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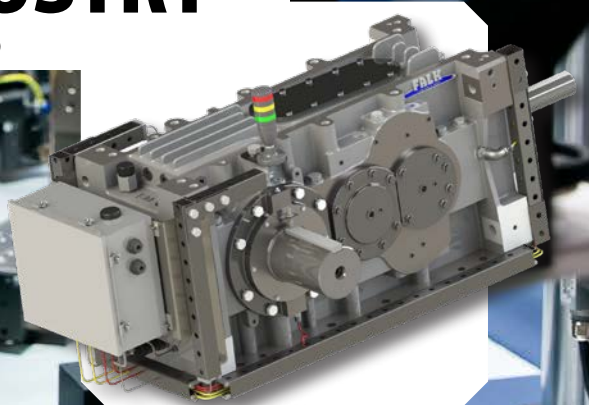
FEBRUARY 2019

MECHATRONICS

• MECHANICAL ACTUATORS • HANNOVER MESSE PREVIEW •

HEAVY INDUSTRY
SMART COMPONENTS



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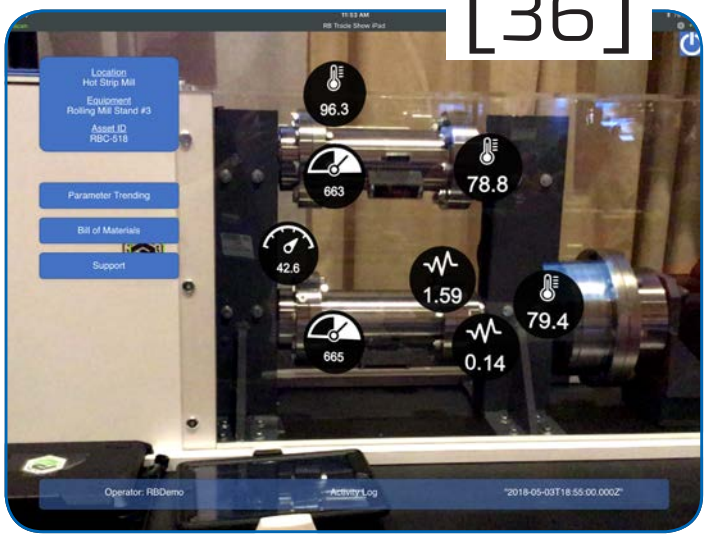

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FEATURE ARTICLES

TECHNICAL ARTICLES

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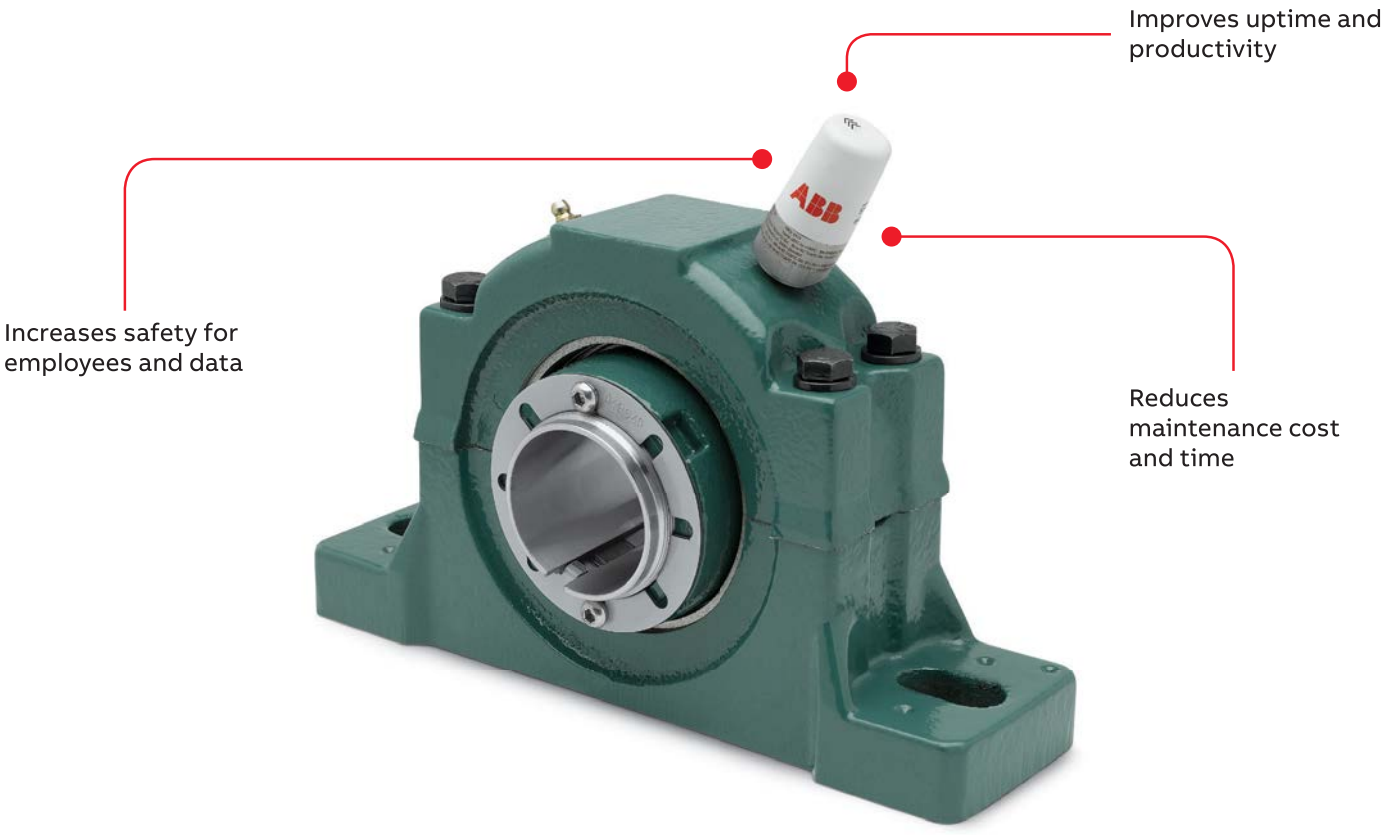
Power Transmission Engineering
VOL. 13, NO. 1



Connect your cast iron to the cloud

The new ABB Ability™ Smart Sensor for mounted bearings is an easy-to-use, condition monitoring tool which provides a quick health indication on bearings in operation without requiring employees to touch the equipment. Evaluating bearings on a regular basis allows vibration and temperature trends to be analyzed and outliers to be detected before a failure occurs.

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new.abb.com

www.powertransmission.com

PTE Videos

The Loke Gyro Swing at Liseberg Amusement Park in Gothenburg, Sweden uses an ABB industrial drive to replicate some of the physics of space travel, safely and precisely while conserving energy. Learn about the application here:.

www.powertransmission.com/videos/ABB-Powers-Amusement-Park-Ride-in-Sweden.-/

Factory Automation

Mitsubishi Electric covers all Factory automation products and shows how Mitsubishi Electric Factory Automation is enabling everyday life, spanning all industries. Learn more here:

www.powertransmission.com/videos/Mitsubishi-Electric-Looks-at-Factory-Automation-/

Editor's Choice:

Servo Needs a Solid Footing

For a servo system, it is important to remember that the servo responds to what its feedback sensor is measuring. For a servomotor, this is normally the position of the back shaft of the motor with respect to the back end of the motor. Remember — they regulate what they measure. Learn more from Don Labriola guest blogger from Quicksilver Controls here:

www.powertransmission.com/blog/servo-needs-a-solid-footing/

Bauma 2019 Examines Sustainability, Digitization and Energy Efficiency

PTE takes an in-depth look at Bauma 2019 taking place April 8–14 in Munich, Germany. Exhibitors include Dana, Bonfiglioli, Liebherr, Comer Industries and more.

www.powertransmission.com/blog/construction-time-again/

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Keeping the world in motion >>

Randy Stott, Managing Editor

Everything's Connected

The theme of this issue is integration.

Mechanical components are being developed with embedded sensors. The components are talking to each other, sending information to the cloud and producing terabytes of big data to help manufacturers better understand their processes, predict problems and control costs.

For evidence, look no further than our article on smart components for heavy industry, beginning on page 36. Maintenance managers at steel mills, mines and refineries now rely on their cell phones and tablets more than wrenches and rags. "Heavy Industry and Smart Technology" describes how the major manufacturers of heavy-duty mechanical power transmission components are making it easier for those managers by building sensors into bearings, motors and gearboxes to capture and analyze data – even in the most remote, difficult to access places.

This issue also takes a look at mechatronics, which is all about the combination of mechanical motion with electronic control. Our article on electromechanical linear actuators (page 18) provides an overview of the different types of mechanical systems available, along with the choices in motors and controls that turn them into smart automation systems.

And if you're looking for the latest in mechatronics and automation, I suggest you consider attending one of the upcoming trade shows where the newest technology will be on display. The biggest of those, of course, is Hannover Messe, which takes place April 1–5 in Hannover, Germany. Our preview of the show (page 22) describes how manufacturing integration and industrial intelligence are taking center stage. Industry 4.0 and the Industrial Internet of Things are two of the buzzwords circulating among the show's organizers and exhibitors.

If you can't make it to Germany this spring, then perhaps Chicago will do. The Automate and Promat shows take over McCormick Place April 8–11. Although you'll have to wait until next issue to read our Automate show preview, you can definitely get a head start by visiting the news sections on *powertransmission.com,* where we've posted booth previews from a number of exhibitors. For more information about the show, go to *automationshow.com*. If you're coming to Chicago, stop by our booth and see us.

But there's one more show I want you to think about and make plans for. It doesn't take place until October, but you should start making plans now. I'm talking about the new Motion + Power Technology Expo, a show that explores the idea of integration in a whole new way. Organized by the American Gear Manufacturers Association, Motion + Power Technology Expo is an evolution of the show that was formerly known as Gear Expo. Instead of just gears, the show now encompasses electric devices and fluid power components. You can read about the new show—including comments about the ideas behind it from AGMA President Matthew Croson—in our article beginning on page 32.

We're already making big plans for our booth at Motion + Power Technology Expo. We'll be recording several sessions of our popular *Ask the Expert LIVE!* show, and we'll be doing live interviews with technology experts throughout the event. By the way, you can watch past episodes of *Ask the Expert LIVE!* online at *www.powertransmission.com/tv/*.

Whether or not you attend any of these shows, we'll be at each of them, gathering information about the latest ways technology is being integrated into mechanical motion. Either way, we hope you enjoy the issue. Thanks for reading.

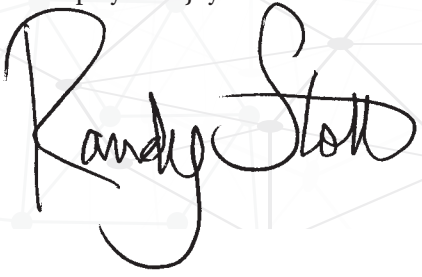

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ABB

RELEASES ABILITY SMART SENSOR FOR BEARING MONITORING

ABB has launched the ABB Ability Smart Sensor for Dodge mounted bearings, part of the ABB Ability Digital Powertrain, that enables "health checks" for bearings. The smart sensor technology provides an early indicator of any potential problems by assessing the condition of bearings from vibration and temperature information. This helps to prevent downtime on applications such as bulk material handling conveyors typically found in the mining, aggregate and cement industries, as well as applications in the food and beverage and air handling sectors.

ABB Ability Smart Sensor for mounted bearings use the latest algorithms to assess, manage and ensure performance of components. Eighty percent of bearing failures are lubrication related and a bearing "running hot" can indicate that proper lubrication procedures are not in place. Monitoring a bearing's vibration can indicate potential system problems.

The smart sensor easily mounts to the bearing and communicates wirelessly via a smartphones or other device. This capability keeps employees safe, enabling easy access to the health data of bearings in locations that may be difficult or dangerous to reach.

"Bearings are critical components in conveyor systems and are often the first indicator of a system problem," says Artur Rdzanek, product manager for sensor technologies, Dodge mechanical products at ABB. "The display of the health status of the bearing enables operators to quickly and safely identify a potential problem, which allows them to schedule maintenance and prevent unplanned downtime."

The ABB Ability Smart Sensor for mounted bearings is part of ABB Ability, which brings together all of ABB's digital solutions and services, each built from a unique combination of sector knowledge, technology leadership and digital expertise. As part of ABB Ability, customers are able to easily compare performance data of bearings across systems or plants.

For more information:
ABB
Phone: (800) 435-7365
www.abb.com

Dunkermotoren

OFFERS COMPACT MODULAR LINEAR MOTOR CONCEPT

With the SA/SC 38 series, Dunkermotoren presents a completely new modular concept for tubular linear direct drives. The highly dynamic three-phase linear motors deliver up to 3,690 N and accelerate at over 200 m/sÂ². The modular design is currently available as actuator version SA (with maintenance-free plain bearing system) and component version SC (for modules). If the linear motor should sweat during its efforts, the standard water connection ensures cooling and doubling of the continuous force. In addition to the integrated SIN/COS linear encoder, further motor feedback variants (SSI, BISS & TTL) will be available next year. Due to the encoder system (patent pending), commercially available servo controllers (up to 800 VDC link voltage) can position the compact linear motor quickly, precisely and reliably. One of the main applications of the SA/SC 3806, 3810 or 3814 will be high-speed applications in the food and packaging industry. Since Dunkermotoren has been a system supplier in drive technology for decades, it will not remain just a solo motor. Pick & Place modules, complete linear axes and a version designed for the food industry will soon follow to facilitate system integration at the customer's site.

For more information:
Dunkermotoren USA Inc.
Phone: (773) 289-5555
www.dunkermotoren.com

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Cincinnati VR

TAPS LEROY-SOMER FOR VARIABLE SPEED MOTOR

Pursuing its constant innovation approach aimed at making its machines increasingly ergonomic and automated, Cincinnati VR has chosen to equip its new pillar drill-thread cutter with a new integrated variable speed motor, the Commander ID300 from Leroy-Somer. This drive solution enables adaptation of the spindle rotation speed according to the material being worked, for a better-quality machining result.

Cincinnati VR, the renowned drills specialist, is also an established player in machining center maintenance. Installed on its historic site of Chambost-Allières in the Beaujolais hills, the company has strong development potential for a widely-used product: the drill. Thanks to its innovation potential and its dynamism, the company enjoys undeniable success in this extremely competitive sector.

Conscious of the problems of duress linked to the use of conventional machine tools, the company focuses its efforts into research and development to design products that address this issue.

In line with this approach, some 10 years previously Cincinnati VR launched its N320 VDA pillar drill with the objective of eliminating repetitive strain injury by relieving the operator of repetitive and stressful gestures. Hence, the downward movement of the spindle is totally controlled by a digital shaft composed of a Leroy-Somer solution (Mb series servo-gearbox controlled by a DIGITAX servodrive) and a GUI for adjusting the movement settings and featuring various user-friendly aids for the operator. Available in several versions, this machine won a number of international awards at major industrial trade fairs.

With its brand-new generation P23V CTCE, Cincinnati VR proposes a smart drill that adapts its spindle speed according to the worked material, for both drilling and thread-cutting. If needed, the tapping return can be made faster to optimize the cycle time. However, in certain materials that require very finely-pitched tapped threads, the tapping return can be executed more slowly, for a better-quality machining result.

Covering a range of 80 to 6,500 rpm, the spindle is equipped with electronic variation courtesy of the Commander ID300, the latest-generation integrated drive for the IMfinity motors from Leroy-Somer. A decentralized system, the speed drive assembly offers dynamic high performance and high efficiency.

Extremely robust, Commander ID300 guarantees ease of use, implementation and operation. Equipped with advanced features, it offers a wide choice of options and adaptations for maximum flexibility.

"As well as these advantages, we were first struck by the extreme compactness of the Commander ID300 enabling perfect integration in our new drill," said Patrice Rivier, technical director at Cincinnati VR. "We were then won over by its peerless low-speed torque performance, its capacity to manage the on-board PLC programming in compliance with standard IEC 61131-3 motion, the Modbus RTU connection and its compatibility with the main GUI brands."

For more information:
Nidec Corporation (Leroy-Somer)
Phone: (314) 595-8940
www.nidecautomation.com

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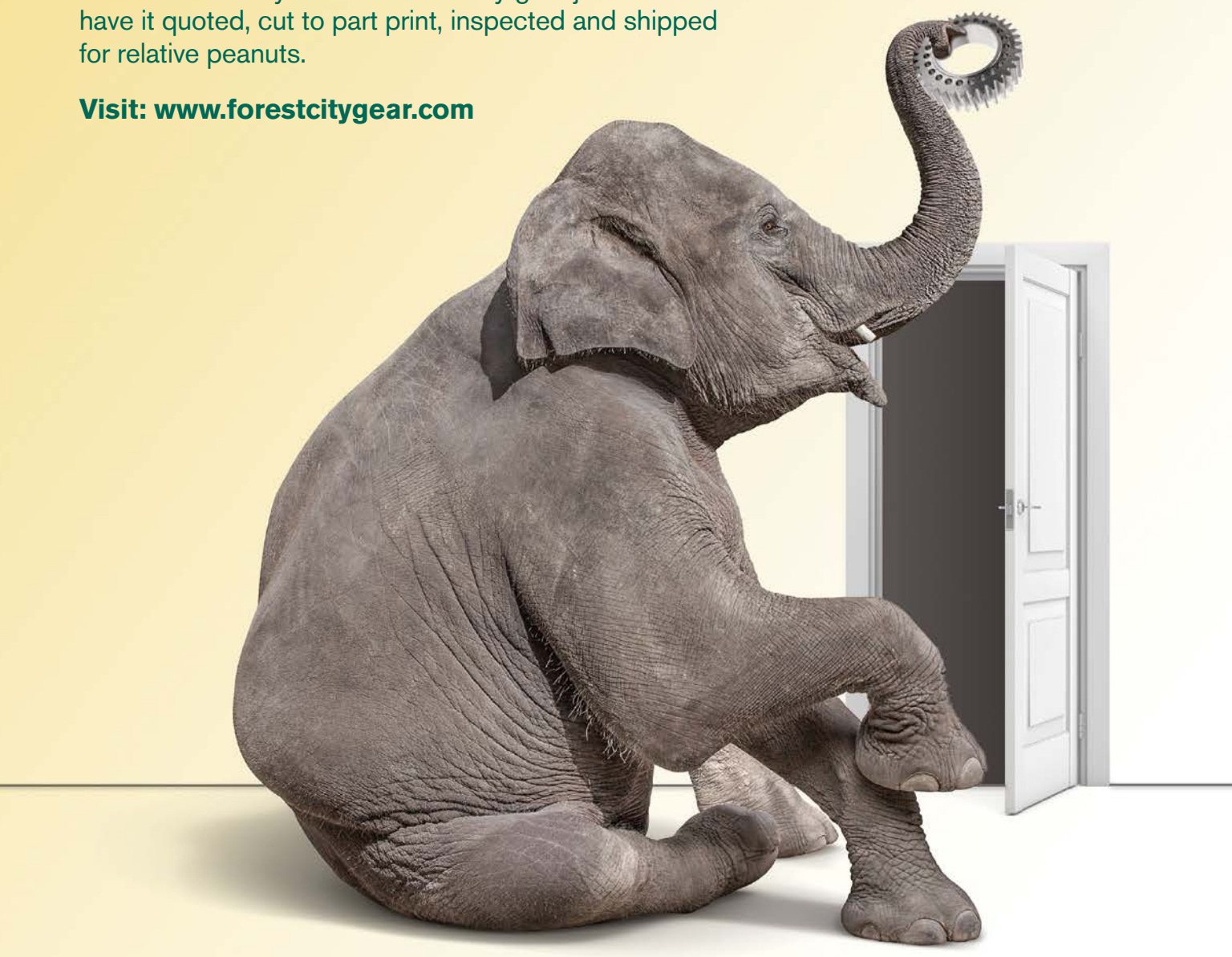

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Miki Pulley

RELEASES ZERO BACKLASH DESIGN FOR ELECTROMAGNETIC CLUTCHES

Miki Pulley CSZ Clutches function utilizing the magnetic force generated by the energized coil providing engagement of input and output members of the clutch. They feature an integrated bearing design making mounting fast and easy while ensuring application concentricity and excellent system runout. CSZ Clutches operate well in temperatures from +14°F to +104° (-10°C to +40°C).

Available in bores ranging from 10 mm to 15 mm, with brake torques ranging from 1.77 ft. lbs. to 7.376 ft. lbs. (2.4 Nm–10 Nm). The CSZ utilizes corrosion resistant materials, and is RoHS compliant like all other Miki products.

"Miki Pulley's CSZ Clutches are a great choice for high performance printing, paper processing, packaging, food processing and textile manufacturing systems," reports Jon Davidson, Miki Pulley sales specialist. "They are proven performers in system applications around the world."

For more information:
Miki Pulley
Phone: (800) 533-1731
www.mikipulley-us.com

Rolling Motion Industries

OFFERS SPEED REDUCERS WITH TRACTION DRIVE TECHNOLOGY

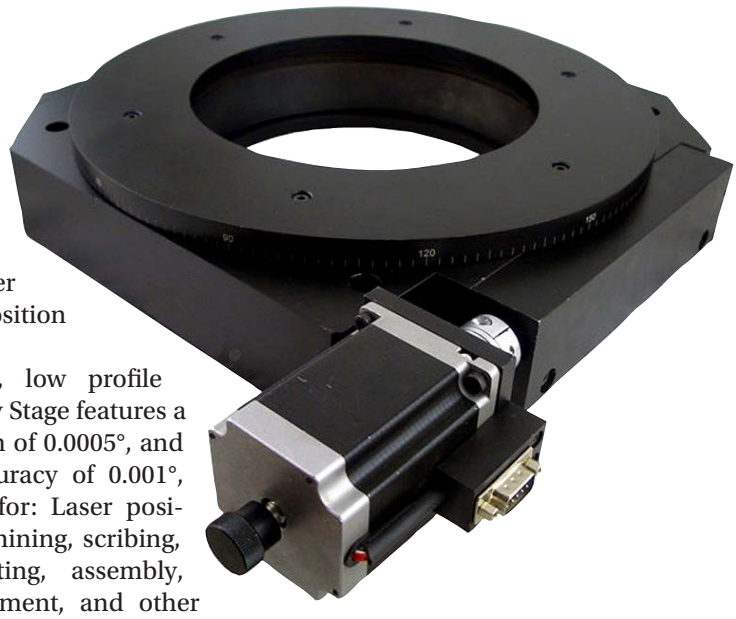
Rolling Motion Industries (RMI) has released for production the next two in its series of highly efficient speed reducers. These 3-to-1 speed reducers use "game changing" traction drive technology. The MAR-17-1-3.1 and the MAR-23-1-3.1 Speed Reducers feature 98 percent efficiency and with only 6 moving parts they typically out last conventional gearboxes and speed reducers by a factor of 3. The MAR17-1-3.1 Speed Reducer is designed for input speeds up to 3,600 rpm with 10 to 20 in/lbs of torque, and the MAR-23-1-3.1 Speed Reducer is also rated for speeds to 3,600 rpm but with an input of 20 to 30 in/lbs of torque. As the output speed is reduced by a factor of 3 the output torque increases by a factor of 3.

Using an engineered traction fluid with a coefficient of friction of just 0.1 to 0.12 that cools and lubricates the traction drive these high efficiency speed reducers generate up to 72% less heat even after days of continuous operation. There is no slippage or lost motion between the input and output shafts even though there is no metal to metal contact as the traction fluid is continuously changing from liquid-to-solid-to-liquid as the driving and driven elements interface in the drive. Creating 38 percent lower dB at 3,000 rpm than conventional gearboxes these people-friendly speed reducers are ideal for use in medical equipment such as mobile hospital equipment and dialysis machines as well as pumps, blowers, fans, turbo and super chargers, conveyers, HVAC systems, and other power transmission and motion applications.

Having low vibration, and no torque losses from 10 to 3,000 rpm, these speed reducers featuring traction drive technology lets a motor operate at peak

OES

INTRODUCES MOTORIZED ROTARY STAGE

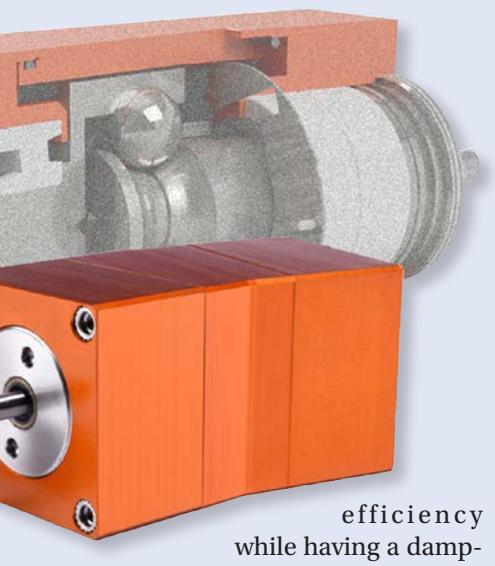


The new AY110-300 Motorized Rotary Stage from Optimal Engineering Systems, Inc. (OES) features a large 180 mm (7.087 in.) open aperture. This precision, large open aperture (hollow core), low profile rotary stage is just 65 mm (2.559 in.) high and it's footprint is only 303 mm by 319 mm (11.929 in. by 12.559 in.) not including the motor. The rotary table of the stage has a precise pattern of threaded holes for mounting custom tooling and fixtures, and holes in the base for easy integration into new and existing applications. The diameter of the rotary table is 300 mm (11.811 in.) and the range of travel is a full 360°, and it is capable of continuous rotation.

The AY110-300 Rotary Stage is also available with a servomotor and optical encoder. The standard model is equipped with stepper motor and a knob for manual adjustment which can be replaced with an optical encoder for precision position verification.

The low cost, low profile AY110-300 Rotary Stage features a very low backlash of 0.0005°, and a positional accuracy of 0.001°, making it ideal for: Laser positioning and machining, scribing, microscopy, testing, assembly, inspection, alignment, and other critical applications. This black anodized stage has a load capacity of 65Kg (143 lbs.) and there is an indicator scale for visual sighting of the angle of rotation. The stage can be ordered with Plug-and-Play with a fully compatible controller from OES.

For more information:
Optimal Engineering Systems, Inc. (OES)
Phone: (888) 777-1826
www.oesincorp.com



efficiency while having a damping effect on a motor's torque ripple. These speed reducers are available with an optional overriding clutch. Incorporating standard NEMA mounting dimensions, these speed reducers can be easily integrated into new and existing applications.

For more information:
Rolling Motion Industries (RMI)
Phone: (860) 846-0530
www.rmidrive.com

Timken

EXPANDS SPHERICAL ROLLER BEARING UNITS WITH DOUBLE-NUT DESIGN

The Timken Company is expanding its line of mounted bearings with spherical roller bearing solid-block housed units that allow for even easier installation and removal for a multitude of applications.

"Timken spherical roller bearing solid-block housed units with double-nut adapters are designed for tough conditions without being hard to use," said Cory Shaw, Timken general manager — housed unit bearings. "Not only are our mounted units stronger on the outside, but they are also smarter on the inside. We design our units to provide high performance, real world maintenance solutions in a wide range of sizes and styles."

Timken spherical roller bearing solid-block housed units now come in sizes up to 15 inches (380 mm), including the new TAA Series units, with added conveniences for customers. Inside each TAA Series unit is a double-nut, tapered adapter sleeve that simplifies bearing replacements in challenging environments.

Timken modified its standard adapter sleeve (with front lock nut) to include a mechanical withdrawal nut on the back end that is factory set for nominal shaft sizes and, if necessary, can be easily adjusted in the field to accommodate actual (under/over) shaft size.

The front locking nut is tightened until the back nut stops against the face of the inner ring, indicating that proper bearing clearance and mounting force has been achieved. This eliminates the need for difficult and often inaccurate in-process measurements of radial internal clearance, helping MRO pros reduce time on the job and improve consistency. (Note: the adapter sleeve can also accept hydraulic nuts.)

For quick dismounting, the front nut is loosened so the back nut can be tightened to unseat the sleeve from the tapered bearing bore, assisting in bearing removal.

For more information:
The Timken Company
Phone: (234) 262-3000
www.timken.com

Klüber Lubrication

OFFERS HIGH-PERFORMANCE GREASE FOR BALL AND CONSTANT-VELOCITY JOINTS

Klüber Lubrication recently introduced Klübersynth J 87-20002 KR, a high-performance automotive grease for ball joints, and Klüberlub HE 71-281, a low-friction grease designed for constant-velocity (CV) joints.

Klüberlub HE 71-281

Friction in an automobile's CV joints can lower efficiency as well as cause excessive heat, vibration, and noise. The special low-friction additives in Klüberlub HE 71-281 minimize this friction resistance and boost CV joint efficiency.

This special CV grease also lowers the temperature in the joint because of reduced friction. The high thermal resistance of synthetic components in the formulation enables the joint to operate reliably at elevated temperatures. Joints can even achieve short-term peaks up to 160°C. The Klüberlub HE 71-281 also has the added benefit of being compatible with normal CV joint boot elastomers, which is a problem that plagues other CV joint grease alternatives.

The improved wear behavior of Klüberlub HE 71-281 was formulated to ensure long component life. This paired with low-friction resistance makes Klüberlub HE 71-281 an automotive grease that optimizes CV joint efficiency for the long term.

Klübersynth J 87-20002 KR

A major problem with ball joints in suspension and steering systems is a high static torque, particularly when joints experience long periods of rest. The friction from high static torque produces noise and a coarse operating feel.

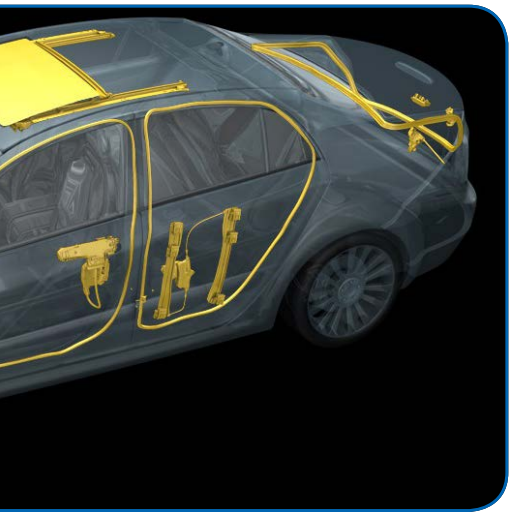
Using high viscosity silicone oil and PTFE as a base oil, Klübersynth J

87-20002 KR is designed to have ultra-low static and dynamic torques in both low-temperature and high-temperature environments. This low torque minimizes stick-slip tendency, micro friction noise and provides a smoother driving experience.

Klübersynth J 87-20002 KR is a ball joint grease that offers reliability. Its good friction properties, adhesion and spreadability at sliding friction parts provide excellent wear protection. Its outstanding water resistance and oxidation stability prevents corrosion. With the exception of silicone rubber, this automotive grease is compatible with a wide range of boot materials, including elastomers and plastics. Its operating temperature ranges from –50 to 180°C, which enables reliable ball joint performance in any climate.

Klübersynth J 87-20002 KR is currently being used in several automotive platforms with new platforms being added daily. It's a high-performance grease that delivers what automobiles need: excellent ball joint wear, noise-free operation, compatibility and low-temperature torque.

For more information:
Klüber Lubrication
Phone: (603) 647-4104
www.klubersolutions.com



Moticont

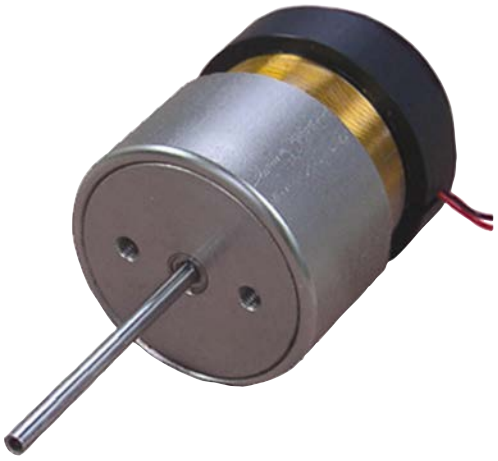
LINEAR VOICE COIL MOTOR OFFERS HIGH SPEED AND RELIABILITY

Moticont's GVCM-051-025-01 Linear Voice Coil Motor features: High acceleration/deceleration, high speed, high reliability, zero backlash, high accuracy, high repeatability, and a 0.5 inch (12.7 mm) stroke length. Also referred to as an *Electric Cylinder*, this linear actuator is an ideal low cost, high accuracy replacement for hydraulic and pneumatic linear actuators. This clean, compact, voice coil motor has a high force to size ratio with 5.3 lbs. (23.5 N) continuous force and 16.7 lbs. (74.4 N) of peak force at 10% duty cycle with a housing measuring just 2.00 in. (50.8 mm) dia. × 1.00 in. (25.4 mm) long.

The precision ground 0.1572 (3.993 mm) diameter shaft has an internal thread, and the housing has threaded mounting holes on each end

for easy integration into current and future applications. This clean, quiet, efficient, low inertia, brushless actuator featuring an internal shaft and recirculating ball bearing is suitable for medical devices, antenna positioning, testing, sorting, assembly equipment, workholding and clamping, scanners and laser beam steering and filtering, laser machining and drilling, wafer handling, optical focusing, and dynamic vibration absorption. The Moticont's GVCM-051-025-01 linear voice coil motor can also be ordered as a complete plug-and-play system including a position sensor, and controller. Is there a need for a smaller or larger diameter motor, one with longer stroke, or more force?

There are currently seven series of Moticont's GVCM motors based on



diameter of the motor, and models based on length of stroke and/or force to select from with additional motors being added to select from.

For more information:
Moticont
Phone: (888) 785-1804
www.moticont.com

Stafford

SHAFT COLLARS OFFER CHOICES FOR FACE MOUNTING COMPONENTS

A full line of off-the-shelf products for face mounting components on a shaft, depending upon specific user design requirements, is available from Stafford Manufacturing Corp. of Wilmington, Massachusetts.

Stafford Mounting Shaft Collars include Flange Mounts with six mounting holes and a keyway plus the Accu-Clamp non-marring and perfectly square clamping feature for mounting a shaft, tube, or pipe to a flat surface or for attaching components to them. Additional solutions include Accu-Mount collars with precision locating hubs and predrilled and tapped holes, and conventional Face Mount Clamp collars with predrilled and tapped holes.

Providing non-marring clamping for various face mounting applications, Stafford Mounting Shaft Collars are available made from aluminum, steel, and stainless steel in 0.25" to 3" I.D. sizes, depending upon the part. The Accu-Clamp Shaft Collars feature an integral clamp on one side while leaving the other flat and perpendicular within 0.001" TIR.

For more information:
Stafford Manufacturing Corp.
Phone: (800) 695-5551
www.staffordmfg.com

Minarik Drives

OFFERS CONTROLS FOR BRUSHLESS DC MOTOR

Minarik Drives has introduced the MDBL Series, a new family of versatile, feature-rich, configurable controls for brushless DC motors. MDBL drives control motors ranging from 90 to 280 VDC, up to 5 amps/1.5 HP, using either 115 VAC or 230 VAC line sources. On-board trim pots allow operators to quickly set minimum/maximum speeds, acceleration/deceleration rates, motoring and regening current limits, as well as the proportional and integral feedback gains.

An onboard microprocessor allows for custom programming the MDBL Series — for tasks as simple as changing the purpose of a jumper or trim pot, or as complex as programming an entire application-specific routine. The MDBL also seamlessly integrates PLC-like functionality into operations, eliminating the need for a separate PLC altogether or enhancing systems without PLCs. These controls are positioning-application capable, with feedback sampling rates of 16 Khz. Each drive is designed for feedback from 120° hall effect sensors and can be commanded with a wide range of analog inputs with Minarik Drives' built-in isolation.

For more information:
Minarik Drives
Phone: (815) 624-6933
www.minarikdrives.com

Realizing the High Precision Load Handling Benefits of Rodless Electromechanical Actuators

Max Miller, Motion Industries and Alexander Schollin, Thomson Industries

Electromechanical rodless linear actuators can offer better load handling in smaller spaces than rod-style actuators, but realizing those benefits requires careful attention at the specification level. Whether you are replacing a failed actuator, looking for better performance or building a new application from the ground up, success depends on how precisely you specify application requirements.

Rodless actuators are designed for advanced precision benefits and offer a wide selection of options depending on the system designers' needs (all images courtesy of Thomson Industries).

Unlike rod actuators, in which a piston extends unsupported beyond the actuator housing, rodless actuators use a carriage (also known as cart or truck) on which a thrusting mechanism moves a load back and forth on a track. Getting the optimal efficiency, reliability and overall performance requires careful balancing of numerous variables.

Whether interchanging actuators or specifying new ones, basic principles are similar. Rodless actuators are distinguished from each other primarily on the basis of the lengths, widths and heights of their profiles. Common dimensions include 40 × 40 mm up to 120 × 120 mm. Within that range, realizing the potential benefits requires a careful analysis of required stroke length, maximum speed, dynamic carriage load and bearing requirements. Through this analysis, motor selection, mounting fixtures and required control adjustments can be considered. Key components for selection are the thrust mechanisms and guide systems, supplemented by determination of the service factor, motors, sensors and other accessories.

Selecting thrust mechanisms

Thrust mechanisms commonly deployed in rodless actuators are lead screws, ball screws or timing belts.

Lead screws: Also, known as acme screws or trapezoidal screws, these deliver rigidity and high thrust in a small package. The action between the screw and nut is sliding, has a high friction factor and is inefficient, although it sometimes can be beneficial in that it provides a self-locking tendency when the system is at rest. Increasing clearance caused by wear between the screw and nut will determine the usable life of the actuator. Some vendors, however, now outfit actuators with plastic, self-lubricating nuts, which extends their lives.

The pressure velocity (PV) limit is another factor impacting lead screw load and speed ratings. Pressure equates to thrust, so as the thrust goes up, the speed goes down and vice versa. Lead screw actuators can have strokes as long as three meters but are most often found in smaller, lighter-duty applications.

Ball screws: Ball screw actuators are much more robust and fit better in most industrial applications. For example, a ball screw actuator built on a 120 mm extrusion with a 32 mm diameter and a 20 mm lead precision rolled ball screw would have a thrust capacity of 12,000 N and a maximum velocity of one meter per second with 3,000-rpm input. The same actuator and screw diameter deployed with a 40 mm lead, however, would have a velocity of two meters per second and a thrust capacity of 8,000 N. A typical precision rolled ball screw and ball nut could have a position repeatability ranging from ±.01 mm or less.

Rolled ball screw actuators offer a cost-efficient solution for applications requiring strokes of up to three meters. Ball screw actuators can be selected to optimize power density or small size per thrust. The L10 life is predictable because the ball nut is essentially a ball bearing and uses the same ISO calculation. The length of the screw affects the load rating, due to the buckling limit, and generally the speed rating, due to excessive vibration. Some vendors, however, add screw supports that enable input speed up to as much as 3,000 rpm, independent of the screw length.

Two other factors that contribute to the load capacity of a ball screw driven rodless actuator are the *ball nut* arrangement and the *carriage length*. A longer ball nut or a double ball nut will increase the thrust capacity, while a longer carriage increases the length or spacing of the bearings and increases the moment capacity. Thomson Industries, for example, offers a ball screw, ball bearing guide actuator with a single or double ball nut. The single nut version of its 80 mm × 80 mm profile unit has a 200 mm — long carriage, a thrust capacity (FX) of 3,500 N and a pitch moment (My) of 180 Nm. The corresponding double nut version has a 280-mm-long carriage, a thrust capacity (FX) of 5,000 N, and a pitch moment (My) of 300 Nm. The double nut is also more rigid and will have a slightly better repeatability and reduced axial play.

Timing belt thrust mechanisms: These actuators are also robust and fit in most industrial applications. Actuators equipped with high tensile strength timing belts can handle large thrust loads, velocities up to 10 m/s and are almost unlimited in length. For applications requiring strokes of more than three meters, they are more cost-effective than rolled ball screw actuators. Timing belt actuators are also clean and contaminant-resistant. A timing belt mechanism built on the same 120 mm extrusion as a ball screw would have a thrust capacity of 5,000 N with a 2,308 rpm input and velocity of 10 m/s. The belt travel would be 260 mm per pulley revolution with ±.05 mm position repeatability.

A motorized lead screw offers increased torque density and improved operating battery life.

Selecting guide systems

Careful specification of the guide systems that support the carriage and all the forces acting on the attached load as it travels is another critical success factor for rodless actuators. These can be specified with plain bearings, ball bearings, cam followers and/or wheels.

***Plain bearings*:** These will have a higher friction factor than the rest, however, they often do not require lubrication and can survive in contaminated or wet environments. Plain bearings also dampen vibration, run quietly and can tolerate short strokes at high cycles. Plain bearings or slide guides run either along the aluminum extrusion or are on a set of rails formed into the extrusion. They can be made of different materials such as hardened steel, stainless steel or anodized aluminum. The plain bushings could also be made of a number of materials, including polymer material, PTFE and many low-friction plastics.

***Ball bearing guides*:** These guides consist of recirculating ball bearings attached to the carriage. The carriages run

on hardened steel rails, which are bolted onto extrusions or steel inserts. The actuators in discussion can use a single profile rail for lighter load requirements, or add an additional rail for applications requiring higher loads and or moment capacity. Ball guides offer high accuracy, high load ratings and medium speeds.

Wheels and cam followers: Simple and economical, these also run on hardened steel rails which are formed into the extrusion, and offer high load capacity, high speeds and medium accuracy. The sealed ball bearings are maintenance free-and contaminant-resistant.

Service factor

The service factor is a key variable in selecting a rodless actuator. After calculating the load, determine the service factor from vendor-supplied load rating in the FX, FY, and FZ directions. The thrust mechanism handles the X component force; the Z component force is the weight sitting on the carriage plus any force perpendicular to the top of the carriage; and the Y component force acts perpendicular to the side of the carriage. From these moment loads (My, Mx, and Mz) pitch, roll and yaw can be solved.

In a typical cycle, a linear actuator accelerates, runs and decelerates at least once during the travel in each direction. There could, however, be many stops along the length of travel. The moment loads is the force needed to accelerate the driven component and its position relative to the carriage. Even driven components with their own guide systems will still have pitch and yaw moments acting on the carriage.

Rodless actuators are highly used in packaging application machines as they provide efficient and precise load handling solutions.

Motor options

Servo or stepper motors are typically the prime drivers for rodless actuators. Standard AC and DC motors are also used to drive linear actuators, but their duty cycle is limited to the number of starts per hour the motor can handle. Actua-

tor manufacturers typically offer metric and NEMA motor brackets with or without a motor attached. The torque and RPM required will ultimately determine the motor's size.

Automating the selection

Linear Motioneering is an online tool that Thomson offers for the sizing and selection of their linear components, including actuators. Users input information such as environment, repeatability, stroke, move distance, move time, duty cycle, orientation, loads and forces, resulting in a customized selection of actuator solutions.

For example, a designer is working on a packaging machine that requires a horizontal axis with a stroke length of 1,500 mm to pick and place products into cartons. By entering the stroke length details, along with other application parameters such as mass connected to the moving carriage, any offset distance from the carriage to the center of the mass, and cycle requirements, they will be presented with the most ideal, economical solutions.

Once the basic actuator is selected, the tool helps accessorize with sensors, mounting brackets and a motor attachment kit, including mounting screws and couplings. A complete model code and pricing are also provided. And finally, it calculates a complete motion profile, including continuous and peak torques, maximum velocities, and expected life.

The right mix

System designers considering rodless linear actuators have many options from which to choose. Almost any combination of lead screw, ball screw or timing belt, implemented with slide guides, ball bearing guides or wheel guides could provide the right solution. Other factors such as cost, availability, environment and service factor will eventually come into play. It is critical to enter the specification task with a thorough understanding of the intended application and objectives across the component lifecycle. **PTE**

For more information:

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Alexander Schollin works for Thomson Industries in product line specialist systems, EMEA & Asia. His responsibilities include developing lead technical training and material while producing new product sales and supporting the reps in the EMEA and Asian regions. Schollin studied nanotechnology with a master in biomedicine at the faculty of engineering at Lund University, Sweden. He has 12 years of experience as a technical representative, project manager and data analyst.

Max Miller received a degree in general engineering from the University of Illinois in 1975 and began his career with Berry Bearing Company in Chicago. He has been with Motion Industries for the past 23 years in various roles including account representative, training instructor, and currently, as an application engineer specializing in bearings and linear.

Hannover Messe 2019

Manufacturing Integration and Industrial Intelligence Take Center Stage in Germany

Matthew Jaster, Senior Editor

Hannover Messe 2019 will focus on the integration, digitization and interconnection of industrial technologies transforming manufacturing today. In recognition of this, the Integrated Automation, Motion and Drives (IAMD) show at Hannover Messe will feature a full range of products and solutions for the factory of the future, including factory and process automation systems, industrial IT, robotics, smart drives, and intelligent hydraulics and pneumatics systems.

The lead theme for Hannover Messe 2019 is "Integrated Industry — Industrial Intelligence."

"We want to focus on the connection between humans and machines in the age of artificial intelligence, particularly regarding how people use algorithms to teach machines to operate intelligently," said Arno Reich, senior vice president, industry, energy and logistics at Deutsche Messe AG. "This overarching theme covers topics such as Industry 4.0, Industrial Internet of Things, platform economies, cobots (collaborative robots), and cybersecurity."

Exhibitors at IAMD will show how manufacturers can use control technology and sensors to integrate automation technology, software and IT into electrical and mechanical drive systems. There will also be a strong focus on robotics. Hannover Messe takes pride in evolving with the changing needs of the manufacturing industry, according to Reich.

"We have an exhibitor advisory board that advises us on industry trends so we can adjust our exhibit program accordingly. For example, in 2018, we combined two exhibition sectors — Industrial Automation and Motion, Drives & Automation — to form the current sector Integrated Automation, Motion & Drives. The change was necessary to reflect the growing use of sensors, controls and networking products in electrical and mechanical drive systems. We also work closely with associations such as VDMA and ZVEI to organize relevant conferences and forums. An example of this is the Motion & Drives Forum in Hall 23, which we co-organize with VDMA," Reich said.

In 2019, the IAMD trade fair will focus on areas like smart sensors, smart drives, modular production, robotics, predictive maintenance and automated logistics systems as well as complete manufacturing solutions.

"Educational opportunities at IAMD include three daily forums: one for automation, one for motion and drives, and one for Industry 4.0. Key topics in 2019 include Industry 4.0/IIoT, 5G, artificial intelligence/machine learning, digital twin, predictive maintenance, cybersecurity, energy efficiency, and sustainability," Reich said.

In 2019, the trade fair is also launching a new career program called BE (Business & Expertise), which offers companies and STEM professionals a platform for targeted career placement and workforce development. "Pupils and students as well as young and senior professionals will find a wide range of events that cover career development and continuing education, including the Job & Career Expo, WomenPower Congress, and the Young Engineers Day on April 4," Reich said.

Hannover Messe presents all key sectors of industry at one place and one time, so visitors gain a comprehensive overview of the industrial value chain. The IAMD fair alone features more than 2,000 exhibiting companies and 9,000 products. "No other event in the world shows the industrial transformation in all facets," Reich said. "Thus,

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Hannover Messe is a must-attend for buyers who want to compare a broad range of technologies and solutions and keep up with global trends. In fact, two thirds of our exhibitors come from outside of Germany."

IAMD attracts roughly 130,000 visitors, so it is a great place to generate new business. Moreover, the customer pool includes fellow Integrated Automation, Motion & Drives exhibitors as well as exhibitors from neighboring sectors such as compressed air and energy. "Exhibitors at Hannover Messe collectively generate roughly 6.5 million business leads on average. Our supporting program features more than 90 conferences, forums and special displays, so Hannover is also a great place to learn and network," Reich added.

With a focus on smart integration and software, Reich believes success depends on close cooperation between IT and automation.

"Each has its own language, structures and approaches, so the challenge is getting the two disciplines to understand each other. When done correctly, smart integration builds communication channels that link people, machines and data; these in turn lead to greater efficiency and enable new business models," Reich said. "In Germany, we see more and more collaboration between the plant and mechanical engineering industries and traditional IT and software companies, such as the ADAMOS alliance formed by DMG MORI, Dürr, Software AG, ZEISS, and ASM PT.

Additionally, software is the central nervous system of smart manufacturing. Not too long ago, automation, motion and drives had little overlap with software. Today, however, digitalization has practically blurred the boundaries between these sectors. "Production and process automation specialists have become digital pioneers while the big software houses are turning more and more to the user industries for customers," Reich said.

The question remains how these concepts and technologies will evolve moving forward.

"We are currently in the midst of a project, Hannover Messe 2025, which addresses this question. Digitalization is changing industry rapidly. As the mirror of industry, Hannover Messe must comprehensively reflect this industrial transformation. Together with key exhibitors, VDMA and ZVEI, we are analyzing the structure and strategic alignment of the entire show. It is too early for results, but I think it is safe to say that the coming years will bring significant change to industry and Hannover Messe," Reich said.

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Booth Previews

The following are some booths *PTE* readers may be interested in if they're attending Hannover Messe in Germany from April 1–5, 2019.

NKE Austria GmbH

HALL 22, STAND D19

At this year's Hannover Messe in Germany, bearing manufacturer NKE Austria GmbH presents bearings with black oxide finish. The protective layer improves run-in and wear characteristics and protects against environmental effects. Especially in critical applications such as wind turbine gearboxes, black oxide finish is a cost-effective and technically viable means of prolonging the service life and performance of rolling bearings.

The black oxide finish forms a protective layer for steel parts. In a multistage chemical process, the surface layer of the treated parts is converted into a 1 to 2 micrometer thin mixed ferrous oxide layer that causes the characteristic black appearance. Black oxide finished bearing components feature a set of special technical characteristics, especially in the case of components that move relative to each other. Multiple protective effects can be achieved if only one functional element (typically the rolling elements) is treated. For best effect, however, all functional surfaces of a rolling element bearing, including the inner and outer ring as well as the rolling elements, should be black oxide finished.

Black oxide finishing is already an established method in other industries. NKE uses this technology to further improve the technical properties of rolling bearings. The method has proven itself in practice especially with full complement cylindrical roller bearings, but other types of rolling bearing are also black oxide finished, depending on the application. NKE offers a large number of black oxide finished rolling bearings. At NKE, this finish is used especially for cylindrical roller bearings, which then carry the suffix SQ94. The most common variants are SQ94B (rolling elements black oxide finished) and SQ94-D (all bearing components except for the cage black oxide finished).

NKE offers both standard and special bearings for all industrial applications. A wide range of standard bearings is available from stock or at short production lead-times. NKE also provides customized products and solutions. In addition to product development and application engineering, NKE provides a full range of technical services, consulting, documentation and training. NKE's products are distributed through 12 international offices and more than 240 distribution outlets in 60 countries. (*www.nke.at*)

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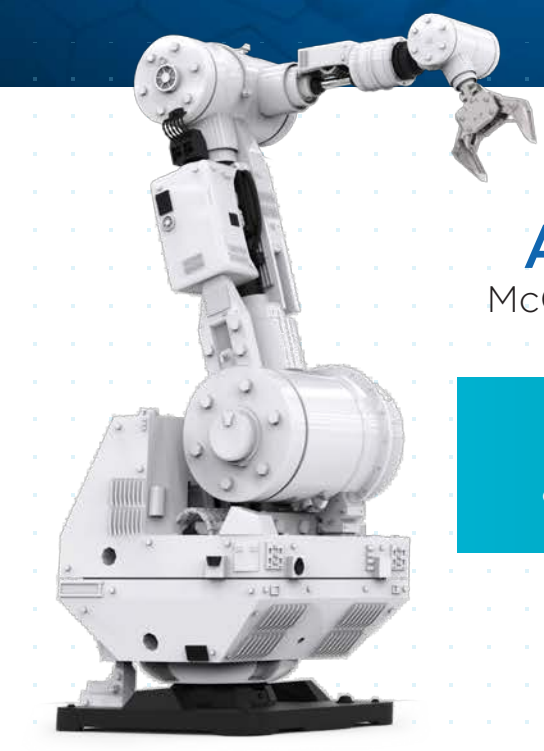

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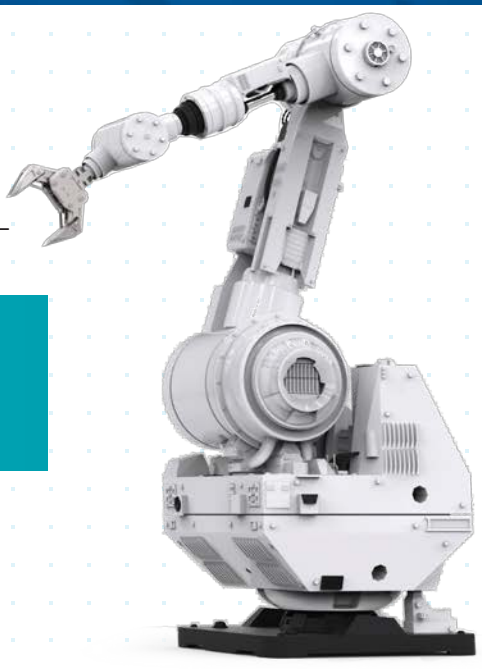
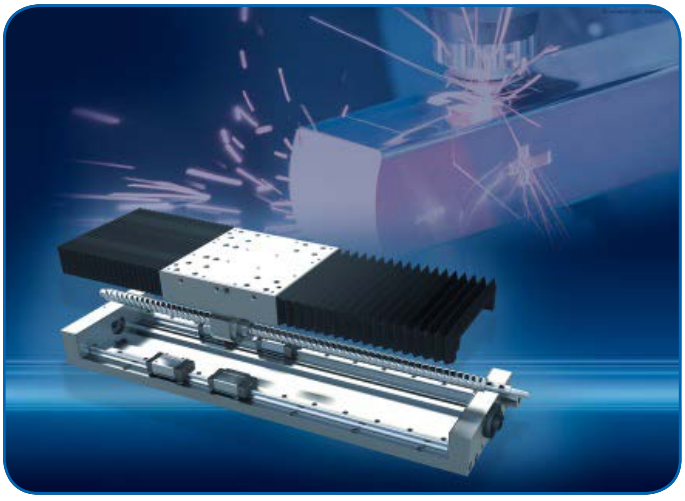


Brought to you by: Association for Advancing Automation

Rodriguez GmbH

HALL 22, STAND D59

The Value Added Products (VAP) division of Rodriguez GmbH develops and builds customized system solutions that are optimized for specific engineering tasks. These customer-specific system solutions are already proving their worth in a whole range of applications and sectors. What's more, each and every one of the optimized solutions is based on high-quality roller bearings and linear technology components from the company's extensive product portfolio. Most recently, the experts at Rodriguez implemented a tailor-made linear guideway table for a welding plant.



The RSTK-35 linear guideway table is part of an upright welding unit for processing various steel profiles. A welding cylinder moves up and down the Z axis of the vertically installed table, covering a maximum travel distance of 150 millimeters. The RSTK-35 linear guideway table has been optimized with a number of products carefully selected from the Rodriguez portfolio — a BRH-35 ball linear guideway with two rails, each with two blocks, a 50 × 10 ballscrew drive with FK5010 ballscrew nut, and a pair of double-row thrust angular contact bearings as the bearing for the ballscrew at the fixing side. (*www.rodriguez.com*)

Igus GmbH

HALL 16, STAND A18

Igus GmbH is a worldwide leading manufacturer of energy chain systems and plastic bearings. The family-run company based in Cologne directly operates in 35 countries, employs around 3.180 people and supplies customers through partners in another 51 countries around the world. More than 100,000 products of the Tribo experts, the so-called "motion plastics," plastic components for moving applications, are available from stock and piece number 1. To optimize the durability of their products and reduce machine costs by predictability of their lifetime, Igus operates the largest test labs in the industry.

One project in particular involves improving a conventional remote-control toy car to make it faster, more efficient and more robust than similarly tuned "series-standard" vehicles in a head-to-head race.

The Association of German Engineers (VDI) and Hannover University (HSH) — jointly launched the JET challenge for tech-savvy youngsters back in 2007. Much like full-scale motor racing today, the challenge goes beyond just cranking up the speed, with energy efficiency playing an equally important role. Visitors to IdeenExpo in June can see the results of this year's JET challenge live in action at the HSH stand, where 25 teams are pitting their 1:10 model racecars against each other on a 20-meter-long track. The rules are strict, with each team given a budget of just 50 euros to play with. Except for the battery, motor and speed controller, competitors have to buy, develop or build all components themselves.

With teams still busy preparing, the pupils from Eugen Reintjes vocational school have decided to upgrade their racecar with a hard-wearing, robust gear train. But since the tight budget pretty much rules out the option of designing a specialist solution, the students hunted high and low for an inexpensive alternative and finally came across the Cologne-based motion plastics specialist Igus. Once the gearwheels had been successfully configured online, Igus printed them using the selective laser sintering (SLS) technique and the high-performance plastic Iglidur I6 — a material that is exceptionally strong.

During a trial at the company's test laboratory, the engineers from Igus ran gearwheels made of polyoxymethylene (POM) and Iglidur I6 at 12 rpm under a load of 5 Nm. Although the milled POM gearwheel failed after just 621,000 revolutions, its printed Iglidur I6 counterpart was still in tip-top condition after one million revolutions, meaning the team from Eugen Reintjes school don't need to worry about breaking down. In fact, the gearwheels have already passed their first trial run, during which the team's energy-efficient racecar reached a maximum speed of 60 km per hour. See these and other similar components and technologies during Hannover in April. (*www.igus.com*)

Baumüller

HALL 14, STAND H12

Gradually electric engines are becoming popular in shipbuilding. The Danish shipyard Hvide Sande has commissioned the engine and automation specialist Baumüller in Nuremberg to deliver a hybrid drive system. The engine combines electric motors with diesel units, which are used only to generate electricity. In port, these can be switched off completely, leaving the ferry moving entirely under electric power. According to Baumüller, the hybrid engine cuts fuel consumption and emissions significantly. The new ferry is not only environmentally friendly, but also fast, at 11 knots. The hybrid drive concept also provides good maneuverability and a reduction in vibration. The ferry is to carry up to 32 vehicles and 196 passengers. It is due for delivery in Fall 2019.

Additionally, smaller businesses are finding themselves increasingly under pressure to digitalize their operations to keep pace with changing production standards. Retrofit strategies for networking and data analysis, while maintaining existing systems, are therefore a great option. The automation architects from Baumüller have developed a solution specifically for this purpose.

BAUDIS IoT enables the continuous recording, archiving, and analysis of machine data, whereby industrial companies can use either an existing cloud environment or an external service provider's infrastructure. The predictive maintenance solution from Baumüller is manufacturer-independent and can be used in combination with any machines. The adaptive, algorithm-based analysis functions can optimize processes or analyze predictive maintenance data, to spare production facilities unexpected failures and downtimes. Due to its open approach, BAUDIS IoT is also suitable for retrofitting and upgrading existing industrial machine environments. (*www.baumuller.com*)

For more information:
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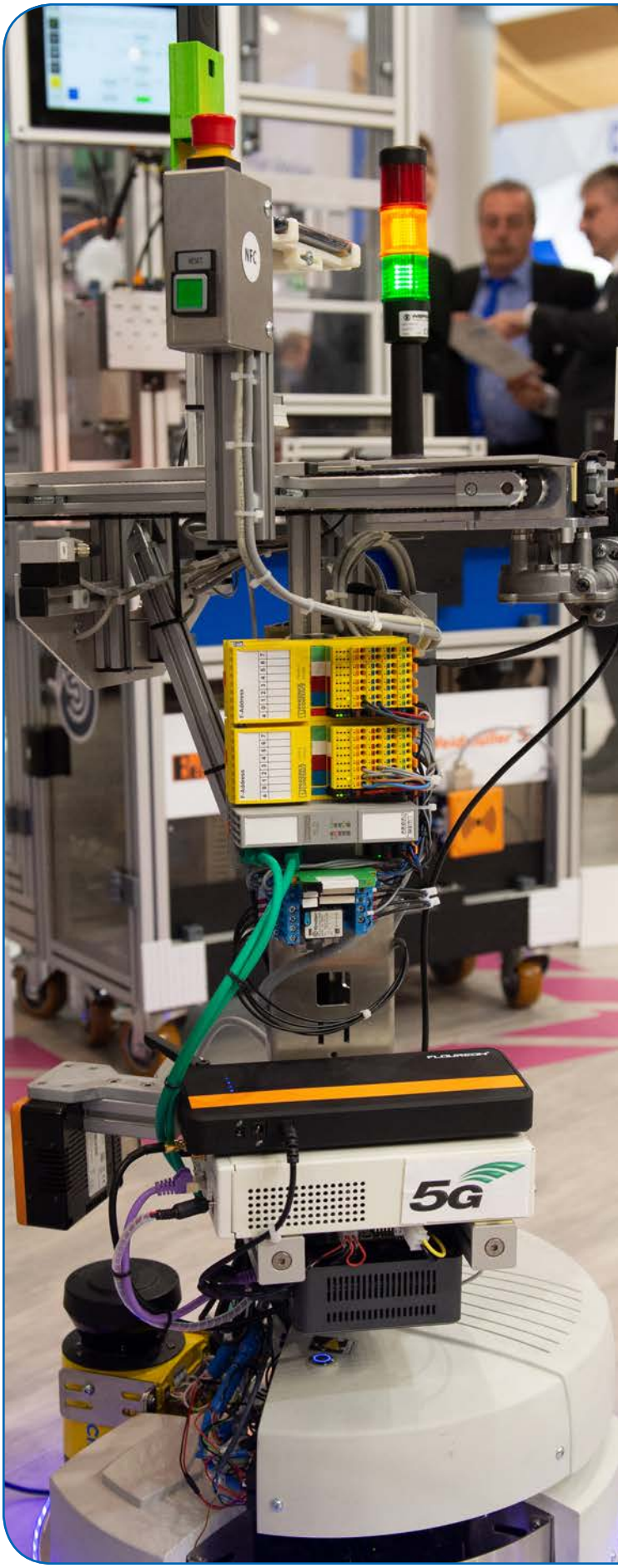
Be sure to check *www.powertransmission.com* for continual coverage leading up to and after the show in Germany.



Gears, Fluid Power and Electric

Gear Expo is Now the Motion + Power Transmission Show

Jack McGuinn, Senior Editor

Motion + Power Technology Expo

Detroit, MI — October 15–17, 2019

The Motion + Power Technology Expo will be held at the Cobo Center. Exhibitors will span the 80,000 sq. ft. of floor space with more than 4,000 attendees visiting their booths. Education classes and the annual AGMA Fall Technical Meeting will be held in conjunction with the Expo. MPT Expo will be co-located with the ASM Heat Treating Society Conference and Exposition. For more information, visit ***www.MotionPowerExpo.com.***

The American Gear Manufacturers Association has evolved its trade show. What was formerly Gear Expo is now the Motion + Power Technology Expo (MPT Expo), an event intended to represent the entire motion and power transmission supply chain. As part of the expansion of the show's scope, AGMA has partnered with the NFPA (National Fluid Power Association) to include a fluid power pavilion and additional educational sessions. The goal is to create a tradeshow that connects manufacturers, suppliers, buyers and experts in the mechanical, electrical and fluid power industries, all under one roof. (See page 34 for a Q&A with Croson for further information.)

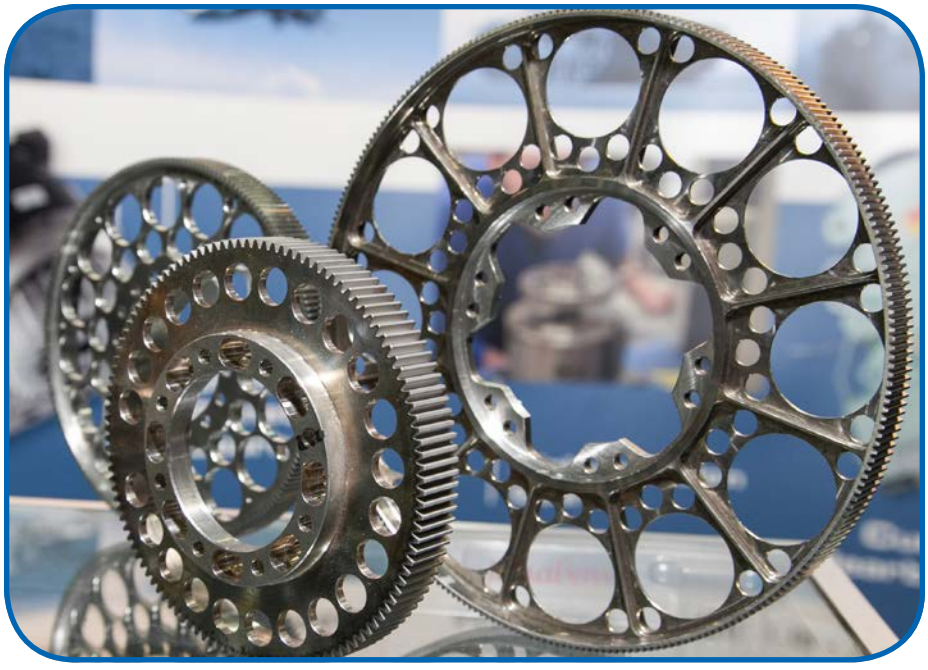
Motion + Power Technology Expo, which takes place **October 15–17 at the Cobo Center in Detroit, MI,** is expected to attract more than 4,000 professionals looking for technical solutions from across the mechanical power transmission, fluid power and electrical drive industries. The event will include technical educational sessions, networking, and a full exhibit hall featuring industry leading companies.

Show Profile

Exhibitors at the Motion + Power Technology Expo will include 300+ manufacturers, suppliers, and experts in the mechanical, electrical, and fluid power industries. The NFPA-sponsored Fluid Power Pavilion has 5,000 square feet of space and room for 50 exhibitors. Educational programs will include the AGMA's usual gear-related courses, as well as the AGMA's Fall Technical Meeting and NFPA Seminars.

MPT Conference

In addition, the show will offer a new opportunity for attendees to learn from industry experts in a two-track seminar series called the MPT Conference. Each session has a 30-minute presentation (one speaker) with an additional 15-minute Q&A portion. Presentation topics include:



Know Your Business (business track)

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For more information, visit ***motionpowerexpo.com/education***. What's more, AGMA is also planning two focused events — one for young professionals and a women's breakfast with industry speakers. Details about the sessions will be available in the coming weeks. Visit ***motionpowerexpo.com/request-information-form*** to receive updates and notification when registration opens on April 1, 2019. **PTE**

AGMA President Matthew Croson Explains How New Show Was Put in Motion

Is it accurate to say that this show will present A-to-Z supply chain providers for the fluid power, mechanical power transmission, and electric drives industry?

The goal of the Motion + Power Technology Expo is to give attendees the complete supply chain. For the upstream buyers, the show will feature forging companies, machine tool manufacturers and heat treat companies. For downstream buyers, the show will feature open gear companies, gearboxes, mechanical power transmission components, fluid power systems, electric drives and also hybrid systems involving multiple technologies.

The overlying concept the AGMA board approved is to evolve the show and position AGMA's tradeshow at the center of all aspects of power transmission, as the industry has evolved.

Was there an ah-hah moment that the NFPA and AGMA decided to partner for this show?
There was. After several meetings with their leadership, and sharing ideas, they recognized that we are a horizontal power transmission show serving a wide variety of markets—and felt like it was a good opportunity to add value to their membership by partnering in a new way.

The technical reality is that our joint end user customers are looking for power transmission solutions, including gears/mechanical solutions, fluid power and electric drive. They recognized that shift, and are supporting the partnership by engaging in a 5,000-square-foot pavilion.

What benefits do you expect to derive from the partnership?
Motion + Power Technology will always focus on growing sales leads for our exhibitors, just like Gear Expo did. In fact, we expect more leads for our long time exhibitors as we draw more customers into the show, where they can have conversations with new customers and showcase their approach to solving power transmission issues.

Can we expect this to be a permanent partnership going forward?
Association partnerships are an important aspect of solving industry challenges. We work with the Bearings association (ABMA) on our Annual Meeting, ASM International for the show for more than 10 years now, and having NFPA being a partner feels comfortable and makes sense for the AGMA Board strategically.

What we have right now are three leading organizations working together to add value to the members and exhibitors we have, by creating a comprehensive showcase of power transmission innovation.

We expect to be focused on this value "permanently" and will work with any association that wants to collaborate with AGMA to grow power transmission solutions.

Have to ask—have any past exhibitors dropped out over this partnership?
Our exhibit sales are outpacing 2017 by 10% and that doesn't include the additional NFPA pavilion. We have discussed this effort as being a three-show cycle in order to achieve the vision and haven't had any drops due to the evolution. But companies do drop from shows for other reasons, and we always experience that. From a technical perspective, our show committee and board leadership believe firmly that AGMA needs to be at the center of all aspects of the power transmission world, and forward-looking companies will want to work with us to make the show as strong as possible.

Machine tool companies should be thrilled with the change, because it ensures more gear company attendance; same with forging companies and heat treat suppliers.

Open gear companies and systems companies should be happy because it allows them to have deeper conversations with customers they may not have known or met.

Gear companies, electric drive and fluid power exhibitors will appreciate that everyone coming to this show is focused on one thing: power transmission innovation.

Is there growth potential for future shows?
Yes. With a complex supply chain such as ours, there are always opportunities to grow. But our key differentiator is not size—it's technical understanding.

Our exhibitors aren't always looking for volume—this isn't a show with 150,000 tire kickers looking at anything and everything. The 5,000–6,000 attendees we get are focused on one thing: power transmission. And they want to speak to engineers who can "get it done." If we get the right exhibitor base, more customers come. And when more customers come, more exhibitors want to be a part of it—and growth happens.

This is the virtuous cycle any show wants to create—and again—AGMA's Board has been clear: they want AGMA at the center of power transmission innovation, and this show evolution is one strategy to help secure that position.

Does NFPA and AGMA have any other partnerships in the works?
Yes. We are partnering with NFPA on their Industry and Economic Outlook Conference (IEOC). This will give AGMA members an opportunity to hear from more than a dozen of the leading manufacturing economists providing forecasts on their customer's markets, as well as the latest Gear Market Forecast from IHS Markit. The conference is extremely well-regarded by attendees, and several AGMA members had suggested that we partner with NFPA on this effort. Members of AGMA's Market Intelligence Committee attended the conference last year, and recommended that we fold our Marketing & Forecasting conference into NFPA's event—which we will do for the first time this summer.

Change is our only constant—and we think the show evolution, and the new partnerships with NFPA, and others—are keys to making sure we keep up with the changes and ensure AGMA is relevant for the next 100 years. **PTE**

Want to know more? Go to ***motionpowerexpo.com/access-trade-show-webinar*** to view a webinar hosted by NFPA president and CEO Eric Lanke and AGMA president Matthew Croson. This informative presentation talks about, among other things, the genesis of the AGMA-NFPA partnership and about what you can expect to experience at MPT Expo.

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Heavy Industry and Smart Technology

Joseph L. Hazelton, Contributing Editor

Heavy industry.

The phrase conjures images of mines and steel mills, of huge caverns underground, of cavern-like factories, of old-line companies operating heavy-duty machines for high-torque work.

That's the image of heavy industry.

Today, though, there's also another image. It's of an operator walking a steel mill's floor, looking at his smartphone or his tablet. He's not on break, though. He's working. He's using his phone to look at real-time data about the mill's machines. He's using the Internet to check that the machines are operating smoothly and to see whether any potential problems have been detected and diagnosed.

With the Internet, he can check without being in a control room or on-site or even in the same state. He can check from anywhere in the world.

Today, in heavy industry, more and more machines can transmit their data in real time to the Internet. This ability comes from smart technology, specifically from sensors that 1) can access complex software to mimic human decision-making and 2) can access the Internet. The smart technology is being added inside the machines to critical components, like power transmission (PT) components (gears, bearings, couplings), to reduce downtime — including unplanned downtime — in order to increase productivity.

Heavy Industry: Continuous Operation

For companies operating in heavy industry, the cost of unplanned downtime is extremely costly. In some cases it can mean the difference between profit and loss for an operation. "To be profitable, they need to minimize their unplanned downtime," says Mike White. "This is why Schaeffler is ac-

VarioSense bearings from Schaeffler make it possible to quickly and easily record and transfer a bearing's operating conditions in order to monitor central machine and process parameters. (Photo courtesy of Schaeffler Group USA, Inc.)

Heavy industries, like the steel industry, are incorporating smart technology into their manufacturing operations. The technology is designed to reduce downtime, including unplanned downtime. The technology uses sensors to obtain data about a machine's operation and analyzes that data using sophisticated software. (Photo courtesy of Bauer Gear Motor GmbH)

tively developing intelligent bearing products. Bearing reliability is often critical to the performance of their operation. By integrating an intelligent sensor to measure temperature, vibration or force, directly into the bearing, valuable data can be obtained — data which can be utilized for early detection of a bearing problem, allowing the customer to proactively schedule and plan for the maintenance." says White.

White is director, regional business unit manager for raw materials with Schaeffler Group USA Inc., Fort Mill, SC. The Schaeffler Group is a global automotive and industrial supplier that develops and manufactures high-precision components and systems for engine, transmission and chassis applications as well as rolling and plain bearing solutions for a wide range of industrial sectors.

Running a factory 24/7/365, though, makes it difficult to maintain machinery. Even regular, preventive maintenance means stopping machines so they can be inspected and possible problems can be addressed. A stoppage may be brief, the time needed to take a machine off the production line and put another machine on the line. Or the stoppage may be comprehensive, bringing the whole line to a halt because there is no other machine.

With smart technology, downtime for maintenance work can be reduced by shifting at least some maintenance from a schedule to as-needed. Also, the case for maintenance work — for a stoppage — can be easier to make.

"You have the data to prove that 'Yes, this is the proper time… to make some inspection,'" says Artur Rdzanek, a global product manager for ABB Ltd., Zurich, Switzerland. Rdzanek's focus is sensors for ABB's Dodge mechanical PT components. ABB's Dodge division makes couplings, enclosed gearing, and bearings and serves many customers in the metals industry, the mining industry, and the oil and gas industry.

Unplanned Downtime: The Real Enemy

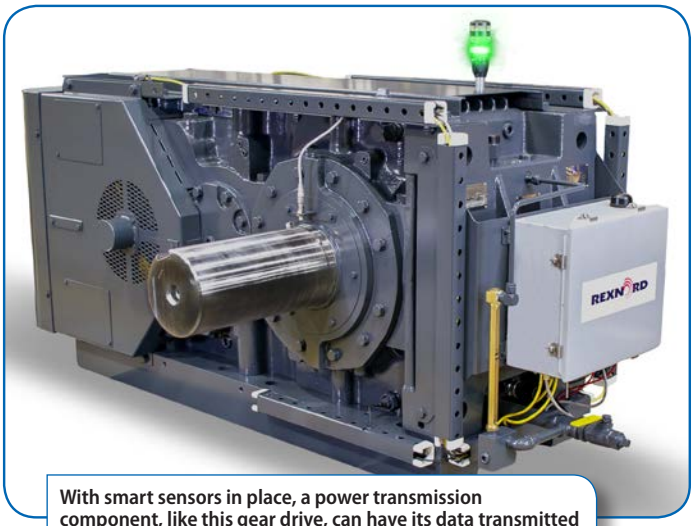
The money effect of unplanned downtime can be stark in heavy industry.

An example is provided by Jason Weber, director, digital solutions for Rexnord Corp., Milwaukee, WI. Rexnord makes bearings, couplings, and gears and also serves the mining industry.

Weber's example is a customer, a Canadian mining company: If it has an unplanned stoppage, with each hour, it loses about $100,000 Canadian.

And unplanned downtime usually doesn't lend itself to a quick fix, like with the mining company. "If they lose a gear drive on one of their main lines at the beginning of a shift, they could be down six, seven hours," Weber says. "The real enemy is unplanned downtime."

Unplanned downtime, however, can be combatted with Industry 4.0. That's a movement to turn factories into smart factories by equipping industrial machines



With smart sensors in place, a power transmission component, like this gear drive, can have its data transmitted to smart services for analysis. The results can then be viewed via a web portal. (Photo courtesy of Rexnord Corp.)

with sensors so their data can be monitored and analyzed by smart software. The sensors and smart software turn PT components into smart PT components with access to smart services.

According to Weber, by using smart PT components and services, the Canadian mining company learned about a few pending problems, allowing it to fix them before they led to unplanned downtime. "We have warned them early of pending issues," Weber says.

Also, he estimates that by learning about the problems in advance, the mining company avoided losing some $500,000 Canadian in unplanned downtime.

Smart technology starts with a sensor that can measure operational aspects of a power transmission component. In its white casing, this sensor can collect data on the mounted bearings so the data can be analyzed by smart software. (Photo courtesy of ABB Motors and Mechanical Inc.)

Smart Software

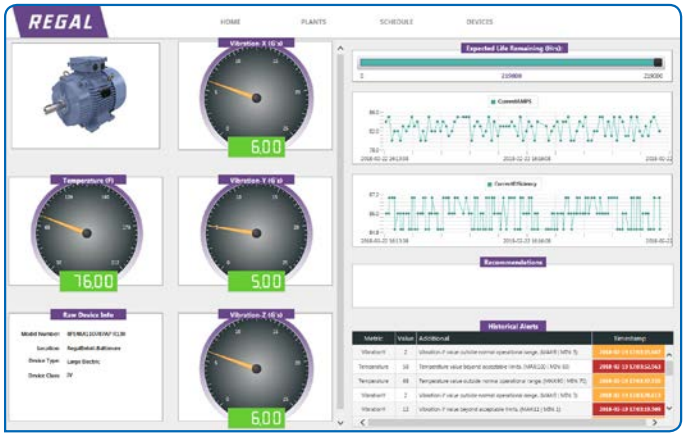
The key to reducing unplanned downtime comes through the PT component's sensor, which has access to smart, predictive software.

The software is predictive because it can take a machine's data — like torque, vibration, temperature, lubrication — can analyze the data, can detect potential problems, and can predict future circumstances, like the remaining useful life of a component. The software can make such predictions by using algorithms.

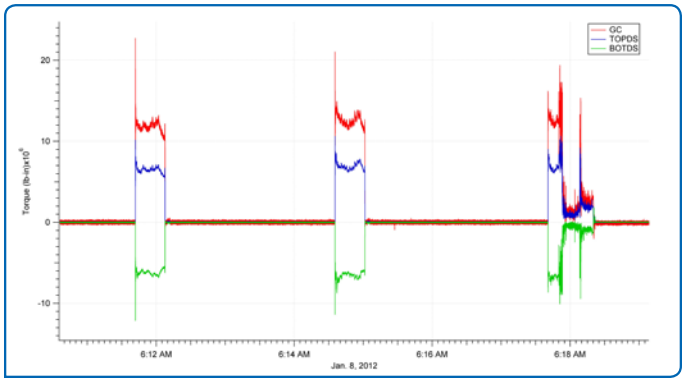
An algorithm is a step-by-step procedure for solving a problem. The procedure uses measured data, like torque and temperature, and is a logical process, so it can be written as software and executed by a computer. Moreover, algorithms can be so sophisticated that they can make decisions like a person would.

Now, an algorithm may be in software that's in a sensor itself, that's in an edge device near the sensor, or that's stored on a server. In all cases, the sensor records data so it can be analyzed by an algorithm.

After analysis, if an algorithm detects a possible problem, it can tell the factory's people about the problem — "Hey, come take a look at this" — so they can fix the problem before it degrades the machine's operation. Moreover, the algorithm can be designed to tell them in an easy-to-understand report that includes actionable information.



Smart monitoring and diagnostic services can collect, analyze, and display various data on a machine's operation, like temperature, vibration, and energy usage; on a component's remaining useful life; and on suggested actions for maintaining the machine's operation. (Photo courtesy of Regal Power Transmission Solutions)



Besides detecting potential problems, smart services can provide real-time data about right-now problems. In this torque graph, the real-time problem is torsional vibration on the drivetrain in a steel rolling mill. After two normal readings, the third reading shows vibration from a failed work roll. (Photo courtesy of Regal Power Transmission Solutions)

An algorithm can also be designed to decide in some cases what should be done to solve the problem, just to get the ball rolling. For example, the algorithm may decide that a component should be replaced, so it will order a new one.

Such smart services and PT components are offered by several companies (see sidebar *Becoming Smart: Products and Services* on page 41).

Now, the ability of a smart PT component to diagnose itself can reduce maintenance costs.

Think of a manufacturing machine as though it were a car. To maintain your car, you have the oil changed regularly, in accord with the automaker's specs: every 3,000 miles or 3 months, for example. Now, imagine your car can tell you when it actually needs to have its oil changed, when the oil is starting to degrade but hasn't yet affected the engine's operation. In that case, you may not need to change the oil for 4,000 miles or 5,000. You can wait until the car tells you to change the oil.

"You can save money just on that," Weber says.

In that case, you were also able to shift your car from one type of maintenance, preventive, to another type, maintenance done only when there's an actual need.

Likewise, a manufacturer using smart technology may be able to shift at least some maintenance from preventive to as-needed. And that shift can lead to another benefit.

Reduced Carrying Costs

Using smart technology, a manufacturer may be able to reduce carrying costs because it can keep a smaller inventory of spare components on-site.

Keeping a smaller inventory may include even customized PT components. No matter the industry, a manufacturer may have to carry custom-made components in stock, laying on shelves in a factory. However, smart technology, may be able to notify a manufacturer of a problem far enough ahead of time that even a customized component can be made and delivered in time for installation before machine failure.

If smart technology is used throughout production, a manufacturer may also be able to manage its consumption of electricity, reducing its energy costs (see sidebar *Reduced Energy Costs* on page 39).

A System of Machines

Of course, machine failure is bad. However, it can be really bad when the machine isn't a stand-alone. The machine may be part of a larger system of machines connected to each other, like by conveyors and robots. In a system, failure in one machine can bring the entire system to a dead stop.

Smart services, however, can be used on a single machine or on a larger system of machines, if the machines are networked by communication technology.

How Smart Services Work

Sensors collect data about their PT components and about the larger machine. The data is analyzed by means of smart services. The services include monitoring and diagnosis and

Smart technology can be used on a single machine or on a larger system of machines, including the equipment that connects those machines, like conveyors and robots. In its gray casing, a sensor monitors the operation of a motor for a conveyor belt. (Photo courtesy of Schaeffler Group USA Inc.)

are offered by the companies that make the smart PT components

The services are offered by the companies that make the smart PT components and include services for monitoring the operation of a machine or system of machines and for detecting and diagnosing problems. While some smart software may be in a component's smart sensor, much is stored on a server, and the server may be an internet one or a private, non-internet one.

After the data is analyzed, the digital services automatically give the end user a report about the PT components or the machine, including specific recommendations for action.

Now, a server is needed because the amount of data to be analyzed and the amount of computing power required can be quite large. In those cases, the data analysis is Big Data Analysis.

And a convenient place for that analysis is the cloud. It already exists — it doesn't need to be set up — and it has abundant computing power for aggregating and analyzing large amounts of data.

"One of the main reasons people use the cloud is for aggregation of data," Eric Huston says.

Huston is vice president, Industry 4.0 applications for Schaeffler Group USA.

He indicates how much data may be aggregated with a hypothetical steel mill with 1,000 machines, each with at least two smart sensors. The total: 2,000 sensors sending information.

Data Security

Naturally, data sent to the Internet for analysis should always be secured. It can be encrypted before transmission. Once on the Internet, it can be secured with measures meant to prevent unauthorized people from accessing it, to restrict authorized people to only data relevant to them, and to store data on only authorized devices.

Also, if the smart services are on the Internet, an end user may be able to solve a problem faster through online help from support people with the company that provided the smart components and services. Those people would be able to remotely access the Internet-based services too in order to help with the problem.

Security measures and remote support notwithstanding, data can be analyzed and problems detected and diagnosed with non-internet servers too, like local ones physically separated from access to the Internet.

"In this world of smart, not everything requires cloud," Huston says. "Some customers, particularly those concerned with data security, are actually requesting non-cloud through edge-processing directly within the smart device."

Retrofitting

Now, a factory can be turned into a smart factory through new industrial machines that were equipped with smart PT components during design and construction, long before the machines were installed in factories. However, a manufacturer may not want to replace installed machines with new ones in order to benefit from smart technology.

For those manufacturers, retrofitting may be an option.

In Huston's experience, the option is available to many companies. "The market — in my mind — is about 50/50," he says, describing the split between 1) machines outfitted with smart PT components during construction and 2) machines retrofitted with them after installation.

Reduced Energy Costs

Another possible benefit of smart PT components and services: reduced energy costs.

This benefit is explained by Karl-Peter Simon, managing director and president, Bauer Gearmotor GmbH, Esslingen, Germany. Bauer manufactures geared motors and serves the metals industry and the material-handling industry.

If a smart sensor can monitor and record aspects of power consumption, that data could then be processed centrally to forecast energy demand.

A manufacturer could then manage its consumption to keep its energy costs down. To do that, the manufacturer has to avoid a peak load. That can be done by turning off some equipment when a peak load is expected. For example, a manufacturer may be able to turn off some fans for a short time.

The reason for avoiding a peak load is straightforward. If a manufacturer gets its electricity via an energy contract, the electricity is supplied at a quoted price based on a specific, expected amount of consumption. If the manufacturer exceeds the expected amount, then the extra energy is charge at a different, higher price.

To manage consumption, though, the manufacturer would need data from across its production operation. Collecting the data is one thing. But, analyzing it to discern patterns of energy usage? That's no small task.

"That's also Big Data Mining." Simon says. **PTE**

"The here and now is adding sensors to existing equipment," he says. "The future is embedded."

The Right Voltage

To bring in smart technology, companies in heavy industry may have to overcome a problem: supplying the PT component's smart sensors with the right type of power, according to Rexnord's Weber.

While heavy industry uses power aplenty, it may not be at the right voltage. As an example, Weber uses a mine where machines were connected to the internet via edge devices. "You might have 480 volts down there to run the motors," he says, "but you don't have 220 or 110 down there to power the edge."

Internet Connectivity

Weber's mine indicates another problem: ability to connect to the Internet.

Internet connectivity may not seem like a problem. Smartphones and tablets work all the time. Internet connectivity is everywhere, but is it on the floor of a steel mill or underground in a mine?

If it isn't, new lines may need to be laid down so connectivity can be gotten to machines to take advantage of smart PT components.

Alternatively, the smart components can communicate with the Internet indirectly. For example, ABB's sensors use wi-fi to communicate with an app on a maintenance employee's cell phone. The employee makes his rounds, gathering data as he goes. Then, when the cell phone has a reliable Internet connection, the data is automatically uploaded, Rdzanek says.

In Weber's experience, though, the problem of connecting to the Internet is disappearing: "Over time, that's becoming less of an issue." And the reason? Advantages through connectivity are a coming thing. "There's more things like what we're doing that need connectivity," he says.

Changing Culture

In Daniel Phillips' experience, the biggest problem is culture, like he encountered with a mill.

Phillips is technical director, services and Perceptive Technologies with Regal Power Transmission Solutions, which is part of Regal Beloit America Inc., Beloit, WI. Regal makes bearings, couplings, and gears and serves the metals industry and the minerals and mining industry.

Culture can be a major challenge because a company may be reluctant to change the way it does things, especially if it has done them that way for decades.

If change comes from the top down, culture may be overcome quickly. If from the top down, the change may be comprehensive, with smart PT components installed throughout a manufacturing site. If from the bottom up, the change may be small at first, a pilot program, to show the benefits of smart technology. A small, initial installation was the case for the mill that Phillips encountered. "Then, they can understand the value of the data, how to interact with it," he says. After a pilot program, a company may be more willing to implement larger installations, with evidence slowly overcoming culture.

A Path to More Productivity

The path of smart technology may seem long: PT components equipped with sensors that can access software, that includes algorithms, which can mimic human decision-making to detect and diagnose problems.

And the path may lead to places that seem strange at first: the operator walking the steel mill's floor, looking at his smartphone, who appears to be on break but is working, reviewing real-time data about the mill's machines.

However, smart technology's path is only part of a much longer trail toward ever greater productivity in industry. As Huston says: "It's just the continued tightening of everything that allows you to be more efficient, more economical, more sustainable, and generate better results." **PTE**

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Becoming Smart: Products and Services

To take part in Industry 4.0, a manufacturer must survey the field of companies that offer smart technology in order to find the companies that offer the smart products and services best suited for the manufacturer's needs. Some companies in that field appear below.

One source of smart technology is ABB Motors and Mechanical Inc., Fort Smith, AR. Previously Baldor Electric Co., ABB Motors and Mechanical is a business unit of ABB Ltd.

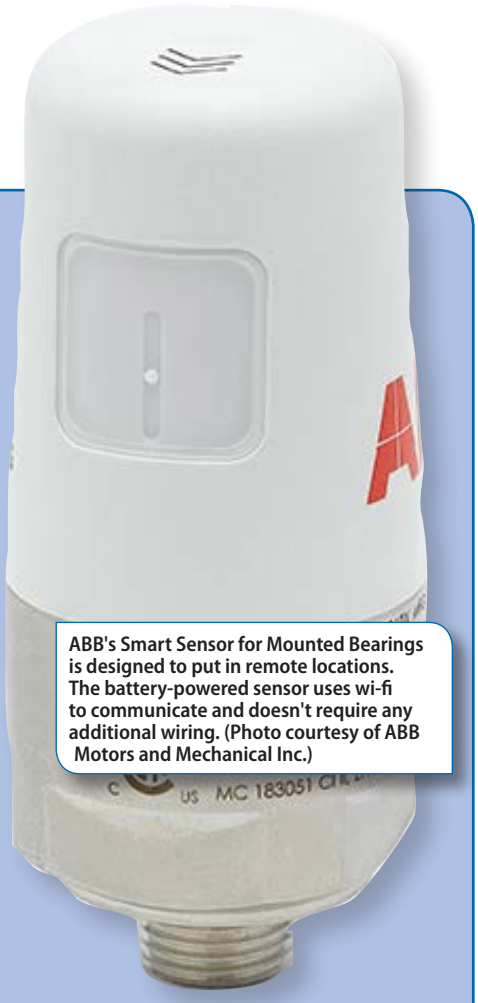
ABB's smart technology, a sensor and analysis software, is for mounted bearings, like ABB's Dodge mounted bearings. Named Smart Sensor, the sensor measures temperature and vibration. The data can be displayed on a smartphone or tablet and can be analyzed for trends on ABB's digital platform, ABB Ability.

Also available for Industry 4.0 is TorqueControl4.0, developed by Bauer Gearmotor GmbH, Esslingen, Germany. TorqueControl4.0 monitors a gearmotor's torque, voltage, and active power and can transmit data to an Industry 4.0 network.

For Regal Power Transmission Solutions, its smart monitoring and diagnostic services are offered under the brand name Perceptive Technologies, through the company's lifecycle-services division.

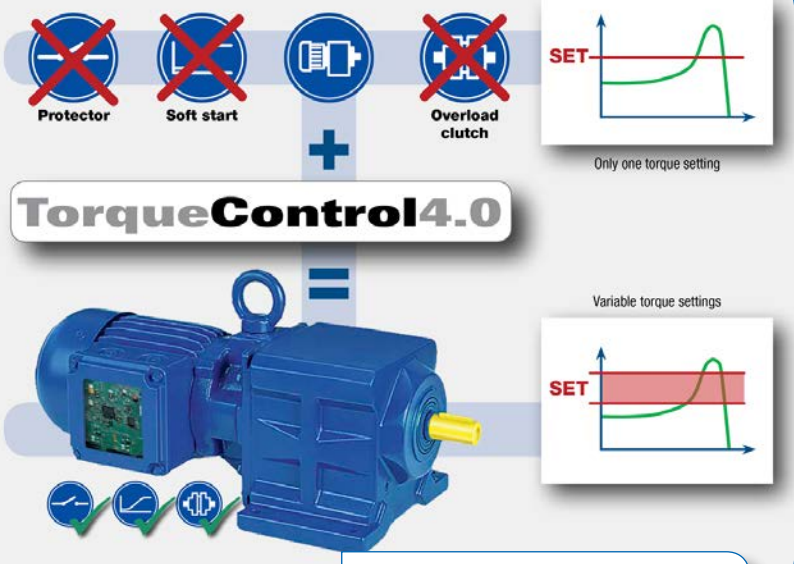
Rexnord offers its smart technology for use on Falk brand A-, Y-, and V-class unit drives. Sensors measure aspects of a gear drive, like temperature, vibration, oil quality, output shaft speed, and then transmit the data to Rexnord's Smart Condition Monitoring System powered by DiRXN. Its software analyzes the data, and results can be viewed on a web portal, Rexnord Connect.

Meanwhile, Schaeffler's monitoring and diagnostic services are aspects of its Smart EcoSystem, which also interacts with the cloud, using data collected from products like SmartCheck for retrofit applications and embedded VarioSense sensor bearings. **PTE**



ABB's Smart Sensor for Mounted Bearings is designed to put in remote locations. The battery-powered sensor uses wi-fi to communicate and doesn't require any additional wiring. (Photo courtesy of ABB Motors and Mechanical Inc.)

Schaeffler's Smart EcoSystem provides the IT infrastructure for the integration of smart components, visualization and analysis tools, and digital services. (Photo courtesy of Schaeffler Group USA Inc.)



Bauer's TorqueControl 4.0 system embeds intelligence into a gearmotor to monitor torque, voltage and active power. (Photo courtesy of Bauer Gear Motor GmbH)

Design Investigations and Indications for Acoustical Optimized Gear Meshes Using Plastic Gears

M. Koop, E. Melnikov and V. Merz

Introduction

When it comes to a steel-gear mesh, there are several common standards and design rules on how to reduce noise emissions in the mesh. But if plastic gears are involved, this is no longer the case. The topic of this presentation is to highlight some of the differences between metal-and-plastic gear meshes, i.e. — which design strategies can be stated as valid for metal as well as plastic — and which are not? This should lead to some basic hints to what a noise-optimized toothing should look like, but also to what might be deleterious effects on other important features, e.g. — strength. The differences will be shown by examples of FEA results demonstrating effects of the lower Young's Modulus and others on specific design strategies. It will also be shown that due to the lower stiffness, some design rules — like aiming for integer numbers of overlap ratios, as it is known, for steel meshes is still not wrong — but the allowable spread around the integer overlap is much higher for yet minor noise emissions. This will be shown with test results as well as FEA. Further, other interesting topics are investigated physically, such as the effects of different tip modifications, etc.

When it comes to noise generation and emission due to gearing movement, the root causes of these generally can be stated as:

- Stiffness variation during the tooth contact
- Tooth meshing impact
- Sliding effects (effects of roughness and relative sliding)
- Geometric errors, such as runout, etc.

Once the structure-borne sound is generated, it has to be transferred through the parts to finally find a surface where it is transferred to airborne sound. Therefore, the damping effects, as well as acoustic impedances of the materials, are main influencing topics.

Regarding different materials in a geartrain, it can be said that there are many investigations regarding the material combination of steel-steel. However, plastic sometimes behaves very differently when it comes to the noise effects of some specific design issues, such as tip modifications and transverse and overlap contact ratios. Calculations and tests indicate that the root causes are still the same, but the specific behavior sometimes changes dramatically, mainly because of the higher deformations caused by lower Young's Module of the plastic material.

Because of the higher deformation of the gear mesh, contact and overlap ratios change dramatically when loads are applied; therefore the optimum of the theoretical, non-deformed calculated contact ratios shifts while under load. It can be seen that there is not a specific optimum at all load conditions if deformation is taken into account.

Also, there are some main effects not driven by the higher deformation itself, but instead the difference between the deformations between both gears if different materials are used. For example, regarding a geartrain where a metal gear is paired with a plastic gear, stiffness modulations can be stated higher, in general — as if the material combination were equal. Even if it is only different plastics that are used, the difference can be particularly high when reinforced and non-reinforced materials are combined. Especially when the plastic gear is the driver, big tip modifications are essential to avoid high pressure and acoustic problems. For an acoustically optimized gear there must also be taken into account some specific plastic behaviors regarding toothing errors. To gain more data and knowledge about the deformation-influenced behavior, several tests were performed in-house.

A Closer Look at Spring Stiffness and Gear Mesh Behavior

In principle, the transmission of circular motion in a perfectly shaped, ideal stiff gear mesh would be perfectly steady. In practice, in a real gear mesh the transmission is not perfectly steady (Refs. 1 and 5). This is caused by changes to the stiffness of the mesh at different meshing positions, as well as other effects like tooth meshing impact and inaccuracies caused by manufacturing [1, 1].

Therefore, the stiffness variability of the gear mesh is an important factor of the noise generation. Because of the different length of the lever arms of a tooth along the path of contact, as well as of other effects like transverse contact ratios (different number of teeth in the mesh at different positions), the stiffness can vary. As stated by FVA investigations regarding steel, an axial overlap ratio given as an integer therefore leads to minimum structure-borne sound emissions [2, 132]. An explanation of this effect is that for an even overlap ratio, every point at the path of contact is utilized as a contact point in a specific transverse section at any angular position of the gear mesh. Put simply, no differences in the stiffness situation occur overall, because at the same time both the less stiff and

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

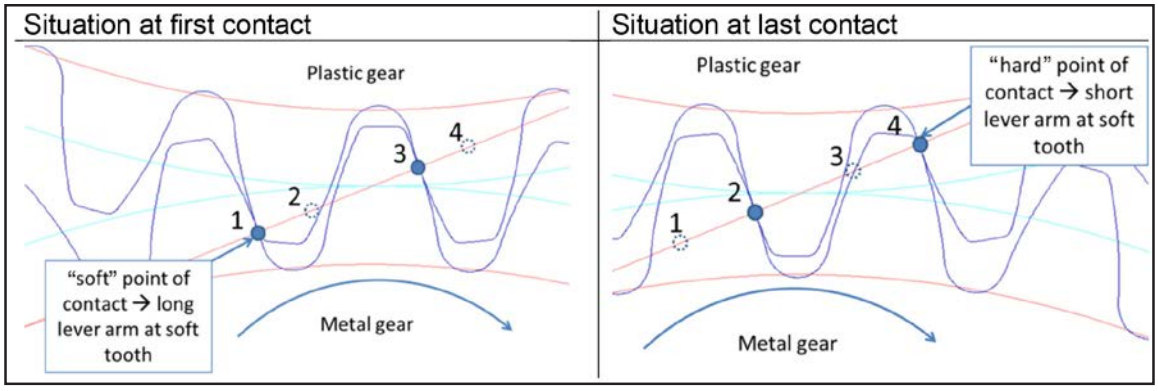


Figure 1 Metal gear as driving gear.

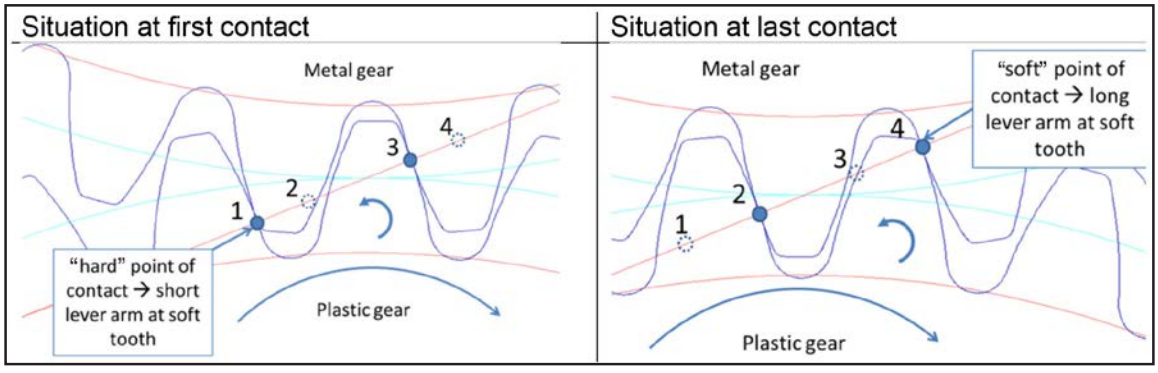


Figure 2 Plastic gear as driving gear.

more stiff contact positions are engaged. This is essentially for a steady transmission; as can be seen (Fig. 1), the lever arm at position 1 for the plastic gear is much longer than at position 4. This means that the stiffness decreases for contact at pos. 1 and increases until the end of contact at pos. 4 — if just one pair of teeth should be in contact. In fact, it must be taken into account that the change of the number of teeth in contact means that positions with two teeth in contact are stiffer than positions with one pair of teeth in contact. Therefore the contact situation slightly after point 2 is the softest position, because one tooth is in contact and the soft plastic gear has the high leverage arm. It can be generally stated that the changes in the stiffness are much higher in the metal-and-plastic combination, because in a geartrain there is always a long bending lever arm at one tooth paired with a short one at the opposite. When the same materials are used, this to some degree averages the effects of changing leverage arms. When it comes to an application with paired metal-and-plastic because of the high difference in the Young's Modulus, the metal tooth almost bends not compared to the plastic tooth and because of that the averaging effect does virtually not exist.

These above-mentioned effects — seen also in Figure 3 — were different material combinations we compared. Here the geometry of the spur-toothed test gear was the base that was modified for the tooth thickness correction as well as for the high-toothed gear. It can be seen that from this point of view, the variations are lowest for the stiffer materials. But, damping here is not recommended, and therefore structure-borne sound emissions for the high stiffness combinations — like steel-steel — are usually worse if the same degree

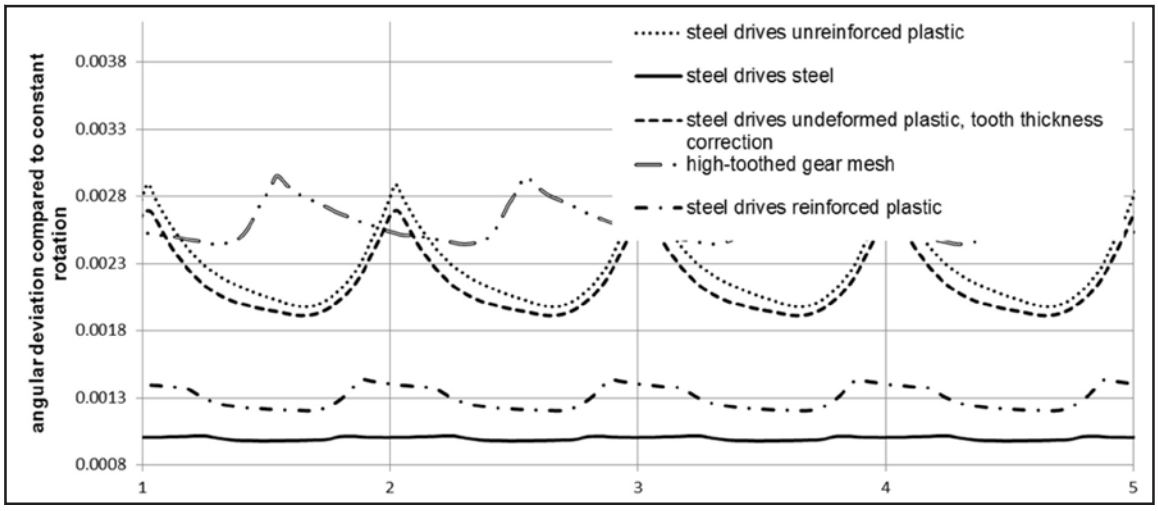


Figure 3 Angular deviations compared to constant rotation for different material combinations and toothings.

of quality level is taken into account.

As can be seen (Figs. 1–2), there is also a significant, principal difference if the metal part is the driving gear or the driver. In a situation where metal is the driving gear, shortly before the next pair of teeth will engage (point 1), the gear mesh is not so soft, because at point 3 there is a short leverage at the soft tooth. Conversely, when plastic is the driver, shortly before the next pair of teeth makes contact there is a low stiffness and high bending in the mesh. That's because here, point 3 is a point of really low stiffness/high leverage at the soft tooth). Therefore for a geartrain in which plastic is the driver, the impact when the next teeth are coming into contact is much higher than when metal is the driver. In this case a tip modification at the metal gear has to be defined relatively large and carefully — to avoid both excessive noise generation and pressure-related failure modes.

Therefore some practical tests were performed regarding the following points:

- Effects of different materials
- Effects of tip modifications
- Effects of changed overlap ratios and loads

Test Rig and Test Gears

For the tests a given test rig was used with given IMS-test gears, but also with specially modified test gears, i.e. — injection-molded parts as well as machined parts were also tested. The injection-molded parts have the benefit of being very close to serial-like production, whereas the machined parts have the benefit of making different geometries possible without too much effort. At the same time, the influence of toothing errors is not so high for the machined parts, since the achievable accuracy is much higher. To avoid misinterpretations, there was also a comparison between machined and injection-molded parts with the same geometries.

Tables 1 and 2 show some of the geometric data of the test gears. For the helical gears, different axial overlap ratios were reached by changing both the tooth width and the helix angle. The examples shown later have changed overlap ratios by modification of the helix angle.

The used test rig is, as shown (Fig. 4), a test setting with three gears in a mesh, whereas the plastic gear represents the intermediate wheel. The powertrain consists of an electric motor (servo synchronous motor), which transfers the power to the input side of the gearbox. A planetary gear transmits the torque. An incremental rotary encoder detects the rotation speed and angle. On the output side of the gearbox you can find a magnetic-powder brake, which applies the load; a torque gauge measures the torque (Ref. 1).

Table 1 Geometry data. spur toothed test gear (Ref. 1)

	Plastic gear	Metal gear
Number of teeth [-]	38	39
Normal module [mm]	1.46	
Normal pressure angle [mm]	20	
Tooth width [mm]	11.5	11.5

Table 2 Geometry data. helical toothed test gear (Ref. 1)

	Plastic gear	Metal gear
Number of teeth [-]	36	36
Normal module [mm]	1.46	
Normal pressure angle [mm]	20	
Helix angle [mm]	23	
Tooth width [mm]	11.5	11.5

The software of the modified wear-test stand allows an operation on a defined rotation speed and torque with rotation speeds up to 300 rev/min used. For the acoustic tests, additionally a ramp-up of the speed was implemented to start the measurement at zero speed, perform a ramp up and then measure also at a steady state speed (Ref. 1).

Acceleration sensors of a mobile acoustic measurement station register the structure-borne sound at significant places. The incremental rotary encoder delivers the necessary speed information needed for the analysis. The analysis leads to a statement about the noise generation caused by the gear in case of different geometric and system parameters. It is also a statement about the equality of the movement translation given.

The test assembly includes a multitude of noise-generating machine elements. A frequency analysis is carried out to the time signal of the acceleration sensors to differ the part of the signal that is really generated by the tested gear set.

Because the additional effort was marginal, sensors are placed at several locations. The best results have been delivered by the bearing point sensor; it's the closest possible point to the test gearing (sensor position shown in Fig. 4).

As shown in the subsequent figures, the toothing entering frequency is clearly visible, although the gear box is really solid. The frequency is also not in the range of interference frequencies caused by test stand components (for example the planetary gear).

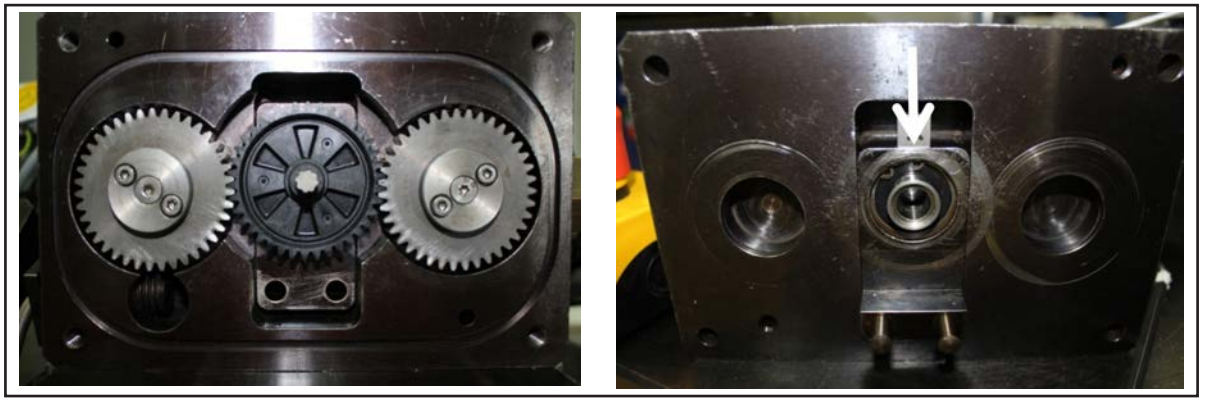


Figure 4 Test setup (left) and position of the solid borne sound sensor (Y-direction) (Ref.).

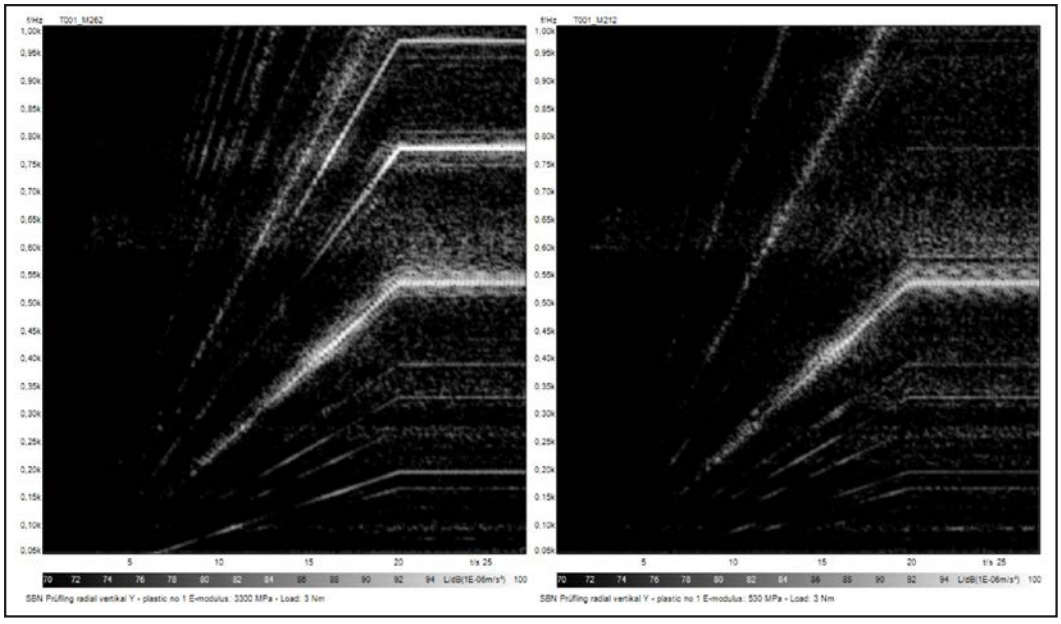


Figure 5 Plastic with higher Young's Modulus (left, 3,300 MPa) vs. plastic with low Young's Modulus (right, 530 MPa) in a steel-plastic-steel gear mesh.

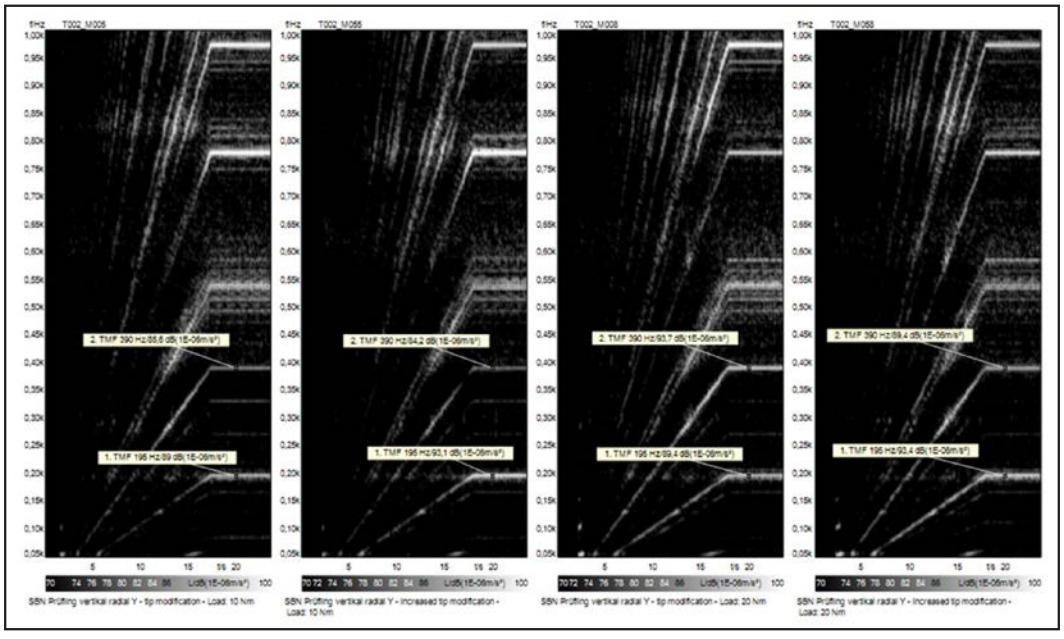


Figure 6 Comparison of parts with smaller modification (chart 1 and 3 from left) and bigger tip modification (chart 2 and 4 from left) at different torques (left: 10 Nm, right: 20 Nm).

Testing Results and Comparison with FEA

All the shown measurements were done as a speed-up test and then, afterwards ran with a constant frequency for some seconds. Here it can be measured the intensity of the structure borne noise at the meshing frequency and also their harmonics.

As shown (Fig. 5), two non-reinforced plastic materials were tested and shown as FFT versus time in a Campbell diagram. At the left side, a material with a Young's Modulus of app. 3,300 MPa was tested, at the right side a material with app. 530 MPa. The load was relatively low with 3 Nm. As can be seen, the less stiffer material didn't create so much noise. Additionally, for the low stiffness material, the missing high sound levels at the harmonic frequencies are noticeable compared to the stiffer material. This can probably be caused by better damping and a less stiff impact, which generally leads to less acoustic excitation of the higher harmonic frequencies.

As shown, there were also some tests performed with different tooth tip modifications. The result was that for both types of modification the torque level had just a small impact on the sound generation at tooth meshing frequency, whereas the 1st harmonic was strongly affected by the torque level. Generally, the smaller modification generated less noise at tooth meshing frequency but more noise at the 1st harmonic. A possible explanation of this behavior is that the modification was made at the plastic gear tooth tip. Therefore, it has especially a benefit at the gear mesh, were steel is the driver (plastic tip is in touch for the tooth meshing impact), which

is even more a benefit at higher loads and therefore higher deformations. Since the test setting is a three gear mesh, the plastic gear at the same time is the driver for the output steel gear. In this stage, the modification is not a benefit, but a disadvantage, since here at first the tip of the steel gear meets with the root of the plastic gear, causing the consequences written in the paragraph above. Here, the stiffness right before the tip impact is reduced and therefore the impact is more energetic. Generally, at this mesh the tip modification is causing smaller transverse contact ratios. The hypothesis is that at this specific gear set, the mesh with the output metal gear is causing more noise because of the worse tip impact situation. Therefore the modification of the plastic tip causes more noise at this frequency. The input metal gear mesh with the plastic gear is softer and has the lower impact stiffness, causing less noise. The influence of this stage can be seen more at the 1st harmonic, since the tip impacts of both stages don't happen at the same time (there is a slightly triangular setup of the gears). Therefore the 1st harmonic is positive influenced by the tip modification with increasing benefit for higher torques. However, regarding this topic, there have to be more tests done for further investigation.

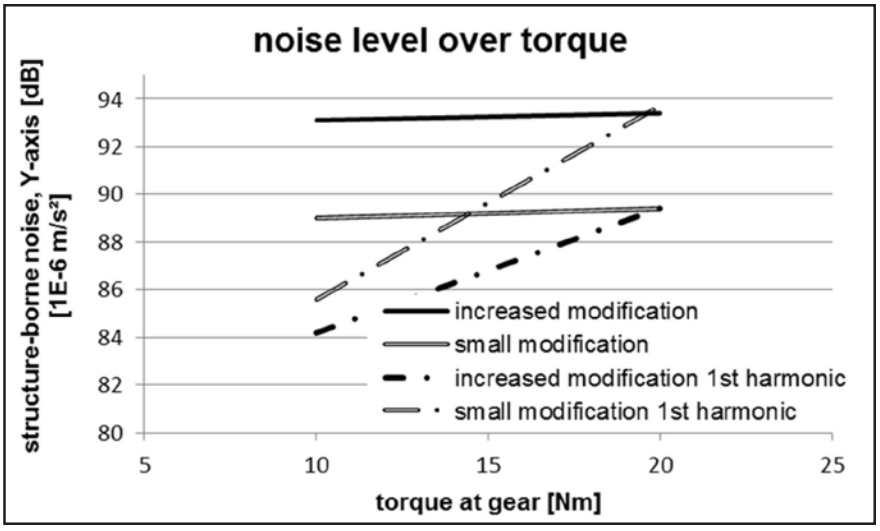


Figure 7 Results of Figure 6 as chart of the structure-borne sound of the tooth meshing frequency and the 1st harmonic.

The above Figures 8, 9 and 10 show the results of some tests as well as the FEA results regarding this topic. As it can be seen, for the parts with the overlap ratio of 1 (theoretically, un-deformed) the noise level is getting higher with higher torque levels. For the 0.8 overlap ratio parts, there is just a very minor increase until mid-level torques and then even a small drop. If you compare this results with the additionally performed FEA, it can be shown that overlap ratios for the parts starting at an un-deformed ratio of 0.8 increase up to 1.8 if deformation is taken into account. If you think of the

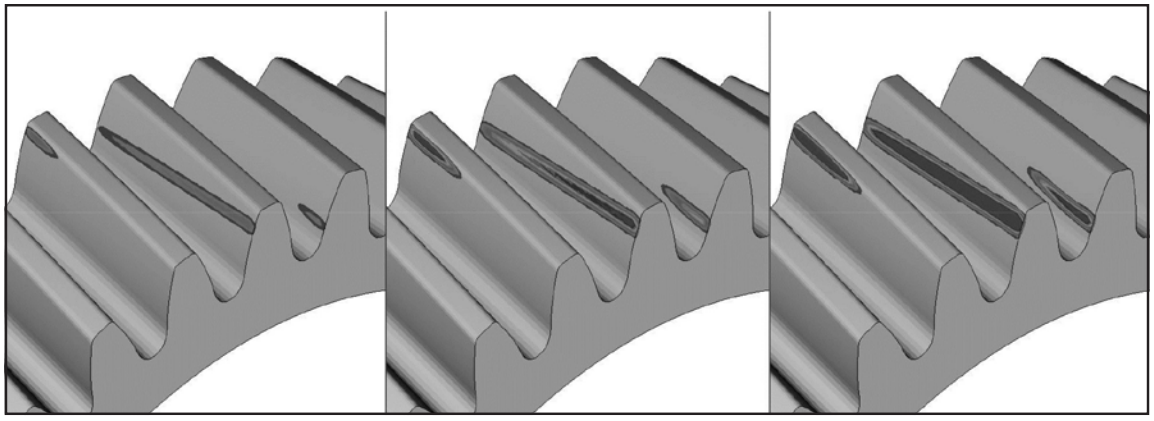


Figure 8 FEA results at different torque levels showing the deformation-induced increase of axial overlap ratio from 0.8 (un-deformed up to 1.8 at max. load).

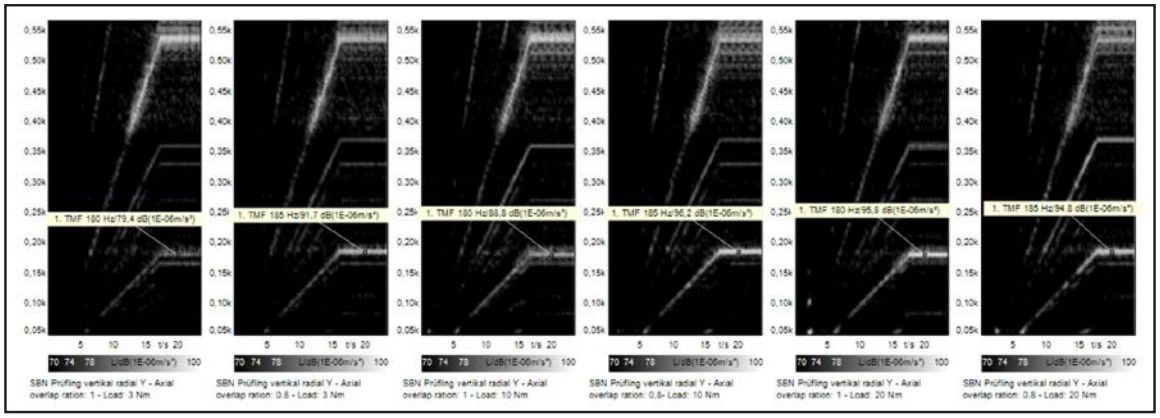


Figure 9 Comparison of parts with un-deformed overlap ratio 1 (chart 1, 3, 5 from left) un-deformed overlap ratio 0.8 (chart 2, 4, 6 from left) at different torques (from left to right: 3 Nm, 10 Nm, 20 Nm).

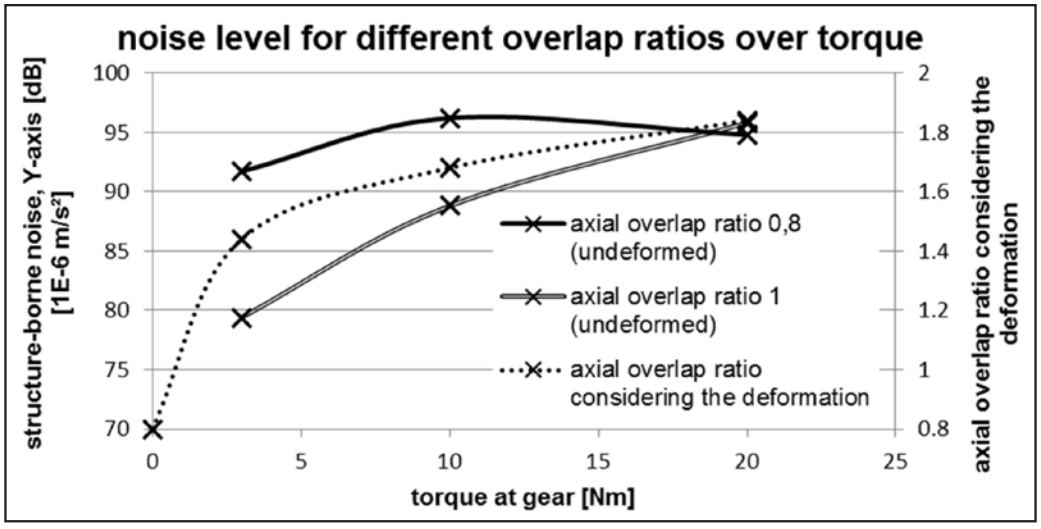


Figure 10 Results of Figure 9 as chart of the structure-borne sound of the tooth meshing frequency over the torque combined with the FEA results for axial overlap ratios considering the deformation.

parts starting with an overlap ratio of 0.8, this means that they were pushed to overlap levels which can be theoretically seen as optimum regarding stiffness variations of the mesh. The parts starting with an un-deformed overlap ratio of 1 will be pushed away from the optimum. As mentioned before, for steel, the optimum would be an axial overlap ratio given as an integer. However, for the plastic gears, both the measurement as well as the calculations show that you have to take into account the deformation-driven change of the overlap ratio to find your optimum. It is likely that the optimum will not be exactly at the even number for the deformed axial overlap ratio but near this number. The reason for this might be that the prolongation of the path of contact happens mainly at the start and the end of it. Therefore in this situation some positions of the teeth representing spring stiffness will be more often in contact or longer in contact than others.

Conclusion

If it comes to a gear mesh which includes plastic, deformation effects have to be taken into account carefully. Some indications regarding the design for an acoustical optimized gear train which are valid for steel can change apparently a lot if you try to transfer them to a gear mesh including plastic. However, at least some of the observed differences are no longer principle ones if you take into account the deformation while checking basic parameters of the mesh like overlap ratios. Therefore there are some basic indications:

- Generally take into account the high deformations at the teeth while evaluating the mesh
- For a plastic — metal or plastic — plastic mesh the deformation under load has to be taken into account while defining optimized tip modifications.
- Under load transverse contact ratios tend to increase. This effect gets bigger when it comes to softer materials, higher loads or higher temperatures.
- Because of this, the theoretical optimized overlap ratio for the un-deformed mesh has to be lower for optimizations regarding higher loads, temperatures or softer materials.
- For plastic, the even number is not always the best value to start with for an un-deformed overlap ratio, since ratios increase under working conditions.
- Plastic materials with smaller Young's Modulus may have better damping, but deformation could be a problem
- Especially for driving/driven situations for a metal gear mesh (high stiffness variation) balancing out the tip modifications is crucial **PTE**

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Fatigue Life Prediction of Spherical Gear Couplings

Ibai Ulacia, Jon Larrañaga, Aitor Arana, Aurea Iñurritegi, and Julen Elizegi

Introduction

Classical coupling load models, still in use, assume a number of teeth in contact for a certain amount of misalignment. However, these models do not account for the tooth stiffness, applied torque or manufacturing errors, which produce a sequential engagement of spline teeth. Therefore stresses could be overestimated and thus fatigue life predictions are rendered inaccurate. Recently, several studies have been performed in order to account for tooth stiffness and tooth spacing errors of such couplings. However, they were only applied in relatively small misalignments (approx. up to 1 degree), compared with the case studied in this research (up to 7 degrees).

In this work a numerical model has been developed in order to predict the fatigue life of highly crowned spline coupling geometry. First, the number of teeth in contact has been evaluated for different misalignment and torque conditions. Next, the fatigue life predictions have been calculated based on the numerically obtained stresses. Finally, fatigue tests have been performed in order to validate the developed methodology. It is observed that the numerically estimated cycles to fatigue failure are close to the experimentally measured fatigue life.

Spherical gear couplings (also known as crowned spline couplings) are mechanical components that allow transmitting torque by means of equally spaced teeth. Moreover, apart from transmitting the driving torque, they also permit accommodation of angular misalignments between the connecting shafts by means of crowned teeth. Spline teeth are very similar in geometry to gear teeth in that the contacting surfaces are defined in both cases by an involute curve or profile. The basic tooth geometry is also defined by three parameters: pressure angle, number of teeth, and module. Standard splines (ANSI B92.2M or ISO 4156) use pressure angle values of 30°, 37.5°, or 45°. However, in special applications where high misalignment is present and the coupling must allow certain axial sliding, smaller pressure angles are also used (14.5°, 20°, or 25°). In the case of the spline couplings used in roll leveling machines and studied in this research, a pressure angle of 30° is selected in order to decrease frictional forces. These spline couplings are also characterized by their spherical shape and the high amount of crowning.

One of the main differences between spline couplings and gears is that, in spline couplings, the load is shared among several teeth while in gears it can be divided between 2 or 3 teeth (Ref. 1). What's more, in aligned conditions the whole tooth flank surface is in contact, while in misaligned conditions only part of the tooth width is in contact, generating a complex load behavior (Ref. 2).

During the dimensioning of a spherical gear coupling the following stresses are calculated: 1) shear stresses in spline teeth (τ_s); 2) bending stresses in teeth root (σ_b); and 3) contact stresses in spline teeth (σ_H). The following equations are generally accepted for such calculations (Ref. 1):

$$\tau_s = \frac{4 \cdot T_n}{d_p \cdot z \cdot C \cdot b_{ef} \cdot \frac{\pi \cdot m}{2}} \quad (1)$$

$$\sigma_b = \frac{12 \cdot T_n \cdot \cos\alpha}{d_p \cdot z \cdot C \cdot b_{ef} \cdot S_f^2} \cdot \frac{d_p - d_i}{2} \quad (2)$$

$$\sigma_H = \sqrt{\frac{2 \cdot T_n}{d_p \cdot z \cdot C \cdot h \cdot \rho} \cdot \frac{1}{\pi \cdot \left(\frac{1-\upsilon_1^2}{E_1}\right) - \left(\frac{1-\upsilon_2^2}{E_2}\right)}} \quad (3)$$

where T_n is the applied torque to coupling; d_p is the pitch diameter; d_i is the internal diameter; z is the number of teeth; C is the ratio of the number of teeth in contact; b_{ef} is the effective facewidth; m is the module; α is the pressure angle; h is the tooth height; ρ is the radius of curvature of the crowned tooth; E is Young's modulus; υ is Poisson's ratio (subscripts 1 and 2 refer to hub and shaft), and S_f is the transverse tooth thickness at the root form.

The value of the number of teeth in contact (C) and the effective facewidth (b_{ef}) is not straightforward. In all the cases, the number of tooth in contact is an estimated parameter that increases the stress value as the misalignment is increased. Early coupling load models, but still used when designing such couplings, assume a number of teeth in contact for a certain amount of misalignment (Refs. 1, 3–4). However, these models do not account for tooth stiffness, applied torque, or manufacturing errors — which produces a sequential engagement of spline teeth. Therefore, stresses can be underestimated and thus fatigue life predictions are inaccurate. Recently, several studies have been performed in order to account for tooth stiffness and tooth spacing errors (Refs. 5–8). However, they were only applied in relatively small misalignments (approx. up to 1°), comparing with the case studied in this research (up to 7°).

Therefore, in this work, a numerical model of spline coupling, a case study has been developed in order to predict

fatigue life of highly crowned spline coupling geometry. First, the number of teeth in contact has been evaluated for different misalignment and torque conditions. Then, the fatigue life predictions have been calculated based on the numerically obtained stresses. And finally, fatigue tests have been performed in order to validate the developed methodology.

Numerical Model of Spline Coupling

Spline coupling geometry. The spherical spline coupling selected for the case study has 13 teeth, 3 mm module and 30° pressure angle (ISO 4156). The circumferential backlash in aligned conditions is 2°. The pre-form part of the spline coupling (Fig. 1) is $d_b = 40$ mm, l = 25.7 mm, $r_1 = 37$ mm y $r_2 = 21$ mm.

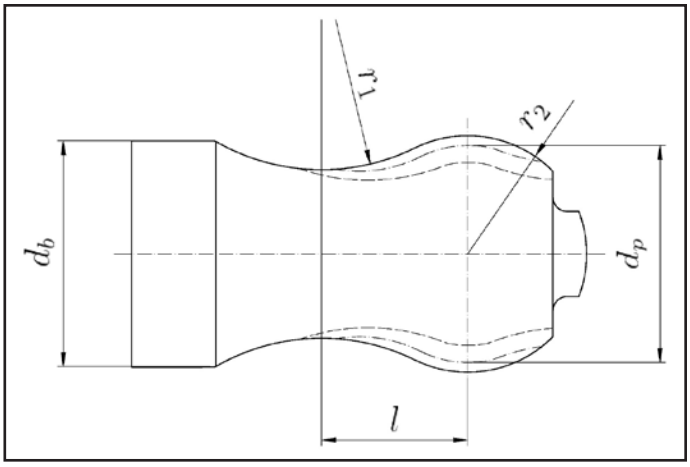

Figure 1 Spherical spline coupling geometry.

Carburized and quenched 15NiCr11 steel material has been employed to manufacture the spline coupling with a minimum hardness of 54–56 HRc, 735 MPa of yield stress, 1010 MPa of ultimate stress, and a fatigue limit of 520 MPa. A linear elastic material model was used with 210 GPa Young's modulus and 0.33 Poisson's modulus.

Mesh. In order to develop the numerical model, the geometry of the spline coupling (external and internal splines) has been scanned using a 3D coordinate measuring machine (Mitutoyo BHN710 with a 0.75 mm pointer). The surface of the spherical spline coupling has been scanned, followed by an automatic meshing procedure that has been developed using the previously scanned points (Fig. 2).

Boundary conditions and case studies. Additionally, rigid connectors have been introduced between the external toothing (crowned teeth shaft) and the center of the spherical part of the spline coupling in order to apply the tilting boundary condition. Similarly, rigid connectors have also been introduced between the end of hub (internal teeth part) and a coaxially located point in order to apply the torque (Fig. 2).

Two different load cases have been defined in the FEM model. In the first step, the internal spline coupling (hub) is maintained (constrained) and the external spline coupling (shaft) rotates to reach the selected misalignment. In the second step, the shaft is constrained and torque is applied to the hub. The contact condition is computed in both steps.

Thirty-two different conditions have been analyzed: 4 different loads (250 Nm, 500 Nm, 750 Nm and 1,000 Nm) and 8 misalignments (0°, 1°, 2°, 3°, 4°, 5°, 6° and 7°).

Fatigue Life Prediction

The spline coupling experiences cyclic bending stresses on the tooth root when it is rotating, starting unloaded (null bending stress), then loaded to the maximum stress level, and finally unloaded to start the next cycle, which corresponds to $R = 0$ fatigue case. The mean stress is considered to be the half of the maximum stress. Moreover, it must be considered that in every revolution, each tooth suffers two loading cycles (Ref. 9). Therefore, the equivalent fatigue stress (σ_{eq}) is calculated after the Goodman criterion (Eq. 4):

$$\frac{\sigma_a}{\sigma_{eq}} + \frac{\sigma_m}{\sigma_u} = 1 \tag{4}$$

being σ_m the mean stress, σ_a the alternating stress (also known as the stress amplitude, is the difference between the peak stresses and the mean stress) and σ_u the ultimate tensile strength (1010 MPa (Ref. 10) in this study).

Once the equivalent stress is calculated, fatigue life can also be estimated from the corrected material's S-N curve (or Wöhler curve). The material's S-N curve is corrected by the component fatigue correction coefficient. For the case study, a fatigue correction coefficient of 0.77 has been selected after the combination of the different factors shown in Table 1.

Table 1 Fatigue coefficients (Ref. 11)

C_s: Surface finish	0.7 (machined)
C_d: Size and geometry	1 (small)
C_t: Working conditions	1.25 (bending)
C_f: Reliability	0.89 (90%)
C_m: Surface treatment	1 (none)

In the present work, the material curve for carburized steel with a fatigue limit (σ_{lim}) of 520 MPa for $2 \cdot 10^6$ cycles (Ref. 10) has been used (Eq. 5).

$$\sigma(N) = \sigma_{lim}\left(\frac{ND}{N}\right)^{\frac{1}{K}} \tag{5}$$

where N is the number of cycles; ND is the number of infinite fatigue cycles ($2 \cdot 10^6$ cycles); and K is the Basquin exponent of Wöhler's curve (in this case $K = 6$ (Ref. 10)). Additionally, in

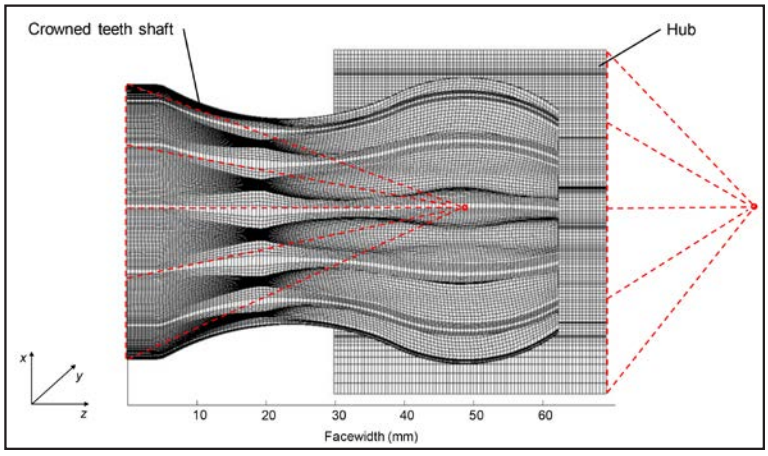

Figure 2 Spherical gear coupling's numerical FEM model.

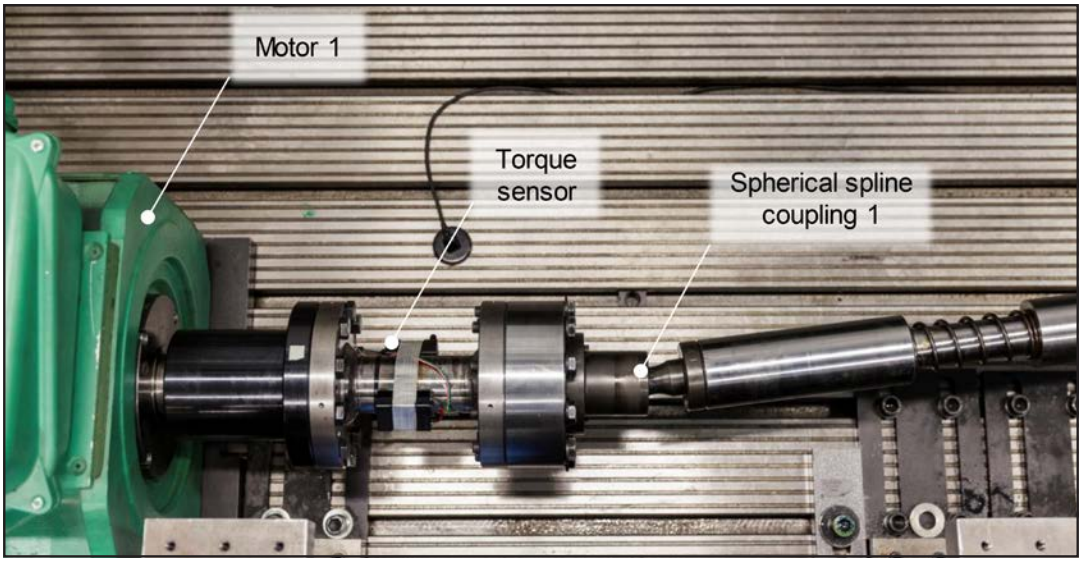

Figure 3 Fatigue test spherical gear coupling test bench.

order to compare other fatigue criterion, classical expressions have also been used to estimate the S-N curve of the material: $\sigma_{lim}(N=1e6) \cong 0.5 \cdot \sigma_u$ and $\sigma(N=1e3) \cong 0.9 \cdot \sigma_u$ (Ref. 11).

Experimental Procedure

Fatigue life tests of the spherical gear couplings have been carried out on a test bench composed of two Leroy Somer CPLS200M0608 electric motors of 176 kW (N_{max}: 8,000 rpm; $Torque_{max}$: 1.2 kNm): one working as an actuator and the other as a brake (i.e. working respectively in speed control and torque control).

In each test two spherical gear couplings have been tested; the selected misalignment for the fatigue tests was 7° (Fig. 3). During the tests, the applied torque has been measured by means of a torque sensor (TorqueTrak 10K) and the temperatures of the two couplings have been acquired by K-type friction thermocouples.

The validation tests of the spherical couplings have been carried out at 900 Nm and 600 Nm. At these conditions, the torque that causes a stress state close to the yield limit of the material and close to the infinite fatigue life condition respectively (as it will be commented in the results section with the stress prediction). All the tests have been carried out at 200 rpm to avoid excessive heating of the spline couplings and the selected lubrication was NLGI 2 consistency grease with EP additives of 140 cSt viscosity at 40°C to minimize wear of spline couplings, as it was observed in a recent work (Ref. 12). Four repetitions were carried out in each condition.

In order to identify the failure of the spherical gear coupling, each specimen has been inspected every 10^5 cycles (and when any abrupt variation of torque or temperature was detected).

Results

Number of teeth in contact. The contact status of the finite element model has been analyzed in order to determine the number of teeth in contact for each condition. Figure 4 shows a comparison of the computed *C* values (ratio of the teeth in contact) at different torque and misalignment conditions with values from literature.

It can be observed that by increasing the misalignment, the ratio of the number of teeth in contact decreases while it increases the torque; this result is in accordance with previous observations (Ref. 5). However, if the results are compared with literature values used for analytical calculations, it is seen that the latter are lower, which turns in overestimation. It is also remarkable that due to the geometry and the initial clearance, all the teeth are in contact up to a misalignment of 3° for the highest torques.

It can also be observed that the number of teeth in contact is torque-dependent. In all the misaligned conditions, the number of teeth in contact increases with the torque. This effect is not taken into account by the classical methods, which in turn results in an overestimation of the predicted stress. Classical methods do not consider the tooth stiffness, and that is why they do not update the ratio of the number of teeth in contact with respect to the applied torque.

Tooth root stresses. Figure 5 shows the contour map of the Von Mises stresses for all the teeth (1 to 13) and misalignments (0° to 7°) at 250 Nm (this torque condition was selected

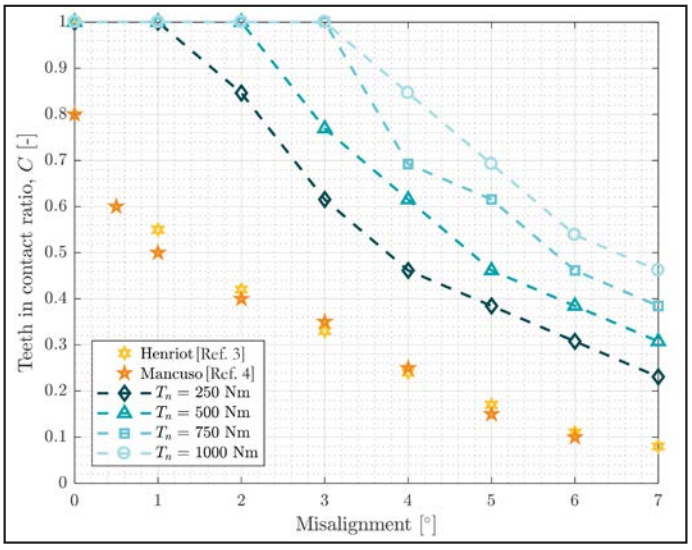

Figure 4 Numerically estimated ratio of the teeth in contact (C) and reference values (Refs. 3–4).

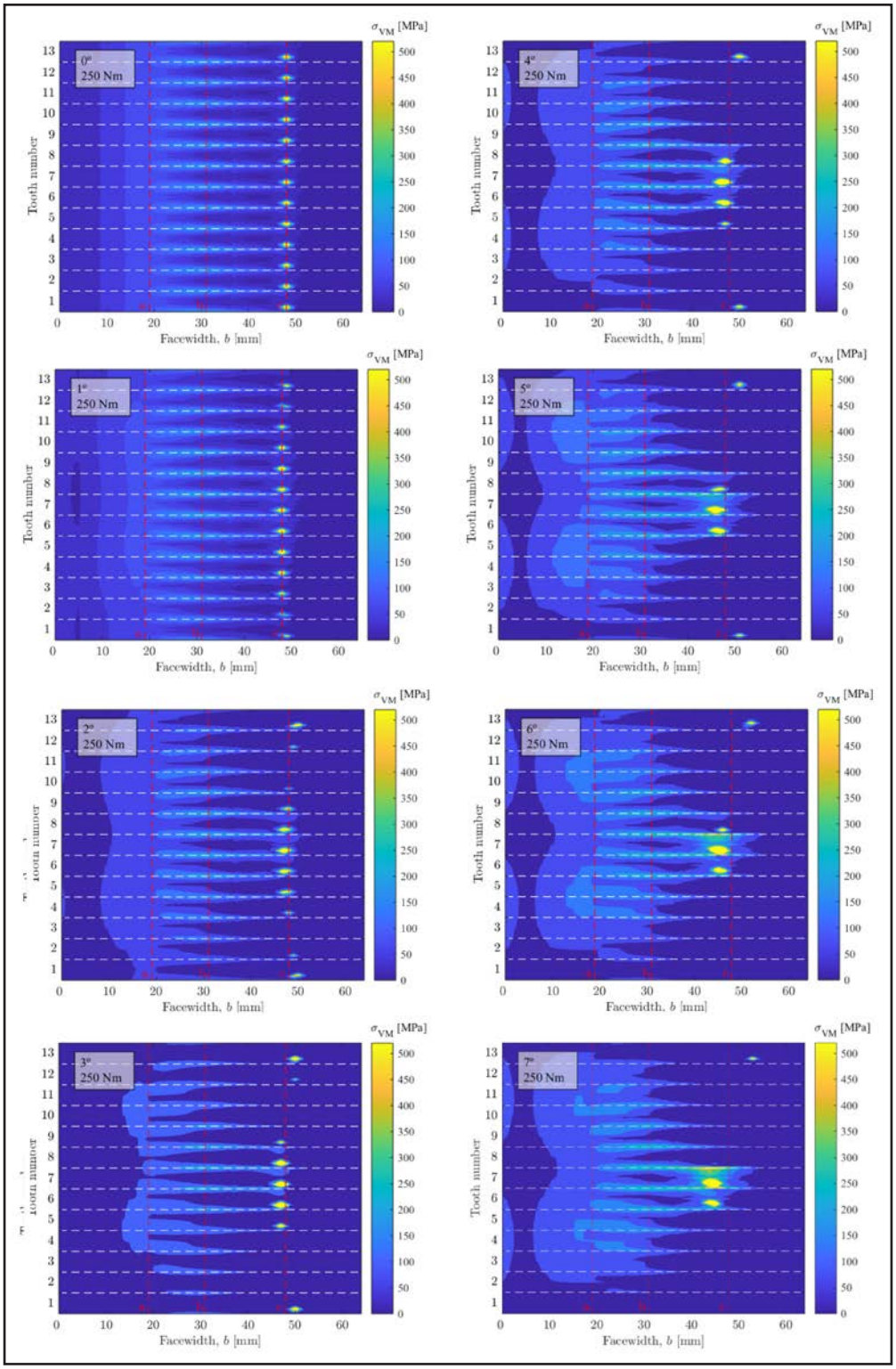

Figure 5 Stress distribution at 250 Nm for different misalignments (1°–7°).

since it shows the highest variation of teeth in contact and it is also representative for the other cases).

The number of teeth in contact (C) varies according to the misalignment, as mentioned in the previous section. The stresses of the teeth in contact are not equal, showing that the contact conditions are different in all teeth in contact. Anyway, these results only show a single loading state and teeth pass through all the situations during a whole rotation.

It can be observed that the contact point (where the maximum contact stress is computed for each tooth) moves away from the reference plane (located approx. at 49 mm), and that the distance moved by the contact point is increased when misalignment is increased. Due to this effect, two different contact zones can be recognized in spline couplings working at large misalignments conditions.

On the other hand, tooth root stresses are only present until

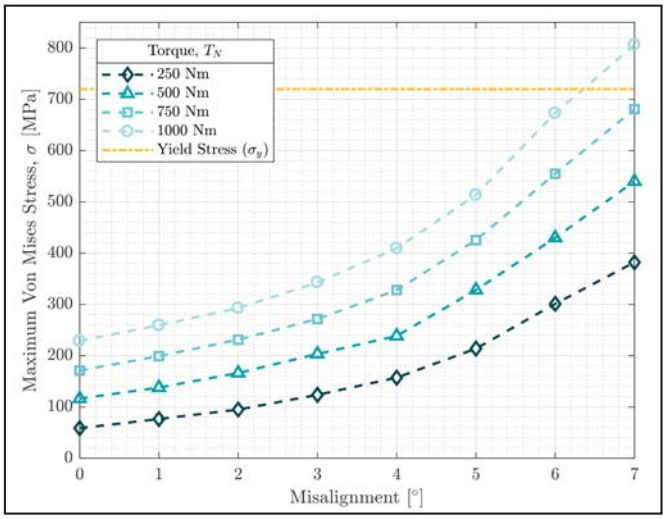

Figure 6 Maximum stress on the tooth root under different misalignment and torque conditions.

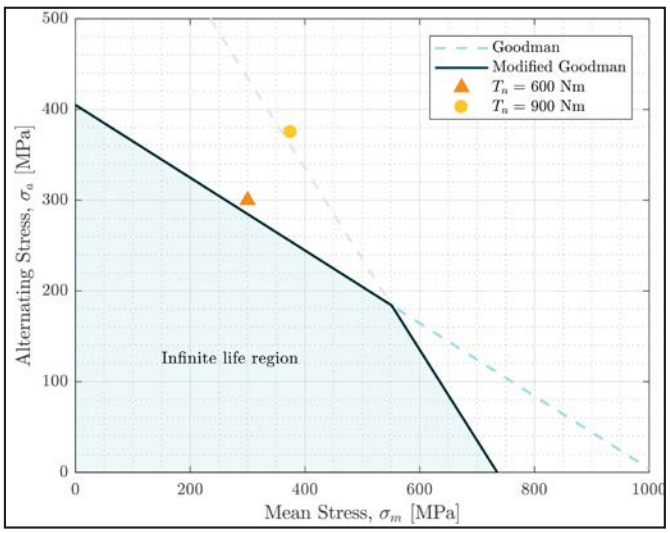

Figure 7 Haigh's diagram showing the modified Goodman relation for infinite life and the stress states of the experimentally tested conditions.

Figure 8 Teeth failure of the experimentally tested spherical gear couplings due to bending fatigue.

the contact point (reference plane), decreasing abruptly after such point. This effect has a direct influence on the estimation of the effective facewidth (b_{ef}), since it is dependent on the misalignment. Finally, it is also observed that the critical section of the coupling is located approximately at 31 mm, where the maximum stresses are placed. Therefore, this area is susceptible to producing a crack initiation that will cause fatigue failure.

Figure 6 shows the maximum stresses on the tooth root under different misalignment and torque conditions. Those stresses have been later used to calculate the fatigue life following the procedure described earlier in this paper.

Fatigue life. Figure 7 shows Haigh's diagram with the modified Goodman relation establishing the infinite fatigue life region for this component. It can be observed that experimentally tested conditions (600 Nm and 900 Nm) are close to the infinite life region and the yield stress of the material respectively, i.e. — covering a broad range over the possible test conditions for considering high cycle fatigue. This is why these two conditions have been selected for the experimental validation of the developed model.

Figure 8 shows a broken spline coupling after a fatigue test performed at 600 Nm and $3.6 \cdot 10^5$ cycles. It can be stated that the coupling failure is clearly due to fatigue, as demonstrated by the signs of crack initiation and propagation. As it has been observed in the stress maps, the crack nucleates near the tooth starting area, which is the point where the highest stress concentration takes place (Fig. 5).

Figure 9 shows the experimentally obtained results for the calculated equivalent stresses (at the test conditions), together with component's S-N curves (obtained from the literature and using the classical theory of fatigue). It could be clearly stated that life predictions, considering stresses obtained with the finite element models, fairly represent the experimentally obtained results:

- In the case of 600 Nm, the prediction is $3.41 \cdot 10^5$ cycles, while testing failure is in the range of $2.7 \cdot 10^5 - 3.92 \cdot 10^5$ cycles.
- In the case of 900 Nm, the prediction is $1.64 \cdot 10^6$ cycles, while testing failure is in the range of $1.29 \cdot 10^6 - 1.65 \cdot 10^6$ cycles.

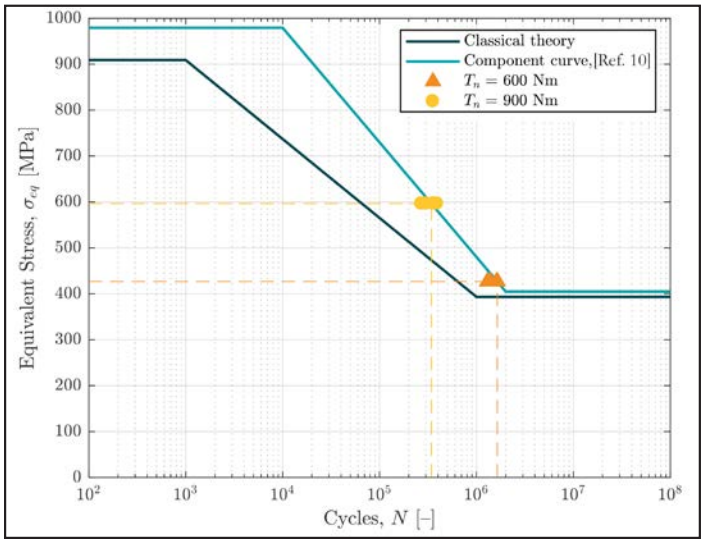

Figure 9 S-N diagram of the component and fatigue test results of the spherical gear couplings.

Conclusions

- In the present work, a finite element model has been developed to predict the stress state of a spherical gear coupling which has been then used to calculate the fatigue life of the component. The main conclusions drawn from the study are listed as follows:
- The number of teeth in contact has been determined for various misalignment and torque conditions. It has been found that it clearly depends on the misalignment and the applied torque as a consequence of the tooth stiffness.
- The values for the number of teeth in contact used in classical analytical calculations underestimate the actual teeth in contact (for the studied highly crowned geometry), which then results in an overestimation of the calculated stresses.
- Increasing the misalignment, the contact point moves away from the reference plane. Therefore, two contact zones can be clearly identified (also in experimentally tested specimens), affecting the effective facewidth suffering the applied torque.
- The experimental fatigue tests have shown a fair correlation with the numerically estimated predictions based on the stresses calculated with the use of finite element models.
- The fatigue crack initiation could be observed in the couplings tested, which corresponds to the position of the maximum stresses at the tooth root of the finite element models. **PTE**

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Improperly Testing Belt Tension Can Easily Damage Small Motors

Don Labriola, Labriola, Quicksilver Controls, Inc.

Most of us want to just instinctively squeeze a belt between a pair of pulleys to test the belt tension. What is not as instinctive is just how much force such a procedure can put on the shaft — often significantly past the manufacturer's rated limits for small motors. This can cause damage to both the shaft and the bearings.

First a diagram (Fig. 1) and a little math. The force calculations are not dependent on the diameter or spacing of the pulleys, but let's assume the pulleys at a spacing of 4 inches (100 mm) for other parts of the discussion where we calculate deflection.

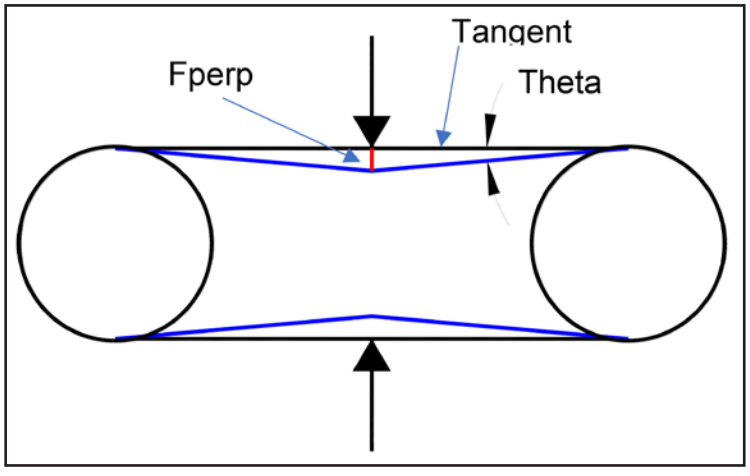

Figure 1 Force calculations.

For a 5-pound squeeze (22N) and a 5 degree angle (0.139 radians), the tangent is 0.132. (or approximately the angle in radians, if you still remember your old-math, small-angle approximations). This says the tangent force from each side is 7.6× larger than the applied squeeze, and both sides contribute to the pull on the shaft; so both shafts see 15.2× the squeeze (half of which is counteracted by the belt to the left and half to the right) — or about 38 pounds" (170 N) of compression. The 5 degrees deflection corresponds to approximately 0.26 inch (6.6 mm) of deflection on each side.

But you say I would not squeeze that hard, more like one pound (4.4 N). So, let's linearize and estimate that the deflection would be about ⅕; so the angle would be only 1 degree. The deflection of each belt would then be about .05" (1.3 mm) — that should not be so bad.

Well, the deflection is now .0262 radians, and Tan (.0262) = .0262 (to 3 significant places), so the force multiplier is now $1/_{.0262}$ or 38.2×. When accounting for both sides of the belt, this is now a multiplier of 38. The unexpected result is that with this lighter force and the smaller deflection, it is still putting almost the same enormous force between the two shafts!

While there was an assumption of linearity of deflection to simplify the calculations — and this is not a perfect assumption and the width of the force application is also not infinitesimally small — but this order of magnitude calculation (given the force and the deflection) is still fairly close. This should cause one to pause to think before you pinch! — especially if you are working with small motors having ¼ inch or smaller shaft diameters. A typical NEMA 17-frame motor specifies no more than 6.2 lbs at .78 inches (28 N 20 mm) from the flange, while a NEMA 23 calls out 17 pounds" at .78 inches (75 N 20 mm) from mounting flange. In both of these cases, the 38 pounds" (170 N) would be well in excess of the motor ratings, bending shafts and or damaging bearings.

A much better way to actually *set* a calibrated belt tension is to provide a metal "sled" holding the motor to which you can attach a fish scale or a known hanging weight (around a pulley if you want a side force). Set the tension, tighten the screws; belt tension is now set to a

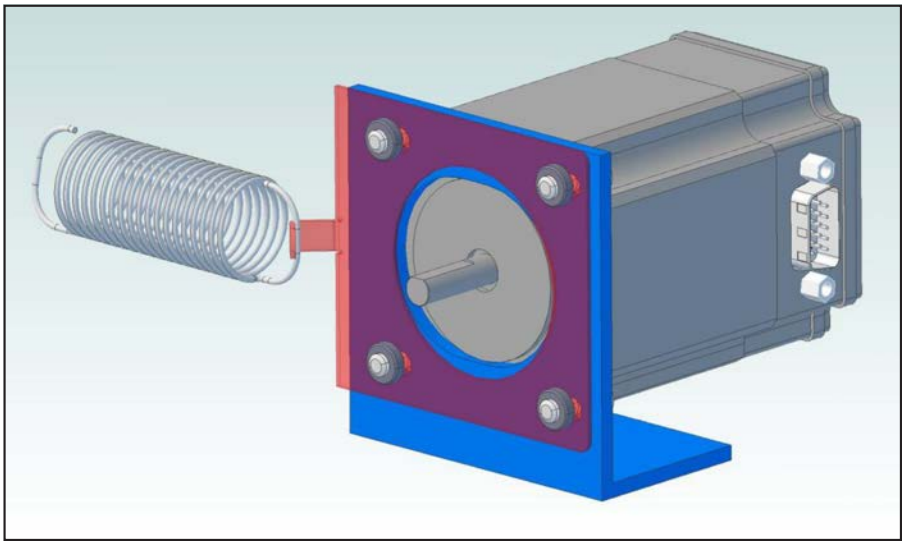

Figure 2 This drawing shows the tensioning plate as semi-transparent only to allow the mounting plate behind it to be seen. This would normally be made of metal. The fish scale is shown as a spring; it is only present while setting the belt tension. After tightening the screws, the spring/scale is removed.

known and repeatable level. This gives your servo systems more repeatable servo tuning, while not accidently damaging shafts or bearings. An example drawing of such a motor "sled" is shown at *www.quicksilvercontrols.com/SP/TD/QCI-TD076_Belt_Tightening.pdf*.

QuickSilver Controls produces compact, high-performance integrated servo motors and controllers and provides assistance in applying them to customer systems.

Disclaimer: As usual with free advice, do not depend on these calculations for your critical designs. Perform these calculations yourselves and/or make the appropriate measurements. The author takes no responsibility for any errors or omissions. The information is only provided for your entertainment and insight into possible issues. **PTE**

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Donald P. Labriola II, president and founder of QuickSilver Controls, Inc., specializes in servo controllers and motors, with a special focus on cost-effective motion control. He has been granted eleven US patents as well as numerous international patents. His background includes over 40 years of motion control including 20 years in medical instrument design. He enjoys gardening, camping and Ham radio — and motion control!

Motion Industries

NAMES NEW PRESIDENT

Motion Industries, Inc. has announced the promotion of **Randall (Randy) P. Breaux** to president on December 12, 2018.

"Randy has an impressive history, having served in numerous management roles during his career," said Paul Donahue, Genuine Parts Company president and CEO. "His extensive experience in both industrial manufacturing and distribution, which includes his sales, marketing, and corporate background, make him an excellent choice to lead Motion Industries. We feel confident that we will continue to see great things from our talented and experienced Motion team under Randy's leadership."

Breaux was most recently executive vice president of marketing, distribution, and purchasing for Motion Industries, and has nearly four decades of experience in the industrial manufacturing and distribution markets. At Motion Industries, he has played a key role in setting corporate direction, strategic acquisitions, growing supplier relationships, advancing marketing activities and most recently overseeing corporate operations. He joined Motion Industries in May 2011 following 21 years with ABB/Baldor Electric Company, a leading manufacturer of industrial electric motors, drives, and mechanical power transmission components, based in Fort Smith, Arkansas.

Breaux joined Baldor in 1989, and held various sales and marketing positions in the company. Just prior to joining Motion, Baldor was acquired by ABB. At that time, he was promoted to vice president of integration by ABB, tasked with bringing the Baldor and ABB electric motor businesses together in North America. He served as Baldor's vice president of marketing from 2001–2011, played a key role in Baldor's acquisition of Dodge and Reliance Electric from Rockwell Automation in 2007, and served as an officer of the company for over 11 years. (*www.motionindustries.com*)

Heidenhain

OPENS NEW WEST COAST ETEL FACILITY

As the Silicon Valley in California and the West Coast continue to be the hub of the semiconductor manufacturing in the U.S., Heidenhain has expanded its motion systems support by establishing an Etel facility in Fremont, CA. This new 2018 office will provide product, service and support of its Etel motion systems designed specifically for that industry and others.

The Fremont office is an expansion of Heidenhain's San Jose, CA, office and provides warehouse space to keep multiple Etel motion systems on site. On display currently is an Etel Vulcano stacked platform motion system, the METIS planar platform, and a demo bench showing Etel single-axis solutions all operating using Etel's AccurET controls.

A cleanroom has been built at this Etel facility to simulate the expected working environment of its operation, and multiple Service Engineers are on hand to provide real-time support. A conference room space has also been established as a meeting area for visitors.

"The opening of this facility in 2018 has allowed Heidenhain to meet the needs of the high-tech and fast-paced nature of Silicon Valley that often demands immediate response and is yet another example or Heidenhain's Customer First initiative," said Daniel Wiseman, Heidenhain Motion System Sales Engineer. "And actually, area customers of all kinds can now walk-in and see motion systems in person. Plus, we can now provide on-site trouble-shooting more easily when required." (*www.heidenhain.us*)

Bell Helicopter and Moog

COLLABORATE ON FLIGHT CONTROL ACTUATION SYSTEM

Bell Helicopter, a Textron Inc. company, has announced a signed teaming agreement with Moog, for the development of the Flight Control Actuation System (FCAS) to support Bell's vertical take-off and landing (VTOL) aircraft and on-demand mobility (ODM) solutions.

"Bell continues to identify solutions and teammates that will achieve new possibilities together," said Bell's Scott Drennan, vice president of innovation. "Within this collaboration, Moog will ensure an advanced, fully integrated actuation system which will provide a safe, reliable and affordable solution for our aircraft."

As a global leader and visionary in the industry, Moog's innovative technologies will bring the design and integration of aircraft actuation systems for flight control to Bell's VTOL aircraft. Moog's experience allows for

systems that meet cost, performance, weight, and reliability requirements.

Ralph Elbert, group vice president and GM Moog Aircraft, stated, "We are absolutely delighted that Moog has been selected by Bell to partner on this exciting program to explore and develop the on-demand mobility market. Moog's role will include providing the all-electric, fly-by-wire actuators and electronics used to direct and control the aircraft's propulsion system and aero-surfaces."

In this collaboration, Bell will lead the design, development and production of the VTOL systems. Moog will lead the design and development of the flight control actuation systems which includes architecture, hardware and software needed for air vehicle flight control actuation management.

As previously announced, Safran will provide the hybrid propulsion systems and Garmin will integrate the avionics and the vehicle management computer (VMC) systems; EPS will provide the energy storage systems, and Thales will lead the flight controls system. (*www.moog.com*)

Schaeffler

PARTNERS WITH PLUG AND PLAY TO EXPAND U.S. STARTUP NETWORK

Global industrial and automotive supplier Schaeffler has entered into a partnership with Plug and Play, a Silicon Valley-based innovation platform that connects startups with established corporations and venture capitalists. Of the 14 industry-specific programs offered by Plug and Play, Schaeffler will focus on technologies from the Mobility and Internet of Things (IoT) verticals, while also keeping an eye on innovations coming out of Energy, New Materials & Packaging, and Supply Chain & Logistics.

"We are excited to engage with our new partners at Plug and Play, who give us a compelling new avenue to uncover trends and opportunities for advancing our 'Mobility for tomorrow' corporate strategy," said Prof. Dr.-Ing. Tim Hosenfeldt, Schaeffler's senior vice president for technology strategy and innovation. "Just as our recently launched 'in-house' startup Bio-Hybrid GmbH has invigorated our efforts to transform personal mobility, Schaeffler looks forward to connecting with the creative minds within external startups who can provide us fresh perspectives to help us meet the present and future needs of our automotive and industrial customers."

With over 20 locations worldwide, Plug and Play's ecosystem will help Schaeffler build on its renowned capacity for in-house innovation — which produced more than 2,400 new patents in 2017 alone — by partnering with external business enterprises and startups to uncover new technologies, products and processes as well as untapped market segments and customers.

"The partnership with Schaeffler brings a new perspective to our mobility ecosystem. We look forward to working closely with our new partners and to introducing them to new technology that supports their mission," says Sobhan Khani, vice president of Plug and Play's IoT, mobility, and real estate and construction programs.

Schaeffler's partnership with Plug and Play is the latest step in the company's mission to tap into Silicon Valley's deep reservoir of creative talent and innovative thinkers. Earlier this year, Schaeffler opened a new office in San Jose, California, whose staff has been tasked with fostering new relationships with potential technology partners and local disruptors to advance Schaeffler's corporate strategy that is dedicated to shaping "Mobility for tomorrow."

(*www.scaheffler.com*)

GE Power Conversion

PARTNERS WITH SULZER FOR PARTS, SERVICES, AND EQUIPMENT

In a move to increase services, parts and new equipment availability, minimize repair times, and reduce downtime, GE Power Conversion has signed an agreement with Sulzer, making it an authorized parts, new equipment, and service provider. GE electrical equipment, such as motors and generators, can now be maintained and repaired through Sulzer's extensive service center network.

Azeez Mohammed, CEO and president of GE Power Conversion, and Jim Mugford, president and global head of Sulzer's electro mechanical services, sign the deal.

As one of the world's largest independent maintenance specialists, Sulzer offers considerable expertise and experience in the repair of large rotating equipment. GE Power Conversion is taking advantage of the Sulzer repair facilities and extensive repair expertise, backed by the technical expertise and know-how from GE PC, to ensure that customers with GE equipment receive an unparalleled service.

The agreement between the two companies enables Sulzer to offer a wide range of services, including warranty work, that will ensure customers receive high quality repairs using original equipment manufacturer (OEM) parts. Sulzer will offer service center repairs as well as a range of field services, including installation, start-up assistance, troubleshooting, routine maintenance, testing and monitoring.

Jim Mugford, president and global head of Sulzer's Electro Mechanical Services, explains: "We are dedicated to providing a superior service to a range of industries. Our track-record in providing dedicated teams of on-site engineers to

deliver best-in-class solutions is second to none. Sulzer's expertise has been recognized by one of the leading manufacturers of electrical equipment, allowing us to offer OEM parts and services direct to the owner/operators."

Sulzer service centers are ISO 9001 certified, with the capabilities to offer complete rewinds, upgrades and engineering enhancements to ensure optimum performance and reliability in addition to performing site disassembly and installation. (*www.sulzer.com*)

Bonfiglioli

LAUNCHES ELECTROMOBILITY PRODUCTION LINE

Bonfiglioli has launched its new electromobility production line in Forlì, Italy.

The new unit — covering an area of about 10,000 square meters — was built in 12 months, and is entirely dedicated to the production of electrical axles for powertrain and wheel drives of different sizes. In this case as well, Bonfiglioli has built this new facility with an environmentally-friendly approach, by implementing energy saving and generation measures, such as an A2 energy class building, full led lighting, a roof-top PV plant (self-consumption mode), as well as a compressors' heat recovery system, all together contributing to yearly savings of approx. 1 MWh, equivalent to over 300 TCO_2

The additional building is completely integrated into the existing plant, which already produces approx. 300,000 products per year. With a total of 39,000 square meters dedicated to production, this facility already serves 200 customers in the construction, wind, agriculture, marine and logistics & intralogistics industries, with a wide product portfolio including yaw and pitch drives, wheel drives, track drives, slew drives and winch drives.

"This new and innovative unit looks to the future and consolidates one of our main strategic pillars — the development of electromobility solutions — by leveraging the existing decade-old competence center we have in Forlì, focused on mobile equipment," said Fausto Carboni, Bonfiglioli Group CEO.

"This expansion gives us the opportunity to better support our customers with innovative solutions for electrical and hybrid industrial and commercial vehicles. We decided to put the best of Industry 4.0 technology at our service, in order to create flexible processes, enhancing quality and productivity standards," added Marco Cesari, mobility and wind industries business unit general manager.

The implementation of Industry 4.0 technologies developed through collaborative robots, AGV, sensors, machine vision systems, interactive working instruction systems, and full data connection systems, allows an extreme optimization of the entire production process. Innovative testing benches — such as the double vibration test — guarantee high quality product consistency.

Flexibility has also been one of the main criteria the assembly line was conceived with, resulting into the capability to manage 25,000 products per year, from 70 kg to 1,200 kg with reduced machine set-up times. (*www.bonfiglioli.com*)

Siemens Lightworks

COLLABORATES WITH HACKROD ON CUSTOM CAR DESIGN

Custom car pioneer Hackrod is using Lightworks' visualization technology Slipstream, part of the Siemens PLM Software Digital Innovation platform, to design their concept speedster 'La Bandita' in virtual reality (VR). Slipstream enables designers to automatically prepare CAD data for stunning high-quality VR, allowing design teams to spend less time on arduous data prep tasks and more time on making design decisions that matter the most.

Hackrod's mission is to enable consumers to design and manufacture their dream car using the latest developments in virtual reality, product engineering, artificial intelligence and industrial 3D printing. Siemens PLM Software, which recently acquired Lightworks, is supplying Hackrod with additional tools in support of their mission, including NX software for product engineering.

For the past four years Hackrod has been developing the use of VR, AI and industrial 3D printing as part of their mission to change transport design. Through the gamification of engineering, consumers will be able to design ready-to-order vehicles in stunning high-quality VR, powered by the Unreal Engine.

One of the significant challenges in realizing this vision is the ability to reduce data prep time for design teams. Slipstream enables designers to automatically prepare all of their CAD data for design reviews in less time. Instead of

spending one day every week manually preparing data for every design review, Slipstream does it automatically.

This allows Hackrod to spend more hours every day focusing on the important things like interating faster, CAD modelling and the ability to be more responsive to customers.

"The Hackrod vision is based on the democratization of design and manufacturing, the idea that it will be as easy to configure the mobility solution of your dreams as easily as playing a video game. One of our greatest challenges is to manipulate heavy manufacturing data in a lightweight consumer facing environment. Slipstream helps us to do this beautifully and clears one of our final hurdles as we follow our mantra of 'game to garage'....on our quest to make the consumer creator in the automotive space," said Felix Holst, chief product officer at Hackrod. (*www.siemens.com/plm*)

Dana

ACQUIRES SME GROUP, SIGNS AGREEMENT WITH HYSTER-YALE MATERIALS HANDLING

Dana Incorporated has announced it has completed the acquisition of the SME Group, headquartered in Arzignano, Italy. The global SME Group designs, engineers, and manufactures low-voltage AC induction and synchronous reluctance motors, inverters, and controls for a wide range of off-highway electric vehicle applications, including material handling, agriculture, construction, and automated-guided vehicles.

The addition of SME's low-voltage motors and inverters, which are primarily designed to meet the evolution of electrification in off-highway equipment, significantly expands Dana's electrified product portfolio.

"Dana's acquisition of SME enhances our ability to address the electrification and hybridization needs of our customers, while also increasing the potential for incremental content per vehicle," said Jim Kamsickas, president and chief executive officer of Dana. "SME's exceptional electric motor and inverter products, which largely support off-highway applications, are highly complementary to the technologies we acquired with TM4, which are predominately focused on light- and commercial-vehicle applications."

"Dana is equipped to provide complete e-Propulsion systems that balance the demands for performance, power density, and weight," said Christophe Dominiak, chief technology officer for Dana. "The addition of SME's low-voltage induction motors rounds out our already robust offering of high-voltage permanent magnet motors and enables us to deliver a complete range of electrified solutions for our customers."

Dana's existing portfolio of Spicer Electrified with TM4 motors and inverters combined with SME's low-voltage motors will expand the company's capabilities to applications ranging up to 250 kW.

The privately held SME Group employs more than 100 people and operates in China, Germany, Canada, and Italy.

Dana's electrification capabilities will be further strengthened by the anticipated acquisition of the Drive Systems segment of the Oerlikon group, enabling Dana to provide products for a broad range of hybrid and electric-vehicle configurations. The transaction is expected to close in the first quarter of 2019.

Additionally, Dana Incorporated announced a strategic, multi-year supply agreement that positions the company as a preferred global supplier of drive and motion products for Hyster-Yale Group, Inc., the wholly owned operating subsidiary of Hyster-Yale Materials Handling, Inc.

Under the terms of the agreement, Dana will leverage its broad design and engineering capabilities, expansive line of field-proven drive and motion technologies, global manufacturing and aftermarket footprint, customer-centric perspective, and expertise as a trusted top-tier supplier to support Hyster-Yale's long-term strategic initiatives.

The agreement encompasses a wide range of lift-truck vehicles sold under the Hyster and Yale brand names, including Class 1 through Class 5 forklift trucks, reach stackers, and container handlers.

"We are thrilled with the opportunity that this long-term partnership brings to Hyster-Yale Group, Inc. and look forward to introducing Dana's products in our various development projects. There is a synergy between Hyster-Yale and Dana that we feel will result in a profitable relationship for both companies," said Steve Karas, vice president of global supply chain management, Hyster-Yale Group, Inc. "Dana has been a core supplier to Hyster-Yale for more than 30 years, which is why we have taken this step in securing Dana's expertise to help us achieve our goals."

Dana has earned numerous supplier awards as a trusted Tier-One supplier, including Hyster-Yale's "Certificate of Merit," "Preferred Supplier Recognition," and "Continuous Improvement Award," which recognizes suppliers who are

Alessandro Pace, president and CEO of the SME Group; Chiara Pace, chief financial officer and general manager of the SME Group; Jim Kamsickas, president and chief executive officer of Dana Incorporated, and; Adolpho Pace, founder and chairman of the SME Group (photo courtesy of Dana Incorporated).

actively engaged in quality improvement, have shown a significant or sustained improvement during the past year, and are committed to prevention of recurrence.

Dana is a leading supplier of Spicer drive and Brevini motion products for material-handling vehicles that are designed to work seamlessly and allow operators to engage, lift, and transport heavy loads with speed and precision.

"Dana is at the forefront in delivering technologies that improve the performance, fuel efficiency, safety, and durability of material-handling vehicles – including market-leading innovations that support electrification and hybridization," said Aziz Aghili, president of Dana Off-Highway Drive and Motion Technologies. "By extending and deepening our long-term collaboration with Hyster-Yale through this agreement, we are proving how we deliver a competitive advantage for our customers." (*www.dana.com*)

Bosch Rexroth

EXPANDS WEST COAST CAPABILITIES

Bosch Rexroth is excited to announce the next phase of its growing west coast presence through the re-opening of its Pleasanton, California facility. First established in the late '90s, what formerly served as a small sales office is now a much larger mixed-use facility that contains not just offices, but engineering, training rooms and conference areas. A stand-out feature is the new warehouse and prototype shop the will be used to develop, build and test proof-of-concept solutions with customers. This space will allow Rexroth to

expand its capabilities in key markets such as the growing aerospace, semiconductor, and electric vehicle markets. Additionally, Bosch Rexroth is also able to leverage its connection with its parent Robert Bosch Corp which allows access to utilize Bosch's state of the art, 104,000 sq. ft. research facility recently opened in Sunnyvale, CA. The new Bosch Rexroth Pleasanton facility combined with the $40 million investment in the Bosch Research facility is just the start of a bright future for Rexroth and the West Coast. As a result of the expansion, Rexroth has opened up more jobs, expanded its project capabilities in key markets, and increased its capacity to support local service and engineering for its customers. (*www.boschrexroth-us.com*)

KMC Global

EXPANDS CONTROLS AND AUTOMATION DIVISION

KMC Global, a group of wholly owned, autonomous companies—including PRAB Inc.—that manufacture equipment designed to enhance how industries process material, is pleased to announce the expansion of its controls and automation division to serve outside markets. This technology-based company provides control panels for industrial equipment plus automation and integration with remote and on-site support capability.

KMC Global Controls & Automation provides a single point of contact for all controls and automation needs and offers a variety of services, including:

- Certified 508A-Listed Industrial Control Panels that are individually built to suit each customer's specifications and component requirements.
- Control Panel Design by a fully staffed team of experts who can create a control panel concept from the ground up or review an existing control panel design.
- Automation & Integration with smart programming that allows customers' equipment to continue doing the jobs that keep them in business.
- Remote & On-Site Automation to assist customers with commissioning equipment, program changes, troubleshooting electrical control components, schematic and project review, and control panel wiring clean-up. (*kmcautomation.com*)

March 2–9—IEEE Aerospace Conference 2019

Big Sky, Montana. The international IEEE Aerospace Conference, with AIAA and PHM Society as technical cosponsors, is organized to promote interdisciplinary understanding of aerospace systems, their underlying science and technology, and their application to government and commercial endeavors. The annual, week-long conference, set in a stimulating and thought-provoking environment, is designed for aerospace experts, academics, military personnel, and industry leaders. The 2019 conference is the 40th in the conference series. Conference topics include aerospace systems, military, civilian or commercial aerospace endeavors, government policies and aerospace engineering and management. For more information, visit *www.aeroconf.org*.

March 6–9—The Mfg Meeting 2019

Tucson, Arizona. Hosted by two major manufacturing trade associations, AMT – The Association for Manufacturing Technology and National Tooling and Machining Association (NTMA), The MFG Meeting brings together the complete manufacturing chain for a unique conference experience. This event provides unparalleled opportunities to network with industry leaders and the agenda topics are designed to address key business challenges and provide actionable solutions. The event is intended for senior leadership, executives, vice presidents, senior sales directors, manufacturing technology's builders, distributors and end users. Learn about the future challenges and opportunities facing the American manufacturing industry, discover new ideas and participate in interactive discussions. For more information, visit *www.amtonline.org*.

March 10–13—PTDA University of Innovative Distribution 2019

Indianapolis, Indiana. Recognized for its excellence in education, the PTDA-sponsored University of Innovative Distribution, in cooperation with Purdue University, is a concentrated, continuing-education program focused on the unique needs of the industrial distribution industry. The four-day program allows attendees to build a custom curriculum from over 40 courses on the key functional disciplines relevant to industrial distribution. Participants earn credits toward their Certificate in Industrial Distribution from Purdue University. CEOs, branch managers, sales and marketing managers, distribution personnel, human resources, inventory managers, training managers and more should consider attendance. For more information, visit *www.ptda.org*.

March 20–22—PTDA Spring Meetings and Leadership Development Conference 2019

Savannah, Georgia. PTDA 2019 Spring Meetings combine governance meetings and the Leadership Development Conference to offer networking opportunities along with powerful education for those looking to enhance their leadership skills and to achieve the goals set forth in the PTDA Strategic Plan. The PTDA Leadership Development Conference is for any up-and-coming leader, including Next Genners or established leaders seeking a skill set refresh. Based on his book, The Culturetopia Effect (included in the registration fee), author Jason Young, a former senior-level manager at Southwest Airlines will provide practical, easy to implement guidance to address the key determinants that make a healthy, productive and profitable culture of any team or organization at the conference. For more information, visit *www.ptda.org*.

March 27–28—Industrial Pack 2019

Atlanta, Georgia. The free-to-attend, two-day event, will feature the industry's most unique trade show experience dedicated to the industrial, in-transit, and protective packaging industry. The event focus is providing both visitors and exhibitors with a unique high-value experience. Whether visitors are coming to learn, source or procure, there will be lots of opportunities for networking. The trade show will be the central hub for meetings over coffee or lunch, plus drinks will be served every afternoon at happy hour. Also planned are casual networking activities that include tours of Atlanta and a Braves baseball game, where visitors have time to forge new professional relationships with colleagues that have shared concerns and challenges. One of the event's most anticipated activities is the second annual IP Awards. This is an evening that provides the perfect environment to celebrate excellence, network and have some well-deserved fun. Pack Testing Live will be a demo area in the exhibit hall to challenge the strength and robustness through stimulation and non-stimulation performance tests. For more information, visit *www.industrialpackexpo.com*.

April 1–5—Hannover Messe 2019

Hannover, Germany. In 2019, the integration, digitization and interconnection of industrial technologies will transform the world's manufacturing industries more than ever before. In recognition of this, the Integrated Automation, Motion and Drives (IAMD) show at Hannover Messe will feature the full range of products and solutions for the factory of the future, including factory and process automation systems, industrial IT, robotics, smart drives, and intelligent hydraulics and pneumatics systems. The unifying theme this year, "Industrial Intelligence," will focus on eliminating production downtime and ensure the seamless integration and operation of all the parts that make up smart factories. Companies like Siemens, ABB, Festo, Bosch Rexroth, Schneider Electric, Phoenix Contact and Beckhoff – have already registered display space. Confirmed exhibitors of intelligent power transmission and fluid power technology solutions include SEW Eurodrive, Schaeffler, Continental, Aventics, Hydac, KTR, Parker Hannifin, Trelleborg and ZF Friedrichshafen. For more information, visit *www.hannovermesse.de*.

April 8–11—Automate 2019

McCormick Place, Chicago. Held once every two years, Automate features the latest in cutting-edge robotics, vision, motion control, and related technologies, the event attracts thousands of visitors from around the world looking for ways to enhance their processes, improve product quality, lower costs, and sharpen their competitive edge. More than 400 exhibitors participate with technologies in drives, motors, actuators, robots, controls, metrology equipment, sensors, software, system integrators and more. For more information, visit *www.automateshow.com*.

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Ask Pneuman

The Pneumatic Soothsayer/Fortuneteller That Answers Questions from the Beyond!

Matthew Jaster, Senior Editor

Escape Rooms have been popular in recent years for their challenging game play, group participation and unique time constraints. Teams have X amount of time (typically 60-minutes) to solve puzzles, ponder riddles and dissect clues in order to escape a variety of themed games. This could include stealing a famous Van Gogh painting or being transported to an Egyptian tomb. The possibilities are endless. And the concept is just, good ole fashioned fun.

One common thread with Escape Rooms across the country, however, is the less-than-exciting reception area. There's always a room where you wait for the game to start. Typically, this time is spent staring at walls, walking in circles or eavesdropping conversations.

The owners of Skeleton Key, an Escape Room experience in Hartford, Connecticut, decided the reception area should be as interesting and inventive as the Escape Room itself. So they came up with the idea to create "Pneuman," a steampunk pneumatic tube system that guests can ask questions—much like the popular Magic 8-Ball—and receive answers from the beyond.

"Years ago, I had purchased a late 1800s brass pneumatic tube system that came out of a department store in the Midwest. I've wanted to use it in a unique project, but couldn't find the right situation to make it happen," said Bruce Rosenabum, Modvic, LLC. "When the folks at Skeleton Key came to me about their Escape Room idea – they actually were thinking about doing a more modern pneumatic tube version (like the clear tubes they use for bank or hospital applications). My tubes were solid brass – so my system was not going to fit."

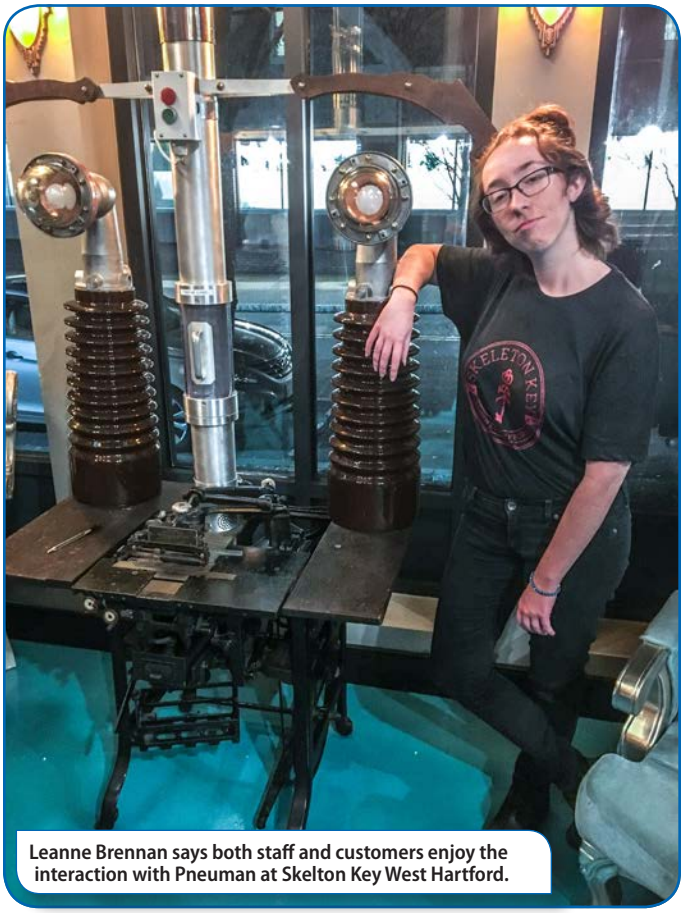
With some ingenuity and creativity, Rosenbaum took an old, early 1900s Addressograph machine (dog tag maker) that would be the perfect 'platform' and interactive base for a modern pneumatic tube system.

"The client provided me the door/tube component and I married it to the platform for the fusion of old and new coming together," Rosenbaum said.

Skeleton Key patrons can huddle together and ask Pneuman personal or political questions or simply questions about the game itself. The pneumatic machine will send answers (from the Great Beyond) to any question posed—keeping folks engaged and busy prior to entering the escape room.

"Staff and customer's alike, love Pneuman with all our hearts," said Leanne Brennan, Skeleton Key West Hartford. "He is the only pneumatic tube in Connecticut with a sassy personality *and* a connection to the spirit world."

The client used a pneumatic tube company to install the system. Simply, a clear acrylic tube that links to sending and receiving stations. An air compressor/motor pump is installed at the receiving station which can suck (like a vacuum cleaner) or blow air. When it sucks air, it *pulls* loaded canisters along the tube toward it. When it blows air, it *pushes* the canisters in the opposite direction. The tubes can go along straightaways or easy curves to cover the areas of necessary travel.

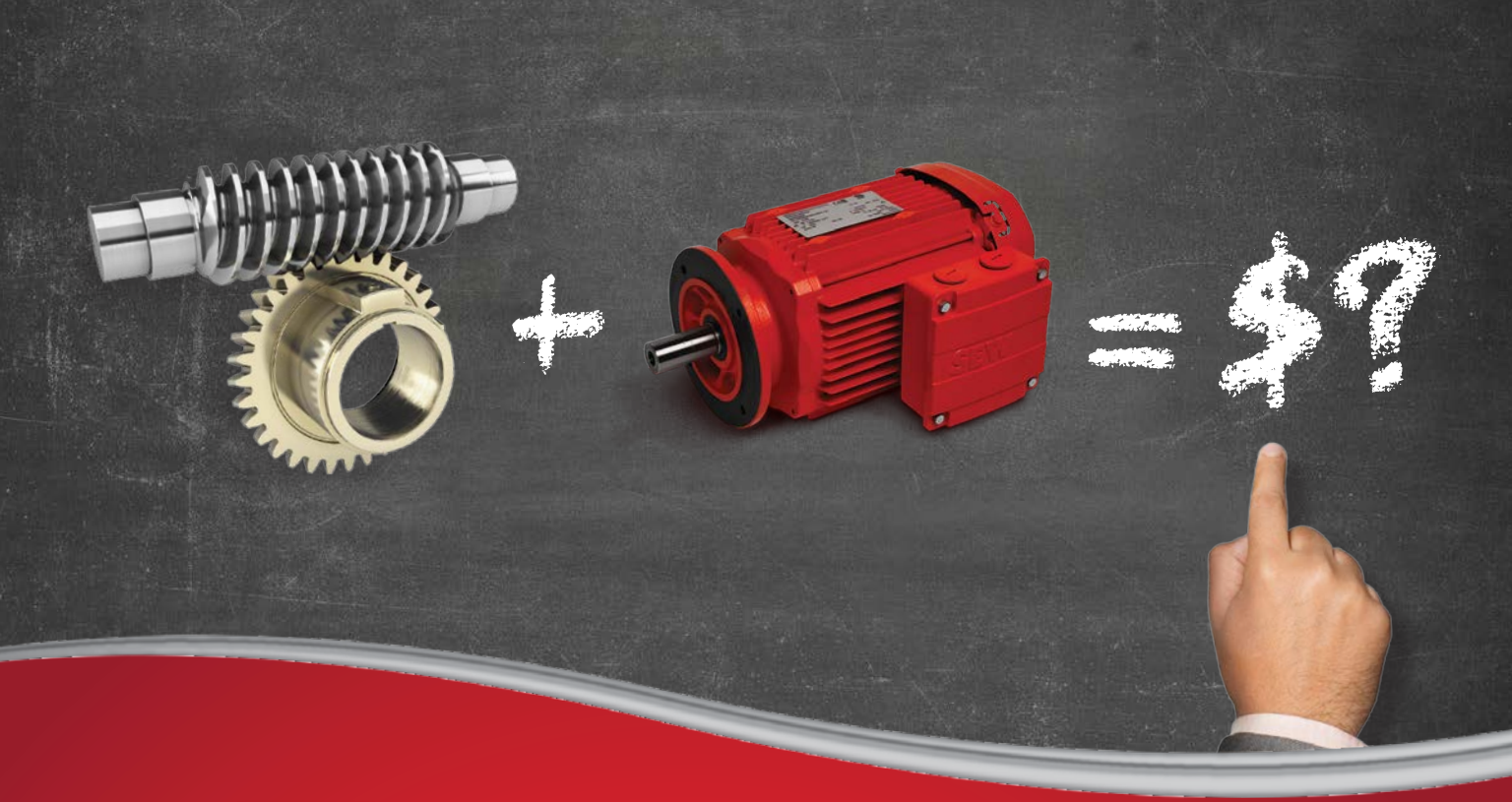


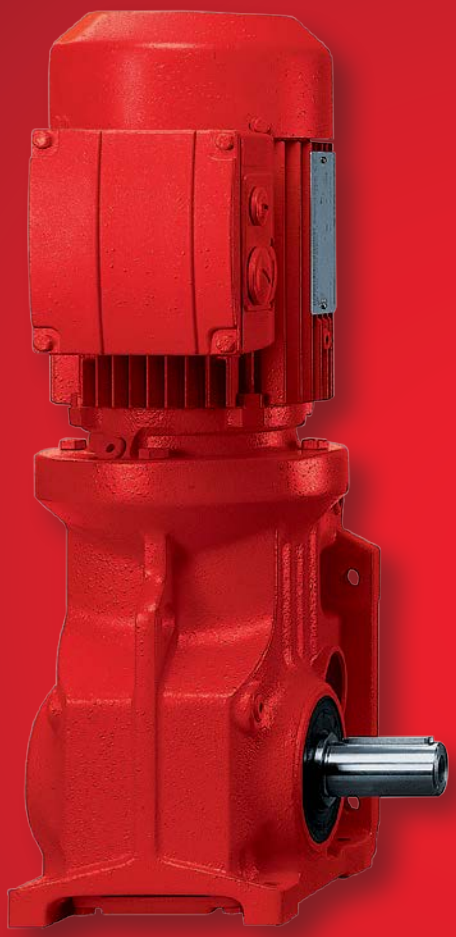
Leanne Brennan says both staff and customers enjoy the interaction with Pneuman at Skelton Key West Hartford.

Inside the tube are the answers to the world's most trivial questions.

Rosenbaum's company Modvic specializes in steampunk art and design. He says the company is currently working on a variety of interesting steampunk projects including a monowheel time machine, a multi-station coffee brew bar, a redevelopment chocolate factory sign using an antique candy kettle and much more. He appreciates the opportunity to use steampunk to enhance the customer experience at Skeleton Key.

"Steampunk art and design at its essence is about creative problem solving, collaboration and resilience," Rosenbaum said. "Those are the exact skills needed to successfully get in and out of an Escape Room." (*www.modvic.com*) (*skeletonkey.com*) **PTE**





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