today's announcement of the revolutionary Online Shop platform is the next step towards the future of manufacturing in our industry," said Schulte.

Schulte describes the features and benefits to the customers: "The configuration tool guides the customer in real-time as to which selections have high availability or significant price differences. The customer is in control of the entire process, from beginning to delivery, all without having to speak with a sales or customer service representative. Our staff is available to help at any point through the live chat feature; or we can be reached using traditional means, like phone or email."

Earlier this year, Bonfiglioli opened its new 75,000 sq. ft. manufacturing space expansion at its North American headquarters. The $5.2 million building expansion nearly doubled the size of the Hebron headquarters facility, meeting the space needs of the growing organization. Bonfiglioli is currently producing four times the volume of business compared to when their North American headquarters opened in Hebron in 2007.

Italian-based Bonfiglioli moved its Northern American headquarters to Northern Kentucky near the Cincinnati/Northern Kentucky International Airport (CVG) in 2007. A geographical logistics powerhouse, the Northern Kentucky/CVG region is within 600 miles of 65% of the United States population; making distribution and commerce ideal for serving the Northern American market.

Since then, the company has grown its North American presence and has more than doubled the number of employees. In recent months, the North American headquarters has shifted its focus from primarily assembly and distribution of gearmotors to manufacturing which improves the supply chain by reducing lead times and provides more responsiveness for North American customers. Serving more industries and applications than any other drive manufacturer, Bonfiglioli North America's full-service facility has grown steadily over the past 20 years, where the revenue is now 50 times more than it was just 15 year ago. Market sectors include construction, food/beverage/tobacco, packaging, material handling, water treatment, agriculture, earth moving, biogas, drilling, metal processing, recycling, wind, mining, forestry, wood processing, textile, biogas and marine & offshore drilling.

shop.bonfiglioli.com/store/?site=bonfigliolib2c

Innovative Rack and Gear

MERGES WITH AVERS MACHINE AND GEAR

For 25 years, Innovative Rack and Gear, located in Wood Dale, Illinois, has developed a solid reputation for quality and service. The company recently announced that it has become a part of Avers Machine & Gear.

INNOVATIVE RACK & GEAR CELEBRATING 25 YEARS

We Help You Move the World

Avers Machine and Gear, located in Schiller Park, Illinois, is a full-service 5-axis machine shop with gear manufacturing capabilities that serves the needs of companies across the United States and around the world.

Innovative Rack and Gear manufactures a wide variety of custom commercial and precision, high quality gear racks for the machine tool, automation, construction, mining, oil, gas, offshore, steel, healthcare, precision instrument, aerospace, and defense industries among others.

"Through the synergies and skilled craftsmen of both world class companies, we will continue to provide the quality gear racks many have come to expect, in addition to a wide variety of gearing and machining capabilities. Uncompromised quality, focused customer service and unrivaled attention to detail will continue to be the cornerstone of the service that we provide to all our customers," said Zen Cichon, president of Innovative Rack and Gear.

www.aversmachine.com
www.gearacks.com

AVERS MACHINE AND GEAR

Heidenhain

OPENS ACU-RITE TECHNOLOGY EDUCATION CENTER

Continuing to emphasize its Customer First initiative during these uncertain times, Heidenhain announces the opening of a new ACU-RITE Technology Education Center in the Chicago suburbs. This new ACU-RITE Technology Education Center (ATEC) is now open with the promise of providing special support to its North American customers and prospects with direct access to see and use all its current popular ACU-RITE machine tool components, as well as the ability to call upon its expert trainers.

Now, by appointment and with safety/cleaning protocols in place, special access can be granted to view and test all ACU-RITE's full line of current products, including its popular controls, digital readouts (DROs), encoders and accessories as applied to various machine tools in many instances. Machine tools currently hosted at ATEC include ACU-RITE's three-axis MILLPWRG2 control system on a vertical knee mill and two-axis TURNPWR control on a tool room lathe, all fully functional.

"We understand the importance of supporting North American manufacturing, maybe more so now than ever before," said John Parker, Heidenhain's business development manager for the ACU-RITE brand. "We believe it is our job to help machinists best equip their shop with the top tools and tips to move jobs through their systems quickly and most accurately. And ACU-RITE machine tool components and experts are here to help make that happen. ATEC is just one more instrument of support."

Custom training sessions can now be arranged at ATEC in Schaumburg, IL, as well as private meetings to review product options and discuss specific application needs. Those interested in a visit to this new technology center can contact any of the Heidenhain/ACU-RITE regional sales managers via the ACU-RITE website or Parker for a personal or small group appointment. Standard training sessions are listed on website. Due to current COVID-19, CDC protocols must be followed.

acu-rite.com/support/

Oelheld

APPOINTS LOWERY AS EXECUTIVE VICE PRESIDENT

Oelheld U.S., Inc. in West Dundee, Illinois, has appointed **Steven Lowery** as Executive Vice President, effective December 1, 2020. Steven has 30+ years of manufacturing and management experience in the metalworking industry. He will lead the Oelheld U.S. team in providing industry-leading metalworking fluids developed using the latest technology and following the firm's guiding principle of HUTEC — Human-Technology for Man, Nature and Machine.

Oelheld GmbH has provided innovative fluid technology for more than 130 years by constantly working on setting new standards with our products, developed through research and development in cooperation with universities, machine manufacturers, and customers to always offer the optimal lubricant solutions

www.oelheld.com

Motion Industries

ANNOUNCES CEO OF THE YEAR AWARD FOR RANDY BREAUX

Motion Industries, Inc. recently announced that **Randy Breaux**, Motion Industries president, is a 2020 award recipient of CEO of the Year, from the Birmingham Business Journal. The presentation honored winners and finalists — elite leaders from a range of industries — at a virtual event December 3.

The CEO Awards recognize excellence among top executives in the Birmingham metro area for businesses of all sizes. Breaux was named CEO of the Year in the category of Companies with more than 300 Employees.

Breaux has four decades of experience in the industrial manufacturing and distribution markets. Previous to becoming the company's president in December 2018, he played a key role in setting corporate strategy, key acquisitions, growing supplier relationships, advancing marketing activities and overseeing corporate operations, as executive vice president. He joined Motion Industries in May 2011 following 21 years with ABB/Baldor Electric Company, a leading manufacturer of industrial electric motors, drives, and mechanical power transmission components, based in Fort Smith, Arkansas.

Breaux currently serves on several nonprofit boards in the Birmingham area. He has held committee and board positions in numerous industry associations, including past chairperson of the manufacturing council for the Power Transmission Distributors Association.

Motionindustries.com

NTN

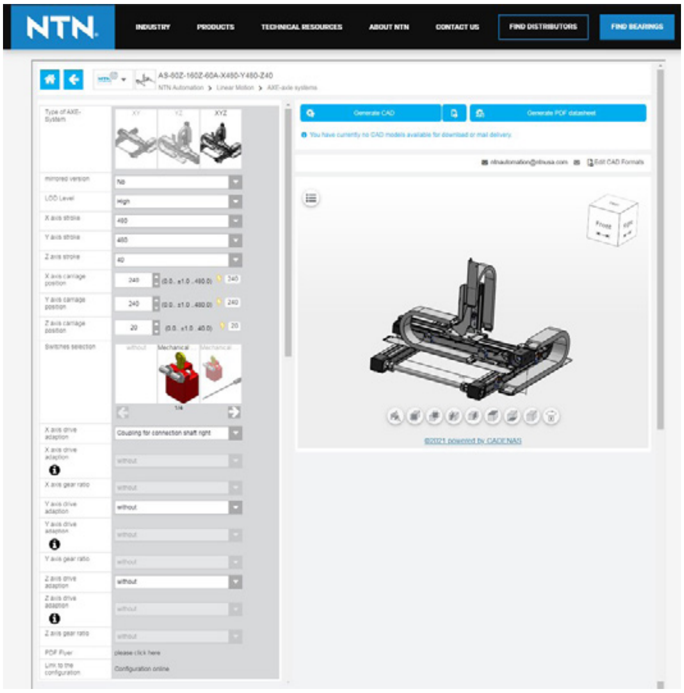
LAUNCHES 3D MODELING AND LINEAR CONFIGURATOR TOOLS

NTN Bearing Corporation of America is pleased to announce the launch of three web-based tools for its NTN Automation division. This suite of interactive tools was recently launched to coincide with the roll-out of the new NTN Americas website in January 2021. These all-new NTN Automation tools include a 3D Linear Modeling & Configuration Tool, a Linear Guide Configurator Tool, and a Linear Guide Interchange Tool.

"The development and implementation of these powerful tools is a milestone in the evolution of the NTN Automation business unit," said Jim Mangan, vice president, NTN Automation, "These three tools represent a major value-add to our customer base as they research, configure and specify components for their custom linear motion systems, and we expect to see increased adoption of these tools as NTN Automation continues to grow."

The 3D Linear Modeling & Configuration Tool allows users to conduct an in-depth search of linear axis, linear guide, or bushing and shafting components, as well as our AXE series of linear axis modules. This configuration tool guides users to specify options for each component or module as they build a custom solution that fits their specific application. .

ntnamericas.com/technical-resources/linear-modeling-configurator/



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Highly Sophisticated War Machines are Tilling New Battleground

Jack McGuinn, Senior Editor

A common if not somewhat cynical reference to our nation's array of military capabilities is thinking of it as a "toy box." And of course if you're going to have a toy box you have to have toys for it.

And holy Pinocchio, do we have toys. Some question the need for so many playthings; some, like the DOD, question why we don't have more.

But without delving into which side of the argument one chooses, what follows are some examples of the technical wizardry that helps keep us safe. What's more, much like NASA, some of these mechanical monsters will one day be reworked for civilian use. Let's take a look.

WildCat Robot

First up—the WildCat Robot from Boston Robotics. It can "run across any type of terrain, since its main purpose is either a cargo-carrying unit or an intelligence-carrying unit." For example, sand dunes pose no obstacle to this leggy warrior. Always in continuing improvement mode, the WildCat currently travels at about 16-25 mph on flat terrain—using a bounding and galloping gait. Imagine a squad of these guys coming at you with no place to run. While this iteration is not a killing machine, gathering enemy intelligence can lead to dire results for the bad guys.

Arquus Scarabee Armored Vehicle (pictured)

Manufactured by a Volvo subsidiary, this tongue-twister debuted at the 2019 Paris Air Show. It's considered a light-armored vehicle that commissioned for service as early as this year. The Scarabee boasts a hybrid drive with ICE (Internal Combustion Engine) and electric motors that provide silent, fully electric operation on missions requiring stealth or long-term reconnaissance. It has a payload rating of 4,000 pounds and remote control capabilities. It weighs in at about 6+ tons, and is powered by a 300-hp diesel engine and an electric 103-hp motor. Lastly, the Scarabee (that's French for beetle, by the way) has an all-wheel steering system that is used for crab-walking across terrain when needed.

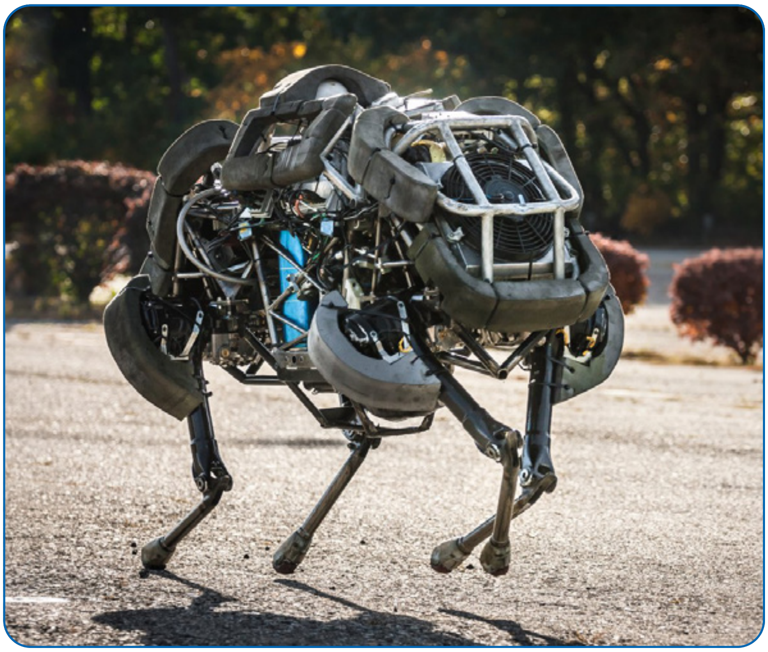
Army Rotorcraft Technology

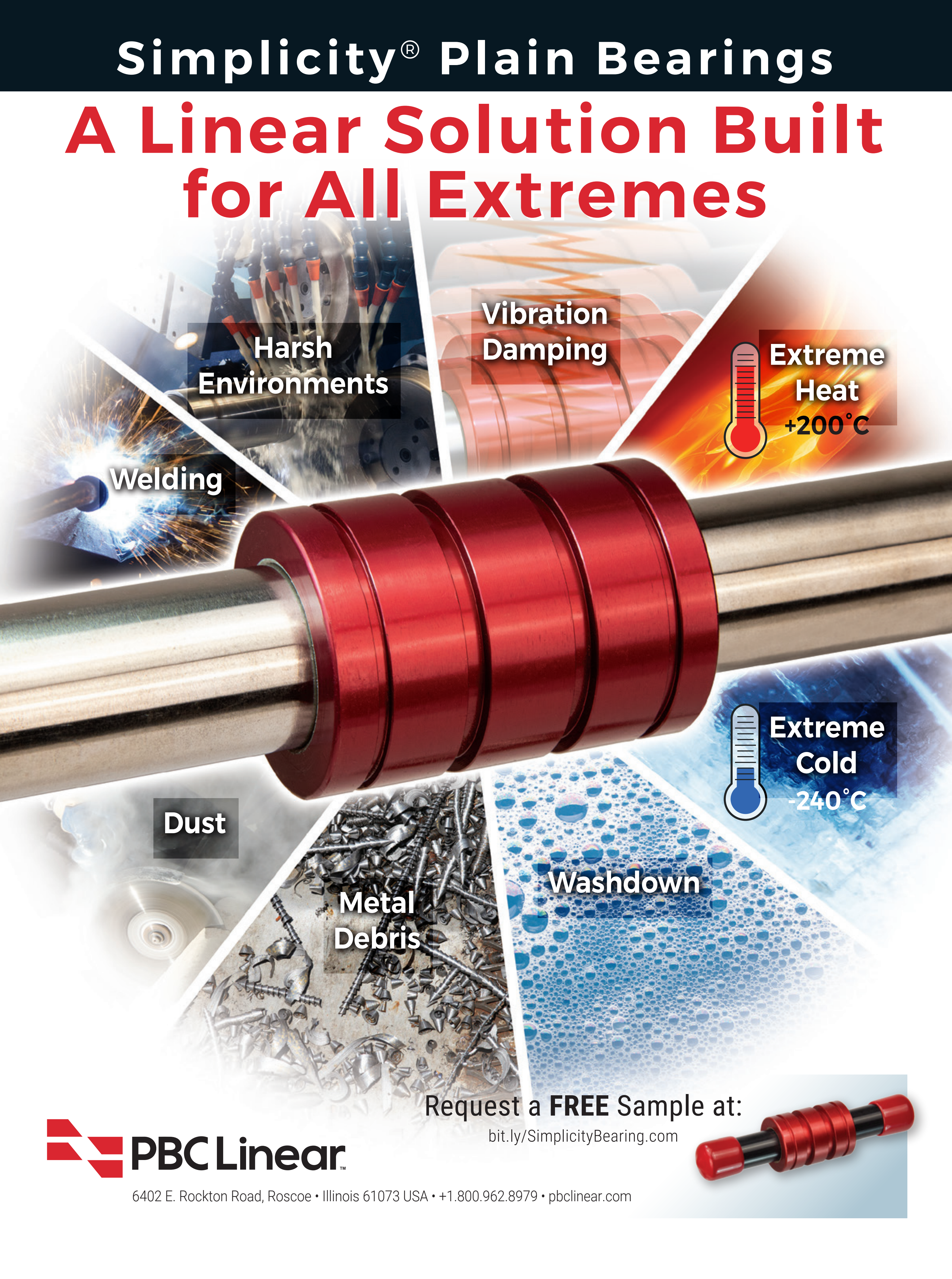
Currently in various phases of testing, combat-resistant rotorcraft is another "martial arts" creation. For instance, its coaxial, co-rotating rotors are intended to result in quieter hovering, a feature that any combat soldier—or enemy—can appreciate. "The purpose of this program is to generate some limited ballistic data that could reduce risk and/or encourage future vertical lift designers to consider CTEF technology," said Brian G. Smith, ARL-SLAD (Army Research Lab/Survivability/Lethality Analysis) aviation analysis team leader. What's more, the Army consider helicopter noise reduction technology a top priority in future rotorcraft design. (An unforeseen benefit: Imagine a future president heading for Marine One, pretending he can't hear questions being screamed at him by reporters.)

Ro-Battle Unmanned Ground Vehicle

This workhorse is designed to undertake certain tasks otherwise done by infantry soldiers, such as convoy protection, armed reconnaissance and others. It moves on six wheels, but these can be replaced with tracks. The robot is capable of traversing uneven terrain and going over some obstacles such as low walls. Robattle's modularity allows it to be fitted with robotic arms, radars and weapons, allowing it to engage in combat. As such, sensitive systems in the Ro-Battle are redundant to allow it to operate after taking damage. The vehicle weighs 7 tons and has the capability of carrying up to 3 tons and communicates using 4G cellular technology.

This has just been a glimpse of the developed and under-development equipment being commissione3d by the military, with price tags in the millions. But there's one aspect to many of these battle machines that cannot be minimized—they are primarily *unmanned* machines of war. The irony is that while these are highly sophisticated, lethal "war toys," the fact that they are unmanned can at least help in reducing body counts. **PTE**





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