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TECHNICAL ARTICLES

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Power Transmission Engineering
VOL. 12, NO. 6

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www.powertransmission.com/news/9085/CTI-Symposium-Germany/

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See the latest white papers from leading suppliers in the power transmission industry. Recent topics include lubrication, rack-and-pinion reducers, hub fasteners, conveyor bearings and speed reducers.

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Randy Stott, Managing Editor

Purchasing Efficiency

You may have noticed a lot of merger and acquisition activity lately in the power transmission industry. In this issue alone, we're reporting Dana's plans to acquire Oerlikon Drive Systems; Timken's purchase of Cone Drive and Rollon, and SKF's plans to sell its linear motion division to Triton Partners (see *Industry News*, page 50).

Earlier this year we've seen other large deals as well. Rexnord purchased Centa Power Transmission. ABB Purchased B&R Automation, Altra Industrial Motion announced it would be merging its business with the motion control portfolio of Fortive (including Kollmorgen, Portescap & Thomson); Sumitomo Heavy Industries announced the acquisition of the Lafert Group. SEW-Eurodrive and GE's Automation and Industrial Controls business announced a partnership wherein they're going to sell each other's products.

And those are just the highlights. It's been a busy year in our industry.

So what does it all mean?

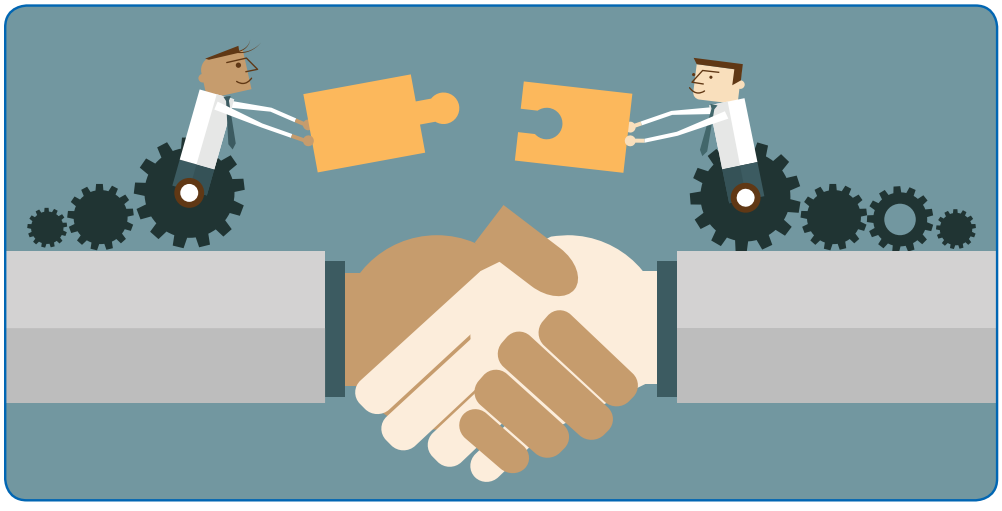
Often, in bad economic times, poorly performing companies get scooped up by larger competitors at bargain prices. But that's *not* what's happening here. Manufacturing is booming, and none of the acquired businesses appears to have been suffering. In fact, in every case that we've seen, these corporate moves are being viewed as additive to each organization's overall offerings and business.

In many ways, this is good news for you, the buyers of mechanical power transmission and motion control products. It's clearly more efficient for you if you can deal with fewer suppliers—but only if those suppliers maintain the level of expertise you require, and only if fewer suppliers don't automatically mean higher prices.

The supplier base for power transmission components and systems has traditionally been very diverse, and it remains so today, despite the fact that the big seem to keep getting bigger. There are still thousands of companies manufacturing gears, gear drives, electric motors, couplings, belts, clutches, brakes and the like, many of them specializing in specific industries or groups of industries, and many of whom have unique technologies or expertise.

Developing relationships with all of those suppliers is a lot of work. In some cases, that work is justified. For example, if a geared transmission is critical to your product's success, you're probably not ordering gears from a catalog. You need a custom gear manufacturer, and you need to find one you can trust. Other times, though, a standard gearbox is just fine, and if you can get that gearbox from the same place you order your bearings or electric motors, you're more efficient. That's why industrial distributors like Grainger, Motion Industries and Kaman have long been such a large part of the power transmission industry.

What I think is best about many of these high-profile consolidations is that we're seeing a concentration of expertise *among* experts. The big aren't just getting bigger. They're getting better. Hopefully this makes your job easier. Let me know what *you* think at *wrs@powertransmission.com*.



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Kyntronics

DELIVERS SMART ACTUATION WITH COMPACT, ENERGY-EFFICIENT SYSTEM

The actuation market is projected to grow from an estimated $38 billion in 2017 to $49 billion by 2022. Given this growth trajectory, the focus is moving away from traditional actuation options that have a myriad of cumbersome deficiencies to more streamlined innovative solutions that provide higher efficiency (lower costs), increased uptime, and integrated-simple connectivity.

The goal is to take advantage of enhanced technologies that can achieve higher efficiencies via factors such as less maintenance, advanced connectivity (field buses), lower weight, compact footprint, accuracy, and energy efficiency.

In response to the customer demand for these actuation efficiency goals, Kyntronics (Cleveland, Ohio), has developed its patent-pending SMART Hydraulic Actuator (SHA) –a development in 'power-on-demand', servo-controlled, variable speed actuation. Made in the USA, this new actuation technology achieves the optimal technological compromise–combining the best advantages of hydraulics and electromechanical servo technology minus their disadvantages engineered in an all-in-one, scalable, modular assembly.

New to the OEM market, the Kyntronics' SHA offers an all-in-one (variable-speed motor, drive, and cylinder) actuation system that precisely controls position, force, and speed in applications requiring from 500 lb. (2,225N) to over 100,000 lb. (445 kN) of force capacity. High force and quick cycle times in a compact package, the all-inclusive system produces strokes up to 120 in. (3,048 mm).

Traditional actuation systems over the past several decades focused on three primary types: electromechanical, hydraulic, and pneumatic. With the advent of Kyntronics SHA, SMART electro-hydraulic actuators now represent a fourth category that leads the growth trajectory of next-generation actuation. Whereas traditional actuation systems all have their distinct advantages, each have inherent core disadvantages — examples include the reliability of electromechanical systems, inefficiency of hydraulic actuators, and the maintenance required with pneumatics.

Kyntronics SHA all-in-one system combines the key benefits of an electronic servo system with the power density of hydraulics. The flexible system can be oriented in any position and features a compact footprint–combining the power to weight ratio advantage of hydraulic technology with the versatility, ease of installation, and control of electric servo technology.

It is powered by a servo motor that drives a hydraulic pump which generates pressure to act on a cylinder to provide optimal mechanical actuation force. The configuration also features a servo drive controller, actuator, manifold, and built-in transducers–providing essential closed-loop precision force and position control. Fieldbus capabilities include Ethernet, CAN, & Serial.

A notable key benefit of the system is the way the differential volume is accounted for between a cylinder's cap and rod ends. To compensate for this differential, the hydraulic cylinder includes an outer low-pressure cylinder with a second inner high-pressure cylinder–creating a chamber between the two. Ultimately, the product delivers high force density in a small footprint with precision, while offering "power-on-demand' energy efficiency–only running when needed.

"The key inspiration for our research and development on the SHA product came from vital input from our customers who wanted to embrace the global trends of increasing automation, higher precision requirements, lower costs, and more connectivity," said Wayne Foley, president at Kyntronics.

"Electro-hydraulic technology has been driving actuation market growth, and we strive to provide our customers and channel partners with unique solutions like the SHA that are ahead of the curve. Our nimble, responsive team of in-house engineers thrive on 'solving the unsolvable' actuation application problem and are equipped to provide the best combination of mechanics, electronics, software, and support solutions in actuation today," added Carl Richter, vice president and general manager.

For more information:

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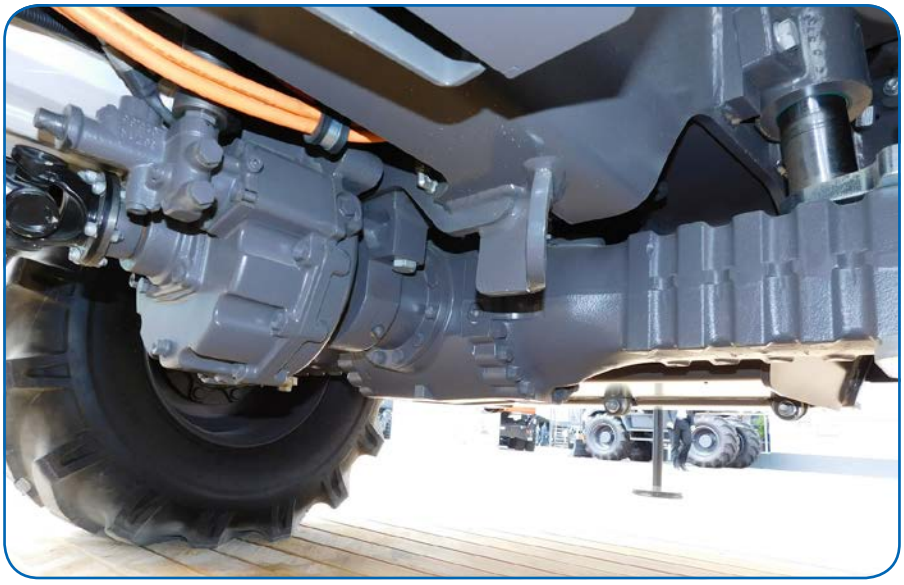
Dana

COLLABORATES WITH MECALAC ON E-DRIVETRAIN

Dana Incorporated has announced that the company has been collaborating with Mecalac to develop a customized e-Drivetrain system for the new Mecalac e12 electric compact wheeled excavator. This vehicle earned the Energy Transition Award earlier this year as part of the 2018 Intermat Innovation Awards.



With the proven Mecalac 12MTX as a base frame, this version is the world's first compact wheeled excavator powered entirely by electricity. Featuring Spicer 112 axles and a Spicer 367 shift-on-fly transmission, the Mecalac e12 wheeled excavator delivers the range, performance, and compact size required to support modern urban construction sites.

"As the European construction market embraces the trend toward zero-emission standards for small to mid-sized vehicles, our customers are demanding great strides in efficiency while also requiring reliable performance," said Jean-Baptiste Rousseau, technologies manager at Mecalac. "Dana was able to adapt the 12MTX drivetrain to add electric drive capabilities within our existing vehicle architecture. With their technical expertise and open collaboration, we developed an optimal solution and accelerated the delivery of this vehicle to market."

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the engine compartment in the Mecalac e12 houses LiFePO4 battery technology—lithium iron phosphate for service life that is three times longer than classic batteries. The batteries can be charged in approximately seven hours.

Dana has a long history of developing drivetrain systems for hybrid and electric vehicle architectures. The company also offers patented battery and electronic cooling technologies, along with fuel-cell technology. In addition, Dana engineers had extensive experience with this particular application because the diesel-powered version of this vehicle also features Spicer drivetrain components.

"As a Tier-One supplier, we understand that the success of electrification in the off-highway industry is driven by performance. These technologies must support a smooth transition to fully integrated electric-drive technologies optimized within a single package, providing both electrified and conventional powertrain options," said Aziz Aghili, president of Dana Off-Highway Drive and Motion Technologies. "Dana's support for new energy vehicles has been considerable, and growing every year, as the importance of engineering for hybridization and electrification is further elevated throughout the industry."

For more information:
Dana Incorporated
www.dana.com/offhighway

Klüber Lubrication

DESIGNS LUBRICATING GREASE FOR MODERN ELECTRIC BRAKE APPLICATIONS

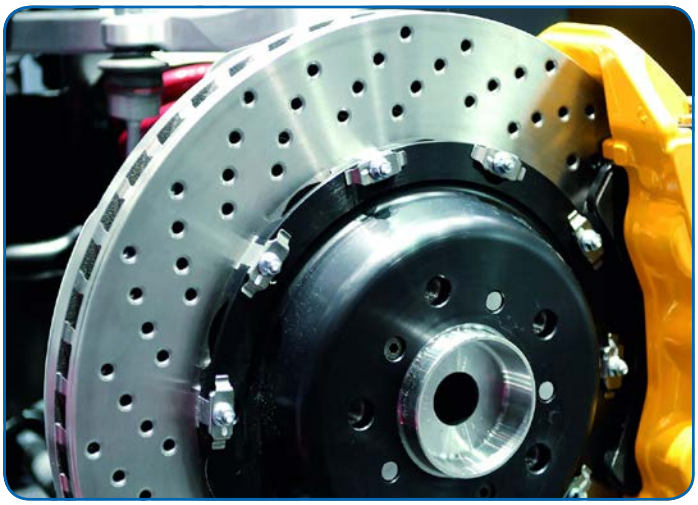
Klüber Lubrication, a worldwide manufacturer of specialty lubricants, has developed Klübersynth GR 46-52 F, a fully synthetic special lubricating grease for actuators in motor vehicles.

In today's vehicles, brake actuators, both for full service brakes and electric park brakes, have become popular as electric assistants, replacing the formerly used hydraulic circuit. EPDM materials continue to be used, which makes compatible lubricants a necessity.

In this context, Klübersynth GR 46-52 F has a specially tailored chemistry to promote compatibility with EPDM. At the same time, it helps save significant costs as an efficient alternative to the frequently used PFPE- or silicone-oil-based lubricants.

Klübersynth GR 46-52 F is a solid lubricant that ensures reliable separation of surfaces, enabling constant start up torques over a long lubricant life. The lubricant helps extend component life with a high proportion of sliding friction as well as with rolling motion. This in turn aids in making the driving experience even safer and more comfortable.

Klübersynth GR 46-52 F was specifically developed for electric brake actuators, mostly small actuators, in motor vehicles. The individual actuation method may consist of spur gears, worm gears, spindle mechanisms, and ball screws. The lubricant is ideal where compatibility with



EPDM and/or brake fluid is required in polymer/steel material combinations.

For more information:

Klüber Lubrication
Phone: (603) 647-4104
www.klueber.com/us/en/

Joral

OFFERS SENSOR FUSION INCLINOMETER FOR PITCH, YAW AND ROLL FEEDBACK

Joral LLC announces a G-force compensated inclinometer that provides feedback for pitch, yaw, and roll. The new technology utilizes sensor fusion, which is the combining of more than one complementary sensing method. The new Joral SGAM and DGAM incline sensors take input by a gyroscope, accelerometer, and magnetometer to provide a 3-axis output for X, Y, and Z as well as new feedback for pitch, yaw, and roll.

The GAM Series sensor provides steady feedback during motion, allowing users to eliminate complex sensor networks with a single G-force compensated inclinometer. Rather than depending on encoders, string pots, laser gates, and proximity sensors to monitor the position of a ladder, fork or platform, users can place one Joral GAM Series sensor on the application to get real-time feedback for absolute control.

Joral has designed the same level strength into the GAM series as other standard Joral products. Rated with a standard environmental protection of IP67, the GAM series sensors are 100% encapsulated. Designed to eliminate the drawback of accelerometer based incline sensors, the SGAM and DGAM inclinometers are J1939 capable, and available in a convenient form factor with common connection options.

For more information:
Joral LLC
Phone: (262) 378-5500
www.joralllc.com

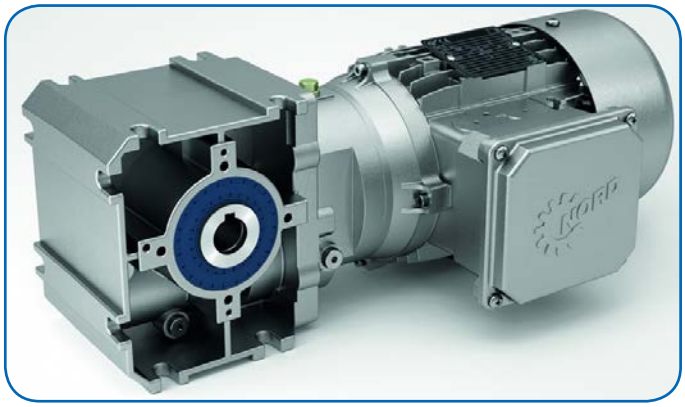
Nord Drivesystems

EXPANDS HELICAL WORM GEAR LINE

Manufacturers across a several industries will benefit from Nord Drivesystem's newest helical-worm gear unit. The re-designed two-stage SK 02040.1 is ideal for conveyors in food and beverage, bottling, manufacturing, warehousing and packaging applications.

The Nord SK 02040.1 gear unit is made from high-strength aluminium alloy. This one-piece die-cast aluminium Unicase housing provides maximum strength and rigidity with low weight. In addition, a new universal mounting design offers significant customer advantages.

Jim Alt, mechanical product manager at Nord, said the SK 02040.1 design is a money saver. He explained, "The Nord gear unit provides nearly 900 lb-in. of torque — which is ideal for countless conveyor and manufacturing applications. It can be quickly installed and offers a smart universal foot/flange housing, and accessories for foot, flange or torque arm mounting. Plus, the aluminium is more than 30 percent lighter than cast iron."



Alt added, "By using aluminium, the Nord SK 02040.1 helical worm gear unit is priced significantly below the product it's replacing — and we expect customers could see double-digit savings compared to competitive products." The gear unit can also be ordered with Nord's nsd tupH sealed surface conversion process, which provides comparable benefits of stainless steel at a 30–50 percent cost savings.

The new SK 02040.1 gear unit offers a wide power range from .16 to 1.5 hp (0.12 to 1.1 kW) and delivers output torque up to 885 lb-in (100 Nm). The wide range of speed ratios (5.3:1 to 330:1) enables optimum adaptation to the customer's requirements.

All Nord helical worm products are available with solid, keyed or keyless hollow bores. The SK 02040.1 geared unit also offers input options to a variety of motors, including direct mounting, NEMA and IEC. The new SK 02040.1 unit is a drop-in replacement to the previous SK 02040 cast iron product.

For more information:
Nord Drivesystems
Phone: (888) 314-6673
www.nord.com

Siemens

EXPANDS WIRELESS CAPABILITIES OF SINAMICS G120 DRIVE SERIES

Siemens has expanded its Sinamics G120 drive series to include an option for wireless commissioning and service. The new Sinamics G120 Smart Access module enables wireless connectivity of mobile devices such as tablets, smartphones and laptops over Wi-Fi to Sinamics G120 and Sinamics G120C drives. The module is setup in a few easy steps using a standard web browser and any standard operating system. Its built-in web server functionality eliminates the need to download additional software, and with its intuitive user interface and menu, the Smart Access module offers users outstanding convenience.

The Sinamics G120 Smart Access Module is available for G120 drives with CU230P-2 and CU240E-2 control units as well as Sinamics G120C drives. Users are free to choose any web browser and any smartphone, tablet or laptop for drive commissioning, parameterization and maintenance. Motors can even be tested in JOG mode. Warning signals and error messages are quickly detected over the wireless link, which can also be used to save or reset drive settings. The Sinamics G120 Smart Access module includes a function that enables the settings from one drive to be copied, sent to other mobile devices and used to commission additional drives.

"This provides an enormous time-savings when handling several drive units. It's also possible to use the Sinamics G120 Smart Access module between different drives of the same series, allowing them to be commissioned using a single mobile device," says Robert Soré, product manager, Sinamics general purpose drives. "In this case, the module acts as a portable storage device with web-based operator unit and wireless client link."

For more information:
Siemens Industry, Inc.
Phone: (847) 640-1595
www.siemens.com

Kinitics Automation

INTRODUCES KPP05 PISTON PUMP

Kinitics Automation has announced the availability of the KPP05 Piston Pump, a shape memory alloy-based positive displacement pump that uses proprietary Bundled Wire technology to deliver a precision stroke. Driven by the company's KLA05 Linear Actuator, the product requires only AC or DC electrical power to operate, and allows for displacement or pressure control when additional sensors are used. This innovative fluid power product offers the functionality of a motor, pump, and proportional valve in a single compact unit.

The KPP05 Piston Pump may also be configured with alternate bore sizes when higher pressures or displacements are required. The product can also be equipped with a variety of accessories, including a range of mounting brackets and an adjustable home position switch. Potential applications for the Kinitics Automation KPP05 Piston Pump include acting as a master cylinder for brake and clutch control, a hydraulic pump for grippers and clamps, and as a precision metering pump.

Also introduced with the KPP05 Piston Pump is the Kinitics KCD125 Controller, which allows the actuator to be used in anything from the simplest to the most elaborate of control strategies. The Kinitics KCD125 Controller utilizes 6–24 VDC power and interfaces with standard control hardware using discrete I/O. A 4–20 mA input is provided for complex control using pressure and/or displacement feedback strategies. The KPP05 Piston Pump can also be used with the Kinitics Automation KCA020 Controller, which utilizes single-phase 120 VAC 60 Hz power.

Dean Pick, president, Kinitics Automation: "Originally developed as a clutch controller for automotive applications, the KPP05 Piston Pump has been engineered to be widely applicable to a range of industrial and commercial uses. Whether operating as a master cylinder or as a metering pump the KPP05 can provide end users with an all-in-one fluid power platform."

For more information:
Kinitics Automation
Phone: (604) 304-1181
www.kiniticsautomation.com

Stable & Streamlined

Gear Drives Focus on Longevity, Quality and Customization

Matthew Jaster, Senior Editor

What drives innovation? Is it the product itself? Is it the engineering team behind the latest technology? Is it simply listening to the customer and determining what needs to be tweaked and modified to work more effectively? These are all acceptable answers, particularly when discussing gear drives.

Whether it's a marine, aerospace, mining, aggregate, packaging or food and beverage applications, manufacturers are focusing on areas like efficiency, flexibility, power-loss reduction and performance to enhance their product offerings in the power transmission industry.

Efficiency On-Demand

For Regal Power Transmission, customers are requiring gearing products that are long-lasting, provide documented cost savings and give them additional options for reducing stockroom inventories.

"We are transitioning from a worm gear design, which, while very popular in the marketplace and economical to produce, is limited because of the inherent sliding friction that is a characteristic of worm gear geometry," said Alton Vilhauer, product/marketing specialist at Regal. "This sliding friction reduces overall efficiency, generates heat and reduces the life of the speed reducer. Instead, we are producing a helical-hypoid product, which we have named the HERA gear drive. The helical-hypoid gearing design is very efficient, has nearly twice the torque capacity of similar sized worm speed reducers, runs cooler and lasts longer because it is rolling action in the gear mesh rather than sliding friction."

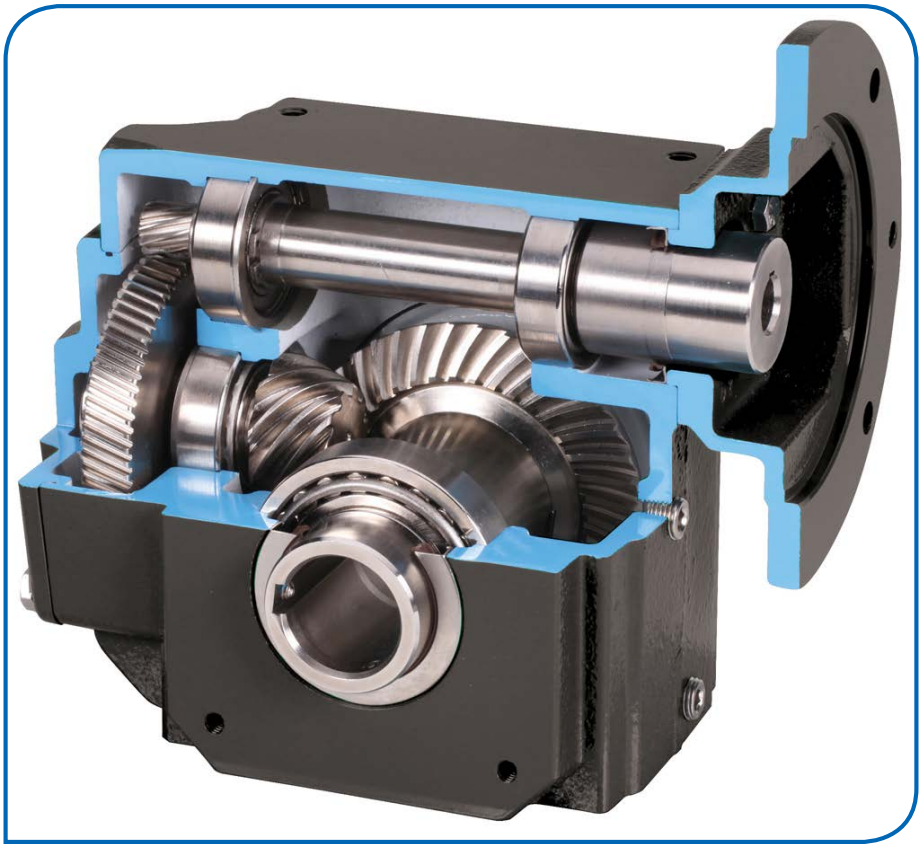
Regal is currently streamlining its manufacturing and assembly equipment and processes in order to produce the HERA gear drive more quickly and efficiently.

"Efficiency is key," added Vilhauer, "As the cost of energy continues to climb, producing a product that saves or reduces energy consumption—not only for our customers, but also in the way we manufacture it—is the direction we are going in our facilities."

One way to become more efficient is to enhance service and support. According to Vilhauer, Regal provides support, expertise and educational training sessions on all of its products and applications as well as on-site diagnostics, product selection assistance, installation commissioning, product monitoring and repair and rebuilds. These offerings all factor in to repeat business and give customers the options they need on the manufacturing floor or in the field.

Another key focal point is getting the product into the customer's hands as quickly and efficiently as possible—a key to success in the industrial environment today.

"Speed to market is one of our biggest challenges," said Vilhauer. "Meeting and exceeding customer expectations is what wins the order these days and keeps customers coming back."



The HERA gear drive solves engineering problems, reduces energy consumption and increases uptime in tough applications.

Application Flexibility

Along with efficiency gains, gears and gear drives need to be much more flexible today than in years past. Meeting the rigorous demands in the marine industry, for example, requires engineering expertise and high levels of customization.

Bonfiglioli offers a robust series of jack-up drives for lifting applications in the maritime sector. Each of the variants has four gear stages. The drives are designed for use on lifting platforms or jack-up vessels, and aside from meeting high performance requirements, they must also be able to deal with the special conditions at sea.

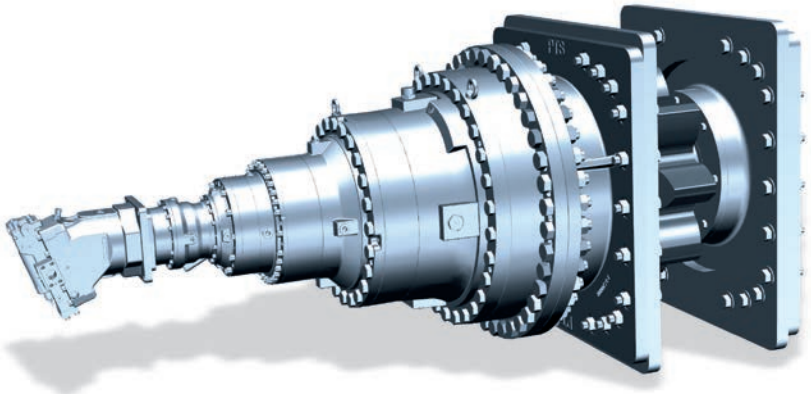
All drives have been approved in accordance with the standards set by the American Bureau of Shipping (ABS). Certificates from Det Norske Veritas and Germanischer Lloyd (DNV GL) and the China Classification Society (CCS) are also available.

The torque range of the lifting application ranges from 163,000 to 1.245 million Nm and the retention force is between 263,000 and 1.766 million Nm. The multistage planetary gears—based on the series 700T by Bonfiglioli—can be powered using a hydraulic or electric motor.

They can also be combined with parallel shaft units, which allow them to be built into smaller spaces. Optimized construction details and highly precise gearing form the basis for high efficiency and reliability of the drives.

Application-specific input and output options complete the offer and provide the necessary flexibility to meet market demands. Additionally, the engineering team is tasked with sizing and project-specific application of the jack-up drives at any time to support its customer base.

Bonfiglioli offers a wide and diverse range of products for lifting, pulling and slewing machinery in marine and offshore applications like shipboard cranes and winches, deck machinery, azimuth thrusters and pipe layers. Products include planetary gearboxes, bevel helical and parallel shaft gearboxes, electric motors and frequency controllers.



Jack-up drives for lifting applications in the maritime sector by Bonfiglioli.

Power Loss Reduction

The Voith BHS AeroMaXX technology for high speed parallel shaft gearboxes is a reliable solution featuring inner housing and optimized sleeve bearings that reduce power loss and oil consumption by 30 percent or more.

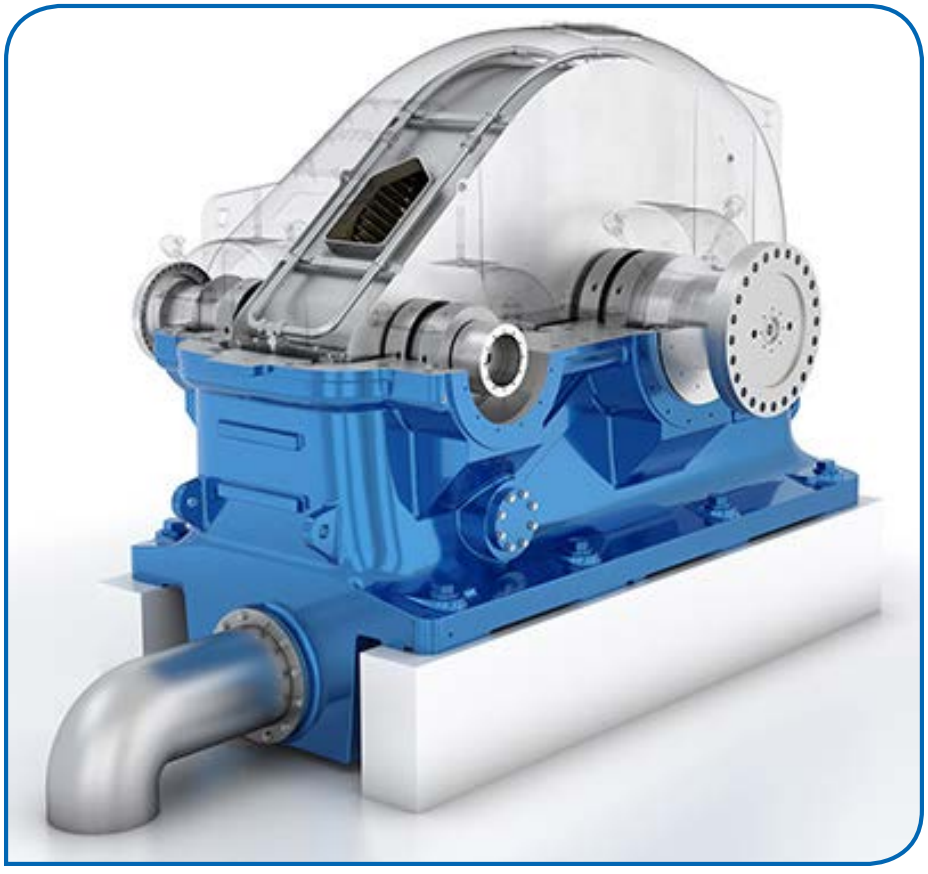
This solution has a passive-mechanical character and does not require any additional accessories. Operators profit from identical design standards, unchanged overall operating behavior and maximum reliability. Voith emphasizes this with a warranty period of 36 months – in both new systems and retrofits. The technology is manufacturer-independent and immediately available.

Due to the high pitch line velocities of up to 200 m/s, oil swirling and oil squeezing in the gear mesh account for a substantial part of the power loss of high-speed turbo gear units. The BHS AeroMaXX technology reduces these losses by separating lubrication and cooling.

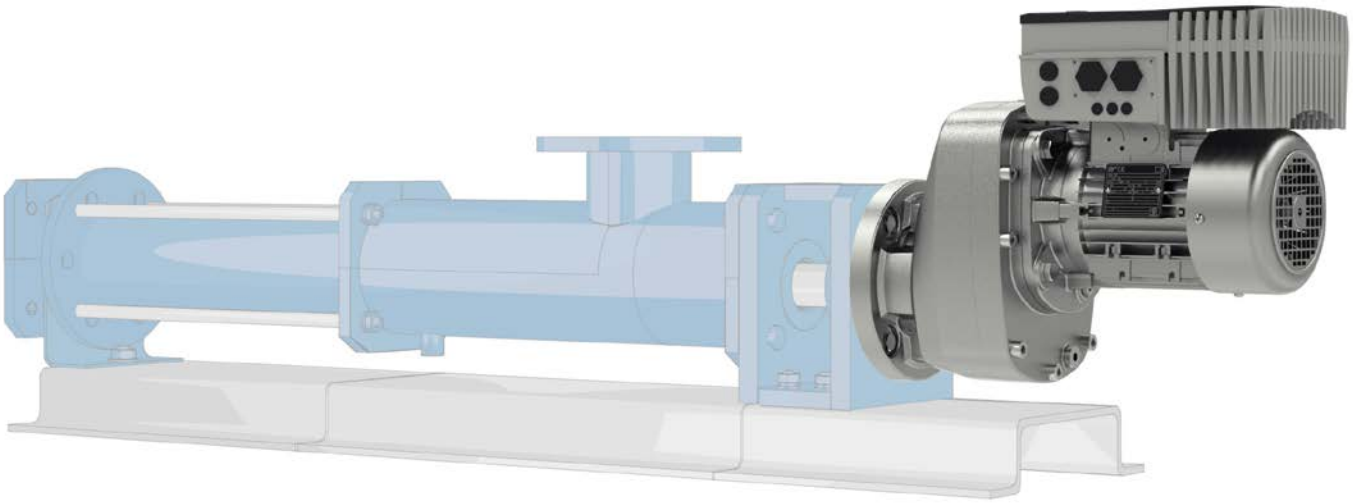
An inner housing in the direct vicinity of the gear set absorbs heat and dissipates it into the bottom area on the external surface on the inner housing via cooling oil. As a result, a substantially smaller volume of oil is required for the actual lubrication of the tooth contact surfaces, and the swirling oil/air mixture is minimized.

In addition to the inner housing, the technology also includes new 'BHS EcoMax' sleeve bearings on the pinion shaft. The hydrodynamic bearings are optimized specifically for the application and guarantee high energy efficiency with significant oil savings.

By combining the inner housing and the specifically designed bearings, BHS high speed parallel shaft gearboxes with AeroMaXX technology achieve efficiency of up to 99.3 percent. At the same time, the oil consumption is reduced by at least 30 percent. Since only passive mechanical elements are used, the improvements can be achieved without any additional accessories or components such as pumps or seals. The overall operating behavior, design standards and dimensions of the gear unit are



Voith BHS high speed parallel shaft gearboxes with AeroMaXX technology achieves efficiency of up to 99.3 percent.



For pump applications, Nord offers highly reliable drive solutions with wide speed ranges and a high radial and axial load capacity.

also not affected by this technology. Related costs for a system operator are amortized by the energy savings alone within one to two years.

BHS AeroMaXX is designed for high pitchline velocities in connection with medium to high powers that, for example, occur in the driveline of power plants with compressors and generators. In these applications, the technology can be retrofitted in previously installed gear units during standard maintenance of the driveline, without additional downtime.

Like other options, Voith emphasizes the simplicity and reliability of BHS AeroMaXX in regards to maintenance and service. An inspection window in the inner housing allows operators to continue checking the condition of the tooth set without opening the top portion of the transmission.

Meeting Performance Demands

Nord Drivesystems offers reliable drive technology with reinforced bearings and increased bearing spacing for the processing industry. This ensures maximum radial and axial load capacities and a higher service life of the gear units.

"Standard gear units are designed to allow for a great number of ratios and, consequently, speeds," said Jörg Niermann, head of global marketing at Nord. "But with regard to component safety, they are sufficiently dimensioned to match the motor power to be expected. The bearings also comply with these expected standard requirements. Usually, a larger gear unit is chosen if the forces at the output shaft exceed the gear unit capacities. This is because a standard housing will not allow the bearing spacing to be increased or a much larger bearing to be implemented."

Nord offers application-specific equipment options that are characterized by high performance and efficiency, specially designed for pumps, agitators, and mixers whose processes result in high radial and axial bearing loads. An agitator version (VL2 bearing) with increased bearing spacing and reinforced bearings as well as a Drywell version (VL3 bearing) with additional oil drip plate and leakage or oil sensor are also available. The bearing spacing of the VL2 and VL3 versions is increased with attachments while the gear unit size remains unchanged.

In addition, Niermann said that the company offers bearings that were intentionally oversized to meet the requirements of applications such as pumps or agitators for the chemical, pharmaceutical, food and water treatment sectors. These reinforced and larger output shaft bearings allow the gear unit to absorb the high axial and radial forces and thus prolong the service life.

Don't Forget the Lubrication

One of the leading causes of gearbox failure is improper lubrication. Viscosity, additives, oil-levels, etc. must be handled correctly in order to get the most out of your equipment. Factors to consider for lubricating your gear drive include the type of gearing, the speed, the materials being used, temperature fluctuations and loading considerations. (*Editor's Note: Read more about lubricating gears and gear drives in the PTE October 2018 issue next month*).

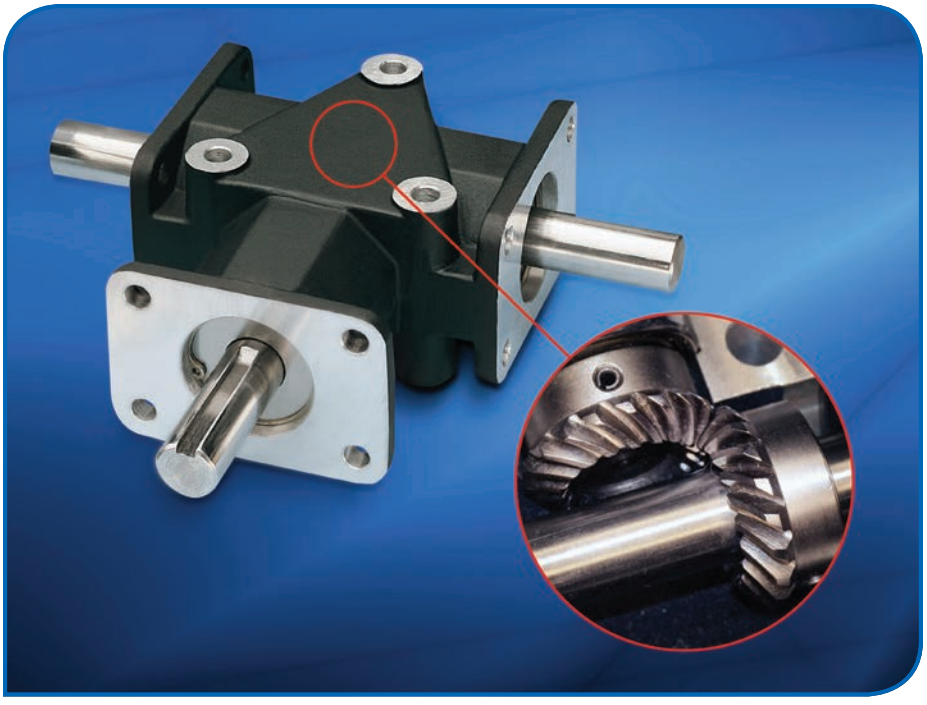
> "As the cost of energy continues to climb, producing a product that saves or reduces energy consumption—not only for our customers, but also in the way we manufacture it—is the direction we are going in our facilities."
>
> **Alton Vilhauer,**
> Regal Power Transmission Solutions

Zero-Max recently unveiled a crown right angle gear drive that is lubricated for life with Beacon 325 premium grade grease. These drives feature heat treated AGMA Class 10 spiral bevel gears. This combination of bearing design and lubrication formulation ensures long-term, maintenance free operation for high performance, industrial applications.

The drives feature long-life, precision hardened and ground ball bearings handling speeds up to 2,000 rpm in most operating environments. The internal gears are permanently mounted to the shafts with the use of a press-fit and locking pins. This provides a very resilient and durable connection for use in heavy load applications while requiring no maintenance.

Lubrication with Beacon 325 grease ensures optimum performance in temperature ranges from –50°C to +120°C without evaporation. This is especially important in sealed for life systems using motors, generators and similar equipment in industrial applications.

Zero-Max ensures similar model sizes have identical performance characteristics when designed into multiple drive setups. To accomplish this, the drives are precision assembled for perfect bearing and gear alignment. The drives are pre-lubricated during assembly, then completely enclosed in a heavy-duty anodized aluminum housing. This design ensures that internal gears stay permanently aligned, lubricated and free of contamination from outside debris. A must under the extreme environments found in material handling, packaging and food and beverage applications.



Zero-Max Crown Drives have heat treated AGMA Class 10 spiral bevel gears that are lubricated for life.

Future Options

Currently, digitalized automation is a major driver of growth in gear drives where high maintenance costs quickly add up. Thus, IIoT solutions as well as the potential for 3D-printing of gears will create opportunities for additional growth. Both areas will be explored in further detail in upcoming issues of *Power Transmission Engineering*.

In regards to IIoT, Regal Power Transmission has already begun to tap into some of digital manufacturing's potential with its lifecycle services and perceptive technologies capabilities.

"We are integrating sensors and software that can help our customers monitor their systems, predict and prevent costly failures, and in some cases even enable them to control their systems remotely," Vilhauer said. "These solutions will increase the lifecycle and efficiency of our gearing products."

In the future, the company will see much more demand for efficient and power-dense gear technologies similar to the HERA gear drive.

"We will also see more incorporation and integration of smart technologies to monitor, predict and control mechanical systems," Vilhauer said.

Bonfiglioli is also focusing on IIoT solutions.

"We have a number of digital initiatives including some IIoT lab and field tests going on. From condition monitoring systems to predictive maintenance, we are firmly convinced that providing these solutions to our customers has become essential to support their growth," Campana said.

Bonfiglioli is monitoring new additive manufacturing technologies that may also be beneficial to the gear market down the road.

"Today 3D-printed geared units are a great opportunity for us in terms of prototyping and we make use of it in these terms," Campana said. "But the cost of machinery and the components produced is still very high and not convenient for production batches compared to traditional processes. There are also still some remarkable limits in material types than can be 3D printed. However, there are some new interesting 3D technologies which promise to overcome such limits coming into the market. We will keep our eyes open as it is potentially a disruptive process."

As far as the future of the gear drive market, Campana at Bonfiglioli sees trends like electrification (the replacement of hydraulic motors for example), hybridization and more energy efficient products that will surely impact gear unit design and processes.

"What we believe it is going to happen is that we will speak more and more about the system rather than single products," Campana said. "This smart system will incorporate IIoT, power electronics, electrical and mechanical products seamlessly." **PTE**

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2018 Engineering Showcase

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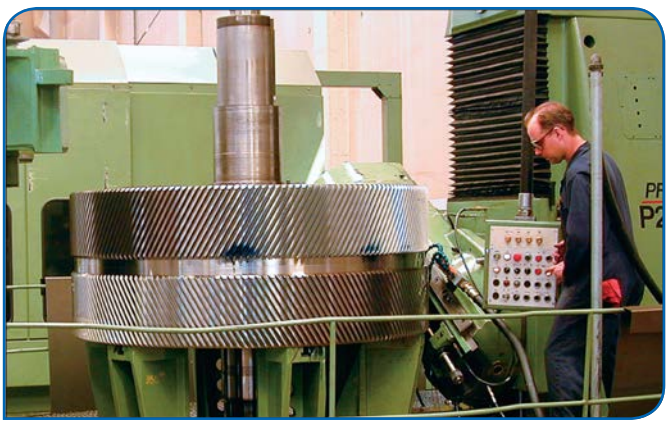
The Gear Works integration into Machinists Inc. in full swing!

On February 5th, 2018, Machinists Inc. purchased the assets of The Gear Works – Seattle, Inc., a world-renowned gear maker with a 72-year history. On June 28th, MI auctioned older, redundant machinery making room for expansion.

Large high quality gears and machining

Machinists Inc. is now one of the largest and most diverse gear manufacturing companies in North America. MI services many industries, including power generation, mining, wind, oil and gas, steel, marine, aerospace, and others.

MI is able to cut gears to 250 inches in diameter and grind gears to 102 inches in diameter. Our wide range of machinery includes CNC gear grinders, CNC gear shapers, CNC gear hobbing machines, and Maag gear shapers. We have a large selection of modern CNC equipment including large CNC lathes, cylindrical grinders, and large 5 axis CNC mills.



Marine Gears

Marine gears are typically double helical and frequently require tooth contact matching in a roll stand. Special care is given to align the apex of both left and right hands exactly perpendicular to the axis of the gear.

Full service gearbox repair and test center

MI operates a full service gearbox repair and test center dedicated to the dependable overhaul and enhancement of gear drives. We service most gearboxes regardless of original manufacturer.

MI is able to improve existing gear drives. We have greatly increased the horsepower capacities and service life of many chronically ill gearboxes by analyzing existing components and providing better gears. We are also skilled at saving existing components and refurbishing parts when possible, resulting in significant savings for our customers.

Industrial Gears

There are many different types of industrial gears with a large variety of service applications and requirements, MI has developed the capability and capacity to successfully complete the most challenging industrial gearing projects.

When necessary, we also assist in redesigning customers' gear trains using modern engineering tools, current design standards, and state-of-the-art manufacturing technologies.

If there is a need for precision gears and power transmission services. MI is able to not just fix, but improve complex gear drives. Call the precision gear machining experts at Machinists for reliable handling of your project.

Machinists Inc. is committed to continually improve our gear making capacity and quality. Call us for an estimate on your next gearing requirement.

Wind Energy Gears

Today, MI manufactures gears for wind turbines that are designed with sophisticated tooth modifications, utilizing the finest metallurgy and the most modern gear manufacturing techniques.

Gearbox Innovation Evolves in Step with Expanding Servo Market

Howard Horn, Product Manager – Thomson, Industries Inc.

Approximately one quarter of all servo motors around the world require some type of gear reduction in their applications. From large satellite dishes to precision medical devices, gearboxes boost torque and reduce speed for servos in order for them to be sized more efficiently. While gearbox fundamentals haven't changed much over the past 20 years, their effectiveness has improved significantly, driven mostly by the need to accommodate advancements in servo technology.

> "Global manufacturers are using more and more automation to meet their ongoing requirements for faster, better and more cost-efficient production."
>
> **Howard Horn, Thomson Industries, Inc.**

Servo motor market expansion

Global manufacturers are using more and more automation to meet their ongoing requirements for faster, better and more cost-efficient production. To meet this demand for continuous improvement, servo manufacturers have been developing motors that are smarter and have a higher torque density for a particular motor size.

The more common NEMA 34 size motor, for example, now puts out two or three times as much torque as it did 20 years ago. And because of the developments in servo technology and performance, the gearhead market has had to make improvements as well in order to offer similar benefits to the end user. Three of the most significant enhancements can be found in the gearing profile, material strength and mounting process.

High-performance gearing profile

Perhaps the most significant advancement in gearbox design is the transition from a parallel shaft profile to a true planetary design. Where traditional gearboxes meshed two gears together on parallel shafts, most high-performance gearboxes today use a planetary arrangement in which the gears mesh at three points of contact. This arrangement provides load sharing between the gears, which increases torque performance and overall life.

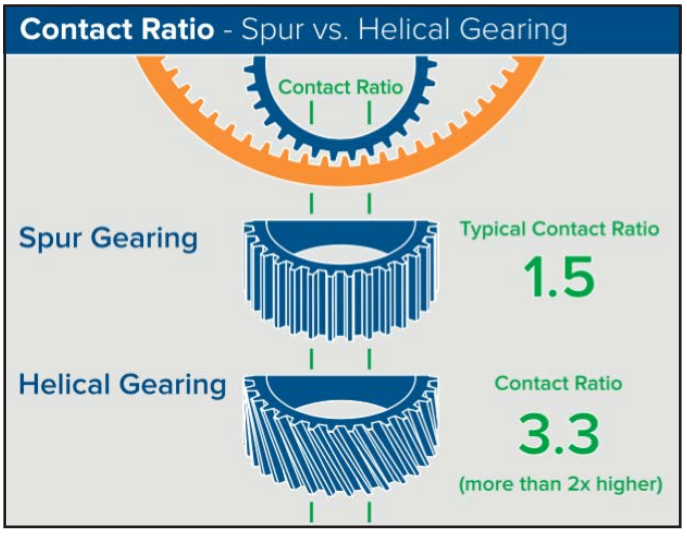
Further improvements on the planetary design can be achieved by cutting the gears on a helix angle. These helical planetary gears increase the number of teeth in mesh at any given time, which produces a stronger, more accurate and quieter-running gearhead.

Heat treat processes

The heat treat processes used on the internal gearing directly impact the overall performance on any gearhead. Some manufacturers use lower-cost, chemical heat treat processes that do not hold up under the extreme torque

Key Gearhead Parameters	
Backlash	The lost motion caused by the clearance between gear teeth
Torsional Stiffness	The torsional wind up in the material components of a gearhead
Rated Torque Capacity	Rated output torque for a given speed and life expectancy
Rated Input Speed	The input RPM associated with the given torque capacity
Peak Torque Capacity	Allowable momentary torque for emergency stop or shock loading
Torque Density	Amount of torque available for a given frame size
Efficiency	% of torque transmitted through the gearhead (less losses)

To better appreciate the benefits of gearhead technology, it is useful to have a firm grasp of its key parameters.



The increased contact ratio from spur to helical gearing will result in increased load sharing, which will lead to longer life (image courtesy of Thomson Industries, Inc.).

or high duty cycle applications. For higher performance and longer life, many manufacturers use a case-hardening heat treat process that increases the hardness layer by more than 30 times compared to alternatives. Even the best and most robust designs will not hold up for an extended period of time if the proper heat treat methods are not used.

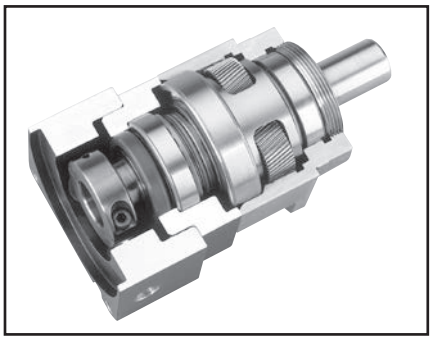
Quick, Error-Free Installation

In the past, mounting of traditional gearheads was a painstaking process. There were several steps that introduced possibilities for human error such as the mounting of the gearhead pinion gear, or sun gear, on the motor shaft. This usually required precise, time-consuming measurements that increased the chance of failure if not done properly. Today, however, most gearhead manufacturers have modified their designs to make mounting procedures faster, easier and free of potential errors. Mounting can now be done in a few easy steps in under five minutes.

Balancing application tradeoffs

While servo motors and gearboxes can be found together in almost every market, gearbox usage varies based on design engineers' needs. Gearboxes are designed for specific applications (or at least for specific application requirements) and provide flexibility when sizing a servo motor to achieve desired operating loads and speeds. However, choosing a gearbox requires some tradeoffs among cost, precision, performance, durability and environmental protection.

Users implementing gearboxes in operations such as snack bar packaging, for example, are more concerned with speed than precision. They are less concerned about backlash or torque than about maximizing



Gears with a higher level of hardness will have less wear and last longer. The Thomson ValueTRUE True Planetary Gearheads increase torque capacity and offer higher precision.

Performance specifications	Physical specifications
• Precision – in terms of maximum backlash tolerated • Manual torque and speed entry, in cycles per hour • Input or output torque • Input or output speed in rpms • Hours of operation per day • Radial load specs	• Gear ratio, usually a function desired output speed or torque • Inline vs right angle orientation • Exposure to shock and vibration • Potential overhang • Need for shaft or hollow-bore input or output • Requirements for sanitation or corrosion resistance

throughput on the packaging line at the lowest cost and longest life, considering the durability of both the gearbox and the servo motor. Customers in wet process food applications, such as cutting bacon slices or producing frozen French fries, also might opt for speed over precision but would value sanitary, stainless steel material that is sealed to meet ingress protection (IP) standards, including protection against high-pressure equipment wash-downs.

Users of gearboxes on robots, on the other hand, would be more concerned about envelope size. They might, for example, be implemented on an arm that is already designed to minimize overhang stress and may not tolerate the further extension an added gearbox might introduce. Precision is also critical here, making the challenge to provide the maximum precision and stiffness in the smallest envelope. Robotics users are more likely to trade off cost for performance and footprint.

Following are examples of key variables to cover when specifying a gearbox:

Many gearbox manufacturers offer tools that help calculate the optimal combination of features. For example, Thomson Industries developed the Micron Motioneering tool, which is an online product sizing and selection platform that facilitates a fast and easy system sizing. The tool assists with the accurate motor sizing and mounting and offers an advanced online ordering technology.

Gearing up for tomorrow

The digital transformation of global industry is well under way. As industrial devices become smarter and more connected, end users will be developing ways to use these new capabilities to add value to their market offerings. Servo motor systems, including their options for high-precision motion control, have been increasing their intelligence to meet these emerging market needs. And as they do, gearbox innovation will continue to match their every step. **PTE**

> "As industrial devices become smarter and more connected, end users will be developing ways to use these new capabilities to add value to their market offerings."
>
> **Howard Horn, Thomson Industries, Inc.**

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Pack Expo: Automation and Education

As Pack Expo approaches Chicago this year, education remains a focal point, while automation continues to rise.

Alex Cannella, Associate Editor

Ask any exhibitor at Pack Expo International and the co-located Healthcare Packaging Expo (Oct. 14–17 at McCormick Place, Chicago) why they're there, and you'll probably get the same response: end users.

"Pack Expo is about getting machine builders and end-users in one place," Tom Jensen, SVP and general manager at AMK Automation, said. "You can turn in any direction and see a customer or a prospect. It's a community and the show provides a great backdrop for collaboration."

Chris Radley, senior manager of global platform commercialization at Kollmorgen, sees it in similar, if differently worded terms. He views most trade shows as either vertical, covering all of a specific industry's processes from start to finish, and horizontal, where the show is focused on many industries and the technologies and products they use, such as automation. And as a vertical show, Pack Expo brings Radley in contact with all manner of OEMs, who are "generally the right people for [Kollmorgen]."

"We can talk to the packaging industry about what the packaging industry needs and what we can do for the packaging industry, as opposed to talking in more of a generic product-centric way that doesn't resonate with everybody." Radley said. "If you're in our business, torques and speeds and power and connectors and things like that may be interesting. If you're in the packaging industry, you're a lot more interested in the product you're producing; not in what we make, but in what we can do to help enhance your value in the product you make."

Photo courtesy of PMMI.

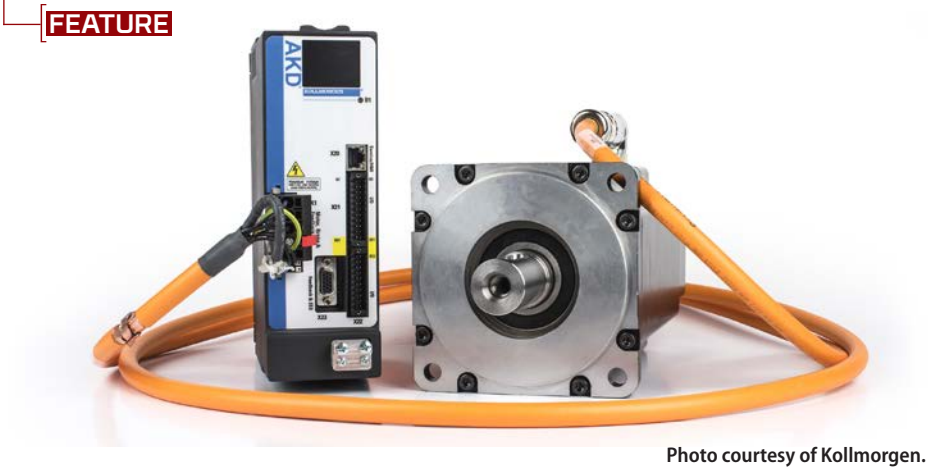

Photo courtesy of Kollmorgen.

That's not their only reason for being there, of course, not by a long shot. Pack Expo also has the benefit of being a massive show, as well as one of the premiere meeting places for the packaging industry's experts, and this year won't be any different. The show is going to cover over 1.2 million net square feet, with 2,500 exhibitors and 50,000 attendees expected, according to Laura Thompson, senior director of expositions at PMMI, the Association for Packaging and Processing Technologies and the owner and producer of the Pack Expo portfolio of trade shows.

And, as ever, educational opportunities are a massive draw for all involved.

"It's a learning venue for us," Radley said. "Because this is where the OEMs come and they roll out their newest machine ideas, so that means we need to be walking around and looking at what they're doing and asking: Are we going where they're going? And if we're not, do we need to change something?"

Naturalistic observation is certainly one way to learn what you need to know about the industry at Pack Expo, but if you don't know where to start, Pack Expo has a heap of educational opportunities.

As ever, educational opportunities remain a focus at Pack Expo, and you'll have no shortage of options to pick from. Their Innovation Stage is packed with 65 different sessions this year. And many of Pack Expo's educational opportunities are also designed to cater to the busy attendee's schedule. They're often quick, 30 minute lectures or discussion panels on topics ranging throughout the packaging industry that take place across multiple stages directly on the show floor.

"People want the education, but you have to find that balance," Thompson said. "You have a huge show floor to cover and so much out there on the show floor. So we've really found that these quick presentations have really resonated with attendees, and that they're able to get some good content and make some connections and still have time to see what they need to see at the show. We know people's time is valuable and we want to make their experience at the show as efficient and educational as possible."

Most notable will be a new stage PMMI has dubbed The Forum, where they're planning on presenting more interactive activities such as small group discussions, hands-on activities, and Q&A sessions. The Forum was a hit at the previous Pack Expo East in Philadelphia, but this will be its debut in Chicago.

Those opportunities are also being extended to students, whom Pack Expo are embracing more than ever. PMMI is expanding their push to get the next generation interested in the packaging industry and will have several events for them to participate in. One will be the Future Innovators Robotics Showcase, which will feature teams of high school students showcasing the abilities of their robots. The other will be the Amazing Packaging Race, a scavenger hunt for college students meant to get them on the floor and interacting with exhibitors.

And alongside all of these opportunities will be the Packaging & Processing Women's Leadership Network breakfast, which according to Thompson, is growing by leaps and bounds each year. Last year saw more than 400 attendees,


Photo courtesy of AMK Automation.

and PMMI is expecting even more to show up this time, as well as several food and packaging industry executives who will be speaking at the event.

"This has really taken off tremendously," Thompson said. "We're always happy to see the number of people who come out for these women's events."

Outside of PMMI's official offerings, there will also be plenty to pursue on the floor.

In particular, automation is becoming increasingly prevalent. Over 50 advanced robotics experts will be exhibiting this year, and while that might sound small compared to the full list of over 2,000 exhibitors, it's a contingent almost as large as some of the show's pavilions, and they have a lot to show off.

A relative newcomer to the scene, AMK Automation is back for their second Pack Expo. Also a newcomer to the North American market, that means that much of what they have on offer is "new."

"We have what machine builders need to grow their business and be more innovative in their offerings," Jensen said. "And we have a solid motion control technology built on decades of experience used worldwide."

Headlining AMK's booth will be their AMKASMART iSA decentralized machine controller. The iSa combines a PLC and drive into a single unit, and when combined with one of AMK's motors, can create a full motion control system without a control cabinet. The iSA also features a three-phase connection and integrated DC-bus power supply. But what Jensen is most excited about is AMK's MAKe middleware, which reduces the expertise needed to run machinery by automatically detecting its components.

"Essentially it removes the need for end-user or OEM engineers to learn proprietary software to program a system," Jensen said. "Plug it in, parameterize the system, and this program auto-recognizes your components and before you know it, your machine is doing what it's supposed to do, when it's supposed to do it. All through a simple to use interface."

On the other side of the automation field will be Kollmorgen, a decades-long veteran of the show that will have their full suite of servomotors and other motion-based automation offerings. Last year, Kollmorgen introduced the AKM2G, a servo motor that iterated upon previous designs to provide 30 percent more torque in the same size housing, and this year, they'll be unveiling the AKD2G servo drive alongside it.

The AKM2G provides a little more than just improved torque. It also has a three-piece housing design instead of the usual two-piece. And thanks to improvements in Kollmorgen's precision during casting, they managed to accomplish said three-piece design without sacrificing sealing integrity. The result for customers is increased flexibility to custom-build their motor using swappable "building blocks" that don't necessarily change the motor itself, but offer more options for housing design. The three-piece design allows for customers to swap out one piece without having to completely change the entire design.

Like the AKM2G, the AKD2G is an iteration on previous models that focuses on significant internal changes. Overall, the focus has been on improving the drive's flexibility while reducing its complexity. The size has been optimized. Customization has been expanded and the drive is now capable of running customized control loops. There's a new, larger screen that can give simpler, more readable information than just an error code. The drive now features an SD card slot, allowing designers to plug a pre-made program directly into the drive, simplifying setup.

"That's one of the big headaches people encounter with drives is the more flexible the drive is, the harder it is to program and set it up," Radley said. "So we've done a lot to enhance that. And at the same time, we've added even more flexibility."

There's more to see than just automation suppliers, however. NORD Gear Corporation is attending Pack Expo for their fourth year, and they'll be presenting a full line-up of helical bevel gearboxes among numerous other products in a brand new booth that will be their largest yet. As James Wubbolding, VP of sales at NORD, put it, NORD plans on presenting both entirely new products, as well as old ones in a new light.

One of the examples of the latter that will be on display will be NORD's SK-02040.1, the smallest of their helical worm gearboxes, which has recently been redesigned to utilize an aluminum alloy housing, making it more lightweight and better able to dissipate heat than it previously was.

The main draw, however, will be their new LogiDrive solution, a combination package of an IE4 permanent magnet

motor and a helical bevel gearbox run by a decentralized variable frequency drive. The gearbox is an existing NORD product, but the drive and motor it's attached to are both brand new.

"The whole idea behind the Logidrive system is reduced energy consumption," Wubbolding said.

Each part is designed with energy efficiency in mind, but the central focus is the IE4 motor. The IE4 rating is a step up from the baseline requirement of premium/IE3 motors as mandated by law. And while it may not be the absolute most efficient motor on the market, it offers noticeable returns over what an IE3 will do. Plus, due to its permanent magnet-based design, the motor still offers its energy savings across variable load points.

"Whether the packaging machine is running fully loaded or lightly loaded, you're able to take advantage of lower energy consumption because you've got a constant magnetic field due to the permanent magnet motor," Wubbolding said.

At first glance, reduced energy consumption might not sound like a winning feature to base an entire product around. After all, energy efficiency is all well and good, but the motor often costs more. But time and again, the math has proven that a more energy efficient motor will be cheaper in the long run by reducing daily operation costs, especially with machines that are always running. In most situations, it's ultimately more cost-productive to go with the more efficient motor.

Wubbolding also believes that, when looked at as a comprehensive package, the LogiDrive's modular nature also provides some additional benefits.

"One of the major advantages are that these are individual components," Wubbolding said. "If for some reason, you did have to replace something at some point in time, you can replace them individually versus having to replace an entire package."

Thanks to the drive's plug and play features, the LogiDrive system is also cheaper and easier to install. And one final benefit is the LogiDrive's ability to control a conveyor system's speed.

"Because you can utilize the variable frequency drive in connection with the permanent magnet motor, you can consolidate the number of ratios that are required for the gearbox." Wubbolding said. "You can optimize the number of units and reduce them by using the motor and the variable frequency drive to control the speed, plus reduce engineering effort and spare parts inventory."

But these are just a few of the thousands of exhibitors that will be descending on Chicago in October. Automation will be a hot topic and motors and drives will be on every corner, but there's plenty more to see in the various pavilions devoted to everything ranging from specific sub-industries such as confectionaries to individual growing technologies such as reusable packaging. And educational opportunities, both from PMMI's bountiful lineup of presentations and from the exhibitors themselves, will be ever-present no matter where you go. No matter what your focus, if you do something in the packaging industry, you'll find something worthwhile at Pack Expo. You'll probably learn something, too!

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Power Transmission Engineering

Monitoring the Health of Plant Machinery

Dr. Colin Hargis, Chief Engineer, Control Techniques

Health monitoring or condition monitoring has been used for many years on machines and in plants where the cost of an outage is high. It allows failures to be anticipated and maintenance or repairs to be scheduled for the least loss of production, as well as avoiding unnecessary periodic maintenance.

It can be as simple as a person touring the plant at regular intervals with portable instruments such as a thermal imaging camera and vibration analyzer, or it might be permanently installed so that data can be gathered remotely over a long period, with the data analyzed off-line and trends identified.

With the increasing use of intelligent devices on machinery, which can be networked and their data gathered remotely at low cost, the possibility for plant health monitoring is increasing rapidly. There is plenty of information available on the web with ideas and offering products for monitoring. Here we will be looking at a range of techniques which take advantage of the special position of the variable speed drive in the machine to access further useful data.

The techniques applied need to use low-cost sensors and to be reasonably non-invasive, to avoid high installation costs, and the risk of damage from the installation process. Simple sensors, such as thermal probes and accelerometers, can be attached to accessible parts and produce a wealth of data.

For example, an accelerometer can often easily be mounted on a bearing support or machine housing to measure radial vibration from a rotating machine, and it can detect defects which cause unbalanced forces, such as broken rotating parts, cracked shafts and misaligned couplings.

A simple amplitude measurement can give general warning of potentially damaging defects, whilst a deeper frequency analysis may be able to focus attention on parts, especially if there are different rotational speeds involved — as in gearbox or belt drives.

Machine or Plant Health Monitoring Using a Variable Speed Drive

The variable speed drive is in a unique position in a machine, since it usually provides the motive power. It is an intelligent device that is closely coupled to the working parts of a machine through its electric motor. It contains information that is used to do its job reliably, but which can be easily accessed and analyzed. In other words — it can be used as an extra set of sensors — at virtually no cost.

A drive has its own internal sensors for various internal temperatures and the motor current, which are provided by the manufacturer to prevent damage to the drive or motor due to abnormal conditions. It may also have a motor temperature sensor connected.

This data is available as drive parameters and can be accessed periodically to give a warning if it is approaching a limit, and to analyze trends.

In a closed-loop control system such as a servo drive, the drive contains data regarding the control variables. It is quite common, for example, to monitor the following error in a position control loop and to raise a flag if the error exceeds a threshold. This could indicate a malfunction such as increased stiffness (impending seizure, obstruction or damage) or backlash (from wear). It is a small step to move from a simple alarm threshold to monitoring the trend of the smoothed data, and alerting the user to a developing situation that might result in future failure.

For tracking errors there must be at least a shaft transducer fitted, which typically tends to be the case in precision motion control applications. In all applications however, the drive also has access to a special measurement that is difficult to obtain by external instrumentation, i.e. — the motor torque.

To measure motor torque conventionally using a transducer is most commonly done by installing a strain gauge or load cell in the fixing of the motor housing. This requires a special motor mounting if it is to give a reliable measurement of torque, and the measurement is affected by the moment of inertia of the heavy motor frame that reduces the sensitivity to the higher frequencies.

Even more difficult is measuring the actual dynamic shaft torque, since this requires a rotating strain gauge to be fixed to the shaft, with telemetry to pass the data to the fixed side. This is an expensive operation, and is done rarely — even for a special test. It is unlikely to be a permanent installation.

The drive, however, has internal data for the torque-producing current in the motor, which is a good proxy for the shaft torque, available at no cost. The data is even available

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when the motor itself is inaccessible, whether deep inside a machine or under water or in a hazardous area. The accuracy of the torque measurement is best in a fully closed-loop system, but even in a simple open-loop drive the torque data is good enough for many purposes except at the lowest speeds.

Once we appreciate that torque data is available in the drive at virtually no cost, as well as the corresponding speed data, we can enter a new realm for machine and plant monitoring. The following is a range of possibilities that we have encountered at Control Techniques.

Readers may have new ideas for types of machines — it takes detailed knowledge of the machine to invent new methods for using the torque data that is released by the drive.

Simple limits for average or peak torqued. The real-time torque data can be smoothed to give a running average value when the drive is active, or the peak value can be captured on a time scale chosen to suit the application; this could be anything — from milliseconds to days — depending on the process. An alarm can be generated if the value moves outside of an expected range (i.e., it exceeds an expected value or, less commonly, falls below an expected value).

Trend of torque. The same torque data can be logged and analyzed for trend over time or against any other variable, with alarms set to indicate an unhealthy trend.

Simple correlations of average torque with speed. In many processes the torque is strongly dependent on the speed, in a well-defined pattern. For example, a fan or pump driving fluid through a fixed duct, pipe or loop, or a network of them, will have a well-defined torque/speed curve. Any significant deviation from the normal curve indicates a change that might represent a problem. Some examples are:

Low torque:

- Broken drive belt or other coupling
- Loss of fluid in pump
- Obstruction to flow; e.g. — blocked filter or screen for an impeller-type pump or fan, could apply also to conveyor, etc.
- Build-up of deposits on fan or pump rotor
- Cavitation in a pump due to air ingress, swirl or other faults (also causes pulsations; see below)

High torque:

- Seizure of rotor or other parts (partial or total)
- Obstruction to flow (positive displacement-type pump)
- Major leakage (impeller-type pump or fan)

A torque/speed profile can be established outside of which an alarm state is generated (Fig. 1).

Multi-variable correlations. In more complex processes the torque will depend on several variables, which might or might not be available to the drive. For example, consider a fan driving air through a system of ducts, some of which have damper controls to vary the local air flow. The torque/speed curve then depends on the positions of the dampers.

If data is available regarding the damper state, or the pressure drop over the dampers, then a multi-variable correlation may be possible to allow for this. Figure 2 gives a simple illustration of the case with two duct branches with dampers.

Another possibility is to use the measured torque and

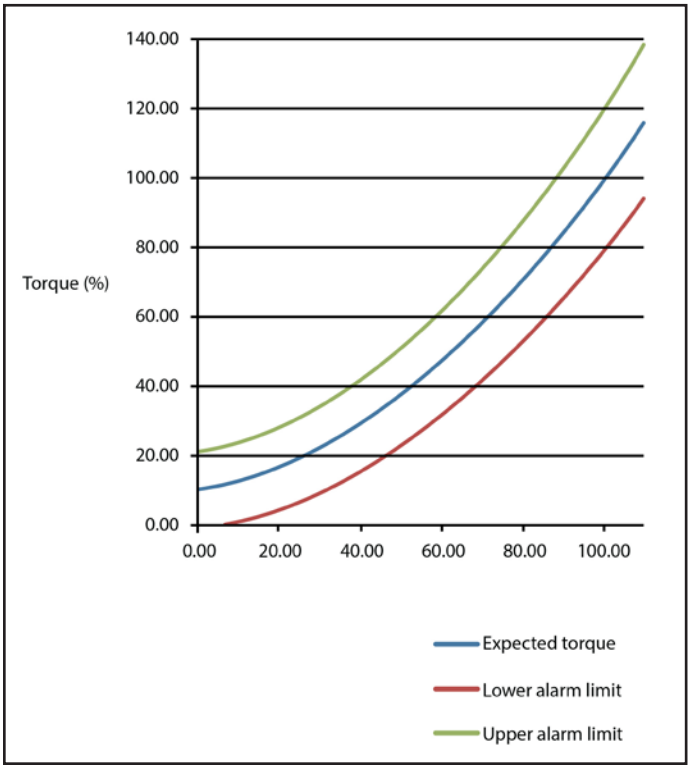

Figure 1 The torque data needs to be subject to sufficient low-pass filtering or averaging to prevent dynamic effects (acceleration torque) or normal pulsations from generating false alarms. Other variables may have an impact, for example a variable delivery pressure of a fluid, so tolerance bands must be set wide enough to prevent false alarms from this cause.

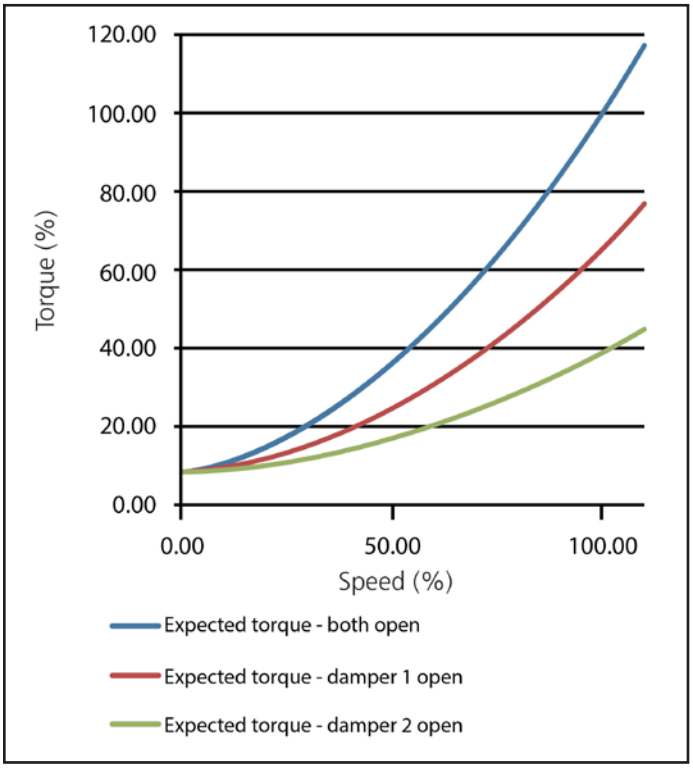

Figure 2 Expected torque for fan with two circuit dampers.

speed values to deduce the flow and pressure at the pump or fan from their characteristic curves, which could then be compared with a measured value from a transducer. Any discrepancy could mean either that the pump or fan is defective or the transducer is defective.

Dynamic analysis of torque. The torque data in the drive has a wide bandwidth and can in principle be used for dynamic analysis. It is quite common for the torque bandwidth to be in the order of 1 kHz or more, although it might not be possible to access and analyze the data at such a high rate – the data communications channel typically limits the data access to about a 250 µs sample interval.

The torque data relates to the electrical torque in the motor, which is transmitted to the output shaft but influenced by the inertia of the motor rotor and the effective stiffness of the motor control algorithm. These form a low-pass filter whose characteristics might not be known.

In a fully closed-loop system it is possible to deduce the transfer function and obtain accurate shaft torque data, so that for example high-frequency torque reversals can be detected. However the measurement does not need to be precisely calibrated in order for comparisons or trend analysis to be successful.

In practice pulsations with frequencies in the region of 100–500 Hz have been usefully monitored from motor electrical torque data.

Blocks of data can be captured in real time and subjected to dynamic analysis off line. Analysis may be in the time domain, for example by calculating the magnitude of fluctuations (overall torque pulsation or fluctuation, r.m.s. amplitude with or without time-averaging, peak values or peak negative values) or in the frequency domain through a Fourier transform with respect to time or some other variable such as position. This can then allow developing changes to be detected, specifically in the pattern of torque pulsation:

- Excessive torsional overall vibration amplitude, wideband or band-limited, e.g. from broken machine parts or cavitation in pumps
- Excessive peak torques which might result in mechanical damage or premature wear
- Frequent torque reversals which can cause gear chatter resulting in premature wear or breakage
- Frequent torque reversals which can cause gear chatter resulting in premature wear or breakage
- Torsional resonances, e.g. from loose couplings, resulting in peaks in the frequency spectrum whose frequency is independent of speed although they may be enhanced at certain speeds
- Torsional pulsations, with one or more cycles per revolution, e.g. from cracked shaft, impeller or gear tooth damage or other mechanical damage, with the possibility of tracing the source in a complex machine from the frequency of the spectral peaks, the speed, and a knowledge of gearbox or other drive ratios

Dynamic analysis of torque with speed correlation In some of the examples given above it is clearly beneficial to consider the shaft speed in conjunction with the dynamic analysis of torque, because pulsations relating to the rotation of the shaft will be at the rotational frequency (once-per-revolution effects) or a multiple of it (e.g. a cracked shaft gives twice-per-revolution, impellers may be at N-per-revolution, gear teeth at N or N1/N2–per-revolution).

It can be helpful to generate compound plots of vibration spectral analysis with speed, which will clearly differentiate N-per-revolution effects from resonance effects whose frequency is fixed, but might be stimulated only in certain speed ranges. These are referred to as cascade plots or waterfall plots, and are widely offered by suppliers of vibration analysis equipment.

Caution — sampling rates and aliasing . Care is needed in systems with rapid torque pulsations. The torque data is sampled at a rate which might be restricted by the capability of the drive to store or export data at the rate it is acquired internally. The sampling frequency will produce alias errors at frequencies such as (fs–fd) where fd is the frequency content of the data and fs is the sampling frequency. To avoid generating confusing new frequency products within the region of interest, fs needs to be kept above about 3 times fd. An added benefit of cascade plots is that alias products are clearly visible, their frequency falling as the speed increases whereas with genuine effects the frequency increases or remains constant.

Artificial Intelligence Analysis

In all of the above I have concentrated on applications where a physical understanding of the process is used to define an expected behavior, and the available data is used to compare actual operation with the expectation. Even if the amplitude scaling is uncertain, the frequencies are unique and trends can be identified. The advantage of this approach is that people involved with the process can understand the data and work from the information and alarm conditions generated to develop a diagnosis for the plant.

An alternative is to use some form of machine learning algorithm to track all the available data and aim to reduce the patterns of normal and abnormal behavior. This is a subject of current research.

Conclusion

The ideas give above are general ones based on a broad picture of a machine with rotating parts, couplings and gears, or a pump or a fan. I hope that by pointing out the special access which the drive gives to some valuable data, especially the dynamic torque data, designers of machines will be able to apply these ideas to their own specific and unique applications. **PTE**

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Influential Criteria on the Optimization of a Gearbox, with Application to an Automatic Transmission

Peter Tenberge, Daniel Kupka and Thomas Panéro

Introduction

In the design of an automatic transmission gearbox, the variation of one parameter can result in different system performances due to the strong interdependencies among all components. For given transmission ratios, component lifetimes and safeties, or space restrictions, improvements in efficiency, noise, and weight can be achieved.

In order to find an optimal solution, it is necessary to perform an analysis of a large amount of gearbox configurations. Using a dedicated design software, an engineer can easily create several variants of a transmission to evaluate. To match the real behavior of the reducer as closely as possible, it is important to take into account the following factors of influence on the simulation results.

In the example of an automatic transmission, when performing a load spectrum calculation, we have to consider the carrier deformation of the planetary stages for the misalignment of the planet axis, and the housing stiffness for the bearing positions. These results have an effect on the shaft deflections and the gear load distributions, and thus indirectly on the reliability of the system. Modifying the carrier shafts and housing design can then be a source of improvement. Thanks to the transmission error and Eigen frequency analysis, it is also possible to estimate the vibration behavior of the reducer. Modifying the shafts dimensions, macro- and microgeometries of the gears, and eventually the positions of the bearings can be necessary in this case. Concerning the power losses calculation, a modification of the macro- and microgeometries of the gears, or the bearings types, can have a considerable impact on the final results.

This paper investigates the influence of the aforementioned parameters on the optimization of a reducer. To validate our analysis, a 6AT gearbox concept is studied and developed in cooperation with the German Ruhr-University Bochum and the Chinese transmission manufacturer Shengrui Ltd.

Presentation of the Model

The model is a 6AT gearbox concept with power variation on the input. Different load spectra are defined in the *KISSsys* interface that is used to perform all the calculations, but only the maximum load condition, representing the most critical case, is used for the optimization below. This spectrum is defined (Table 1) with a requested lifetime of 2 hours for each shifting gear.

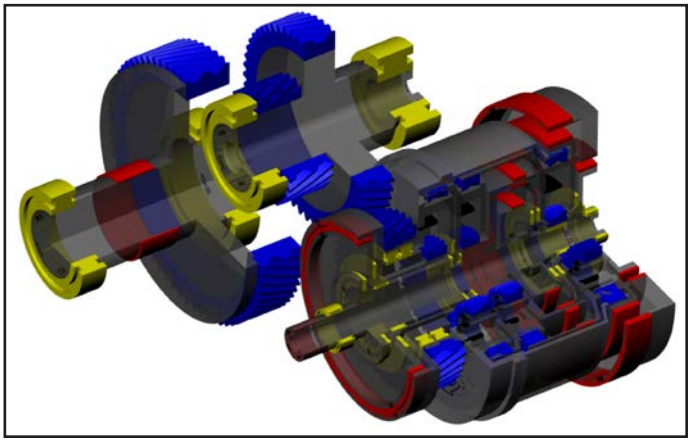

Figure 1 Model overview.

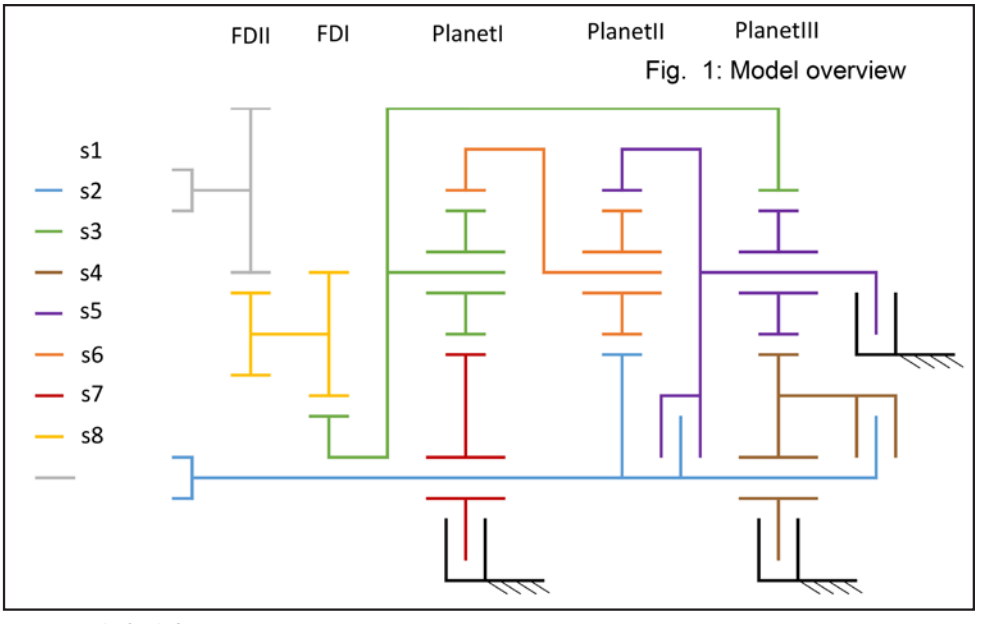

Figure 2 Shafts definition.

This paper was first presented at the International VDI Conference on Gears 2017, Garching/Munich [VDI-Berichte 2294, 2017, VDI Verlag GmbH] and is reprinted here with VDI approval.

When calculating the strength for each shifting gear independently, we can see that the most critical one is the second — mostly because in this configuration the highest torque is applied on the output shaft. Concerning the reliability of the system for each gear shift, we then get the results in Table 2, which is consistent with our previous observation.

In the current state of the gearbox, the bearings are the most critical elements decreasing system reliability. Because of the axial loads, bearing types, and model size, we don't have a wide range of optimization for these specific elements.

Concerning the casing consideration, we can neglect its effect on the bearing positions — especially in the automotive industry, where these elements are normally very stiff.

Table 1 Gear shifts definition

Gear	Ratio	Speed on sl (rpm)	Torque on sl (Nm)	Torque on s8 (Nm)
1	14.555	5000	242.74	–3393.3
2	9.0935	5000	406.51	–3539.8
3	5.6958	5000	450	–2473.4
4	4.2188	5000	450	–1849.5
5	2.9464	4881	450	–1299.5
6	2.229	3905	450	–978.28
R	–9.155	3000	229.75	2020.5

Table 2 Reliability calculation

Gear	Lifetime (h) for 99.9% reliability	Lifetime (h) for 99% reliability	Lifetime (h) for 90% reliability	Reiability (%) for 2h lifetime
1	2.9308	4.2191	5.603	100
2	1.4903	2.074	5.9691	99.121
3	4.0445	5.6288	13.909	100
4	2.5326	3.824	11.236	100
5	7.4115	11.191	32.882	100
6	22.25	33.596	98.716	100
R	3.4608	3.5567	3.924	100

With these inputs defined, we can identify the following most influential criteria to manipulate for gearbox optimization:

- For weight: shafts geometry, gears width
- For noise: shafts geometry, bearings and loads positions, gears tooth profiles
- For efficiency: gears tooth profiles

From this list we can easily estimate a good optimization process:

- First, modify the shafts geometry and gears width to reduce the weight of the gearbox while running the strength analysis to keep safeties and lifetimes above required values.
- Then, while reducing the mass, maintain a stiff design for the dynamics analysis, pushing the Eigen frequencies of the system as much as possible above the meshing frequencies.
- Finally, optimize the gears tooth profiles for a reduced transmission error and improved efficiency while considering the shafts deflections and misalignments.

It is also important to mention that the materials of the different elements, which could also be optimized, were not modified in this study.

Shafts and Gears Mass Reduction

To avoid dimensioning the coaxial group of shafts, we calculate its maximum transmittable torque in its current state. Thanks to the basic formula of the torsional stress, we can then get a corresponding mean diameter that we can compare to the current one. This method allows us to estimate the potential mass reduction of the system by applying the opposite logic and considering the current torque as the maximum transmittable one. This approach is of course just a rough estimation that consists mostly in scaling down the complete shafts with gears and bearings.

We then calculate the transmittable torque of the coaxial group (s1-s6), shafts and gears, for the second gear shift, and get a maximum of around 500 Nm, instead of the current 406.51 Nm, without decreasing its reliability below 99%. At this point we just have to size some bearings because of low lifetimes for this torque. For this torque difference of 23%, the torsional stress formula gives us an equivalent mean diameter difference of around 7% for the coaxial group of shafts.

At first, and to compare our results afterwards, we also apply this method to the idler and output shafts to estimate the total mass reduction of the system. We calculate their own transmittable torque, so without verifying the connecting gears, and get the following results:

- For s7: 2,400 Nm instead of 1,450.96 Nm — thus a variation of around 18% in diameter.
- For s8: 6,000 Nm instead of 3,539.8 Nm — thus a variation of around 19% in diameter.

For the real optimization and the rest of the study, we in fact only consider the virtual input torque of 500 Nm to resize the two parallel shafts and connecting gears, while keeping their reliability above 99%. Here we modify the shafts geometry and gear widths only to avoid creating some interference by modifying the center distances. As the gear safeties are above required values for the coaxial group, we also slightly optimize their width. We can then apply the scaling down of 7% to the whole system on top of these results to achieve the potential mass reduction for the input torque of 406.51 Nm (Table 3).

We then get around 15% off total mass reduction; and when comparing the optimized and theoretic masses for s7 and s8, we can see that we are quite close to the initial estimation.

Table 3 Mass optimization

Mass (Kg)	Initial	Theoretic	Optimized	Optimized + theoretic (7%)
s1-s6	19.26	17.88	19.14	17.78
s7	5.8	4.74	4.86	4.52
s8	10.74	8.67	8.51	7.9
Total	35.8	31.29	32.51	30.19

Dynamic Analysis of the System

A first evaluation of vibrations in the system requires performing a modal analysis. This allows us to identify the Eigen frequencies of the shafts and their mode shapes. We can then compare these values with the potential excitations coming from the meshing frequencies. For this analysis is quasi stat-

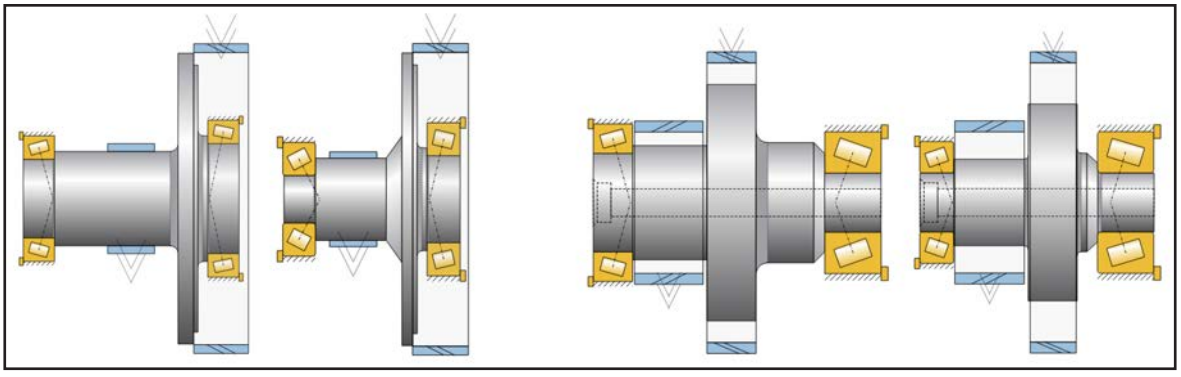

Figure 3 Mass reduction comparison for s8 (left) and s7 (right).

ic, the results should theoretically be the same for all shifting gear. But as we consider the gyroscopic effect to get closer to reality, the Eigen frequencies are different for each operating speed. The same applies to the operating torques since the bearings stiffness calculated from their inner geometry is nonlinear. The study is then made for all shifting gear, but as similar results can be observed, we can summarize the analysis with the second gear again.

We compare the modal analysis of the shafts before and after mass reduction, and can interpret the results quite well on shaft s7. First, we calculate the meshing frequencies of the system (Table 4). Here we don't calculate the harmonics and modulated frequencies with the shafts speeds, as we can already identify some critical frequencies (around 1,300 Hz, and around 1,700 Hz) in the analysis of Table 5.

We can see that the meshing frequency of around 1,700 Hz is no longer critical to the optimized shaft; but the one around 1,300 Hz — more important due to its coming from the excitation of the gear directly mounted on the shaft — is still present and now close to two different mode shapes, i.e. — axial and bending. We can also see that, in general, the Eigen frequencies of the optimized shaft are lower than the initial one for torsion and bending mode shapes. In general, it then seems that the stiffness of the shaft is reduced for these, but slightly increased for the axial deformation.

We can confirm this interpretation by decreasing only the length of the initial design — without changing the diameters — and comparing its modal analysis with the one from the initial shaft (Table 6).

First, we can see that when reducing the shaft length without changing the diameters we manage to push the first torsion mode shape in higher frequencies, thus making the shaft stiffer for this deformation. Concerning the bending mode shapes, we cannot see much difference below 4,000 Hz, simply because the nodes of these modes are mostly located at the position of the right bearing where no change was made for the diameter between all designs.

To get another estimation of the different mode shapes evolution, we compare the distance between loads and bearings when the shaft length and diameters are kept constant, like the virtual shaft displayed in Figure 4. We can clearly see that the shaft gets stiffer against torsion when the loads are close to each other in Table 7, as we can see a very steep part in the torsion mode shape between the two spaced loads as a difference from the close ones (Fig. 4).

Concerning the axial and bending mode shapes, if we look at these

Table 4 Meshing frequencies

	FDI (s7-s2)	FDII (s8-s7)	PlanetI (s6-s2-s5)	PlanetII (s1-s5-s4)	PlanetIII (s3-s4-s2)
Frequency (Hz)	1242.1	632.33	1026.1	1786.9	571.95

Table 5 Eigen frequencies comparison with meshing frequencies

Eigenmode	Initial		Lenght + Diameter reduction	
	Eigenfrequencies	Mode shape	Eigenfrequencies	Mode shape
1	1316.38 Hz	Axial	1219.51 Hz	Bending XY
2	1651.90 Hz	Bending XY	1394.17 Hz	Axial
3	2842.85 Hz	Bending YZ	2381.32 Hz	Bending YZ, Bending XY
4	3785.94 Hz	Bending YZ	3108.07 Hz	Bending YZ, Bending XY
5	4064.81 Hz	Bending YZ	3132.68 Hz	Bending XY
6	16169.46 Hz	Bending XY	15329.62 Hz	Torsion
7	16649.82 Hz	Bending YZ	16137.30 Hz	Bending XY, Bending YZ
8	17928.96 Hz	Torsion	16444.57 Hz	Bending XY
9	18220.94 Hz	Bending XY	19378.30 Hz	Bending XY

Table 6 Eigen frequencies comparison with length reduction

Eigenmode	Initial		Length reduction only	
	Eigenfrequencies	Mode shape	Eigenfrequencies	Mode shape
1	1316.38 Hz	Axial	1211.70 Hz	Bending XY
2	1651.90 Hz	Bending XY	1385.86 Hz	Axial
3	2842.85 Hz	Bending YZ	2375.54 Hz	Bending YZ, Bending XY
4	3785.94 Hz	Bending YZ	3090.85 Hz	Bending YZ
5	4064.81 Hz	Bending YZ	3115.11 Hz	Bending XY
6	16169.46 Hz	Bending XY	18508.19 Hz	Bending XY, Bending YZ
7	16649.82 Hz	Bending YZ	18762.10 Hz	Torsion
8	17928.96 Hz	Torsion	18762.16 Hz	Torsion
9	18220.94 Hz	Bending XY	18775.73 Hz	Bending XY

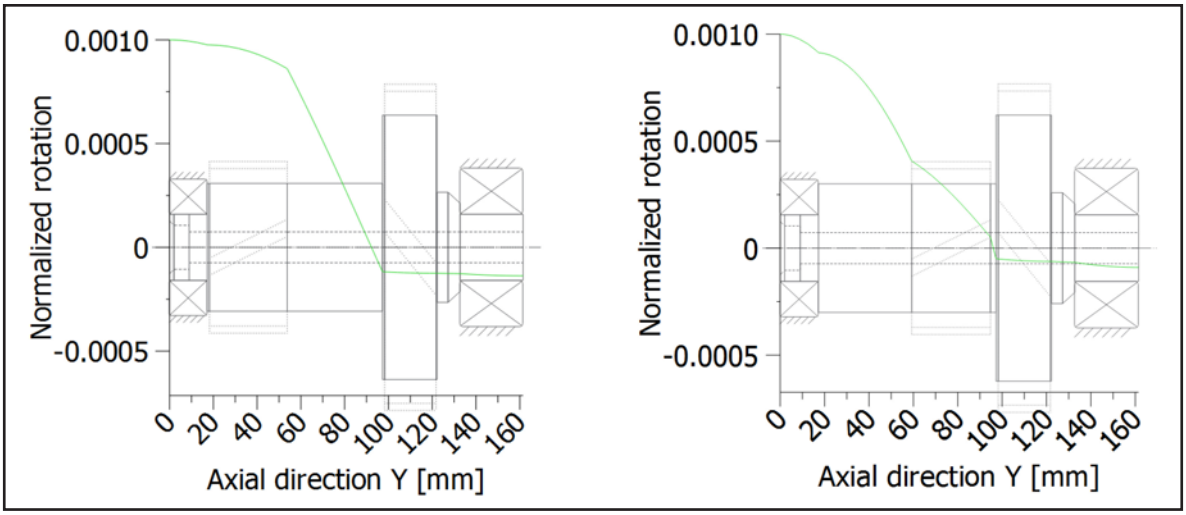

Figure 4 Influence of loads positions, example of torsion mode shape.

Table 7 Eigen frequencies comparison for loads positions

Eigenmode	Spaced loads		Close loads	
	Eigenfrequencies	Mode shape	Eigenfrequencies	Mode shape
1	1264.80 Hz	Bending XY	1264.82 Hz	Axial
2	1313.09 Hz	Axial	1324.87 Hz	Bending XY, Bending YZ
3	2269.41 Hz	Bending YZ, Bending XY	2266.30 Hz	Bending YZ, Bending XY
4	3056.80 Hz	Bending XY, Bending YZ	3014.84 Hz	Bending XY, Bending YZ
5	3259.84 Hz	Bending YZ, Bending XY	3296.86 Hz	Bending YZ, Bending XY
6	6805.40 Hz	Torsion	10500.37 Hz	Bending XY, Bending YZ
7	6938.92 Hz	Bending YZ, Bending XY	11025.08 Hz	Bending YZ, Bending XY
8	7269.97 Hz	Bending XY, Bending YZ	13017.89 Hz	Torsion
9	15257.43 Hz	Bending XY, Axial	19157.14 Hz	Bending XY

results, as well as the ones from the initial shaft where the loads were close and one load was also spaced from a bearing, we can see that spaced loads and bearings seem to be favorable to stiffness against bending, whereas the opposite appears to be favorable to stiffness against axial deformation.

In a general way, we can then say that a more compact design is better to avoid noise generation. But when reducing the mass, the engineer must maintain a stiff design by keeping correct diameters, avoiding mass concentration, and correcting loads positions depending on the mode shapes he wants to attenuate. In this case, the potential excitation emanates from the meshing frequencies.

Gear Sizing for Noise and Efficiency

For the final step of optimization we perform a contact analysis of the different meshes to evaluate and optimize their peak-to-peak transmission error (PPTE), other influential criteria for noise, and power losses. Once again we perform this analysis on the second gear shift with the maximum load provided.

For each gear meshing, we first recalculate the root and flank safeties, considering the shaft deflections, and the tilting of the planet axis from the finite element tool included in the simulation software *KISSsoft*. We can then observe that with the face load factors (KHb) consideration (Table 8), these safeties are much lower than the theoretical ones calculated in the first step of this optimization.

We try then to optimize the gears macro- and microgeometries in terms of transmission error (sizing of the profile modifications as well for a smooth meshing during the same operation) and power losses, considering the face load factors calculations due to the shafts deformations, and for a reliability of the system still above 99%. The center distances and gear widths are kept constant, as well as the gear ratios (with a minimized deviation).

During the sizing functionality, for better wear reduction we then also choose to consider only the solutions that provide a specific sliding below an absolute value of 3, and profile shifts coefficients optimized for a balanced specific sliding along the path of contact between the pinion and the wheel.

As can be seen in Figure 6, the software covers more than 200 solutions for each meshing, from which we can pick the optimum one between transmission error, efficiency and mass. In this example the solution 200 in the top left corner seems to be the best choice in terms of TE and efficiency, and is in the lower range in terms of mass, which doesn't vary

Figure 5 Carrier mesh s2.

so much anyway from the lightest to the heaviest solution. We perform this operation for the 2 gear pairs and the 3 planetary gear sets; and because an improvement of both efficiency and transmission error is not possible in most cases, we therefore tend to accentuate efficiency when the transmission error is quite low; but that is again depending on the direction the engineer wants to take.

We can generally observe in the optimum solutions that the geometries all tend to provide a transverse and overlap contact ratio getting close to 1.5 each. For example, if the overlap ratio is higher, then the helix angle will decrease, and vice versa. For the rest of the parameters, mostly, modules and teeth numbers vary in opposite directions to maintain constant center distances while getting a transverse contact ratio closer to 1.5. And, the pressure angles tend to increase when the bending safeties are much lower than the required ones.

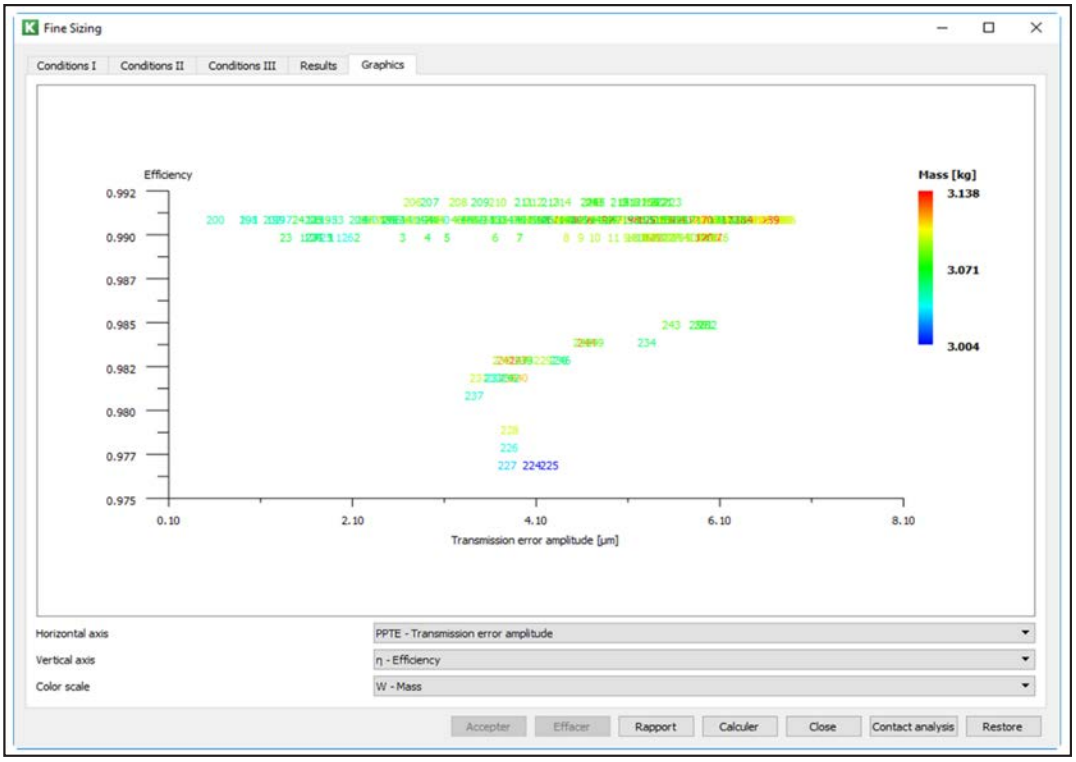

Figure 6 Fine sizing of the gears.

Table 8 Gear sizing results

	FDI (s7-s2)	FDII (s8-s7)	PlanetI (s6-s2/s2-s5)	PlanetII (s1-s5/s5-s4)	PlanetIII (s3-s4/s4-s2)
KHb Initial	1.4381	1.1972	1.3241/1.2374	1.0220/1.0736	1.0910/1.2567
KHb final	1.2775	1.1076	1.2849/1.1926	1.0185/1.0641	1.0891/1.1975
Difference	0.1606	0.0896	0.0392/0.0448	0.0035/0.0095	0.0019/0.0592
PPTE ini. (µm)	2.7733	1.3466	0.210	0.036	0.040
PPTE fin. (µm)	2.5181	0.5793	0.342	0.089	0.135
Difference (µm)	0.2552	0.7673	–0.132	–0.053	–0.095
Efficiency ini. (%)	99.27	97.98	98.90	97.68	99.02
Efficiency fin. (%)	99.39	99.11	99.19	98.67	99.45
Difference (pp)	0.12	1.13	0.3	1	0.45

We can then calculate a total efficiency improvement from around 93% on the initial system, to 96% on the optimized one, when considering only the gear meshing losses. Concerning the transmission error, we can see that the PPTE value is considerably improved for the 2 gear pairs, but slightly bigger for the three planetary stages where the initial value was already very low. Overall, we can say that the optimization for noise reduction on the gears is also successful.

Conclusion

When trying to optimize a gearbox, a considerable amount of solutions exist. If, for a certain system reliability, the perfect solution could be found for noise reduction, it would necessarily be to the detriment of mass and efficiency, and vice versa. Once the objectives of the project have been clarified, an engineer can then prioritize the elements to optimize and find the right balance between the modification of the shafts geometry, bearings and loads positions, and gear tooth profiles. With the help of a designated simulation software like *KISSsoft*, the engineer can then evaluate the dynamic behavior of several geometric variants of a reducer in a very short time, size the corresponding bearings to match the required lifetime, but also evaluate the relation between transmission error, efficiency, mass or other, of hundreds of propositions of gear geometries with optimized profile modifications that match his design limitations. **PTE**

Daniel Kupka, M.Sc. studied mechanical engineering (2007–2012) at Ruhr-Universität Bochum, Germany, including in 2011 the study of automotive engineering, Chalmers TH, Göteborg, Sweden. From 2013 to present (2018), Kupka has worked as a research associate at the chair of industrial and automotive drivetrains, Ruhr-Universität Bochum.

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Prediction of Heat Generation in Transmission Bearings by Application of FEM

Aleksandar Miltenović, Vojislav Miltenović, Žarko Mišković and Radivoje Mitrović

Introduction

Heat generation in bearings is manifested by the power losses of the transmission. Because of the rise in temperature due to heat generation, the appearance of dilatation adversely affects the bearings' geometrical characteristics. Heat generation has an adverse effect as well on the properties of lubricant, its efficiency of work, and rheological characteristics. There are several ways for heat generation within rolling bearings, e.g.: by friction between the rolling bodies and raceways; due to hydraulic resistance of lubricants; friction between the rolling bodies and cage; friction between the cage and rim of rings; and friction between the seals and rings. This paper discusses the first of these five causes, which is considered to be dominant. By application of finite element method, the heat generation between the rolling bodies and raceways was predicted. This paper studies the influence of contact load and angular speed on the heat generation, while taking into the account the thermal properties of the bearing components. Based on performed numerical research, a new method for prediction of heat generation in transmission bearings is proposed.

Problems relating to the determination of the friction-generated heat, temperature distribution and heat partition factor in the transmission bearings are well known in scientific circles, and a great number of studies of the fields of machine elements and tribology deal with them.

Vats (Ref. 1) analyzed thermal behavior of rolling bearings and showed the distribution of temperature as well as heat dissipation through the surface of rolling bearings by using FEM software *ANSYS*. Kushwaha (Ref. 2) focused his study at speed of temperature change in bearings. His simulation showed that the increase of speed leads to a quicker attainment of the steady state of the system. Bishop and Etles (Ref. 3) considered that temperature increase mostly depends on load and speed; they analyzed the thermo-elastic interaction of shaft in plastic casing. Friction temperature is calculated as a function of friction coefficient, contact pressure, and sliding speed. He took into account radial expansion of the shaft while casing expansion was ignored. Hazlett and Khonsari (Refs. 4–5) developed a thermomechanical model using finite elements in *ANSYS*. Thermal analysis was first done for studying friction heat on the contact surface of the casing and the whole surface of the shaft. Results of thermal analysis were used as thermal load for solving the thermos-elastic model. Wang, Conry and Cusano (Refs. 6–7) carried out thermal analysis that is similar to the analysis of Hazlett and Khonsari. Distribution of heat between shaft and bearings was done iteratively by comparison of surface temperature of the radial and axial models.

This paper presents a new method for prediction of heat generation in rolling bearings. The new method combines results of direct-coupled structural-thermal analysis and transient thermal analysis to obtain temperature distribution of the bearing. The proposed method is computationally efficient and enables quick determination of bearing temperature distribution.

Friction and Friction Heat

Friction occurs during sliding of one solid body on the other. During this process with bearings, resistance force becomes heat that causes an increase of temperature in both shaft and casing. A mechanism that transforms can vary, depending on sliding conditions. It is well known that friction of solid bodies and connected friction processes including friction heat and concentrated in real zone of contact between two bodies in relative movement. A majority of authors agree that most energy that is lost in friction contact is transformed into heat. An increase of temperature of shaft and bearing is caused by dissipation of energy known as "friction heat." Assuming that all of this energy is lost as heat in the sliding surfaces within the actual area of contact, then the rate of change of heat generated per unit contact area, q_t, given by Equation 1 is:

$$q_t = \mu \cdot p \cdot \Delta v \tag{1}$$

μ – friction coefficient; p – contact pressure; $\Delta v = v_2 - v_1$ – relative sliding speed

The friction-generated heat is distributed in two bodies in contact, and distribution can be calculated by Fourier law. Fourier law of heat conduction in isotropic solid body, which is moving at a speed v, can be calculated according to Equation 2.

$$\nabla \cdot k\nabla T + \dot{Q} = \rho C \frac{dT}{dt} = \rho C\left(\frac{\partial T}{\partial t} + v \cdot \nabla T\right) \tag{2}$$

$\dot{\mathbf{Q}}$- heat generated per unit volume; k - thermal conductivity; ρ – density; and C - specific heat

Since there is no internal heat generated for the case relating to this operation, and when k is equal and constant, Equation 2 can be written in the form given by Equation 3:

$$k\nabla^2 T = \rho C\left(\frac{\partial T}{\partial t} + v \cdot \nabla T\right) \tag{3}$$

or shortly

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$$\nabla^2 T = \frac{1}{\kappa}\frac{dT}{dt} \quad (4)$$

$$\kappa = \frac{k}{\rho C} - \text{thermal diffusivity}$$

Frictional heating and the resulting contact temperature can have a significant impact on the tribological behavior and failure of sliding components. Temperatures on or near the surface may become high enough to cause changes in the structure and properties of sliding materials, and can cause surface oxidation or even melting of bodies in contact. These temperature increases may be the reason for a change in behavior on the friction and wear of the material. *ANSYS* is used to simulate with numerical method the behavior of bearings in operation. Friction-generated heat is calculated by *ANSYS* software using the heating factor and is given by (Ref. 5):

$$q = FHTG \cdot \tau \cdot v = FHTG \cdot \mu \cdot p \cdot v \quad (5)$$

q – total generated heat; *FHTG* – dissipation factor which takes into account a part of friction energy that is converted into heat; T – friction that depends from contact pressure and friction coefficient; and v – relative sliding velocity.

The analysis considered literature sources that suggest that most of the authors in their research reached two assumptions: first, that the total energy, which is generated due to friction is converted into heat, and second, that equal parts of energy transferred to the two bodies in contact.

A New Method for Prediction of Bearing Temperature Distribution

A schematic depiction of the algorithm of the new method is shown in (Fig. 1). The new method uses the results of friction-generated heat obtained by direct-coupled structural thermal analysis in the time domain as an input of transient thermal analysis. The input parameters of the direct-coupled analysis in the time domain are the coefficient of friction, radial force, and speed. As already noted, the result of the direct-coupled analysis is the value of the generated heat flux at nominal operating conditions; in the nominal operating conditions the obtained heat flux is constant over time.

The determined value of the contact heat flux can be averaged and can be used as a boundary condition in the transient thermal analysis. In this way it is possible to determine the temperature field of bearings at any point in time. The advantage of the proposed procedures is the fact that with the use of moderate computer resources, and for a relatively short time, it is possible to determine the temperature of the bearing. Use of only direct-coupled analysis is not rational because it would require vast computational resources to obtain the temperature distribution in reasonable time. Unlike other authors who mathematically determined the contact heat flux and then used calculated flux in thermal simulations, for the first the time generated heat flux due to friction in the bearings is determined by simulation.

For a proposed new method, a case study was defined. The goal of the case study was to obtain temperature distribution of bearing 6310 made from 100Cr6 steel, subjected to radial load of 4,600 N at a rotation speed of 1,140 rpm. Numerical analysis was performed in *ANSYS Workbench*. Model loads and boundary conditions were defined using joints in order to take into account the rotation of the shaft and the bearing pressure applied to the shaft (Fig. 2). Heat transfer from the model of the environment is defined from all the surfaces with a heat transfer coefficient of 15 W/m2K. It was necessary to define the convection over command interface, as *ANSYS Workbench* currently does not have a graphical user interface for direct structural-thermal coupling. The thermal material properties of bearing steel 100Cr6 are given (Table 1). Properties of the material during the analysis were regarded as constant since the simulation time was short (2 seconds) as the goal of this analysis was to obtain contact flux only and the anticipated temperatures were below 100°C.

In order to perform a direct coupling of the thermal and

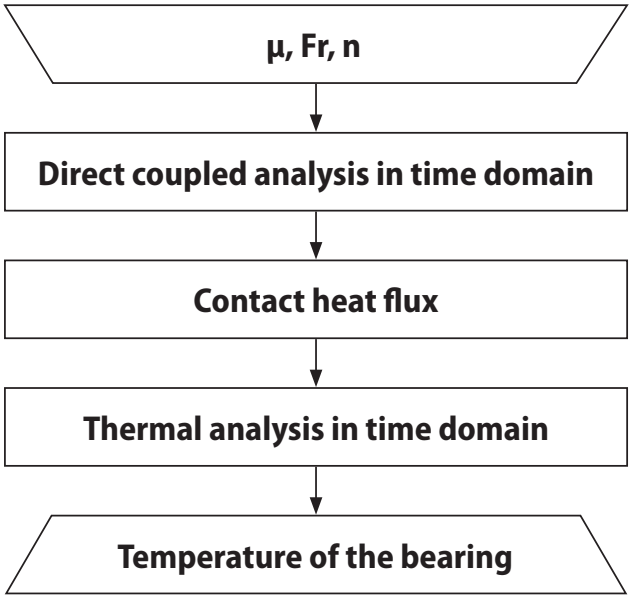


Figure 1 Schematic depiction of the algorithm for the prediction of bearing temperature distribution.

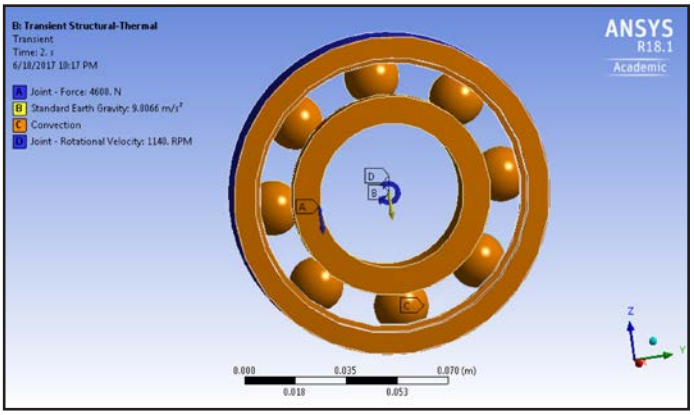


Figure 2 Loads and boundary conditions of a structural-thermal direct-coupled analysis.

Table 1 Thermal properties for bearing steel 100Cr6

Parameter	Value
Stefan-Boltzmann constant, W/m^{2}K^4	5.67×10^{-8}
Specific heat capacity of steel, J/kgK	475
Conductivity coefficient	46.6
The coefficient of convective heat transfer from steel to air, W/m^{2}K	15

structural field, was used in the final element SOLID 226, ANSYS (Ref. 8) to generate a finite element mesh. The discrete model is composed of 59,012 nodes that form 15,989 elements. The contacts between the raceways and rolling elements were defined as the frictional contact, with the friction coefficient value of 0.08. The contacts were treated as symmetrical, with the use of the extended Lagrange formulation.

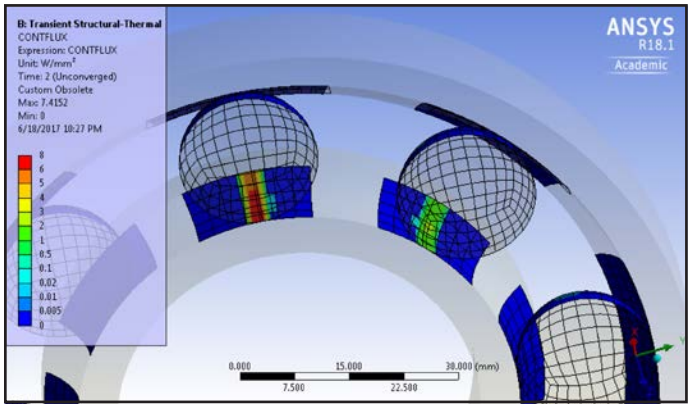


Figure 3 Boundary conditions of thermal analysis in time domain.

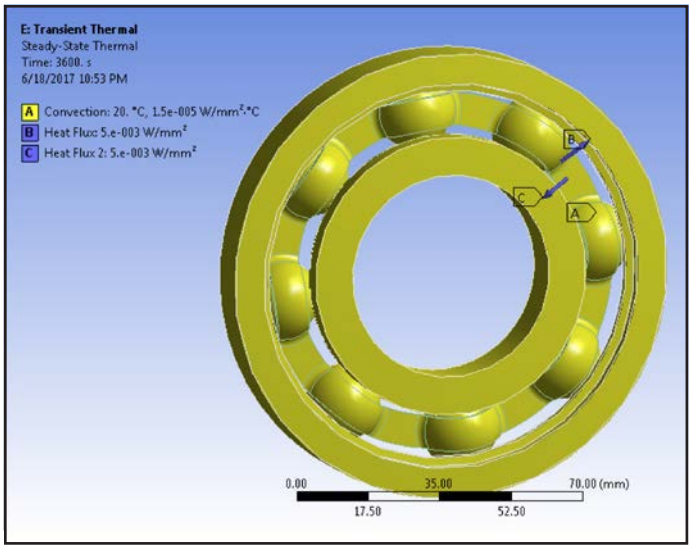
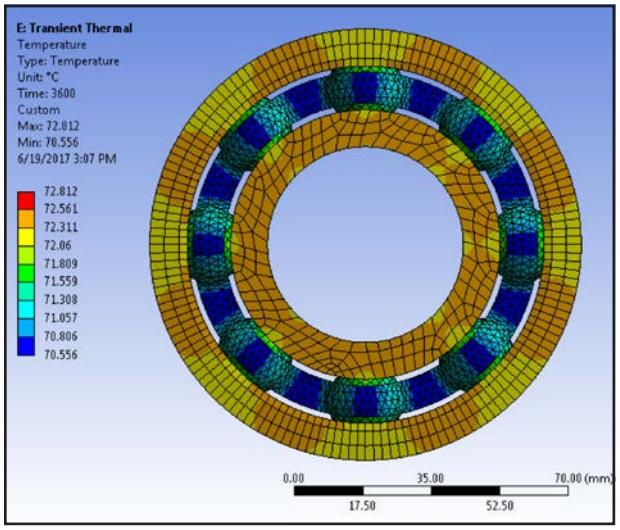


Figure 4 Boundary conditions of thermal analysis in time domain.



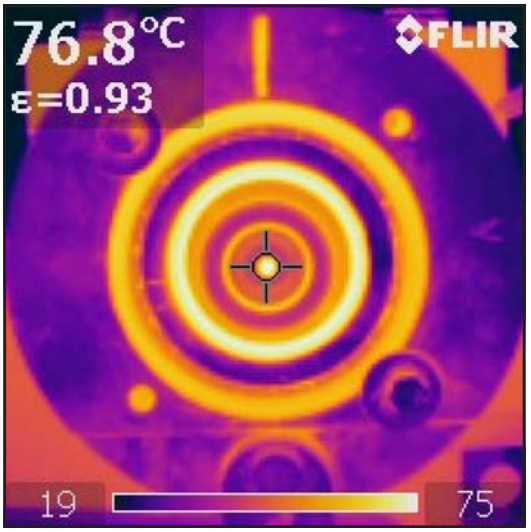


Figure 5 Comparison of numerically and experimentally obtained results.

Stiffness of contacts was automatically updated at every iteration of numerical solution. Software has been assigned to the account for the heat generated by friction through the command interface. Figure 3 shows the distribution of heat flux between the rolling bodies and the inner bearing ring. It is obvious that the heat flux is generated only in contacts were the rolling bodies are in contact with the rolling surface as a consequence of the action of radial load.

The discrete model is transferred to the thermal analysis in the time domain. The obtained contact flux from that previously given was averaged and used as a load in thermal analysis; model and the boundary conditions are shown (Fig. 4).

The result of transient thermal analysis is a temperature distribution of the bearing. Results obtained by simulation were compared with the results obtained experimentally for an experimental setup that corresponds to the above defined case study (Fig. 5). It is clear from Figure 5 that there is a reasonable agreement between the results obtained by a proposed new method and the experimental ones.

Conclusion

This paper presents a new method for determination of the temperature distribution of the transmission bearing; the method consists of two analyses by finite element method performed in succession. The first, directly coupled structural thermal analysis, gives a heat flux generated due to friction at the contact of rolling bodies and the raceways. The resulting heat flux is then averaged on the raceway surface and used as a boundary condition in transient thermal analysis that, as a result, reveals the temperature distribution of the bearing. The performed case study presented here showed that the new method predicts bearing temperature distribution reasonably well, as there is a good agreement between the results obtained by FEM and experimentation. The new method presented in the paper is reasonably straightforward to perform, computationally efficient, and can be expanded to account for temperature-dependent thermal properties. Further research should be directed towards validation of the method for the more realistic conditions, such as existence of radial clearance, friction generation in the contact of the

rolling elements with a cage, as well as other influences that contribute to friction heat generation. **PTE**

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September 29–October 3—WEFTEC 2018

New Orleans, Louisiana. WEFTEC, the Water Environment Federation's Technical Exhibition and Conference, is the largest annual water quality event in the world. WEFTEC is the largest conference of its kind in North America and offers water quality professionals from around the world with the best water quality education and training available today. An increasing number of abstract submittals from experts in the water quality field results in a world-class technical program of technical sessions and workshops that addresses a diverse and comprehensive list of contemporary water and wastewater issues and solutions including: Energy management, plant operations, regulations, research, utility management, recycling and more. For more information, visit *www.weftec.org*.

October 2–5—World of Technology and Science 2018

Utrecht, Netherlands. World of Technology & Science is a chain of technology in one location. The five branches include Industrial Automation, Laboratory Technology, Industrial Electronics, Motion & Drives and Industrial Processing. The Motion & Drives show features hydraulics and pneumatics, mechanical drive systems, vacuums and compressors, measurement and feeback systems and control and networking systems. The Automation show features process automation systems, field instrumentation, sensors and motion control and mechatronic systems and software. For more information, visit *wots.nl*.

October 14–17—Pack Expo International 2018

Chicago, Illinois. North America's largest packaging event will bring together the solutions needed to launch new products and solve production issues. Corporate managers, engineers, sales managers, plant managers, manufacturers and production supervisors, brand and marketing managers, quality controllers, purchasers, research/development and package designers from a wide variety of consumer packaged goods companies (CPGs) will be in attendance. More than 2,500 exhibitors will display state-of-the-art technologies, equipment and materials. The show is co-located with the Healthcare Packaging Expo, bringing pharma/biopharma, nutraceutical and medical device manufacturers together for the latest trends, innovations and solutions. The PACKage Printing Pavilion will showcase smart printing applications, digital color printing options and labeling/coding solutions. The Innovation Stage will feature 30-minute seminars on new technologies and tactics. For more information, visit *www.packexpointernational.com*.

October 16–18—PBIOS 2018

Odessa, Texas. Every even-numbered year the Permian Basin International Oil Show, Inc. (PBIOS) brings together people from every phase of the petroleum industry. Attendees come to learn about the latest technology, the newest equipment, to transact business and renew friendships. Unlike most exhibitions, the Permian Basin International Oil Show, Inc. is a non-profit venture whose sole purpose is educational, designed to serve the oil and gas industry. PBIOS not only showcases the very latest technology, it also honors the industry's past. A working cable tool rig operates daily on the show grounds during the three-day show, surrounded by trucks and oilfield equipment from the 1930s, a key growth period for the industry in the Permian Basin. For more information, visit *www.pboilshow.org*.

Tim Breen

1960–2018

Motion Industries, Inc. is saddened to announce the sudden passing of its president and CEO, Tim Breen.

"Motion Industries has lost a great leader and the world has lost an amazing human being," said Motion Industries Leadership. "Those of us who have been fortunate enough to know and work with Tim have lost a dear friend and an inspiration. Tim leaves behind a great company, a great culture and a great team that he affectionately referred to as 'The Motion Family.' His spirit will forever live on at Motion."

Breen began his career with Berry Bearing Company in 1982 and served there as a sales representative, branch manager, regional manager, and corporate accounts manager. His responsibilities continued to grow after Berry Bearing and Motion Industries joined forces in 1993.

His leadership as both a division officer and group officer distinguished his record and he assumed responsibility of all the U.S. locations in 2011 as executive vice president and chief operating officer. Breen was promoted to Motion Industries president and chief operating officer in 2013, before his promotion in November 2014 to president and CEO. With Breen at the helm, Motion Industries attained its record $5 billion sales goal at the end of 2017.

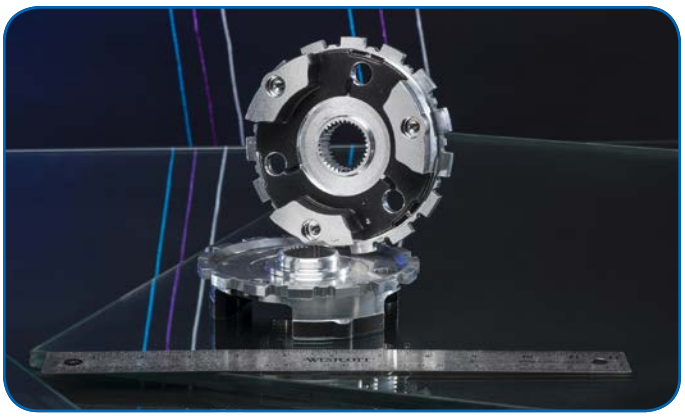
Breen was a past president of the Bearing Specialist Association (BSA), involved in the Power Transmission Distributors Association (PTDA) and was on the board of Junior Achievement of Greater Birmingham. He was an avid golfer, camper and enjoyed boating and watching sports, especially Notre Dame and the Chicago Cubs.

Motion Industries Leadership added, "We will honor his memory by dedicating ourselves to continuing the work he loved, growing the company he led and appreciating the team he loved so much. Tim's guidance and vision have left us in a strong position to continue building the Company's success." (*www.motionindustries.com*)

GKN and Stackpole

RECEIVE PM DESIGN AWARDS

Winners of the 2018 Powder Metallurgy Design Excellence Awards Competition, sponsored by the Metal Powder Industries Federation (an international trade association for the metal powder producing and consuming industries), were announced at the PowderMet2018 International Conference on Powder Metallurgy & Particulate Materials. Receiving grand prizes and awards of distinction, the winning parts are outstanding examples of



PM's flexibility to push forward new concepts and process controls and demonstrate the inexhaustible well of capabilities PM can marshal in the service of component design. Designers continue to choose PM for critical applications such as auto engines and transmissions, medical devices, consumer products, military applications, and more. The Grand Prize in the Automotive—Transmission Category was awarded to GKN Powder Metallurgy for an aluminum planetary reaction carrier made for General Motors. The carrier goes into the all-new GM 9T50 9-speed transmission offered in such vehicles as the Chevrolet Malibu and the Equinox crossover. Compacted of a unique metal-matrix-composite (MMC) aluminum alloy system and mated to an overdrive carrier, this first-of-its-kind two-piece design required industry-first tolerances.

GKN Powder Metallurgy won a second Grand Prize in the Automotive—Engine Category for a copper steel main bearing cap made for FCA US LLC. The part is used in the 2.0 L all-aluminum turbocharged four-cylinder FCA engine launched in the Alfa Romeo Giulia. While powder metal

(PM) main bearing caps have dominated engine design for more than two decades, the design of this part breaks new ground. Requirements for engine weight reduction drove the designers to an "upside down" sculpted version. The novel design delivers a part that is 23% lighter than previous versions and offers a 10% better fatigue strength. In addition, an Award of Distinction in the Automotive—Transmission Category was given to Stackpole International, Canada, for a copper-steel rear planetary carrier made for Ford Motor Company. It's used in the new 10-speed automotive transmission developed by Ford jointly with General Motors that was launched in such vehicles as the Ford Mustang and GM Camaro. The assembly consists of a clutch hub and a spider, which are joined using a novel sinter-brazing concept. The creative design of the ferrous carrier enabled it to win out over an aluminum casting design by delivering lighter weight and superior strength. (*www.mpif.org*)

Dana

SET TO PURCHASE DRIVE SYSTEMS SEGMENT OF OERLIKON GROUP

Dana Incorporated has announced that it has signed a definitive agreement to purchase the Drive Systems segment of the Oerlikon Group, a global manufacturer of high-precision gears; planetary hub drives for tracked vehicles; and products, controls, and software that support vehicle electrification across the mobility industry.

Under the terms of the agreement, Dana will acquire Oerlikon's Drive Systems business for CHF 600 million (approximately $600 million). Committed financing has been arranged to complete the transaction, which will be immediately accretive to earnings upon closing. Subject to customary regulatory approvals, the acquisition is expected to close in late 2018 or the first quarter of 2019.

Consistent with Dana's enterprise strategy, the acquisition of Oerlikon Drive Systems provides numerous opportunities to drive profitable growth. Among them, the transaction:

Complements and extends Dana's current technology portfolio, especially with respect to high-precision helical gears for the light- and commercial-vehicle markets and planetary hub drives for tracked vehicles in the off-highway market;

Provides products, controls, and software that support vehicle electrification in each of Dana's end markets — light vehicle, commercial vehicle, and off-highway;

Optimizes Dana's global manufacturing presence to be closer to customers in key growth markets such as China and India, as well as the United States; and

Adds five research and development facilities to Dana's extensive network of technology centers.

"Oerlikon Drive Systems is a well-respected technology company that has provided exceptional product innovation and customer satisfaction for nearly a century," said Jim Kamsickas, president and chief executive officer of Dana. "A great fit culturally, this investment will deliver significant long-term value by accelerating our commitment to vehicle electrification and strengthening the technology portfolio for each of our end markets while further expanding and balancing the manufacturing presence of our off-highway business in key geographical markets." (*www.dana.com*)

Timken

REACHES AGREEMENT TO ACQUIRE CONE DRIVE AND ROLLON GROUP

The Timken Company has reached an agreement with pan-European firm Chequers Capital and IGI Private Equity to acquire Rollon Group. A leader in engineered linear motion products, Rollon specializes in the design and manufacture of linear guides, telescopic rails and linear actuators used in a wide range of industries such as passenger rail, aerospace, packaging and logistics, medical and automation. Rollon sales are expected to be about $140 million for the full year 2018.

"The acquisition of Rollon will further expand the Timken portfolio of leading industrial brands, allowing us to serve existing and new customers in attractive, high-growth end markets around the world," said Richard G. Kyle, Timken president and chief executive officer. "Like Timken, Rollon is an expert in motion technology and is recognized for developing customized linear motion products for their customers' application challenges. With its proven operating model and value proposition, Rollon will open up exciting new growth opportunities for the company."

Additionally, Timken recently announced that it has reached an agreement to acquire Cone Drive, a leader in precision

drives used in diverse markets including solar, automation, aerial platforms, and food and beverage. Cone Drive sales are expected to be slightly above $100 million for the full year 2018. "We are executing our strategy to profitably grow Timken's power transmission offering across diverse markets around the world," said Kyle. "The acquisition of Cone Drive will deepen Timken's position in attractive, high-growth end markets such as solar and increase our power transmission presence in China. Cone Drive is highly complementary to

our business, and we plan to generate significant sales and cost synergies with this transaction."

Cone Drive is headquartered in Traverse City, Mich., and has manufacturing operations in the United States and China. The company has a global customer base and employs approximately 500 people. The business produces a broad range of highly customizable precision drive products that include Cone Drive and H-Fang branded high-torque worm gears, harmonic solutions and precision slew drives. (*www.timken.com*)

Siemens

INVESTS IN MOTOR TESTING FACILITY

With its celebration of more than 120 years of innovation, market and product leadership, technology and quality, Siemens' Norwood Motor Manufacturing plant recently opened a new Test Observatory.

Opened in 1898, the Norwood facility, just outside of Cincinnati, has undergone a century of change, as the process to manufacture motors and the technology behind them has improved. Norwood has stood the test of time through three industrial revolutions, and is one of the longest continuously operating Siemens' plants globally. With Industry 4.0 upon us, the mechanical motor of old is now a connected device, a valuable plant floor asset capable of providing vast amounts of data with preventative and predictive analytics to ensure more productivity, efficiency and uptime.

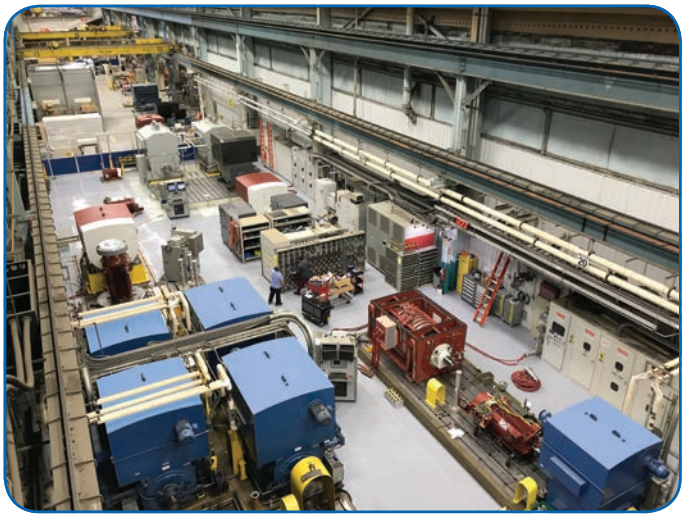
With the largest motor test base in North America, Siemens can combine its century of industry leadership in motor manufacturing with an enhanced customer experience. The new equipment extends Norwood's testing range from 10,000 to 20,000 hp at frequencies from 10 to 300 Hz, thus addressing the market's increased use of variable frequency drives. The new test observatory, akin to an executive suite, allows customers to participate by observing testing through bay windows, direct cameras and mirroring computers, which display real time critical data being gathered by sensors attached to their motor.

The project, which began in 2016, required the removal of 550 tons of soil and concrete from the site, excavating a 13-foot deep hole, driving 114 pilings for stability and building a huge concrete vault to securely support a fully loaded test stand. The test stand weighs 360 tons and rests on a self-leveling air spring system designed to support 500 tons when loaded with motors and drives.

The testing equipment includes two Sinamics Perfect Harmony GH180 drives and two dynamometers. Generating power to test a 20,000 hp motor requires significant amounts of electricity, and by recycling power to the grid, the new equipment reduces power loss by 90 percent.

"At Norwood, we test every motor that we produce or repair — some 30 to 50 tests per week — and these new facilities give us the ability to conduct as many as five motor tests at a time." said Tim Bleidorn, manager, manufacturing excellence. "We expect the customer witness tests to average two to three per week and as many as 120 per year."

In addition to the new test base and observatory, the multi-million dollar investment in Norwood also includes WFL high-precision shaft making equipment and a high-speed balancer, key for two-pole applications at higher speeds and the ability to balance a rotor at up to 12,000 rpm.



"It's exciting and I'm proud that Siemens is investing in the North American market. We have the No. 1 market share in AboveNEMA motors right now and these new capabilities send a strong signal to our customers and competitors that we intend to maintain that position," says Ryan Maynus, AboveNEMA product manager.

With more than 100 patents, the 350,000 square-foot facility is a cornerstone to Siemens AboveNEMA motors. The ISO-9001 certified plant has produced more than 150,000 high voltage motors since 1898. The Norwood plant produces horizontal AC induction motors up to 20,000 horsepower and voltage ranges from 460 to 13,200 volts. The plant also manufactures a complete line of large AC vertical motors up to 8,000 horsepower. (*www.usa.siemens.com/abovenema*)

Triton

SIGNS AGREEMENT TO ACQUIRE SKF MOTION TECHNOLOGIES

Funds advised by Triton have signed an agreement of its intention to acquire the business unit SKF Motion Technologies from SKF Group, listed on Nasdaq Stockholm. Triton intends to form a standalone company under a new brand.

Regulatory approvals, finalization of necessary consultations and other customary closing conditions are underway. SKF's French linear and actuation technology business is dealt with on a separate process, but both parties have the intention to reach an agreement to also divest it to Triton.

SKF Motion Technologies is a global provider of electrical linear actuator components- and systems as well as linear motion products, with market leading positions and differentiated offerings in global niche markets, including high end medical and industrial actuators and roller screws. Headquartered in Gothenburg, Sweden, the company operates nine production sites (Sweden, France (2), Switzerland, Germany (2), US, Taiwan and China), 13 dedicated sales units and employs approximately 1,200 employees.

"We look forward to actively supporting the management and employees as a stable owner by investing in and supporting the growth and development of the company. Our strong industry expertise, gained through other investments and strengthened by senior industry experts, will contribute in taking the company to the next level," said Peder Prahl, director of the general partner for the Triton funds.

"By becoming a standalone entity supported by an experienced and active owner with broad sector expertise, we will improve our ability to advance our positions and offerings in niche markets segments, said Daniel Westberg, managing director of SKF Motion Technologies.

"SKF Motion Technologies operate in a structurally growing market driven by automation with an attractive product portfolio and strong engineering competence. We look forward to apply our experience from other corporate carve out processes to build and grow the company further," said Johan Pernvi, investment advisory professional and advisor to the Triton Funds. (*www.triton-partners.com*)

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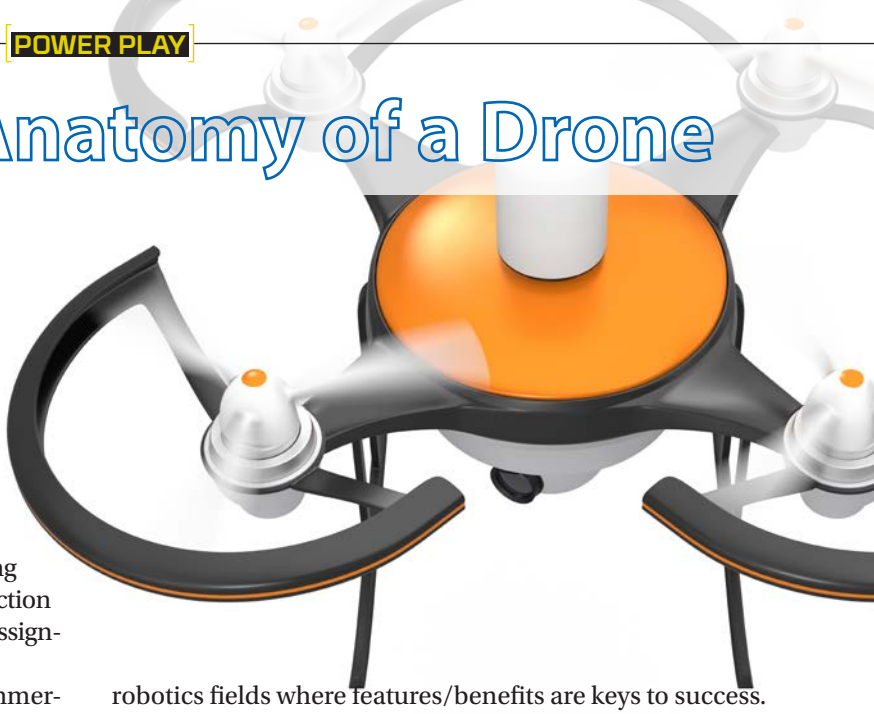
Motor Insight: Anatomy of a Drone

Matthew Jaster, Senior Editor



The skies are full of them in 2018—drones flying around amusement parks, job sites and even your own backyard. There are drone racing leagues on ESPN, drones capturing wide angle shots over film locations and government drones keeping a bird's eye view on the Mexican/America border. You even have farming drones being utilized for field and soil analysis as well as crop spraying. Drones are being employed to study weather patterns, inspect construction sites, deliver packages and for telecommunication assignments.

According to market research, 16+ million commercial drones will be sold per year by 2020. And the value of drone-powered solutions continues to climb — reaching an estimated $130+ billion in industrial applications. This year alone, military drones are estimated to be valued around $12.2 billion. As this is a trade magazine, we won't get into the minutiae of drone requirements, regulations or rules. Instead, we'll focus on the components that help drones safely and efficiently navigate the skies.

Maxon Precision Motors offers Ironless Core DC Brush motors with high efficiency and precise position control for drones, according to Michael Beasley, U.S. aerospace and defense business development engineer at Maxon.

"We also have Brushless DC motors flat and frameless for high power to size/weight ratio, planetary gearboxes for efficient torque transmission, and encoders for accurate positioning and control," Beasley said.

In addition to drone applications, these products can be found in the aerospace, medical, semiconductor and robotics fields where features/benefits are keys to success.

The challenges in providing components for drones includes the power to weight ratio, (size and efficiency) as well as environmental obstacles — temperature, altitude and vibration.

"Maxon meets these challenges by providing strong Neodymium magnets, ironless core technology and minimizing the stator to rotor air gap," Beasley said. "Additionally, temperature, altitude and vibration challenges are met with product packaging, materials and lubricants."

For example, the EC and EC-i flat motors from Maxon provide excellent heat dissipation at high speeds, a flat design when space is limited, high torques and long service life.

So how are these components used on drones specifically?

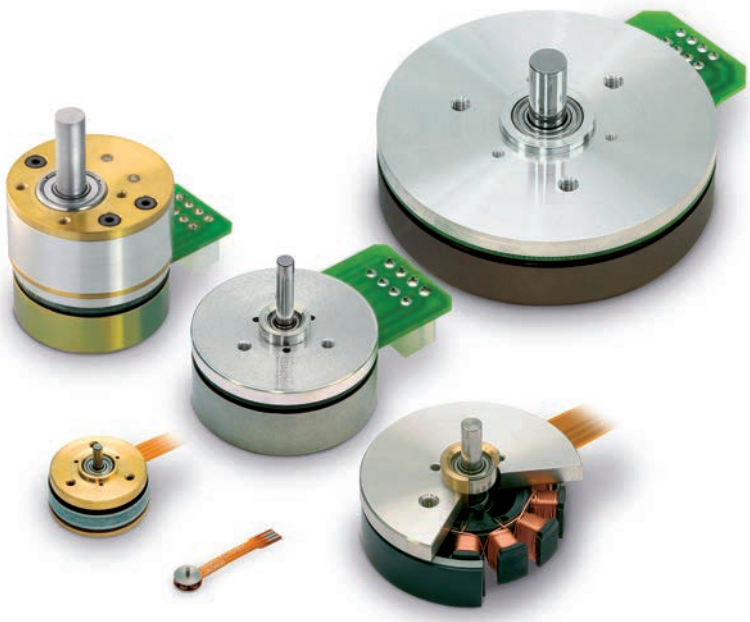
Beasley said the motors may be utilized for camera pan/tilt/zoom and gimbal camera stabilization for surveillance and imaging, generators, various mechanical and locking mechanisms and extension/retraction.

Motors for drones can be brushed or brushless and can provide power, stability and faster equipment. A gimbal mount provides stabilization for the camera to keep aerial shots steady while the drone is maneuvering through the air.

In the future, additive manufacturing and IIoT solutions will allow simple drone assignments like crop spraying or surveying construction sites to provide data-driven analytics. Imagine a drone with a 3D printer attached that can help replace damaged infrastructures? How about a farming drone that studies and reports on the daily development of corn fields?

Maxon is currently developing drone multi rotor propulsion motors to go with its auxiliary functions drives. Beasley is excited about the potential for drone technology in the future.

"We foresee massive increase in drone usage while at the same time ever increasing regulations with an emphasis on quality and reliability," Beasley said. (*www.maxonmotors.com*) **PTE**



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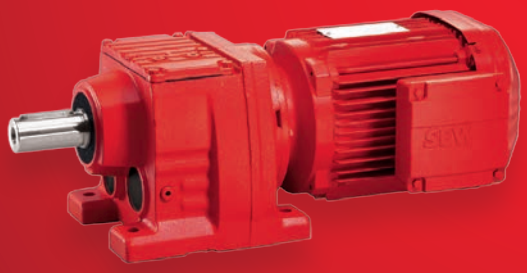

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