Power Transmission Engineering®

AUGUST 2020

COUPLINGS

MOTORS & DRIVES

Power Transmission Engineering is now published by **The American Gear Manufacturers Association**

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Power Transmission Engineering®

AUGUST 2020

A Publication of
The American Gear Manufacturers Association

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Vol. 14, No. 5 . POWER TRANSMISSION ENGINEERING (ISSN 2331-2483) is published monthly except in January, May, July and November by The American Gear Manufacturers Association, 1840 Jarvis Ave., Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00. U.S.

Periodicals Postage Paid at Elk Grove Village IL and at additional mailing offices. Send address changes to POWER TRANSMISSION ENGINEERING, 1840 Jarvis Ave., Elk Grove Village, IL 60007.

Power Transmission Engineering

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Cover image courtesy of Voith

www.powertransmission.com

KISSsoft 2020 Highlights

An overview of the numerous new features in *KISSsoft Release 2020* for gears, shafts, bearings, other machine elements and system calculation. Learn more here:

www.powertransmission.com/videos/KISSsoft-2020-Highlights-/

ABB Robotics Helps with Protective Mask Production

A Swedish company, TikiSafety has experienced a record amount of orders for their protective masks. ABB helped Tiki Safety to speed up their manufacturing process from 6 minutes to 40 seconds. Learn more here:

www.powertransmission.com/videos/ABB-Robotics-Works-With-TikiSafety-on-Protective-Masks-/

Gates Thread Identification

Identifying the coupling helps the termination process of identifying a thread.

www.powertransmission.com/videos/Gates-Thread-Identification-/

Editor's Choice: Shrink Your Start-to-Finish Time with Siemens Software Solutions

Siemens offers an easy-to-use interface to build complex transmission systems. The user begins with the transmission layout setup, arranging the shafts, gears, bearings, etc., and defining the gear meshing conditions for spur, helical and planetary gear systems.

www.powertransmission.com/blog/shrink-your-start-to-finish-time/

Randy Stott
Publisher & Editor-in-Chief

The Show Must Go On… Somehow

Normally at this time of year we talk a lot about trade shows. We go to manufacturing and engineering events because that's where technology-oriented companies often unveil their innovations. Like many of you, we want to see that technology in person, talk to the experts who created it and better understand how it fits into the overall manufacturing and engineering landscape. One of our most important missions is learning about that information and sharing it with all of you.

Unfortunately, this year, there aren't any trade shows. None of us are able to go.

Like with everything else in our lives, the world is trying to figure out what to do about trade shows. Organizers are looking for ways to recover lost revenue. Exhibitors are scrambling for ways to market their products and identify potential customers. And the rest of you – the typical trade show attendees – are looking for efficient, effective ways to learn about the technologies that will make you more effective, productive, efficient and so on.

Most of the trade show organizers have attempted in some way to pivot to virtual events. But that's largely a work in progress. How successful they'll be and how much participation they'll get – both from exhibitors and attendees – remains to be seen.

In July we attended the Hannover Messe Digital Days virtual conference. It included more than 50 presentations centered around the topics of Industry 4.0, Artificial Intelligence, 5G, Smart Energy and Logistics 4.0. You can read about some of the technology presented in Senior Editor Matt Jaster's article, beginning on page 30.

As you are probably aware, Hannover Messe USA was scheduled to be co-located with IMTS in Chicago. The combined shows, which in 2018 had more than 129,000 registrants, will only be offered virtually this year. We'll continue to try to bring you as much information as we can from these new formats. You can learn more about what's being offered at *hannovermesseusa.com* and *imts.com*.

Normally we would also be talking about the Turbomachinery & Pump Symposia, originally scheduled to take place Sept 13–17 in Houston. It, too, will be going virtual this year, although at the time of printing, details had not yet been announced. Visit *tps.tamu.edu* for more information, or check back here for updates as we learn more.

The organizers of Pack Expo, scheduled for November 8–11 in Chicago, are committed to having an event this year. As of July 20, they're planning a hybrid event that includes both in-person and virtual elements, although it's still possible that due to COVID restrictions, the event may end up 100% virtual. Visit *packexpointernational.com* for updates.

Similarly, SPS (smart production solutions), scheduled for November 24–26 in Nuremberg, Germany, is planning a hybrid event. The show organizers are committed to hosting an in-person event that keeps attendees and exhibitors safe through a detailed safety and hygiene plan and rules for strict enforcement of social distancing. Full details regarding the virtual components of the 2020 show have not yet been released. For more information, visit *sps.mesago.com*.

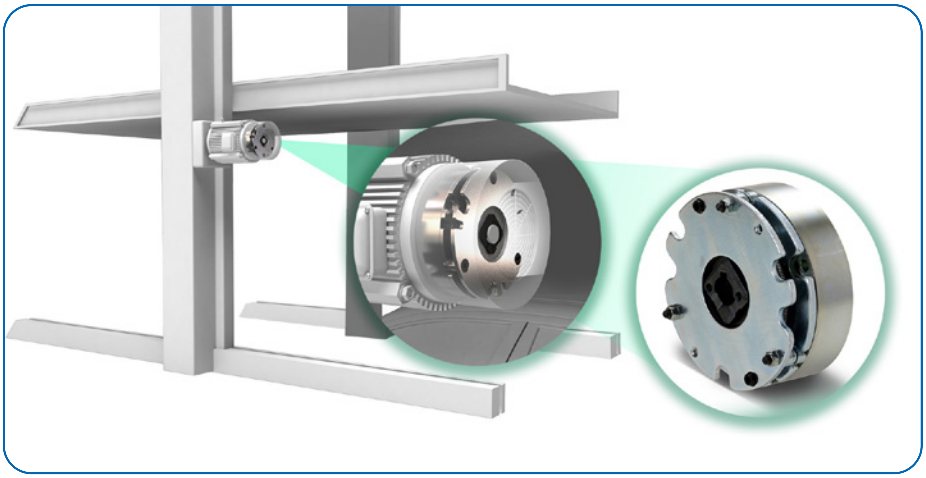
Significant mechanical power transmission technology will be presented at each of these shows. Whether they're in-person, partly in-person or completely hybrid, we remain committed to bringing you as much information about that technology as possible. Our advertisers and other suppliers in the industry continue to innovate, and they are constantly sending us updates about their new technologies. Regularly stopping by *www.powertransmission.com* is a great way to stay up to date, because we post new product information there every day.

No matter what happens with the coronavirus, shutdowns and travel restrictions, *Power Transmission Engineering* isn't slowing down. You can count on us to keep the information flowing about mechanical power transmission and motion control products.

P.S. We are extremely hopeful that things will return to normal in 2021. We're already making plans for our exhibit at MPT Expo in St. Louis next year. This promises to be one of the most significant American events for our audience, and the only one that focuses specifically on power transmission. Book your calendars for Sept. 14–16, 2021. I know it's still a long way off. But we hope to see you there! Visit *motionpowerexpo.com* for more information.

Miki Pulley

BXL BRAKES DESIGNED FOR CHALLENGING ELEVATOR AND LIFT APPLICATIONS



Miki Pulley announces introduction of its spring actuated BXL Brakes designed for the challenging requirements of elevator and lift applications. Designed exclusively for dynamic braking, these brakes are designed for constant elevator usage where long service life with high wear resistance is required.

BXL Brakes feature minimal torque fluctuation, even when stopped from maximum rpm. This ensures a smooth elevator and lift stop without any jarring motion. Also important, these are very quiet operating brakes. Excessive braking noise is minimized by the brake's flat spring design strategically located on the brake's rotor hub.

Additional features include a lightweight component, space saving design configuration, long service life, stable and reliable braking power. Easily installed, these Miki Pulley BXL Brakes require no maintenance.

Miki Pulley BXL Brake specification range:

- Brake torque: 1.475 ft/lb. to 16.226ft/lb. (2 Nm–22 Nm)
- Brake outer diameter: 3.268" to 76.221" (83 mm to 158 mm)
- Ambient Temperature: 14°F~104°F; (–10°C~40°C)

Additional applications include robotic systems, printing presses, food and paper processing systems, packaging equipment, textile manufacturing systems and many servo & stepper motor driven systems plus many more.

For more information:

Miki Pulley US
Phone: (800) 533-1731
www.mikipulley-us.com

Voith

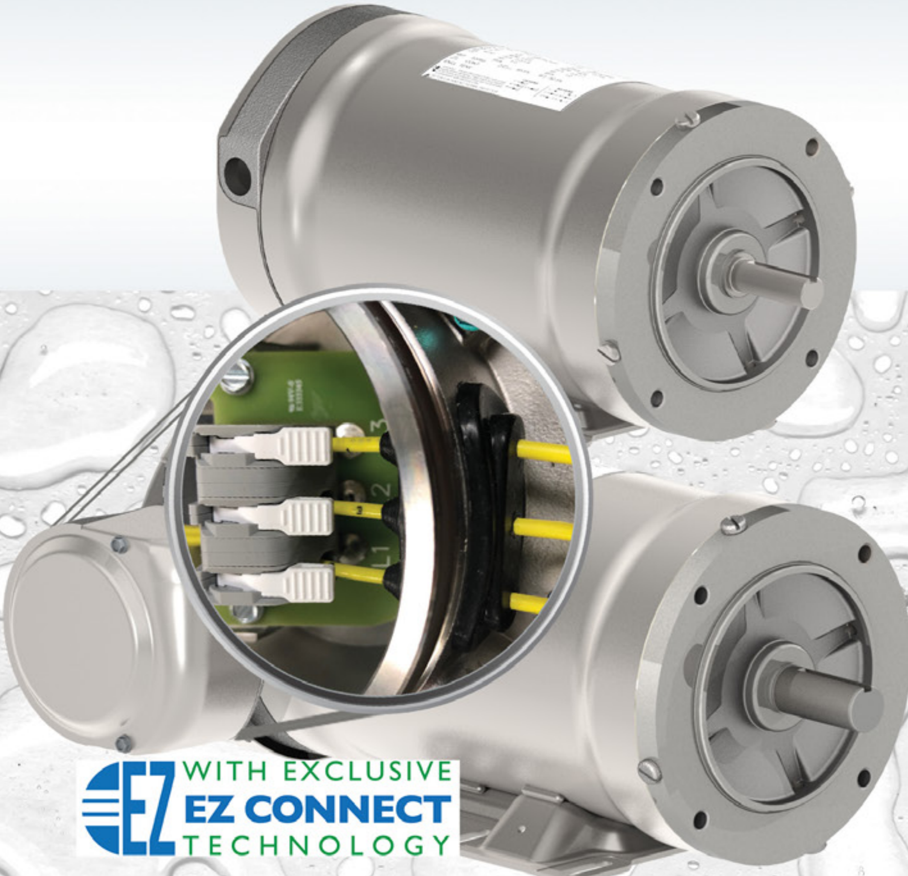
DELIVERS ELECTRIC SCHNEIDER PROPELLER TO SHIPPING COMPANY

Voith will deliver eight electric Voith Schneider Propellers (eVSP) to the Norwegian shipping company Østensjø, thus enabling resource-saving and energy-efficient operation of the four offshore wind supply vessels. The four ships will be built in Spain and are already equipped for the application of CO_2-neutral hydrogen technology. Among the advantages of the new eVSP are, in particular, the high efficiency and reduction of complexity, as the permanent-magnet synchronous motor is already integrated in the propeller.

Furthermore, the best possible maneuvering performance is a decisive factor for use in the offshore wind industry. Accurate dynamic positioning (DP) even under harsh environmental conditions, very fast starting and leaving of the wind turbines, and a safe and quick transfer in the offshore wind farm are critical factors for smooth operation.

Comparative calculations have shown that a VSP-driven ship can maneuver safely at significantly higher wave heights, thus offering the operator an economic advantage. Due to the very fast and accurate thrust adjustment, the VSP can reduce the rolling motions of the ship by up to 70 percent, both when the ship is moving and when it is stationary at the wind turbine.

A Complete Range of Motors and Drives for the **Toughest Wash Down** Applications



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The electric Voith Schneider Propellers are also characterized by very high efficiency and are optimally integrated into the ship's design. In model tests with ducted screw propellers, an average advantage of 15 percent for the eVSP was measured with regard to power requirements in transit. The electric version of the VSP is also characterized by lower fuel consumption in dynamic positioning, because it acts very quickly against disturbing wind, wave and flow forces.

Resource-saving new development

The eVSP is a new development of the Voith technology group. With this new type of gearless propeller, the permanent-magnet synchronous motor is directly integrated into the VSP. The drive system combines the technology of the VSP with more than a decade of electrical know-how of the Voith Inline Thruster (VIT).

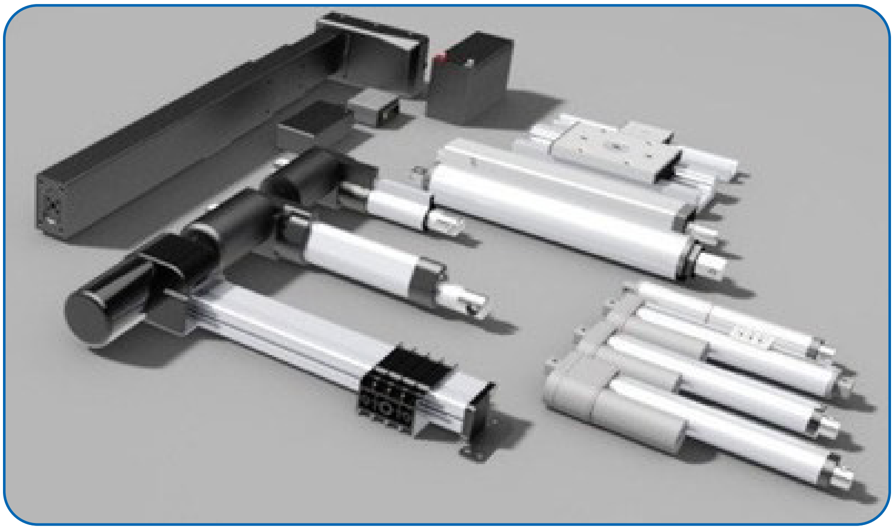
The advantages of the eVSP are easy to recognize: An increase in efficiency due to the elimination of gears and the reduction of bearing points, as well as a very high motor efficiency, also in the partial load range, which is particularly relevant in the offshore sector. In addition, no separate electric motor is required and shaft lines are also eliminated.

For more information:
Voith
Phone: (717) 792-7095
www.voith.com

Firgelli Automations

OFFERS SMART CONTROLLER FOR LINEAR ACTUATORS

Firgelli Automations recently introduced its new Smart Synchronous Controller for linear actuators. Feedback Linear Actuators are used extensively in industry for applications where precise motion control is required. Firgelli has been manufacturing Feedback Linear Actuators for



year and its most recent new model named "The Bullet Series" got its name from the unique inner expansion rod apparatus, which resembles a bullet being pushed out of the barrel of a gun.

The Bullet Series features sleek looks and versatility, with some "calibers" of the actuator series offering high-tech options like a built-in hall effect sensor for feedback, which allows for position and speed control. However a Smart Control box had until now yet to be developed, because Firgelli wanted the Smart Controller to have the ability to accept multiple feedback options, and all work within one Controller.

"We've been coming up with innovative solutions to linear movement problems since 2002, but the Smart Controller takes Firgelli's passion for precision and adds a next-level control to it," says Firgelli CEO and founder Robbie Dickson. "Over the years, we've noticed that the uses of our products occasionally put them in products where synchronization is required, so we wanted to make a high-performance Smart Controller that offers the flexibility to accept different sensor inputs such as Hall effect, Optical and potentiometer inputs."

For more information:
Firgelli Automations
Phone: (866) 226-0465
www.firgelliauto.com

Heidenhain

ANNOUNCES LATEST RENCO ENCODER

Heidenhain is proud to announce the release of its next generation of Renco brand rotary encoders to the market. This new generation includes an upgraded R35i model and a successor to the RCML15 encoder with the R35iL low profile encoder. Both solutions are equipped with a new Opto-Asic that provides additional features and improved functionality to users.

The Renco R35i and R35iL encoders are ideal for use in brushless DC motors or stepper motor solutions. Their compact size combined with the high level of performance and availability make these products the top choice for applications such as medical devices, warehouse robotics and laser scanning.

Both encoders now come with a brand-new Diagnostic and Field Programming (DFP) feature not before seen on incremental encoders of this type. This DFP functionality allows users to perform mounting checks, quick and simple diagnostic functions, and electronic commutation setting which can reduce mounting time of each encoder up to 10 minutes.

Additional features include an extended tolerance on mounting specifications, increased output frequency performance up to 1.83 MHz and reduced height down to 8.6 mm. All these improvements are specifically included to increase availability and ease of use of the encoder.

For more information:
Heidenhain Corporation
Phone: (847) 440-1191
www.heidenhain.us

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ZERO-MAX®

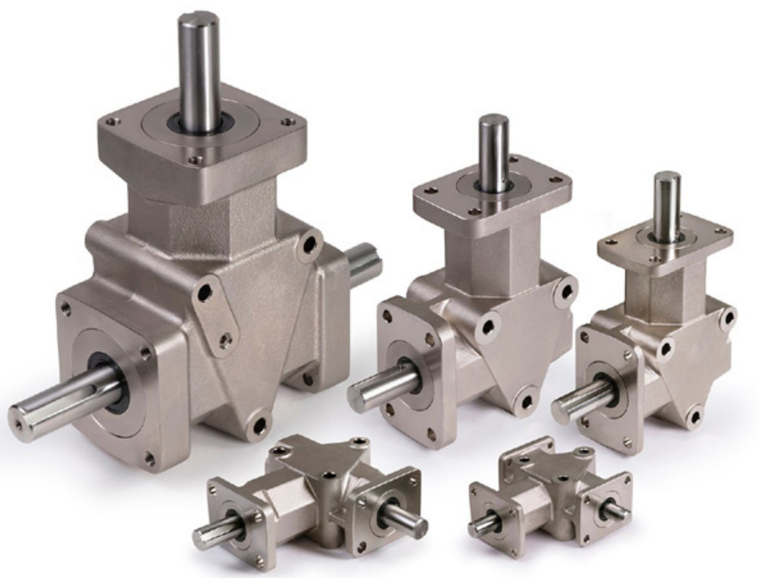
Zero-Max

OFFERS IP65 RATED CROWN RIGHT ANGLE GEAR DRIVES

Tested and certified by an independent laboratory, the IP65 Rated models feature a nickel plated housing for corrosion protection and are now available in 1:1 and 2:1 ratios and 2-way, 3-way, and counter-rotating shaft configurations for reliable and quiet transmission of power. With a successful 60-year application history, Crown Gear Drives are a proven design that are now open to new application opportunities with this IP65 Rating.

Ideal for food processing and food packaging applications, and harsh environments requiring frequent washdowns, these Crown Gear Drives feature Ingress Protection, sealing the Crown Gear against environmental concerns such as dust, dirt and water infiltration from water jets. They also feature nickel plated housings, corrosion-protected stainless-steel shafts and NBR covered shaft seals, adding more protection from washdown chemicals and process chemicals present in challenging applications.

Capable of speeds up to 2,000 rpm, IP65 Rated Crown Gear Drives feature heat treated AGMA Class 10 spiral bevel gears and are lubricated for life with H1 Rated Food Grade Grease. Additional features include a sealed and tamper proof design, precision hardened and ground ball bearings, maintenance free operation, and grease lubrication to ensure optimum performance in temperature ranges from -20° C to +100° C (-4° F to + 212° F). Wider operating temperature range available upon request.



Most important, these Crown Drives have a bright, clean, water-shedding design that is free from bacteria traps.

Zero-Max Crown Gear Drives are available in many sizes and models for a wide range of horsepower, torque and shaft speed requirements. Featuring a low backlash design, these drives are available with 1:1 and 2:1 ratios and shaft diameters of 3/8, 1/2, 5/8, 3/4 and 1-inch. Stocked in Minneapolis, MN for fast shipment, modified and special designs are also available by quote.

For more information:
Zero-Max, Inc.
Phone: (800) 533-1731
www.zero-max.com

Gates

EXPANDS CARBON DRIVE PORTFOLIO

Building on a 40-year legacy of designing and manufacturing belt-drives as a lower-maintenance, rust-free, quieter and stronger alternative to chain drives for two-wheelers, Gates Carbon Drive is refreshing its overall product portfolio with new and expanded component lines, offering next-generation sprockets, belts and cranksets optimized for ebikes, entry-level commuter and extreme performance bicycles.

These new offerings add to Gates' portfolio of mobility solutions covering a wide variety of applications:

- idetrack (ST): For seasonal, recreational cyclists looking for their first belt-driven bike (new)
- Carbon Drive Network (CDN): for seasonal, recreational cyclists who commute occasionally
- Carbon Drive Commute (CDC): for cyclists who bike or ebike for many kinds of urban trips (new)

- Carbon Drive Xtreme (CDX): for cyclists who ride pavement or dirt year-round
- Carbon Drive Expedition (CDX:EXP): for cyclists up for toughest, grittiest pavement or dirt adventures (new)

For more information:
Gates Corporation
Phone: (303) 744-5800
www.gatescarbondrive.com

KEB America

INTRODUCES HIGH CAPACITY SPRING-SET LOAD BRAKES

KEB America has introduced their new High Capacity Load brake. The brakes use a spring-set (power-off) design and are electrically released. The brakes are offered in graduated sizes up to 3,200 Nm (2,360 ft-lb).

"These brakes are ideal for critical lifting applications that require secondary braking. This includes cranes, hoists, and lifts", says KEB Marketing Manager, Jonathan Bullick.

The brakes feature a number of standard features including noise reduction, a manual bolt release mechanism, and an integrated mounting flange. Brake options include a microswitch for engagement feedback, a manual hand release, and an IP54 rated cover. The brakes are manufactured at KEB America's facility outside Minneapolis, MN and are available for sale immediately.

For more information:

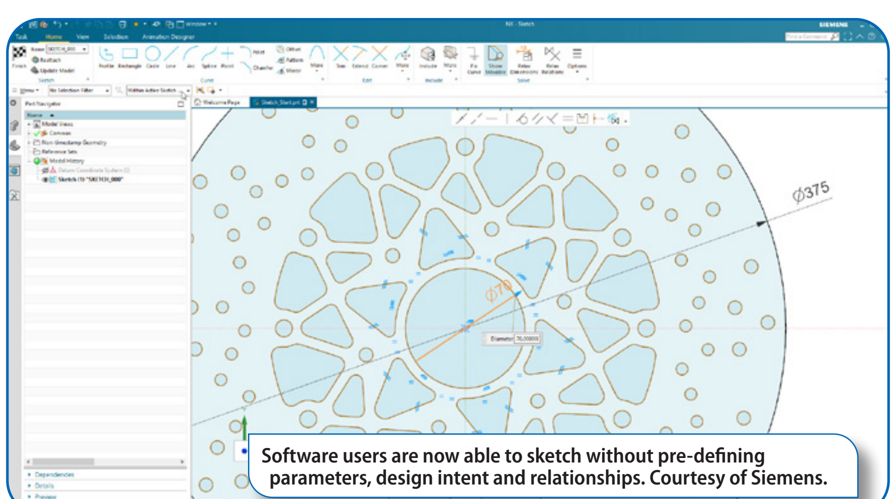
KEB America, Inc.
Phone: (952) 224-1400
www.kebamerica.com

Siemens Digital Industries Software

ANNOUNCES NX SKETCH SOFTWARE TOOL FOR CAPTURING 2D CONCEPTS

Siemens Digital Industries Software is announcing a new solution for capturing concepts in 2D. The new *NX Sketch* software tool revolutionizes sketching in CAD, which is an essential part of the design process. By changing the underlying technology, users are now able to sketch without pre-defining parameters, design intent and relationships. Using Artificial Intelligence (AI) to infer relationships on the fly, users can move away from a paper hand sketch and truly create concept designs within *NX* software. This technology offers significant flexibility in concept design sketching, and makes it easy to work with imported data, allowing rapid design iteration on legacy data, and to work with tens of thousands of curves within a single sketch. With these latest enhancements to *NX*, Siemens' *Xcelerator* portfolio continues to bring together advanced technology, even within the core of modelling techniques, helping remove the traditional barriers users have experienced to dramatically improve productivity.

"The ability to make intelligent changes to 2D entities that one imports



Software users are now able to sketch without pre-defining parameters, design intent and relationships. Courtesy of Siemens.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into the new sketcher is astounding," said Steve Samuels, CEO of Design Visionaries Inc.

Analysis has shown that in an average day or workflow, around 10% of a typical user's day is spent sketching. In addition, within current design environments most concept sketching is happening outside of the CAD software due to the level of rules and relationships that must be decided on and built into the sketch by the user up front. Often designers in concept design stage do not necessarily know what the final product may be, which requires a sketching environment that is flexible and can evolve with the design. *NX* offers the flexibility of 2D paper concept design within the 3D CAD environment, as the first in the industry to eliminate upfront constraints on the design. Instead of defining and being limited by constraints such as size or relationships, *NX* can recognize tangents and other design relationships to adjust on the fly.

"Sketching is at the heart of CAD and is critical to capturing the intent of the digital twin," said Bob Haubrock, senior vice president, product engineering software at Siemens Digital Industries Software. "Even though this is an essential part of the process, sketching hasn't changed much in the last 40 years. Using technology and innovations from multiple past acquisitions, Siemens is able to take a fresh look at this crucial design step and modernize it in a way that will help our customers achieve significant gains in productivity and innovation."

For more information:
Siemens Digital Industries Software
Phone: (800) 498-5351
www.sw.siemens.com

H2W Technologies

OFFERS SINGLE AXIS LINEAR STEPPER MOTORS

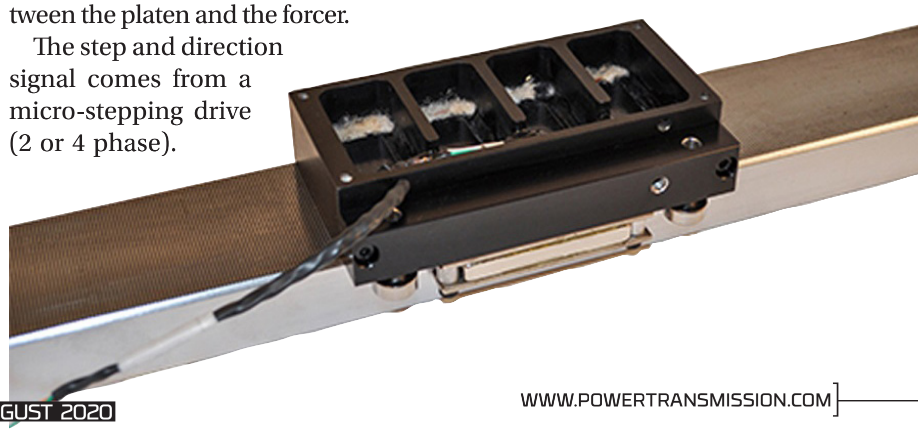
H2W Technologies' single axis linear stepper motors are ideal for high-speed open loop positioning applications. They can perform at speeds of up to 80 in/sec [2 m/sec] and strokes of up to 68 in [1.7 m]. Linear stepper motors are capable of very precise position, velocity, and acceleration control when coupled with a micro-stepping drive and indexer.

The moving assembly called the "forcer" is supported by magnetically preloaded air bearings that are embedded in the active surface of the forcer, and on a single side of the platen to minimize the physical contact of bearings on the platen. The bearings are designed to support the customer's payload and to maintain the required 0.0005 in to 0.0010 in [12 to 25 micron] air gap between the platen and the forcer.

The step and direction signal comes from a micro-stepping drive (2 or 4 phase). An indexer is required to send step and direction signals to the driver. For 2 phase motors, the full step is 0.010 in [250 microns] and for 4 phase motors the full step is 0.005 in [125 microns]. With micro-stepping, resolutions in the order of 0.5 to 1 micron are achievable.

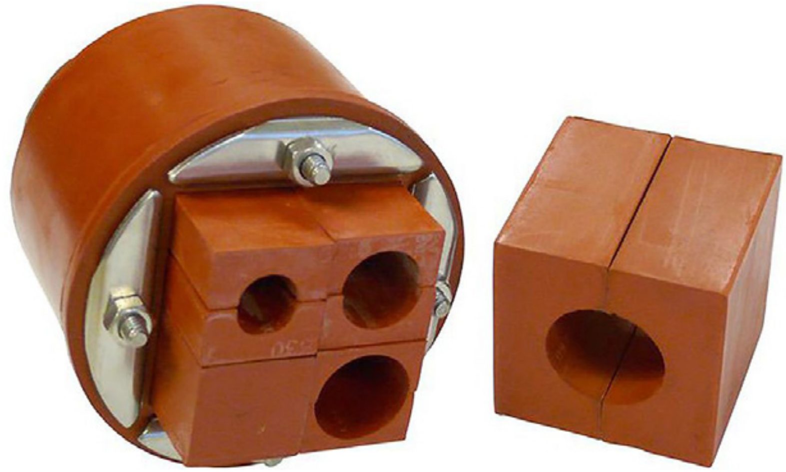
The single axis linear stepper motor is a complete air bearing positioning system with the motor, the bearings, and the positioning system all built into one compact package. Integrating a linear encoder with the stepper motor allows for a hybrid, closed loop positioning system.

For more information:
H2W Technologies, Inc.
Phone: (888) 702-0540
www.h2wtech.com



Emerson Automation Solutions

MULTI-PLUG SYSTEMS OFFERS CABLE AND PIPE SEALING SOLUTION



The Nelson Firestop MPS Multi-Plug System by Emerson is a proven cable and pipe sealing solution, for use in commercial building, wall and floor penetrations, as well as in marine bulkhead and deck applications, offshore platforms and power stations. As convenient as it is cost-effective, it offers fast, simple installation that requires only common hand tools.

The Nelson Firestop MPS Multi-Plug System stops fire from spreading through pipe sleeves or case round openings where cables and pipes carry electricity, potable water, HVAC systems and Internet to the building or ship. To bring a structure back up to its original fire rating after a hole is cut into it, the system creates an airtight seal at the opening, preventing passage of fire, water, gas, sound and blast pressures by utilizing Tecron rubber modules that fit snuggly around the pass-through pipes and cables. This helps extend the time needed to safely evacuate a building or maritime vessel in the event of a fire, while also limiting property loss and water damage.

When installing the circular MPS Multi-Plug penetrator, the contractor is afforded the simplicity of a grid format for assigning cables. Each cable is placed between a pair of grooved insert blocks that fit into the MPS Multi-plug penetrator in a modular fashion, with the grid allocating space in a series of squares. Bolts are tightened to compress the blocks against cables and pipes to establish a rigid seal. Interchangeability of the MPS block modules helps the contractor save time and achieve flexibility when firestopping multiple size cables and pipes within a single MPS Multi-Plug system.

For more information:
Emerson Automation Solutions
Phone: (888) 889-9170
www.emerson.com

Solar Tracker System Helps Overcome Site Topography Challenges

RBI Solar relies on TB Wood's custom jaw couplings to provide long-lasting performance in tough environments.

Edited by Matthew Jaster, Senior Editor

Solar tracking system installations have grown to become the largest market in the solar panel mounting industry. Tracking system popularity has expanded as more customers recognize the advantages compared to fixed solar rack systems for certain applications. The ability of solar tracking system mounted photovoltaic (PV) modules to follow the sun provides substantial improvements in energy yields.

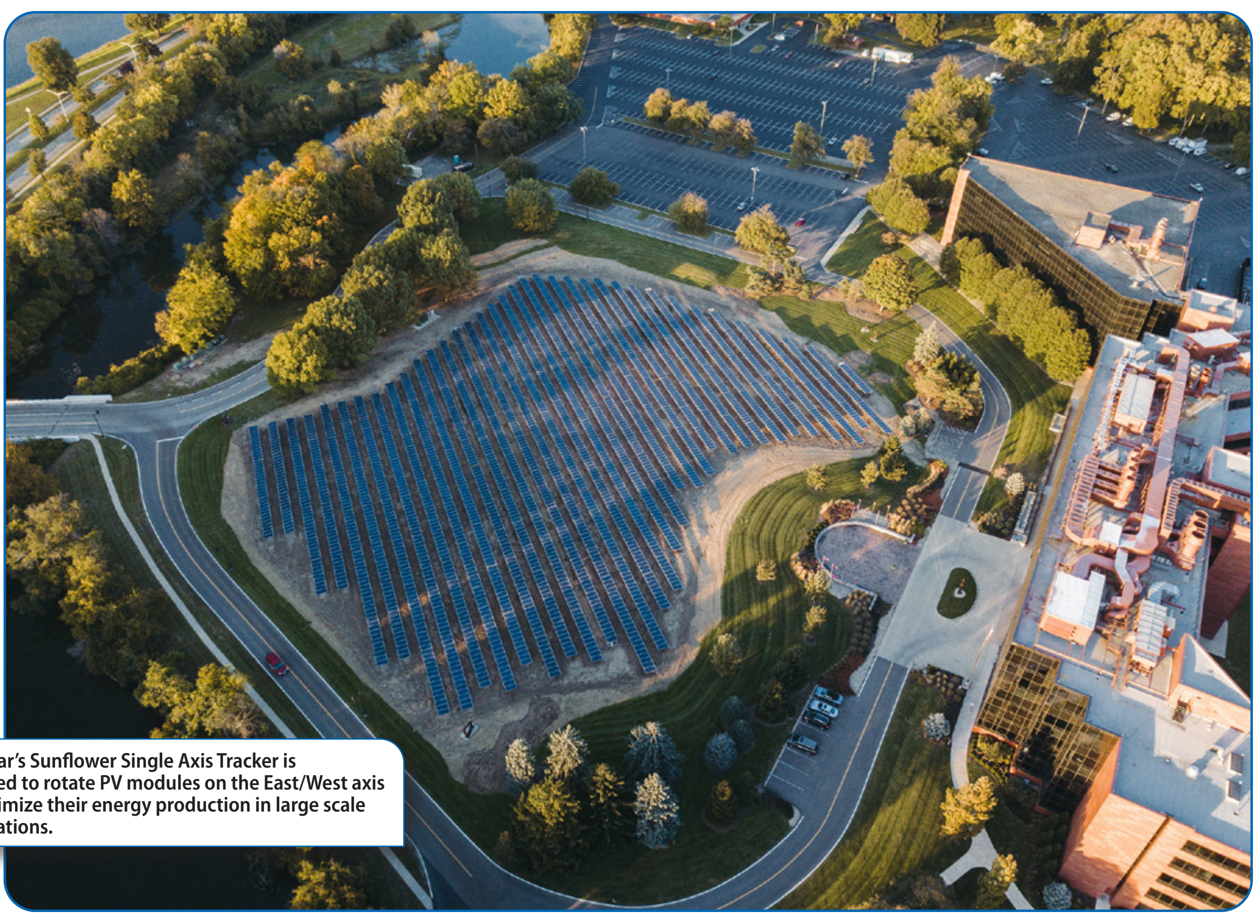
To meet market demand, RBI Solar has introduced the Sunflower Single Axis Tracker that is designed to rotate PV modules on the East/West axis to maximize their energy production. The new system is aptly named since young sunflowers turn to face the sun as they track it across the sky.

"RBI is a well-recognized industry leader in the design, manufacture and installation of solar mounting systems for commercial and utility-scale projects," said Eric Oetjen P.E. at RBI. "We provide single-source responsibility and peace of mind for EPC (engineering, procurement and construction) customers and project developers throughout the United States. Developing a unique solar tracking system was a natural way for us to expand our product portfolio while providing a solution to an industry need."

Unique Alternative Architecture Provides Many Advantages

Most trackers in the marketplace rely on large motors and heavy steel members to rotate full rows of PV modules at a time. In large scale installations, rows can be up to 400 ft. long, containing as many as 120, 72-cell PV modules. The reason they need heavier steel vertical posts is because, as the large number of modules rotate, they create bending/torque stress. This stress is transferred and increases along the row from post to post.

To accommodate this stress, competitor systems need to



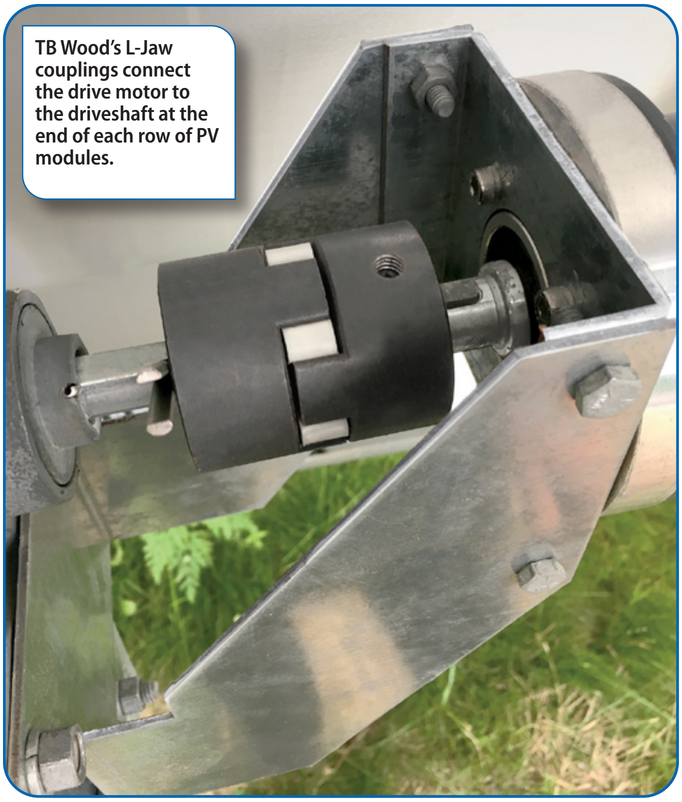
RBI Solar's Sunflower Single Axis Tracker is designed to rotate PV modules on the East/West axis to maximize their energy production in large scale installations.

utilize increasingly larger post sizes as the posts get closer the drive motor. For example, posts at one end of the row, near the drive motor may be size W6x9, while posts at the far end of the row may be size W6x20.

The engineering team at RBI has developed a tabled (sectioned) system design that utilizes gearboxes. A gearbox is positioned at each post to transmit rotational torque into each foundation post instead of the motor shaft. This prevents accumulation of stresses to the motor. The result is a more load-balanced system that can drive long rows in a more cost-effective manner.

"These gearboxes provide two main advantages," Oetjen said. "The design in non-back-drivable, so rotational stresses are absorbed at each post and not transmitted back to the motor. This allows us to use the same small post size throughout our entire system. This reduces cost and installation time."

"Secondly, because each row is made up of approx. 35 ft. sections, large arrays can be installed over uneven terrain," Oetjen added. "Our Sunflower system allows each section of approx. 12 modules to be adjusted at each connection point, to accommodate various topographic conditions. This is a major difference compared to competitor systems that require relatively flat surfaces, since their module rows are made up of one continuous, rigid approx. 300 ft. section."



TB Wood's L-Jaw couplings connect the drive motor to the driveshaft at the end of each row of PV modules.

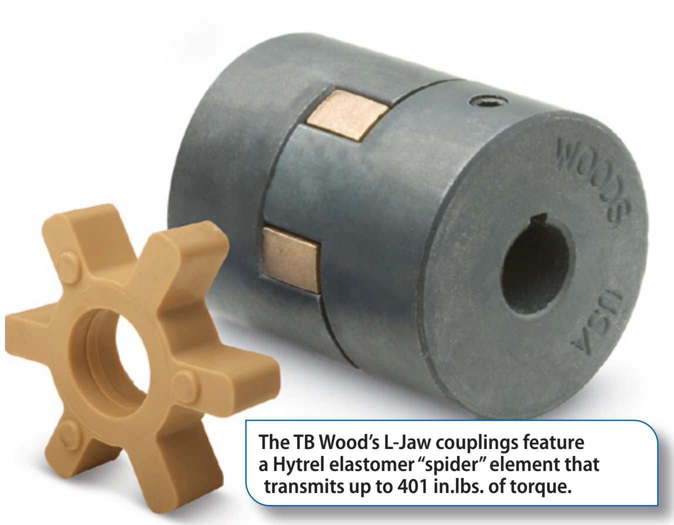
A Small Component with a Large Role

The Sunflower system, designed for commercial/utility grade applications, required a reliable coupling solution to connect the drive motor to the drivetrain at the end of each row of PV modules. The RBI engineering team evaluated options and determined that an L-Jaw coupling was the most economical choice that met the system requirements.

During the tracking system development process, RBI began searching for a coupling source that not only offered the right coupling type and quality level, but also convenient face-to-face support.

"The team at TB Wood's was willing to work with us to customize the bore geometry of their L-Jaw coupling to provide a better connection to our driveshaft design," Oetjen said.

"L-Jaw couplings are an excellent solution to connect two shafts and accommodate misalignment when ease of installation and low cost are the primary considerations. These couplings operate with an elastomer element in compression, and they offer a 'fail safe' design (to a degree)," said John Smihal, product manager at TB Wood's. "If the elastomer 'legs' of the 'spider' fail, the coupling can still transmit torque through the hubs."



The TB Wood's L-Jaw couplings feature a Hytrel elastomer "spider" element that transmits up to 401 in.lbs. of torque.

To meet the solar array application specifications and torque requirements, the modified L095 L-Jaw couplings supplied utilize a Hytrel "spider" element with a torque capacity of 401 in. lbs. The couplings feature standard sintered steel hubs (made in the USA).

"We worked closely with RBI to revise our standard L-Jaw coupling bore design to accommodate their unique shaft geometry and provide a more secure hub-to-shaft connection," Smihal said.

"The TBW L-Jaw couplings provided the most flexibility, durability and consistent quality for our solar track system," said Oetjen. "However, the overall interactions we had with TBW outweighed all other considerations. We were able to rely, with confidence, on their experienced and knowledgeable team as they provided engineering expertise and exceptional service and support, including fast responses, problem-solving skills and timely delivery."

Several large Sunflower system installations have been completed and the TB Wood's couplings continue to provide reliable, trouble-free performance. **PTE**

For more information:

RBI Solar
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Voith SafeSet Couplings Prevent Catastrophic Failure at City Scrap & Salvage

Edited by Matthew Jaster, Senior Editor

City Scrap & Salvage, Akron, Ohio, began operation in 1947 as a small, family-owned scrap yard. For three generations, the company has provided a place where everyone, from large corporations to residential neighbors, can exchange scrap metal for profit. From automobiles and auto parts, to aluminum siding, stainless steel and appliances, City Scrap has the technology and equipment to meet a variety of scrap metal needs.

The organization boasts the area's only automotive shredder. This shredding machine has two, 1,500 hp natural gas engines, known as 'Thunder Pumpkins.' These gas engines are designed to perform reliably in isolated, mission-critical, and demanding applications. Featuring a durable design, these flexible 'rich-burn' and 'lean–burn' alternatives cover a wide variety of applications and varying emissions compliance levels. They are specifically designed for demanding industrial applications and backed by more than a century of engine-building experience.

Retrofit Saves the Day

When City Scrap & Salvage experienced a catastrophic failure of the driveline between the motor and rotor of its automotive shredder, the company called on Voith Turbo for a potential manufacturing solution. Without torque overload protection, an unshreddable item entered the shredder and the machine stopped suddenly. The inertia continued, causing unexpected damages and machine shutdown.

Voith offered a solution to City Scrap & Salvage to prevent unshreddable items from causing large-scale damage, by installing a protective line of security against torque overload. Voith's SafeSet torque limiting coupling was chosen.

Kyle Kluttz, vice president, new business sales, Voith, said that the SafeSet torque limiting coupling was created to prevent costly damages, shutdowns, and downtime. This retrofit to the existing automotive shredder gave Voith an opportunity to demonstrate the value of its SafeSet products.

According to Kluttz, SafeSet torque limiting couplings prevent machine damage in high value rotating equipment.

When City Scrap & Salvage experienced a catastrophic failure of the driveline between the motor and rotor of its automotive shredder, the company called on Voith Turbo for a potential manufacturing solution.

90 MISSILES
330 SAILORS
1,100 MILES OUT TO SEA
ZERO ROOM FOR GEAR DRIVE FAILURE.

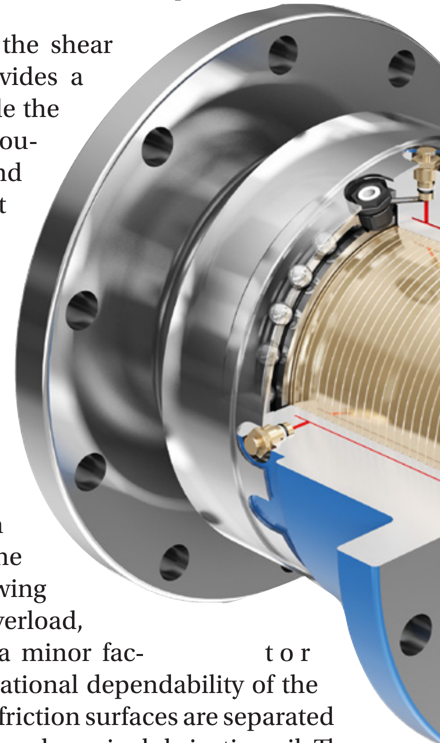
They work like a mechanical fuse in the driveline by protecting the system from costly breakdowns.

SafeSet only releases when the set torque is really exceeded. This allows the driveline to always operate at the maximum level, without risking damage from overload. The set release torque remains constant over time, regardless of the number of load cycles. SafeSet provides accurate protection throughout the life span of the driveline and avoids unnecessary downtime and repairs.

The SafeSet coupling includes a twin-walled hollow sleeve. Friction is generated upon expansion by pressurized hydraulic oil. The integrated shear tube holds pressure to ensure a constant but easy adaptable torque transmission. In an overload situation the SafeSet slips and the shear tube shears off. Oil pressure drops and the frictional surfaces separate. Then the SafeSet rotates on the bearings without transmitting any torque. Torque capacity is available between 1 and 20 000 kNm. These couplings run on the simple principle of friction and flexibility—there's no material fatigue, a constant torque transmission and adaptability.

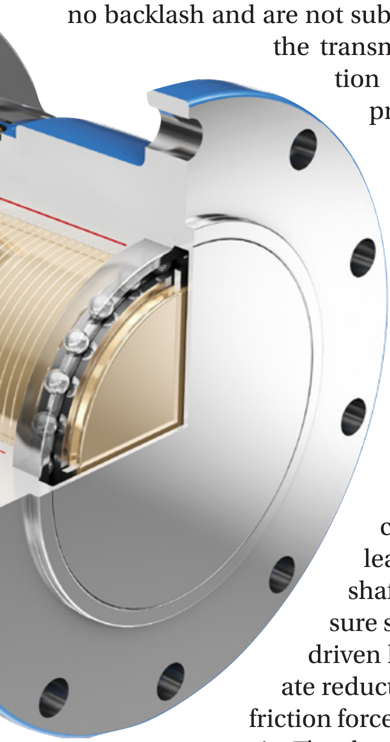
Design Specifications

The basic hydraulically pressurized, friction-based torque limiting coupling is made up of an inner and outer sleeve that are assembled and welded at the ends. This assembly forms a twin-walled hollow sleeve which can be oil pressurized up to 1,000 bar/14,500 psi after the machining of the necessary pressurization and shear tube ports have been completed. The design of the shear tube and mating seat provides a reliably sealed system, while the size of the torque limiting coupling determines the size and quantity of shear tubes that are to be used. The friction surface is specially treated to prevent wear during the slip phase of the coupling release. Once the SafeSet coupling has released it rotates on bearings preventing wear on those friction surfaces.



The bearings remain static during operation. The bearings only rotate following a release due to torque overload, which makes bearing life a minor factor when considering the operational dependability of the coupling. The bearings and friction surfaces are separated from the pressurized sleeve and require lubrication oil. The lubrication oil is used for two things: Bearing lubrication during a release condition, and to maintain a predictable friction coefficient across the friction surfaces which results in a precise release torque relative to the applied pressure.

Another advantage is that torque limiting couplings have



no backlash and are not subject to material fatigue because the transmitted torque is through a friction surface. The applied hydraulic pressure generates a defined frictional force between the pressure sleeve and the shaft. The applied pressure determines the release torque of the coupling. Therefore, an increase or decrease of applied pressure, working within the torque limiters adjustment range, will result in an increase or decrease of the release torque.

If the operating torque exceeds the pressure-based release torque setting, the driving shaft will rotate relative to the pressure sleeve which is connected to the driven load. This results in an immediate reduction in applied torque when the friction force changes state from static to dynamic. The shear ring that is fixed to the driving shaft rotates relative to the pressure sleeve and breaks off the top of the shear tubes. Upon contact, the oil pressure in the coupling drops and the applied frictional force in the coupling is reduced releasing the torque limiting coupling and providing full separation of the driving and driven components of the drive chain.

Back on Track at City Scrap

The SafeSet disengaged the driveline a total of four times in 40 months, each time protecting the driveline from catastrophic damages at City Scrap. The initial investment was paid back with the first torque overload within 12 months of start-up. The coupling disengages the shredder driveline upon sudden unplanned stops due to unshreddables.

Sudden stops create a high torque event that stresses drive components resulting in damages, reduced life, and ultimately catastrophic failure. Even worse, catastrophic failure creates a life-threatening safety hazard for shredder operating personnel.

Thankfully, the retrofit coupling solution allows the automotive shredder to do what it does best—smash, crush and grind metal down to smaller, more manageable pieces. **PTE**

For more information:

City Scrap & Salvage
Phone: (330) 753-5051
Cityscrap.com

Voith
Jim Fraser
Product Sales Manager
New Business Sales MM
Voith Turbo North America
Jim.fraser@voith.com
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Stock Drive Products/ Sterling Instrument

Precision CNC Machined Components

Stock Drive Products/Sterling Instrument (SDP/SI) manufactures small mechanical components for all applications. Our precision gears, machined parts, molded components, and drive assemblies can be found in high-tech operating rooms, movie sets, military operations, space exploration, and even on Mars. Partnering with OEMs around the world we manufacture and manage supply chain of components required for medical, surgical robotics, aviation, satellites, defense, automation, and commercial industries.

Established in 1950, SDP/SI designs, manufactures and builds custom subassemblies with world-class quality and reliability for all applications. Completed December 2016, our 96,000 square foot state-of-the-art Hicksville, NY facility houses the latest manufacturing, industrial automation, and inspection equipment. Employing skilled machinists, CNC programmers, inspectors, engineers, and customer service personnel, we meet the highest-quality standards your business deserves.

Facing a design challenge? SDP/SI supports many Fortune 500 companies in new and exciting projects. Applying years of experience, product knowledge, and design acumen our engineering and manufacturing teams provide innovative solutions through part selection, modifications, or custom design. Sometimes the best solution is the simplest. Standard components are a cost-effective option and with 87,000 machined and molded components offered, SDP/SI is the engineers preferred source.

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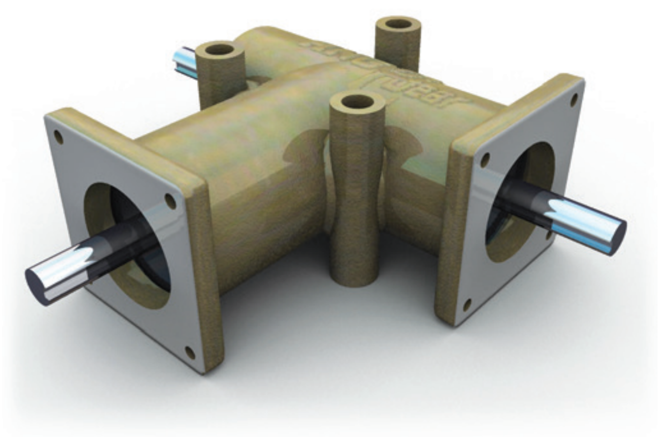
www.sdp-si.com

Andantex USA

Anglgear™: Made in the USA, Powering Industry Worldwide

Andantex USA's objective over the years has always remained the same: to provide innovative, high-quality gearboxes and solutions for use on industrial machinery. The Anglgear™ right angle drive is an example of our commitment to our customers' needs and applications. Since purchasing this product line more than 30 years ago, the Anglgear™ has grown into a product that is now used in various applications across the printing, converting, packaging, general purpose and aerospace industries.



In addition, we also supply all branches of the military, conforming to contracts specifying various MIL SPEC requirements.

The Anglgear™ line consists of 14 different models available from stock in both an Inch and Metric series and sold worldwide. ***We take pride in the fact that all Anglgear™ drives are assembled and shipped from our headquarters in New Jersey. Here, we manufacture, and inspect every unit that goes out the door. This ensures consistent quality in all our gearboxes.***

Our standard units are available from stock in 1:1 and 2:1 ratios, with 2 shafts or 3, 2 flanged or 3 flanged units, and are lubricated for life before being shipped.

Over the past 10 years, we have seen that a huge part of our growth in this line is due to the fact that we will modify our units to meet our customers' design specifications. **It doesn't matter if it's a one-piece special order or a quantity order;** our engineers will work with our customers to give them the best solution for their application and needs.

Examples of our modifications include various shaft lengths and configurations, including shafts with flats, splines, holes, etc. We also offer 3-way units with counter-rotating output shafts, as well as custom housings with flanges and bosses removed for custom mounting applications, special materials, bearings, seals and epoxy coatings as needed. We can provide units with special backlash upon request, and offer various options for grease including food grade, high temperature and radiation resistant.

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FOR MORE INFORMATION
1705 Valley Road, Ocean Township, New Jersey 07712
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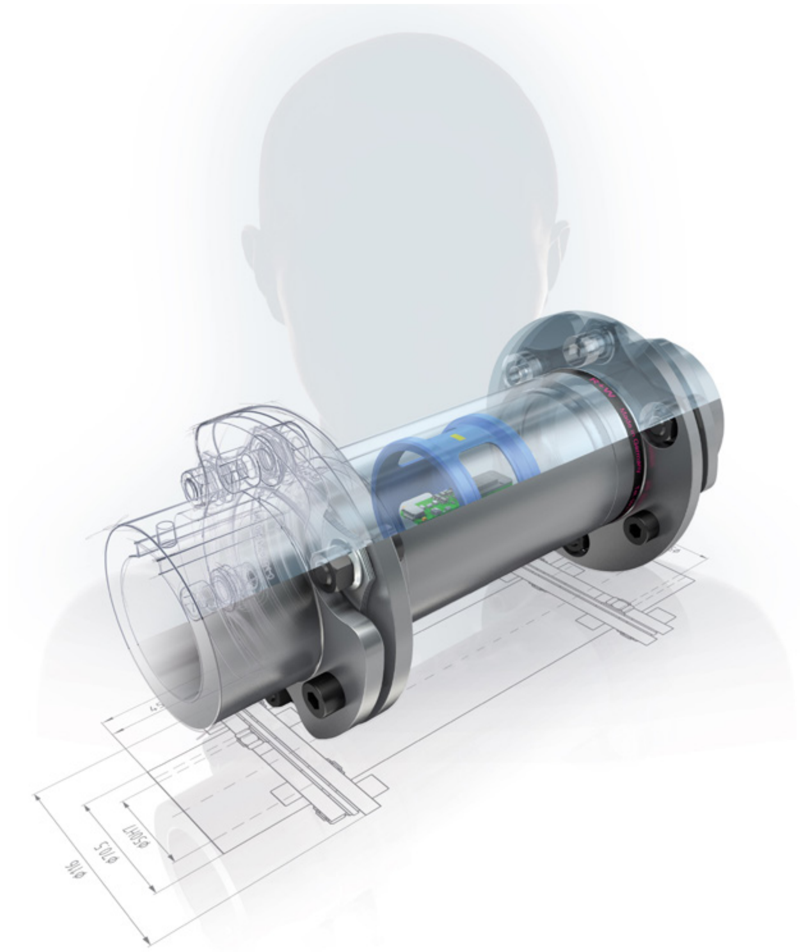
www.andantex.com

R+W Coupling Technology

Connection Elements of the Future

R+W has always stayed in the forefront of breakthrough coupling technology and does its best to exceed customer's requirements and expectations. An ever-expanding product line helps them design the most optimal solution for nearly every application in any industry. Recently, they have taken their first step towards building the coupling of the future.



A new intelligent coupling system from R+W provides wireless transmission of torque, speed, vibration, and axial load data in near real time to an app or gateway for integration into control systems for user monitoring. This development is significant because actual application torques cannot be accurately monitored by motor drives, historically leaving users to either guess or to build external sensors into the driveline. This adds significant cost and is not always possible due to space constraints. The coupling system comes with a user-friendly app which not only displays average, minimum, and maximum values, but also provides the ability to overlay charts in real time to help identify correlations. Rechargeable batteries are used in the first-generation design, but developments for an inductive power supply are currently underway which will facility uninterrupted data transmission.

Over the past 30 years, R+W has established itself as a precision coupling expert. With these intelligent couplings, they plan on providing more useful data to machine builders and enable them to optimize their driveline design, run condition monitoring, and plan predictive maintenance activities. Customer's demands and requirements are always a top priority, and a team of engineers is standing by to assist you with customized solutions for complex coupling applications. Find out what the coupling technology leads can do for you and get the best connection, worldwide.

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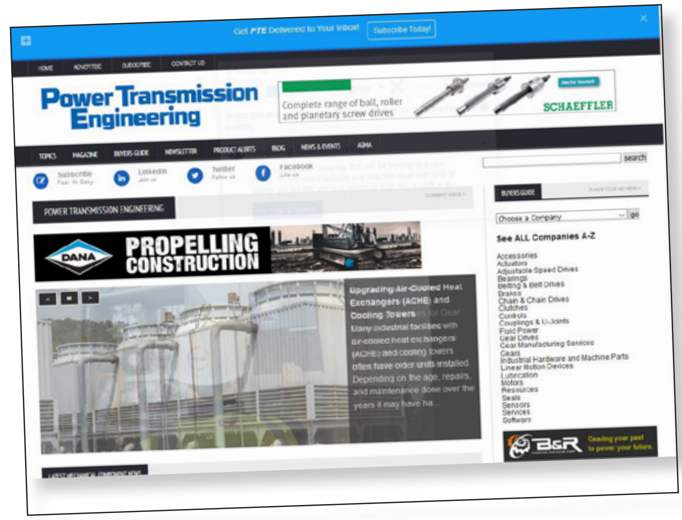
But don't stop there! Just type what you're looking for into our search box at the top-right of any page, and you'll find just as much great information from our archives on virtually any topic related to mechanical power transmission and motion control, whether it's gears, bearings, motors, clutches, chain, gearboxes and more.



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Hannover Messe USA Goes Digital

Matthew Jaster, Senior Editor

There would have been an incredible lineup of products and technologies in Chicago in the Hannover Messe USA pavilion at IMTS 2020—everything from cobots and smart factory automation solutions to digital twins and mechanical power transmission components. Unfortunately, the planet had other ideas this year and we continue to conduct business on laptops, smartphones and Zoom meetings for the foreseeable future. This doesn't mean we can't imagine perusing McCormick Place in search of intelligent bearings, new control systems, IIoT solutions, and gearbox software.

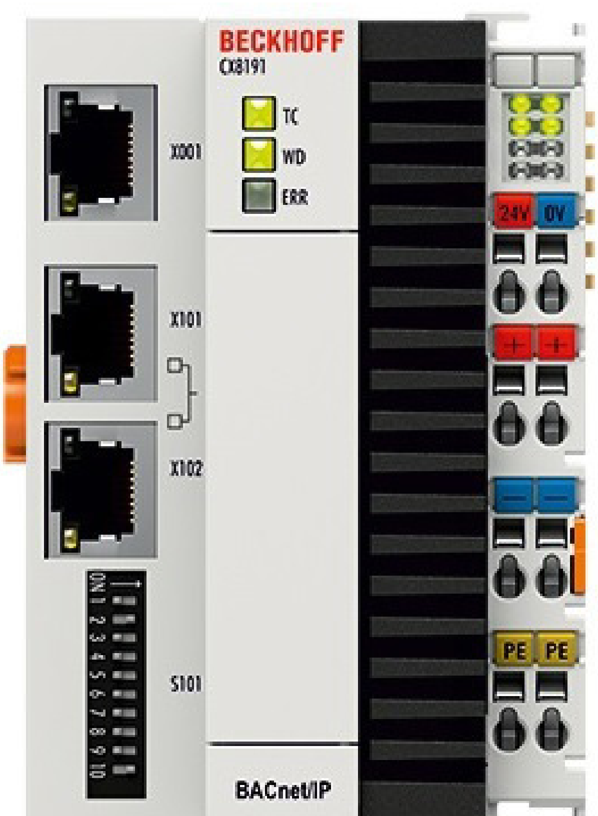
Beckhoff Automation

INTRODUCES CONTROL SYSTEM AND PANEL PC

CX8191 Control System

The CX8191 is a control system with a switched Ethernet port. It supports the BACnet protocol. E-bus or K-bus terminals can be attached as required; the CX8191 automatically recognizes the type of I/O system connected during the start-up phase.

The control system is programmed with TwinCAT 3 via the fieldbus interface or the additional Ethernet interface. TwinCAT 3 licenses must be ordered via the TwinCAT 3 price list. The BACnet license is already installed on the device and does not need to be ordered separately.



BACnet (Building Automation Control Network) is a standardized, manufacturer-independent communication protocol for building automation. Areas of application include HVAC, lighting control, safety, and fire alarm technology.

In conjunction with the EL6861 BACnet-MS/TP terminals, the CX8191 can act as a router to MS/TP networks including support for several MS/TP networks. In addition, further protocols and services can be supported, such as OPC UA, MQTT or Modbus TCP/RTU. Therefore, the CX8191 is a virtually universal device that can be used very flexibly, from control tasks through to gateway functions.

CP32xx Panel PC

With the CP32xx series, a high-end Panel PC with multi-touch can be used directly in the field. The devices in a slender aluminum housing feature complete IP 65 protection and are designed for mounting arm installation. The Panel PCs offer maximum computing power with processors of the latest generation, such as Intel® Celeron® or Core™ i3/i5/i7.

A choice of seven different multi-touch TFT displays, in sizes between 12-inch and 24-inch and 4:3, 5:4 or widescreen 16:9 formats, are available. Cooling is achieved by means of cooling fins on the outer wall as well as fans inside the closed housing. The operating temperature range is 0 to 45 °C.

The Panel PC features an integrated rotatable and tiltable mounting arm adapter for a 48 mm diameter mounting arm tube. There is a choice of attaching the mounting arm from above or below. The connecting cables are laid through the mounting arm. The Industrial PC connections (up to six) with IP 65 connectors are positioned in the large wiring space and are easily accessible. The wiring area can be opened easily without dismounting the device from the mounting arm, offering fast access to the IP 65 connectors for power supply, Ethernet and optional fieldbus or USB. Prefabricated cables in various lengths are available for all connections. The C32xx series Panel PCs are supplied with a 24 V power supply unit, optionally with integrated uninterruptible power supply (UPS). A battery pack can be connected externally and installed on a DIN rail in the control cabinet.

The CP32xx Panel PCs are equipped with one or two hard disks, SSDs or CFast cards or combinations thereof. With the on-board RAID controller, two same hard disks, SSDs or CFast cards can be mirrored. The data media and the lithium battery of the system clock are accessible from the rear under the cover. There is a PCI slot in the CP32xx. A factory-fitted FC9062 PCIe module with two additional Ethernet ports can be added. NOVRAM is also available as PCIe module for fail-safe data storage.

For more information:
Beckhoff Automation
Phone: (952) 890-0000
www.beckhoff.com

Igus

LAUNCHES PLAIN INTELLIGENT BEARINGS

Presented last year as a prototype, igus has now developed its first isense plain bearing series with five iglidur materials for predictive maintenance. Whether in the food industry, textile machines, forklifts, or construction machines, with the intelligent isense plain bearings, users receive a durable and lubrication-free solution that provides information about their wear. Maintenance can be planned in good time and machine and system failures are prevented.

Wear-resistant parts such as plain bearings must withstand extreme loads in machines and plant. If one of these bearings fails, there will be big trouble. For this reason, igus presented the first study of an intelligent plain bearing at the Hannover Messe 2019. The principle: technology integrated in the bearing detects wear in advance and gives the user a signal in good time when the wear limit is reached. Maintenance can be planned in advance, and unnecessary

replacement and unplanned machine and system failures are avoided. After many series of tests in the 3,800 square metre in-house test laboratory, igus has now developed the first isense standard range for its lubrication-free iglidur plain bearings.

"The catalog range includes five materials with which we can cover a large part of highly stressed applications," said Stefan Loockmann-Rittich, division manager iglidur plain bearing technology at igus GmbH. The FDA-compliant material iglidur A180, which is specifically designed for use in the food industry, the heavy-duty bearing iglidur Q2E for use in construction machinery and agricultural engineering, the all-rounder material iglidur G, the endurance runner iglidur J as well as iglidur P210 as a specialist for pivoting and rolling applications are also included. igus offers all intelligent plain bearings in three dimensions each with an inner diameter of 20, 30 and 40 millimetres. Further sizes and materials will follow.

To connect the isense plain bearings, igus has four suitable cables with an oil-resistant and media-resistant PUR outer jacket, in four standard lengths of one to ten metres, in its portfolio. In addition, the user has the choice between two connector types. The sensors measured data can be integrated by the machine and equipment operators into their systems in different ways. igus offers three readout units for this purpose: either the user can manually read out all plug-in points or install a control unit with a red/green display on the machine which provides information about the condition of the plain bearings. Another possibility is the connection to *icom.plus*. For this purpose, a radio module sends the sensor data by wireless transmission to the communication module. From here, the integration of data to the IoT, cloud system or to the customer network is possible on a wire-bound basis. "The customer has the freedom to read the data in the way that suits him best," said Loockmann-Rittich.

For more information:
Igus
Phone: (800) 521-2747
www.igus.com

Emerson's

ALUMINUM CYLINDER BOOSTS MACHINE SPEEDS AND CUTS DOWNTIME

Machine builders and their end-user manufacturers can increase machine speeds and reliability with the new Aventics TM5 TaskMaster aluminum cylinder from Emerson. The National Fluid Power Association (NFPA)-compatible pneumatic cylinder reduces cost, energy consumption, equipment wear and downtime.

With its rugged aluminum body construction and a steel piston rod, the TM5 TaskMaster features Emerson's state-of-the-art pneumatic cushioning technology that allows an ideal cushion adjustment to slow down the piston to a stop by the time it reaches the endcap. Ideal cushioning reduces the time it takes the cylinder to complete a stroke, allowing an improvement in efficiency that significantly boosts machine speed and lowers endcap hammer. Ideal cushioning also reduces cycle time and enables the TM5 cylinders to carry higher loads without sacrificing cylinder performance.

The cylinder incurs less stress and there is no end-of-stroke bounce or end-cap slamming, which is a main source of cylinder wear, slowness and noise. Ideal cushioning thus lengthens cylinder operating life and reduces downtime related to cylinder failure. Additionally, it reduces machine noise and vibration while reducing energy consumption.

"The all-new TM5 TaskMaster gives machine builders and end-user manufacturers the tools to make their machines faster and more reliable," said James Ward, vice president engineering, machine automation, Americas, at Emerson.

"It's the highest performing and most reliable TaskMaster cylinder ever produced, so it gives them an opportunity to build a competitive advantage."

The NPFA-compliant TM5 is the latest addition to the TaskMaster line of aluminum cylinders, an industry standard for 50 years. The TM5 TaskMaster is supported by a full suite of web-based design and integration tools, with many products preconfigured and ready to order. With no additional engineering time for setup, Emerson's online configurator provides a product part number, pricing and 2D and 3D CAD drawings in one convenient place. In addition, all product information and spare parts can be found in the Aventics Pneumatics Shop.

TaskMaster TM5 provides a high-quality and readily available interchange cylinder to meet OEM and machine requirements. In combination with the online tools, a fast-delivery program allows for quick turnaround of orders, reducing lead times for customers. From configuration to production, Emerson's process is completely automated.

For more information:
Emerson Automation Solutions
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www.emerson.com

Festo
CONTINUES TO ADVANCE DIGITAL SOLUTIONS

Festo is advancing digitalization in all its corporate divisions. Many aspects of Industry 4.0 are already reality today in the Festo Group. Festo is leading its customers and employees into the digital future. To this end, the company is developing new future-oriented concepts founded on the triad of innovative and energy-efficient technologies, intuitive human-machine collaboration, and education and further training.

In the 1950s, Festo became the first company in Europe to use compressed air as a drive medium in automation. The company now offers over 30,000 products and system solutions for pneumatic and electrical automation technology which, thanks to a large variety of modular systems, can be tailored to specific customer applications in many different factory and process automation industry segments. These include pneumatic and electric drives, valves, servo controllers, motion control, valve terminals, installation-saving connection technology, handling and assembly technology, air preparation equipment, fittings, vacuum technology, position and quality inspection, sensors and control technology.

The core product range comprises components from every phase of the pneumatic and electrical control chain, with which around 80% of all applications can be accomplished effortlessly and quickly. Festo also offers a wide range of modular systems solutions and standard handling systems.

Important industry segments are the automotive sector, the food and packing industries, electronics and assembly, biotech, pharmaceuticals and cosmetics, medical engineering and laboratory automation, the chemical industry and water treatment.

mart products, connectivity, the mining and interpretation of data, including via the cloud, and dashboards for visualization, already offer added value for customers. Products like the energy efficiency module E2M, IO-Link-capable components, the CPX-IOT gateway or interfaces like OPC-UA contribute to this process. Another basic requirement for successful and consistent digitalization is mechanical, electrical, and intelligent connectivity through software solutions, enabling all customers to find their bearings quickly and intuitively.

Festo is promoting this with an open automation architecture and a large product portfolio made up of axes, motors, and controllers. Standardized software tools are also being developed: configurators for smart engineering, the Festo Automation Suite for easy commissioning and the digital maintenance manager Smartenance for reliable operation. Digitalized pneumatics such as the Festo Motion Terminal VTEM (see photo) makes pneumatics more flexible than ever before. The reason: apps define the function, but the hardware remains the same.

In addition, data analytics, machine learning and artificial intelligence are shaping the agile product development of the future. With the takeover of Resolto Informatik GmbH in 2018, the competence in the field of AI has been further expanded.

Festo Didactic offers a comprehensive range of learning solutions for the trend topics of digitalization and energy turnaround. The learning content is specifically tailored to these topics in learning paths and conveys the skills that will be in demand among the specialists of tomorrow. Technological knowledge is imparted both in team-oriented training sessions on physical learning systems and, increasingly, independently of time and place through digital online learning options. Festo LX (Festo Learning Experience) is the new online portal for learners and trainers, which stands for customized, motivating learning in vocational training.

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NUMgear

OFFERS PROFILE GRINDING CYCLOID TECHNOLOGY MODULE

The NUMgear Profile Grinding Technology Module for Involutes and Technology Module for Cycloids are set between user input from an HMI and the CNC. It takes the gear and tool data as input and calculates the shape of the gear tooth as well as the path of the dresser to create the corresponding grinding wheel.

Most robotic systems demand smooth, precise, and reliable low speed movement. Deriving that movement from a motor that runs optimally at, say, 1,000 rpm necessarily involves some form of speed reduction gearbox. Designers typically have a choice of two types of reduction gear box — planetary drives and cycloid drives.

Planetary drives (or gearboxes) use one sun gear in the middle and planet gears around it, all imbedded into a ring. All of the gears, including the ring, have involute profiles. These types of drives are ubiquitous — they are used in a broad diversity of applications, including cars and other road vehicles, and are produced by virtually every gear manufacturer in the world.

The other type of speed reduction gear drive is the cycloid gearbox. The input shaft drives an eccentric bearing that in turn drives the cycloidal disc in an eccentric, cycloidal motion. These gears do not require real gear wheels.

Gearboxes that use cycloid gears have very few moving parts and are some of the most efficient and reliable speed reducers available today. Single stator/rotor combinations can accommodate ratios as high as 300:1 and can provide efficiencies in excess of 93 percent.

The market for gears and gearboxes will still increase in years to come. With the rise of electric car drives, the demand might not be in the numbers, but in the quality of gears. Less noise, more compact, and better performance are the requests of the gear industry.

For mass production of involute gears Threaded Wheel Grinding is the obvious choice for external gears when it is all about speed.

For more information:

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Mitsubishi Electric

OFFERS NEW MODULES FOR SAFETY SYSTEM

Mitsubishi Electric has enhanced the capability of its MELSEC iQ-F series PLCs with two new modules forming the basis of a compact, integrated safety system. The modules simply connect to an FX5U or FX5UC PLC CPU and reduce wiring requirements. Machine builders and systems integrators can easily and quickly implement a safety control system as no programming is necessary.

A key focus in the development of the new modules was to provide simplicity of set-up for the safety application. A rotary switch on the front of the module enables the user to select from nine types of built-in programs, eliminating the need to load or develop the required sequence programs for safety control. This significantly reduces set-up time compared with a conventional architecture. The principle of simplicity also extends to visualization. The PLC's built-in web server make it easy to monitor the status of both the standard control and safety control system.

As well as simplifying the set-up of the safety application, the new modules also reduce the man-hours required during the engineering phase of a project. The FS5-SF-MU4T5 safety module and FX5-SF-8D14 safety input expansion module connect directly to the PLC. This eliminates the additional wiring that would be required for a traditional safety controller or when constructing a system with safety relays. Connection of the safety I/O has been simplified through the use of spring clamp terminals on the new modules.

The addition of the new safety modules to an FX5 PLC enables users to build a compact safety system that is certified to Category 4, PLe and SIL3 international safety standards.

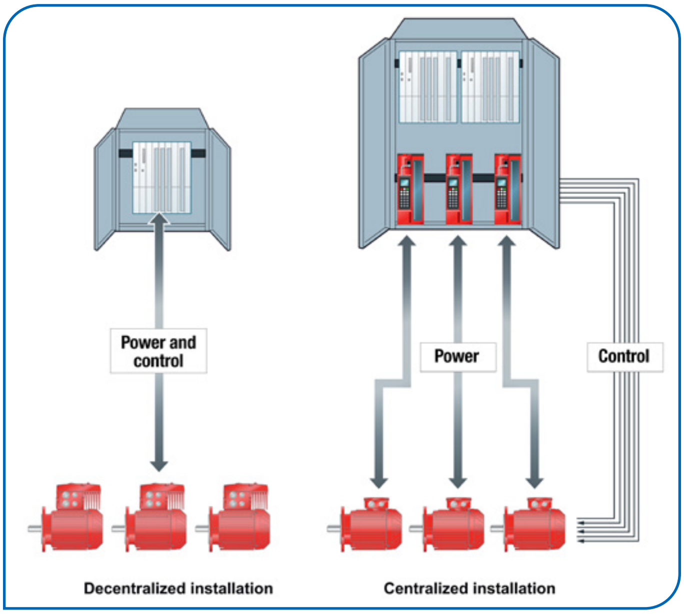
For more information:

Mitsubishi Electric Automation, Inc.
Phone: (847) 478-2100
us.mitsubishielectric.com

Centralized vs. Decentralized: Choosing the Right Type of Motor Control System

Bryce Egelin, Motion Industries, and Jason Oakley, SEW Eurodrive

Are you looking for one simple formula to help you choose between centralized and decentralized motor control? Unfortunately, such a formula does not exist. However, evaluating the overall size of the system, comparing labor and material costs, and maintaining flexibility can help guide engineers in the right direction. Designing with the correct architecture in mind from the start allows for more flexibility in the future. Let's look at each control type to help decide which is best for your application and work site.



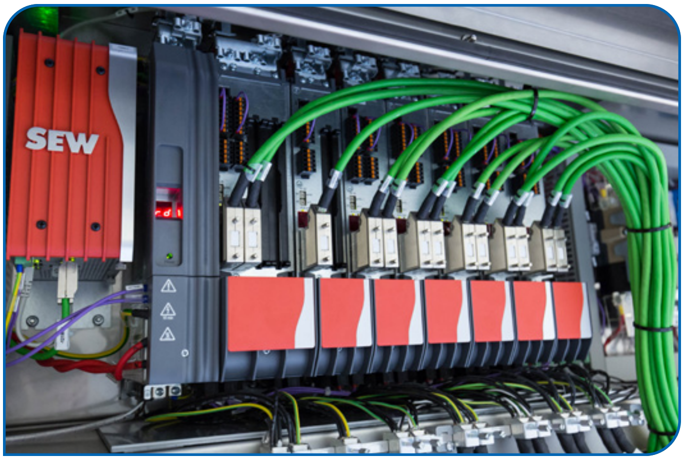
Power and control cabling can be a determining factor when designing a motor control system. The project footprint and number of control axes are common cost considerations. (Image courtesy SEW-Eurodrive)

Centralized Motor Control

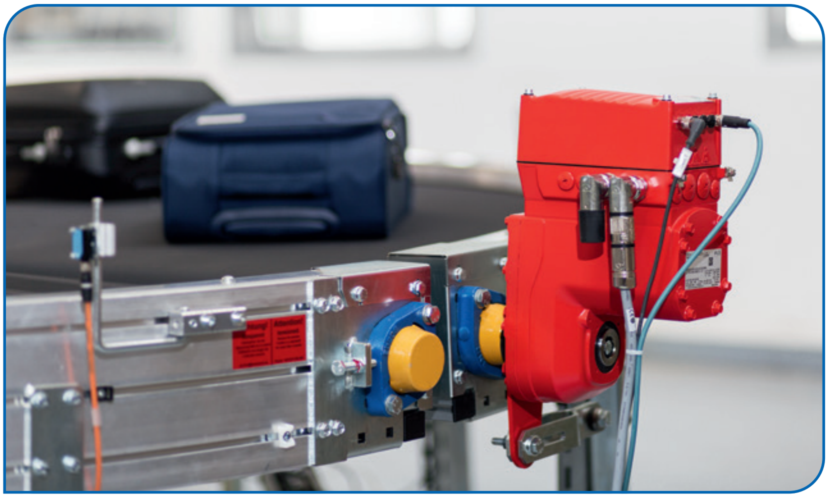
What is a centralized system? As the name implies, the controls for the system are centrally located, generally in an enclosure or multiple enclosures. Oftentimes some facilities will have electrical vaults, motor control centers, and even e-houses that centrally contain the controls for their systems. As you look into each of these centralized concepts, whether they are small or large, generally all of the system's peripheral devices are terminated in one location. For example, in a distribution center with multiple conveyors, the conveyors' system controls can be found in large control panels near the equipment — or sometimes far away from the equipment — depending on the application and environment, as well as the installation site itself. These centralized systems often contain electrical cabinets (See image bottom right) that house the PLC, motor controls, and branch circuit protection for all of the equipment. Each of the individual devices in the system are wired and connected directly back to a central point; these systems are generally designed for dedicated purposes.

When laying the foundation of a new project, it is important to know what key factors should be considered when deciding if a centralized system is the right fit. Certainly, the first thing to consider is the size of the system itself. Centralized systems tend to take up a lot more real estate in a facility when compared to a decentralized system, giving a centralized system a disadvantage. Ideally, it is best to keep a centralized system small in terms of the number of devices connected to it. This would help in keeping the cost of the installation low and manageable. The installation on a large-scale centralized system can be very overwhelming due to the cost of materials and labor to wire everything back to a central point. However, the environment of the application also plays a role in choosing whether a centralized system is right for the application. If your application requires your equipment to be in harsh environments with harmful liquids, hazardous gases, high temperatures or sometimes even washdown requirements, a centralized approach can be a more appropriate method to meet these requirements. Centralized systems can offer a great deal of protection against environmental challenges, making them a more appropriate choice.

If flexibility and expansion are important for the application, that can be a challenge for a centralized system. When



Typical centralized control cabinets house the motor controls, PLC, and circuit protection. Motors and other devices are wired back to this central point. (Image courtesy SEW-Eurodrive) designing the system, you must have a good idea ahead of time for what the additions will be in the future. Centralized systems are often times not modular or expandable. If an application calls for these characteristics, it can oftentimes cost more to make a centralized system flexible. Generally, a centralized system is designed for a dedicated purpose and is usually not altered or added to after the fact.



Decentralized control can include add-on components mounted on or near the motor. This modular installation can include onboard variable-frequency drives (VFDs), I/O ports, and various fieldbus options. (Image courtesy SEW-Eurodrive)

Maintenance and troubleshooting is another area to consider when deciding if a centralized approach is right for a given application. With anything, maintenance is the key to the life of the hardware within the system. Centralized systems will typically have some form of thermal management on them. It may be a simple filter fan or a form of a closed loop cooling method like an air conditioner, an air-to-air heat exchanger, an air-to-water heat exchanger, etc. No matter what cooling device is used, it needs routine maintenance to keep it and the system up and running. Maintenance and troubleshooting go hand-in-hand with these systems. If a centralized system is not maintained properly, it would be very tough for a technician to identify any problems. Keeping these systems clean will provide easy maintenance and troubleshooting if a problem should arise. Ideally, in a centralized system, if there is an issue a technician can look at a central location to identify the problem in the system.

Common applications that utilize a centralized system include small conveying processes, packaging equipment, palletizers, food and beverage processing, material handling, dedicated manufacturing machines, and processes apart of larger manufacturing systems.

Decentralized Motor Control

What is a decentralized system? Simply put, the motor control functions are removed from a central control cabinet and distributed close to the motors. Add-on drive components can also be integrated into a unit that is mounted on or near the motor in the field. Those components can include variable-frequency drives, motor starters, I/O, disconnects, integrated brake and overload control, fieldbus, power, and safe stop functionality. The automotive industry was one of the first to adopt this concept in North America, because it simplified production-line changes and reduced vehicle manufacturing and engineering costs. Decentralized control systems eliminate the long cable runs that are expensive to install, easy to damage, and time-consuming to change.

Similar to centralized control, decentralized systems rely on a few factors that help engineers decide if it will be the best fit for their application. The machinery footprint is often considered first. Both the floor space required for the machinery and the number of axes being controlled will help dictate whether or not a decentralized control system will be ideal. Applications that require cable runs that cover significant distance or applications with more than 10 axes are perfect opportunities to implement a decentralized control system. Another point to consider is local control requirements. Local control is possible in decentralized topologies because operators have access to motor control functions directly at the machine. This functionality is exclusive to decentralized systems so it should be included in your decision making process on control system topology.

Environmental conditions also play a hand in determining if a decentralized control system will work for your application. Centralized installations provide the best protection in the most challenging environments, but decentralized systems provide decent protection as well. Decentralized equipment typically has higher IP ratings than traditional cabinet components to compensate for washdown and other corrosive environments typically found closer to the production line. However, it can be difficult to meet all of the challenges that can be associated with a decentralized solution. In the harshest environments, costs can quickly rise if you need to control the temperature of electronic components. In some cases, it is more efficient to regulate a centralized cabinet with heaters, air conditioners, fans, and weatherproof panels.

Flexibility and modular configuration are the most beneficial features of a decentralized system. If your goal is to future-proof your application, choosing a decentralized layout will provide the most flexibility when processes or configurations change, since control functions are located in close proximity to motor location. With the modular configuration of decentralized systems you can also easily grow or reduce a system simply by removing or adding sections to an application. For example, in a conveying application it would be possible to add additional conveyors sections or even reconfigure existing conveyors to fit a new layout without the hassle of having to redesign a centralized panel to accommodate for the growth of the system. The bottom line is that this allows engineers to create new machines, or add-on sections from already developed modules, making the application more efficient.

Advantages of a decentralized method of motor control are often determined by the application footprint and number of motors. Applications with 10 or more motors are ideal for a decentralized drive configuration. In applications that contain a considerably larger number of motors, implementing a decentralized control system often yields the greatest cost savings. Installation costs are greatly reduced by avoiding expensive cable runs and labor associated with a centralized motor control system.

Another feature of a decentralized control system is lower maintenance costs. Troubleshooting can be easier and less labor intensive since technicians no longer have to be stationed at both the control panel and the machine to identify and correct problems. Cabling and communication errors are easier to diagnose at the unit, since many manufacturers locate a fault-code LED display on the front of their units. Pre-wired plug connectors can also reduce costs by reducing the disconnection time and lock-out/tag out safety issues associated with conduit box connections. Plus, fewer wires from a central location to motors results in less potential for cross-talking noise and electromagnetic interference which is a major source of machine downtime.

Across many industries, decentralized designs are now used for a variety of applications such as rotary and lift tables, automotive assembly, food and beverage processing, packaging, warehouse logistics, and other material handling applications.

Applications that have long cable runs and multiple axes are typically the best opportunity for a decentralized control installation. Machine expansion can also be easier and less expensive. (Image courtesy SEW-Eurodrive)

Which system is best for my application?

In summary, although the last decade has brought an increase in moving to decentralized motor control installations, using the traditional centralized cabinet enclosure can still be a viable option. There are benefits to each, and the decision on which way to go should not be a quick one. To find your best option, common considerations include the number of motors in use, the length and cost of cable runs, space savings, equipment cost comparisons, point-of-axis control needs, and flexibility for future expansion. Comparing the pros and cons of these options can help guide your choice in motor control options. **PTE**

For more information.

Visit *MotionIndustries.com/pte* or ask your Motion Industries representative about SEW Eurodrive's Movigear, a mechatronic drive unit solution (*tinyurl.com/ybjaoapd*).

Jason Oakley is an Electronics Product/Application Engineer at SEW-Eurodrive's U.S. Headquarters in Lyman, South Carolina. During his six years with SEW, Oakley has implemented countless decentralized and centralized control systems, and specializes in SEW's newest product line, MOVI-C® modular automation system. He completed his M.Eng. in Industrial Engineering at Clemson University.

Bryce Egelin is an Automation Specialist at Motion Industries and covers Arizona and Southern Nevada. He has been with Motion Industries for almost 10 years, starting in the company's Southern California UL 508A panel shop building and designing industrial control panels for various centralized and decentralized applications. In 2016, Egelin moved to Arizona to take on the Automation Specialist role, promoting and selling systems. He completed his BSE in Electrical Engineering at ITT Technical Institute Corona, California.

Closing the Loop around a Transverse Flux Hybrid "Step" Motor — The Degrees of "Closed Loop"

Don Labriola, P.E.

Transverse magnetic flux motors — also known as step motors — become *Hybrid Servos* when you operate them closed loop. This is the same transformation that happens between running a 3-phase synchronous motor from line voltage as opposed to running it closed loop as a brushless servo. In the case of hybrid motors, there are many degrees of what is advertised as "closed loop," and thus significant differences in the performance improvements seen.

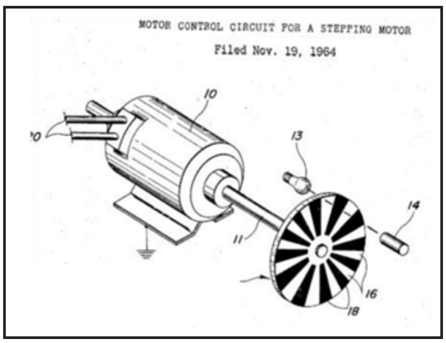


Figure 1 Early level 1 closed loop step motor using encoder.

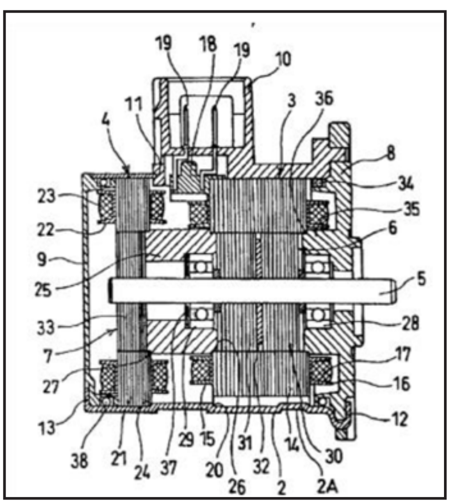


Figure 2 Step motor including resolver for closed loop.

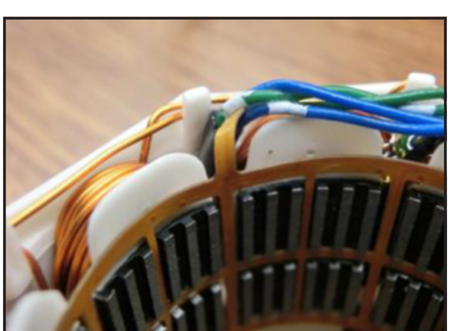


Figure 3 Mosolver construction.

Position Feedback Sensors

There are multiple position feedback sensor methods, as well as "sensorless" methods. One of the earlier methods, still popular, is the use of an optical encoder (Patent US3353076 from 1967). The encoder was used to adjust the step position of the motor to "obtain maximum torque without loss of synchronization." The circuitry taught in this patent keeps the motor error from exceeding 1.5 full steps; for full step, maximum torque is obtained by keeping the step angle between .5 and 1.5 step (1 full step average). Patent US4584512 improves on this by providing 64 microsteps to reduce the torque ripple. Newer encoders have higher resolutions to allow a finer position measurement. There are also better control techniques which we will get to later in the article.

Resolvers are absolute position sensors over their sensing interval. A drive signal drives a coil that generates a signal into at least 2 phases of sensor. Figure 2 shows a step motor with a resolver built into the same case (Patent US6849973). The resolver built with the same number of poles allows for easy commutation of the motor. Conventional resolvers require a separate excitation source — usually sinusoidal and a resolver to digital (R/D) converter — used to estimate velocity and position from the received phases. As the excitation passes through zero twice a cycle, the sensor is "blind" at these intervals, so the R/D must estimate what is going on in that time interval; this estimation can cause some phase distortions in the feedback information. Resolvers are not sensitive to most environmental factors, but they typically add size and weight to the motor and require additional electronics to drive and sense the signals.

Patent US7075196 describes the "mosolver" (a contraction of motor and resolver) in which we add a sensor winding into the slightly modified stator of a standard microstep-capable step motor. The motor windings provide the excitation, the existing rotor and stator gate the magnetic field through the coils on the sensing winding to provide sine- and cosine-related signals that are used for feedback as well as for commutation. The measured AC component of these signals comes from the ripple current resulting from the chopper drive. These signals are fed into spare A/D channels on the controller. These show a resolution of 32,000-counts-per- revolution. Additionally, the sampling rate equals the chopping rate of the motor preventing blind intervals from occurring.

Magnets can also be attached to the rear motor shaft and sensed by various hall sensor arrangements (Fig.4 — Patent US6064197). The single magnet plus hall sensors have sufficient resolution for avoiding step loss, but (at the time of my most recent research for those showing accuracy specs) at ~ .2 degree max error (11 bit) may not be quite sufficient accuracy for high-performance commutation and control

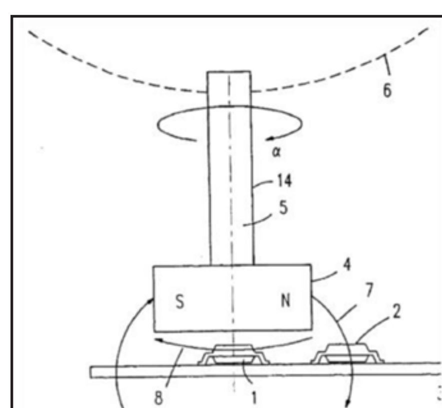


Figure 4 Hall angle sensor with magnet.

of the high pole count hybrid motors 1.8 degree motors. This area — like so many in motion control — continues to advance.

There are also electric field-based position sensors that use multiple, electrically conductive plates to resolve position. As with the resolver, the conversion time and phase implications of having "blind" periods in the conversion, as well as timing variations in the conversion sampling point, may hinder their use with the high-speed commutation of high-pole count motors. Again, the continuing advances may resolve these issues.

High-speed operation of these motors, for example a 1.8 degree motor at 4,000 rpm corresponds to

13,333-steps-per-second, or about 75uS per step (90 electrical degrees). Even a small variation in the sampling time of any sensor results in a variation in the measured position for that sample period from what the actual position measured would have been if it had been timely measured. The variation in measured position ends up varying the commutation angle, which causes a torque variation, and also varies the apparent velocity and position, both of which cause the control system to respond to the noise in these measurements, causing vibration in the operation of the motor. It is thus necessary to have a tight window on the sampling time of any of the position feedback devices used. With an 8,000-count-per-revolution encoder, for example, a 7.5uS variation in the sample time would correspond to 9 degrees of commutation angle and 8 counts of encoder error. One of the sensors examined had a sampling time uncertainty on the order of 100uS, so the sampling variation and latency are important specifications to investigate.

"Sensorless"

Multiple techniques use current sensing to estimate motor angle and/or velocity while the motor is in motion. These range from methods to improve damping to those that adjust the commutation points while moving to reduce loss of steps. The more advanced techniques use a Kalman filter to estimate the motor angle from the measured current versus the applied voltage using knowledge of the motor model.

A couple of other patents show integrating the voltage across the motor winding to estimate motor position from the integral of the back-EMF, while trying to compensate for the I*R voltage drops; another patent teaches the use of an 8-wire motor. One set of windings is used to drive the motor, and the second winding for each phase to directly sense and integrate the back-EMF, looking at the integral at of the back-EMF at points in time that the chopper is turned off (while recirculating).

Common to all back EMF techniques is the need for the motor to be in motion with enough velocity to induce a sufficient back-EMF for the measurement. For those measuring the back-EMF directly by monitoring the winding currents, the minimum speed to switch from open loop to closed loop can be significant. The final settling position of the motor is left to the motor torque stiffness curve, as the position when stopped is not able to be measured. This can leave significant position error in the presence of friction or load, as noted in the next section.

Torque versus Error in Open Loop Stepper

As stated earlier, there is a wide diversity of what is referred to as "closed loop" in the advertising of "closed loop" steppers and hybrid servo motors. This often leads to some confusion when comparing these systems to conventional servo motors. We will first review how torque is generated in the standard open-loop step motor, and then go into the range of modifications to these behaviors. For the comparison of closed loop stepper motors and hybrid servos, to simplify the discussion, we will assume (unless stated otherwise): 1) that we are using microstep-capable hybrid servos; 2) that the current to these motors is being controlled at a reasonable resolution to allow microstep; and 3) that any detent torque is significantly below the 100% torque level. We will also assume (for now) that 4) the drive voltage is high enough to properly control the current at speed, and 5) that the current vector length I_peak is held constant, with the two phases are driven as:

I_Aphase = I_peak * Sin (Theta)

And

I_Bphase = I_Peak* Cos (Theta)

Where "Theta" is the electrical angle of the motor which equals 50 *, the physical angle (for a 1.8 degree step motor).

First consider static winding currents (Theta constant). We describe the error angle as being the difference in actual electrical angle of the motor as

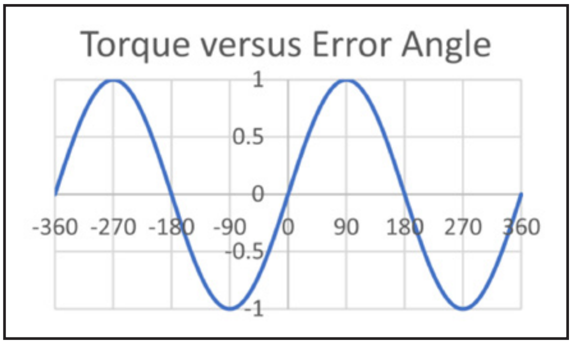


Figure 5 Torque vs error angle.

compared to the (friction-free) settling position of the motor for a given winding drive angle Theta. The torque generated is approximately a sine function of the error angle (Fig. 5). Zero error angle will produce zero torque. We consider the direction of error such that a positive torque will move the error angle value in a negative direction (to the left on the graph), while a negative torque will move the error in a positive direction (to the right on the graph). Thus, between -180 (electrical) degrees and +180 degrees of error, the resulting torque will try to drive error angle towards 0. For errors between -540 and -180, the torque will try to move the error toward the -360 degree point, while error angles between +180 and + 540 degrees will produce a torque which will try to move the error towards +360 degrees of error. Another way of stating this is that when the motor is energized in open loop, exceeding 180 electrical degrees (2 full steps) of error causes the motor to seek the next stable region, i.e. — 360 degrees or 4 full steps away — resulting in what is known as "losing steps."

Another important consideration is that generating 100 percent torque requires an error of (+/-) 1 full step (90 electrical degrees), and that any error except these points results in reduced torque. For stability of operation, the open loop stepper is typically used at between 25% and 30% of its full torque rating to avoid lost steps. The step sequence may also need careful attention, especially for high inertias.

Finally, notice that error *must* be present to produce *any* torque. Friction in the system will prevent the motor from actually reaching the zero error angle, and there will be two extreme resting positions, according to the direction of settling, i.e. — if the residual friction forces are positive or negative. If the load rings when settling in and/or there is significant friction, then there may be significant uncertainty in the final position of the motor even if the microstepping accuracy of the driving currents is perfect! Add the typical 5% step accuracy of the typical motor, and errors can accumulate quickly.

Closed Loop Stepper

The *zeroth* level of "closed loop" is to fix the motion after making it. The motion is made open loop and the result inspected, and then the motor is commanded to "fix" the motion so that the end position is close to the desired commanded move. Lost steps are corrected. The motor may overshoot significantly, or significant correction time may be needed if the motor lost sync early in the motion and the error was significant.

Mechanical collisions may occur and cutting edges may travel too far before being reversed. Liquid flow rates may not be consistent. Reversing of a pump after the liquid has been delivered will often not be effective in correcting the overshoot!

The *first* level of "closed loop" control is only asserted when the error of the motor reaches an error threshold point. (I think of it as open loop with guard rails; like you find on the kid's car rides at amusement parks. Not precise but it keeps you on the track!) For the early full step drivers this style of trajectory adjustment was used to keep the maximum error below 1.5 steps, allowing the motor to operate at the maximum average torque by jumping between .5 and 1.5 steps (1 step average). This same technique with a higher-resolution microstep drive limits the absolute value of the error to 90 electrical degrees or 1 full step, represented by Max T curve (Fig. 6).

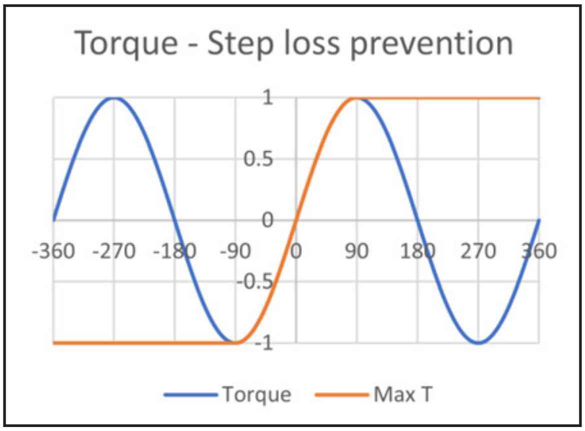


Figure 6 Peak torque closed loop stepper.

The trajectory generator controlling the current to the windings is modified by the feedback to prevent the difference between motor phasing and motor position from exceeding 1 full step, proving maximum torque for acceleration and deceleration. However, when the error is less than 1 full step, the motor reverts to open loop operation. This first level of closed loop has the advantage that no tuning is needed and the motor is prevented from losing steps. The feedback resolution requirement is typically lower, allowing lower-cost feedback. However, the open-loop issues with resonances (which include both vibration when running and ringing when settling), stopping error, stiction, and motor heating remain. No feedback loop is present to help reduce the position error at the end of travel, nor to help damp the oscillations of high-inertia systems. While some systems include the ability to drop the current to a lower holding level to reduce heating, the motor efficiency still remains quite low. High inertias may also get into a limit cycle where the error swings back and forth between the limits — both in motion and when the commanded motion has ended.

Some "sensorless" solutions only work in this first level of "closed loop," with the additional issue that they also lose the ability to prevent step loss at low speed where there is not sufficient back-EMF. Others go to the next level — at least while in motion.

The *second* level of "closed loop" is often called "field-oriented control." These operate the motor as a 2-phase brushless motor. The position information is used to commutate the motor, keeping the phase of the winding current in phase with the back-EMF to optimize the torque generation. (Field weakening used in more advanced field-oriented control makes this a bit more complex than described here, but that is another paper!) When less torque is required, the common method is to reduce the motor current vector, as commanded by a control law. There are patents which show the angle being reduced instead, such that the motor current remains constant (such as adjusting the angle of a microstep driver), and others that show a mix of the two, with both a current reduction and an angle reduction. Keeping the angle optimal and reducing the current is the most common method.

As field-oriented closed loop drives, the motor with only the current needed to produce the torque needed at that instant in time, the motor efficiency is significantly improved while also maximizing available motor torque. If field weakening is also implemented, then the motor speed and torque range can be significantly extended.

Full-Time Hybrid Servo

The highest stage is full time full servo control. This requires continuous monitoring of the rotor position so that the servo can control the error when the position is settling, as well as when the motor is in motion. It also commonly operates the motor using field-oriented control. A control law compares the actual and desired motion (position, velocity, and for some controllers, acceleration) and calculates the torque required to realize the desired motion (to the degree that it can). The torque can also be controlled, either as a limit or as a demanded value. This allows the error to approach zero even if the load on the motor is significant. Torque ripple can be minimized while the resulting speed can be made very steady. If there is sufficient damping in the system to allow the gain to be reasonably high, stiction can also be readily overcome. This is especially important when operating pumps (or other devices) with sliding seals.

Low-speed resonance. Low speed resonance is caused by the interaction of the open loop motor and the rotor inertia; Figure 6 shows the torque versus error angle. This same curve also (basically) applies when the motor is rotating (given the length of the current vectors remain constant). If the angle remains between +/- 90 degrees, we can approximate this as a k*theta spring (fairly accurately for small angles, not quite accurate for larger angles). This "spring" interacting with the rotary inertia of the motor forms a 2nd-order typically underdamped system. When the step rate hits the resonance frequency, a strong vibration can build up and the motor can lose in excess of ninety percent of its rated torque. The motor may lose sync all together.

If the same (microstep-rated) motor is sinusoidally commutated (i.e. — field-oriented control) using an angular position sensor, the torque remains almost constant as the motor is rotated (at least for lower speeds before the torque drops down). This looks like a simple force and an inertia (and a little damping) and the system looks first order. This does not have complex poles; the low-frequency resonance has thus been eliminated. This allows the motor to slowly ramp velocity without the noise and vibration that the low-speed resonance usually provides. Note that the zeroth and first-order "closed loop" stepper arrangements do not suppress this resonance.

Damping the Motor

The standard current-based choppers present the motor windings with a very high dynamic impedance. The bearings in most step motors are also commonly high quality, so they offer few losses. The basic motor and driver thus have very little intrinsic damping. Even with closed loop control, the system may exhibit relatively low damping. Although field-oriented control may reduce the low-frequency resonance, most motor systems drive some type of inertia through the springiness of the shaft and often a coupler. The motor inertia coupled through the spring of the shaft (etc.) to the load inertia forms another resonance (if not more than one if belts and pulleys are involved). These resonances can limit the gain allowable in the system before the system becomes noisy and finally unstable.

A viscous inertial damper shown (Fig. 7) (Patent US 4123675) may be added to the motor shaft to add mechanical damping to the system. The damper consists of a case surrounding an inertial ring which is coupled to the case by a viscous oil (or ferro fluid as in this patent).

The loose coupling through the oil is modeled as a dashpot coupling to the inertia ring. Any acceleration, including rotary oscillation of the shaft, will cause shearing of the viscous oil which will then couple torque to the inertial ring. If the motor speed is essentially stable, the inertial ring will come up to speed and will not put a continuous load on the shaft. The shearing which occurs when the inertia speed is not equal to the case speed dissipates power (p = torque * speed difference) into heating the oil. This provides significant damping to the motor system. The viscosity of the oil and the inertia of the ring can be varied to optimize the system. If you go through the math, this damping shows up as a significant phase boost in the system covering up to a couple of octaves width. The phase boost provided to the control system makes tuning the system much simpler, especially those involving significant inertias.

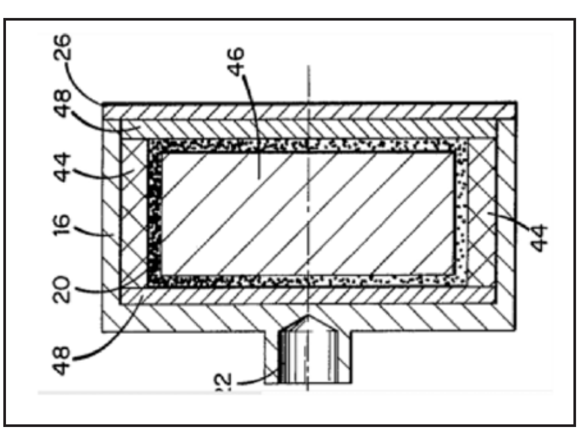


Figure 7 Viscous inertial damper.

The PVIA (position, velocity, integral, acceleration) used by QuickSilver Controls simulates the torque reflected to the motor by a viscous inertial damper, allowing a very similar damping to be accomplished via software without the size and cost constraints of a physical viscous inertial damper.

QuickSilver Controls also breaks from most drive implementations by driving the motor with a PWM voltage mode technique which approximates the high impedance of a current drive at lower frequencies while transitioning to a lower impedance of the voltage drive at higher frequencies. This allows normal torque control at the nominal movement frequencies while adding significant damping at higher frequencies where vibration may occur. To observe the damping present when driving these motors from a low-impedance source, short all the leads of a step motor and try to rotate the shaft. The significant damping will be immediately apparent. This voltage control method also eliminates the mid-frequency "resonance."

Results

The hybrid servo motors, when properly driven, are exceedingly responsive. Figure 8 shows a QCI-MV-23L-1 (1 stack NEMA 23 frame mosolver) doing a full revolution, start to stop, in 36 milliseconds. This is an acceleration from stopped to ~2,500 rpm in 12 milliseconds, slewing for 12 milliseconds, and then decelerating back to stopped in the final 12 milliseconds. The final settling is to within 45 counts (.5 mechanical degrees) over the whole last third of the motion, and to within approximately .1 degrees mechanical by 40 milliseconds. A 20-degree indexing takes about 7 milliseconds, depending on motor, load and power supply voltage used.

Proper driving of a hybrid servo motor can also provide high efficiency over a wide range of speeds. Figure 9 shows the measured efficiency of the X34HC-2 SilverMax integrated hybrid servo at various voltages. The efficiency includes both the motor and the driver losses. Efficiencies are between 70% and 85%, from a few hundred rpm through approximately 2,200 rpm. **PTE**

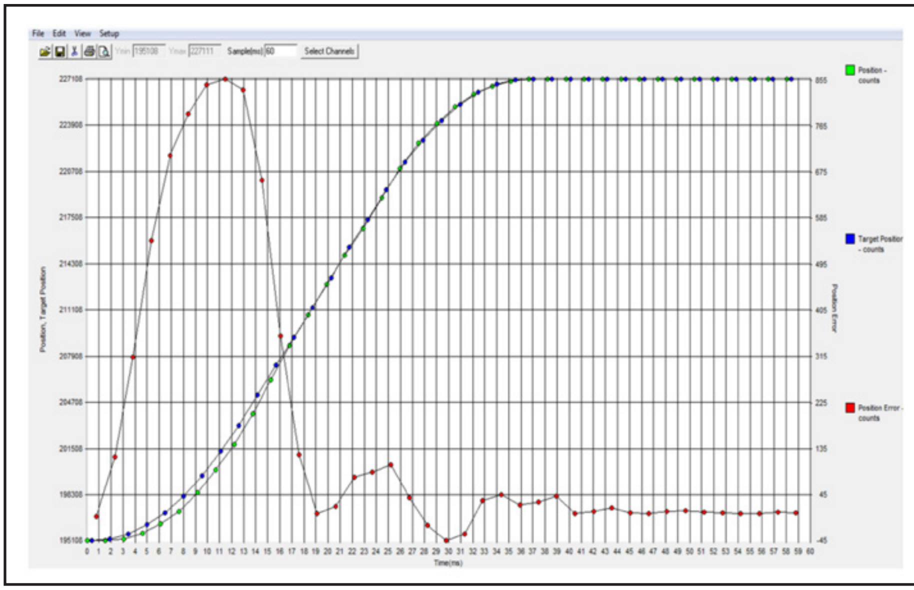


Figure 8 Rapid indexing of a QCI-MV-23L-1 mosolver.

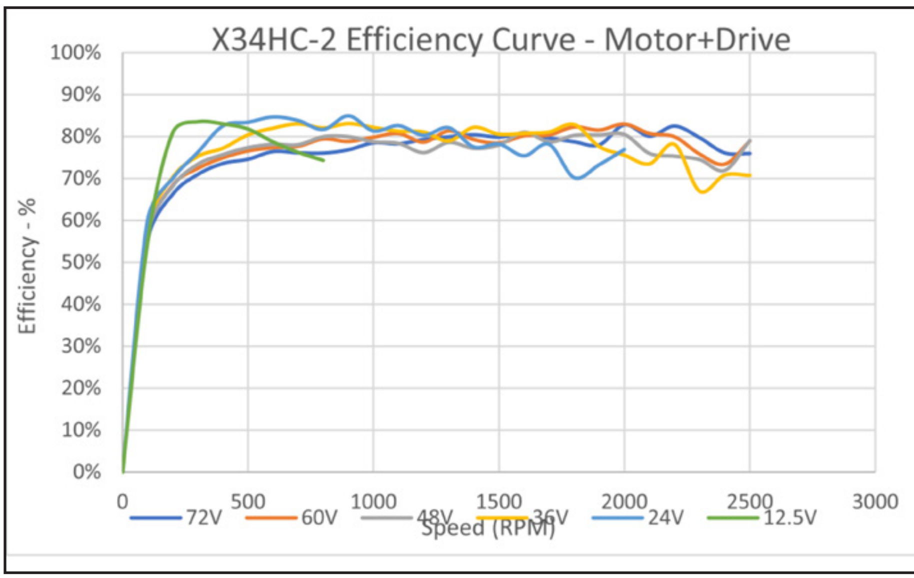


Figure 9 Efficiency versus speed.

Donald Labriola P.E. is president at QuickSilver Controls, Inc. He has been working with step motors since high school, and has had these motors operating field-oriented closed loop control since 1984.

Monitoring Concept Study for Aerospace Power Gearbox Drivetrain

Dr.-Ing. Sebastian Nowoisky, M. Sc. Mateusz Grzeszkowski, M. Sc. Noushin Mokhtari, Dr. Jonathan G. Pelham and Prof. Clemens Gühmann

Introduction

Rolls-Royce is pioneering the UltraFan (UltraFan is a registered trade mark owned by RR PLC) engine family architecture containing a PGB in a power range of 15 to 80 megawatts (Ref. 12). The new engine architecture must be more economical than the existing Trent engine family. The consumption of fuel is around 25 percent less than on a Trent 700 power plant (Ref. 13). To increase the efficiency of the UltraFan, a planetary gearbox is introduced between fan and intermediate pressure compressor. This enables running the turbine to rotate faster and allows a reduced fan speed. Subsequently, the bypass ratio will be increased and the

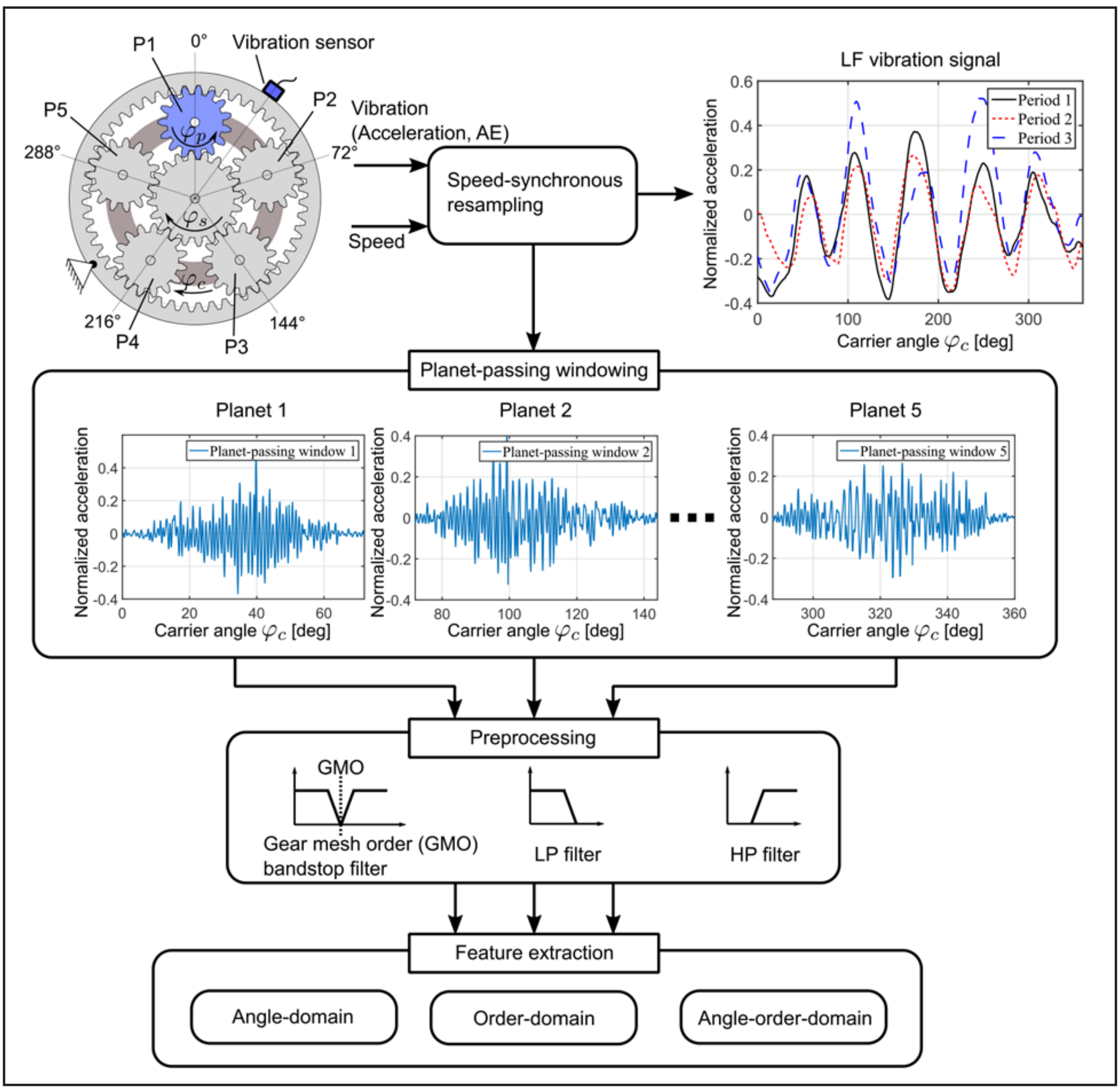


Figure 1 PGB monitoring method.

This paper was first presented at International Conference on Gears 2019, 3rd International Conference on High Performance Plastic Gears 2019, 3rd International Conference on Gear Production 2019, Garching/Munich (VDI-Berichte 2355, 2019, VDI Verlag GmbH, Page 269–286)

emitted noise level decreased. To build up monitoring capability for the novel gear technology, it is essential to enable additional digital services as a part of the Rolls-Royce digital strategy (Ref. 4).

The PGB is designed as a planetary gearbox; the gear ratio is used to reduce the fan speed, and will be able to transfer 100,000 hp (Ref. 14). In 2017 in the test facility at Dahlewitz, during a test run 70,000 hp was transferred by the PGB, setting record power level (Ref. 11). Due to heavy loads and high operation hours, hydrodynamic journal bearings are going to be integrated (Ref. 2). Hydrodynamic journal bearings offer advantages over roller bearings for high rotational speeds, impact loading or heavy oscillations, and vibrations.

Using a gearbox in a turbojet engine introduces additional failure modes such as gear wear, pitting, and gear teeth cracks (Ref. 1). The rotor's synchronous resampling method is the state of the art for gearbox vibration monitoring and serves to significantly reduce noise. A more advanced wavelet analysis is compared with conventional order analysis or time domain feature extraction. Acoustic emission signals, as well as acceleration signals, are subjected to these methods. A trade between methods and signals is made to facilitate the selection of a suitable gear monitoring system.

Power Gear Box (PGB) integrated journal bearings are a focus of this research activity. The presented method allows the monitoring of journal bearing mixed friction events in a planetary gearbox (Refs. 2–3). The drawback on the previously presented method used with a subscale journal bearing rig application is that it depends on a measurement position close to the bearing. Therefore a WDTU is essential to transfer the acoustic emission signal acquired close to the journal bearing across the rotating carrier to the stationary part of the gearbox.

In this paper methods and opportunities will be presented to detect journal bearing mixed friction, as well as how to transfer the data from the rotating to the static part of the gearbox. A mockup was built to support appropriate testing of the WDTU prior to the test on a subscale gearbox being carried out.

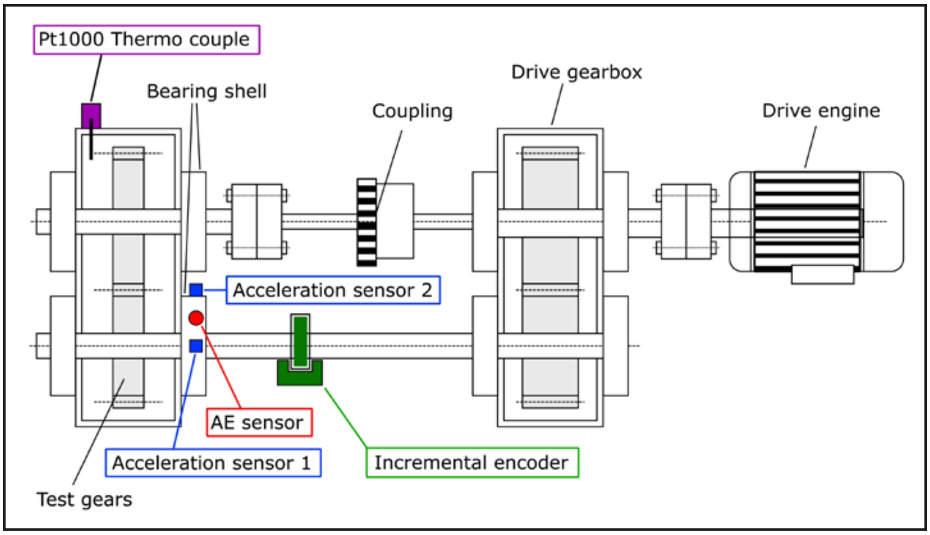


Figure 2 Sensor instrumentation for the B2B gear test rig.

Gear Monitoring on PGB

An evaluation of the PGB system design process resulted in the requirement to monitor the gear train to detect possible gear failures such as gear wear, pitting and gear teeth cracks. Depending on the gear failure, several physical measurands — like acoustic emission (AE), acceleration, oil particles, and temperature — can be measured. However, further investigations have shown that AE and acceleration sensors are best suited for early fault detection in the case of the above-mentioned failures, due to their short response time to propagating faults.

Planet-passing monitoring method. Since the vibration signals in the gear train have a vibration periodicity with respect to the gear meshing patterns, the following signal processing method for gear monitoring is shown in Figure 1 using acceleration signals. The acceleration signals were recorded on the planetary test bench of the FZG of the TU Munich (Ref. 8).

The presented method aims primarily at the detection of locally distributed failures on the planet gears and the sun gear. The main idea is to monitor the vibrations of the meshing tooth of each planet gear separately to detect anomalies in the vibration patterns when faulty teeth are in contact. First, the time-dependent vibration signal, which can consist of acceleration sensor and AE sensor signals, is merged with the carrier speed sensor and transferred to the angle-domain using speed-synchronous resampling. This signal processing step reduces the smearing effect in the spectral representation, which can be caused by speed fluctuations. The low-frequency (LF) vibration signal in the upper-right corner of Figure 1 shows the amplitude modulation effect that results in an increased vibration amplitude when a planet gear is directly below the vibration sensor mounted on the ring gear. After the resampling method, the vibration data are windowed with a window width of 360°/N_p, where N_p is the number of planet gears of the planetary gear. The center of the window is at the carrier angle point if a planet gear intermeshes right near to the vibration sensor. In the preprocessing step, various filters such as low-pass filters, gear mesh band-stop filters for revealing the vibration sidebands, and high-pass filters are applied to the window-shaped vibration signals to feed the feature extraction methods in the last step of Figure 1. Afterwards, features are extracted from the angle-domain vibration signal (e.g.: root mean square (RMS), kurtosis, crest factor) and from the order-domain of the vibration signal (e.g.: FM0, FM4, NB4, NA4, sideband level factor) (Ref. 24).

In addition to the method presented, non-resampled vibration signals are also windowed in the time-domain and used for preprocessing and feature extraction to allow a detection of abnormal vibration characteristics in the vibration signals that occur throughout the gear train due to gear failures.

Further tests on the FZG planetary gearbox (Ref.8) are planned this year to evaluate the method presented for monitoring the planetary gear train.

Pitting detection. The method presented above was developed to enable gear failure detection in a planetary gearbox. However, since one of the main gear failures, apart from tooth wear and gear teeth cracks, is macropitting, a failure-specific investigation must be conducted to provoke pitting. Therefore, the following section presents a pitting detection method that was evaluated with the help of load-carrying capacity tests on a back-to-back (B2B) test bench.

The test rig used is standardized to DIN ISO 14635 (Ref. 20) and consists of a power circuit consisting in particular of test gears, a drive gearbox, a torsional shaft and a coupling (Fig. 2). Five different gear variants with respect to their macro geometries, such as pitch deviations and flank roughness, as well as their final manufacturing step, were investigated to demonstrate the robustness of the pitting detection methods (Ref. 1). After a defined running-in phase, the pitting tests were carried out with a constant load of 950 Nm and an engine speed of 2400 min^{-1}.

Since the formation of pitting on the tooth flank leads to a disturbed vibration characteristic with periodic loading of the spur gears, vibration sensors were used (Fig. 2). Two identical piezoelectric acceleration sensors were placed on the bearing shell of the test gears to measure the radial accelerations resulting from locally distributed vibration. In addition, one piezo ceramic acoustic emission sensor (AE) was mounted on the bearing shell.

The AE sensor is able to measure high-frequency AE pulses above 50 kHz that are generated by the excitation of elastic waves when a pitted tooth flank is in tooth engagement. In addition, the oil temperature was measured with a Pt1000 thermocouple and the instantaneous shaft rotation angle of the torsional shaft with an incremental magnetic encoder.

After the measurement data acquisition, quantifiable indicators for pitting detection are obtained from the data. First, the vibration data is merged with the incremental encoder data and resampled. In the next step, sensor-dependent features are extracted from the acquired sensor signals. The features are extracted from the four central moments and the root mean square (RMS) values of the time domain signal and from the spectral power density of the vibration sidebands between the harmonics of the gear mesh order. In addition, significant features are extracted from the coefficients of continuous wavelet transform (CWT) and are described in more detail in (Ref. 1). To evaluate the relationship between the pitting progress and the feature values, the Fisher discriminant criterion (Ref. 21) was used. With this criterion value, the features with the highest sensitivity to pitting damage can be found.

The kurtosis feature of the CWT coefficients generated by the AE sensor and the calculated spectral power densities of the vibration sidebands between the 7th and 8th harmonic of the gear mesh order generated by the acceleration sensors provided the most robust features for all gear variants tested. Figure 3 shows the normalized feature values with the highest sensitivity to pitting damage of a test gear variant with a comparatively high single pitch deviation. The complete test results for the other test gear variants can be found in (Ref. 1).

The pitting tests revealed that the features calculated from acceleration sensor data should be obtained from the sideband spectrum, and the features calculated from AE sensor data should be obtained from the CWT coefficients. Although the results did not show that AE sensors allow earlier pitting detection than acceleration sensors, the AE technology has the advantage that the high-frequency range of the AE sensor improves the separability between pitting-induced acoustic events in the high-frequency range and test bench vibrations in the low-frequency range. However, due to the higher sampling rate required and the associated higher hardware costs, first of all it must be examined whether the benefit justifies the higher effort.

Journal Bearing Monitoring

For hydrodynamic journal bearings, wear is the most essential damaging mechanism as a result of mixed or dry friction. These friction states are caused by conditions like low speeds, overload, start/stop cycles, insufficient oil supply or oil contamination. A breakdown of this component could have a negative impact on the product reliability, which causes high maintenance costs and downtime. Therefore, the journal bearing should be monitored sufficiently.

The literature provides several possibilities to detect damaging friction states of journal bearings, such as monitoring the bearing temperature, friction torque, electrical transfer resistance between shaft and bearing, oil and vibration analysis (Refs. 17–19). All these possibilities are either not feasible for the PGB application or reach their limits for early fault detection. A suitable opportunity to detect mixed or dry friction at an early stage is the use of acoustic emission (AE) technology. The

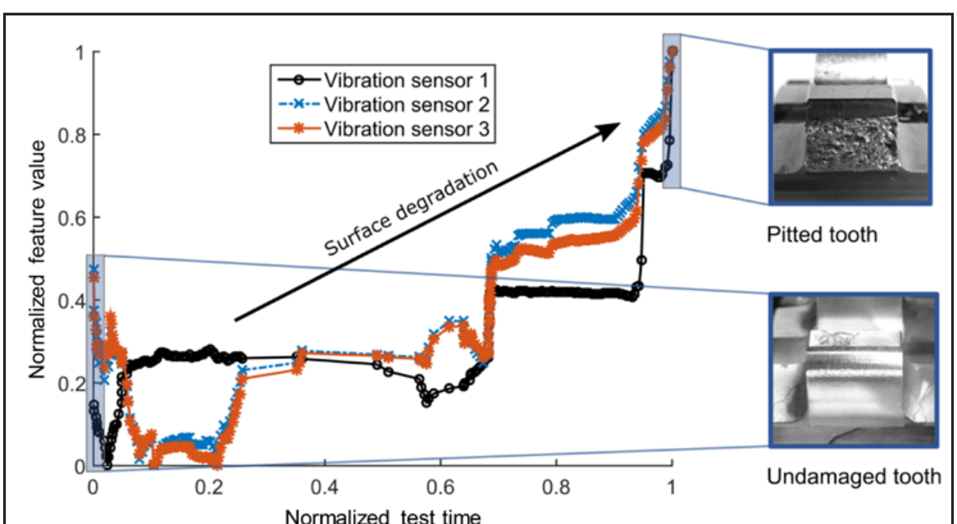


Figure 3 Pitting detection features.

acoustic emission technology provides a sensitive and robust method to detect friction conditions. In this work investigations were done at the classification of the three basic friction conditions fluid, mixed, and dry friction based on AE signals and pattern recognition techniques to provide a condition-based maintenance for hydrodynamic journal bearings. The suitability of these methods for monitoring the degradation state of hydrodynamic journal bearings is also shown. For this purpose, tests on subscale test rigs were done.

To differentiate between the three basic friction states, several speed ramps have been run from high speeds to low speeds at a constant radial load. Figure 4 shows the raw AE signals (top), where the left figure illustrates the fluid friction state and the right figure the mixed friction state. Some modulation effects can be seen within one cycle for the mixed friction state. These modulation effects are indications for mechanical friction.

In (Ref. 10) it is shown that these effects could be used to localize friction within the journal bearing. The continuous wavelet transformation (CWT) was used to analyze the acquired AE signals (bottom figures). During mixed friction conditions, besides the low frequencies which occur in fluid friction, also frequencies above 100 kHz occur. It can be concluded that in frequency bands lower

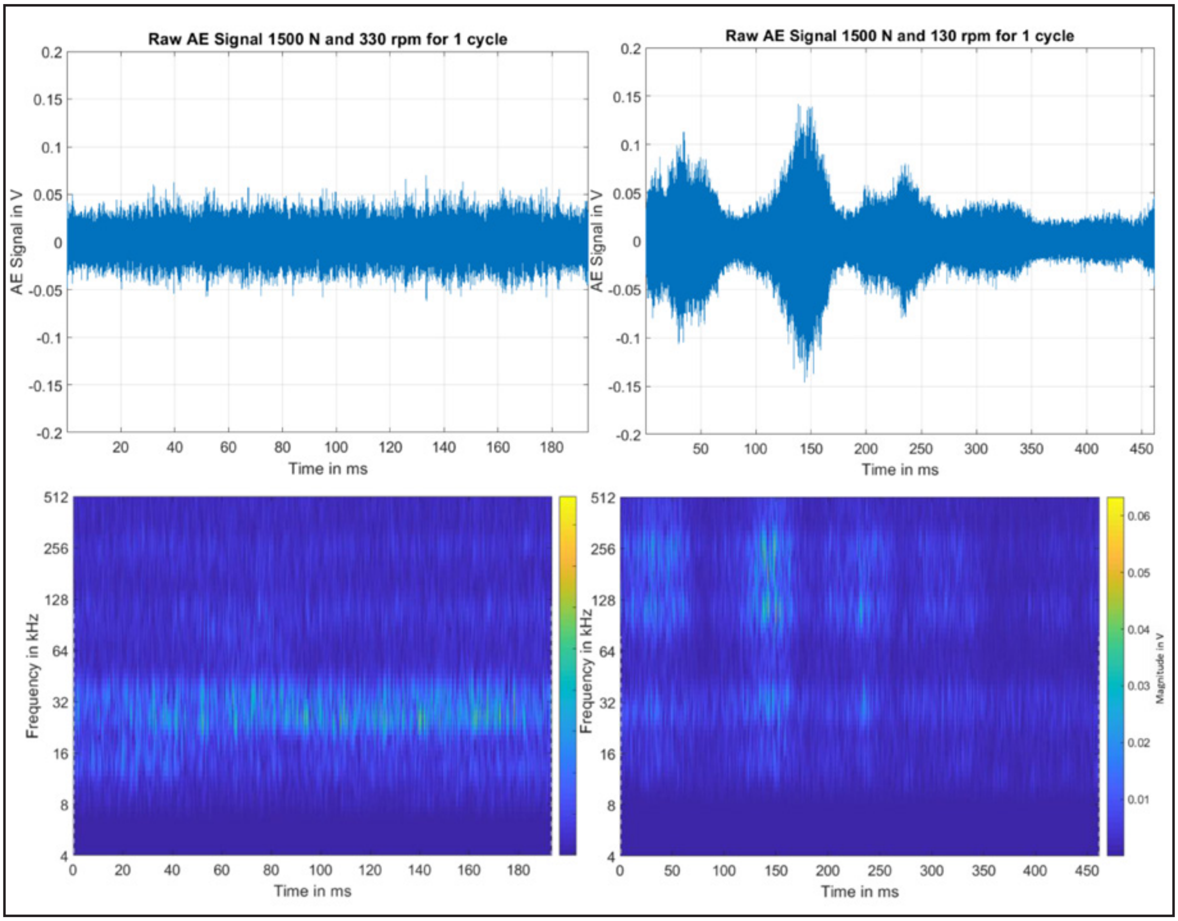


Figure 4 Comparison of raw AE signal and CWT of AE signal from fluid friction state (left) with raw AE signal and CWT of AE signal from mixed friction state (right).

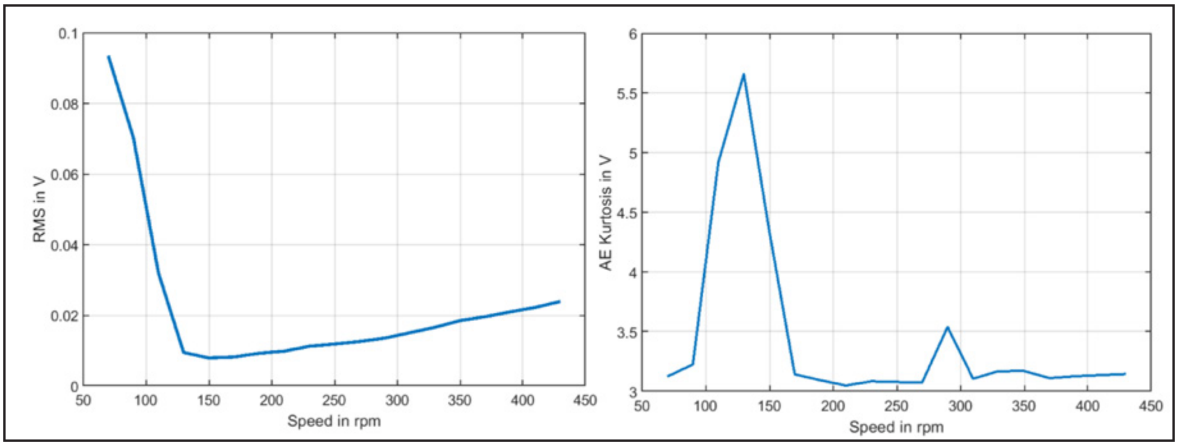


Figure 5 RMS and kurtosis of pre-processed AE patterns for a speed ramp at a constant load.

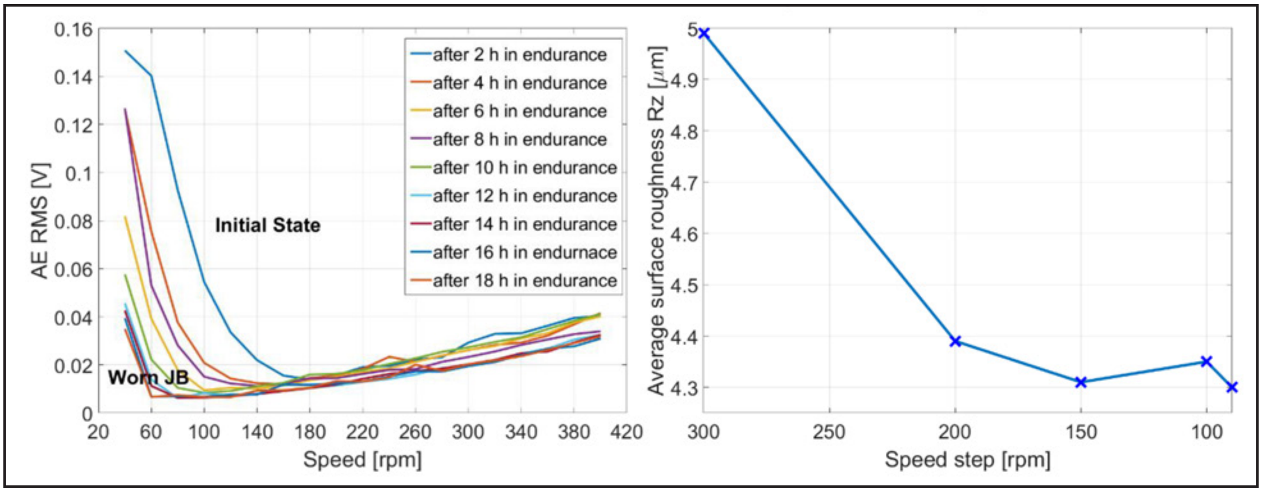


Figure 6 Degradation levels indicated by AE RMS for speed sweeps from 40 to 400 rpm, constant load of 1,500 N (left). Average surface roughness over different speed steps (right).

than 100 kHz the differentiation between fluid, mixed, and dry friction is not possible with the AE technology (Ref. 3).

Due to this result, only frequency bands over 100 kHz should be considered. Therefore methods for extracting distinct frequency bands (e.g. CWT, STFT, etc.) should be used as pre-processing steps before extracting features for the classifier. Several features were extracted from the pre-processed patterns. The most promising features are the RMS and the kurtosis for differentiating between the friction states (Fig. 5). These results and methods were verified at other subscale test rigs. The extracted features can now be used as the input for classifiers. The support vector machine classifier offered good results for the classification of the friction states.

To monitor a journal bearing it is not enough to only identify the actual friction state; the actual degradation state of journal bearings should be analyzed as well. The degradation of journal bearings is typically characterized by the actual wear depth. Short time wear experiments were done at the TU Berlin test rig. During these tests the journal bearing was driven for an overall time of 18 hours at constant operating conditions to generate wear.

After every step of 2 hours, identical speed ramps were driven and the pattern recognition methods were applied. Figure 6 shows that the feature changes over the degradation state. This result shows that it is possible to monitor the degradation state, which is the actual wear depth, by using the AE technology in combination with suitable pattern recognition techniques (Ref. 2).

In order to be able to predict the remaining useful lifetime (RUL) of journal bearings, long-term wear tests must be done. These experiments are part of current research work. For this purpose, the TU Berlin test rig has been modified so that long-term experiment conditions can be set.

One specific challenge when using the AE technology for the PGB application is the position of the AE sensor. The nearest static part of the PGB is the ring gear on which the sensor can be mounted. However this position is not acceptable because the gear mesh contact between ring gear and planet gears acts as a low-pass filter so that high-frequency friction signals are filtered out. In order to successfully apply the developed monitoring methods on the PGB, the AE sensor must be mounted as close as possible to the mixed-friction area; this area is rotating, which makes a wireless data transfer necessary.

Wireless Data Transfer Unit

As depicted on the left-hand side in Figure 7 — the generic arrangement of a planetary-style gearbox with the bearing between planet and carrier.

As stated previously, an acoustic emission sensor must be able to measure up to 1 MHz bandwidth (25) in a position close to the journal bearing. Hence a signal transfer from the rotating carrier to the static part of the gearbox is required. Beginning with common environmental requirements of a gearbox, the data transfer must deal with an oily environment, temperatures above 120°C, and strong vibrations caused by the gear train. A system engineering-based assessment was carried out to understand the requirements of a WDTU solution. As a result, a sensor node containing comprehensive electronics, e.g. — as presented in (Ref. 16) — can't be applied. Currently available high-temperature electronics either do not meet the functional requirements or the expected reliability

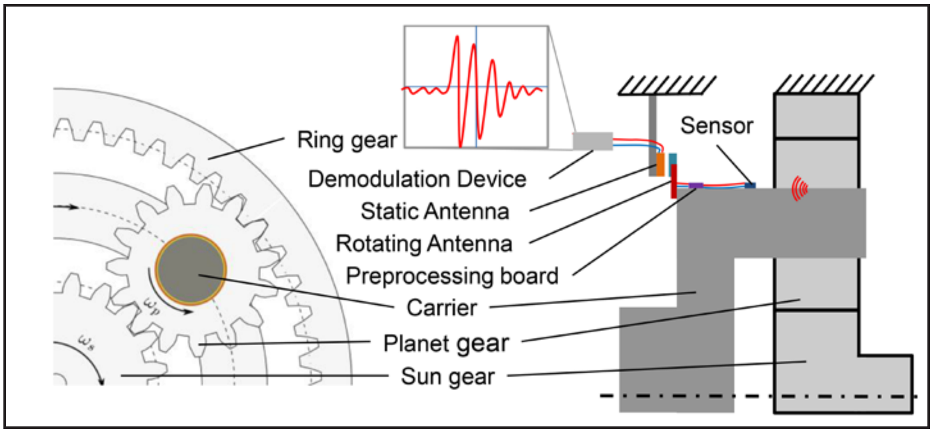


Figure 7 Schematic of planetary gearbox and applied wireless data transfer unit (WDTU).

levels. However, in further investigations a WDTU could be identified that had already been tested on PUMA helicopter main gearboxes (Refs. 22, 6 or 15) .The WDTU from Cranfield University [UK] meets the requirements of the measurement chain for the gearbox environmental conditions.

The WDTU works on a principle similar to homodyne radar and, in some respects, to a near-field RFID (radio frequency identity device) (Ref. 23); the system is depicted in Figure 8. The transceiver (A) generates the carrier signal and transmits it through a coaxial cable (1) to the matching network (B) that is used to tune the characteristic impedance of the static antenna with which it is connected by a pair of wires (3). The static coil transmits this carrier wave to the rotating antenna, where it is picked up by a twisted pair of wires (4) and rectified and smoothed within the processing unit (C). This creates a DC voltage which is used to power an amplifier and filter stage that is connected by a cable (5) to the sensor (D). This is where it differs from RFID, as this sensor signal — after it has been filtered and amplified — is used to tune the resonant frequency of the rotating antenna using a varactor diode. This allows a continuous signal to be transmitted that is representative of the desired signal from the sensor.

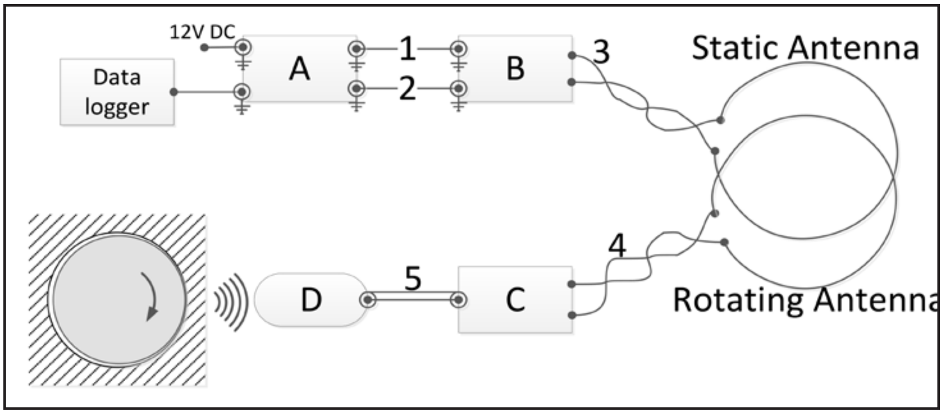


Figure 8 WDTU system overview.

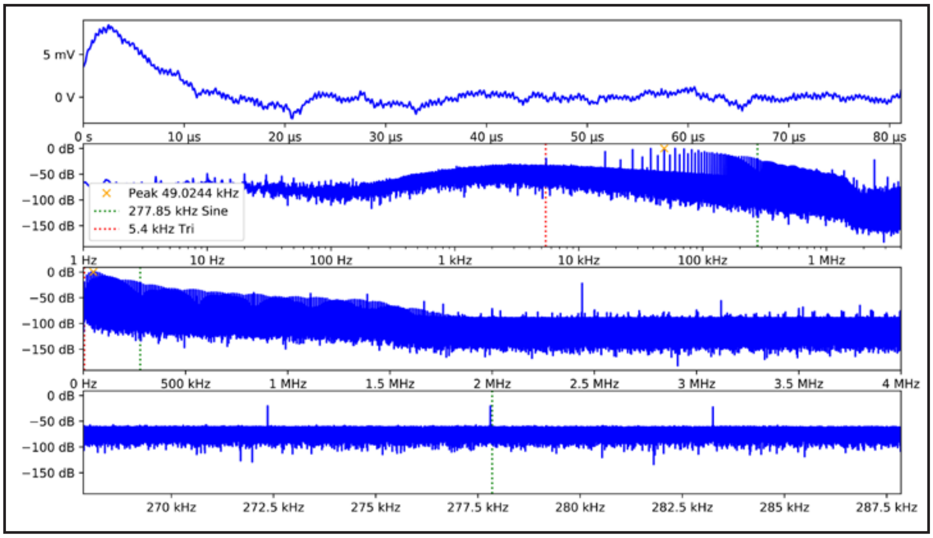


Figure 9 Test result sub-scale WDTU at 2200 min-1.

The static antenna detects this resonant frequency modulation as backscatter of the transmitted signal, which is then sent back to the transceiver (A) via a coaxial cable (2) where it can be recovered by comparison to the carrier wave signal used to drive the static antenna.

The design of the system presented some challenges due to the mass and size constraints combined with the environment within which the device needs to operate. Additional complexity was created by the need to include good RF shielding and grounding when sensor elements can create a ground loop through the device under test.

The combination of journal bearing mixed friction detection and WDTU enables a detailed monitoring of a JB inside a planetary gearbox. A mockup test was executed to represent the integration of the antennas in the subscale planetary gearbox to demonstrate the ability of the WDTU to cope with the speeds and perform the signal transfer. The dominant gear mesh signal is represented by a triangular wave signal and an estimated 1,000 times smaller sinusoidal signal at 277.85 kHz represents occurring mixed friction of the journal bearing.

The test demonstrates that the mixed friction signal can be transferred and extracted (Fig. 9). The red dotted lines highlight at 5 kHz the gear mesh from the signal generator. The signal from the simulated mixed friction can also be seen highlighted by the dotted green line at 277.85 kHz. What remains, is the ratio of the dominant gearbox gear mesh and the subsequent harmonics compared to the mixed friction pattern.

Conclusion and Outlook

In this work new monitoring concept studies are presented for a power gearbox integrated into a TurboFan power plant (UltraFan). Different methods were assessed to monitor gear vibration and the associated benefits and drawbacks have been identified. For dynamic engines such as a jet engine, rotor synchronous resampling is recommended due to rotational speed fluctuations and the resulting smeared frequency spectrum. This helps to significantly minimize the signal noise and to detect an anomaly in the order spectrum earlier than without resampling.

Acoustic emission sensors provide a sensitive method to monitor the journal bearing for different purposes such as mixed friction detection, coating degradation, and coating defects. In a planetary gearbox a wireless data transfer unit is required to measure close to the bearing friction area up to 1 MHz bandwidth.

A proven technical data transfer solution could be identified, which had been demonstrated on helicopter applications with roller bearings. The

WDTU is modified to accommodate the requirements of the power gearbox and the purpose to measure mixed friction conditions in journal bearings. Further tests are planned on a sub-scale planetary gearbox (Ref. 8) to verify, that the presented methods are capable to achieve monitoring capability for gears and journal bearings. **PTE**

Acknowledgment. Thanks to Julian Worskett of JWD Ltd. for his invaluable radio communications expertise. Thanks to the team from the FZG of Dr. Michael Otto and Uwe Weinberger for the support to integrate the WDTU into the sub-scaled gearbox and the test opportunity. Thanks to the team of WZL—Dr. Christoph Löpenhaus and Philipp Scholzen for the support during the pitting test campaigns. Many thanks to the participating colleagues and researchers involved in this monitoring study work for a planetary gearbox. We also acknowledge financial support through funding from the BMWi within the Luftfahrtforschungsprogramm LuFo.

For more information.

Questions or comments regarding this paper? Contact Sebastian Nowoisky at *Sebastian.Nowoisky@Rolls-Royce.com*.

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Dr.-Ing. Sebastian Nowoisky studied electrical engineering focused on measurement and automation technologies at the TU Berlin (TUB) and the University of applied science in Brandenburg (FHB). He received a diploma in 2008 at the TUB (Dipl.-Ing.) and in 2006 at the FHB (Dipl.-Ing. (FH)). He is working at Rolls-Royce Deutschland Ltd & Co KG since 2014 as System Architect and is the tech lead coordinating research activities to develop a gearbox diagnostic system. In 2016 he became a Ph.D. at the TU Berlin in the field of mechatronic parameter identification of gearboxes. He previously worked 5 years at the TU Berlin as research assistant focused on the field of automated car gearboxes and building up a gearbox test environment. In his professional experience, since 2008 Nowoisky has worked as project engineer in the maintenance department at ThyssenKrupp Metal Forming.

M. Sc. Mateusz Grzeszkowski is currently a research assistant at the Chair of Electronic Measurement and Diagnostic Technology of the Technical University of Berlin with the emphasis on pattern recognition methods for the monitoring of spur gears and planetary gears. He has received a Bachelor and Master Degree at TU Berlin in the field of Electrical Engineering. His experience in machine monitoring started during his master thesis, where he developed a diagnosis system for monitoring a rail wheelset axle using a non-destructive acoustic emission measurement technology at Bundesanstalt für Materialforschung und-prüfung (BAM). After graduating, Grzeszkowski started his research work with the topic on diagnostic methods for monitoring planetary gears at the Technical University of Berlin in cooperation with Rolls-Royce Germany.

M. Sc. Noushin Mokhtari studied mechanical engineering at Leibniz University of Hanover and aerospace engineering at the Technical University of Braunschweig. Since 2015 she works as a research assistant at the Chair Electronic Measurement and Diagnostic Technology of Technische Universität Berlin. Mokhtari's areas of expertise include the data-based diagnosis and remaining useful lifetime prediction of hydrodynamic journal bearings, as well as signal processing, pattern recognition and classification of acoustic emission signals.

Dr. Jonathan G. Pelham is a Research/Teaching Fellow in Flight Data at the Cranfield University Safety and Accident Investigation Centre. In his role as a CSAIC Research/Teaching Fellow in Flight Data, he researches the use of machine learning and data analytics to better understand aircraft flight and improve methods to learn from operations, as well as how to investigate incidents and accidents using UAS (Unmanned Aerial Systems). He has a Ph.D. from Cranfield University, a BEng in Aerospace from Sheffield University and a Postgraduate Certificate in Robotics from the University of Western England. His Ph.D. research focus was the application of IVHM (Integrated Vehicle health Management) techniques to UAS using artificial immune systems to identify faults throughout the aircraft's life. This was a large-scale drone mission simulation within MATLAB with 10000+ hours of simulated flight including multiple scenarios and mishap modes drawn from accident reports of in-service unmanned aircraft. Pelham has a wide variety of industrial experience from sources as diverse as Mclaren Racing and the UK Queen Elizabeth Class carrier project, where he was the Lead Engineer for Fire Detection systems onboard ship.

Prof. Dr.-Ing. Clemens Gühmann studied electrical engineering and has been head of the Chair Electronic Measurement and Diagnostic Technology since 2003 at the Technische Universität Berlin. Gühmann's areas of expertise include the measurement technology and data processing as well as the diagnosis, predictive maintenance, modeling, simulation and automatic control of mechatronic systems.

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FEM Analysis of the Load Distribution over the Face Width of Helical Gear Pairs Considering Deviations, Misalignments and Deformations

Prof. Dr. Eng. A. Mihailidis; Dipl. Eng. A. Psarros

Introduction

The load carrying capacity of spur gears may be calculated by ISO 6336 using influence factors. The face load factor $K_{H\beta}$ considers the impact of the non-uniform load distribution over the face width. Even if the gears had perfect geometry, the load would not distribute uniformly along the contact lines. The face load factor depends on deformations of all parts of the containing gearbox and mainly of the teeth, gears and shafts as well as on manufacturing and assembly deviations.

A nonlinear multi-point meshing model was developed by Zhou et al (Ref. 1) for determining the face load factor of spur gears. Multiple non-linear springs were used along the path of contact and rigid bars connected the gear with the shaft, which was modeled by beam elements. The process was iterative, and the results were compared with those obtained by finite element analysis (FEA). Roda-Casanova et al (Ref. 2) investigated the face load factor in straight spur gears, as calculated by ISO using finite elements. They considered the shaft diameter, misalignment and center distance errors, as well as the position of the gears on the shaft. Results were compared with ISO 6336. Yuan et al (Ref. 3) developed a coupled loaded tooth contact analysis (LTCA) model and a Timoshenko beam element model of spur and helical gears. Both static and dynamic cases were investigated and compared with a 3-D finite element approach. Four supporting layouts were chosen considering the power flow and the position of the bearings and the gears on the shafts. Results showed the contact

	Pinion	Gear
Number of teeth z	13	24
Addendum modification coefficient x	0.8	0.374
Tip diameter d_a [mm]	16.25	26.4
Module m [mm]	1	
Helix angle p [degrees]	0	
Centre distance a [mm]	19.5	
Face width b [mm]	15	
Bottom clearance c_p [mm]	0.25	
Basic rack	DIN 867	
Backlash [μm]	30	

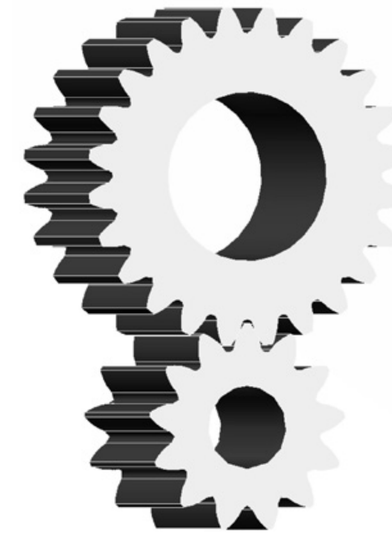


Figure 1 Gear data of the modeled spur gear.

	Pinion	Gear
Number of teeth z	13	24
Addendum modification coefficient x	0.8	0.757
Tip diameter d_a [mm]	16.85	28.65
Module m_n [mm]	1	
Helix angle p [degrees]	20	
Centre distance a [mm]	21	
Face width b [mm]	15	
Bottom clearance c_p [mm]	0.25	
Basic rack	DIN 867	
Backlash [μm]]	30	
Gear shaft diameter [mm]	6	15
haft length L [mm]	45	

Figure 2 Gear data and of the modeled helical gear pair.

This paper was first presented at International Conference on Gears 2019, 3rd International Conference on High Performance Plastic Gears 2019, 3rd International Conference on Gear Production 2019, Garching/Munich (VDI-Berichte 2355, 2019, VDI Verlag GmbH, Page 193–202.

pattern for each case and it was concluded that a torque increase results in stronger vibrations due to higher mesh misalignment.

Generally, two approaches are used for calculating the load distribution, based on multi-body dynamics and FEA. It is not only useful for validating the results — it also allows for much more detailed geometry modeling and therefore offers good accuracy. Custom numerical models have the advantage that they are in most cases solved in much less time.

In the current study, FEA is used. First, a simple model of contact between two parallel cylinders is made. Comparing the results obtained with those calculated following the well-known Hertzian theory, the mesh parameters and quality criteria are established. Next, a straight spur gear model is solved considering only the deformation of the teeth. After evaluating the results, a helical gear is modeled, considering again only the deformation of the teeth. Next, the deformation of the shafts is introduced and pitch errors imposed to the model. Gears remained in the same position in all above cases in order to directly compare the results.

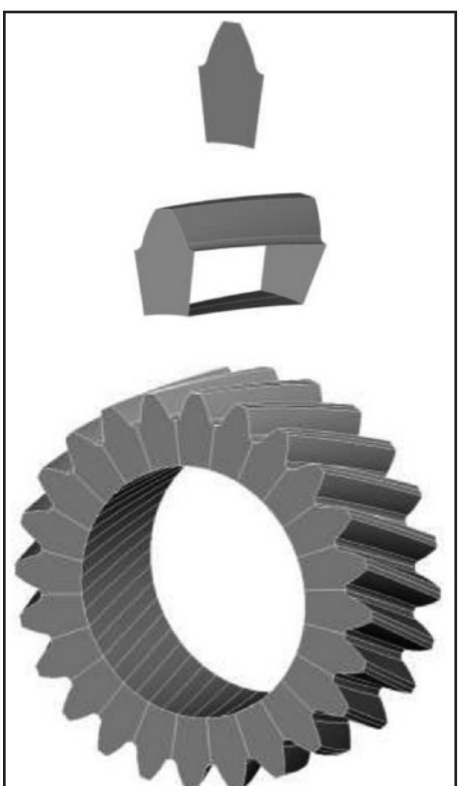
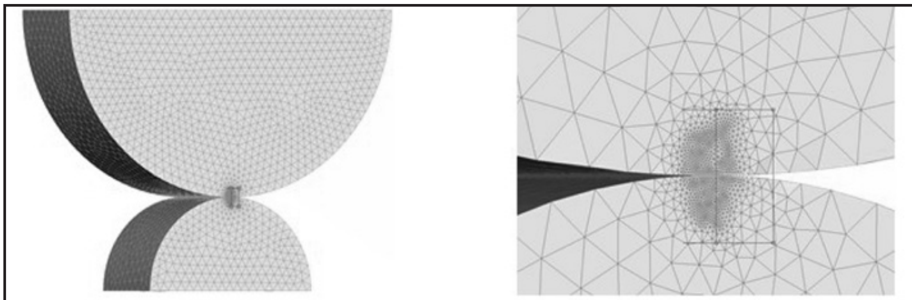


Figure 3 Generation of a 3-D helical gear model in three steps.



Radius r [mm]	Radius R [mm]	Width [mm]	Material	Force [N]	Number of slices
10	20	10	Steel	7000	10

Figure 4 Hertzian contact model data and mesh.

Gear Pairs

In the current study two gears pairs are modeled. The first consists of a straight spur gear pair; its main data are shown (Fig. 1). The second gear pair consists of helical gears (Fig. 2). The impact of the deformation of the supporting shafts and the pitch errors of the active flanks are investigated for the more general case of helical gears. All gears have the same face width and they are made from case hardened steel. The gears are fixed in the center of their shafts.

Finite Element Modeling

Geometry generation. Modeling is carried out using the *ANSA* (Ref. 4) and *META* (Ref. 5) software of *BETA-CAE*. At first, a geometrically perfect 2-D gear tooth segment is created by rolling a rack on the pitch circle of the gear. Then, by axially shifting and rotating a 3-D helical tooth is generated. Finally, the complete gear is built as a circular pattern (Fig. 3).

Meshing. The mesh should be fine enough in order to account for the Hertzian footprint width and the deviations. Keep in mind that both are usually some orders of magnitude smaller than the overall teeth dimensions. Of course, it should be considered that the overall number of elements must be as low as possible. Therefore, the critical areas must be managed in a special way in order to obtain reasonable results. In the current model, there are two, i.e. — the first includes the contact lines defined by the intersections of the active flanks and the plane of action of the meshing gears; the second is defined by the root fillet of each tooth flank. The mesh is generated in two steps. At first, the surfaces defining the gears are meshed using triangular shell elements. Then, using them as reference, the volume mesh is generated using triangular elements. In order to define the abovementioned areas, so-called "refinement hexahedral boxes" (MORPHBOX) are used; surfaces inside them are meshed with different mesh parameters. The meshing procedure is automated using the mesh generator provided by the pre-processor (BATCH MESH). Since many snapshots need to be generated and solved, the process is fully automated using *Python* scripting.

In order to define the mesh parameters and quality criteria, a well-known model of cylinder-to-cylinder contact is solved and evaluated by the Hertzian theory; the model is presented in Figure 4. One hexahedral box was used in order to define the region of interest. Surfaces inside the box are meshed using the "solids structural mesh" algorithm with 0.04 target element length and allowable range 0.02 … 0.5 mm. Transverse planes are meshed using the so-called "CFD" algorithm, which provides fast and smooth transition from fine to coarse mesh. The growth rate was set to 1.5 and the allowable range of the element length 0.03 …0.5 mm. In all mesh algorithms, the minimum/maximum element angle was limited to 45^0 …75^0.

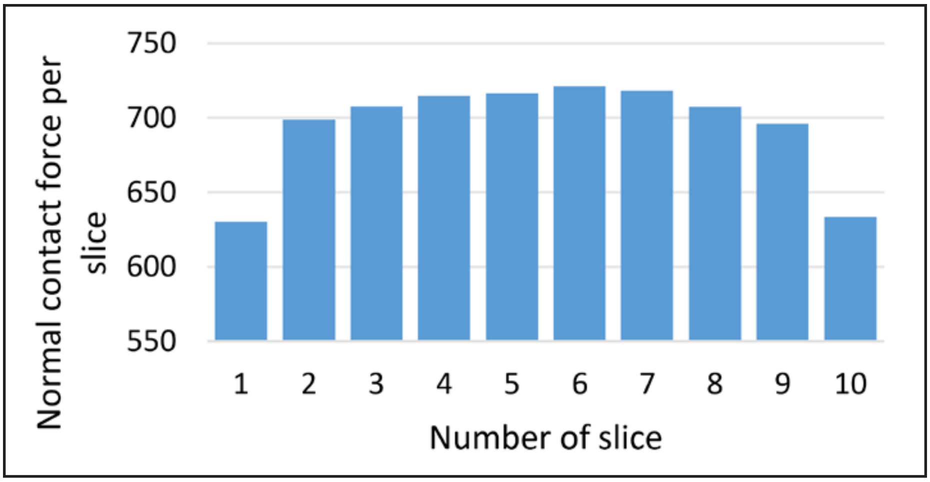


Figure 5 Contact normal forces distribution in cylinder.

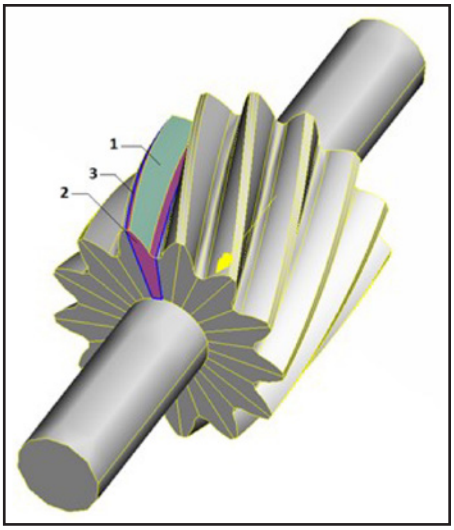


Figure 6 Surfaces used in morphing.

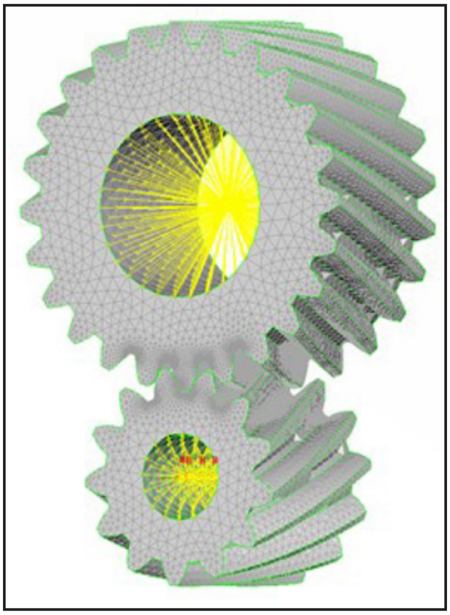


Figure 7 Members support modeling.

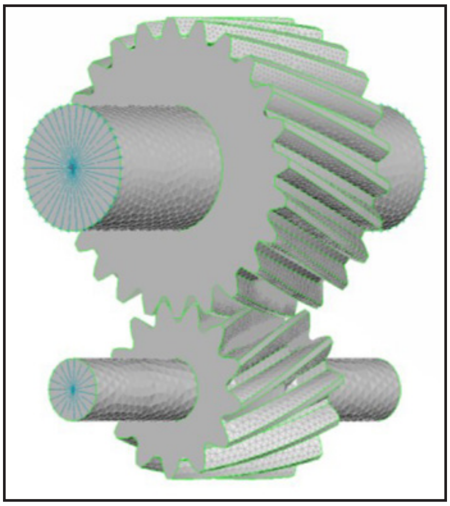


Figure 8 Gear pair including shafts.

The contact normal forces distribution is shown (Fig. 5). It is obvious that the resulting normal force per slice is smaller at the edges than in the middle of the width, because the stiffness is smaller there. According to the analytical solution, the mean value of contact force is almost 677 N-per-slice — which is well confirmed. Therefore, the above-mentioned parameters are used in the next steps of the study.

Morphing. Morphing is a tool provided by *ANSA* and it allows for shape modifications that can be applied in both finite element model and geometry. Using morphing reduces the modeling time required because it helps to avoid going back in the geometry generation stage or even in CAD model. Usually, morphing is applied using boxes containing the geometry which will be modified. However, a special procedure called "direct morphing" is applied without morphing boxes. This can be performed either by specifying "frozen" areas and "morphing" zones, or by fitting the initial edges to target curves.

In the current case, "direct morphing" is used and specific boundaries are defined, regarding the geometry.

Pitch errors can be modeled as angular displacements of the active gear flanks. The displacement angle can be selected in such a way that the thickness of the tooth is changed at a chosen magnitude. In Figure 6 the affected surfaces are shown: 1 (green colored) is the morphing surface, 2 (purple colored) the affected surfaces and finally 3 (blue lines) the boundaries of the morphing action.

Boundary conditions. At first, modeling the shaft is ignored. Rather, the gears are modeled with a bore in the center. Torque is applied uniformly along the width on the inner surface of the pinion bore using multi-point constraints ("MPC", "RIGID" type). In this way, the deformation of the teeth is the only parameter affecting the load distribution.

The gear was considered fixed at the inner surface of its bore; Figure 7 shows the support of the pinion and the gear.

Next, the shaft's geometry is inserted in the model. As expected, the deformations of each shaft affect the load distribution and it needs to be considered. The shafts are supported by bearings; at one end by a locating bearing and at the other end a floating one. They are modeled using the "COUPLING" of "DISTRIBUTE" type of elements in order to have a statically well-defined model and allow the shafts to deform in the way they actually do. The bearings are considered very stiff compared to the gears, and they are not included in the model. In Figure 8 the gear pair including the shafts is shown.

Solution Scheme and Results

Figure 9 shows an overview of the solution scheme and the *Python* scripts developed.

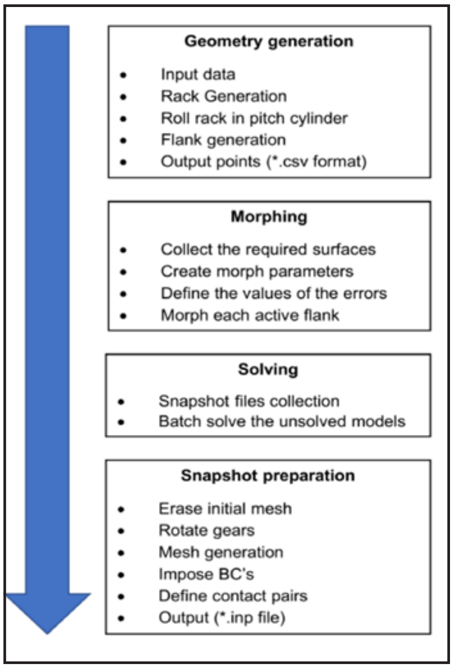


Figure 9 Overview of the Python scripts used.

position in order to emphasize the parameters that influence the load distribution. On the left-hand side, the resulting contact footprint is presented; on the right-hand side, the load distribution along the width is depicted; each gear is sliced per 1 mm.

At first, in spur gears (Case A, Fig. 10) the load distribution is uniform in both snapshots, as expected, because perfect geometry is assumed and only deformations of the teeth are considered. In the second snapshot, two gear pairs are in contact and the load is uniformly distributed along the face width of both.

Next, in helical gears (Case B, Figure 11), the contacting flanks are three because of the overlap ratio of helical gears. The load distribution along the lines of contact is almost uniform. The deviations occur from the varying curvature and stiffness. In both cases (A and B) only the deformation of the teeth is considered.

The deformation of the shafts is introduced in Case C, Figure 12. Compared with the previous case a slope in the load distribution is observed. Finally, Case D, Figure 13 demonstrates the profound impact of the pitch errors:

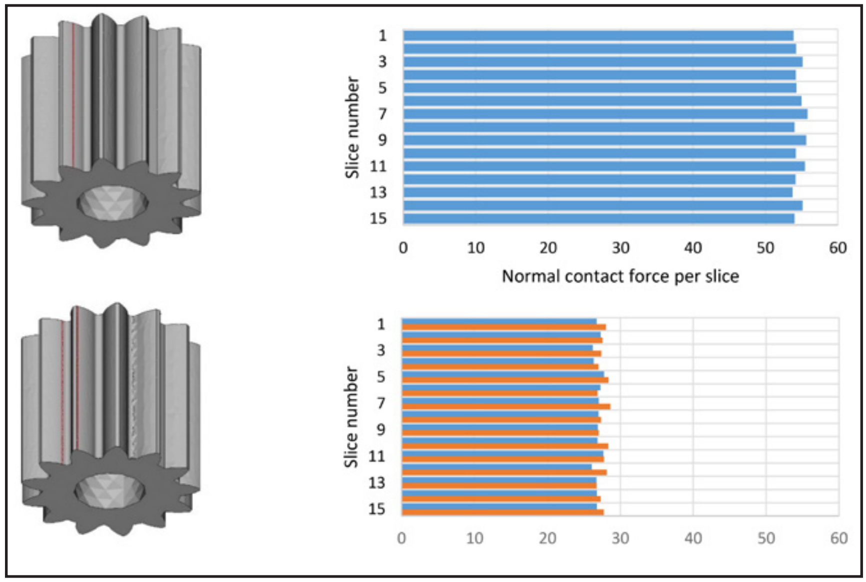


Figure 10 Case A results.

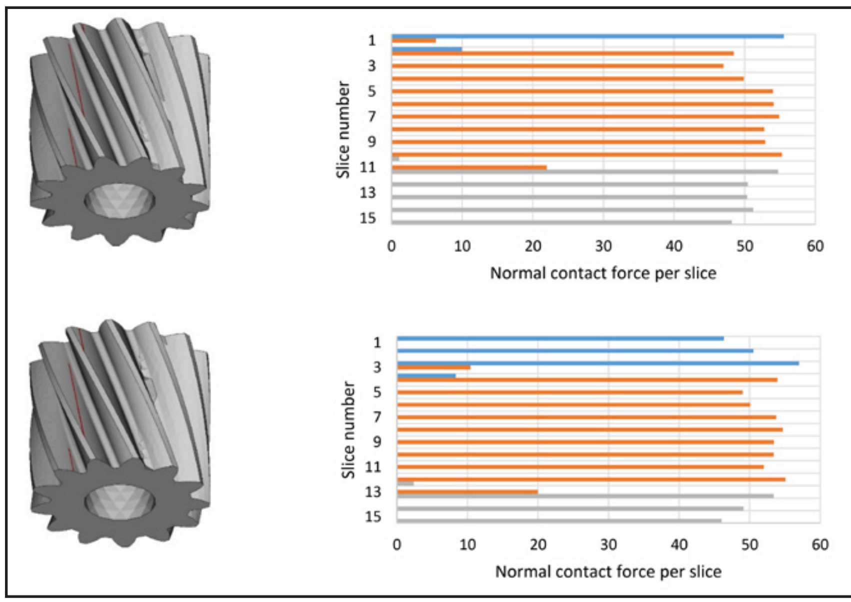


Figure 11 Case B results.

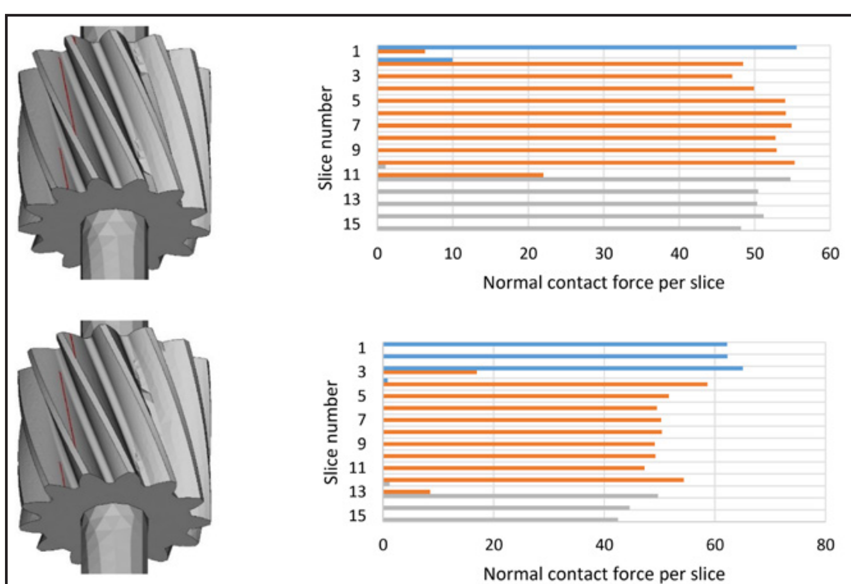


Figure 12 Case C results.

One active flank may contact and consequently transfer no load at all, resulting in increased loading on the rest of the active flanks.

Conclusions

The load distribution along the face width of spur gear pairs was analyzed in the current study. Both straight and helical geometries were considered. In order to define the mesh parameters, and the quality criteria, a simple model of two contacting parallel cylinders was made. The analysis used smart software techniques in order to keep the number of elements as low as possible. Also, extensive *Python* scripting was employed in order to accelerate recurrent tasks during the modeling procedure.

Results confirmed that load distribution is affected by the deformation of other members of the transmission besides the gear teeth. Furthermore, manufacturing deviations strongly affect the load distribution. In extreme cases, they can determine the actual number of active flanks. Next steps of the research may include a multi-snapshot analysis or the calculation of K_{HB} coefficient. **PTE**

Acknowledgment. This project is supported by BETA CAE Systems, which provides the *ANSA* and *META* software.

For more information.

Questions or comments regarding this paper? Contact Prof. Athanassios Mihailidis at *amih@auth.gr*.

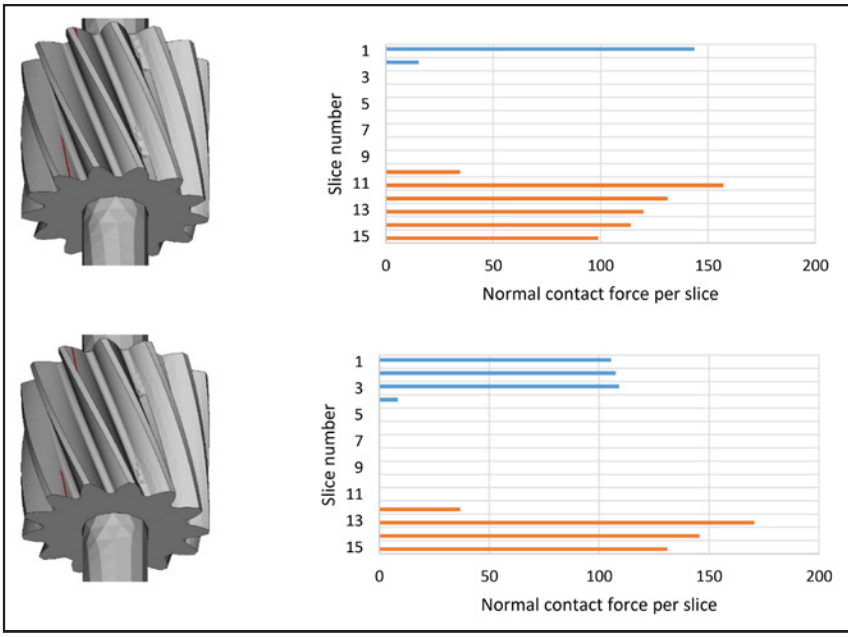


Figure 13 **Case D results.**

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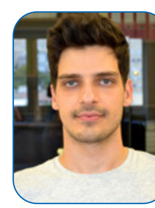
Athanassios Mihailidis is Professor and Director of the Laboratory of Machine Elements & Machine Design of the School of Mechanical Engineering of the Aristotle University of Thessaloniki. His research interests include machine elements, gears and power transmission systems, tribology and thermo-elastohydrodynamic lubrication, as well as automotive engineering. Mihailidis is a founding member of the Balkan Tribological Association as well as of the Balkan Association of Power Transmissions.



Andreas Psarros studied mechanical engineering at the Aristotle University of Thessaloniki. Currently, he works as a Research Assistant in the Lab. of Machine Elements and Machine Design.Psarros's research interests include gears, planetary gearboxes and additive manufacturing — especially lattice structures and their properties for use in machine elements.

Eaton's Vehicle Group

LEVERAGES INDUSTRY 4.0 TECHNOLOGY DURING PANDEMIC

Eaton recently announced its Vehicle Group has been leveraging advanced Industry 4.0 technology to help its global operations safely navigate the ongoing COVID-19 crisis and continue to service its customers.

Eaton's Vehicle Group envisions Industry 4.0 as both operational and informational technologies, enabling autonomous production systems that are connected, optimized, transparent, proactive, and agile. Supported by an integrated ecosystem, the technologies are composed of augmented reality, rapid application development, autonomous robots, digital simulation, and additive manufacturing.

"I'm proud of our Vehicle Group team and their ingenuity, especially during the COVID-19 pandemic," said João Faria, president, Vehicle Group. "By leveraging augmented reality, we are able to continue to support our operations remotely and continue the development of new products, ensuring our customer deadlines are met despite the global challenges we are all facing."

Here are examples of how the Vehicle Group is using Industry 4.0 technologies:

Displaying 3D images and connecting remotely to improve safety

To enable remote assistance and critical activities, Vehicle Group teams are using Microsoft's HoloLens 2 augmented reality goggles that offer the capability to display 3D images in physical spaces and connect remotely. This remote assistance technology ensures that ongoing work can be performed while keeping everyone safe.

Enhancing training and expediting review processes through augmented reality

Augmented reality also assists with knowledge retention and ongoing training. For instance, the Vehicle Group identified an opportunity to use the technology to train operators and engineers on new equipment, which would have traditionally been conducted by instructors who travel to the various remote sites. Additionally, the technology has proven critical for recent customer reviews and approvals.

Analyzing data to reduce costs, improve quality and reduce lead times

Eaton's Vehicle Group is interconnecting plant systems and machines to collect, analyze and report real-time information, which optimizes plant floor management and provides visibility to real-time production issues in order to address them right away. These efforts are designed to reduce lead times; maintenance, repair and operations (MRO), inventory, indirect labor/direct-labor costs; as well as increase performance and improve quality.

Implementing robots to promote safe distancing and increase productivity

To optimize manufacturing flow and eliminate the need for forklifts and other human-operated transport machinery, the Vehicle Group is using autonomous automated guided vehicles (AGVs) or autonomous mobile robots (AMRs). In addition to improving the flow of materials throughout a manufacturing facility, AMRs and autonomous AGVs increase safety and allow for social distancing while also lowering costs.

COBOTs, which are robots intended to interact with humans in a shared space or to work safely in close proximity, are being used to safely handle complex and repetitive tasks. This results in improved consistency and accuracy during the manufacturing process.

Using digital simulation to improve production efficiency

Another way the Vehicle Group is increasing productivity is by using digital simulation applications to define which solution and/or combination of factors will result in the highest output. These applications can run several scenarios by changing parameters, such as the number of operators, work in process material, cycle times, operator standardized work and many others. The applications are being used to define new manufacturing cells and assembly lines or to redesign existing ones. In most cases, the Vehicle Group is seeing productivity increase from 10 to 30 percent via higher production output or reduced amount of investment needed.

An engineer inspects a urethane methacrylate (UMA) impeller that was 3D printed using digital light synthesis (DLS) technology. Courtesy of Eaton.

Leveraging 3D printing tools internally to expedite processes

Additive manufacturing is leveraged to improve safety, quality and efficiency by designing and producing tools, poke-yokes and gauges internally on both polymer and metal materials. This allows fast reactions (shorter lead times), reduced purchase costs and highly customized solutions. For example, lead times can be reduced from weeks to days, while reducing costs from thousands to hundreds. (*www.eaton.com*)

Dana

MAKES CHANGES TO OFF-HIGHWAY LEADERSHIP TEAM

Dana Incorporated has made recent changes in the company's off-highway leadership team.

Jeroen Decleer has been named vice president and general manager of mobile Europe for Dana Off-Highway Drive and Motion Systems. Decleer has been with Dana since 2004 and has directed global sales, product and program management, and strategy for its off-highway business unit since 2016.

Decleer earned a master's degree in engineering with a specialization in automation from Katholieke Hogeschool Brugge-Oostende in Belgium. He also has a master's degree in European business from EHSAL Management School in Brussels, Belgium, as well as a master's degree in international relations and global affairs from Università Cattolica del Sacro Cuore in Milano, Italy.

As part of this promotion, Decleer takes over responsibility for managing Dana's off-highway operations in Europe from **Rino Tarolli**, who is retiring from Dana after 23 years with the company.

Lastly, **Marcus King** has been promoted to vice president of off-highway global sales, business development, strategy, and program management, in addition to his current role in leading all of Dana's business units in China. King has worked for Dana since 1995, holding numerous leadership positions with increasing responsibility in IT, purchasing, program management, and operations. He has served in strategic leadership roles in China for the past 13 years.

King earned a bachelor's degree in manufacturing systems engineering from Coventry University in the U.K., and he recently completed an Advanced Management Program at IESE Business School in Barcelona, Spain. (*www.dana.com*)

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

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Electric Bikes — Wired for Fun

Jack McGuinn, Senior Editor

There is absolutely no doubt that riding an electric bicycle will not stir up cinematic memories of Marlon Brando (*The Wild One*) or Steve McQueen (*The Great Escape*) tearing it up on their hogs. Think more Pee Wee Herman and his *Great Adventure*.

But that's okay, because doing so would be comparing apples to oranges. Electric bicycles—or E-bikes—are exactly that—i.e., conventual-looking bicycles that happen to be powered by battery-charged engines.

But there's obviously more to it than that—much more.

Electric bikes are becoming very popular in countries around the world—where traditional bikes lave long been common in Asian countries and Europe—but also in the United State. The reasoning for such popularity is that E-bikes are, for example, a good alternative to traditional bikes for long commutes, for those in need of physical therapy with physical limitations of some kind, or, because they are simply *fun*.

Surprisingly, perhaps, some of the basic technology for E-bikes existed (and even patented) by scientists over 100 years ago.

Essentially, electric bikes are fitted with a battery-powered motor that provides some extra oomph to the ride. Some bikes use a throttle, others are pedals-powered. And the pedal part is key in that E-bikes are not fully motorized, as are mopeds or dirt bikes. The rider still has to pedal to make it go, so E-bikes are a far cry from a traditional motorcycle.

The power supplying battery is rechargeable, of course. Thus these bikes are perfect for exercise, while also assisting riders who require. Mobility and help in getting around for those that need it—a great combination. No surprise that research shows E-bike riders use them much more than regular bikes.

Given the high traffic density and extreme levels of CO_2 in dense population centers in China and Japan, E-bikes are the perfect replacement for automobiles wherever practical. What makes affordable, lightweight E-bikes possible? Generally speaking, five technological advancements, some of them *very* technical—especially regarding the motor:

1. A high-energy-density, lithium-ion chemistry rechargeable battery that was introduced by Sony in 1992 and that now powers electric cars, mobile phones, and most other modern devices. Typical electric-bike batteries weigh only 6–7 pounds and can provide 1,000 cycles of charge/discharge. The batteries are protected by electronic systems that prevent excessive temperatures and prevent damage from excessive battery discharge. Hidden inside the Bosch Active Line Plus motor housing is an array of gears, circuitry and a permanent magnet motor. Despite its complex nature, it still has Q factor, or width between cranks just 10mm greater than a standard bicycle.
2. Light, powerful, and long-lasting electric motors**.** These are brushless permanent-magnet DC motors, their small size made possible by the same very powerful neodymium rare-earth magnets (10 times more powerful than Alnico) that have made recent automotive starters so tiny.
3. Accurate, affordable non-contact torque sensors that measure the torque you apply to the pedal shaft. The shaft is magnetized in a particular direction and the torque applied by your pedaling, by just barely twisting the shaft, alters that magnetization in a measurable way, an effect known as magnetoelasticity.
4. Power electronics based on fast-switching, high-current insulated-gate bipolar transistors (IGBTs). The sensors serve to continuously monitor the angular position of the motor's rotor. A computer-phased IGBT switching of battery current to the motor's many stator windings generates a rotating magnetic field that stays just ahead of the whirling permanent magnets of the rotor, thereby strongly pulling them around at motor speeds from zero to 4,500 rpm or higher. Motor torque is multiplied and its speed reduced by two or more stages of gear reduction to assist you in driving the front sprocket.
5. Digital connectivity that can allow you to communicate with your bicycle's motor system from a smartphone or other handheld device. Although this is not necessarily key to the basic functioning of an E-bike, the interface allows for great control of performance and insight into remaining range versus speed, percentage of boost, and more, that reduce range anxiety and increase our enjoyment of E-bikes.

For all practical purposes, there are two types of e-bike.

"Factory" E-bikes are designed from scratch as E-bikes. "Kit" E-bikes are ordinary bicycles with an electric motor kit retrofitted. These types of E-bikes come in many styles—from commuter bikes to full-suspension.

And they're all built for fun and clean-energy mobility. And showing up on streets around the world in ever-growing numbers. **PTE**

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