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APRIL 2022

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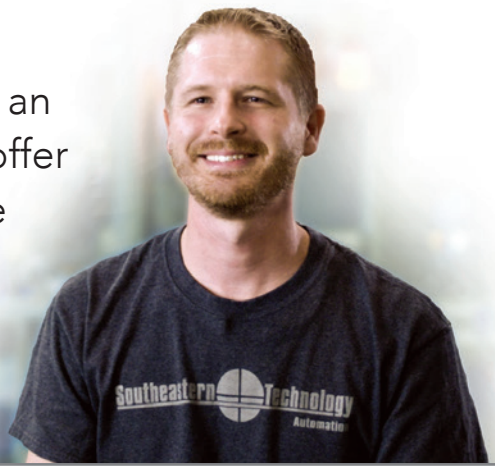
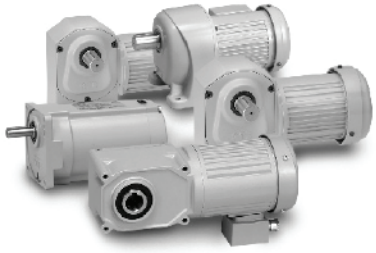
RYAN MILLER,
Owner and Engineer Manager
Southeastern Technology Automation



Brother leads the way, by shielding its entire line of standard gearmotors with the industry's best warranty. No matter how far the journey or how rough the path, rest assured you've got the protection you need right "at your side."



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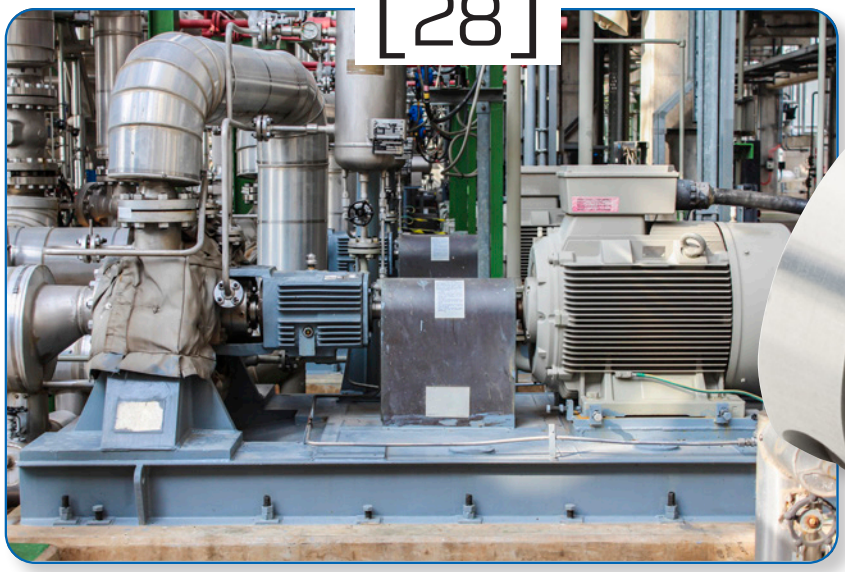
Power Transmission Engineering®

APRIL 2022

A Publication of
The American Gear Manufacturers Association



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Power Transmission Engineering
VOL. 16, NO. 3

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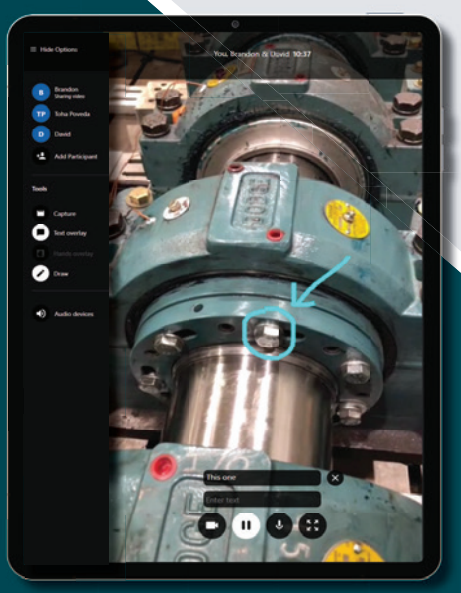

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PTE Revolutions:
SKF Plain Bearings Utilized for Suspension Bridge

Bearings from SKF are playing a key role in a record-breaking engineering project—the world's longest suspension bridge, which recently opened on March 18, 2022, in Turkey. The bridge was completed 18-months ahead of schedule.

www.powertransmission.com/blogs/1-revolutions/post/8506-skf-plain-bearings-utilized-in-suspension-bridge-project

Large Gear Market Preps for Rebound

Although the large gear market remains volatile, analysts expect significant revenue increases from 2022—2025. Key vendors are being asked to expand their market capabilities and provide the latest/greatest equipment to manufacture gears in less time.

www.powertransmission.com/blogs/1-revolutions/post/8486-large-gear-market-preps-for-rebound

PTE Videos:
Regal Rexnord Motor Minute

Regal Rexnord Motor Minute technical tips provide you with information to enhance your motor knowledge. Supplied in a one minute or so video format giving you the ability to learn on the go, on a break, or whenever you have a minute to learn. This Motor Minute technical tip provides details on why direct drive motor shafts have a flat side. Learn more here:

www.powertransmission.com/media/videos/345

Power Transmission Engineering

AGMA MEDIA
1840 Jarvis Avenue
Elk Grove Village, IL 60007
Phone: (847) 437-6604
Fax: (847) 437-6618

EDITORIAL
Publisher & Editor-in-Chief
Randy Stott
stott@agma.org

Senior Editor
Matthew Jaster
jaster@agma.org

Senior Editor
Aaron Fagan
fagan@agma.org

ART
Art Director
David Ropinski
ropinski@agma.org

ADVERTISING
Advertising Sales Manager & Associate Publisher
Dave Friedman
friedman@agma.org

Materials Coordinator
Dorothy Fiandaca
fiandaca@agma.org

CIRCULATION
Circulation Manager
Carol Tratar
tratar@agma.org

ACCOUNTING
Luann Harrold
harrold@agma.org

MANAGEMENT
President
Matthew Croson
croson@agma.org

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

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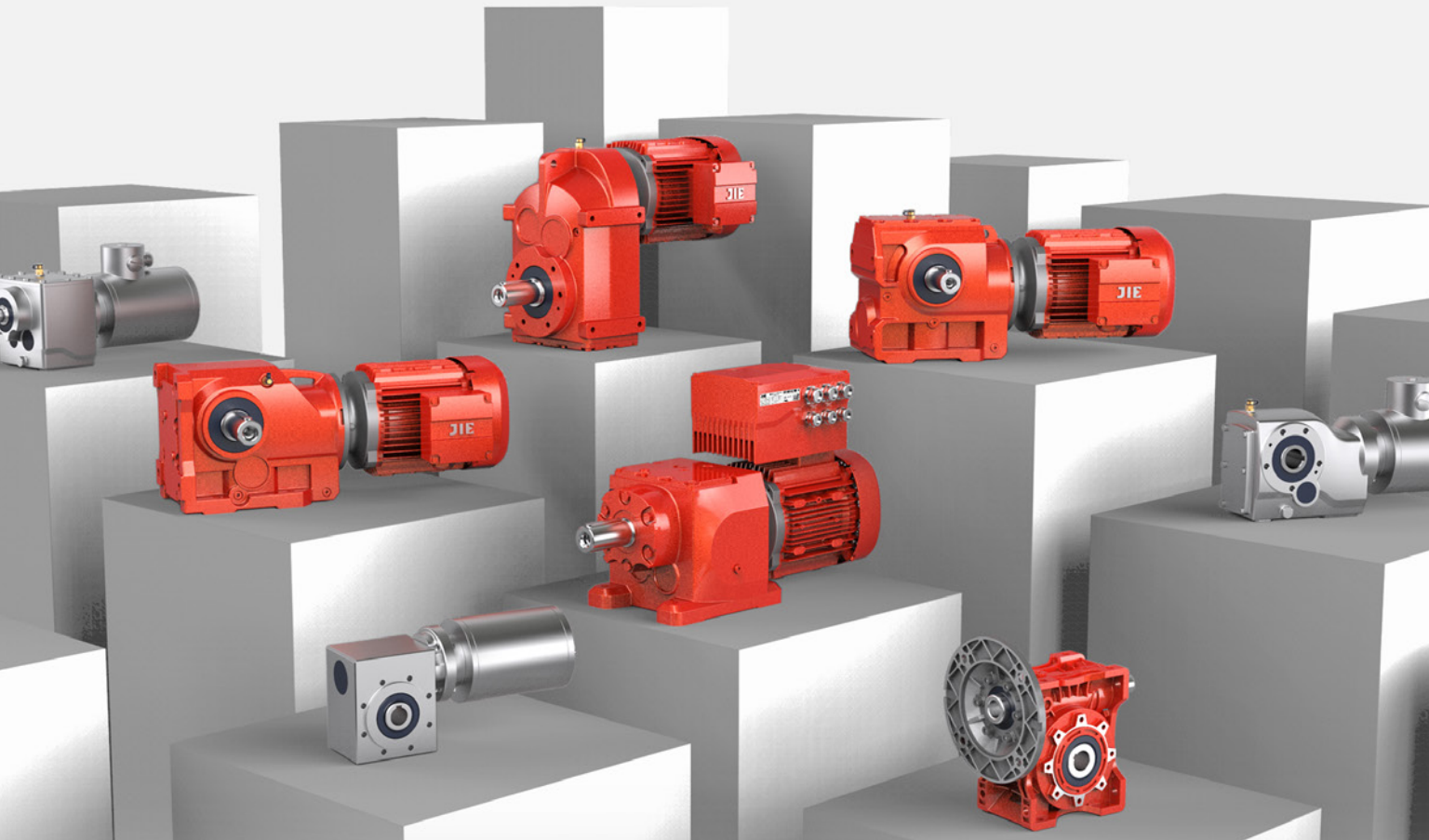

Options are Worm gear unit; Helical inline, Parallel shaft, Helical bevel and Helical worm gearmotor; Available in aluminum, cast iron and stainless steel housing.

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Randy Stott
Publisher & Editor-in-Chief

Dual Milestones

After 15 Years in Print and 25 Years Online, the Power Transmission Engineering Brand is Stronger than Ever

This issue marks the 15th anniversary of the launching of *Power Transmission Engineering* as a print magazine. Happy birthday, us! We created this magazine to provide a technical and informational resource on gearboxes, bearings, couplings and other mechanical power transmission components.

We modeled *PTE* after our longstanding flagship publication, *Gear Technology*, with a strong focus on technical content—and this model has served us well over the years. But even more so, we wanted *PTE* to be the resource for the users and buyers of power transmission components, spanning a diverse readership including design engineers as well as plant engineers and MRO professionals.

Our goal has always been to provide you with information on the latest technologies related to mechanical components, and we strive to bring you articles that teach you how things work—both from a cutting-edge, research-oriented perspective as well as a hands-on, how-to approach.

But our journey in this industry didn't begin with the print magazine. In fact, we got our start when we launched *powertransmission.com* 25 years ago, in 1997. Back then, we called it "The Power Transmission Home Page." It was a place for product and industry news, feature articles and, perhaps most importantly, our online Buyer's Guide, which remains a central part of our online presence even today.

Speaking of which, I'm pleased to announce the launching of the completely revamped *powertransmission.com*. We've got a sleek new design and some major upgrades in terms of how we handle video and other new media.

The online Buyer's Guide, which was already the most comprehensive directory of suppliers of mechanical power transmission components, now has a number of major new upgrades. For example, videos, news items and articles about companies are automatically attached to their Buyer's Guide listings, so you have access to even more relevant information about which suppliers might be the best links in your supply chain.

In addition, we've increased our focus on video, so you can watch and learn about the latest technologies in gears, bearings, motors, gear drives and more.

Of course, no celebration of milestones would be complete without acknowledging those who helped us get where we are. We definitely couldn't have gotten this far without the support and enthusiasm of our advertisers. As I looked back over the past issues of the magazine, I'm proud to say that many of the same companies who took a chance on us 15 or 25 years ago have become the "regulars" who are still advertising with us today. Thanks to all of our advertisers for recognizing the value in what we do and helping support our ability to continue doing it.

And let's not forget the importance of you, the reader. Without you, there'd be no point in any of this. So thank you for giving us purpose, direction, feedback and criticism. Please consider renewing your FREE subscription by visiting powertransmission.com/subscriptions.

We look forward to spending another 15 or 25 years with you. As always, thanks for reading.

Randy Stott

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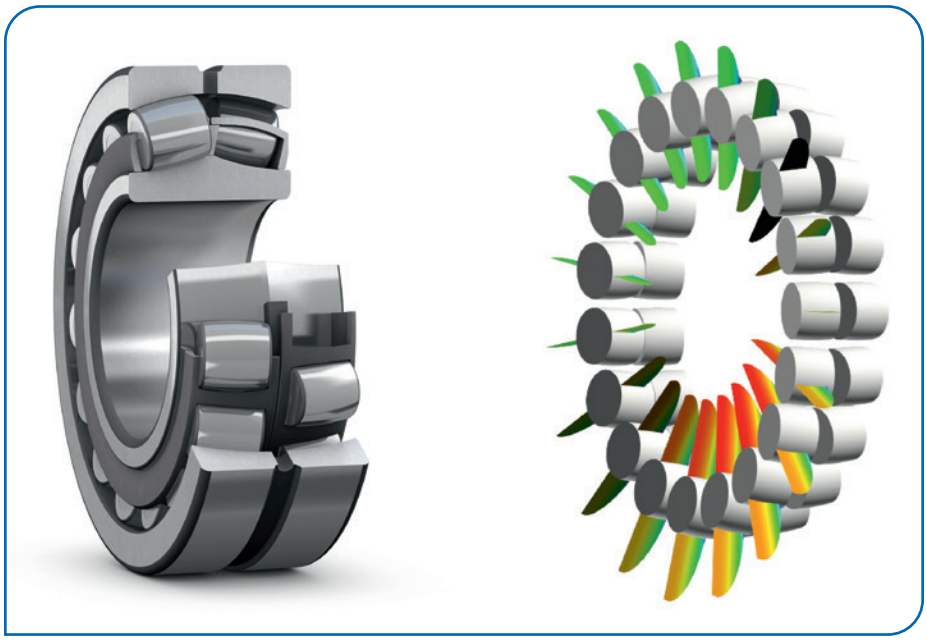
HEDZER TILLEMA, PRODUCT LINE MANAGER ENGINEERING TOOLS, SKF B.V., THE NETHERLANDS

Prediction of Bearing Performances

Predicting rolling bearing performance in operation is an essential task when designing and developing transmission systems. On one hand, bearings must meet the requirements for the desired service life. But the bearing arrangement is also a major factor defining the system stiffness. In the context of gear systems, an accurate prediction of shaft displacement is of fundamental importance, especially when sizing gear tooth modifications. The accuracy of shaft and bearing modeling is thus a key element to ensure reliable operation of such systems.

A comprehensive approach to consider rolling bearing stiffness is described in the ISO/TS 16281. By modeling the internal geometry of a bearing, realistic bearing reaction characteristics can be obtained using Hertzian theory. KISSsoft had implemented this method years ago and continuously improved its application. In combination with its efficient finite difference solver, this allows an adequate and fast shaft analysis and helps to quickly design and size gear systems including tooth modifications.

To calculate the bearing reaction, the ISO/TS 16281 requires details on the internal geometry such as number of rolling elements, rolling element diameter, length, and pitch diameter. This is typically referred to as the bearing's internal macrogeometry. Bearing designers and manufacturers also optimize and tune further details, such as raceway and rolling element profiling. Since these details are sensitive intellectual property, usually no information is available about this so-called microgeometry. On the other hand, it is typically not very difficult to obtain the macrogeometry from a bearing. Although mostly not available as bulk data, these values can usually be derived from the drawings provided by the manufacturers.

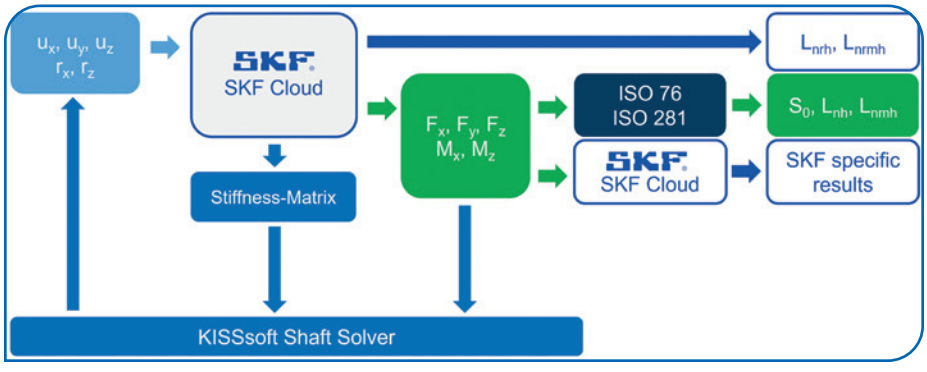


Calculations according to ISO/TS 16281 accurately predict bearing stiffness and rating life by *modeling* and considering the bearings' internal geometry.

KISSsoft: Features and Methods

KISSsoft comes with a large bearing database with catalog data of thousands of bearings from several manufacturers. Most of these bearing records do not include internal geometry data. For the user of the software, it would be inefficient having to input more than just a handful of bearing internal geometry details. To still enable the profound bearing stiffness and rating life model of the ISO/TS 16281, *KISSsoft* estimates a bearings internal geometry based on the rating numbers, dimensions and other characteristics.

Unlike the catalog methods such as the ISO 76 or the ISO 281, which are more of a postprocessing kind, the ISO/TS 16281 is an integral part of a gear system calculation. A bearings stiffness is nonlinear and therefore very much dependent on the operating point, i.e., the load, displacement/misalignment as well as the bearing clearance. From a calculation point of view, this means that an iterative approach is required. The bearing stiffness affects a bearings reaction force, the bearing reactions forces affect the bending of a shaft system and that bending again defines the operating bearing stiffness. The calculation is considered successful, also referred to as converged, if no more relevant changes between the



The SKF cloud services seamlessly integrate into *KISSsoft*'s m.odular calculation structure.

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iterations are detected.

In a single iteration step, the bearing calculation can be considered independent of the surrounding shaft system and encloses distinct boundaries, or more appropriately, a clear interface. As a main input, simply the displacement and rotation of the inner versus the outer ring are required. In return, the calculation provides the corresponding reaction forces and moments as well as an operating bearing stiffness matrix. These results can then be used in the shaft calculation for the next iteration step.

SKF Bearing Stiffness Cloud Service

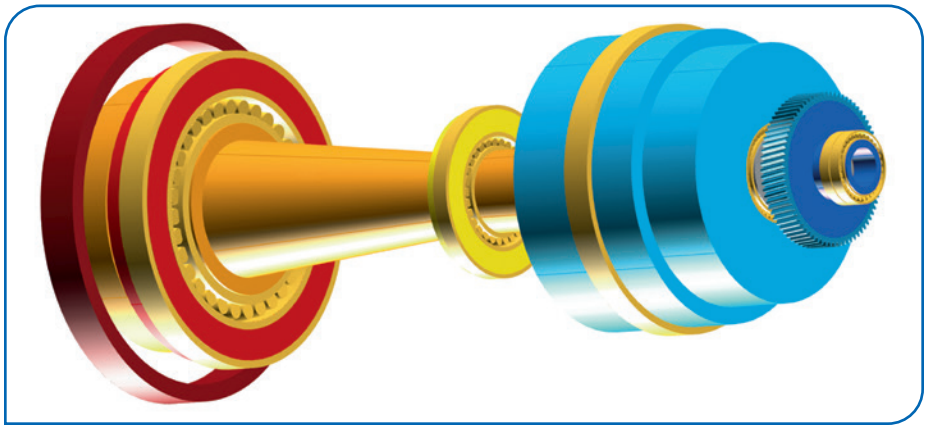
This well-defined interface makes the underlying bearing calculation interchangeable and allows for a very modular setup. Following exactly this design philosophy, a new SKF bearing stiffness cloud service was integrated as part of collaboration project into the latest *KISSsoft* release: The shaft systems calculation remains the same, but the bearing calculations themselves are performed in the SKF cloud, connected through a web API. That approach gives *KISSsoft* users significant benefits for their SKF bearing calculations: The SKF calculation service itself has access to detailed macro and microgeometry and involves decades of experience in calculation-based prediction of bearing performance. There is no need for the *KISSsoft* user to have access to any of these internal details, as the modular interface simply requires the cloud service to return a bearings reaction force, reaction moment and operating stiffness. Furthermore, the new SKF service also provides nominal and modified reference rating life results, considering those internal geometry details as well.

System Calculation with Cloud Benefits

Running a shaft system calculation with several bearing calculations performed on a cloud service would typically result in a major increase of calculation time, as each iteration incurs a call to the interface through the internet. Therefore, *KISSsoft* internally first runs the calculation with its own implementation of the ISO/TS 16281. Like this, a reasonable initial state can be used when switching to the SKF bearing cloud service, thus requiring only a couple of additional iterations through the web interface.

By using the new SKF bearing stiffness cloud service in *KISSsoft*, users can obtain more realistic calculation results for their shaft designs with SKF bearings. This propagates to all subsequent and connected gear and system calculations including tooth modifications sizing and improves the design scope. It is considered that cloud-based calculation and data access are an overall trend and other bearing manufacturers are expected to provide similar services in the next years as well. For the users of gear design software, such as *KISSsoft*, this is well appreciated as it drastically reduces the gap between standardized and publicly available information and nondisclosed, proprietary manufacturer know-how.

kisssoft.com
skf.com



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Binder USA

ANNOUNCES SHORT VERSION OF SERIES 423 M16 CONNECTORS

Binder USA recently announced a new short version of its series 423 M16 connectors. These compact shieldable cable plugs and sockets, each with a cable clamp, are available in 10 solder and 5 crimp male and female versions to suit various pin counts. They are ideal for applications where space is tight and IP67-level protection is required, such as sensor and actuator technology, test and measurement, automation and industrial controls, and process technology.

Solder versions are designed for maximum wire gauges of 0.75 mm^2 or AWG 18 (2 to 8 pins), and 0.25 mm^2 or AWG 24 (12 to 19 pins). Rated voltages are 32 V or 150 V, depending on the pin count, with rated impulse voltages 500 V or 1.500 V, respectively. Rated currents at 40°C range from 3 A to 7 A. All solder products are equipped with brass contacts as well as bronze sockets and are specified for a temperature range from –30°C to +95°C.

Crimp products are designed for wire gauges of 0.14 to 1.0 mm^2 or AWG 26 to AWG 18 (4 to 6 pins), and for 0.14 to 0.75 mm^2 or AWG 26 to AWG 20 (7 to 8 pins). Rated voltages are 32 V or 150 V, with rated impulse voltages are 500 V or 1500 V, and the rated currents are 5 A or 6 A, respectively. The temperature range extends from –40°C to +100°C.

binder-usa.com

Sumitomo Drive Technologies

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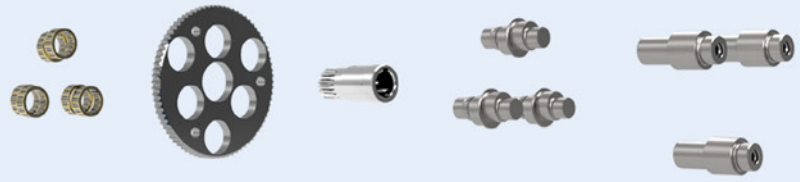

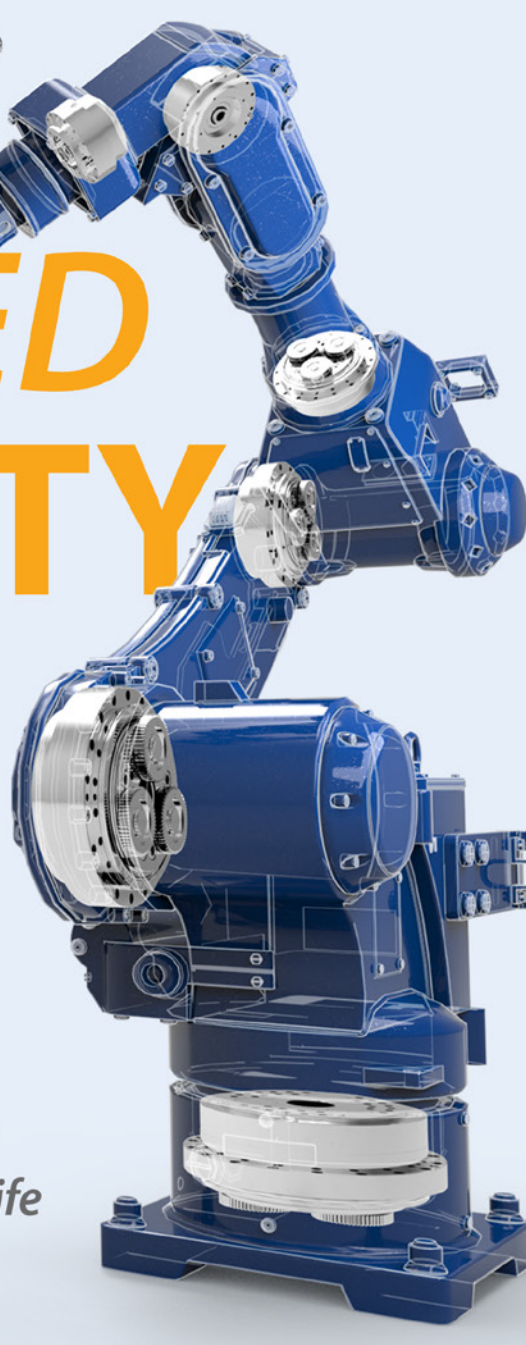

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Couplings from JW Winco transmit rotary motions and torques from shaft to shaft. They also even out tolerances and mechanical deflection that would otherwise result in damage to drive or measurement configurations.

JW Winco recently added couplings of aluminum and stainless steel that include designs for positive and non-positive connections. Multiple bore diameters, various, stiffness and hardness levels of the coupling body as well as an optional keyway allow very specific customization to the given use case. In general, all couplings compensate for offsets and misalignments, accommodate runout error and axial motion, and dampen vibrations and impacts to varying degrees.

At the application level, there is a choice between position and motion control or torque and power transmission.

For position and motion control, the rotary motion must be transmitted with very high precision and accuracy. This requires a coupling type that functions with zero backlash in the direction of rotation and has high torsional stiffness. Typical applications include servo and stepper motors for linear axes, industrial robots and test benches.

For torque and power transmission, on the other hand, the focus is on pure force transmission. This calls for couplings that can withstand high torques and heavy loads while functioning reliably in harsh conditions. Typical applications include conveyor systems, pumps and agitators, and packaging machines.

jwwinco.com

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S.S. White

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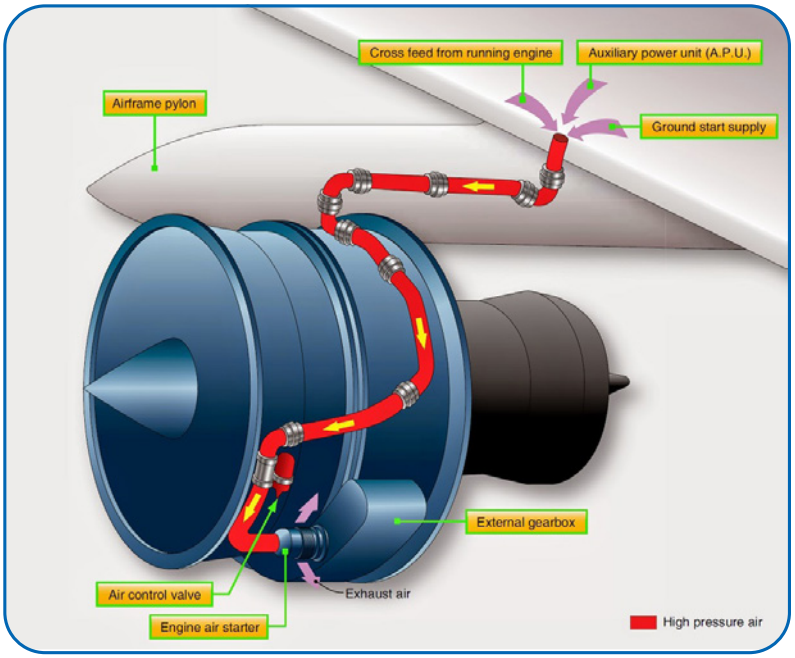
S. S. White Technologies is supplying flexible rotary shafts specifically designed to transmit rotary torque for the manual override on the Honeywell Aerospace Starter Air Valve used on GE9X turbofan engines selected to power Qatar Airways 777-8 freighters and Singapore Airlines 777-9 aircraft.

The Honeywell Aerospace Air Turbine Starter (ATS) consists of two components, the Starter and the Starter Air Valve. The Starter Air Valve controls air flow from the Engine Bleed, APU or Ground supply to the ATS and has significant built-in operational and protection features. One of the many features incorporates an S. S. White flexible rotary shaft that allows ground crews to manually actuate the Starter Air Valve in case of an operational failure thus enabling the aircraft to still be dispatched avoiding flight delays and cancellations.



In addition, all S. S. White aerospace flexible shaft products are designed utilizing a unique computer modeling software program developed by S.S. White called *Perflexion*. This program allows the design engineers to more fully model the behavioral characteristics of the wire bundles within the shaft core and arrive at an optimum product that provides maximum bending flexibility and torsion strength while allowing minimal torsion deflection with up to a 30 percent improvement over competitive products.

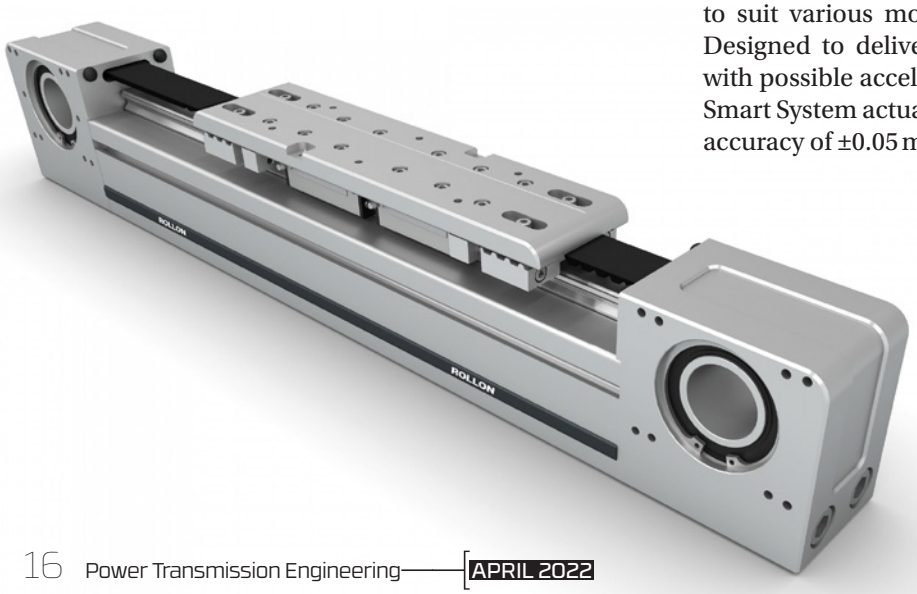
sswhite.net

Rollon

OFFERS SMART SYSTEM ACTUATORS

Rollon has updated its Smart System lineup of belt-driven linear actuators with a new design that supports heavy loads and ensures low maintenance operation in automated manufacturing, packaging machines and food and beverage equipment.

The actuators have a self-sustaining anodized aluminum frame and a steel reinforced driving belt, and they are engineered to provide stiffness for greater load capacity. Symmetrical heads on both ends of the actuators allow users to assemble the gearbox in one of four different positions. The Smart System is designed to make it easy for customers to create multi-axis systems such as a two-axis Y-Z system, two parallel axis system or a three-axis X-Y-Z system using simple brackets and plates.



Rollon offers three types of Smart System actuators to suit various motion and installation requirements. Designed to deliver speeds up to five meters/second with possible acceleration of 50 meters/second^2, Rollon Smart System actuators also achieve a high repeatability accuracy of ±0.05 mm.

rollon.com

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Lubriplate's complete line of premium quality gear oils has been formulated to provide unsurpassed performance in a wide range of gear reducers.

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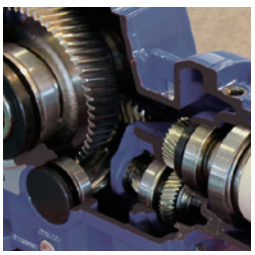

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- Provides excellent lubricity and oxidation resistance.

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- High-quality, petroleum-oil based, extreme pressure (EP) gear oils.
- Meets military specification MIL-PRF-2105E and MIL-L-2105D.
- Conforms to API categories GL-3, GL-4, GL-5, MT-1.

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- Heavy-duty, tacky, red, extreme pressure (EP) petroleum-based gear oils.
- These tacky, adhesive, extreme pressure oils cling tenaciously to gear teeth.
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- Meets military specification MIL-PRF-2105E and API classification GL-5.

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Southern Gear

EXPANDS BEVEL GEAR PRODUCTION

Southern Gear has added two rebuilt Gleason No. 102 Generators to its production capabilities to meet growing demand for smaller, high-precision straight bevel gears produced with the Coniflex process.

The 102s add capacity to Southern Gear's straight bevel gear production capability, which also includes Gleason No. 14 and No. 104 Coniflex Generators.

"While these dedicated, manually operated machines might seem out of place alongside the advanced CNC machines occupying most of our shop floor, they are still an excellent solution for the production of small straight bevel gears using the highly desirable Coniflex method," explains Southern Gear President Karen Malin. "Most importantly, we have the experience and operators needed to take full advantage of these machines."

The addition of the Gleason 102 Generators is part of a multi-million dollar, company-wide investment in new technologies, methodologies and processes that, over the last several years, has, according to Malin, added much needed capacity to Southern Gear's vertically integrated shop floor.

southerngear.com

SKF

CHOCKS ALLOW FOR EASY MOUNTING AND IMPROVE ROTATING EQUIPMENT PERFROMANCE

SKF has developed a new range of adjustable chocks with higher load capacity and an increased adjustment range.

The Vibracon E series — which includes four different models — has improved self-leveling and height adjustment. The chocks allow all types of rotating equipment to be mounted easily and accurately to base frames and either steel or concrete foundations.

"They help to simplify the installation of rotating machinery, which improves technical and economic performance," says Rene Vermeulen, senior engineering sales manager at SKF.

The chocks accommodate angular differences of up to 4° between machine and mounting base — without having to machine the base or install epoxy resin chocks. This self-levelling ability, combined with height adjustment, reduces the possibility of a soft foot in the production line. The chocks can also lower the cost of equipment foundations — whether designed-in or retrofitted

The four products in the Vibracon E range are: carbon steel chocks; surface treated chocks; stainless steel chocks; and low-profile elements.

Carbon steel chocks are suitable for indoor applications, such as on the factory floor. Surface-treated products are for more extreme environments such as humid or salty climates. Stainless steel variants are aimed at the most demanding conditions, such as in the oil & gas industry. Low-profile elements offer an economic alternative to more expensive milled chocks, shims, or epoxy resins.

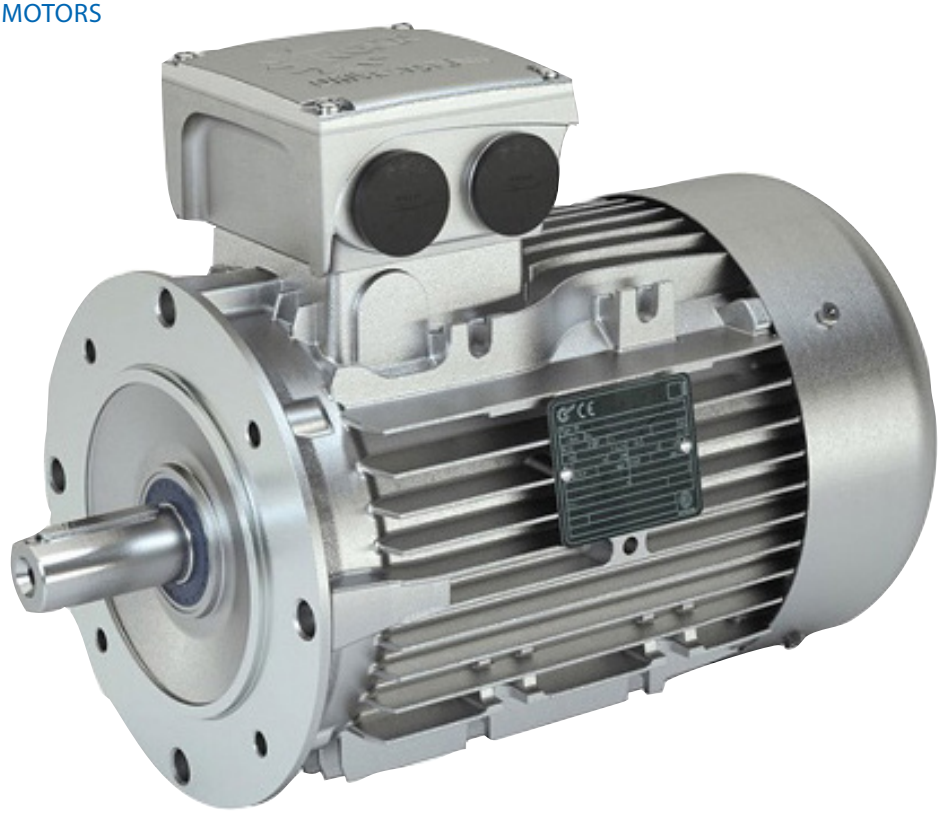
A broad range of specialist adjustment tools — available from SKF — allows technicians to alter chock height with maximum safety and comfort. In addition, the chocks are backed by SKF's expertise in maintenance and shaft alignment.

SKF also offers a product selection tool that simplifies the process of choosing exactly the right chock for a particular application.

skf.com

NORD

REDESIGNS 100 FRAME ASYNCHRONOUS MOTORS



NORD's newly redesigned 100 frame motors are the first step in updating their asynchronous motor portfolio with an optimized electrical, mechanical and visual design. The new 3 hp and 4 hp premium efficient motors offer a simplified assembly including the elimination of a copper rotor as the motors produce the same energy efficiency without it. This change results in reduced costs and sell price to the consumer. Not changing in the design are the outer dimensions and the mounting options available — — direct mount, NEMA and IEC, making the new motors drop-in compatible for existing systems. While the new motors will be the preferred offering beginning Q1 2022, legacy versions are not being immediately discontinued and will still be available for a period.

The exterior of the motor has new curved cooling fins that have been adapted in depth and shape. These fins curve around the terminal box and the motor to enhance airflow and optimize cooling. Sharp edges and corners have been removed from the terminal box to smooth the design and provide easier maintenance. The need for NPT adapters has been eliminated as there are now directly integrated imperial and metric conduit connections for ease of use and reduction of parts.

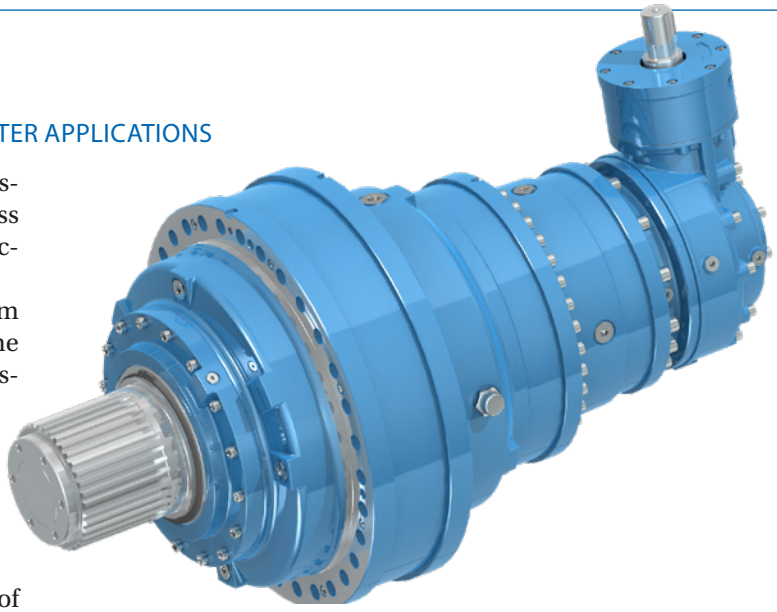
Additionally, curved feet on the new design give the motor greater strength, stability and a streamlined appearance. The fan cover has also received an updated radial design and the screws of the hood have been rotated by 45 degrees, making them accessible in case a variable frequency drive is installed.

Along with visual updates, the 100 frame motors have several mechanical updates such as an optimized rotor fan assembly and encoder installation. The rotor fan has been designed with a quick click mechanism for simple install or removal, making maintenance and replacements fast and easy. The incremental encoders have full impact protection and improved torque support added to the bearing shield. The encoder position itself has been moved between the fan and the B-end bearing shield. These assembly changes result in protection against mechanical influences and better cooling of the motor as the encoder is not blocking the fan inlet. In addition to moving the encoder position, retrofitting of encoders is now possible and with the aid of a plug-on shaft, incremental encoders can easily be retrofitted to a standard motor without replacing or reworking the rotor. Special options such as a CAN-based absolute encoder, hand wheel and cast-iron fan are still available for configuration.

nord.com

Dana

LAUNCHES BREVINI S-SERIES FOR BIOGAS AND WASTEWATER APPLICATIONS



Dana Incorporated recently launched Brevini S-Series industrial planetary gearboxes specifically engineered to address the durability and reliability requirements of biogas production and wastewater treatment facilities.

Available now, Brevini S-Series gearboxes with maximum output torques up to 290 kNm are customized to drive the mixing systems used in digesters to facilitate heat transfer and keep temperatures uniform for the production of fuel-quality biogases.

Brevini S-Series gearboxes have been installed in hundreds of biogas plants throughout Europe and the Asia-Pacific region over the past 10 years. They are configured with water- and corrosion-resistant seals to propel drag chains and flights in the sedimentation tanks of wastewater treatment plants, and they meet strict international standards for preventing the ignition of flammable gases.

Providing maximum output torques of up to 140 kNm, Brevini S-Series gearboxes for wastewater treatment plants are custom-built with corrosion-resistant designs, special seals allowing for continuous submersion, and a high reduction range for improved torque.

"Dana has made a deep, robust commitment to supporting environmental responsibility in our operations, supply chain, and the products we create," said Jeroen Decleer, senior vice president, Off-Highway Drive and Motion Systems for Dana Incorporated. "Brevini S-Series gearboxes contribute to our sustainability initiatives by playing an integral role in the production of renewable biogases that reduce the reliance on fossil fuels."

brevinipowertransmission.com

Heidenhain

SPEED SENSOR OPTIMIZES MACHINE TOOLS

The new WMK 3010S rotational speed sensor from AMO is now available, and provides users of milling and turning machines a better option for operation of their main spindle. Besides providing speed data, the WMK 3010S also supports the capturing of operating status data of that spindle thus optimizing many costs related to the operation of the machine.

Available in North America through parent company Heidenhain, this new AMO speed sensor includes a USB interface which allows the operating status of the spindle to output to the machine control. This enables the user to record rotational speed, operating time, temperature and more.

The rugged, inductive, incremental scanning head on the WMK 3010S is available with a 1Vpp interface. It has a minimalist modular design, allowing this IP67-rated product to be installed in existing customer designs without significant modifications. It is available in the common industry line count increments and can be operated up to a max of 50,000 rpm.

heidenhain.us

Mach III

CUSTOM CLUTCH SIMPLIFIES SALMON CROWDER SYSTEM

Mach III recently supplied custom torque limiters for a salmon hatchery in Port Armstrong, Alaska. This hatchery uses moving fences — or "crowders" — to push adult salmon from one end of a 50-foot raceway to the other end, corralling the fish for egg and milt harvesting. The hatchery uses a direct drive motor system that must be manually operated.

Once the fish density reaches its predetermined limit, the operator turns off the drive. As the salmon are removed from the crowder's receiving end, the density lessens and the operator turns the drive on again to push more fish forward. In an ideal situation, the operator would activate the crowder, which would continuously push the fish forward as other salmon are removed, thus maintaining a consistent density.

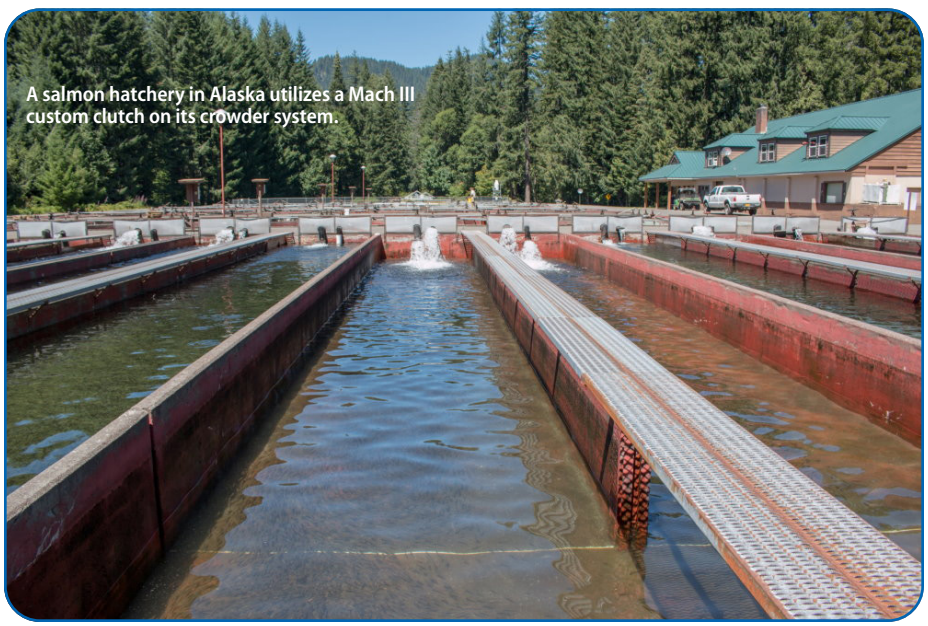
Although the company had friction torque limiters in place, these components required frequent disc replacement. What this company needed was a hands-off motion control solution that could begin slipping once the system reached its preset resistance point, all while inching the salmon forward with constant pressure.

To meet these application requirements, Mach III engineers designed a custom C5D2K-002 clutch to retrofit the hatchery's crowder system, enabling the operators to monitor the operation without worrying about manually turning the drive on and off. The clutch incorporates a dual port rotary union for actuation and is sealed for protection against the wet environment. The drive disc is ventilated via an air inlet and filter vent, allowing cool air to flow through the case and dissipating the 213-watt thermal load from the disc's continuous slipping.

Additional specifications of this custom clutch included 1,557 inch-pound (in-lb) capacity, operating pressure of 30–40 pounds per square inch (psi), and cooling air pressure at 5–10 psi.

In addition, because the initial rotations per minute specification was higher than needed, the hatchery installed a variable frequency drive (VFD) to reduce the drive motor speed, cutting down the friction temperature from 240° to 120°F. After installing the new clutch, the company has informed us that it has been functioning flawlessly, enabling the hatchery to successfully harvest 50 million eggs with zero problems. Thanks to the hatchery system's higher efficiency and throughput, our client can now begin its egg-take procedures without worry.

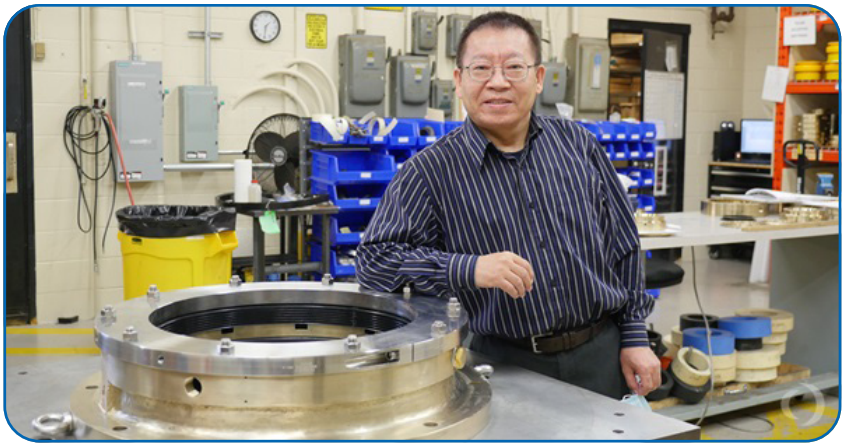
machiii.com



A salmon hatchery in Alaska utilizes a Mach III custom clutch on its crowder system.

Thordon Bearings

INTRODUCES WATER LUBRICATED SHAFT SEAL



Thordon Bearings BlueWater Seal is a new propeller shaft seal with a unique Safe Return to Port (SRTP) design that specifically meets commercial shipping industry needs for low maintenance and robust shaft seals. The Thordon BlueWater Seal completes the COMPAC open seawater lubricated propeller shaft bearing system.

Commenting on the development, Thordon Bearings' Technical Director, Anthony Hamilton, said: "The BlueWater Seal meets growing market demand for a complete propeller shaft line solution from a single source. Although we can offer the seal as an individual component, it forms a fundamental part of the Thordon COMPAC open seawater lubricated propeller shaft bearing system."

The COMPAC system includes Thordon's proprietary seawater lubricated COMPAC bearings, shaft liners, ThorShield anticorrosion shaft coating, a Thordon Water Quality Package, a Thordon Bearing Condition Monitoring System and the new BlueWater Seal.

The seal can be installed to all vessels with shaft diameters between 300 mm to 1,000 mm (11.8 to 39.4 in) and is simple to install, operate and maintain.

This technology, developed in-house by Chief Research Engineer Gary Ren, allows the facing elements of the seal to operate almost without any friction. In practical terms, it means the seal is much better suited to variable and low draught conditions — a key benefit to a globally operating merchant ship.

During comparative trials on Thordon's full-scale test rig in Burlington, Ontario, Canada, the seal operated without friction spikes and considerably less friction than similar seals leading to reduced wear, longer life and less maintenance.

"This seal minimizes water leakage and dramatically improves hydrodynamic and lubrication efficiency," explained Hamilton. "The development is a real boon to those ship owners and operators looking to adopt an open seawater lubricated shaft line arrangement as the entire propeller shaft line system can now be sourced from one company," he said.

thordonbearings.com

Breaking the 4th Industrial Wall

Trends in Mechatronics and Motion Control in 2022

Matthew Jaster, Senior Editor

Manufacturing is facing constant challenges stemming from labor shortages and disrupted supply chains to productivity declines and the high replacement and maintenance costs of legacy equipment. Trends in mechatronics and motion control include equipment upgrades, e-commerce, a push for more robotics and automation and faster software and IIoT solutions.

What to do with legacy equipment?

The options when it comes to machine upgrades today are limitless, but the most cost-effective strategy greatly varies on a case-by-case basis. Many machine builders will tell you legacy equipment data remains untapped and should not be pushed aside for newer technology, but instead incorporated. Data migration in legacy equipment is the process required to move data that was stored in an old system into a new system. The motion controller is a perfect example of this.

"Siemens does a great job in migrating legacy equipment," said Kevin Wu, motion controller product manager at Siemens Industry, Inc. "The PLC controller can do so much more today than it could in the past. The biggest obstacle might be that you can add *too* many features to a new controller today, so it becomes a challenge to determine how much goes into it and where or when should you stop."

"In the past, you'd have multiple motion controllers for vision, safety, drives, etc.," added Craig Nelson, senior product marketing manager at Siemens Industry, Inc. "Now you can put all of these capabilities in a single motion controller. This represents our push lately for ease of use. We're trying to make it easier to adapt these technologies for our customers and partners."

Process Control and Engineering is a Siemens Solution Partner that provides machine builders and OEMs with integrated engineering services. Project manager Alejandra Cota discussed how mechatronics plays a role in robotic integration today:

"Many of the projects we're working on involve integrating old CNC machines with robotic technology. For example, we recently integrated a 7-axis robot for complex handling into a legacy machine," Cota said. "This is where the industry is going. How do we make these old systems more efficient through the integration of mechatronics?"

The Siemens Mechatronic Systems Certification Program (SMSCP) combines the German dual education system with Siemens' in-house know-how.

She added that in her three years with the organization she's seen a major growth shift in the use of industrial robots. "These robots are able to replace some high-cost machines and they represent a huge opportunity today for companies to save money."

Maximizing shop floor efficiency

Ask any manufacturer what's at the top of their wish list in 2022 and many will respond with the same answer: increase manufacturing output and maximize shop floor efficiency. New robotic and automation solutions are created daily to address these challenges.

"The pandemic accelerated far-reaching global mega trends — from labor shortages and supply chain uncertainty to the individualized consumer and growing pressure to operate sustainably and resiliently — leading new businesses to look to robotic automation," says Marc Segura, robotics division president at ABB. "As technology opens new opportunities for meeting customer demands, new trends will continue to emerge that will further drive demand in areas where robots have traditionally not been used."

One trend today is sharing knowledge in order to create new international standards, automation technologies and IIoT utilization.

"KUKA is gaining valuable insight that we can incorporate so that global companies like Danfoss, Universal Robots or the LEGO Group can successfully drive forward the automation and digitization of their productions on a scientific basis," said Kim Reeslev at KUKA. "To achieve this, it must be as easy as possible to connect the individual machines in the production halls with the cloud. And it is precisely for this purpose that the open architecture of the Open Industry 4.0 Alliance has now been successfully trialed."

The Open Industry 4.0 Alliance in Europe enables its members to actively advance the fourth industrial revolution. It offers an opportunity for participating companies to exploit new synergies and

The adoption of robots is driving demand for new skills that require education and training.

accelerate company growth. The objective is to bring like-minded industrial companies together to promote interoperability and digitization.

openindustry4.com/de/

An emphasis on e-commerce

The pandemic didn't create the thriving e-commerce market taking place across both the consumer and industrial markets, but it certainly heightened its importance.

In 2021, Regal and Rexnord combined to create an expanded range of products and services. The merger included four distinct business segments including motion control, climate solutions, commercial systems and industrial systems. The newly formed Regal Rexnord Corporation highlighted its desire to provide conveying solutions that "keep e-commerce flowing."

Edge tools from Regal Rexnord include product selection modules for belt drive, bearing and gearing products and mechanical power components, as well as bearing registration and a belt drive efficiency calculator. These tools are easier to use, mobile-friendly and fully integrated. Edge product selection modules assist users in selecting the right power transmission mechanical components based on their specific application requirements. Once they install new bearings products, the bearing registration allows users to not only register their bearings but also manage assets on the Regal PT mobile app. The belt drive efficiency calculator helps users calculate how much money they can save on energy consumption by using Browning belt drives.

ABB also sees an e-commerce push in packaging, warehouse and distribution industries.

"This trend will see the growth of lighter, smaller robotic applications, enabling the expansion of automation into new areas of warehousing and distribution operations. As artificial intelligence in robotics matures and learning robots become mainstream, expect to see these technologies deployed alongside AMR technologies, orchestrated and managed by intelligent software to provide enhanced flexibility, speed and efficiency," Segura added.

Automation, motion and drives at Hannover Messe

Electric vehicles, medical applications, consumer goods, warehousing and distribution are just a handful of areas where robotics and automation are gaining momentum. Hannover Messe 2022, taking place May 30–June 2 in Hannover, Germany, is your best bet to see some of these technologies in real world applications.

Schaeffler, for example, will offer an expanded range of precision strain wave gears and a sensor-based strain wave gear, both for use in articulated arm robots with a payload of up to around 20 kg.

"We are adopting a new, innovative approach with the integrated torque sensors, both in design and technological terms, which has aroused considerable interest among our pilot customers," said Ralph Moseberg, head of the industrial automation business unit at Schaeffler.

Schaeffler will also present its portfolio of PSC-series high-precision planetary gearboxes for industrial robots in Hanover. These are characterized by a torsional backlash that is ten times lower and a service life that is three times longer than the market standard.

Mechatronic system products from Festo process a lot of data and compress it so that it can be used as diagnostics for maintenance. In the future, predictive maintenance on the basis of artificial intelligence will offer additional possibilities in comparison with traditional condition monitoring approaches. Data from the devices will be merged and evaluated using analytics models and cloud-based solutions. Festo will discuss some of these technologies during Hannover Messe.

"We have decades of application knowledge in sensors and actuators that we can now combine with domain and data science knowledge. This will open the door for artificial intelligence," said Jan Bredau, head of application software for system solutions at Festo.

Faster software and IIoT solutions

Mechatronics Concept Designer (MCD) from Siemens Digital has easy-to-use modeling and simulation which allows users to quickly create alternative design concepts early in the development cycle. Unlike a model-based tool, *MCD* allows you not only to see what it looks like but validate that it works. This validation is enabled by the re-use library, from which you can quickly add data to the functional model. This data includes joints, motion, sensors, actuators, collision behavior, and other kinematic and dynamic properties for each component. This allows a physics-based, interactive simulation to verify machine operation. This verification helps you detect and correct errors in the digital model.

Schaeffler will offer an expanded range of precision strain wave gears and a sensor-based strain wave gear during Hannover Messe 2022.

The fact that all the heavy lifting can

happen digitally is a sign of things to come.

"We react faster to everything today," Siemen's Nelson said. "We can get projects going in the simulated world in the cloud without any hardware. We're really making strides in how quickly some of these new technologies can come to market."

Wu said that Siemens can take any project with robotics and get it up and running as quickly as possible in 2022. "Instead of spending weeks and weeks on programming, we're looking at adaptability and user-friendly solutions that we can provide in days."

These solutions are incorporating AR and VR tools as well.

"Data collected from intelligently automated processes will be analyzed by producers to make more informed decisions. At the same time, more advanced and responsive simulation and programming software tools, such as those in ABB's *RobotStudio*, will cover the entire life cycle of robotic applications — from commissioning to onstream productivity — using AR and VR tools to simplify automation for customers," added Segura at ABB.

Nelson also mentioned the industries push for new power devices to make drives smaller and more efficient in the future, but he believes it will be a few years before this becomes a disruptive technology. "The priority today seems to be industrial communication," he said.

"Cloud computing, cybersecurity, all of these technologies that have been impacting consumer products are becoming more relevant in the industrial market," added Wu at Siemens. "This will impact motion control. Our end goal is to make these products and technologies less complicated."

abb.com
festo.com
kuka.com
hannovermesse.de/en
regalrexnord.com
schaeffler.us
siemens.com

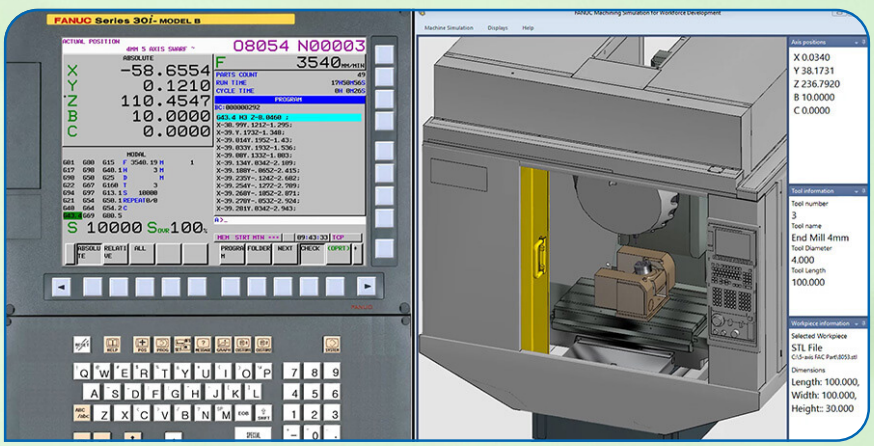
FANUC focuses on workforce development

As manufacturing adopts more robotics and automation, the industry will require its workforce to do different types of duties. FANUC America recognized years ago that while companies wanted to add more technology, there was not enough supply of skilled workers in the field to support the demand.

"We're deploying such advanced technology, such as with the emergence ofcobotsand data analytics, trying to get a workforce to keep up with that is very challenging," said Paul Aiello, executive director of education for FANUC America.

There are two pathways to workforce solutions, as Aiello explains: Upskilling incumbent workers and developing talent in the pipeline. "We work on both fronts," said Aiello. "For employers that want to upskill their workers in a very rapid, intense training course, we have FANUC Academy."

FANUC Academy offers coordinated workforce training, some funded through schools. Classes can also take place at FANUC locations. Additionally, in-house training solutions for businesses are available as well.



Machining Simulation for Workforce Development.

As for the acquisition side, FANUC America started the Certified Education Program, or CERT, to help build a talent pool filled with people that have current and relevant skills in manufacturing. Since the effort began in 2010, the CERT network has grown to over 1,300 partner schools. Through the partnership with FANUC America, these high schools, post-secondary colleges and universities, now offer education and certification programs using cutting-edge automation technologies that meet businesses' labor demands. "We make sure schools have access to real industrial equipment and real-world technical curriculum," said Aiello. "This is to ensure they are building a workforce that aligns with the industry's needs."

Whether future workers need to gain a basic understanding ofrobotic operations and programmingor need to understandintegration of advanced automation systems, FANUC America has a solution.

Automation and digital manufacturing will unlock opportunities for many businesses in the United States. Innovative manufacturers are looking at ways to seize on this opportunity now and make big investments in new processes and tools.

fanucamerica.com

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Rapid Advancement at Automate 2022

Robotics and automation will continue to enhance manufacturing production for the foreseeable future

Matthew Jaster, Senior Editor

Boston Dynamics has a mobile robot named Spot that can detect anomalies and prevent manufacturing floor shutdowns. FANUC, alone, boasts 100+ robot models for high-speed, high-precision shop floor applications. There's even a couple of KUKA robots scheduled to serve drinks at bars across the globe (*Editor's Note: See article on page 56*). Robots are faster, smarter and more versatile than ever before, but it's still that ole fashioned human element that will determine the outright success of these technologies.

"People will always be the most important part of an automated solution," said Jeff Burnstein, president of the Association for Advancing Automation (A3). "Plant managers, engineers and designers will take advantage of these technologies by letting the robots handle the dangerous and dirty work while they focus on designing solutions, overseeing production processes and collecting data."

They will all come together in Detroit, Michigan for Automate 2022, June 6–9, 2022 at the Huntington Place Convention Center to discuss the latest trends and emerging technologies in areas like robotics, automation, mechatronics and motion control. Burnstein, a 40+ year vet of the industry, said the exhibition will examine everything from autonomous mobile robots, and artificial intelligence to collaborative robots and enhancements to machine vision.

"Attendees are going to hear a lot about workforce development and they're going to encounter startups that are thriving in these markets," he added. "These are not far-fetched, futuristic topics you'd find in science fiction films — they are practical resources that can be applied across the manufacturing sector today."

Integrated Systems & Other Trends

By combining sub-systems or subcomponents into a more manageable platform, organizations can reduce operating costs, enhance productivity and improve efficiency. System integration in the mechanical power transmission segment involves areas like mechatronics and motion control.

The key to the expansion of automation lies with systems integration, according to Burnstein. "A lot of end customers deal through system

integrators," he said. "It's the reason we highlight at least two dozen system integrators at the front of Automate."

Another trend is e-commerce, where we've seen several advancements over the past decade. The pandemic forced suppliers to find methods to get products to their customers faster. This led to more autonomous robots, more picking technology, sortation, packaging, etc.

"The pandemic had all of us sitting at home ordering things online. There was just no way all these organizations could staff up appropriately even without the pandemic. Many still had difficulties keeping up with orders during the holidays, for example," Burnstein said. "Now every day is holiday time for a lot of these companies. This led to more mobile robots, even traditional robots involved in helping them meet the demand. This is something we'll be keeping a close eye on not just in the United States, but globally."

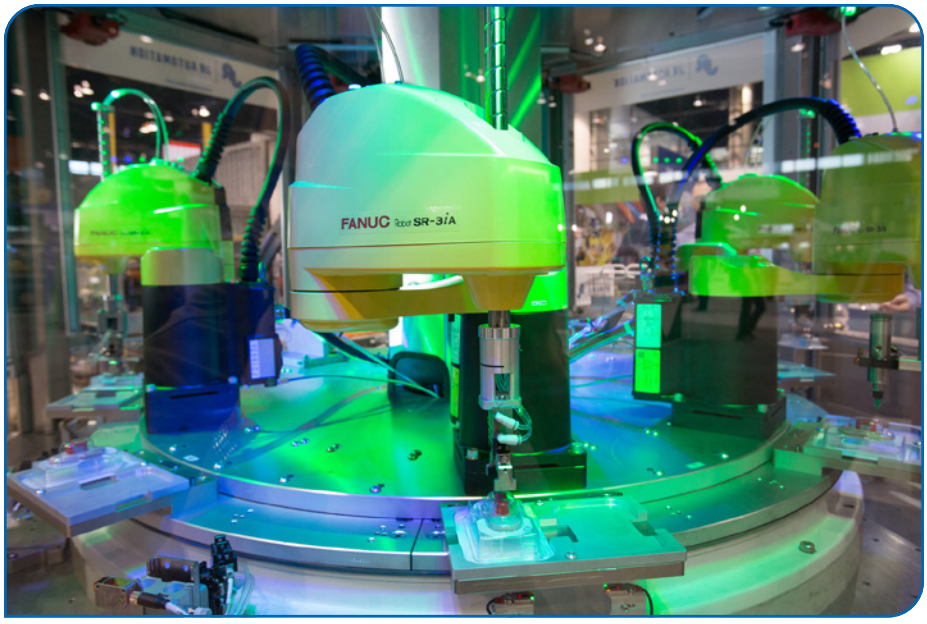
Data analytics is another evolving trend.

"You can collect all this data, but what are you really doing with it? How can this data help you better understand your processes? Companies are going to be looking for information like this. What can artificial intelligence do for me?" Burnstein added. "This is certainly of interest to small or medium-sized companies moving forward."

A Motor City Road Map

The showrunners are excited to be returning to the city of Detroit where many of these technologies were first established.

"When you think about manufacturing, automation and assembly lines, Detroit is at the heart of all that. It's a city that a strong association with automotive, but the city is expanding beyond automotive. Now you have all these other industries here like defense, pharmaceuticals, supply chain benefits being so close to Canada, etc.," Burnstein said. "We're impressed with how much the city and the State of Michigan is really promoting the show. It's also great to see how important workforce development issues are here in Michigan."



With its 3 kg payload, 400 mm horizontal and 200 mm vertical reach, the FANUC SR-3iA is ideally suited to smaller-scale robotic assembly, pick and place, inspection and packaging applications.

The Automate trade show is committed to Detroit for 2022, 2023 and 2025 when it gets back to its biennial cycle post-COVID. "Detroit has a lot of interest in making sure our automated future has a space for everybody," Burnstein added.

Launch Startups

The Cowen Startup Challenge, "Automate to Outperform" will take place on June 7, 2022. This year's competition is sponsored by Cowen, a multinational, independent investment bank and financial services company. Companies entering the challenge must:

Operate in the automation space (robotics, vision, motion control, AI)

Been founded in the last five years

Raised less than $5 million USD since creation

Not be affiliated with or belonging to a larger group

Ten finalists will vie for the top $10,000 cash prize by pitching their technology solution to a panel of industry expert judges. All finalists will also be awarded a complimentary exhibit space on the Automate show floor to engage with more than 20,000 attendees.

"The imperative to automate has never been a higher priority across virtually every industry and we increasingly look to the innovative, bright minds from startup companies to lead the way," said Peter Finn, managing director, industrial technology at Cowen. "Startup entrepreneurs play a critical role in the development of new technology."

Past winners include Innovative Mechatronic Systems B.V (2019) for its Archimedes Drive, a toothless gearbox; Apellix (2017) for its software-controlled aerial robotics; and Soft Robotics (2015) for its innovative gripping solution.

"There's so much money that's being invested in startups right now. This is a very unusual time in history for robotics and automation. I can tell you that there was a long stretch of time where people weren't really looking to fund robotics. Now, it's flipped. If you have a good idea, there's venture capital available for it. Last mile delivery, any kind of advances in picking, all these machine advancements that are being discussed. This startup competition reflects the exciting changes taking place across the industry," Burnstein said.

The ABB YuMi cobot is designed for a new era of automation where people and robots work side-by-side on the same tasks.

A Cultural Change

In the 1990s, the robotics and automation industries had its fair share of skeptics. There were concerns that the hardware couldn't evolve like the software; there were affordability issues; a general feeling that the industries were never going to be as big or as profitable as promised.

"Companies are now able to afford investments because of new business models such as leasing, robots as a service, etc. Costs have come down and there is so much opportunity out there," Burnstein said. "There's all these new warehouses and distribution centers being built, for example, and they're all going to be automated."

While many of these gains started within the automotive industry, Burnstein reflected on the changes that took place in 2020.

"In 2020, for the first time ever most robots ordered by companies in North America weren't for automotive applications. It wasn't that automotive was getting smaller, it's just that these other spaces were growing. Areas like

The PHD series offers seamless integration for Universal Robots that utilize standard PHD pneumatic grippers.

agriculture, construction, and restaurants. By next year, there's going to be more discussion on these emerging markets that really weren't prominent," Burnstein said.

Additional areas where robotic and automation demands increased in 2020 included life sciences, pharmaceuticals, biomedical and food and consumer groups.

Practicality & Purpose

The collaborative robot — or cobot — is a perfect example of how the industry is evolving. Here's a robot intended to physically interact with humans in a shared workspace on the manufacturing floor. Burnstein said that people like what the promise of collaborative robots offer a manufacturing operation. "Smaller investments, quicker assembly, the flexibility to provide a safer working environment.Small to medium-sized companies can very easily find a situation where the implementation of a collaborative robot on the manufacturing floor will assist with a practical application."

A3's main objective is to provide companies with the information they need to apply these robotic and automation technologies. "This is accomplished with webinars, training sessions, case studies and trade shows like Automate," Burnstein said. "The warehouse industry used traditional lift trucks, cranes, etc. ten years ago, but robotics and automation are playing a much larger role in that space today."

How can collaborative robots benefit your operation? How can automation reduce manufacturing floor complexity? How can the industry simplify the tools to make these technologies more accessible? These are some of the questions that will be examined when the industry comes together in Detroit this summer.

"You need designers, installers, manufacturing leadership to play a role in this. It's the people that are going to change the workforce in the future, and the robotic and automation technologies will reenforce these changes."

automateshow.com

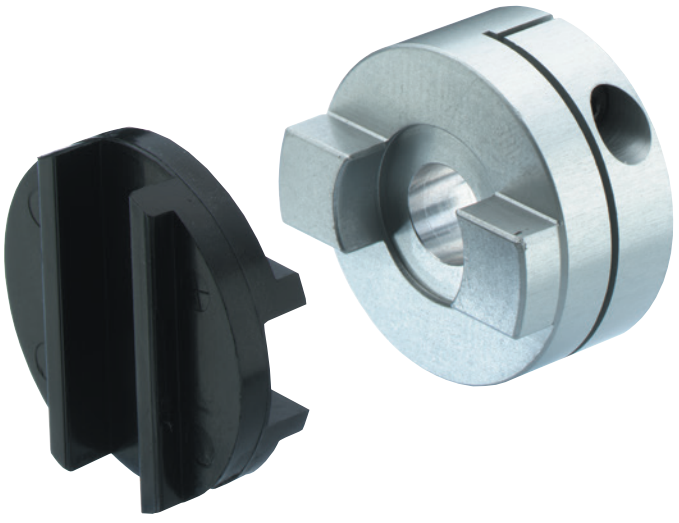
Annual order summary in North America for robotic units.

The Flexibility Factor

A Closer Look at Huco Oldham Coupling Customization

Matthew Jaster, Senior Editor

A flagship coupling in the Huco range, the Oldham solves the problem of side forces due to misalignment.



Exploded version off the Oldham coupling.

Misalignment couplings that bend or flex do cause some side loading on bearings and shafts as the coupling tries to spring back. Of course, over prolonged use this can result in rapid deterioration of bearings, extra load on the motor, and eventual coupling fatigue.

The Oldham coupling design accommodates misalignment by allowing sliding between metal hubs and a plastic disc so not to create any lateral forces. This effectively protects equipment from the side loads, improving reliability. Discs are made from engineering plastics, and are replaceable and interchangeable for different properties. Standard discs are Acetal, for strength, but Nylon discs can also be chosen for resilience, or damping properties. PEEK discs are sometimes chosen to insulate against electric current leakage or heat transfer. Furthermore, the disc can provide overload protection, as it will break under extreme load to protect associated equipment. The Oldham's three-piece construction allows easy assembly and installation too. While a general-purpose coupling, the Oldham is particularly suited for use in stepper driven positioning, as it handles high torques while still delivering high accuracy.

"Various available Oldham coupling disc materials provide users with the flexibility to tailor a coupling to meet their specific application requirements," said David Lockett, Huco managing director.

Capping and filling machine (courtesy of Cap Coder).

Custom Demands

The precision applications that Huco's couplings are designed to fit demand a high level of specialization. The design of a motion systems in, for example, medical devices or food production lines varies greatly, so a 'one size fits all' approach isn't optimal for precision couplings. The coupling may have to fit a predetermined shaft size or operate within the constraints of existing device packaging. To meet this need, Huco can extensively customize couplings to meet unique requirements.

Huco can design and deliver custom Beam, Bellows and Oldham couplings to fit shafts from <1 up to 50 millimeters in diameter. Designed to provide couplings in low volumes to support prototyping, testing or small production runs, customers can expect the design process to be complete in a

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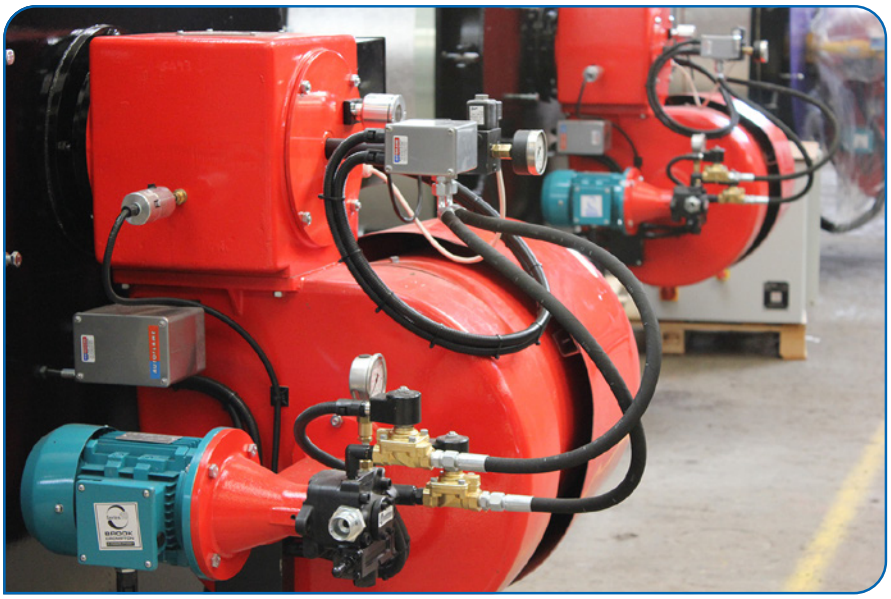

Cochran engineers selected Oldham couplings from Huco to meet its burner performance specifications.

few days and orders produced and delivered within 10 working days.

The service is enabled thanks to a high-tech lean manufacturing facility which allows custom designs to be realized quickly. This also means that Oldham and Beam couplings can be machined onto custom shafts as a complete assembly. Injection molding and 3D printing are also available to produce unique components.

Different coupling designs accommodate misalignment in different ways. Huco's standard range of couplings offers design engineers a wide range of solutions to accommodate it, along with consistent zero-backlash capabilities, to safeguard the reliability of associated equipment.

Couplings with zero-backlash were needed to support Cochran's burner models.

However, when it comes to specifying couplings for precise machinery, a standard coupling will not always provide the specialization that is often required.

"For engineers requiring a single coupling, machine builders building and testing a new prototype or device makers starting a production run—an off-the-shelf item may not provide an optimal solution to secure reliability and performance," Lockett said.

"To serve these specialized devices and machines, Huco has built a global customization service based on a proven range of standard couplings," Lockett explained. "Our extensive in-house capability means that custom solutions can be delivered efficiently, exactly to specification. Ultimately, we've found that providing couplings for precision applications is anything but standard."

Application Examples: Cap Coder and Cochrane, Ltd.

Cap Coder, a British manufacturer of standard and custom capping, filling, labelling and coding machines, needed precision couplings for use on its equipment. The couplings connect the drive motor to the torque capping heads on low-to-medium volume filling and capping machines utilized by beverage and pharmaceutical customers.

Positioned within the main capping torque head, the coupling is considered one of the machine's most critical components as it reliably and repeatedly transfers power, while maintaining position and controlling the applied torque to the container cap.

After a review of available alternatives, Cap Coder chose to install Huco Oldham couplings on all capping head assemblies incorporated on its various machines. Oldham style couplings were selected due to their precision and reliability. Cap Coder has not had a Huco coupling failure on any of its machines that have been in service less than five years, many operating on 24/7 production schedules.

The Oldham coupling design transmits torque through a central disc that slides over tenons on the hubs under controlled preload conditions. To meet the capping torque head requirements, Huco supplies complete three-part Size 33 Oldham couplings comprised of two aluminum clamp-style blind hubs and an acetal disc that provides high torsional stiffness and long backlash-free life. The 1.31 in. (33.3 mm) dia. couplings feature a 79.7 in lb. (9 Nm) peak torque rating.

"Precision couplings are essential for transmitting power to the capping head and maintaining position control," said John Walsh, sales director at Cap Coder. "The Oldham coupling provides us with both precision and reliability in

application. The performance of the coupling as part of our CC720 Mk IV capping head has been more than satisfactory."

He continued, "The Oldham is now featured in all capping heads that we produce, becoming a part of every capping and filling machine in our range. This decision has been vindicated, as we have never experienced a coupling failure on one of our machines that is less than five years old."

Cochran, Ltd. is a global designer and manufacturer of industrial boilers and burners. The company needed reliable precision couplings for use on its range of combustion burners. The couplings are fitted between air servomotors and dampers on most burners. On some burner models the couplings are installed between gas servomotors and butterfly valves.

Various coupling solutions were explored. However, most couplings did not offer the precision required and suffered backlash and eventual failure resulting in poor combustion and excessive emissions.

Ultimately, Cochran engineers selected Oldham couplings from Huco to meet its burner performance specifications. The precision engineered Huco couplings provide stable movement with no backlash throughout the actuated range. This results in reliable combustion and reduced emissions.

Huco supplies complete three-part Size 41 Oldham couplings to meet the requirements of most Cochran burner models. The through bore couplings are comprised of two aluminum clamp-style hubs and an acetal disc that provides high torsional stiffness and long, backlash-free life. The 1.62 in. (41.3 mm) OD couplings feature a 151 in.lb. (17 Nm) peak torque rating.

Since introduction of the Huco Oldham coupling, Cap Coder has not had a coupling failure on any of its machines.

altramotion.com/en/our-brands/huco

Learn more about the history of the Oldham coupling here:
powertransmission.com/articles/225-john-oldham-the-coupling-personified

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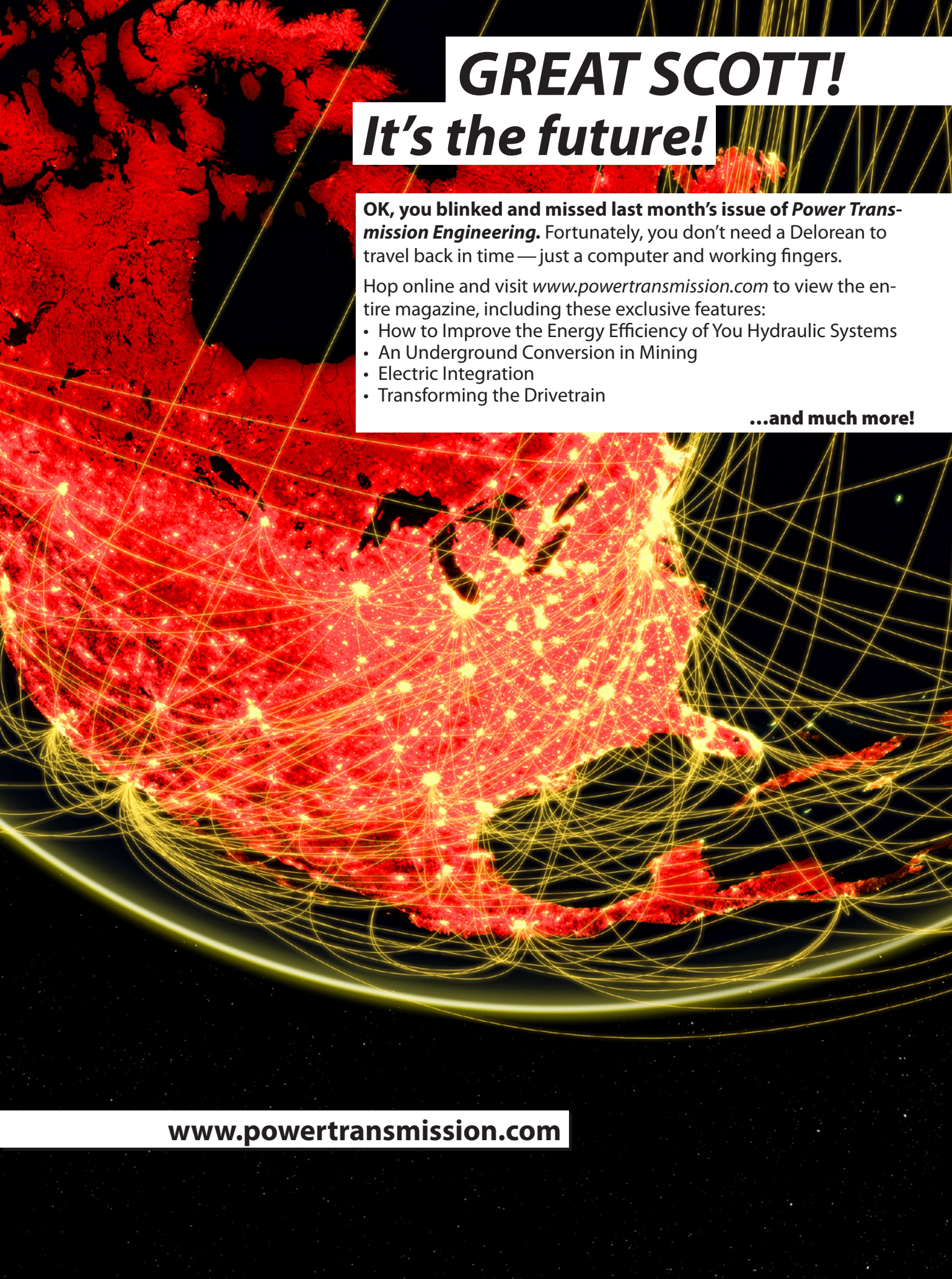

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Holistic Evaluation of Involute Gears

Anita Przyklenk, Tom Reavie, Martin Stein and Robert Frazer

State of the Art in Gear Metrology

Gear evaluation strategies for testing the surface geometry of involute gears are commonly carried out according to the standard ISO 1328-1 (Ref. 1) and VDI/VDE guidelines aiming for the determination of helix, profile (Ref. 2) and pitch deviations (Ref. 3). These deviations refer to single helix, profile line, and pointwise inspections of specific gear teeth, which is sufficient in most cases and has been demonstrated by international intercomparisons (Refs. 4, 5). The deviations on the gear flanks are caused by manufacturing defects due to various error sources. Therefore, identifying these error sources is essential for the improvement of manufacturing processes.

Two different types of defects can occur during the manufacturing process (Refs. 6, 7). First, systematic defects caused by the positioning of the tool, tool wear, or other sources. This results in the same, reoccurring deviation on each tooth. Therefore, the associated systematic manufacturing defect can be specified, if only single teeth are tested. Second, individual defects caused by changing conditions during the manufacturing process like temperature gradients, tool vibrations, spindle positioning errors and other drifting effects. Individual manufacturing defects can occur on any tooth and can only be accurately evaluated if all teeth are tested (e.g. Ref. 7). In order to characterize different sources of defects properly, measurements should refer to a common reference coordinate system, and an error separation method has to be applied. However, error separation is most efficiently achieved when all measurements have taken place in the same reference coordinate system. A common reference system would also lead to a more accurate determination of the deviations. So far, this approach has not been established in gear metrology.

As well as evaluation of profile, helix and pitch deviations, harmonic analysis of measured 2D trace data is routinely used by some industries to control gear noise (Refs. 8–10) and characterize machine tool performance (Refs. 11, 12). Evaluation of 3D surface measurement data has not been investigated.

Introduction

This article consists of two parts: holistic evaluation and residual analysis. The first part is on the holistic gear surface evaluation approach, where the 3D model strategy is introduced, followed by a description of the holistic evaluation algorithm and one application example. By means of the application example, two possibilities are presented which use different determined geometry parameters to describe the gear surface. In the second part (Analysis of Harmonic Content), obtained residuals of both inversion methods are analyzed regarding their harmonic content by means of discrete fast Fourier transformation (FFT) and discrete wavelet transformation (DWT). These transformations are introduced in the simpler 2D case using synthetic and measured data, then expanded to 3D using pseudo-measured data. Figure 1 gives an overview on the structure of this article.

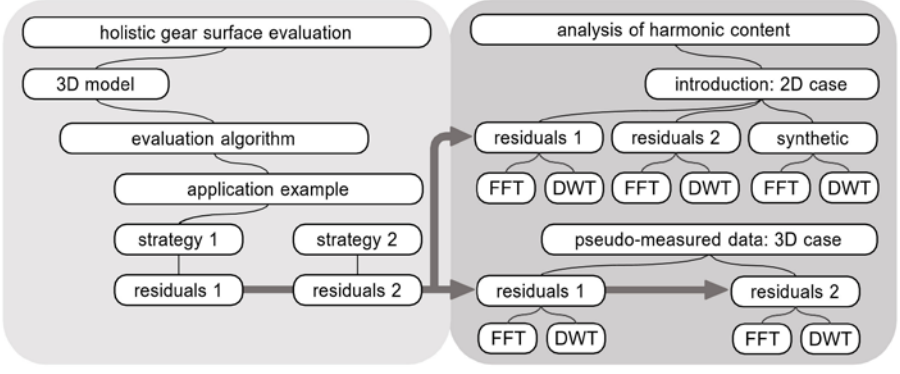

Figure 1 Structure of the presented work.

Holistic Gear Surface Evaluation

3D-Gear Model Strategy

A three-dimensional surface model according to Härtig and Stein in their article "3D involute gear evaluation — Part I: Workpiece coordinates," (Ref. 13) has been applied as a so-called form element, which is an essential part of the inversion algorithm's objective function. The origin of the coordinate system is located on the center of the non-datum face. The Cartesian coordinates (x,y,z) on the gear surface are described by involute coordinates (r, φ_b, z). Therefore, the involute gear's surface is expressed with

$$\begin{aligned} x &= r \cdot \cos(\varphi_b + hand \cdot c \cdot z + flank \cdot \mathrm{inv}(\alpha_t)) \\ y &= r \cdot \sin(\varphi_b + hand \cdot c \cdot z + flank \cdot \mathrm{inv}(\alpha_t)) \\ z &= z \end{aligned} \tag{1}$$

where *hand* and *flank* denote the slope direction and the tooth flank direction, respectively. The following relations apply:

- radius r in mm
  $$r = r_b / \cos(\alpha_t) \tag{2}$$
  with the base radius r_b in mm and the transverse pressure angle a*t* in rad
- helix coefficient in mm/mm describes the value of the helical slope

$$c = \tan(\beta_b)/r_b \quad (3)$$

with the helix angle at base circle βb in rad

- involute function in the transverse plane in rad

$$\mathrm{inv}(\alpha_t) = \tan(\alpha_t) - \alpha_t \quad (4)$$

with the transverse pressure angle αt in rad

The relation between the transverse pressure angle α_t and the radii is as follows

$$\alpha_t = \arccos(r_b/r) \quad (5)$$

Holistic Gear Evaluation Algorithm

In order to realize holistic gear evaluations, a three-dimensional object-orientated inversion algorithm has been implemented in *MATLAB*. The core of the algorithm is based on the approach by Sourlier and Bucher in their article "Exact best fit algorithm applicable to sculptured surfaces or to any non-regular surfaces in parametric form," (Ref. 14) aiming to fit parameterized form elements S into a measured point cloud $P_n = (x_n, y_n, z_n)$ that is composed of helix and profile measurements of all gear flanks, by solving a non-linear least squares problem with the Gauss-Newton method. A special feature of this approach is the distinction between three kinds of degrees of freedom. Those are the running parameters of the parameterized involute gear surface summarized in matrix $U = (z, \alpha_t)$, the geometry parameters represented in parameter vector $p = (r_b, \varphi_b, \beta_b)$ and the pose parameters to enable rotations and translations by applying a rotation matrix A and a translation matrix T on the form element during the inversion respectively.

This method allows the separation of dimension, form and pose. If, in addition, the helix and profile line measurements of gear surfaces were carried out in a common reference system, an error separation procedure is applied automatically. This allows an enhanced determination of deviations leading to an improved ability to determine manufacturing defects.

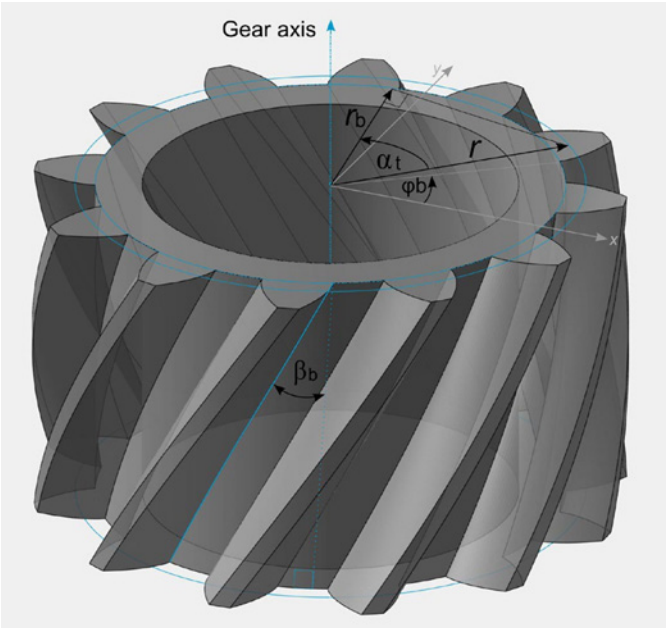

Figure 2 Involute gear with its coordinate system and geometry parameters.

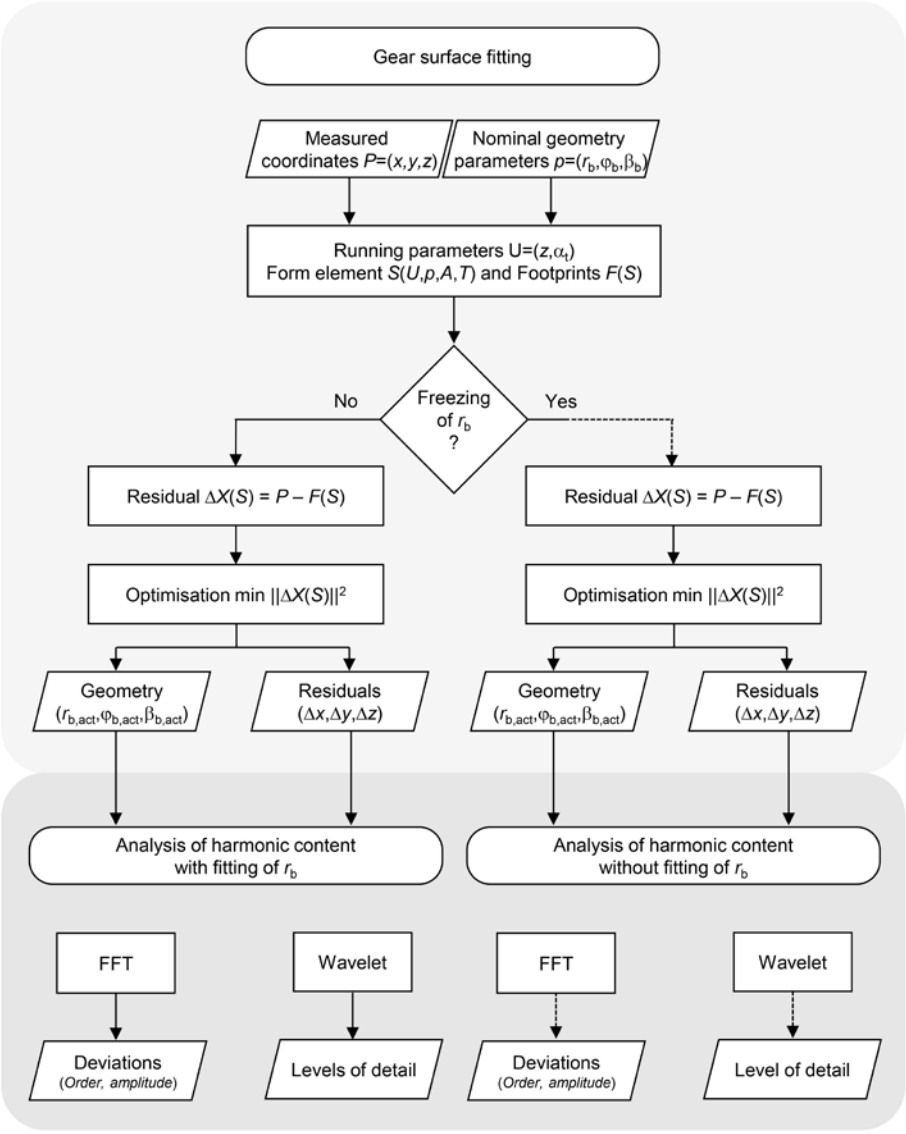

Figure 3 Flowchart of the holistic evaluation approach.

The objective function consists of residuals calculated by the difference between n measured points P_n and n projected foot points $F_n(S)$ on the surface of the shape element $S(U,p,A,T)$.

$$\Delta X_n(S) = P_n - F_n(S). \quad (6)$$

The objective function to be minimized is calculated with

$$\min \|\Delta X_n(S)\|2 \quad (7)$$

where ||...|| denotes that the Euclidian norm has been applied.

The optimization process is finished as soon as one of two defined termination criteria is achieved. Either when the specified maximum value for the iterations is reached, which is 25, or after the threshold for the solution update is reached, which is 10^{-12} mm.

The obtained inversion result consists of geometry parameter sets for each individual gear flank and the associated residuals.

In order to provide a connection to conventional evaluation procedures two possible settings have been implemented. Firstly, the algorithm also applies to 2D-single helix and 2D-profile measurement evaluations. Secondly, there is the possibility to freeze specific parameters during the inversion process. For example, the base radius can be set to be nominal and consequently would not be taken into account as with conventional evaluations.

In the second stage of the novel evaluation method, the determined geometry parameters and the corresponding residuals were used to perform an analysis of the harmonic content on the shape deviations. For this purpose, the 3D-residuals have been unwound over their reference lengths and analyzed by means of fast Fourier transformation (FFT) and discrete wavelet transform (DWT) as discussed in the second part of this paper. The final result is a set of deviations described by order and amplitude (FFT) and level of detail (DWT). Figure 3 shows the workflow of the evaluation steps by means of a flowchart.

Application Example

A workpiece-like artifact featuring different types of microgeometry corrections (also referred to as flank modifications) has been measured on a high-precision coordinate measuring machine under temperature-controlled laboratory conditions with $T = 20°C \pm 0.2K$. The nominal parameters of the artifact are summarized in Table 1 and Figure 4 shows a photo of the artifact.

Nine helix line and nine profile line measurements were carried out on each flank. A total of 432 lines were measured to map the surface of the 24

Table 1 Nominal gear parameters of the artifact

Number of teeth N	12
normal module mn/mm	12.000
normal pressure angle an/deg	20.0000
helix angle β/deg	30.0000
base circle diameter/mm	153.289
facewidth b/mm	110.000

Figure 4 Gear artifact.

Table 2 Overview of inversion results, which are the geometry parameters rb, jb and bb for 24 flanks of the twelve gear teeth. Nominal rb is put in brackets.

tooth	r_b fitted	r_b le/mm	φ_b le/rad	β_b le/rad	r_b ri/mm	φ_b ri/rad	β_b ri/rad
1	yes	76.650302	6.236183	0.489148	76.628715	5.856188	0.488996
	no	(76.644581)	6.236219	0.489117	(76.644581)	5.856287	0.489083
2	yes	76.636606	5.712631	0.489043	76.626965	5.332570	0.488983
	no	(76.644581)	5.712581	0.489085	(76.644581)	5.332680	0.489080
3	yes	76.637858	5.189084	0.489078	76.633454	4.809085	0.489018
	no	(76.644581)	5.189055	0.489114	(76.644581)	4.809155	0.489079
4	yes	76.631840	4.665440	0.489074	76.626543	4.285656	0.488958
	no	(76.644581)	4.665359	0.489142	(76.644581)	4.285769	0.489057
5	yes	76.635290	4.141934	0.489057	76.630183	3.761839	0.489033
	no	(76.644581)	4.141876	0.489107	(76.644581)	3.761929	0.489112
6	yes	76.631258	3.618153	0.489076	76.624655	3.238284	0.488978
	no	(76.644581)	3.618069	0.489147	(76.644581)	3.238409	0.489088
7	yes	76.632840	3.094693	0.489063	76.628654	2.714682	0.488999
	no	(76.644581)	3.094619	0.489125	(76.644581)	2.714782	0.489086
8	yes	76.642853	2.570870	0.489177	76.636152	2.191390	0.488972
	no	(76.644581)	2.570859	0.489187	(76.644581)	2.191443	0.489019
9	yes	76.634810	2.047368	0.489043	76.632809	1.667267	0.489020
	no	(76.644581)	2.047306	0.489095	(76.644581)	1.667341	0.489085
10	yes	76.639058	1.523792	0.489123	76.632667	1.143961	0.488982
	no	(76.644581)	1.523757	0.489153	(76.644581)	1.144036	0.489047
11	yes	76.655610	1.000059	0.489168	76.648719	0.620139	0.489112
	no	(76.644581)	1.000128	0.489109	(76.644581)	0.620113	0.489089
12	yes	76.655627	0.476441	0.489193	76.648067	0.096674	0.489117
	no	(76.644581)	0.476511	0.489134	(76.644581)	0.096652	0.489098

gear flanks. The density of the scanned points is specified by the difference of neighbored measuring points on the surface by means of the running parameters a*t* and *z*. The minimum helix and profile line angular resolution is ≈0.6 rad and along the *z*-coordinate ≈1.1 mm and ≈11 mm respectively.

The gathered lines are collected in one single point cloud and have been evaluated as described in the Holistic Gear Evaluation Algorithm section, above.

Geometry Parameters

In order to figure out individual manufacturing errors, fitted geometry parameters are available for each tooth per its left and right flank. The evaluation was carried out as illustrated in Figure 3. In one case r_b has been fitted ($r_{b,act}$) and in another case r_b was frozen at the nominal value ($r_{b,nom}$). A summary of the data of the determined geometry parameters is given in Table 2.

Nominal r_b is larger than the actual fitted with the exception of teeth 1, 11 and 12. The largest difference is on tooth 6 with $\Delta r_b = r_{b,act} - r_{b,nom} = 13.323\,\mu m$ at the left flank and $\Delta r_b = 19.926\,\mu m$ at the right flank. The smallest differences are located on the left flank of tooth 8 with $\Delta r_b = 5.523\,\mu m$ and on the right flank of tooth 12 with $\Delta r_b = 3.486\,\mu m$.

This difference is shown for all determined geometry parameters $\Delta = p_{act} - pnom$ in dependence of the tooth number in Figure 5. Figure 5a shows the difference of radii on left flanks. Those of φ_b and β_b are illustrated in Figure 3b. Figure 5c and 5d show corresponding results for the right flanks.

Whenever $r_{b,nom}$ does not meet $r_{b,act}$, the inversion algorithm tried to compensate this misfit by adapting the other geometry parameters φ_b and β_b. For instance, in Figure 5a Δr_b is positive on tooth 4, which means that $r_{b,nom}$ is larger than the actual $r_{b,act}$. This leads to a reduced φ_b in Figure 5b and to an enlarged φ_b in Figure 5d.

The effect is reversed when the nominal value is smaller than the actual one, as indicated by tooth 11 and 12 in Figure 5a and Figure 5c. The left flank has been fitted with an enlarged φ_b in Figure 5b and a reduced φ_b in Figure 5d.

If r_b is not fitted, then the influence on the angles is observed on all teeth with one exception that is tooth 1.

The correlation between $\Delta\beta_b$ and Δr_b is caused by the relationship given in Equation 2. To achieve a certain value for the actual helical slope, β_b has to be increased if nominal $r_{b,nom}$ is larger than $r_{b,act}$ and has to be decreased if $r_{b,nom}$ is smaller than $r_{b,act}$. This correlation is observed for left and right gear flanks.

Residuals and Form Deviations

In addition to the determined geometry parameters, the residuals $DX(S)$ of the holistic evaluation according to Equation 6 were also examined. Figure 6 depicts $DX(S)$ in µm obtained by inversion with fitting of r_b. $DX(S)$ is shown at the position of the form element S with color coding. Red denotes plus metal and blue minus metal. In the green areas $DX(S)$ approaches to zero. Individual manufacturing deviations on each tooth flank are represented in one single reference coordinate system. Some of the teeth (4,6,7,8,10,12) are obviously manufactured with helix crowning. On the basis of $DX(S)$ introduced here, the enhanced determination approach of profile deviations is described in the section "Analysis of Harmonic Content," below.

A comparison of the foot points on the shape element $F(S)$ acquired by

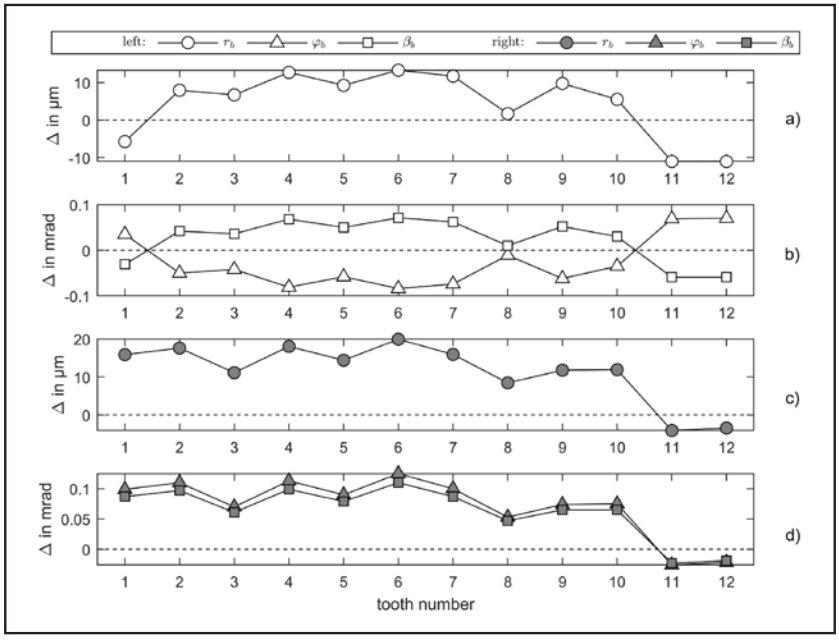

Figure 5 Differences between geometry parameters obtained with and without fitting rb.

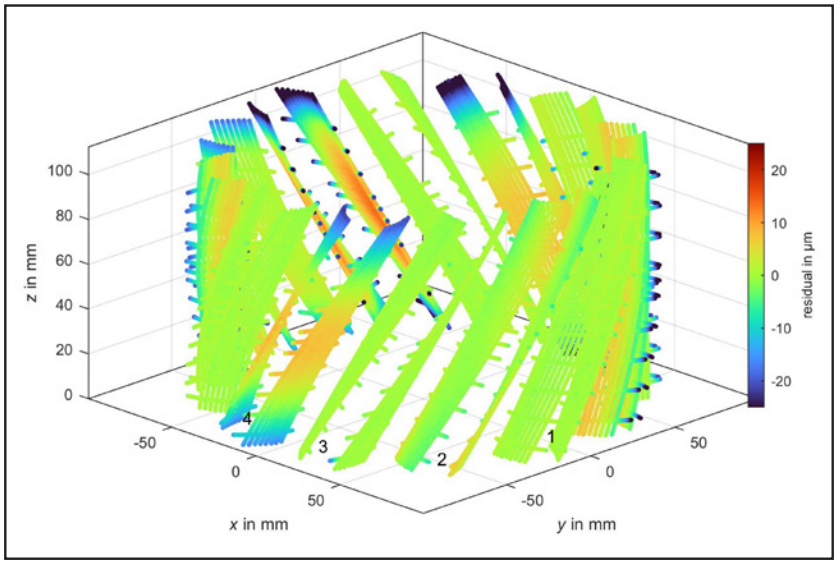

Figure 6 Residuals obtained by the inversion result with base radius fitting. Tooth 1 to 4 are labeled.

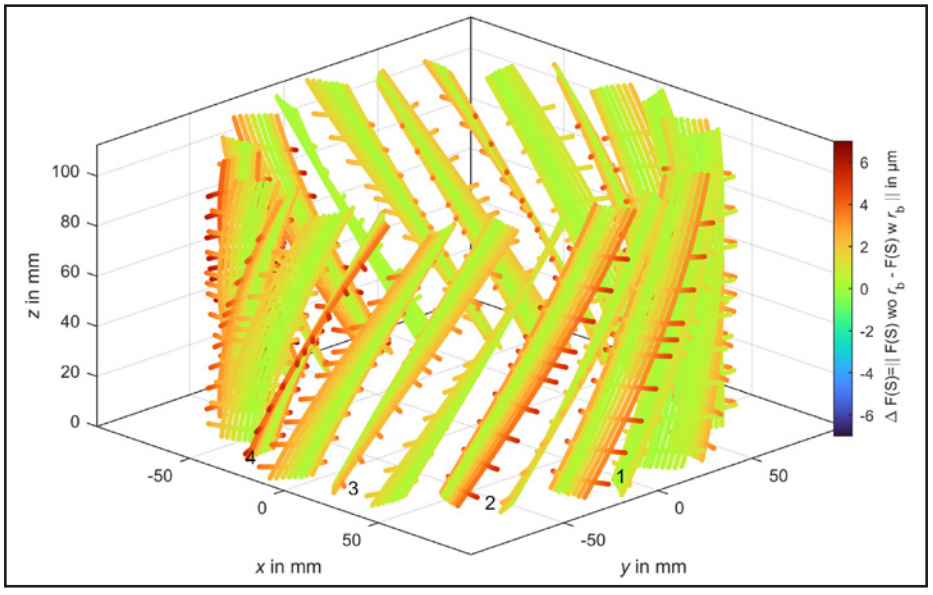

Figure 7 Difference between obtained foot points without and with fitting. Tooth 1 to 4 are labeled.

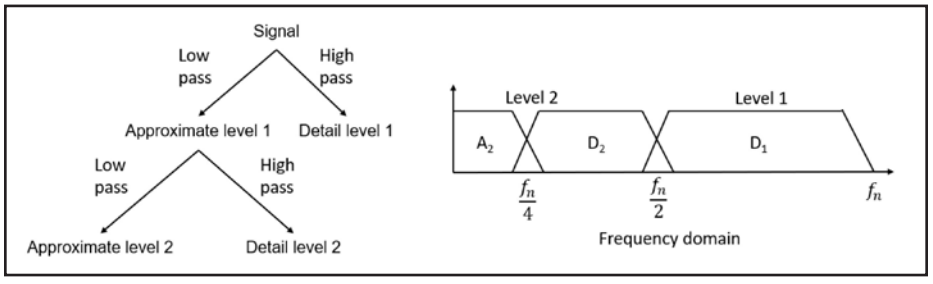

Figure 8 Discrete wavelet transform (a) multiresolution analysis flow chart (b) frequency coverage of coefficients.

Table 3 Synthetic profile harmonic content

Amplitude in µm	Order	Location
2	1	Full trace
1	7	Full trace
1	9	Full trace
0.5	30	Full trace
0.5	50	40 to 50 mm length of roll

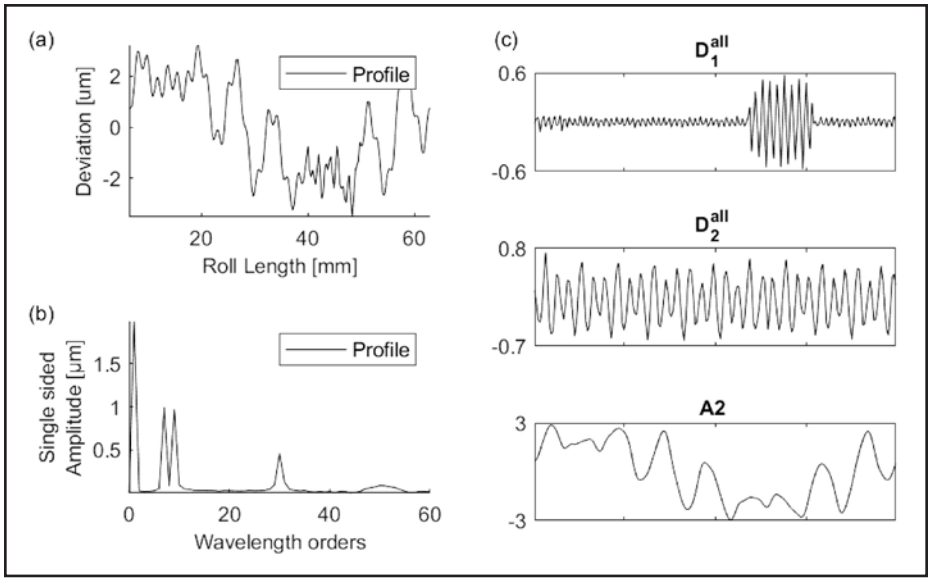

Figure 9 Synthetic profile (a) trace (b) DFT single sided spectrum results limited to 60 orders (c) DWT levels of detail.

the two inversion methods with and without fitting of r_b is discussed based on Figure 7. $\Delta F(S)$ is calculated with the Euclidean norm of the distance between $F(S)$ without and with fitting of r_b. $\Delta F(S)$ is shown at the coordinates of the form element S determined with fitting of r_b. Whenever nominal and actual r_b are particularly far away from each other, the gear flanks are depicted in red as a function of the radius as illustrated on tooth 2 and tooth 4. This effect is particularly significant close to the base and addendum circle.

Tooth 4 will be investigated in Section 4.3 in detail. On tooth 4, the conventional from deviations of profile, helix (VDI/VDE 2021-1:2018(E), Ref. 2) and pitch (VDI/VDE 2613:2003, Ref. 3) taken from the measuring protocol of the CMM are:

$f_{H\alpha}{}^{le} = -9.256\,\mu m$ and $f_{H\alpha}{}^{ri} = -12.763\,\mu m$ at $L_{AE} = (153.530–196.000)\,mm$

$f_{H\beta}{}^{le} = -1.194\,\mu m$ and $f_{H\beta}{}^{ri} = -3.468\,\mu m$ at $b = 110.000\,mm$

$F_p{}^{le} = 6.384\,\mu m$ and $F_p{}^{ri} = 15.578\,\mu m$ at $r = 111.277\,mm$

Analysis of Harmonic Content

Harmonic Evaluation Methodology Background

The discrete Fourier transform (DFT) splits a signal into sine waves and is used in numerous applications to analyze the frequency content of a signal. It is calculated using the fast Fourier transform (FFT) — an optimized implementation of the DFT (Ref. 15). The Fourier transform has only frequency resolution and no position resolution, computing only if a frequency occurs across the whole signal but not where it occurs.

The discrete wavelet transform (DWT) splits a signal using wavelets (Ref. 16). Many different wavelets exist and can be tuned for specific applications (Refs. 17–20). Discrete wavelets are not continuous and are scaled and translated to discern information about both frequency and position. A common strategy with a wavelet transform is multiresolution analysis, where the signal is split into sub-signals which represent different frequency ranges of the original. This works as a filter bank where the signal is high and low passed, using the wavelet as the filter, splitting

the signal into detail and approximate sub-signals relating to high and low frequency content respectively, as seen in Figure 8a (Ref. 21). At the next level the approximate signal is split again covering successively narrower frequency bands (Fig. 8b). This has the effect of giving greater resolution in time for higher frequency content which allows us to know information about the position of frequency as well as the order.

The signal can be reconstructed at any level of detail by combining the lowest level approximate sub-signal and the related detail sub-signals. This is useful because machining or surface finish characteristics can be limited to a frequency range which when separated are easier to understand. ISO 16610-29:2020 performs a multiresolution analysis using spline wavelets and has examples for a milled surface and ceramic surface (Ref. 22).

2D Trace Analysis

A synthetic profile has been constructed with the harmonic content in Table 3 to demonstrate the two transforms. The 50th order harmonic occurs over a section of profile to provide a simple representation of a damaged region, or a region affected by temporary vibration of a machine tool. The synthetic trace and analysis by DFT and DWT are shown in. The DWT was used to perform a two-level multiresolution analysis using Daubechies wavelet 6 (db6).

Considering the DFT single sided frequency spectrum (Fig. 9b), the harmonic amplitudes have been correctly calculated for the first four harmonics but the 50th order harmonic amplitude cannot be discerned and is spread around several orders. However, the DWT has correctly identified the existence of the 'damage' in the detail level 1. It is not possible from Figure 9c to identify specific harmonic frequencies but the effect of harmonic content from a range of frequencies can be seen in each subplot with orders 1, 7, and 9 in A2, order 30 split between D2 and D1, and finally order 50 in D1.

Tooth four measured mid profile inverted with base radius fitting has been analyzed in Figure 10. The deviations are from the involute form element in the transverse plane. A 1st order sine wave is obvious in the DFT plot (Fig. 8b) with an amplitude of almost 0.7 microns, with the next highest at the 5th order with an amplitude of 0.25 microns. Otherwise, there is no obvious other harmonic peaks, a common problem with high quality gears where the deviations, and thus harmonic amplitudes, are very small.

The DWT (Fig. 10c) highlights a waviness profile in D2 and D1 with a range of 0.6 microns. This is where the DWT and multiresolution analysis can be useful to monitor machine tool performance or surface finish performance. For example, cutting errors due to machine tool vibrations may not be in the same coordinate axes and will not directly relate to a harmonic in the DFT plot, or may not exist for the full cutting time and would then be spread around the frequency plot. The DWT levels of detail show the effect of vibrations without having to know the frequency.

Another example of this is in Figure 11, which is the same profile but evaluated without fitting the actual base radius and exaggerated profile slope. Without first removing the slope or windowing the signal the DFT plot (Fig. 11a) has many frequencies spread across the spectrum obscuring any useful frequency information. However,

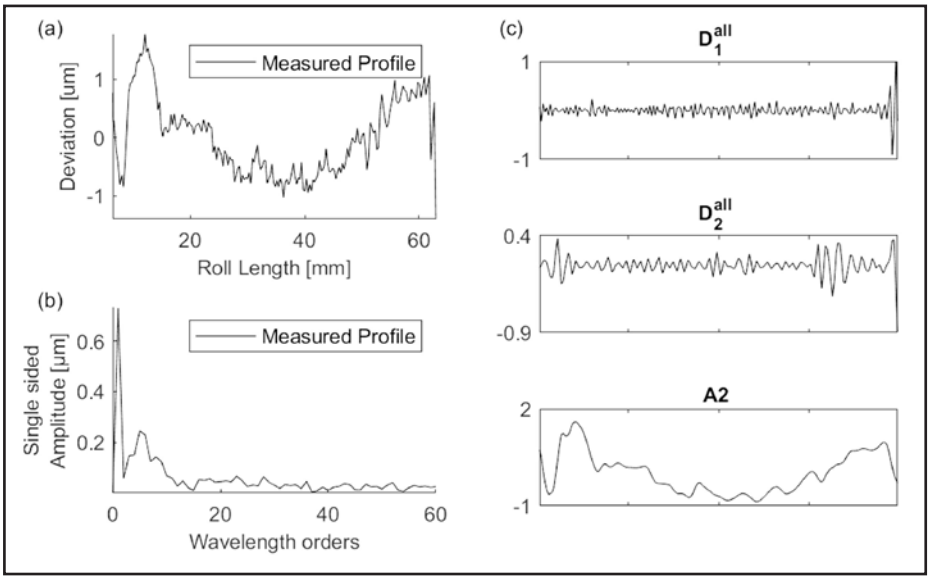

Figure 10 Measured profile fitted with rb (a) trace (b) DFT single sided spectrum results limited to 60 orders (c) DWT levels of detail.

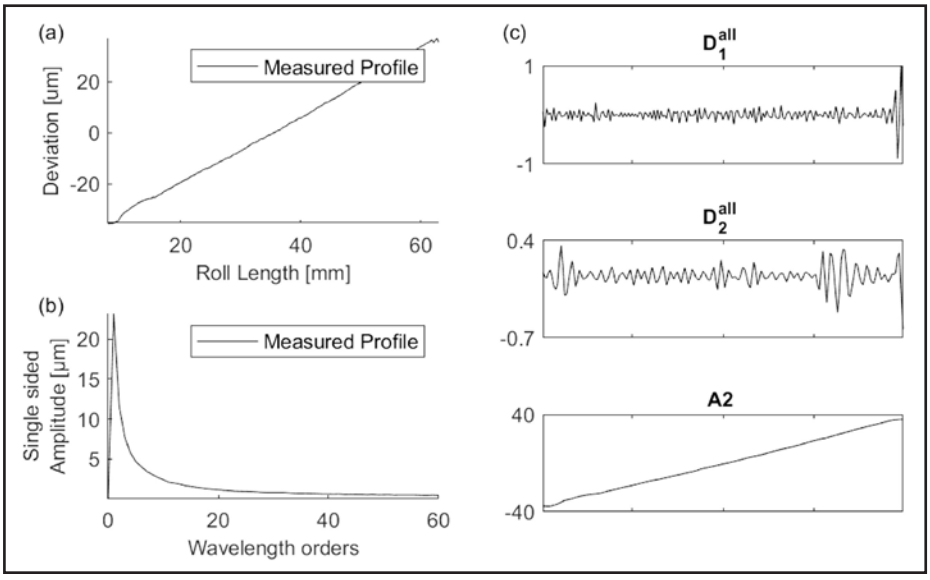

Figure 11 Measured profile fitted without rb (a) trace (b) DFT single sided spectrum results limited to 60 orders (c) DWT levels of detail.

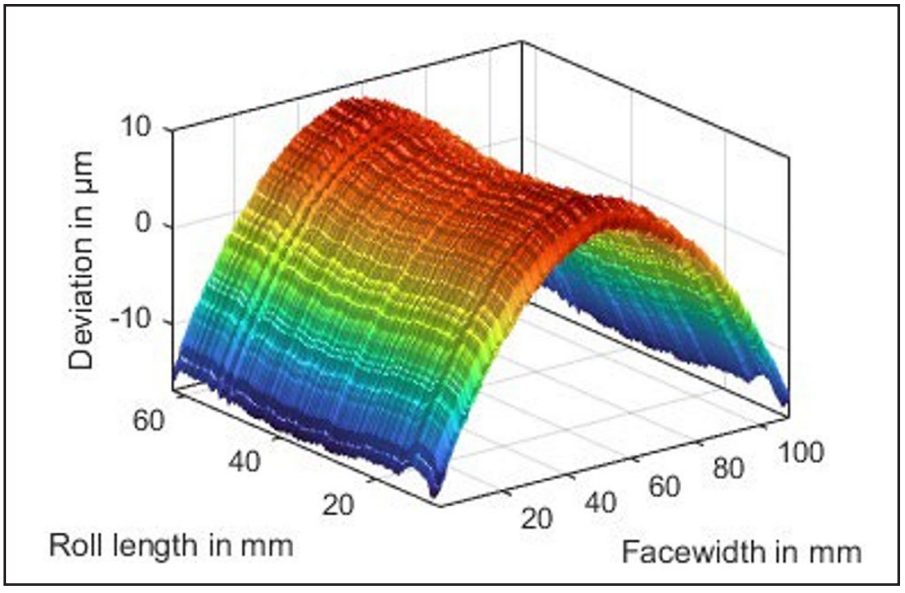

Figure 12 Tooth 4 pseudo-measured surface.

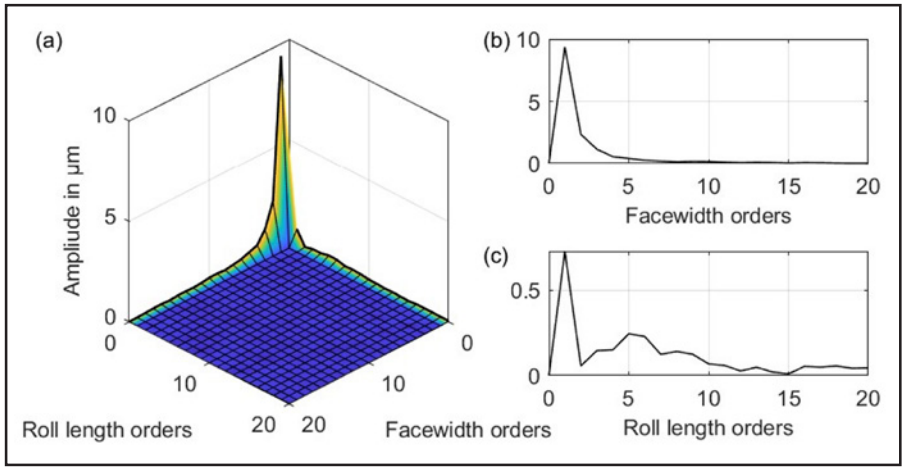

Figure 13 Surface DFT amplitudes limited to 20 orders (a) isometric view (b) face width order slice (c) roll length order slice.

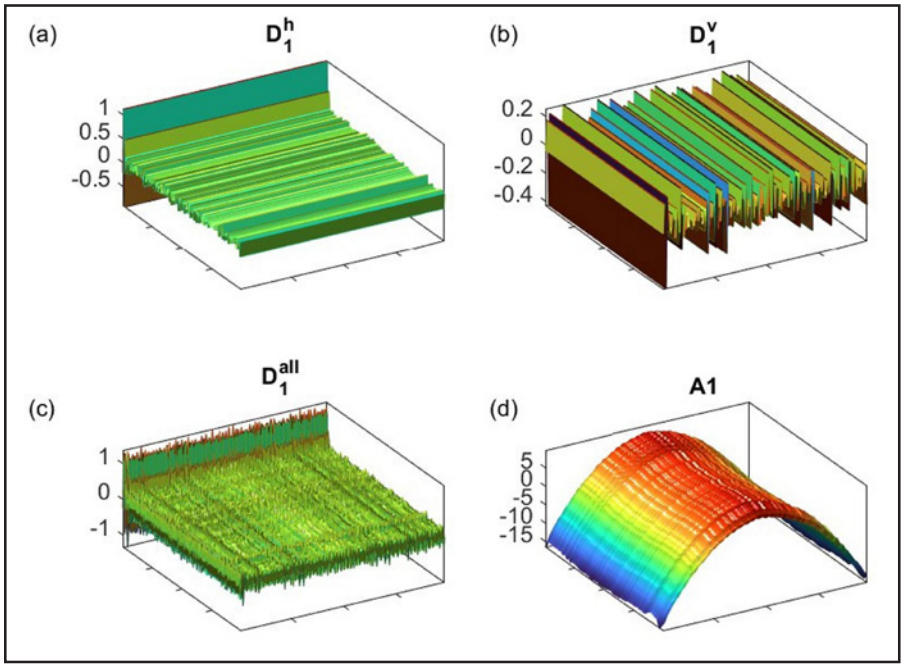

Figure 14 Surface DWT (a) horizontal, (b) vertical, (c) combined detail surfaces and (c) approximate surface.

the DWT filters this out at the approximate level leaving the higher frequency information visible in the detail levels.

3D Surface Analysis

Extending the 2D methods to 3D is simple to compute but complex to understand. A pseudo-measured surface has been created for analysis by layering tooth four mid profile and helix (fitted with r_b deviations) into a grid, giving the surface in Figure 12 (L, b, and d refer to roll length, face width, and deviation from involute respectively).

Discrete Fourier Transform

The 2D DFT amplitudes are shown in Figure 13 in isometric view and with slices of the roll length and face width harmonics. Two perpendicular lines of content can be seen which relate to the face width and roll length orders. If there was any harmonic content at an angle, such as produced with generator grinding, a corresponding angled line would be visible.

In this case the frequencies have been dominated by the DFT trying to describe a 0.5 order harmonic — the helix crowning in Figure 12. This will be a common problem for gears which will typically have some sort of microgeometry correction as in the example discussed here. A solution would be to window the surface before transforming or to fit the microgeometry and remove this before analyzing harmonics.

Discrete Wavelet Transform

Extending the DWT to 3D adds even more complexity as at each level of detail a surface is split into one approximate and three detail sub-surfaces: horizontal, vertical, and diagonal. Figure 14 shows a one level DWT using Daubechies wavelet 6 (db6). The following should be noted:

- The approximate surface has separated out the crowning and some low frequency profile effects
- Horizontal detail relates to profile harmonics and a has a similar shape to the combined D1 and D2 of Figure 9c
- Vertical detail relates to helix harmonics
- The diagonal detail deviations were negligible at 10^{-15} µm and are not shown

- D^{all} is a combination of the horizontal, vertical, and diagonal details

Discussion and future work

The 3D-evaluation approach presented here is suitable to determine individual manufacturing errors on each gear tooth. An error separation method has been applied that includes the 3D measuring strategy on CMMs and the holistic point cloud inversion by separating running, geometry, and pose parameters. In the end one set of geometry parameters per gear flank is determined in a common reference system. In addition, two possible methods of evaluating measured point clouds were presented. The base radius, one of three geometry parameters in the 3D-gear surface model, has been either fitted during the inversion or not. Observed differences are listed in the following. Merits and drawbacks are denoted by (+) and (–).

Comparing inversion methods

+ Inversion with fitting of r_b enables the determination of the actual geometry parameters per gear flank: $r_{b,act}$ φ_b and β_b.
– Inversion without fitting of r_b results in $r_{b,nom}$ that has an effect on the other actual geometry parameters φ_b and β_b. Compared to the alternative approach, it has been observed that the fitted φ_b and β_b compensate for the incorrect radius, so that other actual geometry parameters are obtained.
– Inversion without fitting of r_b results in residuals with an artificial slope error. When analyzing the harmonics, this error leads to polluted FFT spectra. The DWT filters out the slope at the approximated level of detail are not affected.

Comparing harmonic methods

+ FFT shows specific harmonic frequency and amplitude
– FFT cannot discern content that exists for only a portion of the measurement
– FFT spectrum gets polluted by slope errors or other common microgeometry corrections, especially if the base radius has not been fitted in the previous inversion of point clouds
± DWT does not show specific frequencies but can show the effect of a frequency band
+ DWT can discern the location of content that exist for only a portion of the measurement
+ DWT filters can filter out slope errors and common microgeometry corrections in the lowest approximate level

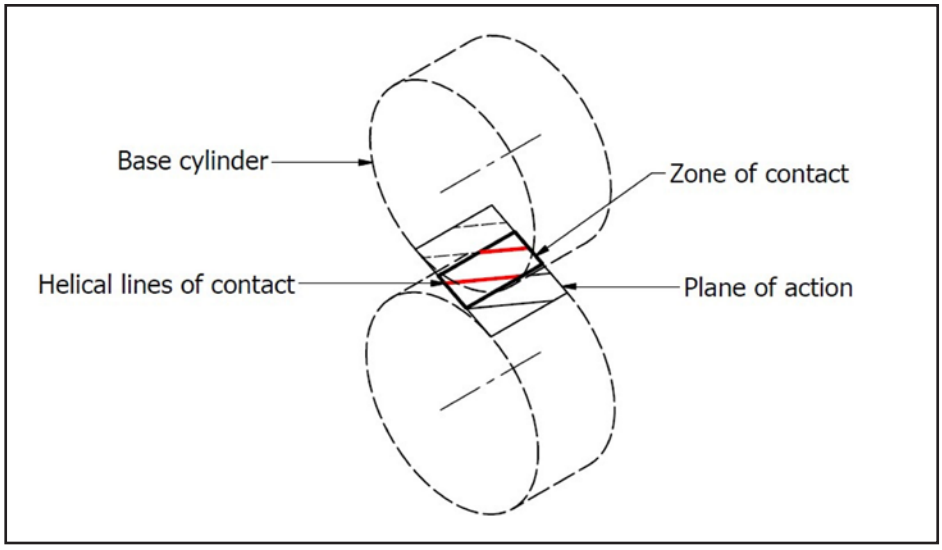

Figure 15 Lines of contact.

Analyzing a surface compared to a 2D line trace provides additional information about the whole flank and allows for better understanding of errors from machine tools, predicts potential vibration issues or detects damage that is not captured within a single profile and helix trace.

This is useful but analyzing an individual gear flank surface geometry to understand how these errors relate to the gear's performance is difficult as best and misleading at worst. This is particularly the case for helical gears with angled lines of contact (Figure 15) over the tooth surface. Pinion and wheel gear pair surfaces combine, at different points in time different number of teeth are in contact, gears run eccentrically in bearings and then when load is applied, gear teeth and shafts deflect. All of these obfuscate the effect of measured harmonics on the functional performance of the gear.

The obvious next step is to use the measured data in a tooth contact analysis (TCA) model. These models usually assume nominal macro and micro geometry or at best consider ranges to profile and helix deviation slope limits and micro geometry corrections to predict gear performance. However, we can import the actual measured 3D surface deviations into TCA models to predict gear performance in terms of transmission error, bending and contact stress, scuffing risk and friction losses (Ref. 23). We can then use these results to determine fitness for purpose directly or develop tolerances based on modeled performance if the TCA model has been verified. This may be of real benefit for high value gears used in, for example, wind turbine gearboxes.

Harmonic analysis characterization can also be useful as a method for robustly and efficiently transferring the measured 3D surface deviations to TCA models and digital twin models. By using the data from these transforms, the surface can be defined to an appropriate resolution by controlling how many harmonics to include in the deviation surface characterization. The resolution may be different based on the desired performance to modelled. For example, if noise was more important for a certain application, fewer harmonics are required to characterize this compared to the requirements of contact stress or scuffing risk simulations. The DFT and DWT are reversable and can be used by the TCA program to reconstruct the surface to the resolution defined by the metrologist, blurring the lines between design and metrology.

Acknowledgements

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Anita Przyklenk obtained a BSc, MSc and Ph.D. in Physics from TU Braunschweig, Germany. Since 2018, she is a postdoctoral research fellow at Physikalisch-Technische Bundesanstalt (PTB) in the working group for gear and thread metrology. Her research topic is three-dimensional and holistic gear and screw thread evaluation methodology. She is the Secretary of the European Metrology Network for Advanced Manufacturing by the European Association of National Metrology Institutes (EURAMET).

Tom Reavie joined Newcastle University's Design Unit in 2017 after completing his master's degree in mechanical engineering. His work involves design of mechanical power transmissions with a focus on gear design and analysis. Tom is a member of the UK's National Gear Metrology Laboratory (NGML) and he is completing a Ph.D. alongside his research in gear metrology.

Martin Stein has studied mathematics and physics at Leibniz University Hanover, Germany, and finished his Ph.D. in 2012. He's been heading the working group for gear and thread metrology at Physikalisch-Technische Bundesanstalt (PTB) since 2014. One of that group's main research areas is metrology for large gears as used in wind energy systems. Martin Stein is an active member in national standardization bodies for gear metrology of the VDI/VDE and DIN. He is a lecturer at TU Braunschweig for the MSc course on Metrology and Measurement Technology.

Rob Frazer received a BSc in Mechanical Engineering and Ph.D. from Newcastle University. He is a senior engineer with the Design Unit at Newcastle University and spent the last 35 years working with gears and gearboxes. Rob leads gear measurement research at the UK's National Gear Metrology Laboratory (NGML), is chair of British Standard Institute (BSI) gear committee, MCE-5 and a member of the ISO gear accuracy working group (ISO TC60 WG2). He provides technical support to the British Gear Association's (BGA) research committee, helps deliver its training programmes and teaches on Newcastle University's MSc and MEng Mechanical Power Transmissions Module.

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Lenze

ANNOUNCES MANAGEMENT CHANGES

Lenze recently announced the appointment of president and CEO Tom Mathias to the Lenze Americas executive team.

"We are delighted to have Tom join our North American team," said Christian Wendler, chairman of the Lenze executive board. "With his addition, we have gained an executive manager with in-depth industry knowledge and many years of relevant experience. Tom was very successful in his management positions at various industrial companies. We look forward to having him lead our Lenze Americas team into the future and drive our company growth in this very important market. Lenze's automation expertise can make a real difference for machine builders looking for higher productivity, better energy efficiency, and lower system cost."

Mathias' 25 years of experience in the industrial automation industry include roles of increasing responsibility with GE, FANUC, Parker Hannifin, and Omron in Europe, Japan, and the Americas. Most recently, he was president & CEO of Omron Robotics & Safety Technologies. Mathias has expertise in global general management, sales leadership, and merger/integration.

"Lenze is a world-class automation company, and I join the team with both a deep respect for the company's history and genuine appreciation for our future potential in the Americas," said Mathias. "I'm thrilled to join the Lenze organization and look forward to working together with our customers, partners, and employees to continue delivering best-in-class automation solutions."

Mathias holds a Bachelor of Science degree in electrical and electronics engineering from the State University of New York at Buffalo.

In addition, Lenze recently announced the appointment of Vice President of Sales and Marketing Michael Harper to the Lenze Americas executive team.

"We are excited to welcome Mike to the Lenze Americas team and look forward to supporting his plans to strategically develop sales and significantly expand our market share in North America," said Christian Wendler chairman of the Lenze executive board. "His in-depth knowledge of robotics, motion control, and industrial automation will be a real asset to our sales channel and our customers."

Harper is an experienced sales professional, with extensive expertise in strategic growth leadership and sales management. His industry background includes many years in sales leadership positions at Festo, Soft Robotics, and AutoGuide Mobile Robots.

"I look forward to contributing to Lenze Americas continuous path of growth in North America and reinforcing its strong reputation as a responsive and technology-forward automation company," said Harper. "For me, customer success and satisfaction should be the key drivers in every step of our business development and improvement."

Harper holds a Bachelor of Science degree in mechanical engineering from Georgia Tech and an MBA in finance from East Carolina University.

lenze.com

Velo3D

ADDS PAWLIKOWSKI TO BOARD OF DIRECTORS

Velo3D, Inc. has strengthened its board of directors with the addition of General Ellen Pawlikowski, an experienced commander and board member with strong roots in the aviation, space, and defense industries. This background and her in-depth knowledge of customers' needs will support the growth in adoption of Velo3D's additive manufacturing technology within these critical industries.

Pawlikowski's appointment to the board is effective March 15, 2022. Additionally, the 12-person board will decrease in size to nine members with the planned resignation of early company investors Ricardo Angel, Jory Bell, David Cowan, and Sven Strohband following the company's successful completion of the public listing on The New York Stock Exchange.

In addition to being an accomplished leader, Pawlikowski is an engineer with experience in research, development, and testing and has a deep understanding of customer needs. Her business acumen coupled with technical expertise will help Velo3D during its period of rapid growth in adoption of its end-to-end metal additive manufacturing solution.

"The Velo3D team is focused on delivering real-world results and meeting the promises we've made to our customers, investors, partners, and employees, and Ellen's track record shows she can help us meet our challenging goals to land and expand within critical industries and broaden the adoption of our additive manufacturing technology," said Benny Buller, Velo3D CEO and founder. "We're honored to have Ellen join the board and her extensive experience working with innovators and leading organizations will help us capitalize on the blue-ocean opportunity ahead of us. I am also immensely grateful for the contributions of Ricardo, Jory, David, and Sven to the board over the course of their service and for believing in the vision of Velo3D."

Pawlikowski currently serves on the boards of Raytheon,

SRI international, and Applied Research Associates. She served in the U.S. Air Force for 36 years and retired as a 4-star general. Her last assignment was as the Commander of the US Air Force Materiel Command.

"Velo3D is a critical tool to innovation in the aerospace, aviation, and defense industries and I strongly believe that its technology can be transformative to its customers," said Pawlikowski. "While it's amazing to see how Velo3D is empowering customers to solve their biggest challenges today, I think that its additive manufacturing technology will be even more impactful on innovation in the future."

Pawlikowski has a Ph.D. in chemical engineering from the University of California, Berkeley. She also has a B.S. in chemical engineering from the New Jersey Institute of Technology.

velo3d.com

Motion

ANNOUNCES NEW VICE PRESIDENT

Motion is pleased to announce the promotion of Jon Tart to vice president of the company's southeast group, effective March 1, 2022.

Tart was promoted from his position of Baltimore division vice president. Starting with Motion in 1996 as a customer service representative, he transitioned to the corporate training program in 1997, then moved to a sales territory in 1998. Since then, Tart has served as branch manager of two branches, division sales manager, area vice president of corporate accounts for the northeast and the southeast, and Baltimore division manager.

Tart will report to Kevin Storer, executive vice president, branch operations.

"Jon's impressive background and his ability to leverage his vast experience and competitive nature will ensure success in the years ahead," said Mr. Storer. "I look forward to seeing him successfully lead the southeast group to new heights."

A graduate of East Carolina University, Tart holds a bachelor's degree in marketing and an MBA.

motion.com

General Motors

ANNOUNCES $7 BILLION EV INVESTMENT

General Motors Co. recently announced an investment of more than $7 billion in four Michigan manufacturing sites, creating 4,000 new jobs and retaining 1,000, and significantly increasing battery cell and electric truck manufacturing capacity. This is the single largest investment announcement in GM history. The investment includes construction of a new Ultium Cells battery cell plant in Lansing and the conversion of GM's assembly plant in Orion Township, Michigan for production of the Chevrolet Silverado EV and the electric GMC Sierra, GM's second assembly plant scheduled to build full-size electric pickups.

"Today we are taking the next step in our continuous work to establish GM's EV leadership by making investments in our vertically integrated battery production in the U.S., and our North American EV production capacity," said Mary Barra, GM chair and CEO. "We are building on the positive consumer response and reservations for our recent EV launches and debuts, including GMC Hummer EV, Cadillac LYRIQ, Chevrolet Equinox EV and Chevrolet Silverado EV. Our plan creates the broadest EV portfolio of any automaker and further solidifies our path toward U.S. EV leadership by mid-decade."

A new battery cell plant will be built by General Motors in Lansing, Michigan.

These investments are the latest step toward accelerating GM's drive to become the EV market leader in North America by 2025. The Orion and Ultium Cells Lansing investments will support an increase in total full-size electric truck production capacity to 600,000 trucks when both Factory ZERO and Orion facilities are fully ramped. GM has been the leader in U.S. full-size truck deliveries over the past two years. In addition, the company is investing in its two Lansing-area vehicle assembly plants for near-term product enhancements.

As previously announced, GM will continue to strategically manage the conversion of its North American manufacturing footprint through unprecedented speed, flexibility and precision. Through site conversion and new facilities, GM is uniquely positioned to stay ahead of the growing demand for electric vehicles while balancing the need to aggressively compete to win in today's market with strong products.

gm.com/commitments/electrification

Solve Industrial Motion Group

HIRES TAYLOR AS CIO

Solve Industrial Motion Group is expanding its executive leadership team with the addition of Jim Taylor in the role of chief information officer (CIO). Taylor comes to Solve with a track record of helping companies in growth mode implement transformative software solutions and business technology platforms that help progress their operations.

"Bringing Jim on board is a huge win for us, our customers, distributors and supply chain partners," said Lisa Mitchell, CEO of Solve. "With 25 years in leadership positions, he has the experience to help drive Solve's enterprise evolution."

Taylor comes to Solve from Daseke, a specialized transportation and logistics company. As the CIO and a senior vice president, he was responsible for the management, governance and technical direction of the company. His role included oversight of transportation management systems, business intelligence, data centers, HR systems, cybersecurity and more.

Prior to his time at Daseke, Taylor managed all technology support at Transportation Insight, a transportation logistics company. For nearly a decade, he contributed to the company's growth. He's also held IT roles with Ryder, DSV/ABX Logistics, DHL/Exel and Redwood Systems.

Since Audax Private Equity acquired Solve in July 2021, the industrial bearings and power transmission components company has been strategically growing its product lines, services and staff. Taylor is the first of several new hires slated to join Solve's executive leadership team.

solveindustrial.com

Verusen

EXPANDS LEADERSHIP TEAM

Verusen has announced it has expanded its leadership team with the appointment of John Head as senior vice president, sales and customer success. Reporting directly to Paul Noble, Verusen Founder and CEO, Head will lead direct sales, customer success, and global channel partnerships.

Head joins Verusen from Honeywell Connected Buildings, where he most recently led sales and GTM for the Americas. He has extensive experience in the AI/ML space selling cloud software to Fortune 1000 companies and scaling sales teams. His appointment continues the growth momentum at Verusen, following the company's recent $25 million Series B funding. The Company now has over 60 employees and has plans to continue its hypergrowth in 2022.

"The team is excited to bring John on board to expand our global sales, channel, and customer success for Verusen," said Paul Noble, Verusen Founder, and CEO. "Our customers, partners, and investors are excited about the optimization and risk mitigation outcomes we deliver — both in time and costs — that accelerate trust in capabilities when it comes to building adaptable and resilient supply networks. Having a sales pro who understands the AI/ML selling space is a big win for us, and we look forward to John's contributions moving forward."

verusen.com

Heidenhain

OFFERS EDUCATION SUPPORT PROGRAM FOR MANUFACTURING

To assist in training the next generation of manufacturing professionals, Heidenhain is offering a collection of educational services and products to meet the demands for today's digitization of data in NC metalworking.This worldwide initiative called the Heidenhain Education Support Program (HESP) promises to bring the latest advancements on the shop floor to current classrooms of vocational training centers, universities, and corporate trainee programs.

Digital services and their remarkable speed are now commonplace and only growing.With HESP, Heidenhainis making its own important contribution to training the next generation of metalworkers by providing highly cost-effective, state-of-the-art resources to educators that can include computer programming stations, software and learning materials for fast and highly accurate milling and turning needs. HESP also includes offers to train the trainers at significantly reduced prices.

Heidenhain's programming stations are based on the same software foundation as its CNC controls, thus making

them ideal vocational training tools to give students the confidence they need to program in the manufacturing world. HESP's learning materials include practical course supplies for explaining complex topics, as well support posters for the classroom.

Those that are familiar with Heidenhain will especially appreciate the special opportunity for educators to obtain Heidenhain's Connecting Machining package of functions and its StateMonitor MDA software, as well as the option of its online HIT (Heidenhain Interactive Training) program. Full program details are available on the HESP microsite.

hesp.heidenhain.com

Daimler and Siemens Digital

PARTNER FOR NEXT GENERATION VEHICLE SOLUTIONS

Siemens Digital Industries Software has announced that Daimler Truck has adopted Siemens' *Simcenter STAR-CCM* software to develop next-generation, CO_2-neutral vehicles. *Simcenter*, part of Siemens' *Xcelerator* portfolio, will provide Daimler Truck with the computational fluid dynamics (CFD) solution it needs to transform its CAE development process to a full digital twin-driven multiphysics environment.

Daimler Truck plans to use *Simcenter* to improve aerodynamic performance, as well as explore and optimize innovative e-mobility propulsion and energy management systems including battery cooling and hydrogen technology. The software will also help support legacy combustion engine and exhaust system design and associated CO_2 reduction.

In addition to software, Siemens and Daimler Truck are to partner in the training of young engineers to create the high-level simulation specialists that will assist in ensuring Daimler Truck maintain their leadership in the market.

"We are proud to have Daimler Truck as the newest member of our ever-expanding customer family," said Edwin Severijn, senior vice president and general manager, EMEA, Siemens Digital Industries Software. "Digitalization is critical to sustainable industrial innovation in the transportation sector and by providing insight into the real-world performance of products, *Simcenter STAR-CCM+* can accelerate innovation for a better tomorrow."

sw.siemens.com

KUKA Robotics

ANNOUNCES PERSONNEL CHANGES

KUKA Robotics has named Casey DiBattista and Vancho Naumovski to key leadership positions. Casey DiBattista is now the chief regional officer of KUKA North America, and Naumovski is the new vice president and general manager of operations for the United States.

DiBattista was formerly KUKA's regional vice president of sales North America and has been involved with the automation industry since 1982.

"Excellence is achieved with the right people and resources in the right positions to support growth," said DiBattista. "As KUKA continues to expand in North America, our regional perspective and borderless approach ensure we continue to set industry standards for product performance and support at every stage of the process chain."

Vancho Naumovski has more than 25 years of experience in the manufacturing sector and comes from the engineering side of automation. His background includes specific work in welding and laser technologies along with welding process improvement.

"When it comes to robotics, every solution must be developed with the customer in mind," said Naumovski. "By being receptive to the feedback of both our employees and customers, while also implementing effective process improvement strategies, we can ensure success at all levels."

kuka.com

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‘Shakr’ Not Stirred

Human/robot collaboration moves from factory floor to behind the bar

Matthew Jaster, Senior Editor

Toni has mastered the art of mixing cocktails—swirling high-proof liquor through the air and elegantly swinging the shaker. Unlike most bartenders, Toni is mounted on the counter and boasts two mechanical arms (KUKA KR Agilus robots). This fully automated robotic bartender—from Italian company Makr Shakr—serves fresh drinks via an app.

“Making the perfect cocktail is as much about technical skills as it is about ingenuity. Our robotic bartending unit Toni excels on the former. But inventiveness remains a fundamentally human prerogative,” said Emanuele Rossetti, CEO at Makr Shakr.

Now the engineers at Makr Shakr have further developed the bartending robot, with new movements and features that have been put to test for the first time during a duel with world class flair bartender, Silvia Daniela Istrate.

“For this challenge, we accomplished our most ambitious research and development leap in acrobatics ever,” said Alessandro Incisa, chief technology officer at Makr Shakr: “Our Toni robotic unit can perform an unprecedented sequence of spiral pouring, vertical and horizontal throwing, while deftly handling more than 150 bottles and virtually endless cocktail combinations. Soon, these movements will be performed by Makr Shakr’s robotic bartenders in our bars all around the world. Even before that, you can discover the acrobatics in our video, where everything is real– no computer graphics whatsoever.”

No matter where in the world guests visit a Makr Shakr bar, ordering a drink is always very simple: They select their drink via an app and the info is transmitted to the barkeeper robot. As soon as the drink is ready for pickup, the guest is notified via push message. There is also an option for customers to create their own drinks.

“It’s fascinating what our machines are capable of and where they are used around the world. This duel between robots and bartender shows once again that the best result is achieved when the strengths of man and machine complement each other,” says Michael Otto, chief sales officer of KUKA Robotics.

The bar system has demonstrated its brand-new skills in front of an equally extraordinary opponent. Istrate has participated in international competitions and won several prizes, including best female bartender at the Roadhouse World Final 2018 and 2019.

A competition putting her shaker skills against a robot was also a new experience:

“Working with Toni was unbelievable. I wasn’t expecting to feel comfortable working with a robot, and it’s more than that. It‘s definitely a real collaboration between colleagues,” said Istrate.

Bartender “Toni” has mastered the art of mixing cocktails — and competes in a new video with world-class flair bartender Silvia Daniela Istrate.

The collaboration between human and machine continues to produce fascinating results. How long, however, will it take before Toni can pour us a drink AND solve our personal problems?

kuka.com
makrshakr.com
https://youtu.be/5AUs3j2mkrQ

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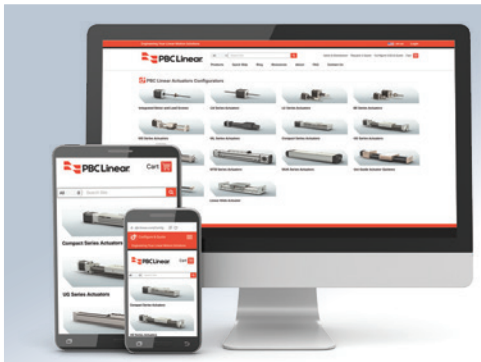

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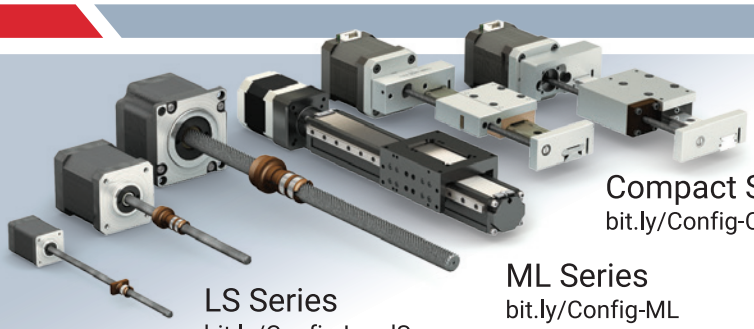

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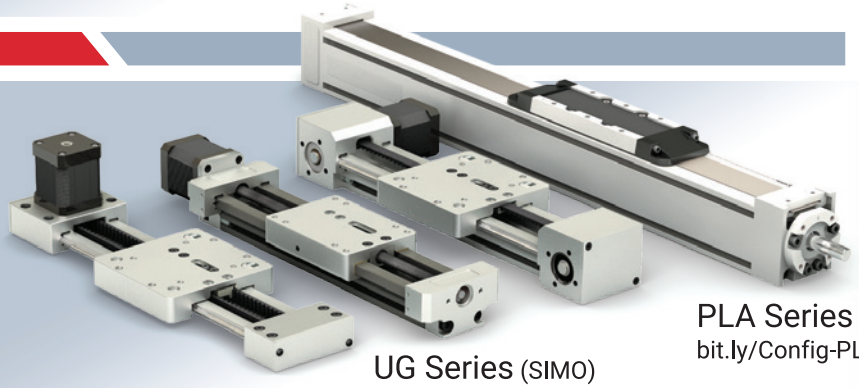

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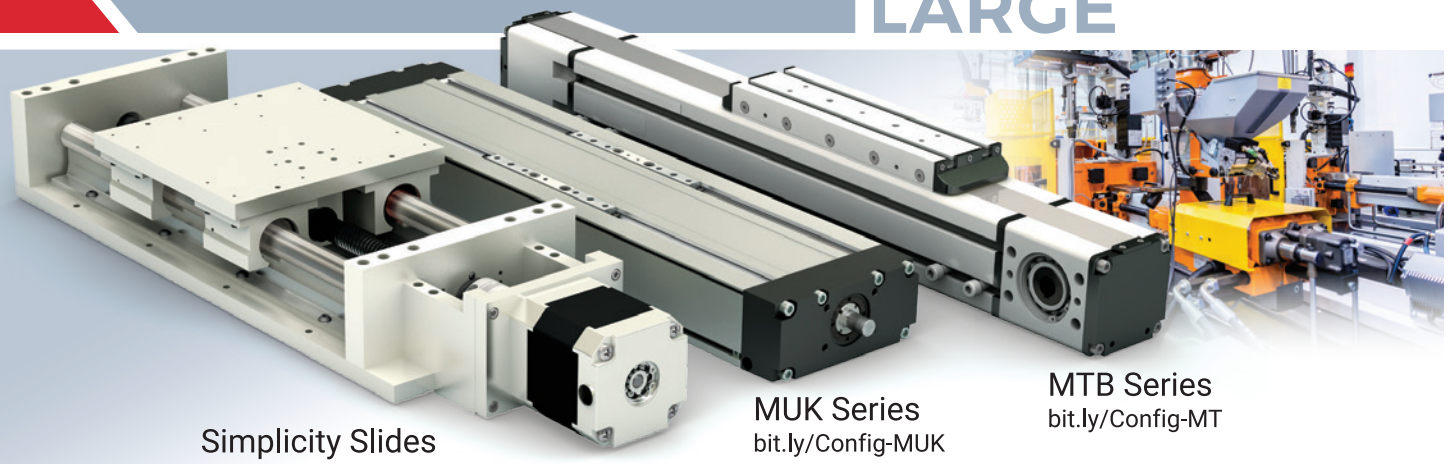

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