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TECHNICAL

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High-Ratio Planetary Gearboxes for Next-Generation Robotics
Variation of Servomotor Efficiency

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FEATURE ARTICLES

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PTE Extras

E-Mobility Boot Camp

Electrification is changing the automotive industry wholesale. This online article looks at training and transmission technology courses available in the e-mobility sector today. Coursework includes examining gearbox structure to battery technology to health and safety issues. This expansion continues to prepare engineers, manufacturers, and technicians for the shift toward electric vehicles.

powertransmission.com/blogs/1-revolutions/post/9096-a-crash-course-in-e-mobility-training

Ansys Offers Multiphysics Simulation for EV Motor Development

Environmental commitments by automakers and governments are at the wheel in this modern EV era, driving the development of new vehicle architectures that meet expectations for both volume and space reductions, combined with lower product costs and greater product reliability. EV developers are finding a competitive edge through efficiency gains not only in new battery pack technology and electronic components, but also through new developments in electric machines.

https://www.powertransmission.com/blogs/1-revolutions/post/9101-ansys-offers-multiphysics-simulation-for-ev-motor-development

Sugar Refinery Dryer Fan with NSK Europe

The production of sugar is quite a complex process. A sugar refinery suffered from premature bearing failures on its dryer fans. The NSK engineers were called to help in this short bearing case study.

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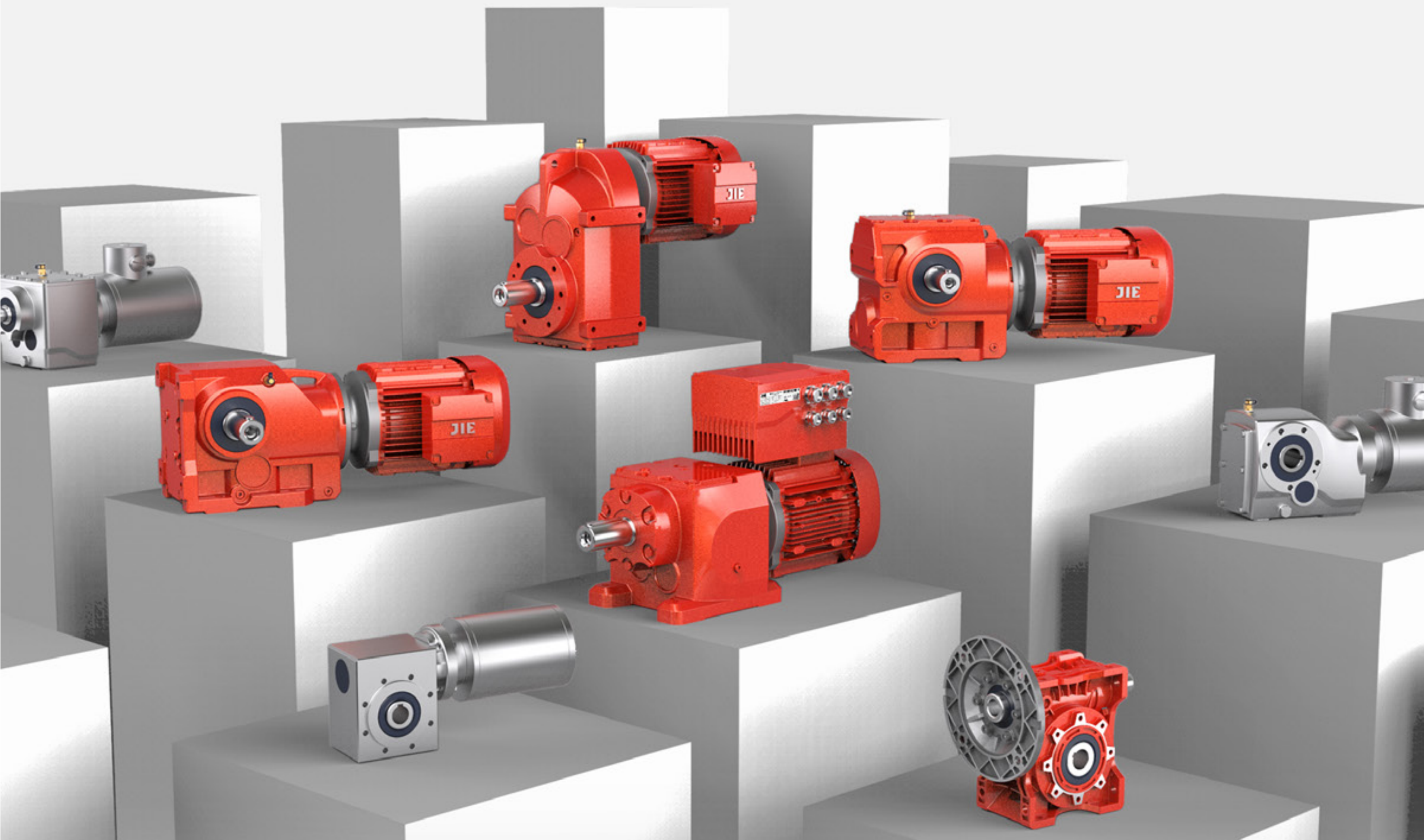


Randy Stott
Publisher & Editor-in-Chief

There's Nothing Artificial About Our Intelligence

Since OpenAI's public introduction of ChatbotGPT, the Internet has been abuzz with talk about artificial intelligence and the implications of machines that can think and write and carry on conversations at least as well as some humans.

People in a wide variety of industries are wondering whether their jobs are safe, and if so, for how long? After all, the latest version of Chatbot GPT has passed the bar exam and the U.S. medical licensing exam. It has scored 5s on numerous AP exams, and it does better on the SAT than most human students. So, many people are beginning to wonder how long it will be before computers will be good enough to replace teachers, lawyers, doctors, accountants, computer programmers and (gasp!) journalists.

If you haven't yet played around with Chatbot GPT, you should. Just go to *chat.openai.com*, create an account and start asking questions. At first, you might be surprised at how thorough, well-written and comprehensive the responses are. But at the same time, with a little more digging, you might also be surprised at how misleading or even dangerous those responses could be.

I asked the chatbot things like "Explain the best way to design a spur gear" and

"How do you choose a coupling for an industrial application?"

The answers I got weren't very in-depth or nuanced. But they didn't seem terribly far off, either. To a layman, they might even sound authoritative.

And that can be a real problem if you rely on it too easily. OpenAI admits that their chatbot doesn't really know how to distinguish truth. Chatbot GPT is kind of like a clever politician, because it's very good at telling convincing lies. Everything it says sounds reasonable, and if you're not a subject matter expert, you might not know the difference.

Here at *Power Transmission Engineering* and our sister publication, *Gear Technology*, we work very hard to make sure the information we provide you comes from reliable, knowledgeable sources with expertise in the subjects we cover. Even more importantly, we attribute that information so you can judge its merit for yourself.

When we give you an article like "The Variation of Servomotor Efficieny in Different Applications" (page 42), you can see that it's written by Donald Labriola of Quicksilver Controls, a recognized expert in his field. You may have read others of Don's articles in our magazine, and so you probably already know you can trust what he says about motion control. The same goes for Norm Parker, who this issue gives us part 2 of his article on "Ball Bearing Inner Ring Fits and Creep" (page 46). Norm is a Technical Fellow at Stellantis, and he brings that credibility with him in his writing.

So, no, I don't think artificial intelligence is going to replace our editors or writers any time soon.

Still, though, AI is getting better every day—and the pace of that change is legitimately frightening. Despite the dangers, I can also see its value. For example, a journalist writing an article on a subject he's never written about might use Chatbot GPT as a really solid starting point. It might give him a basic framework for thinking about a subject that would make it a lot easier to formulate interview questions to put before a true subject matter expert. Instead of floundering around to figure things out on his own, he might save a lot of time by using AI as a foundation for further exploration.

And that's how I think you should use it, too. Figure out how it can help you be more efficient. Figure out how to use it as a tool to help you do your job better. Because there's no doubt that AI is a powerful tool, and there's also no doubt that it's here to stay.

Randy Stott

Freudenberg Sealing Technologies

DETERMINES CARBON FOOTPRINT OF SEALS

Low-friction seals ensure that engines and machines run with greater energy efficiency and thus contribute to climate protection. Freudenberg Sealing Technologies wants to live up to its responsibility as a manufacturer of such seals and is now developing a method to determine the carbon footprint from the production of seals and other components.

How many grams of CO_2 are in a sealing ring? And by what means is it possible to minimize the greenhouse gas footprint from the production of components already during the design phase? Dr. Meike Rinnbauer and Volker Schroiff at Freudenberg Sealing Technologies want to provide knowledgeable answers to these questions. The project they have worked on in a team for the last two years aims to accurately determine the carbon footprint of Freudenberg products. The start of the project already yielded a fundamental insight: "Two factors have a significant impact on the emissions balance of a component," Rinnbauer explains. The first factor is the selection of the material from which the seal is made and the second is the seal's manufacturing process. Transport, on the other hand, was shown to have a substantially lower impact during analyses at the start of the project and is therefore negligible in the current assessment.

Freudenberg Sealing Technologies has developed its own "Green Index" to ascertain the greenhouse gas balance of materials. The background: Climate-relevant emissions are not the only environmental properties of chemical substances that should be considered in internal comparisons and evaluations of materials and processes. "For example, we try to avoid toxic precursors as much as possible to ensure our employees' occupational safety and also take other environmental impacts into consideration," Rinnbauer says. Since modern seals often consist of material compounds, all individual components are examined to avoid setting misguided incentives for the selection of certain materials.

To determine the global warming potential (GWP) of individual material components, Freudenberg Sealing Technologies uses an expert database that complies with the ISO 14044 standard for life cycle assessments. This process utilizes average, site independent GWP values for each individual substance, independently of its specific origin. In the future, however, it is expected that manufacturer- and site-specific parameters will be available along the entire supply chain. "This would also enable us to select future material suppliers not only on the basis of cost, quality and availability but also according to sustainability criteria," says Rinnbauer. Then the sum of the GWPs weighted according to material proportions yields the entire GWP of a sealing material. At the same time, the harmfulness of individual material components is checked based on Freudenberg's own occupational safety guidelines and the European REACH chemicals regulation. Depending on the harmfulness class, a penalty factor is assigned, which currently ranges from 1 (harmless) to 2 (persistent). The highest single value determines the factor that is multiplied by the total GWP. This ultimately results in a dimensionless value that can be used to assign the seal material to a specific sustainability class in the Green Index. Once they have been determined, all index values are stored in a materials database used throughout the company and are then available to the development engineers.

The effect resulting from the weighting process can be illustrated based on two fluoroelastomer materials (FKM), both of which are used for seals in the industrial sector. The first compound does not contain any harmful material components at all and has a greenhouse gas potential of 9.4 kilograms of CO_2 per kilogram of material. The second compound has a lower greenhouse gas potential of only 8.0 kilograms of CO_2 per kilogram of material, but it contains a hazardous material, which results in a classification as "not sustainable" in the Green Index. Since the lower sustainability is assigned a malus of 1.66, the first compound performs better in the overall assessment. However, an example of a polyolefin-based seal for fuel cells also shows that a material can be very sustainable even if it contains a persistent catalyst at a small proportion of 0.08 percent. Freudenberg Sealing Technologies has not yet made a final decision on how and to what extent sustainability factors should be considered beyond the GWP. "The important thing," Rinnbauer says, "is that

our optimization isn't one-dimensional. When selecting materials, we also consider the service life and wear resistance that influence our customers' eco-balance."

Measured instead of estimated

Another thing is clear: The energy used to manufacture seals results in CO_2 emissions, unless the energy supply to the production plants has already been fully converted to sources that are neutral regarding greenhouse gas. "The great challenge is to correctly allocate the CO_2 emissions generated by energy that is supplied or created at a production site to individual material batches or products," Schroiff explains. One prerequisite for this is knowledge backed up by measurements of how much energy is used in the individual process steps, specifically in relation to the weight, volume, or surface area. Based on the company's core processes, a team at the Weinheim headquarters examined the specific energy consumption and other environmentally relevant parameters, such as the amount of technical or "engineered" waste consisting of partially or fully processed material. This kind of waste arises, for example, because products do not receive their final shape until they are finely machined in the production process. The four examined core processes include the mixing of the material, molding including vulcanization, coating, and reheating. In terms of material weight, the mixing proved to be similarly energy intensive as the molding and vulcanization. "But what surprised us in particular was that reheating consumes almost as much energy as the molding and vulcanization," says Schroiff.

Sample products

In conclusion, the Freudenberg team transferred the results to two sample products, a Simmerring made of fluoroelastomers (FKM) as used in the automotive industry and general mechanical engineering, and a housing part made of polyamide 6.6 with a functional coating for electromagnetic shielding. This revealed significant differences: For the Simmerring, the molding and vulcanization account for about half of the total production-related energy consumption. It is possible to reduce the CO_2 emissions by a third overall using an optimized molding process that does not require post-processing. For the housing part, the production of the plastic material accounts for a significantly higher proportion of around 40 percent of the energy input, while the coating accounts for about one-tenth. In the production of polyamide components, too, the material and possibly the technical waste account for a significant proportion of the total emissions.

Even if many materials and processes still need to be studied in more detail before transferring the methodology, a clear tendency is evident: "The greatest leverage for manufacturing components in a more climate-friendly way lies in avoiding waste during the production, at least as long as we are still using fossil energy," Schroiff explains. Therefore, Freudenberg Sealing Technologies is resolutely focusing on waste-preventing production technology. By using cold runner injection molding with valve gate technology alone, the company already eliminates around 70 tons of waste per year and emits 600 tons less CO_2.

freudenberg.com

Regal Rexnord

LAUNCHES THE REXNORD CURVE SYSTEM WITH 1540 SERIES MATTOP CHAIN

Regal Rexnord Corporation introduces its new Rexnord Curve System with 1540 Series MatTop Chain for conveyor lines requiring a zero tangent 180 and/or 90-degree curve. The system offers a tight inner radius (420 mm) and small transfer (15 mm), for greatly improved space utilization and package handling.

The new Rexnord Curve System enables head-to-tail transfer of even small and light cases without the need for micro pitch conveyors, transfer modules or plates. A consistent small nose radius across the width of the conveyor and smallest transfer available in the industry result in a safe small gap between the Curve System and the adjacent conveyor. This eliminates the need for roller transfer bars while providing more flexibility in container types when changing lines. Consistent angular speeds of the system's modular belts ensure that products travel through the curve without rotation.

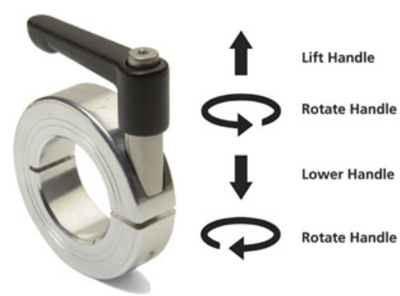
The Rexnord Curve System uses the lowest number of bearings for zero tangent curves in the industry, minimizing the need for maintenance. The drop-in solution can easily be integrated into existing conveyance systems. It uses multiple, industry standard width chain strands and can be installed by a single person. Its bevel curve retention system ensures a flat conveying surface and easy chain removal.

"The Rexnord Curve System has a cohesive design for optimal performance and ease of maintenance," said Chad Walker, global product manager, Regal Rexnord. "The product features several industry bests, in both tightest inner radius and smallest transfer, which offer customers unprecedented benefits in both space utilization and package size handling flexibility."

rexnordemea.showpad.com

Ruland

EXPANDS RANGE OF QUICK CLAMPING SHAFT COLLARS



Ruland recently expanded their range of quick clamping shaft collars with clamping lever to include bore sizes up to 3 inches or 80 mm. These shaft collars allow the user to install, remove, or reposition the collar without the use of tools. The user simply turns the lever to loosen and tighten the collar on the shaft.

Quick clamping shaft collars with clamping lever combine a standard Ruland shaft collar with a custom designed lever designed to replace collar hardware. This creates a toolless shaft collar that can be rapidly adjusted, making them an ideal fit for packaging, printing, and other applications where frequent setup changes and adjustments are needed. The handle is steel with a textured zinc plated finish, allowing the user to easily grip the handle regardless of lubricants or other contaminants that may be on their hands. The stud is made from stainless steel to allow for increased corrosion resistance when combined with the zinc handle.

Ruland shaft collars have tightly controlled face to bore perpendicularity for proper alignment of mating components. Ruland identifies this work surface with one or two circular grooves on the face of the shaft collar to assist with installation. Perpendicularity is critical in applications where the shaft collar will be load bearing as it ensures even surface contact with the mated component.

Ruland's expansion of quick clamping shaft collars includes bore sizes ranging from 1-3/4 inch to 3 inches and 42 mm to 80 mm. They are offered in high grade 2024 aluminum with an anodized finish for light corrosion resistance, 1215 lead-free steel for high strength and durability, and 303 and 316 stainless steels for increased corrosion resistance. Quick clamping shaft collars with clamping lever are available in one piece style and two-piece styles, giving the designer the flexibility to use the collar without shaft end access.

All Ruland quick clamping shaft collars are manufactured from select North American bar stock in Ruland's factory in Marlborough, Massachusetts, under strict controls using proprietary processes. Levers are sourced from Otto Ganter GmbH and inventoried in Ruland's factory for same day shipping with in-stock shaft collars.

ruland.com

TSN

PLAYS ROLE IN NETWORK TECHNOLOGY EXPANSION FOR SERVO DRIVES

The capabilities of servos are advancing at an accelerating pace, driving the rapid growth of next-level motion control systems. These devices can enable innovative industrial automation applications and processes thanks to cutting-edge hardware, software and, most importantly, communications

technologies that support data-intensive operations.

Tom Burke, global strategic advisor at CLPA, looks at the enabling solutions that are driving servo performance.

Today's servo drives are truly a thing of engineering beauty. They can meet exacting requirements for accuracy, precision and dynamism by offering fast cycle times in the microsecond scale and the ability to synchronize hundreds of axes. As a result, machines can move faster, in a highly repeatable manner, increasing productivity and throughput. Mitsubishi Electric's servos are known for their advanced encoders, with high resolutions to detect vibrations and harmonics, as well as algorithms to dampen them.

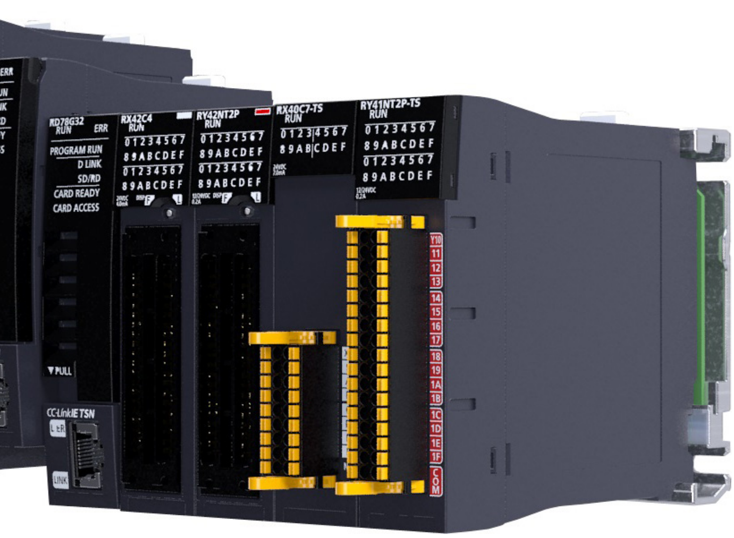
Advanced servos also offer key tools, such as auto-tuning, to set up complex machines easily and efficiently while also optimizing drive operations. In effect, it is possible to reduce the settling time, control overshoot as well as suppress vibration and resonance via servo gain adjustment functions. As a result, users can benefit from quieter servo axes that consistently operate at their best cycle times and at peak performance while reducing energy usage, downtime, and maintenance activities.

Moving into the realm of business intelligence, competitive and future-oriented servos can benefit from condition monitoring and predictive maintenance using artificial intelligence (AI). More precisely, sensors on servo amplifiers and motors can generate accurate, real-time data on the status of internal components and mechanical devices linked to the drives. This information is then fed to machine learning (ML) algorithms to enable predictive maintenance recommendations, identify anomalies, and flag potential issues ahead of time. Thanks to the application of AI, it is therefore possible to fix any wear and tear only when it is needed, preventing failures from occurring and optimizing maintenance schedules.

Combining bandwidth and TSN to futureproof servos

All these advanced functionalities, which can open the door to new and improved systems, are backed by equally sophisticated industrial communications that leverage the latest, most promising technologies. High-bandwidth, high-speed industrial Ethernet, and Time-Sensitive Networking (TSN) are playing a key role in driving the speed, accuracy and all data-driven functions of servos forward.

More precisely, real-time gigabit transmissions can support the immediate transfer of large volumes of data from servos to controls and vice versa. This is ultimately enabling the creation of systems with ever-shortened pulse widths for increasingly demanding applications. TSN, on the other hand, can improve synchronization accuracy, thanks to the IEEE 802.1AS standard, and support the sharing of different types of data traffic. Therefore, it empowers servos to transmit and receive diverse data packets, such



as time-critical messages for control operations as well as less transient information, e.g., for AI analytics and predictive maintenance, without congestions or delays.

While 1Gbits transmission speed and TSN, taken individually, can help servos deliver state-of-the-art capabilities, when integrated into a single network technology, they have a synergistic effect. The combination of the two enables servos to deterministically handle large volumes of data of any kind at high speed, so that they can be smart and effectively support digital manufacturing applications.

Currently, the only network technology that offers both features is the open industrial Ethernet CC-Link IE TSN. As the first solution for industrial communications with TSN functions, CC-Link IE TSN is already being used by automation vendors to deliver unprecedented performance. When looking at servos, a prominent compatible product is Mitsubishi Electric's MELSERVO MR-J5, coupled with motors equipped with the company's encoders.

Performance for smart manufacturing

The incorporation of gigabit bandwidth and TSN deliver enhanced performance across MR-J5 multi-axis servo systems. In effect, it ensures that the drives can relate to a multitude of devices – including safety equipment, which can be linked on the same network as standard control products, like inverters, HMI and I/O. Even more, it is possible synchronize up to 256 axes.

Thanks to the MR-J5's compatibility with CC-Link IE TSN, users can also benefit from communication cycle times of 31.25 µs and a frequency response of 3.5 kHz. Ultimately, it is possible to reach a maximum motor speed of 6,700 r/min. This high-level performance does not come at the cost of a more complex set-up process, as a quick auto-tuning function generates all of the gain values automatically within approximately 0.3 seconds.

When it comes to additional analytics for business intelligence, CC-Link IE TSN supports the AI-driven predictive maintenance functions within the MR-J5. These are used to detect mechanical component deterioration on the machine long before any maintenance requirements arise, optimizing scheduling and ensuring uptime. Finally, CC-Link IE TSN also supports Simple Network Management Protocol (SNMP), enabling information technology (IT) applications to access such components for asset monitoring and management.

am.cc-link.org/en/

Bosch Rexroth

INTRODUCES SMART FLEX EFFECTOR SENSOR-BASED COMPENSATION MODULE

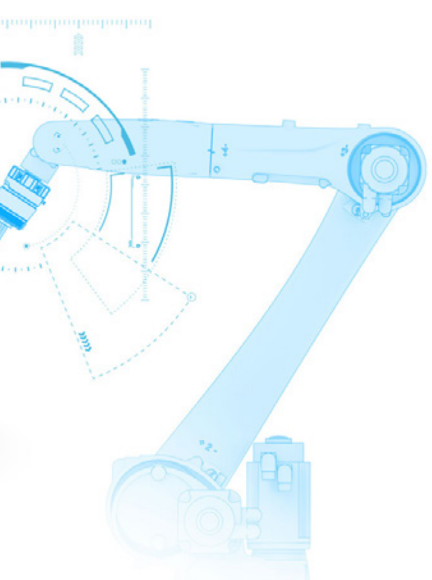
Small component, significant impact: The Smart Flex Effector, a new, sensor-based compensation module from Bosch Rexroth, gives robots and Cartesian linear systems human-like sensitivity and thus offers new opportunities for factory automation. Processes that are difficult to manage can now be automated, optimized and monitored through simple retrofitting. Thanks to a kinematics system that works independently in six degrees of freedom, the tactile device with sensi-

tive touch precisely records the position of the work piece and passes the information to the robot control unit for active compensation purposes. Typical applications include joining processes with minimal tolerances, complex assembly work or difficult handling tasks. Errors and rejects are minimized, and teaching and commissioning can be carried out more easily and quickly.

The Smart Flex Effector is designed for handling loads of up to 6 kg. For machine manufacturers and users, it opens up a wide range of new applications which were difficult or not possible with previous equipment, such as passive compensation units, force torque sensors and visual systems. The applications range from process automation and quality monitoring to teaching and the controlled handling of objects.

Quantum Leap in Process Automation

With its differentiated kinematics, the Smart Flex Effector is able to correct processes with great complexity and tight tolerances, such as in the case of positional deviations between the tool and the work pieces or in complex joining processes with minimal tolerances. Thanks to this tactile sensitivity, tasks that were not automatable can now be performed by robots.



Quicker Teaching

In another area, the Smart Flex Effector also reduces the time previously needed for teaching processes. Thanks to the 6D position recording, the robotic control system can read the exact coordinates for gripping and placing points directly. Repeated learning during operation is therefore possible in an automated manner. Robots can also be taught manually – simply by moving them into position by hand.

Sensitive Handling of Objects

Even during sampling, the Smart Flex Effector can be used to recognize positional deviations and, with the help of the sensor system, determine the exact position of the object. The robot accurately picks up assembly or handling objects, positions them in a controlled manner and places or sorts them reliably. Even parts made of glass or other fragile materials can now be handled safely. To ensure maximum productivity, the compensation module can be actively moved into the zero position and electromechanically locked for fast transfer runs.

Improved Quality Thanks to Transparency

As part of process monitoring, the Smart Flex Effector not only makes documentation easier, but quality can be improved too, as deviations are recognized immediately and either corrected or reported to the control system. This avoids errors and unnecessary costs owing to rejects or follow-up work.

High Connectivity, Easy Installation

The Smart Flex Effector offers an RS-485 interface as well as an I/O interface for exchanging data. Installation is extremely easy: For a passive compensation function, the Smart Flex Effector is simply screwed to the robot flange and the gripper. The locking function and data transmission are available as soon as the unit is connected to the power supply and the control system.

boschrexroth.com/en/us/smartmechatronix/smart-flex-effector

Plug & Produce Sensor Production

Sensata utilizes Bosch Rexroth Smart Function Kit for mechatronic application

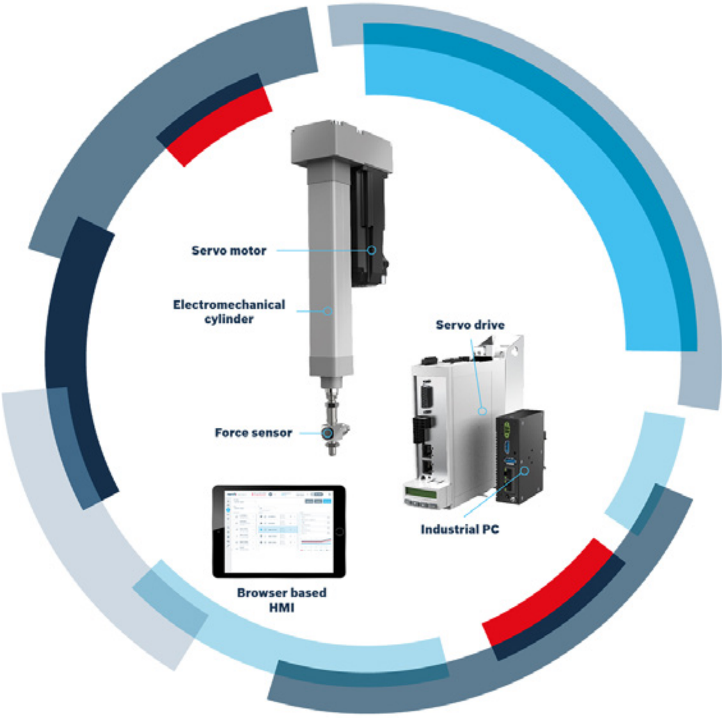
Tim Voog, Bosch Rexroth

With its flexible multiproduct line for rotary encoders, Sensata has developed a sustainable solution. The heart of the precise sensor assembly system: The Smart Function Kit for pressing processes. The complete mechatronic package with preinstalled software reduces the programming to a minimum. Engineering, commissioning, and quality assurance become quicker, easier, and more cost-effective.

The production of various sensor types in small batches on a single line, the autonomous configuration of production modules, the automatic commissioning and recording of process data: the international manufacturer Sensata was focusing on these futuristic requirements and looking for a set-up for a flexible multiproduct line for rotary encoders.

Easy Commissioning, Flexible Manufacturing

The rotary encoders are used in self-propelled transport shuttles to determine position and distance. On this newly planned line, the circuit board and the disc for the sensor unit are placed in the housing and then fixed with a lid.



The mechatronic solution for the critical, product dependent pressing process needed to be not only precise and reliable but also cost-efficient.

"We're always trying to make our processes simpler and to do as much as we can ourselves—ideally with standard components and without programming effort," said Jean-Marc Hubsch, engineering manager in Sensata's Industrial Encoders division. According to Hubsch, the idea of a production line which can cost-effectively produce 1,000 or 10,000 versions of a sensor system in small batches is new, but future oriented. Preconfigured modules, which his team merely needs to put together and parametrize for commissioning, are key.

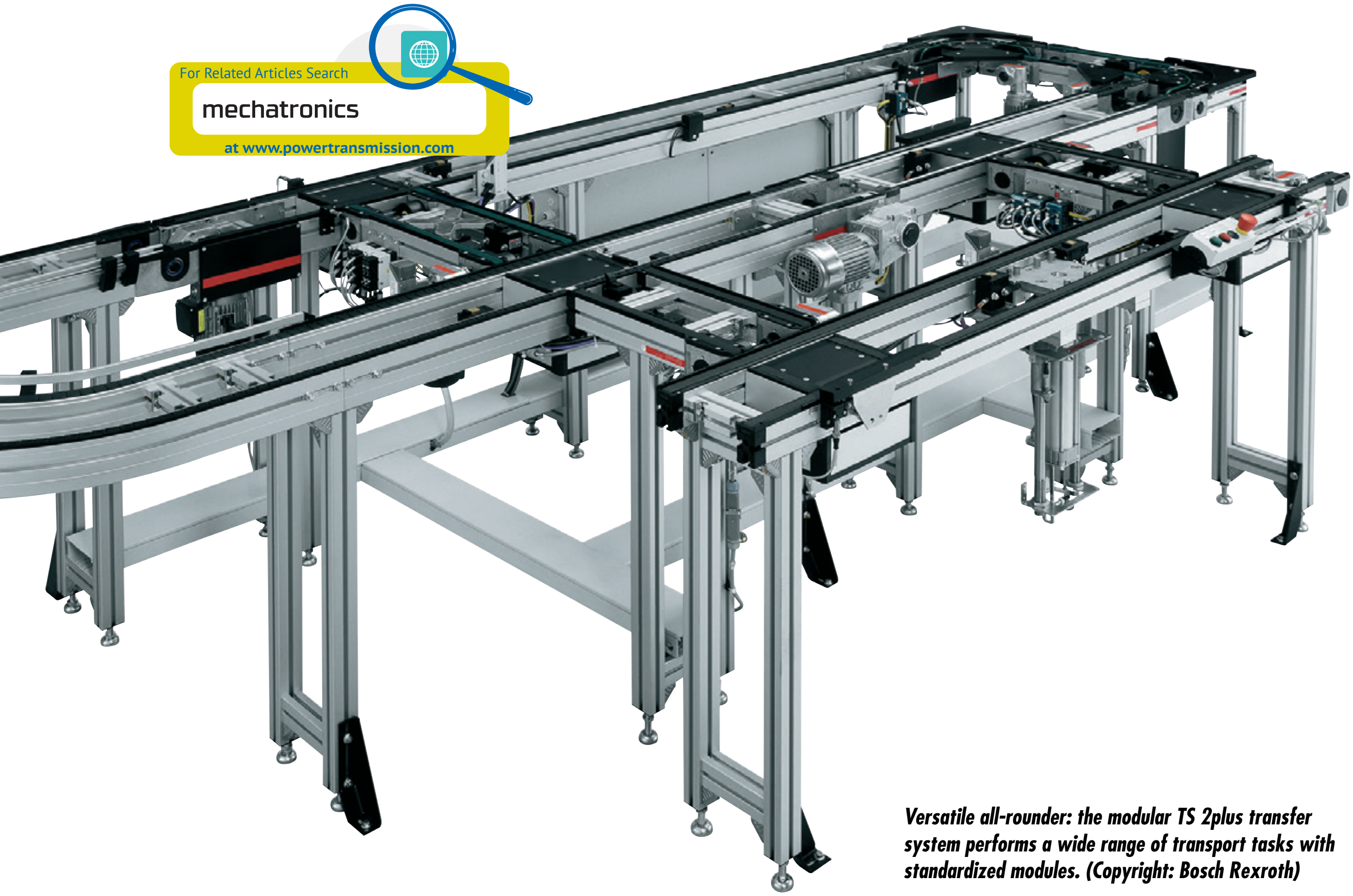
Smart Function Kit for Pressing Processes

The construction engineer saw the appropriate solution at the Hannover trade fair in 2019: The Smart Function Kit from Bosch Rexroth—a mechatronic package including mechanical, electrical and software, for standardized pressing and joining applications within the force range from 2–30 kN.

"This easy-to-use kit is not only interesting for system integrators, but it also benefits end customers like Sensata, who have their own process know-how," Rexroth Project Manager Laurent Steinmetz explained. The Smart Function Kit for pressing and joining applications combines proven standard components like an electromechanical cylinder (EMC), a force sensor, a servomotor, a drive controller, and an industrial PC with an intuitive HMI software, running device-independently on the browser and can be operated via tablet.

Zero Programming

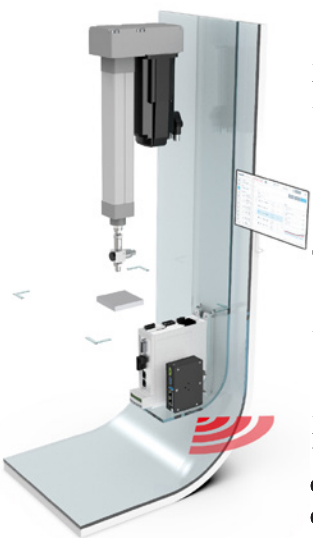
The Sensata engineers made use of visual programming: instead of coding line by line, they selected predefined software blocks and created a sequential workflow via drag and drop. In order to define the individual processes in the joining procedure, they simply enter the associated parameters. The drive controller is automatically parametrized and commissioning is supported by a wizard.



Versatile all-rounder: the modular TS 2plus transfer system performs a wide range of transport tasks with standardized modules. (Copyright: Bosch Rexroth)

"Compared to the previous practice, the engineering time is reduced by up to 95 percent," said Steinmetz. The simple analysis of the pressing process with validation elements ensures time savings within the operation phase.

For monitoring purposes, status information and process results including a force displacement curve are shown and recorded live. "All data are transferred straight to our IT system where they are stored and analyzed for quality assurance purposes," reported Hubsch. "This means much greater transparency during production."



Precise Individual Processes

The high quality and precision of each individual hardware component were also reasons why Sensata engineers chose the Smart Function Kit. It's current task of pressing in the housing flange with the help of three distance bolts, is carried out with a maximum force of 800 daN and +/-0.02 mm accuracy. Although the configuration of the products on the line varies considerably, the solution is 100 percent reliable. In the final stage of the production line, the Smart Function Kit obtains the individual production parameters from a chip on the workpiece pallet via an RFID solution.

Scope for Line Integration

To further simplify the engineering of the line, Sensata also opted for a modular transfer system from Bosch Rexroth. The Rexroth TS 2plus system likewise comprises standard components which can be combined flexibly. The line is also controlled by the XM21 embedded control system from Rexroth. Thanks to open interfaces, the Smart Function Kit can even be integrated easily into line control systems from third-party providers if necessary.

Smart from Dimensioning to Maintenance

Hubsch explained that with the flexible transport system and the integrated Smart Function Kit, Sensata has found an easy-to-use system kit which allows high-quality and cost-effective joining applications. Thanks to Rexroth's *LinSelect* software tool, the dimensioning process is straightforward. The convenient online configurator helps with finding the appropriate composition and enables the download of the CAD files before ordering the final system via the Rexroth e-shop.

"All components were supplied already preconfigured in a single package," said Hubsch. Bosch Rexroth is now looking to further develop the software by adding additional function blocks, e.g., a predictive maintenance module for optimizing maintenance.

In the next step, Hubsch would like to increase the number of sensor types on the line. There are also plans to duplicate the line and install it at other international sites. With the help of Bosch Rexroth's global support, the solution will be internationally scaled and will continue to grow step by step.

boschrexroth.com
PTE

Production of different types of rotary encoders at Sensata: the Smart Function Kit for Pressing reduces engineering, commissioning and quality assurance costs. (Copyright: Sensata)

Smart MechatroniX for the Factory of the Future

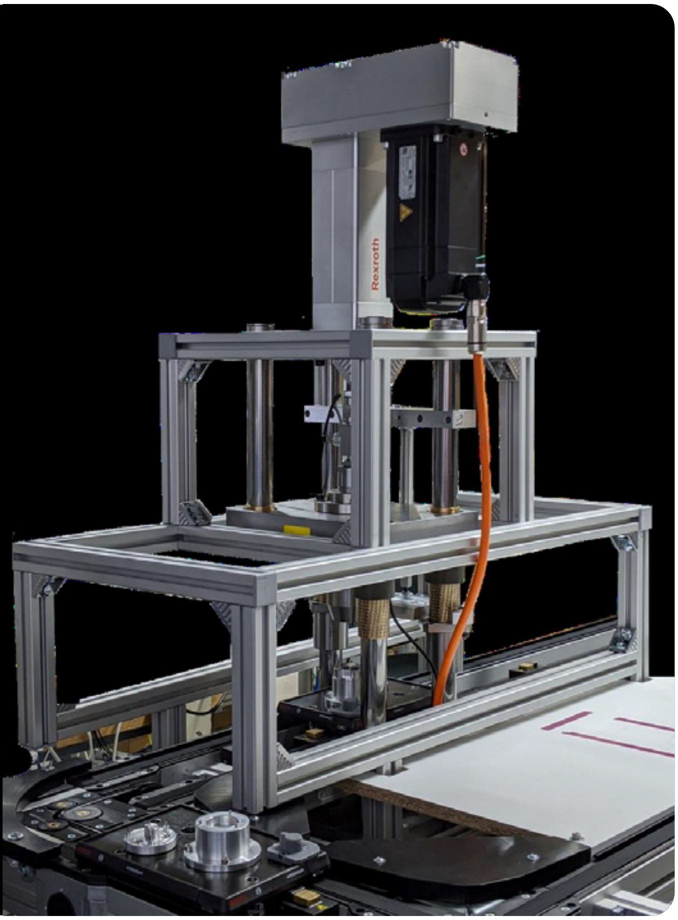
The Smart Function Kit from Bosch Rexroth is the first of three innovative solution packages offered as part of the new Smart MechatroniX solutions platform. According to the motto "Plug & Produce, Perform, Proceed" pre-configured and ready-to-use system solutions comprising proven hardware and intelligent software are paving the way for the Factory of the Future.

The Smart Function Kit for pressing and joining tasks is followed by one for handling tasks: a Cartesian single or multi-axis system that's combined with proven linear motion technology components, innovative control systems and software to form a perfectly tailored complete package.

Another Smart MechatroniX solution, the Smart Flex Effector, will follow later. This is a sensor-supported compensation module with independent kinematics in six degrees of freedom which is designed to increase handling accuracy.

Editor's Note: *See page 14 for additional details.*

boschrexroth-us.com/smartmechatronix



Having a Ball: The Technology Behind the Ball Drop

The New Year's Ball Drop wouldn't be possible without a sophisticated electromechanical system that must operate reliably during the most critical 60 seconds of the year.

Oscar Lopez, Service Manager, SEW-Eurodrive

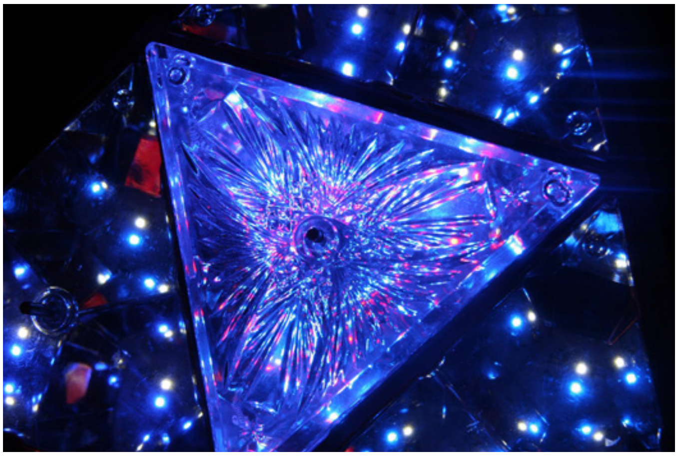
More than a billion people around the world unite to ring in the New Year, their eyes set upon the glittering New Year's Ball in Manhattan. Thousands are gathered at Times Square—the famed "Bow Tie" of Midtown—braving the December cold and peering through glasses with numerically shaped frames. Millions more tune in from their various screens at home. With so much riding on its descent, the Ball, along with the mechanical and electrical systems responsible for its operation, must operate like clockwork.

Central to its success is a powerful winch system that includes a combination planetary and helical-bevel gear unit from SEW-Eurodrive. This unit—which runs at 7.5 rpm with a 235.89 gear ratio, output torque of ~31,500 pound-inches (lb-in) and 40 hp brake motor—joins a sophisticated set of subsystems that work together to raise and lower the 11,875-pound Ball, making the New Year celebration possible.

About the Times Square Big Ball

Responsible for this seventh and latest iteration of the Ball, including its structural engineering, mechanical design, systems integration, light fixturing and rigging, is Hudson Scenic Studios (hudsonscenic.com), a specialist in custom fabrication, automation and bespoke finishes for the entertainment and architectural industries.

Constructed in 2008, this Ball is twice the size and three times as bright as the preceding Centennial Ball. A geodesic sphere with a 12-foot diameter, the Big Ball features 2,688 Waterford Crystal triangles that are bolted to 672 light emitting diode (LED) modules. Each module, which is attached to the Ball's aluminum frame, contains 48 red, blue, green and white LEDs, totaling 32,256 lights that can create millions of color combinations and kaleidoscope patterns.



The Big Ball features 2,688 Waterford Crystal triangles.

On December 31st at 6:00 p.m. EST, this Big Ball—as it has done for over a decade—rose to the top of its 130-foot mast in One Times Square, where the Ball resides year-round. Then, at 11:59 p.m., it began its 75-foot descent, the timing of which was tied to a global positioning system (GPS).

When the countdown hit zero, the Ball dropped behind the seven-foot-tall New Year numerals shining above Times Square. Its lights turned off, and the 2023 numerals, along with the New Year itself, were suddenly brought to life.

"In that moment, the whole world unites," said Jeffrey Straus, president of Countdown Entertainment, LLC, the co-organizing company behind the Times Square Ball Drop.

The Ball's Permanent Home

Built in 2007 to commemorate the Times Square Ball Drop's 100th Anniversary, the Centennial Ball was the first design to incorporate LED technology instead of incandescent and halogen bulbs. Its elegance and energy efficiency inspired Jamestown LP, the owner of One Times Square, to commission the construction of the current Big Ball, which remains a permanent, sparking fixture in Times Square all year long.

The Winch System and Gearmotor

For 87 years following the first Ball Drop in 1907, the Ball was raised and lowered by six men with ropes and a stopwatch—a solution that is far from practical, if even possible, for the current six-ton Ball. "Although it operates on a limited basis, the Ball must always remain functional," said Brant Underwood, senior project manager at Hudson Scenic Studios.

Whether the Ball is descending on New Year's Eve or serving as a backdrop for tourist photos the rest of the year, its full weight—including the LED modules, aluminum frame and electrical system at its center—is supported by a powerful winch system. Designed for inverted mounting below the mast platform, this winch includes a two-line system and 42-inch drum with helical grooving. Two 3/4-inch wire ropes, which connect to the Ball, wrap around the drum in opposing directions, maximizing handling control and keeping the winch system as compact as possible.

Also hooked up to the drum is the SEW-Eurodrive gearmotor that holds the weight of the Ball at full torque. The machine incorporates a planetary and helical-bevel gear, AC motor, encoder and brake. A closed loop regenerative variable frequency drive (VFD) uses the encoder to provide highly accurate speed control of the motor. According to Underwood, this regenerative VFD is what turns the winch "into a kind of generator" during the 60-second Ball Drop. "As it resists the load of the Ball during the 75-foot descent, the regenerative system pushes power back to the electrical grid," Underwood added.

A gearmotor is a combination gear unit and motor, usually an AC or servo motor. Its central function, which is performed by the gear unit and its gear unit stages, is to transmit the motor's force from the input end to the output end, thereby acting as a kind of converter of speed and torque. In most applications, the gear unit slows down the motor's rotational speed while at the same time transmitting higher torques than what the electric motor can accomplish on its own.

The SEW-Eurodrive gearmotor incorporates two gears—a planetary gear that produces most of the required torque for the Ball application, as well as a helical-bevel gear. Other components include an AC motor, encoder, and rectifier brake.

The powerful winch system supports the Ball's full weight—including the LED modules, aluminum frame and electrical system—all year-round.

A Monumental Feat in Welding

During the Ball's construction in 2008, various metalworkers, welders, fitters, finishers, machinists and assemblers clocked in more than 3,000 hours of labor, earning the Ball the American Welding Society's Extraordinary Welding Award in 2014. This award, which is given to welded structures with historical importance, celebrated the Gas Tungsten Arc Welding (GTAW) process that was utilized in the Ball's aluminum frame construction. In particular, workers arranged the structure into 180 triangular faces, each of which was made from 4-inch-diameter tubes and welded together via GTAW.

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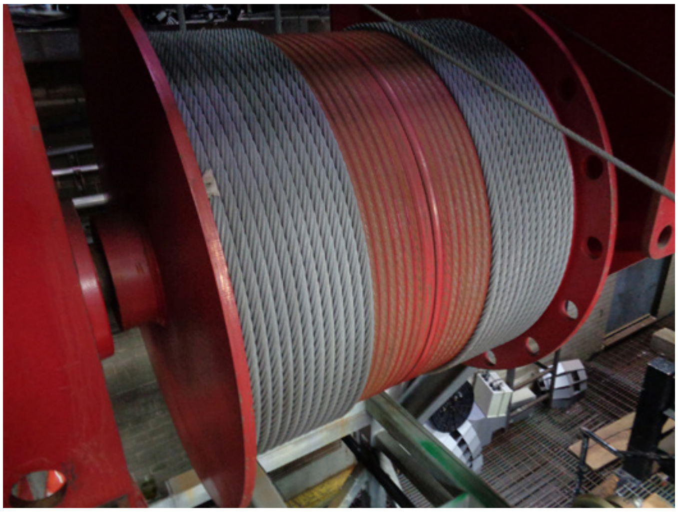
Transporting the Massive Mast

According to the Hudson Scenic team, the Ball's 130-foot mast was one of the largest pieces of steel to ever enter New York City. The mast, which was pre-rigged with all the necessary cable management components, was brought across the George Washington Bridge after midnight on the back of an articulating dolly trailer.

- *Horsepower: 40 Hz*
- *RPM: 7.5*
- *Voltage: 230/460 V*
- *Shaft: 90 mm*
- *Flange: 450 mm*
- *Brake voltage: 230 AC*
- *Brake torque: 221.2*

Essential to the winch system is the SEW-Eurodrive gearmotor.



The winch also includes two ¾-inch wire ropes that wrap around the drum.

Rounding out the winch system is a programmable logic controller (PLC) for controlling all the movements, as well as roughly 20 to 30 multiconductor cables that supply power and data to the whole system. Operators can control the Ball using either a local controller or the human machine interface (HMI) on the 22nd floor of One Times Square.

"The local controller is a secondary interface that acts as a redundancy," Underwood said. "Using a handheld device, we can go out onto the roof and raise or lower the Ball from there."

Remote Control Means More Safety

Because the roof of One Times Square contains various signs, railings and other building appendages, the ability to control the Ball remotely creates a critical failsafe. "It can be a tight space up there," Turnstall says. "Sometimes there's only a foot of space between the Ball and other building elements. If the Ball descends too low, for example, we need a way to stop it before it hits something and cracks a crystal. Having this ability to control the Ball remotely means there are more eyes on it, ensuring it's handled and treated with the utmost of care."

Along this topic of safety, the Ball includes an emergency (E)-stop function, as well as various subsystems and I/O control that enable operators to monitor aspects of the Ball's position and operation. Examples include the ability to monitor the Ball's power, as well as sensors that will alert operators if the main disconnect switch turns off.

Improving the Ball's Reliability Through Routine Servicing

Times Square is one of the most frequently photographed buildings in New York City. "This fact makes routine maintenance critical for the Ball's ongoing operation, as well as for the forward-facing presentation of the building," says Ryan Tunstall, senior vice president of development and construction at Jamestown, L.P., which owns One Times Square.

To ensure the winch system will perform its annual duty, the Ball is raised and lowered roughly once a month. SEW-Eurodrive technicians also come in and provide regular inspections of the gearmotor.

The Ball is in good hands. We drain the oil, inspect the internal components of the gearbox, and analyze the oil samples in a lab. The elemental analysis tells us whether there's any abnormal wear taking place in the equipment. We often apply these same maintenance techniques to other machines.

The gearbox—which was recently serviced by SEW-Eurodrive technicians in early December 2022—has very minimal wear and tear. As the unit ages, the plan is to "be more aggressive" in terms of making technical recommendations.

Fortunately, the gearmotor doesn't need extensive servicing due to its limited operational frequency. Because of the low duty cycle, the gearbox rarely experiences a significant rise in temperature, which has a direct effect on the health and longevity of the equipment.

To 2023—and Beyond

According to Straus of Countdown Entertainment, the Ball, with a billion eyes on it each year, depends on the gearmotor and winch system to ensure the New Year starts. "One year, when the Ball was still controlled by ropes, a person even got tangled up, causing the Ball to stop halfway through its descent and delaying the New Year," Straus said with a chuckle. "Thanks to the winch system, we've never had an issue."

seweurodrive.com

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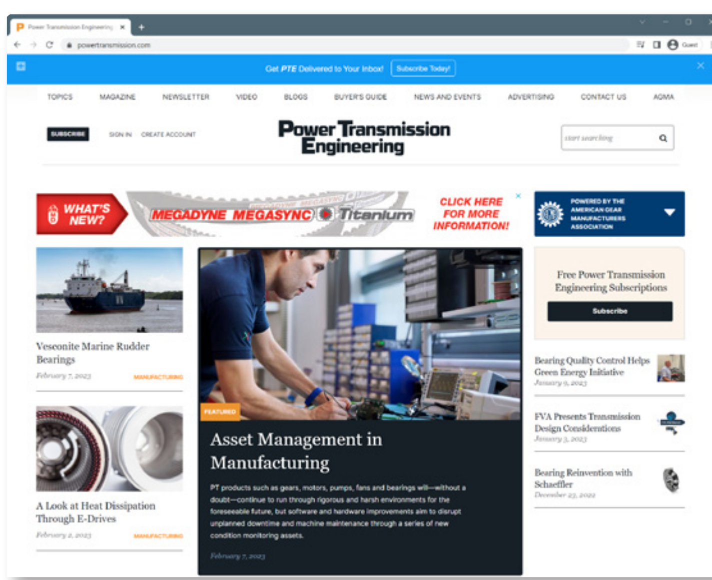

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Industrial Transformation at Hannover Messe

Trade show examines resource-efficient, climate neutral production technologies in 2023.

Matthew Jaster, Senior Editor

Hannover Messe 2023 provides the latest technologies in robotics, automation, motion control, IIoT, fluid power, e-mobility, material handling and more. *PTE's* sweet spot, so to speak, are the vendors in the drive, fluid power, and motion control segments.

"Drive and fluid technology components are the central building blocks of machines, for power and motion, but also as a source of data for digital value-added services and crucial to the performance of customer products – this is what we will be showing at Hannover Messe," said Hartmut Rauen, deputy executive director of VDMA.

The following round-up examines some of the motor, gear and drive technology featured in Hannover this April.

Cantoni Motor (Hall 6, Stand C22)

High Efficiency low voltage NEMA motors SIE series (in the range from 1 up to 250 hp) are designed to withstand the most extreme, severe-duty applications (in compliance with the NEMA Premium requirements).

The NEMA Premium efficiency electric motors program refers to single-speed, polyphase, 1-250 hp, 2, 4, and 6 poles, NEMA Design A or B, continuous rated, squirrel cage induction motors.

These motors are designed for long life and reliable operation in most extreme industrial applications.

NEMA motors can operate in severe duty applications thanks to heavy-duty cast-iron construction. Special shaft sealing systems have been applied to increase the level of protection against contaminants.

They also offer NEMA brake motors. Apart from standard executions, they offer special JM/JP motors designated for driving of pumps.

The entire range of NEMA motors is certified according to CSA and UL standards.

Three-phase induction motors with output range from 0.06 kW to 2,500 kW with foreign ventilation (forced ventilation). Foreign ventilation is supplied independently of the main motor and built in the fan cover. Motors are adapted for speed control by frequency converter.

Cantoni Motor manufactures a wide range of traction motors (output power from 50 to 1,500 kW), and traction generators. Motors for various traction vehicles: trams (including low-deck trams), trolleybuses, subway, and locomotives.

Electromagnetic brakes are designed for braking rotating parts of machines and their task in areas such as emergency stopping, immobilizing machine actuators, acting as a positioning device, and minimizing run-on times of drives.

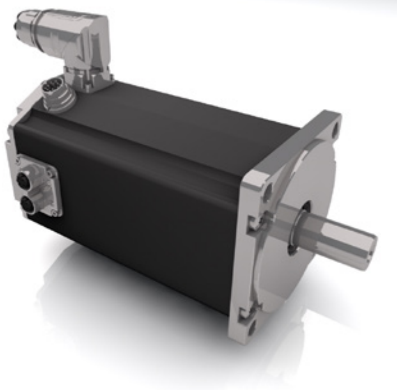
These brakes can be used in many application areas including industrial cranes, wind power plants, platforms, escalators, warehousing, cranes and more.

The Cantoni Group supports young and passionate engineers from Czestochowa University of Technology (Politechnika Czestochowska) in the implementation of innovative projects and appreciates their contribution to the development of advanced technology of the future.

For years the group has succeeded and has been awarded in many domestic and international competitions for their advanced projects including the Mars Rover.

cantonigroup.com

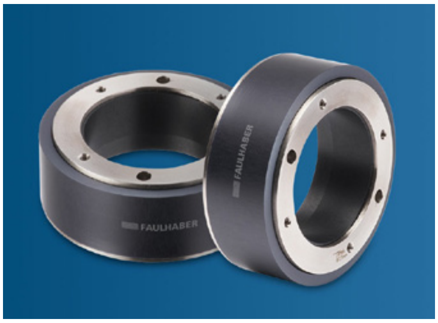
Dunkermotoren (Hall 6, Stand B08)



Following the BG 66, BGE5510 and BG 95, the BG 75 brushless DC motor is now also available as a dPro version. With a continuous output power of up to 590 W, peak power of up to 1,700 W, and a peak torque of almost 5.8 Nm, the BG 75 dPro is more powerful than all other versions of the BG 75 series – with a supply voltage of just 24 or 48 VDC. This means more power in the same space, allowing machines to be built even more compact in the future. These characteristics makes the BG 75 dPro the perfect partner in the application fields of logistics, robotics, as well as machine and plant engineering. It can, for example, be used equally in the food, semiconductor, and electronics industries, or can operate as a drive for AGVs (Automated Guided Vehicles). Connection and programming is as easy as for all motors of the dPro family and is done either via CANopen or one of the Industrial Ethernet interfaces Profinet, EtherCAT or Ethernet/IP. The hybrid connector used for this reduces the cabling effort to a minimum. The motor can then be programmed, controlled, and monitored via the "Drive Assistant 5" commissioning and configuration tool and/or MotionCode.

dunkermotoren.com/en

Faulhaber (Hall 6, Stand B22)



With its DM66200H series, Faulhaber is upgrading performance for motors with an internal opening (aperture). As a direct drive, the new hollow shaft motor operates backlash-free and can be integrated into different applications with very limited effort. It achieves performance values in terms of both speed and torque. Its exceptionally wide aperture has a diameter as large as 40 mm. The drive is characterized by low weight and an extremely slim design. Thanks to minimal wear (bearing only), it is ideal for maintenance-free continuous operation.

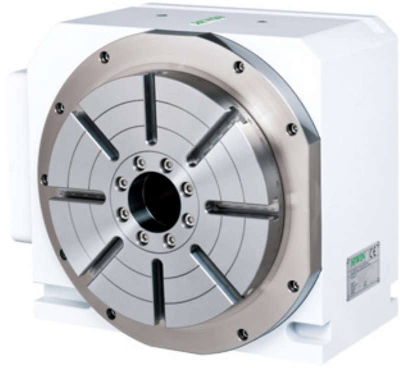
The DM66200H hollow shaft motor offers a completely new drive solution for applications that require a very large aperture. The rotor runs around the opening and drives the mechanics surrounding this opening directly without the need for a transmission. Due to the design, it is extremely energy-efficient and requires neither a brake nor an encoder.

Despite the large aperture, the moving mass of the rotor remains small, making speeds of up to 2,000 rpm possible. The motor reaches a dynamic torque of up to 180 mNm and can move correspondingly large loads. With a high resolution of 1.8° in full-step mode, it can execute positioning tasks precisely in open loop operation.

Originally developed for precision optics applications, the DM66200H hollow shaft motor is suitable for many different application areas. It can be used wherever cables need to be guided through the aperture or in cases where gases, fluids or light signals are to pass through the opening. Apart from the field of optics - e.g., for microscope stages, apertures, zoom lenses, laser beam controls, etc. - it can be used for impellers and prostheses, in robotics as well as for many different control and positioning tasks. Other potential applications are turntables, antennas as well as air and gas extractors.

faulhaber.com

Hiwin Corporation (Hall 7, Stand D32)



Hiwin Corporation linear motors are direct drive, plug and play solutions. Linear motors are capable of fast accelerations and high speeds, while providing precision and accuracy. Hiwin offers standardized linear motor designs but customizable options are available. Aside from single-axis linear motors, these stages can be combined to form cross tables or even gantry systems.

Hiwin rotary tables are ready-to-install rotary axes consisting of a torque motor, bearing, motor housing, and positioning measuring system. Hiwin rotary tables are zero-backlash, extremely rigid, optimized for high torques, have robust dynamics and are especially well suited for tasks in a wide range of automation processes. Their lack of gear needed results in high efficiency and a quiet operation. Various sizes in diameter and height are available with the option to add a servo drive for a complete plug and play solution.

Linear axes and multi-axis systems for positioning tasks in automation. Linear guideways provide linear motion by re-circulating rolling elements between a profiled rail and a bearing block. The coefficient of friction on a linear guideway is only 1/50 compared to a traditional slide and they can take loads in all directions. With these features, a linear guideway can achieve high precision and greatly enhanced moving accuracy. Hiwin Corporation offers multiple linear guideway series, each featuring different options for sizes, loading capabilities, accuracies, and more.

The company's strain wave gearing system has three basic components: a wave generator, a flex spline, and a circular spline. The elliptical shape of the wave generator, rotating against the thin, tooth lined flex spline, drives or is driven by the rigid circular spline which has more teeth than the flex spline. The result is a gear system that will reduce speed and increase torque. The unique properties of the strain wave gearing system allows it to achieve much higher gear ratios than other gear reduction solutions in a more compact space.

hiwin.us

I-MAK Reductor Varyator (Hall 6, Stand A39)

Available in one or two stage of gears, the IR Series gearboxes provide optimal solutions for a large range of applications. The unicase housing of the gearbox and the gears offers a perfect balance between power and space optimization.

Designed to last, the helical bevel gear units IRK series are perfectly adapted for applications in need of high efficiency gearboxes. The gear design also offers quiet operation. These advantages guarantee a noise free and low maintenance gearbox.

The worm gear units, IRS series, remains one the best solutions for simple applications in need of high ratios. This gearbox unit also offers assistance where backstops need to be strong and resistant.

The parallel helical shaft gear units YP series remain the optimal solution for complex and space limited applications. The fully reversible design of the gearbox offers a large range of mounting positions. The gears combinations allow high loads and the options for low output speed makes it the ideal solution for a large range of applications.

Imakreduktor.com

Lafert (Hall 6, Stand B25/2)

Smartris is the new complete package solution including gear, servomotor and drive for AGV systems, and combines the extensive technological competences of two companies. Lafert customized solutions for electric motors and drives meets Sumitomo expertise in gears and gearboxes. Both brands have strong reputation respectively in the motor and gear market and in the AGV sector, and with this new integrated package they are offering very competitive advantages and benefits.

HP Combi is two-in-one, an innovative marriage between a permanent magnet synchronous motor and a variable frequency drive (VFD). The Combi package combines the IE5 Ultra-Premium Efficiency of Lafert's permanent magnet synchronous motors with the VFD, achieving the highest energy efficiency standards. The range of motors utilizes the technology behind brushless servomotors and asynchronous motors to generate the high torque density that allows up to a 50 percent reduction in size and weight.

High Performance Motors (HP) is an innovative range of PM (Permanent Magnet) Synchronous Motors, achieving IE4 and even IE5 Super Premium Efficiency level, that offers improved efficiency and reduced operating costs.

This uniquely engineered product combines the electrical design of brushless servomotors with the mechanical design of AC Induction Motors. The result is a compact motor range primarily targeted toward HVAC applications in pumps, fans, compressors, and blowers, where there is an emphasis on reducing the operating cost or weight and size of the motors.

The complete range is supplied as stand-alone motors (HPS range) to be controlled by a separate drive or as motor/drive integrated units (HPI range), specifically designed for their energy saving potential.

Lafert places great emphasis on materials research. This has resulted in reduced dependency on rare earth magnets, allowing for the use of more readily available permanent magnets, which ensure price and supply stability into the future. Following this development work Lafert has introduced a second generation of PM Synchronous Motors, named HPF, achieving IE4 Super Premium Efficiency level, with more stable and reduced production costs without applying rare earth magnets.

lafert.com

NKE Austria (Hall 5, Stand B05)

NKE manufactures bearings with ceramic rolling elements. Technologies are advancing rapidly and bearings must meet more sophisticated and varied requirements under increasingly demanding operating conditions.

In response to these special needs, NKE Austria and FERSA have committed to the development and manufacturing of hybrid bearings. Hybrid bearings can be used in new applications where conventional steel bearings have not been beneficial. For example, bearings with ceramic rolling elements are especially designed for applications where high-grade electrical insulation is necessary and/or high speeds occur.

Furthermore, NKE premium hybrid bearings possess excellent performance characteristics, like extended service life and reduced friction.

NKE spherical roller bearings are used to support high radial loads and compensate for misalignment of the bearing positions and/or increased shaft bending. This type of bearing is suited for applications with high loads and difficult operating conditions. NKE spherical roller bearings were designed to withstand such conditions in demanding operational environments. In order to achieve maximum strength and longevity high quality bearing steel is used. An optimized inner design with an increased number of rollers allows for higher load capacities of our products. The inner design is optimized for challenging operating conditions, reduces wear and heat and therefore the usage of lubricants. This results in less downtime and reduced effort and finally to a reduction of costs.

NKE provides bearings with oxide ceramic insulating layers on the bearing ring. Applied with plasma technology, the insulation has a guaranteed breakdown resistance of at least 1,000 V AC or DC.

nke.at/en/

Rollon by Timken (Hall 6, Stand B39)

Rollon offers the TH Series where the linear axis is fitted with a preloaded ball screw drive and ball guides with a ball chain. Due to its design features, it is especially well suited for applications requiring high performance and precision. The applications for the TH Series include laser applications, dosing robots and various handling tasks. This linear axis is characterized by high intrinsic rigidity and load bearing and offers additional flexibility with one or two carriages.

Compact Rail is the product family of roller sliders with guide rails made of cold-drawn roller bearing carbon steel. The raceways are located on the inside of a C-profile, thus protecting them from soiling. Fixed bearing rail, compensating bearing rail and compensation rail enable combinations for all applications in which deviations in parallelism must be compensated in one or two planes. Easyslide is the product family of compact linear ball bearings for high load ratings with long service life. They are equipped with one or several sliders per rail. If several sliders are used, they can each run, independently of one another, in their own ball cage or synchronized in a common ball cage. Different slider lengths and strokes can be selected. All Easyslide guides are particularly easy to mount. Easyslidel linear ball bearings are used in sliding doors on vehicles or machines and the like. The system made up of rail, slider and ball cage is particularly easy to mount, and is economical and reliable.

rollon.com/usa/en

R+W Antriebselemente (Hall 5, Stand A48)

The low-wear, flexible gear couplings from R+W are used in a wide variety of industries. Particularly in heavy-duty operation – such as on the high torque shafts of mixers, rolling mills, crushers, test stands and conveyors – gear couplings transmit torques from 1,900 to 2,080,000 Nm with high torsional rigidity and low backlash. To ensure optimal performance, R+W manufactures both the coupling hubs and the flange sleeves with precise crowned gearing, made from high-strength steel.

Durable, reliable, and flexible: these characteristics make industrial couplings ideal for all applications that require maximum safety and performance in the face of constant and extreme loads. Engineers and operators across a wide range of industrial sectors are aware that machine component failures and downtime drive up cost and, in the worst cases, can lead to accidents – making proper industrial coupling selection critical.

The main advantages of elastomer couplings include vibration damping, easy installation, zero backlash transmission, and electrical isolation. Whether for machine tools, packaging machines, automation systems, printing machines or general mechanical engineering - the uses for elastomer couplings are as diverse as their requirements.

Elastomer couplings are part of a wider group, known as jaw couplings, the key component of which is an elastomer segment inserted between two hub halves. This elastomer insert is the heart of the elastomer coupling. It transmits torques from 0.5 to 25,000 Nm without backlash, and compensates for axial, lateral and angular shaft misalignment. When properly selected for size and hardness, the elastomer insert optimizes the entire drive train and exhibits important characteristics, such as vibration damping, torsional stiffness, and thermal stability.

rw-couplings.com

Neugart (Hall 6, Stand B48/1)

The Neugart WPLHE combines all the advantages of the successful PLHE, as a right-angle variant.

Specifically, the WPLHE features both the gearing of a proven economy gearbox and a high-performance output bearing with preloaded tapered roller bearings, which are otherwise commonly used in precision gearboxes (such as the PLN and the PSN). This means that the new right-angle gearbox tolerates high radial and axial forces of up to 8,000 N at the output. For example, pulley drives with high radial loads can also be implemented in right-angle designs.

Compared to the coaxial PLHE the motor is rotated by 90° in this case, the WPLHE offers the ideal solution in confined spaces, for example in packaging and other special machines. It is an economy right-angle gearbox offered with a pre-mounted pinion as an option. This makes it particularly suitable for space and cost-sensitive rack-and-pinion drives. There are 13 different pinions from which to choose: with choice of straight-cut or helical-cut teeth, from module 2 to 3, with numbers of teeth from 15 to 27.

Thanks to the output geometry with square output flange and long centering flange that has become established on the market, the WPLHE is easy to implement. Several different output shaft variants - smooth, keyed, splined or with pre-mounted pinion - mean that the right-angle gearbox can be used in a wide range of applications. It also offers IP65 protection, making it suitable for harsh, dusty, and dirty environments. Food-grade and low-temperature lubricants are also available for the lifetime lubrication commonly provided by Neugart.

Additionally, the company will feature its economic planetary gearbox line for a wide variety of drive solutions.

neugart.com

Wittenstein (Hall 6, Stand D23)

Highlights from Wittenstein at Hannover include the following:

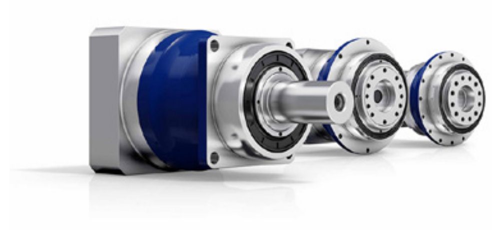
With cymex 5 sizing software, the entire drivetrain (application + transformation + gearhead + motor) can now be sized and designed quicker and more reliably. Its calculations are considerably simplified by predefined standard applications. Optimally sized and more efficient motors are achieved by abstracting all important influencing factors.

The ultra-compact and dynamic IDS3010 is a contactless measuring sensor for the engineering industry. With a data acquisition bandwidth of 10 MHz, the IDS3010 simultaneously tracks up to three axes at velocities of 2 m/s. The sensor provides a position resolution of one picometer and reaches working distances of up to five meters.

The alpha Value Line is universally suitable: it represents the most economical solution whatever the requirements for driving any axis in virtually any industry. Each input or output interface for the alpha Value Line was developed as a compatible add-on for Wittenstein alpha's existing high-end portfolio.

With the servo actuator TPM+, precision planetary gearheads and synchronous servomotors are integrated without a clutch for a unit that is flexible in its application. In combination with short overall lengths, high power-density, and smooth running: this marks a whole new level of performance - along with practical, graduated performance settings that ensure greater operating efficiency in all your production applications.

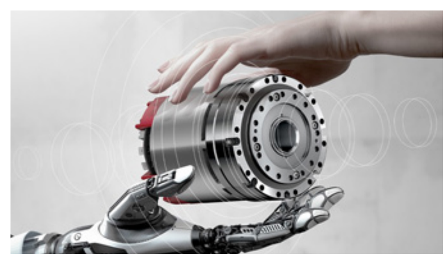
Experience extraordinary dynamics thanks to modern motor technology



with high power density, a low moment of inertia and optimal torsional rigidity. Benefit from a reduced installation length: The coupling-free connection between motor and gearbox and the space-saving attachment of motor instruments make the TPM+ DYNAMIC 50 percent more compact than conventional gearbox motors. Helical-toothed precision planetary gearboxes ensure low-vibration and silent operation.

wittenstein-us.com

Sumitomo (Hall 6, Stand B25/1)



Sumitomo's booth will include actuators, ball bearings, gearmotors and more. TUAKA offers a fully integrated actuator including a powerful driver. As an option the product can be configured with a torque sensor as well as with a second encoder on the output. Additional safety features are also available with a safety-level up to SIL3 PL-e.

Angular contact ball bearings can integrate directly into a gearbox housing. The improved design provides very accurate motion quality with increased torque density and bearing capacity. They are ideal for robotic and machine tool applications. The fully sealed modular design is available with motor adapter and clamping ring.

The right-angle hollow shaft gearmotor with IE5 ultra-premium efficiency motor is compact and highly efficient drive-package consisting of motor, gear and VFD. High input speeds up to 3,600 rpm.

The new E CYCLO series features high rigidity due to its internal roller bearings. This is significantly higher when compared to the competition. Therefore, the E CYCLO can achieve higher performance in a smaller design envelope and thus lower costs.

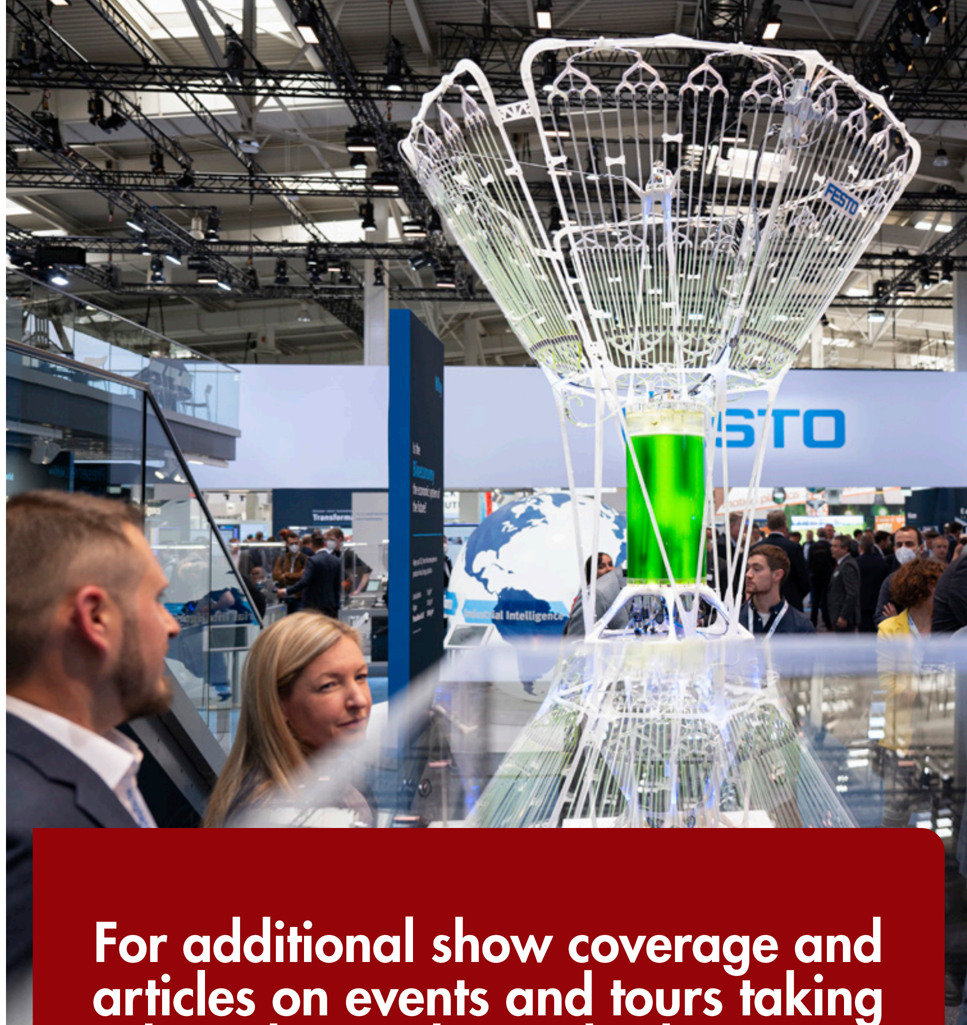
sumitomodrive.com

Timken (Hall 6, Stand B39)

Timken Quick-Flex elastomeric couplings can withstand harsh conditions, yet need minimal maintenance. They're easy-to-install and require no lubrication. With a lifespan that can match that of your equipment, you can keep your overall cost of ownership competitively low. Timken Quick-Flex couplings can directly replace most coupling configurations, thanks to the design's versatility. Plus, you won't need large inventories of spare parts for couplings. There's no metal-to-metal contact with Timken Quick-Flex couplings, so customers can save money by not replacing hubs or other metal components. For harsh environments, including washdowns for food processing, Timken offers a stainless-steel version of each coupling.

timken.com

PTE



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Precision Coupling Basics—Stiff or Stiff Enough?

When selecting couplings for precise motion applications there are often questions about the most suitable approach for optimizing both performance and economy.

Andy Lechner, R+W Coupling Technology

Torsionally stiff line shaft couplings are ideal for linking belt-driven linear actuators which will be used in tandem to support the loads overhead.

Precision flexible shaft couplings come in two basic forms, both of which are designed to operate without backlash or excessive inertia while compensating for inevitable misalignment offsets between motor/gearbox and load. Torsionally stiff couplings are made with metallic flexible elements and with the intent to eliminate as much twisting deflection as possible so that the rotation of both shafts is kept as well synchronized as can be. Vibration-damping elastomer couplings almost always use a plastic buffer between the driving and driven hub to filter out and absorb unwanted vibration and shock loading. Precision elastomer coupling designs also include considerations to eliminate backlash with a preload between the plastic buffer and jaw hubs, but some torsional wind-up is inevitable. As a rule of thumb, metal bellows couplings possess a torsional stiffness approximately ten times greater than that of comparably sized elastomer couplings, but the latter offers its own advantages in terms of helping to ensure smooth running in addition to being somewhat lower in cost. Choosing between the two styles of precision coupling usually starts with an assessment of torsional stiffness requirements.

In each of the following four scenarios, which address the most common precision coupling applications, either type could be determined to be the best choice. One way of beginning the process of deciding between them is to consider a default selection and then qualify it for the individual situation. The most important criteria to consider up front are mechanical advantage, required positional accuracy of the load, rate of acceleration/deceleration, and the inertia ratio between the driving and driven ends of the coupling, each of which has a significant impact on how torsionally stiff the coupling needs to be to keep up with the overall performance requirements.

Ball Screws and Lead Screws

The most common linear motion application for precision couplings is to connect servomotors to ball and lead screws. In these situations, it is typical to have a precise target for positioning accuracy, even down to a few microns or less, since this is the type of linear motion system that's used most often in machine tools and semiconductor wafer handling equipment. Considering this it would be easy to assume that torsionally stiff couplings are always the way to go—and they often are. But perhaps surprisingly, the best choice is more often a precision elastomer coupling. This is because, depending on the linear travel per rotation (lead), the mechanical advantage provided by the screw mitigates the effects of torsional wind-up as it pertains to linear positioning accuracy. Compared with other mechanical motion components, there is also a relatively low input torque required to generate the desired thrust, velocity, and position of the load, which in turn means less torsional strain on the coupling and less wind-up.

For example, consider a typical application for a ball screw with a 10 mm lead, which will require an input torque of 15 Nm to generate the desired 1 ton of thrust in its end use.

Option A: Bellows coupling
Torque capacity: 15 Nm
Torsional stiffness: 23,000 Nm/rad

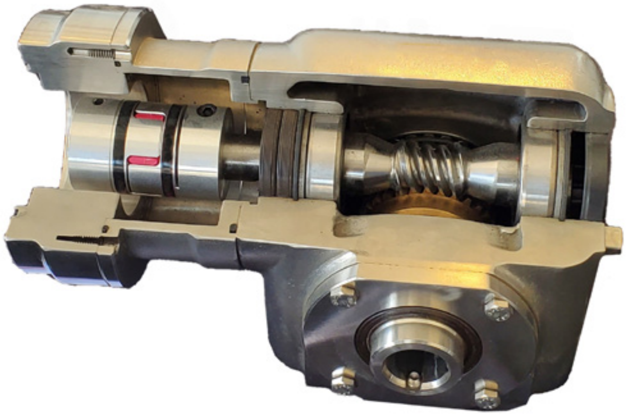
Option B: Elastomer coupling
Torque capacity: 21 Nm
Torsional stiffness: 2,300 Nm/rad

Going through a simple calculation for linear positioning error which is attributable to coupling wind up we see that both couplings hold up quite well.

$$\frac{\text{Torque (Nm)} \cdot \text{Screw lead (mm)}}{\text{Torsional stiffness (Nm/rad)} \cdot 2\pi} = \text{Linear position error (mm)}$$

Bellows coupling: 0.001 mm
Elastomer coupling: 0.010 mm

Naturally, the bellows coupling outperforms the elastomer coupling in the same 10:1 proportion as the difference in torsional stiffness. While there are many applications for ball screws that would require that the coupling contribute something as small as one micron (0.00004 in.) to linear position error, most everyday applications run very well with coupling wind up contributing the 0.010 mm caused by the elastomer coupling under full load, which is still less than half a thousandth of an inch. This is especially true when linear encoders are being used to control the final positioning of the load and prompt motors to adjust accordingly. As the ball screw lead increases, so too does the linear position error attributable to the coupling, but the rough order of magnitude stays the same. The elastomer coupling is most often the right choice except in cases of the most extreme of positional accuracy requirements.



Vibration-damping couplings are normally the practical choice when driving the inputs of precision gearboxes.

Belt-Driven Linear Modules

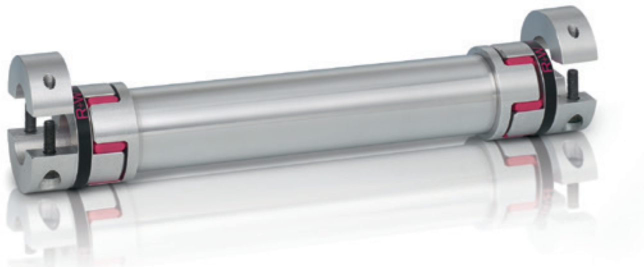
Used more for speed of material handling than for the high thrust and precision positioning of ball screw drives, belt-driven linear actuators might initially be considered to require relatively low torsional stiffness in the couplings that connect them to their driving components. The opposite is true in many cases. For the same reason that they are used for higher rates of travel and with less emphasis on thrust beyond acceleration, there is no mechanical advantage between the input shaft of the actuator and the resulting linear motion. This is also why precision gearboxes are almost always needed to assist the motor in producing sufficient acceleration torque and overcoming load inertia, whereas ball screw systems rarely need them. In these situations, the coupling sits at the business end of the drive line, rotating in a one-to-one ratio with the pulleys that create the linear motion. This also makes torsional wind-up much more conspicuous.

In many cases, the base level X axis of a positioning system built on belt-driven linear actuators is also running in tandem with a second actuation module, which helps to support the moment loading created by the additional componentry and payload moving overhead. Instead of powering the second actuator with a separate motor, drive, and gearbox, it is usually much more economical to synchronize these X and X' axes mechanically with line shaft couplings. To keep the carriages of the two modules inline and prevent binding against their linear guides, it is important that they be synchronized throughout the motion profile.

One possible configuration involves center driving the two actuators with a motor and dual output gearbox mounted between them, and a line shaft coupling connecting each of the two gearbox output shafts to its respective actuator shaft. This minimizes the impact of torsional wind-up by, in theory, having equal wind-up between the two line shaft couplings, provided that they have the same overall length, and that the torque loading is approximately even between the two actuator carriages. But this method is not without its own challenges. Center driving the two modules requires that an additional framework be available for mounting the gearbox, which is often not there. It is also more costly than using a simpler gearbox on one end, where it can be supported by the frame of the actuator itself, and with a single line shaft coupling linking the two modules. Determining whether this easier method is feasible is often a matter of weighing the torque load on the line shaft coupling against its torsional stiffness and the resulting positioning error. Going slightly oversized with the line shaft coupling often helps to make this possible. It is also important to note that the X and X' actuators are linked at the carriages by their shared load, and together with their respective linear guides, assist in keeping everything moving together. But when coupling wind-up causes excessive drag in the driven actuator, the ability of the linear bearings to carry along smoothly is lessened. A good rule of thumb is typically to keep this would be position error under 0.2 mm.

Considering another common set of parameters for a gantry style system with 1.5 m between modules and a drive pulley radius of 50 mm, wind-up and positioning error between bellows and elastomer couplings might look like something like this:

Option A: Bellows coupling line shaft
Applied torque: 60 Nm
Torque capacity: 150 Nm
Torsional stiffness: 16,000 Nm/rad



Option B: Elastomer coupling line shaft
Applied torque: 60 Nm
Torque capacity: 150 Nm
Torsional stiffness: 3,600 Nm/rad

$$\frac{\text{Torque (Nm)} \cdot \text{Pulley radius (mm)}}{\text{Torsional stiffness (Nm/rad)}} = \text{Linear position error (mm)}$$

Bellows coupling error: 0.19 mm
Elastomer coupling error: 0.83 mm

In this example a bellows type line shaft is necessary to maintain smooth running, although in other situations the torque loading is sufficiently low enough that elastomer type couplings are up to the task.

Gearbox Inputs

Another area in which it might be assumed that torsional stiffness should be maximized is on the input shafts of gearboxes being used to generate precise motion. Depending on the gear ratio, using a bellows coupling on the input is often but not always overkill. This is even in the case of precision gear drives with very low backlash ratings. Consider again the difference between backlash and torsional windup. Where backlash is completely lost motion which must be compensated for, torsional windup in precision couplings still allows for a high level of position repeatability in both directions. Loaded in one direction and then relaxed, the elastomer coupling system returns to a zero position, and will go on to behave in exactly the same way in the other direction, providing a mirror image in the resulting position when the same load is applied. This is often more manageable than the lost motion associated with backlash.

Using the same example couplings and 15 Nm input torque as above, and with a 9:1 reduction ratio:

$$\frac{180}{\pi} \times \frac{\text{Torque (Nm)}}{\text{Torsional stiffness (Nm/rad)}} \times 60 \div 9 = \text{Output position error (arc min)}$$

Bellows Coupling: 0.249 arcmin
Elastomer Coupling: 2.49 arcmin

Assuming the load at the output of the gearbox has a diameter of 500mm, the difference in the position of its outer rim between an elastomer coupling torque load of 0 Nm and 15 Nm is only 0.18 mm. While the ratio also mitigates the impact of backlash at the output in the same way, it is still permanently lost motion. While within its rated torque capacity the coupling torsional stiffness is treated as linear as torque load is applied, and if there is minimal variance in torque load applied at different load position targets, there is also a proportionally reduced difference in the load position as it pertains to coupling wind up. Unlike the gear teeth themselves, the coupling is also virtually guaranteed to start at a zero position with regard to directional loading and position error when first installed and commissioned, making it much more predictable. For precision gearbox inputs, consider elastomer couplings first and move on if more stiffness is needed.

Direct Coupling Servomotors and Gearheads to Their Loads

When motors and gearheads need to direct drive roller shafts, lever arms, indexing tables, or any other mechanical device that is intended to be rotated into position, coupling torsional stiffness plays an outsized role in machine performance. As the radius of the load increases, the positioning error resulting from coupling wind up increases rapidly. After all, one degree of wind up in a coupling driving an arm with a radius of 1 m results in a position error of 17.5 mm at the end of the arm. Considering that rotational moment of inertia is a function of the square of the radius of the load multiplied by its mass, abrupt deceleration of an object with a large radius into position can also cause a large amount of overtravel when torsionally softer couplings are being used. Even smaller diameter loads can become problematic when driven by couplings with insufficient torsional stiffness when gearboxes are not used to support the inevitable inertia mismatches between servomotors and their driven machine components. Gearboxes address inertia mismatch by the square of their ratio, meaning for example that a 5:1 gearbox reduces the influence of reflected inertia on the motor shaft to a twenty-fifth of what effect it would have without a gearbox. Since servo drives are normally seeking to rectify the velocity and position of the motor shaft every several milliseconds, overtravel of a load pulling the shaft forward which is delayed by wind up in a torsionally soft coupling can make it impossible for the system to keep up, resulting in high-frequency oscillations and failure to operate. Therefore, when selecting couplings that will be directly used to manipulate a driven load with a significant radius or moment of inertia, especially when load position targets need to be reached rapidly, torsionally stiff couplings are normally the best option.

In each of these typical application areas, there are exceptions to the rules that guide the default selections. But knowing where to start can save a lot of time and prevent getting lost in the sea of different precision coupling options that exist on the market today. Even within the two basic categories of torsionally stiff and vibration-damping precision couplings, multiple designs of flexible elements exist to address varying needs for misalignment compensation levels and to optimize torsional damping. More choices still exist beyond that to include a wide variety of hub types to suit different installation situations. As always when selecting precision drive components, it's best to contact manufacturers for guidance as to the ideal choice.

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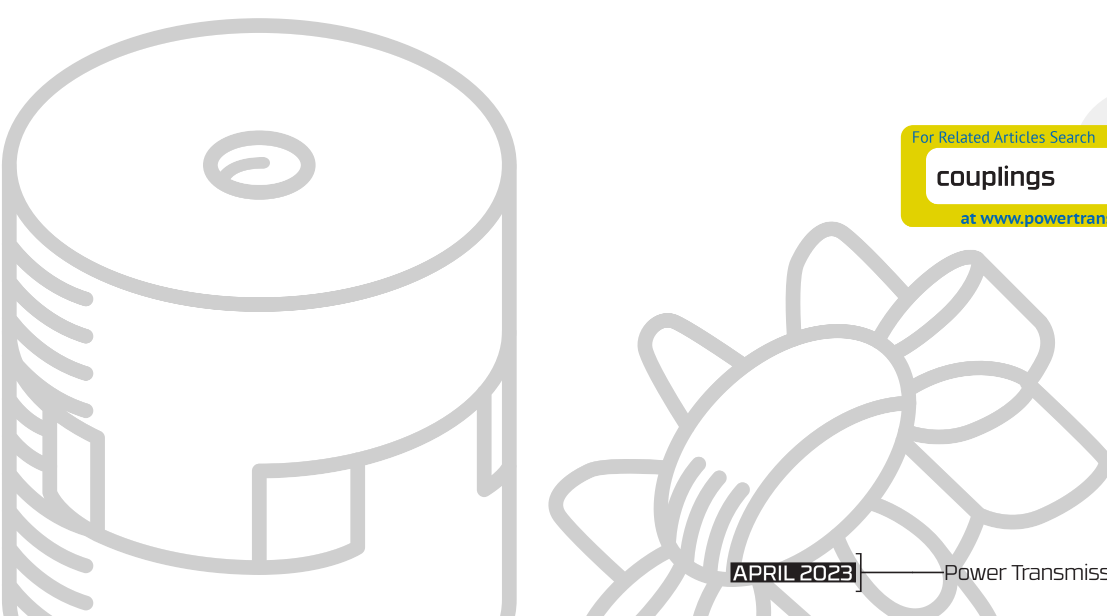

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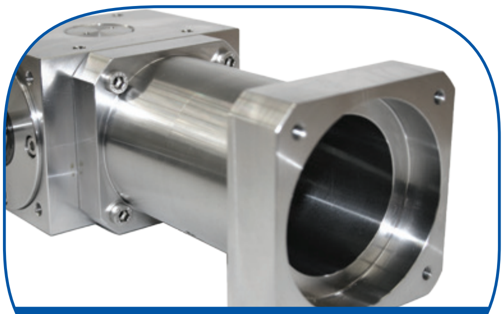

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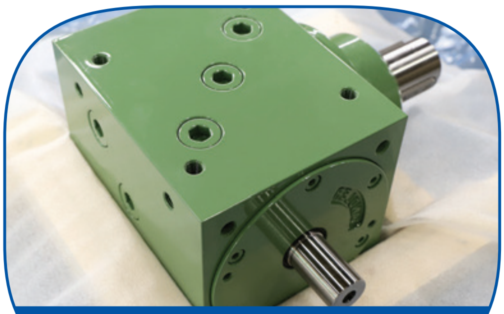

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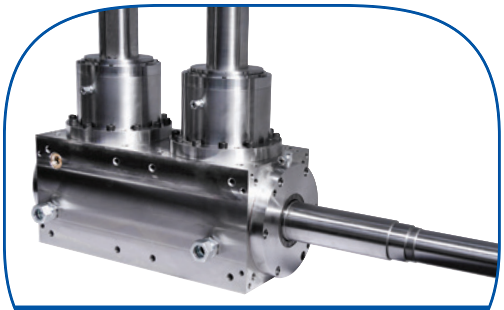

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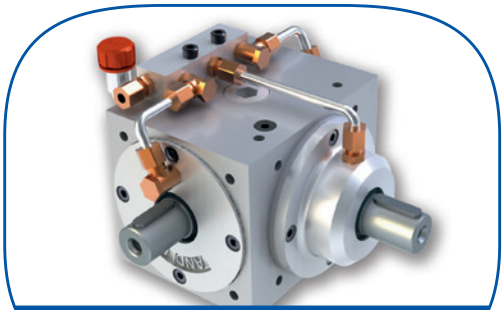

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FEATURE

KISSsoft Supports Student Racing Team in Taiwan

Mechanical engineering theory, design and practice come into play for NYCU Vulpes Racing Team

Yu-Ting Yeh, NVR Vulpes Racing Team

2021 Formula Student Taiwan

NYCU (National Yang Ming Chia Tung University) Vulpes Racing—founded in 2008—is a Formula Student Team that combines mechanical engineering, industrial design, public relations, video production and marketing expertise. Using skills, knowledge, and creativity, the members of the team are setting targets to a global level.

The team goal is to cultivate the members' interests and knowledge of cars. The three core curriculums for the students are theory, design, and practice. By visiting companies, going to exhibitions, and discussing with other professionals, they can improve themselves.

In 2012, the team went to the United States to participate in the Formula Hybrid, showing its commitment to making cars and discovering new technologies.

In 2021 they participated in the Formula Student Taiwan (FST 2021) along with several other competitive teams from various universities. In the end, the team managed to complete the 19.5 km race within 16 minutes and 56 seconds and went back home with an incredible P1 finish. In this race the team managed to show its true potential and the high performance of the petrol powered VR5.

But the story doesn't stop there, since the students are currently planning to compete in the 2023 FSAE Japan with a brand-new car, the electric VR7, following the current trend of the automobile industry.

History of the Program

The American 3 and SAE International organized a consortium to make the Formula SAE a magnificent and international convention, in which more than 100 university teams have participated. More than 80 percent of universities accept participation in the event as a credit. The competition site, aided by the many supporting companies, also functions as an opportunity to recruit students who are aiming at being active as engineers in the automotive industry in the future.

Formula SAE Japan is an opportunity for students to develop skills for object creation "MONO-ZUKURI" (the act of making), which in turn contributes to the expansion of the Japanese automotive industry. This competition was started in 2003 as a public activity for self-motivated students to cultivate various skills involved with object creation, and as training for those who will one day play critical roles in the future of the automotive industry.

Students can create an object by themselves, which enables them to deepen their understanding of technology, cultivate their practical abilities and strive enthusiastically to achieve higher levels of accomplishment. The competition intends to aim at nurturing engineers who are rich in originality through an environment of object creation, in which they can learn the essence of object creation and the processes this entails, as well as experiencing team activities, and the difficulty, interest and enjoyment of object creation.

There are essentially four key philosophies for the Formula SAE Japan competitions:

- The competition will contribute to revitalize engineering education at universities and national colleges of technology by providing opportunities for object creation.
- Students themselves will organize a team to develop and produce a small racing car in the formula style, so that they can learn the essence of object creation and its relevant processes, and feel for themselves the difficulty, interest and enjoyment of object creation.
- The competition will focus on the overall activities surrounding object creation, in other words not only the running performance, but also the marketing, the planning, the design, the production and the cost aspects of a vehicle.
- The competition is an opportunity for students to improve their own abilities and to provide an opportunity for them to present their skills as valuable resources to companies.

Design Flexibility with *KISSsoft*

The team is using *KISSsoft* to design and optimize the gearbox. First it was quite difficult to get everything in the right way. But after trying all sorts of things, the members of the team have managed to learn and understand the meanings of all the different parameters.

While they were designing the gears and bearings, they've realized that using *KISSsoft* can truly make things so much more efficient. Not only that, but the software has also brought many more design options. Also, the integrated fault detecting system is very useful to the students since it can effectively reduce the chances of failure when designing and the messages are tremendously helpful for them.

After designing the first version of the gears, the next thing to do was the stress analysis. The first thing the members of the team did was to understand the meanings of various diagrams, like fatigue and maxim stress. And what they have noticed is that the main problem of the first design is poor reliability, which could probably cause a breakdown during an event. The steering angle from the simulation was also not as great as expected. It had bad shape, stress concentration, poor fit between gear and track. After some inspections and discussions, they've figured out how to possibly fix the problems. They optimized the shape; they adjusted parameters and re-simulated. With all the information in hand, it was time for the team to go back to the drawing board.

The second version had some similar problems. But after analyzing the data, the team has made some changes to keep the design progress on the right path. Considering the progress, the team decided not to make the steering rack by themselves, but to buy ready-made ones. The best thing about *KISSsoft* is that they can observe the force conditions of our parts. They can easily get the parameters they wanted with the help of *KISSsoft*, which is way more convenient than the software we've used before.

The steering gears are the first parts to be designed and produced in house. So, it has been a challenge for them to collaborate with *KISSsoft* to help them in the design activities all the way from scratch. This software has improved efficiency and reliability, which is one the most important things about racing. This does not only improve our car's performance but was also essential for our driver's safety. What's more important is that *KISSsoft* has elevated our professional level. The gears with the parameters designed at the beginning were mathematically feasible, but it was found that they were not feasible after being drawn through software. The team has the data assistance of professional software to verify the design. They are looking forward to putting it on the car and seeing how it performs.

After participation in the 2023 FSAE Japan with the electric VR7, the NYCU Vulpes Racing Team is planning to participate in other races worldwide.

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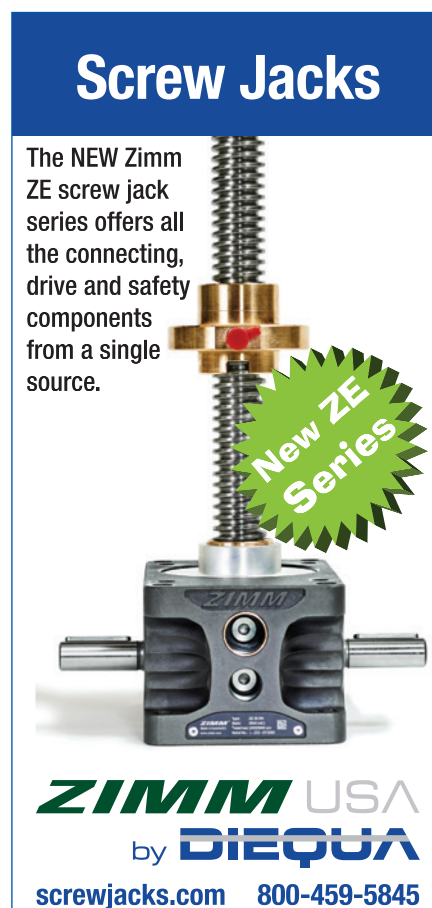
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The Variation of Servomotor Efficiency in Different Applications

Don Labriola, Quicksilver Controls

Unlike HVAC applications, servomotors are not normally operated at the same speed or torque for extended periods, thus the overall efficiency of a servomotor is not easily given a single numeric value. The efficiency varies greatly with the application, and thus different applications favor different types of servomotors.

Standards for Conventional Use Synchronous Motors.

Standard motor efficiency classes—IE1 though IE5—are taken using very specific conditions to allow the motors to be quantitively compared. The motors under these classes are compared using direct AC line operation between 50 and 1,000 V, from 1 or 3 phase mains, are limited to 2, 4, 6, or 8 pole motors, and with a power rating of 120 W to 100 kW. The motors are tested at their continuous rated power (at which they may operate without exceeding specified insulation class). Their efficiency varies with line frequency, and so there are different efficiencies for 50 Hz versus 60 Hz operation. The very specific operating conditions reduce ambiguity, which allows for more accurate comparisons between manufacturers.

So how do we compare servomotors?

Efficiency is defined as:

$$\eta = Po/Pi$$

We will use power in watts for both input and output power.

Output power is the mechanical output power at the shaft:

$$Po = w * T$$

where radial frequency w is measured in radians per second and torque T is measured in Newton-meters.

Electrical input power is measured as watts.

As servomotors use driver electronics, they do not normally operate directly from the line voltage. Further, the voltage and current waveforms driving the motor windings may be complex, thus it is often easier to measure the combined driver and motor efficiencies. This allows the input power to be measured where waveforms are simple, requiring less sophisticated equipment for accurate measurement, and such measurements additionally include the losses of the drive which are important for the total system efficiency. If there is a DC bus input, this is simply: $Pi = Vi * Ii$; For AC input, the input power needs to include power factor, including harmonic distortions in the input current. Measuring a particular motor and driver as a set also helps restore some repeatability to the measurements, as the efficiency of the motor will vary with the drive due to harmonic content, chopping style and frequency, commutation method, internal bus voltage, and any output filtering within the drive.

Direct Permanent Magnet versus Indirect Permanent Magnet Motors

Synchronous motors, used to implement both continuous speed motors and brushless servomotors, have several divisions. One dividing category breaks the motors into direct permanent magnet motors, which have the magnets directly facing the rotor-stator air gap, and indirect permanent magnet motors, which have soft magnet materials between the magnet and the air gap. Direct permanent magnet synchronous motors are not normally (not easily) able to have their fields weakened, while the extra soft magnetic material in the indirect permanent magnet motor allows this weakening to be done much more easily.

Direct Permanent Magnet Motor Modeling

The direct permanent magnet motors (also known as surface permanent magnet or SPM) normally do not support field weakening, and produce a fairly flat torque constant over speed, with only a slight droop at higher speeds as losses commonly increase with speed. The current required for a given torque is the torque divided by the torque constant:

$$I = T/Kt \,(T \text{ in Nm}, Kt \text{ in Nm/A}, I \text{ in Amps})$$

A first order approximation of the drive voltage includes both the back-EMF of the motor and the resistive losses:

$$V = I * R + w * Kv$$

With w in radians per second,and Kv in volts per radian per second then the numeric value of Kv and Kt will be essentially the same (with Kt slightly lowered to lump in other losses; if the losses are accounted for separately, then Kt and Kv should be equal).

For a given torque and velocity:

$$Pi = I * V = \frac{T}{Kt} * \left\{ \left(\frac{T}{Kt} \right) * R + (w * Kv) \right\}$$

$$\eta = \frac{Po}{Pi} = (w * T) / \left[(T/Kt) * \left\{ T * \frac{R}{Kt} + w * Kv \right\} \right]$$

$$\eta = \frac{Po}{Pi} = (w * T) / \left\{ w * \left(\frac{Kv}{Kt} \right) * T + R * \left(\frac{T}{Kt} \right)^2 \right\}$$

We can bring in another motor factor called "Motor Quality." When the motor is stationary, the power dissipated in the winding resistance to generate the stationary torque may be calculated:

$$Ps = I^2 * R = \left(\frac{T}{Kt}\right)^2 * R$$

If we define motor quality as:

$$Kq = Kt/\sqrt{R}$$

Then the resistive dissipation for a given torque is:

$$Ps = I^2 * R = \left(\frac{T}{Kt}\right)^2 * R = \left(\frac{T}{Kq}\right)^2$$

Motor quality Kq is a useful motor parameter when comparing motors as it stays constant over different voltage and current ratings for the same motor mechanical design. That is fewer turns of a heavier wire at the same current density gives the same motor quality. The quality factor goes up with the number of poles, with the gap magnetic field strength, and with the radius of the motor, and goes down with the portion of the stator wiring that is not producing motor torque—the end windings, as this increases the resistance but not the torque constant of the motor.

Looking at the efficiency again, we get:

$$\eta = \frac{Po}{Pi} = (w * T) / \left\{ w * \left(\frac{Kv}{Kt}\right) * T + \left(\frac{T}{Kq}\right)^2 \right\}$$

A quick look at the equation says that at zero velocity, efficiency is zero, and will increase with velocity for a given torque level. There is a constraint on velocity, as the back-EMF grows with velocity, and the driver cannot force current into the winding when the back-EMF exceeds the power supply voltage.

For a given torque, the resistive losses term $\left(\frac{T}{Kq}\right)^2$ will remain essentially constant while the torque producing input power term, $w * \left(\frac{Kv}{Kt}\right) * T$ will vary directly with speed (w). (This is an approximation as the Kv/Kt ratio includes terms like windage and hysteresis, but for the broad stroke we will ignore these smaller terms for a simpler comparison.)

Taking Torque T out of the numerator and Denominator we get:

$$\eta = (w) / \left\{ w * \left(\frac{Kv}{Kt}\right) + T * \left(\frac{1}{Kq}\right)^2 \right\}$$

For a given power supply voltage, the maximum no torque speed will be determined by the back-EMF voltage plus the resistive voltage drop of the windings equaling the power supply voltage.

$$Vbuss = w * Kv + \frac{T}{Kt} * R$$

$$w * Kv = Vbuss - \frac{T}{Kt} * R$$

$$w = \frac{Vbuss}{Kv} - \frac{T * R}{Kt * Kv}$$

If we approximate $Kt \sim Kv$ just while determining the maximum speed, we get:

$$w = \frac{Vbuss}{Kv} - T/Kq^2$$

We can see that low velocity constant (and thus torque constant) motors favor higher speeds to obtain a given output power, while high velocity constant motors favor lower speeds. A higher motor quality Kq allows for a higher efficiency at a given torque, given that the motor speed is obtainable for the given motor and power supply voltage.

Indirect Permanent Magnet Motors

The indirect Permanent Magnet Synchronous Motors (IPM or IPMSM) contain soft magnetic materials between the permanent magnets and the rotor-stator gap. The presence of magnetic material between the gap and the rotor magnets enables the gap field strength to be reduced (or even enhanced) by adjusting phasing of the stator current relative to the rotor angle. Adjusting the In-Phase (Id) component of the stator current can subtract from (or with opposite phase add to) the gap flux which produces back-EMF associated with the torque producing Quadrature (Iq) component of the stator flux.

But why would it be advantageous to reduce the torque constant of the motor?

The losses in a motor are mostly determined by speed and by current squared, while the output power is determined by current and back-EMF. The motor driver is also constrained in that to control the current through the motor, the back-EMF needs to be less than the DC bus voltage. The efficiency is thus optimized when the back-EMF is almost equal to the DC bus voltage; this state produces maximum output power versus the losses associated with producing that level of output power. (Note that the driver requires some voltage to overcome the winding inductance so as to achieve the commanded current, and this overhead voltage increases with motor frequency.)

This ability of the IPM motor to vary the gap flux strength allows the voltage constant for the IPM motor to be dynamically varied. This extra degree of control of the IPM motor allows the control algorithm to keep the back-EMF of the motor near the DC bus voltage over a wide speed range, resulting in high efficiency and power levels over this same wide speed range. Contrasted, The direct PMSM motor sees its best efficiency and highest power only when it is operated at nearly at full speed, where the back-EMF for the motor approaches the DC bus voltage.

Reluctance Torque

The Indirect Permanent Magnet motors also normally exhibit what is called Salience—that is the reluctance paths for the direct and quadrature field components are not the same, with the direct component having a lower reluctance. As the field angle is advanced with respect to the rotor—that is the direct flux is increased compared to the quadrature flux, the torque produced by this reluctance variation in the motor is also increased (up to a point), further enhancing the total output torque, adding to the power associated with the quadrature current component and the back-EMF voltage.

There are tradeoffs in the level of salience and the torque ripple for a given motor design, with more salience generally producing more torque but also more torque ripple and higher detent torque associated with the increased salience.

IPM Models

The advantages of allowing the control algorithm to vary the motor torque constant and to utilize reluctance torque also means that the equations for power and efficiency versus speed are also highly dependent upon the particulars of both the motor design associated with reluctance torque and the algorithms and the optimizations chosen. The data presented for the IPM will show the motor performance as measured for a particular IPM (hybrid servomotor) the SilverMax QCI-X34HC-1 is shown both without field weakening and with a particular choice for control of field weakening.

Efficiency at Zero-Speed?

Servos not only move a load at varying speeds, they also can maintain a position. If the output speed is zero, then the output power is also zero, and thus the efficiency is zero. Yet the actual power needed to maintain the position still varies significantly between different motor and controller sets. The "Motor Quality" factor (Kq) is a measure of the losses associated with such a holding torque:

$$Kq = T/\sqrt{P}$$

Where T is in Newton-meters, and P is the power loss ($P=I^2*R$) associated with producing the holding torque ($T=Kt*I$) in watts. Higher torque constants and lower resistance produce higher motor quality values, reducing the power needed to hold a given torque.

The torque constant (Kt) goes up with the number of turns, with gap strength, and with the number of motor pole pairs, while the resistance goes up with the number of turns (for a given cross section times fill factor provided for the winding). The resistance also goes up with the length of the end windings (which add to the resistance but not to torque generation), which vary with the various motor designs.

Comparing Results

Figure 1 shows the efficiency of a direct permanent magnet synchronous motor versus speed operated at 100 percent torque. The efficiency does not reach 50 percent until the motor is up to approximately 2,500 rpm, with some 75 percent efficiency at 8,000 rpm.

Figure 2 shows the torque is relatively constant over this same speed interval, dropping only about five percent from 0 to 8,000 rpm.

Figure 3 shows the resulting power is nearly linear with speed. A 260 W rated motor at 8,000 rpm only produces approximately 34 W at 1,000 rpm, while wasting nearly 80 for an efficiency of 30 percent.

Figure 4 shows that the efficiency of the same direct permanent magnet synchronous motor only reaches some 50 percent at 7,000 rpm, with only 12.4 percent efficiency at 1,000 rpm.

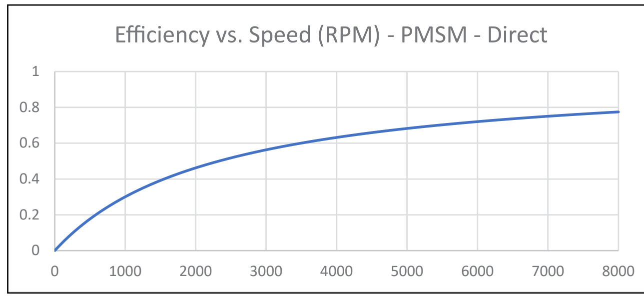

Figure 1—Efficiency vs. Speed for Direct PMSM motor at 100% torque.

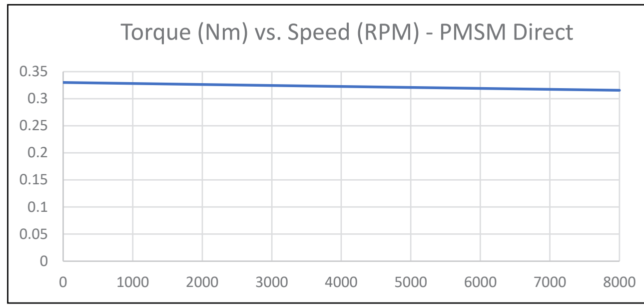

Figure 2—Torque vs. Speed for Direct PMSM motor at 100% torque.

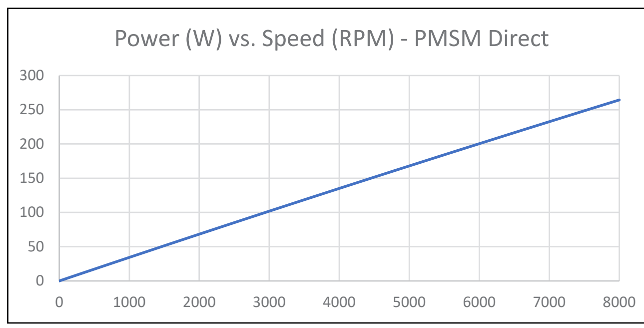

Figure 3—Power vs. Speed for Direct PMSM motor at 100% torque.

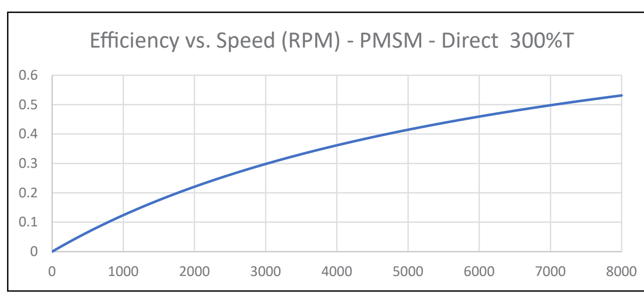

Figure 4—Efficiency vs. Speed for Direct PMSM motor at 300% torque.

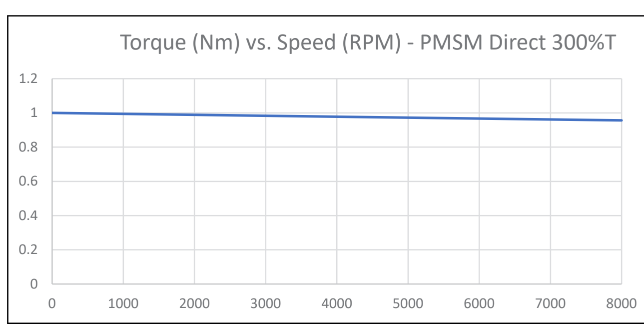

Figure 5—Torque vs. Speed for Direct PMSM motor at 300% torque.

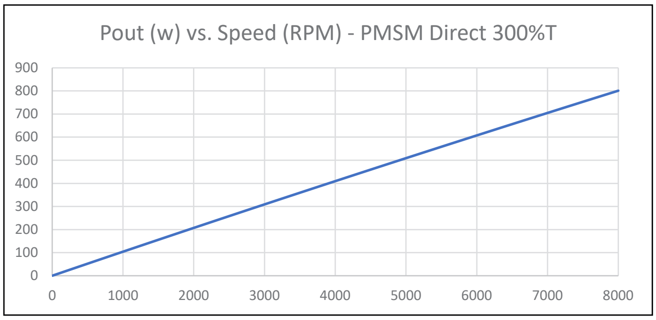

Figure 6—Output Power vs. Speed for Direct PMSM motor at 300% torque.

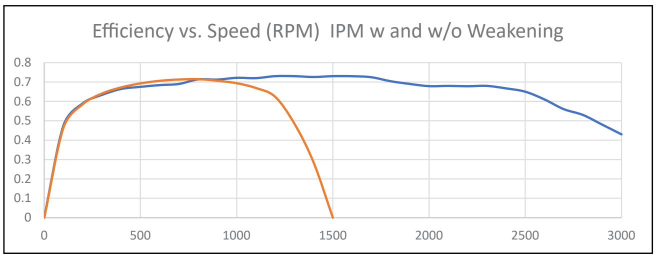

Figure 7—Efficiency vs. Speed for Indirect PMSM with and without field weakening at 100% torque.

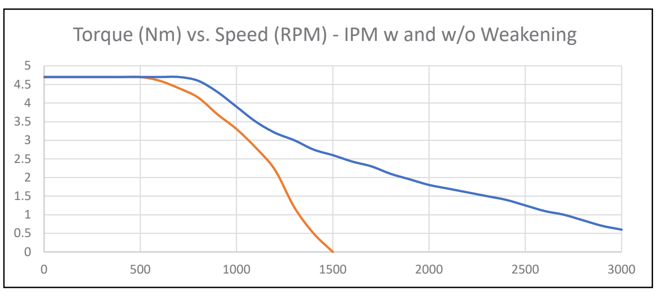

Figure 8—Torque vs. Speed for Indirect PMSM with and without field weakening at 100% torque.

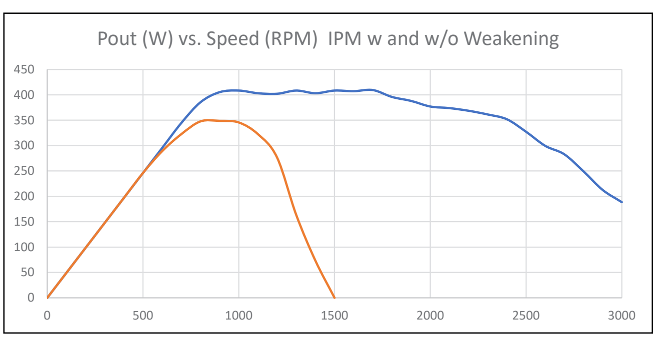

Figure 9—Output Power vs. Speed for Indirect PMSM with and without field weakening at 100% torque.

Figure 5 shows the resulting tripling in output torque, with Figure 6 showing the improved peak power, but the losses are above 710 W over the full speed range, which requires a very low duty cycle to prevent overheating.

Figure 7 shows the efficiency for the Indirect Permanent Magnet Synchronous Motor. The broad curve represents the motor when operated with field weakening, while the narrow curve shows the same motor if field weakening is not utilized. The following comparisons will all reference this motor utilizing field weakening. The 50 percent efficiency is achieved at about 150 rpm and remain above 50 percent up to approximately 2,800 rpm, with a broad peak efficiency of 73 percent (including the driver/controller electronics). The losses at full torque at zero speed are just 55 W.

Figure 8 shows a constant torque of 4.7 Nm through about 700 rpm, which then drops down as the field is weakened. The field weakening significantly extends the torque curve as compared to the same motor without field weakening.

Figure 9 shows the power initially is linear with speed, and then remains high over approximately a 3:1 speed range.

Summary

The use of field weakening with indirect permanent magnet synchronous motors allows for broad high efficiency and continuous output power curves. These motors as hybrid servos typically utilize a narrower effective gap which limits the ratio of peak torque to continuous torque to about 150 percent. The direct permanent magnet synchronous motors utilize a larger gap length allowing a higher peak to continuous torque ratio, typically 300 to 1,000 percent, but the resulting heating is 9x to 100x the continuous rating, resulting in low allowable duty cycles. The typically lower pole count face magnet designs are optimized for lower torque higher speed applications, often requiring gearheads for use with belts and lead screws applications, while high pole count indirect permanent magnet synchronous motors (such as hybrid servos) are optimized for direct drive applications.

Applications that require significant holding or low speed torques—such as direct drive of lead screws and belts, and for such applications as lifting or fixturing, precision pumping or milling (other than the spindle) may benefit from the broad efficiency and power curves fan from the IPM motors used in hybrid servomotors.

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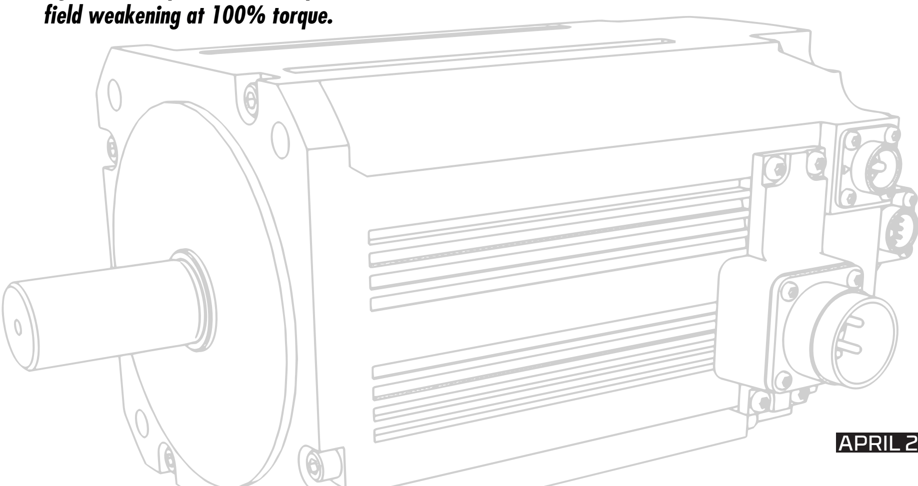

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quicksilvercontrols.com

Ball Bearing Inner Ring Fits and Creep (Part 2)

Norm Parker, Technical Fellow, Stellantis

Figure 1—Differential hub cracking on high load test due to wear of material from insufficient press fit.

Welcome back to Part 2 of our inner ring and creep discussion. We left off with our creep calculation resulting in a 10.5 µm minimum inner ring fit to avoid creep. For the sake of making clean dimensions, let's call it 10 µm on the lower end and the upper end is simply whatever your manufacturer can hold. For the 6205, something around 20–25 µm tolerance range would be expected. Often this can be accomplished with hard turning alone. Surface finish is not *too critical* here. Most bearing manufacturers will recommend a 0.8 Ra for *small* bearings and 1.6 Ra for large bearings, without clearly defining what a *large* bearing is. The main consideration for surface roughness is that if the surface is too rough, the peaks of the material will plow off during the bearing press resulting in less of a press fit than intended.

j5	j6	j7	k5	k6	k7	m5	m6	n6	p6	r6	r7	Diameter Classification (mm) over	incl.
+ 3 − 2	+ 6 − 2	+ 8 − 4	+ 6 + 1	+ 9 + 1	+ 13 + 1	+ 9 + 4	+ 12 + 4	+ 16 + 8	+ 20 + 12	+ 23 + 15	+ 27 + 15	3	6
+ 4 − 2	+ 7 − 2	+ 10 − 5	+ 7 + 1	+ 10 + 1	+ 16 + 1	+ 12 + 6	+ 15 + 6	+ 19 + 10	+ 24 + 15	+ 28 + 19	+ 34 + 19	6	10
+ 5 − 3	+ 8 − 3	+ 12 − 6	+ 9 + 1	+ 12 + 1	+ 19 + 1	+ 15 + 7	+ 18 + 7	+ 23 + 12	+ 29 + 18	+ 34 + 23	+ 41 + 23	10	18
+ 5 − 4	+ 9 − 4	+ 13 − 8	+ 11 + 2	+ 15 + 2	+ 23 + 2	+ 17 + 8	+ 21 + 8	+ 28 + 15	+ 35 + 22	+ 41 + 28	+ 49 + 28	18	30

Figure 2—NSK Rolling Bearings E1102k c.19.

Now we consider our shaft tolerance range of 10–20 µm. If we review the standard shaft fit chart in Figure 2, we see that this custom range falls between m6 and n6.

If we review our standard fit table in Figure 3, you will notice on the load condition column that a Heavy Load is defined as > 13 percent of the dynamic load rating Cr. We have designed our creep loads for 50 percent of Cr, so falling near the n6 range makes perfect sense. Applying these fits is very easy. The 6205 inner ring bearing tolerance is 25 0/-0.010 mm. Bearings are usually written in negative unilateral tolerances like this. The *nominal* diameter (what we call it by), 25 mm is the largest diameter. We size our shaft by taking the bearing nominal bearing diameter and applying the fit tolerances. Our shaft diameter is simply 25.01–25.03 mm.

Now let's see how we use this value for our internal clearance. For this example, we will look a solid and hollow shaft. Most of the large bearing manufacturers have a fit tool on their website. I like Koyo's, it is easy to use and customize, they include both 3 sigma and min-max methods.

Editor's Note: *For the Koyo Bearings/JTEKT Corporation example in Figure 4 the name 'Koyo' is immediately associated with the word 'bearing.' This is the website for JTEKT's Koyo bearing brand. Here, you will find product information and case studies relating to bearings and oil seals. You can also download technical calculation tools, CAD drawings and various catalogs to help you with the bearing selection process.*

The 3-sigma method can be useful if you have confidence that your parts will follow a normal distribution. If you expect to see parts at the limits, you may prefer the min-max method which uses the true limits of the parts.

Load Conditions		Examples	Shaft Diameter (mm) Ball Brgs	Shaft Diameter (mm) Cylindrical Roller Brgs, Tapered Roller Brgs	Shaft Diameter (mm) Spherical Roller Brgs	Tolerance of Shaft	Remarks
Radial Bearings with Cylindrical Bores							
Rotating Outer Ring Load	Easy axial displacement of inner ring on shaft desirable.	Wheels on Stationary Axles	All Shaft Diameters			g6	Use g5 and h5 where accuracy is required. In case of large bearings, f6 can be used to allow easy axial movement.
	Easy axial displacement of inner ring on shaft unnecessary	Tension Pulleys Rope Sheaves				h6	
Rotating Inner Ring Load or Direction of Load Indeterminate	Light Loads or Variable Loads (<0.06C_r(1))	Electrical Home Appliances Pumps, Blowers, Transport Vehicles, Precision Machinery, Machine Tools	<18	—	—	js5	
			18 to 100	<40	—	js6(j6)	
			100 to 200	40 to 140	—	k6	
			—	140 to 200	—	m6	
	Normal Loads (0.06 to 0.13C_r(1))	General Bearing Applications, Medium and Large Motors(3), Turbines, Pumps, Engine Main Bearings, Gears, Woodworking Machines	<18	—	—	js5 or js6 (j5 or j6)	k6 and m6 can be used for single-row tapered roller bearings and single-row angular contact ball bearings instead of k5 and m5.
			18 to 100	<40	<40	k5 or k6	
			100 to 140	40 to 100	40 to 65	m5 or m6	
			140 to 200	100 to 140	65 to 100	m6	
			200 to 280	140 to 200	100 to 140	n6	
			—	200 to 400	140 to 280	p6	
			—	—	280 to 500	r6	
			—	—	over 500	r7	
	Heavy Loads or Shock Loads (>0.13C_r(1))	Railway Axleboxes, Industrial Vehicles, Traction Motors, Construction Equipment, Crushers	—	50 to 140	50 to 100	n6	More than CN bearing internal clearance is necessary.
			—	140 to 200	100 to 140	p6	
			—	over 200	140 to 200	r6	
			—	—	200 to 500	r7	

Figure 3—NSK Rolling Bearings E1102k Fit Table A85.

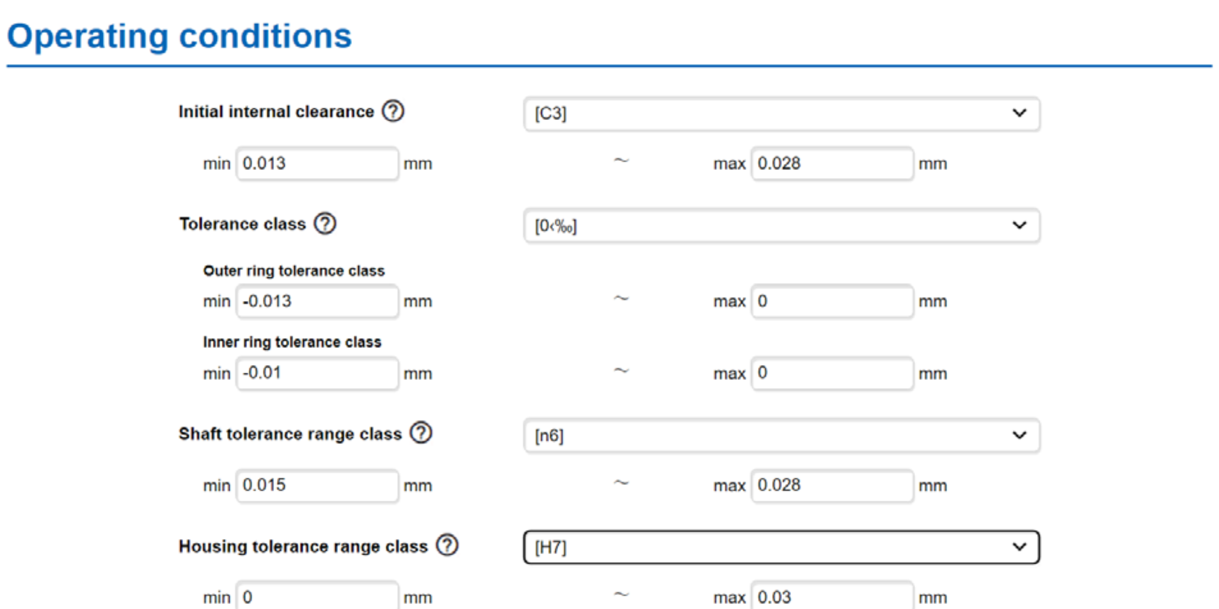


Figure 4—koyo.jtekt.co.jp/en/calculation/operating_clearance/?pno=6205

You can usually rely on bearings falling within the center 50 percent of the tolerance range. If we say that we want to the 3-sigma method to stay above zero, our solid shaft falls a little off by 2.7 µm. This is an easy enough fix by dropping the shaft diameter by ~ 3 µm, but recall, that number was set for a reason, creep. This is the game we have to play. Revisit your creep calculations and see what that does for your operating load. Perhaps it only affects a very small portion of your cycle, or it may cut into a high load test that you need to avoid creep on. Effective clearance includes temperature conditions which we aren't worrying about right this minute.

3σ method | Max-Min method

Residual clearance	-0.0027mm ~ 0.0153mm
Effective clearance	-0.0027mm ~ 0.0153mm

Figure 5—Internal Clearance Results for solid shaft.

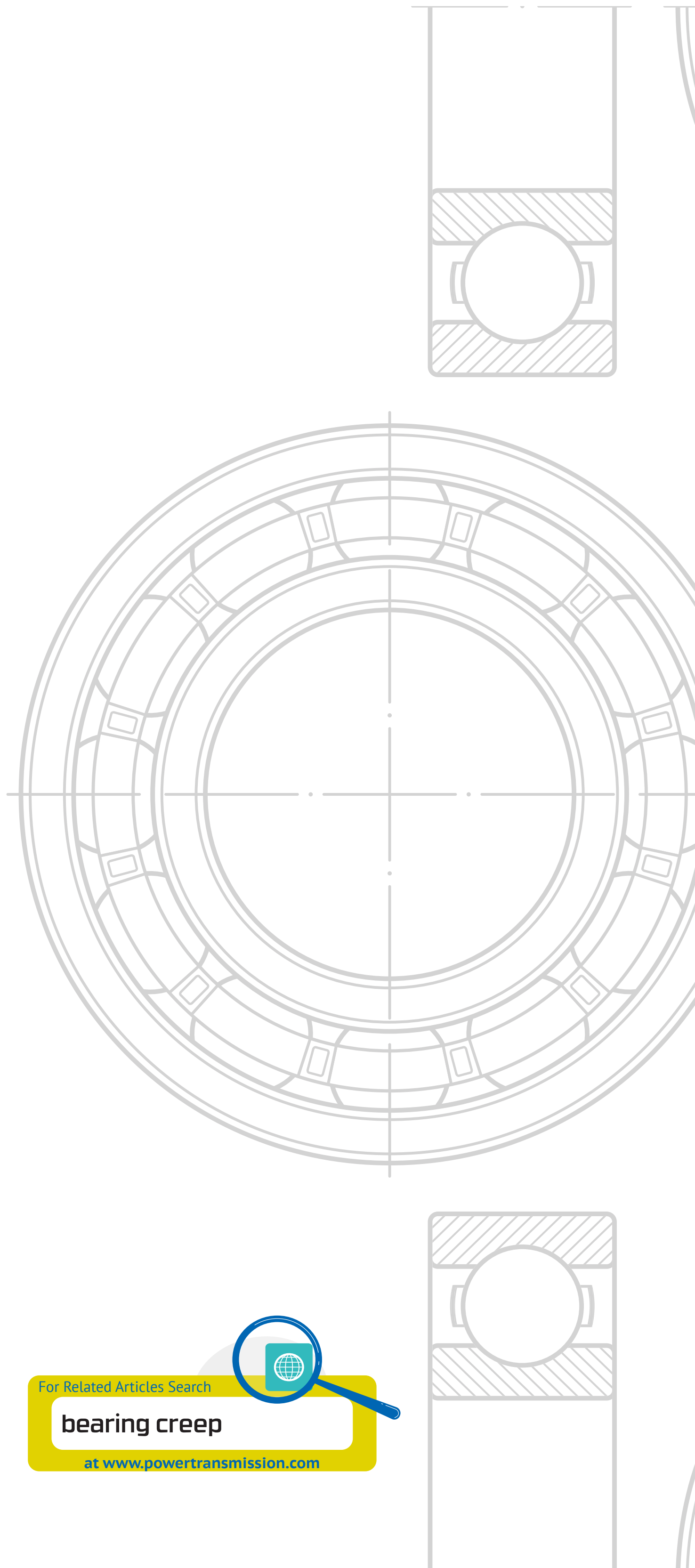
Now I take this exact same calculation and add a 15 mm through hole to the shaft (5 mm wall thickness if you prefer) and look how dramatically the clearance changes. I get almost 7 µm of internal clearance back due to the shaft compliance. Recall in the previous article, I mentioned that I often assume a 1 class higher fit for hollow shafts—this is the reason.

3σ method | Max-Min method

Residual clearance	0.0004mm ~ 0.0175mm
Effective clearance	0.0005mm ~ 0.0175mm

Figure 6—Internal Clearance Results for hollow shaft.

Ok, I'm going to leave you with that to stew on for this article. I have a blast with shaft and housing fits; I find this an enjoyable part of the job. It is often challenging, there is often not a perfect answer. You will find yourself with simultaneous problems of not hitting your creep numbers and having high hoop stress and pushing your clearance to the limits. I hope I can talk you into enjoying this process rather than losing sleep over it. Think of this like being a meteorologist and learn to confidently say that we have a 50 percent chance of rain. Until next time, enjoy!



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On the Potential of High-Ratio Planetary Gearboxes for Next-Generation Robotics

Pablo Lopez Garcia, Anand Varadharajan, Stein Crispel, Dirk Lefeber, Tom Verstraten, Marcin Wikło, Georgios Vasileiou

The earliest example of a gear train dates to at least 2,000 B.C. when Chinese engineers built a chariot that used a complex planetary mechanism made of wooden gears to let a dragon head continuously point south when driven around (Ref. 1). In Greece, a surprisingly advanced Antikythera gearbox mechanism, incorporating at least 37 precisely crafted bronze gears, was built years later, between 205–60 B.C. (Ref. 2).

Ever since then, engineers have used the extensive versatility of planetary gearboxes to integrate scientific advances and materialize the dreams of their creative minds. In the 15th century, Leonardo da Vinci dreamed of a helicopter he could not build, limited by substantial technological barriers. Almost 500 years later, scientific advances allowed engineers to build planetary gearboxes with sufficient torque density to enable Sikorsky and De la Cierva to build helicopters that could lift their own weight. Today, advanced planetary gearboxes enable many of the most impressive engineering masterpieces of our time, including helicopters, cars, submarines, wind turbines, and industrial robots.

In robotics, planetary gearboxes were used in the joints of the first generations of industrial robots, but limitations to minimize backlash resulted in their replacement with other gearbox technologies. Today, cycloidal drive (CD) gearboxes are used in over 75 percent of the joints of industrial robots—especially the proximal joints—while strain wave drives (SWDs) represent around 20 percent—typically in the more distal joints—and planetary gearboxes are relegated only to a fraction of the remaining 5–7 percent joints (Ref. 3).

The arrival of modern collaborative robotic devices seems to be drastically altering this paradigm. These devices have a marked need for lightweight actuation that has strongly favored the use of SWD gearboxes in their joints. Simultaneously, a trend can also be rapidly identified toward using planetary gearboxes again in robotics. Cobot manufacturers like Kinova and Automata incorporate self-developed planetary gearboxes in some of their models, while the recent interest in quasi-direct drive solutions is also favoring planetary solutions, both in research (Ref. 4) and in commercial products like Genesis' Reflex gearbox (Ref. 5) or the robotic drives proposed among others by T-Motor, DynaDrive, Maxon, Spinbotics, Dephy, or the MIT's actuator (Ref. 6). In fact, the recent incorporation of Melior Motion's PSC gearbox in Kuka's KR Iontec robot and the acquisition of the former by the Schaeffler group (Ref. 7) could also be an indication that manufacturers of traditional industrial robots are also starting to look at planetary alternatives for their future robotic joints.

This paper uses an assessment framework for robotic gearboxes previously developed in (Ref. 5) to systematically analyze the motivations behind this apparent planetary gearbox's comeback. "An Assessment Framework for Robotic Gearboxes" introduces the most relevant elements used in our proposed assessment framework. "A Comparative Study of Robotic Gearbox Technologies for Collaborative Devices" includes a comparative analysis of the most decisive parameters that impact a robot's performance for the most common gearbox technologies. "Highlights from Current Research Activities on Robotic Planetary Gearboxes" highlights relevant research activities in this domain, and "Conclusions" summarizes our findings.

An Assessment Framework for Robotic Gearboxes

A significant characteristic of robotic gearbox technologies is their considerable ability to substantially improve one specific performance aspect through an adequate selection of some of its parameters. Inevitably, this form of optimization results in reduced performance in other functional aspects of the gearbox. For example, planetary gearboxes show considerable backlash compared to other technologies like SWDs or CDs. Yet, a high level of preloading in the teeth contact can substantially alter this status quo and make a planetary gearbox exhibit zero backlash. The direct consequence is a significant loss in efficiency, which makes this approach impractical in most cases. This high versatility represents a sizeable obstacle when selecting an adequate technology for a robotic application. Here, we follow an approach suggested in (Ref. 5), which focuses on understanding the underlying characteristics of available gearbox technologies and selecting a technology that provides a good starting point for the most relevant parameters of the considered application, such that adaptations are minimal.

Key Enabling Aspects (KEAs) for Collaborative Robotic Solutions

Future robotic solutions must be compatible with the unstructured and unpredictable environments of human offices and homes to unleash their full potential to improve our lives. Further, they must also be capable of physically interacting with us directly without needing safety fences to protect our integrity. Robotic devices with this ability are commonly termed "collaborative," and they require a significantly higher level of mastering movement than traditional industrial robots.

In general, collaborative robots must be inherently safe for human interaction, this being an essential requirement and a preliminary condition for achieving good productivity in most collaborative tasks. In addition, although good precision is frequently a valuable asset, accuracy and repeatability requirements are substantially less demanding than for conventional industrial robots. Another highly desirable aspect of most collaborative robots is low consumption, reducing recharging frequency, and contributing to a sustainable future. Finally, being able to bring a robotic device into a specific position manually with moderate effort is also a highly desirable asset: it enables programming by demonstration and, for devices working in parallel with our body like exoskeletons or orthoses, it significantly improves wearability.

Another aspect increasingly playing a role in selecting robotic gearboxes for collaborative applications is noise. This is a direct consequence of the environment where collaborative devices should ultimately be deployed, including homes, offices, and other areas where the general noise level is substantially lower than in a factory. Typical gearbox noise levels tend thus to represent a compelling disturbance.

These five aspects—safety, moderate accuracy, high efficiency, manual configuration, and noise—play, together with affordability, a privileged role in establishing the utility of a robotic device in the future, which justifies referring to them as the six KEAs for collaborative robotic solutions.

Gearbox Engineering Requirements Behind the Robotic KEAs

A previous study (Ref. 8) using a Quality Function Deployment approach revealed a strong correlation between a robotic device's main movement performance parameters (e.g., speed range, torque range, efficiency, etc.) and the gearboxes used in its joints. Here, our study follows a similar approach to link the functional needs of a robotic device with the underlying engineering requirements of its gearbox to show that, to achieve good performance in the six KEAs for future robotic devices developed in "Key Enabling Aspects (KEAs) for Collaborative Robotic Solutions," the following gearbox parameters play a preeminent role:

Reduction Ratio and Torque Density

The gearbox's reduction ratio has a crucial impact on the weight and size of the electric motor required to do a specific job and thus on the total weight of a robotic actuator. For the gearbox itself, the available ranges of reduction ratios and their impact on the gearbox's weight tend to be strongly conditioned by the gearbox technology, as we will demonstrate in more detail in "Reduction Ratio and Torque Density."

Power density is traditionally a crucial requirement for any gearbox. This property evaluates how large a gearbox needs to be to cope with the transfer of a certain amount of mechanical power, a decisive aspect as the size tends to be directly linked with weight and cost, aspects that must usually be minimized in most applications. In robotics, torques tend to be considerably large while speeds are moderate compared to other common industrial devices. This is particularly the case in collaborative robotics, where the reference is the human body, which can produce high torques but typically moves at moderate rotational speeds. The human ankle provides a good example: for an adult male running, the ankle can develop remarkably large torques—close to 350 Nm—while rotational speed is typically limited to moderate values, not significantly exceeding 60 rpm (Ref. 9).

This need for high torques and moderate speeds in robotics, combined with the significantly larger power densities that high-speed/low-torque motors can achieve (Ref. 10), explains why most robotic actuators are composed of a relatively high-speed (high power density) electrical motor combined with a high-ratio gearbox to achieve the higher torque-speed ratios that the robot needs. Indeed, the most effective and popular strategy to reach the highest possible actuator torque density is to select an electrical motor with a large power density and combine it with a gearbox with a high ratio (and large torque density) (Ref. 11).

For a robotic device, size and mass are very restrictive aspects. Larger and heavier robots are substantially more expensive and need more powerful—thus, larger and heavier—actuators to be moved and execute their tasks. For an industrial robot, its own weight is commonly twenty times larger than the maximum payload (Ref. 12). The robot's weight is strongly conditioned by the weight of its actuators (Ref. 13). For collaborative robotic devices, the need to be inherently safe in case of impact with a human induces substantial speed restrictions according to ISO/TS 15066, with a determining effect on a robot's productivity. An effective way to minimize this restriction is to substantially reduce the robot's weight and thus that of its actuators, which explains why the ratio between self-weight and payload tends to be smaller (typically around 4:1 to 10:1, according to our experience). Linked to this, and again also according to our own experience, the contribution of the actuator's weight to the overall robotic weight tends to be more significant for collaborative robots.

Weight plays thus a central role for the actuators of a collaborative robotic device, which needs to provide substantial torques at moderate speeds to power the robot's movements. Consequently, torque density is a fundamental aspect of any robotic gearbox, while the choice of the gearbox's reduction ratio becomes pivotal due to its direct and fundamental impact on its own mass and that of the motor, and thus on the actuator's torque density.

Gearbox Efficiency

Losses are generated on the effective contact of two surfaces when these move with respect to each other, and they are inherent not just in solid bodies' contact but also in fluids and gasses. The function of a gearbox is the transfer of mechanical power, which involves multiple of these body contacts between its gearwheels, bearings, lubricant, air, sealings, etc.

For a robotic gearbox, losses are detrimental because they contribute to a faster depletion of the battery and thus either larger (e.g., heavier) batteries or the need for frequent charging, both nondesirable options for a collaborative device. Further, low efficiency means that a fraction of the power input in the gearbox cannot be converted into output torque, and thus, a larger motor is required to cope with the robot's task.

A popular classification of losses in gearboxes distinguishes first between load-independent (or no-load) and load-dependent losses, assuming that these are not coupled (Ref. 14). No-load losses refer to the gearbox losses when no external load is applied to the gearbox and originate from sliding and rolling friction on the elastohydrodynamic (EHD) contact between the gear teeth (typically neglected in unloaded conditions) in mesh and the bearing contacts (mainly drag losses), as well as through lubricant churning inside the gearbox, lubricant pocketing between the gear teeth, and friction with the sealings. On the other side, load-dependent losses originate from contact forces and relative sliding and are frequently analyzed following a Coulomb friction model (Ref. 15).

This separation between no-load and load-dependent losses is instrumental in evaluating a gearbox's suitability for robotic operations (Ref. 1). Robot operations tend to involve frequent changes between low-torque and moderately-high-speed conditions, where no-load losses are decisive, and high-torque with low-speed conditions, where the load-dependent losses are then determinant (Ref. 16). The result of this situation is that, almost systematically, the effective efficiency of a robotic gearbox when subject to typical robotic-operation conditions falls well below 50 percent, even when the gearbox peak efficiency that the manufacturers reflect in the datasheet is often close to 85 percent (Ref. 5).

Our assessment framework incorporates thus one parameter to reflect the effect of the no-load losses (starting torque) and two other parameters to reflect the load-dependent losses (peak efficiency and latent-power ratio [LPR]). Starting torque indicates the torque that needs to be applied to a gearbox's input shaft to initiate movement on its output shaft under unloaded conditions, thus providing a good characterization of its no-load losses. On the other side, our research indicates that the load-dependent losses are mainly driven by the gear teeth' meshing efficiency and gearbox topology. Indeed, the sliding mechanism under which losses are primarily generated in gear tooth contact is susceptible to the gearwheels' normal forces and relative speeds. In most robotic gearboxes, their internal configuration results in composed rotational movements and relative gearwheel speeds that are an order of magnitude larger than for an inertial system, in which the gear shafts are connected to a fixed housing through bearings. These composed rotational movements lead to substantial losses in the gear meshings. Chen (Ref. 17) introduced a latent power concept that we apply in our LPR ratio to characterize this phenomenon. The LPR for a meshing (j) is calculated by multiplying the torque input (τ_j) in the meshing (j) and the speed input in this meshing, seen from a non-inertial observed moving with the gearbox carrier (C) at a speed ($\omega_j - \omega_C$). Dividing this by the input power to the gearbox (P_{In}) we obtain the LPR of meshing (j) as λ_j:

$$\lambda_j = \frac{\tau_j(\omega_j - \omega_C)}{P_{In}} \tag{1}$$

The meshing losses on each meshing can now be estimated using Ohlendorf's Equation 2 to relate the power losses (L_j) on that meshing to its LPR (λ_j), the input power to the gearbox (P_{In}), a friction coefficient between the meshing's teeth surfaces averaged through the complete contact line-of-action ($\mu_{m,j}$), and a meshing loss factor ($H_{v,j}$) that depends on the macrogeometry parameters of the gear teeth of the gears involved in that meshing:

$$L_j = (\lambda_j) \cdot [P_{In} \cdot \mu_{m,j} \cdot H_{v,j}] \tag{2}$$

$$H_v = \frac{\pi}{z_1}\left(\frac{1}{z_1} \pm \frac{1}{z_2}\right)(1 - \epsilon + \epsilon_1^2 + \epsilon_2^2) \tag{3}$$

where

Z_k is the number of teeth of gear "k"

ϵ is the meshing's contact ratio

ϵ_1 is the approach contact ratio

ϵ_2 is the recess contact ratio

For a reference meshing in which the gear shafts are rigidly connected to a fixed housing through bearings (thus ω_C=0), the losses (L_{ref}) are instead:

$$L_{ref} = [P_{In} \cdot \mu_{m,j} \cdot H_{v,j}] \tag{4}$$

And we can write that:

$$L_j = (\lambda_j) \cdot L_{ref} \tag{5}$$

Equation 5 shows that the LPR can be interpreted as a multiplication factor of the meshing (load-dependent) losses that these meshing would see in a conventional parallel shafts gearbox in which the housing is rigidly fixed, and all gear shafts are connected to this housing directly through bearings. Adding the LPRs of all meshing in a gearbox, we obtain a reasonable estimation of the amplification factor of the gearbox's topology on the meshing losses, which provides a valuable and complementary perspective on the load-dependent losses to the peak efficiency value from the catalog.

Actuator's Backdrivability

Backdrivability indicates an actuator's mechanical compliance to be driven from the load side. As the mechanical compliance (C_i) relates angular displacement (α) to torque (τ), it can easily be confirmed that, assuming in the first instance no losses, adding a gearbox with a gear ratio (i_G) increases the effective mechanical compliance of the load seen from the motor (mot)—thus reflected to the motor side, or forward (Fwd) compliance—multiplied by the factor (i_G^2), while at the same time, the compliance of the motor seen this time from the load (L)—thus reflected to the load side, or backward (Bck) compliance—is reduced, multiplied by the factor ($1/i_G^2$):

$$C_{mot} = \frac{\partial \alpha_{mot}}{\partial \tau_{mot}}; C_L = \frac{\partial \alpha_L}{\partial \tau_L}; \tau_L \approx i_G \cdot \tau_{mot}; \alpha_L \approx \frac{1}{i_G} \cdot \alpha_{mot} \rightarrow C_{mot} = i_G^2 \cdot C_L \quad (6)$$

$$C_{L,Fwd} = i_G^2 \cdot C_L; \text{ seen from the motor (Forward Compliance)} \quad (7)$$

$$C_{mot,Bck} = \frac{1}{i_G^2} \cdot C_{mot}; \text{ seen from the load (Backward Compliance)} \quad (8)$$

According to the above definition, an actuator's backdrivability will be determined by its backward compliance, thus by the mechanical compliance of the motor's rotor, including its three components, stiffness, inertia, and damping—divided by the square of the gearbox's reduction ratio. In reality, the gearbox's compliance also has a specific contribution to the overall actuator's backward compliance. For stiffness and inertia, the effect of the square of the reduction ratios makes the motor's rotor the dominant contributor to the actuator's reflected inertia and stiffness by a large margin (Ref. 18). For damping, gearboxes tend to have substantially larger losses than the few bearings' mechanical losses of the motor's rotor, such that the effect of friction in the gearbox should actually be accounted for when evaluating backdrivability.

Typically, motor rotors, gearbox gears, and shafts are manufactured in high-strength steel with very large stiffnesses such that their contribution to the backdriving compliance—particularly after reflecting them to the load side—can be neglected. Thus, for rigid enough actuators, backdriving is typically governed by the combined effect of damping (friction) in the gearbox and motor and by the inertia of the motor's rotor.

In principle, this analysis correlates acceptably well with the general understanding in the robotics community that high gear ratios result in very high rotor inertias when reflected to the load side, due to the effect of the square of the gear ratio, making these actuators practically non-backdrivable. This reasoning underlies the recent interest of this community in direct-drive (DD) and quasi-direct drive (QDD) actuators, which try to minimize gear ratio to enable better backdriving properties. Prominent examples of this strategy are given by Ref. 6 and Ref. 19. But, in our experience (Ref. 20), there are some fundamental flaws in this strategy: first and foremost, even if the recent development of high-torque electrical motors has improved their torque density, the torque densities of DD and QDD actuators are significantly lower than what is possible using high ratio gearboxes, and we have seen in "Reduction Ratio and Torque Density" how relevant this aspect is for a robotic gearbox. Secondly, high-torque motors tend to have substantially larger rotor inertias, such that, in the end, the gain in reflected inertia that results from reducing the reduction ratio is surprisingly limited. And finally, when the backdriving accelerations are not very large—as is commonly the case in collaborative robotics—it is actually damping—mainly gearbox friction—and not inertia that plays the dominant role in backward compliance.

The results obtained by Matsuki et al. (Ref. 21) and Lopez et al. (Ref. 18) testing backdrivability in prototypes of Wolfrom-based gearboxes with substantially improved efficiency correlate well with this hypothesis.

To characterize the backdrivability of a gearbox, our assessment framework, therefore, uses the parameter backdriving torque, which is usually provided by the manufacturer in the gearbox's datasheet.

Gearbox Hysteresis and Transmission Error

Current robotic gearboxes have been engineered to match the demanding accuracy needs of conventional industrial robots. Positioning and repeatability accuracies in the range of ±20 μm are not unusual for industrial robots with six to seven joints and total arm lengths close to two meters. In the structured and highly predictable environment in which these robots operate, positioning accuracy is the key to success.

Collaborative devices must cope with the uncertainties of human environments like our homes and offices, in which the position of objects is not precisely known and where humans, animals, etc., can emerge from nowhere in almost no time. A strategy based on extreme positioning accuracy is thus not a practical solution. Most collaborative devices are actually well-served with ten to twenty times smaller positioning accuracy than those typical in industrial robots. Collaborative robots use advanced sensing and force-control techniques to more effectively adapt to their less predictable and quite unstructured environments.

There exists thus a fundamental paradigm change in terms of positioning accuracy between conventional industrial robots and collaborative robots. As this change of needs is narrowly related to the movement capabilities of a robot, it is directly mirrored in the accuracy needs of the gearboxes used in its joints.

In our assessment framework, we have chosen to use two parameters—hysteresis and transmission error—to characterize the accuracy of a gearbox. Gearbox hysteresis is a statically determined curve with a loop shape that results from representing the angular displacement of the gearbox output versus the output torque, with fixed gearbox input, during a loading cycle in one rotational direction until nominal torque, immediately followed by unloading, and then repeating the process in the other rotational direction. This curve is particularly useful for a number of reasons:

- The surface between the loading and unloading curves corresponds to the gearbox's efficiency.
- The lost motion (or position error), which integrates the effects of torsional stiffness and backlash behavior, indicates how much the gearbox output can rotate with a blocked gearbox input and can be directly determined from the hysteresis curve as the difference between the maximum and minimum angular displacements of the gearbox output at zero torque.
- The deviation of these curves from a straight line indicates a nonconstant gearbox stiffness that changes under load as a result of internal torsion, deformations—for example, in the gear teeth—and flattening due to high Hertzian stresses. It is particularly relevant for the gearbox's dynamics.

When the hysteresis curves are not available from the manufacturer, lost motion and stiffness variation can be used as alternative parameters to assess the hysteresis of the gearbox.

The transmission error is a dynamically determined error that indicates the deviation percentage of output angular speed with respect to the theoretical output speed, calculated by dividing the input angular speed by the reduction ratio. This parameter describes the accuracy of a transfer function between the movement of the gearbox's input and output. It is critical for accuracy and results from the interaction of concentricity and other assembly errors with indexing errors, tooth corrections, stiffness variations during meshing, and other geometrical deviations.

Manufacturing Complexity

Collaborative robotics has the potential to extend robotics beyond manufacturing areas and mass production into our homes, offices, and other areas where more customized services and products are provided or manufactured. Good affordability is a highly desirable property often limited by the traditionally high cost of robotic gearboxes to materialize this potential. For a cobot with six or seven degrees of freedom—thus six or seven joints and actuators—the high cost of its gearboxes often represents an unsurmountable obstacle for broader adoption.

Although cost is thus a fundamental parameter for a gearbox for future robotic solutions, the original assessment framework in Ref. 5 could not integrate cost as a parameter due to the difficulty of obtaining, from an academic environment, gearbox cost evaluations that could be directly compared to each other.

Here, we suggest an indirect measurement of gearbox affordability by assessing its manufacturing complexity. For that, we take advantage of the fact that robotic gearboxes are typically manufactured in large series. Thus, a high level of cost optimization can be expected both in terms of materials and manufacturing. Further, gearbox materials are typically steel based for all technologies, while gearbox size and weight are already accounted for in our assessment framework, such that differences in material cost should not be significant and can be expected to be driven by gearbox size/weight. Accordingly, we hypothesize that the complexity of the manufacturing process of a given robotic gearbox technology can be used as a direct estimation of its relative cost and thus its affordability for similar sizes and weights.

Noise, Vibration, and Harshness (NVH)

The noise was another element not included in the original assessment framework (Ref. 5) because NVH performance is rarely included in the datasheets of robotic gearboxes. Given the importance that our own experience indicates that gearbox noise could play in the future for gearbox selection, we have decided to incorporate a noise assessment into our analysis.

To do this, we will take advantage of the determinant role of transmission error—an integral part of the gearbox hysteresis—in the NVH behavior of a gearbox and use this as an initial estimation of the NVH response of gearbox technology. Where available, we will combine this with NVH specifications obtained from the manufacturers' datasheet and compare these with available theoretical and empirical studies from existing academic literature.

A Comparative Study of Robotic Gearbox Technologies for Collaborative Devices

Reduction Ratio and Torque Density

For SWDs, this range is directly conditioned by the number of teeth of the circular spline and usually goes from 30:1 to a maximum of 160:1. In principle, the reduction ratio does not seem to impact weight or size substantially—the whole range is available for most standard sizes—but in practice, lower ratios tend to have lower nominal and acceleration (repeatable peak) torques (Ref. 5). This means that, for a given load, a lower ratio results in larger sizes, as we can see in Table 1.

Gear Ratio \ Volume (mm^3)	1.45E+05	2.02E+05	2.84E+05	3.28E+05	5.27E+05	1.04E+06	1.79E+06
30	-	11	30	56	100	217	-
50	8.3	18	43	70	113	281	484
80	-	27	54	92	176	395	675
100	9	28	54	96	178	402	738
120	-	-	54	98	204	433	802
160	-	-	-	98	216	459	841

Table 1—Acceleration Torque (in Nm) of harmonic drive gearboxes (models SHG, CSG, SHF, CSF, and HFUS) classified by gearbox volume and gear ratio, showing how low ratios tend to require larger volumes to achieve high acceleration torques, from Ref. 22.

In pure CDs, the ratio range is about 35:1 to a maximum of 120:1 for sizes compatible with most collaborative applications (outer diameter below 120mm), and it is again a direct result of the number of teeth of the ring gear. As was the case in SWDs, the whole ratio range is typically available for most standard sizes. Still, it does not affect nominal and acceleration torque in this case (Ref. 23). This means that, contrary to what happens in an SWD, reduction ratios within this range do not directly impact gearbox dimensions or weight. Higher torque densities can be achieved by increasing the input speed, but the unbalance resulting cycloidal geometry requires adding a second cycloidal drive and a ring to cope with speeds beyond around 8,000 rpm for small-sized gearboxes (Refs. 24, 25, 26).

CDs with an additional spur-gear pre-gearing stage—frequently termed "rotary vector" or RV cycloids—behave in principle similarly to pure CDs. Still, the additional pre-gearing allows for larger versatility. For collaborative compatible sizes, the reduction ratio range goes here from around 40:1 to 170:1. The reduction ratio does not affect nominal or acceleration torques, equivalent to what happens in pure CDs.

A yet different cycloid alternative is proposed by Onvio and termed a "differential gearing" cycloidal system. In this system, two cycloidal discs are bonded together such that the relative difference in the number of teeth of the two cycloidal discs and the two rings results in a high-ratio configuration when one of the rings is grounded and the other used as an output. Through preloading the rings, minimum backlash can be achieved with this configuration, capable of reaching gear ratios up to 256:1 (Ref. 27).

Planetary gearboxes are extraordinarily versatile, and their configuration has a strong impact on the reduction ratio. The most broadly found configuration is a simple epicyclic in a planetary configuration (Ref. 28), thus with a grounded ring gearwheel. We will be using the term planetary gearhead to refer to this configuration throughout this report. Planetary gearheads have several fundamental advantages that have earned them a clear adoption dominance in industrial settings, including reaching very high-power densities—thanks to the possibility of split power flows between multiple planets—and a very robust topology. Their reduction ratios are though substantially limited to a theoretical maximum of 12:1 (Ref. 29), but, in practice, this range is often reduced to a minimum of 3:1 and a maximum of 8:1 (Ref. 30), as beyond these values, the Hertzian loads—typically on the sun gearwheel—require larger gears that result in unpractically large gearbox sizes.

When larger ratios are required, as is the case for most robotics applications, it is either possible to connect multiple gearheads in series with each other or to diverge to another planetary compound (multistage planets) or coupled (carrier shared between multiple stages) solutions (Ref. 28).

High-Ratio Planetary Configurations

The search for suitable planetary configurations that can achieve higher gear ratios than a conventional planetary gearhead has produced abundant literature. In general, these works tend to highlight the excellence of the conventional planetary gearhead topology, which results in conveniently balanced surface and bending stresses on the gears, better efficiency, and well-balanced load distribution on the different gearbox elements. This ends up making it surprisingly difficult to find configurations that can achieve lower weight and/or size even for substantial reduction ratios.

In 2002, White devoted an article to the derivation of highly efficient two-stage planetary gearboxes in Ref. 31, where he focuses on efficiency and gear ratio. He identified arrangements that avoid internal power recirculation to improve efficiency and bearing life.

Recent advances in computation provide the opportunity to make systematic reviews of the extensive versatility of planetary gearboxes for a specific objective. This approach is now broadly generalized and has also been applied by Salgado and Del Castillo to complete White's initial list of configurations in 2014 (Ref. 32). These authors performed a valuable systematic analysis of all possible planetary configurations with four to six links on their ability to provide suitable transmission ratios and combine that with good topological efficiencies. The most interesting configurations are shown in Figure 1. Before that, in Ref. 33, the same authors had also studied the topological efficiency of different planetary configurations. To simplify their calculations, the authors use a reference meshing efficiency of 98 percent assumed constant for all gear meshing contacts in any planetary configuration.

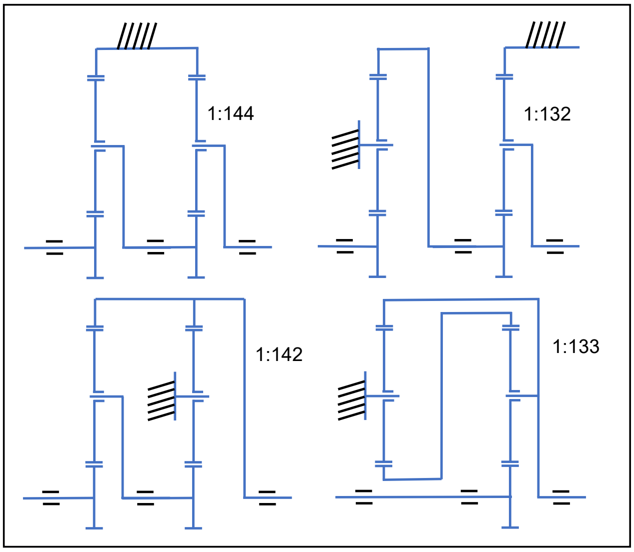

Figure 1—Six-link PGT configurations with the ability to provide high gear ratios (reference values given next to each configuration) with good efficiency, according to Ref. 32. Compared to a Wolfrom configuration, these solutions result in comparable overall gearbox dimensions, but the achievable gear ratios are lower (indicated next to the configuration).

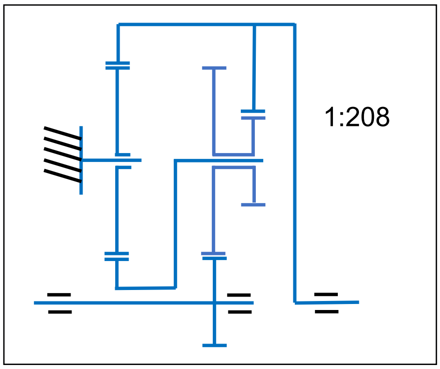

Figure 2—Six-link configurations capable of providing high ratios at the cost of low efficiency (Ref. 32).

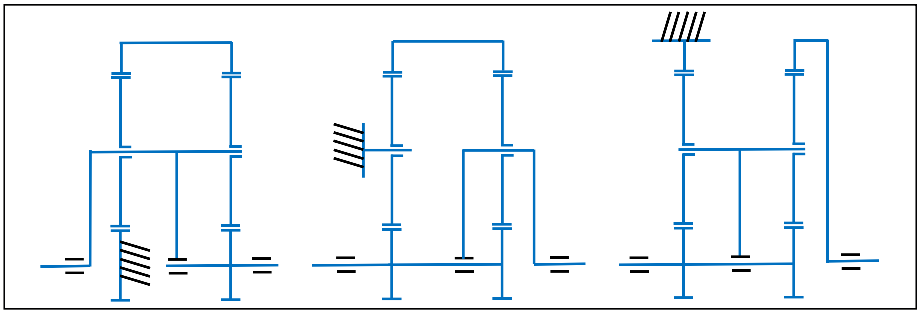

Figure 3—Six-link PGT configuration, derived from the conventional gearhead configuration but capable of providing larger gear ratios while maintaining good efficiency, according to Ref. 32.

Henriot had already tried in 1998 to make a similar analysis of planetary configurations capable of combining high gear ratios and good efficiency (Ref. 32). Henriot's approach is maybe less systematic but certainly more pragmatic, pointing at the need to incorporate dimensional criteria in this type of analysis. Consequently, Henriot analyzes the potential of selected configurations to achieve high gear ratios while maintaining good efficiency and a compact shape. He proposes a set of configurations with six links and an excellent ability to produce high gear ratios (see Figure 2) which he points leads to low efficiency. In his analysis, he includes specific considerations for each analyzed configuration in terms of (i) potential improvements in the meshing efficiency of each gear meshing contact, (ii) the need to increase the gearbox size to avoid teeth overloads in some particular configurations, and (iii) manufacturing considerations. Considering the individual gear meshing contact efficiency provides a more holistic perspective of efficiency beyond a merely topological impact analysis. Henriot proposes a variation of the conventional gearhead shown in Figure 3, which can produce relatively high gear ratios (1:208) while maintaining good efficiency (above 96 percent, according to Henriot's estimations).

In 2013, Kapelevich (Ref. 34) also reviewed some particular high-ratio configurations. He followed again a very practical approach that is more in line with that of Henriot and includes the ability to produce high ratios, efficiency, compactness, and manufacturing considerations.

Mulzer attempts, in Ref. 35, a systematic review of possible high-ratio planetary configurations that could be used in the auxiliary actuation of automobiles. He incorporates a very comprehensive list of requirements in his classification criteria, including cost, efficiency, manufacturing complexity, number of shafts, number of bearings, number of gearwheels, compactness, load capacity, velocities inside the gearbox, bearing loads, and axial length. For a specific reference use case (10 Nm, diameter 45 mm, and axial length 15 mm), he establishes that the most significant potential to achieve high gear ratios in a compact shape is provided by the Wolfrom configuration, which he ultimately selects to build and test his prototypes.

Hoehn and Gwinner put a particular emphasis on lightweight aspects in their analysis in Ref. 37. Comparing three different configurations for three target gear ratios (5:1, 25:1, and 125:1), they demonstrate the advantage of the conventional planetary gearheads in terms of efficiency, but also that configurations using a double ring gearwheel—as in a Wolfrom gearbox—provide the most promising alternative to limit weight.

A high-ratio planetary configuration, which has historically received a lot of attention from gearbox engineers and is often targeted in the previous studies, was first proposed in 1912 by Ulrich Wolfrom (Ref. 38) and is often referred to as a Wolfrom gearbox (the term 3K gearbox is more frequently found in Russian and Japanese literature, whereas in the U.S. this configuration is often referred to as a compound gearbox, due to the use of multistage planet gears). Popular variants of the original Wolfrom gearbox design include the Ferguson (Ref. 39) and the Rossman (Ref. 40) designs, shown in Figure 4, but all of these configurations share a remarkable ability to produce very high gear ratios in a very compact shape and with nicely balanced surface and bending stresses and internal load distributions. The main limitation of Wolfrom—and by extension Ferguson and Rossman—gearboxes is a surprisingly low efficiency that has earned this gearbox the name "mystic gearbox" in Japan (Ref. 41), which we analyze in further detail in "Gearbox Efficiency and Actuator's Backdrivability."

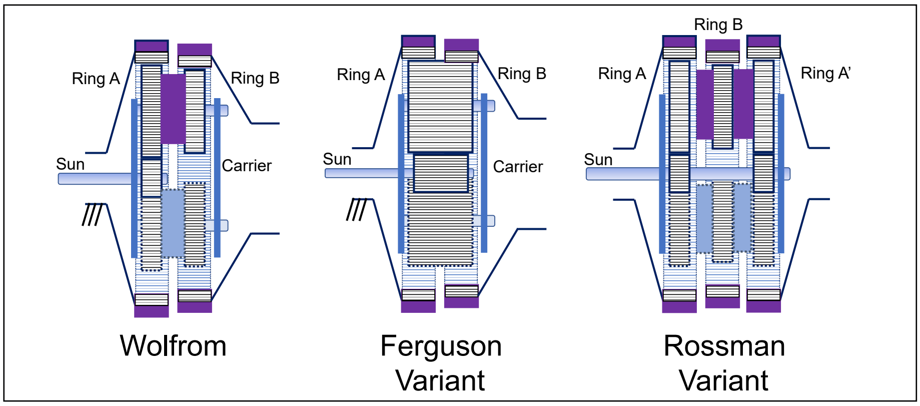

Figure 4—The original configuration proposed by U. Wolfrom in 1912, compared to a variant based on Ferguson's paradox principle (Ref. 39) using continuous planet tooth geometry and to a variant proposed by Rossman in Ref. 40.

Gearbox Efficiency and Actuator's Backdrivability

In this section, we will be assuming gear ratios around 100:1 to obtain comparable metrics.

Planetary gearboxes have starting (no-load) torques below 2 percent of the nominal input torque, where the internal configuration of both CDs and SWDs leads to values around ten times larger, in the range of 10 percent to 20 percent (even up to 27 percent for some cycloidal designs) of the nominal torque (Ref. 5). This provides a significant efficiency advantage for planetary gearboxes in robotics, where operation at partial loads is frequent.

Conventional planetary gearheads can reach peak efficiencies beyond 90 percent, assuming gear ratios over 100:1 and particularly if these can be achieved using two-stage configurations. Still, they tend to be larger and heavier than other compact robotic gearbox solutions and have thus a significant disadvantage for modern robotics. Restricting thus the comparison to high-ratio configurations with high torque densities, peak efficiencies can go up to 85 percent for all three compact gearbox technologies considered here and do not represent a significant differentiation factor. CDs achieve high peak efficiency thanks to their fundamentally rolling friction contacts, while planetary and SWD gearboxes take advantage of tooth macrogeometries optimized for low losses. Both CD and SWD gearboxes also benefit from the positive impact on the efficiency of having a similar number of teeth between meshing gears.

The third efficiency parameter in our assessment framework, LPR, shows in Ref. 5 a more favorable starting point for planetary gearboxes and CDs incorporating a pre-gearing stage (LPR values around 30) than for pure CDs and SWDs (LPR values around 100). Conventional gearheads have here a substantial advantage that they cannot exploit again due to their larger size and weight.

In terms of backdrivability, the effect of inertia can be neglected as all considered gearboxes are selected to provide the same output torque and have the same gear ratio. The backdrivability capacity of the three gearbox technologies is thus mainly conditioned by the gearbox's efficiency at low torques and thus by the starting torque, which has been described in the first paragraph of this section and confirms that the backdriving torque of the planetary gearboxes is substantially lower than for CD and SWD technologies.

Gearbox Hysteresis, Transmission Error, and Noise

SWD transmissions have complex dynamics that include nonlinear viscous friction, nonlinear stiffness, hysteresis, and transmission error. Transmission error is attributed to manufacturing and assembly error and the spline's deformation in SWDs. Ref. 42 determines the fast Fourier transform (FFT) of the measured transmission error in a Strain Wave SHF17-120-2AS-R-SP Harmonic Drive transmission and identifies the main component at twice the input frequency of the transmission, which correlates well with the manufacturer's indications that specifies a total positioning accuracy error around one arc·min (Ref. 41) and with the results of Ref. 43. Components at this frequency are typical for misalignment issues in the input shaft. However, in the SWD, it could also be the consequence of unbalances in the oval-shaped wave generator. Although of lower relevance, other significant components in Preissner's analysis (Ref. 42) correspond to three times the input and output frequencies; the latter typically results from unbalance in the output shaft. These other two frequencies are not explicitly highlighted in the manufacturer's documentation.

A typical hysteresis curve of a SWD transmission is shown in Figure 5 and corresponds to the effects of the transmission stiffness (hysteresis slope) and the Coulomb breakaway friction torque (hysteresis plateau), reflecting lost motion values around 1–3 arcmin.

For CDs, lost motion is also usually specified to be below one arcmin. Still, transmission error amplitude is typically lower (below 70 arcsec) than for SWDs, according to the manufacturer's indications (Ref. 45). In CDs, transmission error tends to have its primary component at higher frequencies that correspond to the number of pins multiplied by the input frequency, followed by twice this frequency typically due to pin misalignment (Ref. 46). A third important component also occurs at twice the transmission's input frequency, owing to the eccentric character of the cycloidal gear's wobbling movement. Wiklo's analysis (Ref. 47) indicates a larger contribution of manufacturing errors than stiffness variation to the final transmission error, which correlates well with other works that mainly identify the tolerance between the cycloidal disc and the pin-rollers as the most critical (Ref. 48).

Conventional planetary gearheads tend to show higher lost motion values (around 5–10 arcmin) (Ref. 48), which can be reduced to 1–5 arcmin in precision gearboxes, using pre-tensioning and thus negatively affecting efficiency. They also have a more complex transmission error footprint, which is strongly dominated by the multiple meshing contacts between the different individual gears and the related

Figure 5—Typical hysteresis curve of a SWD transmission including the effect of torsional stiffness (slope of the curve), Coulomb friction (breakaway torques at zero displacement), and lost motion at 0 Nm torque. Figure reworked from Ref. 44.

manufacturing errors and changes in stiffness, similar in their origin to what happens in the CDs.

There is very little literature available on high-ratio configurations other than planetary gearheads, the gear bearing drive (GBD)—a Wolfrom-based configuration—analysis in Ref. 49 being one of the few exceptions in which the largest error component was caused by inaccuracies in the output ring gear assembly (3.2 arcmin), followed by the meshing frequency between the planet and the ring gearwheels (1 arcmin). In terms of hysteresis, Ref. 50 measured 2–3 Nm Coulomb dissipation.

None of the engineering catalogs of several consulted manufacturers provide values for CD or SWD transmissions in terms of airborne noise. For planetary gearheads, Neugart specifies a maximum of 60 dB of sound pressure level from 1 m, measured on input running at 3,000 rpm, no-load, and with i=5 (Ref. 48). According to our analysis, this topic is not yet the objective of research literature for CD or SWD gearboxes.

Manufacturing Complexity

There is almost inexistent literature referring to the manufacturing method of the SWD, and little is known in academic circles other than that this manufacturing process is particularly complicated, especially that of the flexspline. Based on patent sources, we have established that this flexible, thin-walled gear with external teeth is manufactured through hot-forging, followed by turning, teeth machining, and shot peening (Ref. 51). In this process, the machining of the teeth is particularly sensitive due to the small modules involved and the flexibility of the blank, which requires precise clamping of both the outer and inner sides of the flexspline (Ref. 52). Another element that complicates manufacture is its effect on the material properties of the diaphragm on the closed end of the flexspline, whose deformation determines the torsional stiffness and has been the focus of active development activities in terms of wall thickness and manufacturing methods, from initial welding to deep drawing (Ref. 53) and ultimately hot forging (even machining for larger sizes, according to nonvalidated sources). The bearing manufacture for the wave generator is also mentioned as particularly challenging in some literature (Ref. 54). According to the manufacturers, this manufacturing complexity is behind the relatively high cost of the SWD transmission. However, it must also be noted that the small number of components of a SWD gearbox represents an advantage, certainly during the assembly process.

The manufacturing process of CDs is better known. It is based on the accurate machining of the different components, typically using 5-axis CNC machines and customized bearing solutions for some manufacturers like Spinea. The manufacturing challenge for CDs is clearly machining accuracy due to their high sensitivity to even the slightest center-distance deviation—a direct consequence of the cycloid teeth geometry—in terms of transmission error and Hertzian loads on the pins. As a result of these demanding manufacturing accuracy requirements, CDs tend to be also expensive, although significantly less than SWDs, according to our own experience.

The RV configuration described in "Reduction Ratio and Torque Density" takes advantage of the spur pre-gearing to adapt the gear ratio maintaining the same cycloidal disk geometry, which reduces manufacturing cost thanks to the larger series. A sensitivity analysis using the Sobol methodology of the RV CD (Ref. 55) shows that the highest influence on transmission accuracy is given the runout of the eccentric cam, while the clearance of the cycloidal disc's main bearing, pin gear tooth groove error, and accumulative pin gear pitch error have more limited influence. The smallest influence is derived from carrier assembly errors and the bearing clearance between the carrier and frame.

To reduce the mass or to increase torque density, some manufacturers like Spinea use customized bearing solutions where a bearing raceway is integrated within the part. The gearbox's output is expected to carry out the high output torque along with the bending moment. To avoid using two rolling bearings, cross-rolling bearings are introduced. The solution is well known in the SWD gears.

Manufacturing simplicity is a fundamental advantage of planetary configurations, as highly optimized manufacturing processes, including hobbing, shaping, skewing, grinding, etc., have been developed for involute-profile gears and are currently available for different sizes of manufacturing series and materials (Ref. 56). While substantially simplifying manufacture, involute teeth geometry makes these devices less sensitive to center-distance errors, with load-sharing between multiple planets (mainly affected by manufacturing and assembly accuracy of the carrier) and the manufacture of stepped planets for some high-ratio configurations representing the highest manufacturing challenges. Yet, as we have seen in "Gearbox Hysteresis, Transmission Error, and Noise," high-precision gearwheels are needed when low transmission errors are required, which tend to substantially impact manufacturing costs and can typically not reach the same levels as CDs and SWDs.

Highlights from Current Research Activities on Robotic Planetary Gearboxes

The PSC Gearbox of Melior Motion

Melior Motion GmbH from Hammeln, Germany, proposes since 2015 a PSC planetary gearbox with three stages, developed explicitly for industrial robots and automation applications based on a patented system to regulate friction wear. The three-stage spur-gear configuration can reach gear ratios up to 200:1 with efficiencies beyond 90 percent (Ref. 57).

Although the exact number of teeth of the gearwheels is not given, it can be estimated to achieve values around LPR=3. Yet, the high-accuracy focus of this gearbox typically involves high-preloading that could condition efficiency at partial loads. This aspect could not be confirmed as the current technical catalog does not include sufficient elements.

According to the manufacturer, this gearbox uses many planets (five) to enable better load sharing and torque densities. Practically though, a PSC gearbox with 325 Nm acceleration torque and a gear ratio of 100:1 weight 5.2 kg, which is considerably larger than CDs of similar characteristics (Ref. 5).

Kuka incorporates this technology in their KR Iontec and Cybertech industrial robotic manipulators (Ref. 7).

The Orbitless Drive

From Vancouver, Canada, Orbitless also proposes a very innovative planetary gearbox. Incorporating a secondary, eccentric carrier capable of providing reaction forces, the Orbitless Drive eliminates the need for a ring gearwheel.

In its basic Prime configuration, the Orbitless Drive results in lower pitch velocities and improved noise behavior and efficiency (Ref. 58). The possible gear ratios achievable with this configuration are limited to approximately half of those of a similar, conventional planetary gearhead (Ref. 59). For higher ratios, Orbitless proposes a design variant that uses a small teeth-number difference on the planets and idler gearwheels to achieve gear ratios up to 15:1.

The Traction Drive

Nidec-Shimpo has recently introduced a novel Traction Drive that minimizes transmission error and noise, taking advantage of its gearless, rolling contact. It can achieve up to 30:1 gear ratios, and the idea is not novel to Nidec, which has been producing this type of planetary gearboxes since 1952, mainly for industrial transmissions. Conventional traction drives (CVTs) are also known for some automotive CVTs. Due to the high contact pressures, they use the capability of some lubricant, traction fluids to solidify (crystalize) in the region where the rollers contact: the crystalized molecules line up regularly and can be used to transfer torque from one of the rollers to the other.

The novelty of this Traction Drive lies in its ability to transfer larger torques with a smaller size, solving a traditional limitation of traction systems and increasing the pressure capability of the rollers by modifying their shape and contact footprint. The current size (100 mm outer diameter) and payload (peak torques up to 20 Nm) are interesting for in-wheel applications as the very low noise level (40–50 dB). Still, no standard product datasheets are yet available (Ref. 60).

The Reflex Torque Amplifier

Genesis Robotics, Canada, recently introduced a gearbox compatible with their LiveDrive motor called the Reflex Torque Amplifier. This gearbox builds on a Wolfrom-based configuration but uses injection-molded gearwheels and can achieve gear ratios up to 400:1.

The underlying topology is that of the Rossman-variant of the Wolfrom gearbox, including a large number of planets. Another exciting aspect of this topology is the use of tapered planet gears and helical teeth to preload the system and reduce noise (Ref. 5).

The Archimedes Drive

IMSystems, Netherlands, is a spin-off of the Delft University of Technology. Their Archimedes Drive follows again a topology based on the Rossman-variant of a Wolfrom gearbox, characterized by the use of toothless rollers, similar to the Traction Drive principle.

The controlled deformation of the roller planets enables torque transmission following an acting principle similar to that of the wheels of a car (Ref. 5).

The Bilateral Drive

The Fujilab, Japan, proposes a highly backdrivable gearbox for robotic applications that is again based on a Wolfrom configuration. With this topology, this device was able to combine gear ratios of 102:1 with forward efficiencies of 89.9 percent and backdriving efficiencies of 89.2 percent. The backdriving starting torque achieved was an impressive 0.016 Nm (Ref. 5). This gearbox is currently under development and is not commercially available yet.

The Gear Bearing Drive (GBD)

The NASA Goddard Space Flight Center, USA, introduced a new concept of a GBD that the Northeastern University of Boston further developed. It is based again on a Rossman-variant of the Wolfrom gearbox topology, adapted to include a carrier-less design and gear bearings that are rolling contacts radially aligning the gears. In this manner, the GBD can be seen as a symbiosis of a traction drive and a Wolfrom planetary gearbox (Ref. 5). This gearbox is also currently under development and is not commercially available yet.

The R2poweR Gearbox Technology

The Brubotics group of the Vrije Universiteit Brussels, Belgium, has recently presented their R2poweR high-ratio, highly-efficient gearbox technology. This technology, initially aimed at human-centered robotics applications, combines the use of low-loss gear tooth macrogeometries with topological modifications of the original Wolfrom planetary gearbox design that enable substantial improvements of the LPR and the meshing efficiency, thus giving the possibility to make very high gear ratios (275:1) compatible with load-dependent efficiencies of 85 percent using 3D-printed, plastic gearwheels. Their most recent results also include promising backdriving torques below 1 Nm for an R2poweR prototype manufactured in steel with rapid-prototyping means (Ref. 18).

Conclusions

This report uses an assessment framework for compact robotic gearboxes to verify if the apparent observation that compact planetary gearboxes could currently initiate a come-back process to participate in the next generation of robots.

We identify six KEAs for collaborative robotics—safety, moderate accuracy, high efficiency, manual configuration, and noise—and how a series of gearbox parameters strongly condition these: reduction ratio, torque density, efficiency (starting torque, peak efficiency, and LPR), hysteresis, transmission ratio, cost (manufacturing complexity), and noise.

Using this framework, we compare the performance of customary gearbox technologies—SWDs, CDs, planetary gearheads, and high-ratio planetary gearboxes—to demonstrate that planetary gearboxes have a better starting position for collaborative robotics than for conventional industrial robots. The main reasons are (i) a larger configuration versatility, which can be used to obtain larger gear ratios in compact shapes—and thus higher actuator torque density—(ii) lower starting torques, which result in substantially better efficiency at partial loads, and (iii) simpler manufacture, which results in better affordability. Further, a quick review of the most relevant research activities in robotic gearboxes seems to provide further evidence that corroborates the vast potential of planetary gearboxes in modern robotic applications.

In conclusion, although this analysis could not provide conclusive evidence of planetary gearboxes becoming dominant in future robotic applications, it demonstrates a high level of attention from the robotics research community and remarkable technological suitability, confirming that planetary gearboxes have a realistic chance for broad adoption in the next generations of robotic devices.

PTE

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Statements presented in this paper are those of the authors and may not represent the position or opinion of the American Gear Manufacturers Association.

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Airbus

SELECTS NIDEC LEROY-SOMER TO DEVELOP ELECTRIC MOTORS FOR ZERO-EMISSION ENGINE

Nidec Leroy-Somer has signed an agreement with Airbus to develop an electric motor for its hydrogen-powered fuel cell engine prototype, as part of Airbus' ambition to bring the first zero-emission commercial aircraft to market by 2035. The long-standing expertise and extensive know-how of the French electric motor manufacturer, who already provides proven advanced technologies to many demanding industries, such as Navy, Nuclear, Railway, Automotive and Robotics is now collaborating on Aviation decarbonization.

High level requirements

Leroy-Somer, part of the Japanese Nidec Group since 2017, is entrusted to design and develop a series of electric motor prototypes which meet very high requirements in terms of safety, reliability, energy-efficiency, and lowest weight for the targeted power. Its skilled Research & Development Team is also challenged to explore breakthrough technologies and innovations to optimize the architecture of the aircraft propulsion system. Project management, design, engineering, and prototyping will all be done from its headquarters in Angouleme, France.

Meeting the performance

Prototypes, designed for performance and integration in Airbus' zero-emission hydrogen powered fuel cell engine, will first be tested on ground using dedicated test benches. Following the initial qualification and validation, a second phase of in-flight testing will be conducted.

"We are pleased to have been selected by Airbus to provide our expertise in high efficiency electric motors and contribute, through our innovative R&D teams and solutions, to this ambitious eco-friendly commercial aviation project. This important milestone for more sustainable mobility, presents several challenges that we are committed to overcome, to serve the global community" said Jean-Michel Condamin, president of the Commercial and Industrial Motors Division.

For over 100 years, Nidec Leroy-Somer has been designing, developing, and manufacturing drive systems recognized for their quality and longevity in all industrial and commercial sectors. Always at the forefront of innovation with a deep expertise of various motor technologies and the related power electronics, it has built up a relationship of trust with many OEMs for whom it has carried out projects with very tight specifications, developing customized solutions with high added value. More than ever, to tackle global warming and the energy crisis, the electric motor has become a key player and Nidec Leroy-Somer is a renowned solution provider with its proven high energy efficiency IE5 motor DYNEO+ used in many different industrial fields.

Jean-Michel Condamin, president of the Commercial and Industrial Motors Division, Nidec Leroy-Somer.

Eric Coupart, chief technology officer of the Commercial & Industrial Motors Division, also added: "We are proud of this acknowledgement of our ability to cut energy bills & carbon emissions through tailor-made solutions, in one of the most severe environments. Our world-class R&D capabilities will bring to Airbus sustainable and powerful smart technologies with best-in-class energy efficiency for the near future of the Aviation."

acim.nidec.com/motors/leroy-somer/

Southern Gear

ANNOUNCES HUBZONE CERTIFICATION

Southern Gear, a veteran-owned small business specializing in the manufacture of precision gears, is pleased to announce its certification as a Historically Underutilized Business Zone (HUBZone) business by the United States Small Business Administration (SBA).

With HUBZone certification, Southern Gear is now eligible to compete for the program's set-aside contracts and receive a 10 percent price evaluation preference in full and open contract competitions. The SBA offers HUBZone certification to businesses operating in historically underutilized business zones, with a goal of awarding at least 3 percent of all federal contracting dollars to HUBZone-certified small businesses each year.

HUBZone
Historically Underutilized Business Zone
CERTIFIED

Certification requires that at least 35% of the company's employees live in a HUBzone—an important indicator of Southern Gear's commitment to providing employment opportunities for employees from these underserved workforce areas to employment on federal projects.

"Our customers, many of whom are leaders in the aerospace, military, and defense industries, consider HUBzone a key criterion in their vendor selection process," says Southern Gear President Karen Malin. "This certification is just another way in which we're meeting their requirements, while at the same time creating jobs and investing in our local community."

southerngear.com

Bonfiglioli

AGREES TO ACQUIRE SELCOM GROUP

Bonfiglioli has agreed to acquire Selcom Group from funds controlled by


TURBOMACHINERY
AND PUMP
SYMPOSIA
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STAFF

Avenue Capital Group and Europa Investimenti. Selcom Group specializes in the design, production and sale of electronic boards, electronic products, as well as software and solutions for customers in the industrial, biomedical, automotive, intralogistics and home-appliance automation sectors. Completion of the transaction is subject to customary regulatory approvals.

Selcom Group, headquartered in Castel Maggiore (BO), had 2022 turnover of approximately 150 million euros (of which 60 percent from Italian production), generating +15 percent growth over the previous year despite the market shortages of electronic material. The company employs approximately 750 employees across four production plants in Italy (about 40 percent of the total) and two plants in Shanghai (Qingpu).

With a production capacity of approximately seven million electronic units/year, Selcom Group's production plants are able to meet demands for high volumes and high mixes. Its production capacity is supported by a highly qualified organization and fulfilment of sophisticated quality standards. Furthermore, Selcom Group completes its value proposition with system integrator activities by supplying turnkey automation systems to customer specifications.

Selcom also stands out for its engineering area where it employs about 70 people between Italy and China. This company area includes research and development and process engineering for hardware, software and mechanics as well as the in-house design of product validation test methods which, together with a high level of service and close collaboration with the customer, it completes the differentiating positioning of the company in the market.

"We saw in Selcom an excellent opportunity for Bonfiglioli: it is a company with great electronic technical skills, both in terms of design and process, that are absolutely complementary to ours," says Fausto Carboni, CEO of Bonfiglioli. "Furthermore, on a commercial level, it is an extremely dynamic and motivated company, established in Europe and China, two strategic markets where it serves numerous customers who are among the largest and most important in their sector. This is strong testament to the company's professionalism and competitiveness."

Selcom Group represents a decisive strengthening of the electronic soul of Bonfiglioli, which was born in 2001 with the acquisition of the German Vectron Elektronik Gmbh, today Bonfiglioli Vectron Gmbh, a group company that designs and manufactures electronic drives for electric motors mostly for industrial uses. This acquisition will increase Bonfiglioli's development capacity, guaranteeing greater production verticalization, higher competitiveness and stronger control of quality standards.

Sonia Bonfiglioli, president of Bonfiglioli, states: "The impact of Industry 4.0, the increasingly evident pervasiveness of robotic systems in production and logistics processes, as well as the accelerated trend of the electrification of vehicles of all types, require even greater focus of Bonfiglioli in the development of mechatronic solutions of which electronics are obviously a fundamental component. The acquisition of Selcom finds its fundamentals in our desire to engage even more vertically in the design and value chain of control and power electronics. Furthermore, we are very happy that the acquisition concerns a company that today boasts multinational offshoots, but which was born and developed in Italy and in particular in the Bologna area; we are certain that the physical proximity to Bonfiglioli will further help to create synergies and solutions for our customers with high added value."

bonfiglioli.com

Timken

ACQUIRES AMERICAN ROLLER BEARING COMPANY

The Timken Company has acquired the assets of American Roller Bearing Company (ARB), a North Carolina-based manufacturer of industrial bearings. ARB's offerings join Timken's portfolio of engineered bearing solutions. ARB, which boasts a large U.S. installed base and strong aftermarket business, generated sales of more than $30 million in 2022.

"ARB's end-market mix, customer base and aftermarket position fit our Timken business model extremely well," said Richard G. Kyle, Timken president and chief executive officer. "We're proud to welcome ARB and its employees into The Timken Company."

ARB employs approximately 190 people and operates manufacturing facilities in Hiddenite and Morganton, N.C. Prior to this transaction, three generations of the Succop family owned and operated ARB since its founding in 1911.

timken.com

Forest City Gear

COMPLETES ANNUAL AS9100/ISO 9001 QUALITY AUDIT

Forest City Gear recently completed and passed its annual AS9100/ISO 9001:2015 quality system audit. The third-party audit company, Quality Systems Registrar (QSR), evaluated Forest City Gear's quality management systems to ensure compliance with AS and ISO standards.

The audit—performed yearly as part of AS and ISO certification—focused on processes and systems structured to ensure risk mitigation and customer satisfaction. This involved reviewing quality policies, analyzing standard operating procedures, and verifying records establishing conformance.

"The audit is a way for a third party to objectively measure the effectiveness of our processes," said Amy Sovina, quality assurance manager. "We use feedback from the audit results to improve our processes, which ultimately leads to a better customer experience."

AS9100/ISO 9001:2015 certifications run on a 3-year cycle. The audit performed in January is known as a "surveillance" audit: a shorter annual audit to ensure compliance. Forest City Gear will host a 5-day audit for recertification in 2024.

forestcitygear.com

ZF

UNVEILS 5G CAMPUS FOR JEVERSEN COMMERCIAL VEHICLE TEST TRACK

ZF's Commercial Vehicle Solutions (CVS) division has further underlined its commitment to advancing 'Next Generation Mobility' by investing in 5G digital connectivity. Equipping its commercial vehicle test track at Jeversen, Germany, with its own powerful campus network enables enhanced testing of 'Big Data' backed solutions which are increasingly facilitating the next levels of Mobility as a Service (MaaS) and Transportation as a Service (TaaS). This includes supporting the development of Levels 4 and 5 autonomous driving which demands seamless connectivity and enormous data management capabilities to enable autonomous vehicle control and the highest levels of safety.

"Our first 5G campus network equipped test track sets another powerful milestone in the Group's 'Next Generation Mobility' strategy," said Dr. Christian Brenneke, senior vice president of product engineering with ZF's Commercial Vehicle Solutions division. "Ensuring that we continue to support our customers with rigorously tested, cutting-edge innovations, our advanced network capabilities will enable us to meet future advances and technology changes."

"Based on an open intelligent Radio Access Network using a virtualized, cloud-based and open architecture, the new network ensures a stable transmission infrastructure with low latency and high security," points out Dr. Rolf Reinema, vice president IT Workplace, IT Infrastructure & Operations, IT Security at ZF. "It can safely transmit commands to and from the vehicles in near real-time, its rapid handover capability ensures a seamless end-to-end data flow in moving vehicles."

"It took us just six months to set up this system for indoor and outdoor coverage using antennas that optimally ensure reliable handovers between base stations, even during high-speed vehicle maneuvers," Dr. Reinema added.

Unlimited Digital Connectivity Powers 'Next Generation Mobility'

ZF's Jeversen test track, located in Lower Saxony, Germany, incorporates a mix of curves, straight and low-speed sections, replicating a wide range of road conditions to simulate real-life situations. Combining this track configuration with advanced 5G capabilities will further enable ZF to emulate different autonomous driving use cases, ranging from low-speed automated yard operations to high-speed highway operations. It also enables connectivity with roadside infrastructure such as traffic lights and gates. Being independent from mobile service providers, ZF can quickly and flexibly adapt the campus network to meet changing technology requirements and rapidly expand it to support future innovations.

Further improving the global test facility's digital and cyber security, flexibility and reliability, ZF's network supports seamless remote access and data transfer from test vehicles to cloud-based storage as well as rapid downloads. Manufacturers, suppliers, industry partners and other ZF guests of the Jeversen facility will also benefit from the new network. This includes high quality audio and video streams from moving demonstration vehicles and track-side cameras which can be seamlessly transferred to the visitor center to demonstrate ZF's latest innovations.

zf.com

May 22–25—Cleanpower 2023

Cleanpower 2023 (New Orleans) unites the most knowledgeable minds in clean energy to chart the future of this powerful industry and discuss the opportunities ahead. As previous attendees attest, the conference grows clean energy businesses by gathering key decision makers and stakeholders across the wind, solar, storage, hydrogen, and transmission industries for discussion, deal making, networking and fun. The trade show not only brings together the different technologies that make up the renewables mix; onshore wind, offshore wind, solar, storage, and transmission but also the different segments within the industries; manufacturers, construction firms, owner operators, utilities, financial firms, corporate buyers and more. Cleanpower will feature the latest products, services and technologies coming to the renewable energy industry.

powertransmission.com/events/947-cleanpower-2023

May 22–25—Automate 2023

Between intimate workshops, news making keynotes, networking events, innovation competitions and live demonstrations, Automate offers comprehensive automation education and cutting edge robotics, vision, AI, motion control and other technologies. Automate delivers the latest innovations in manufacturing automation technology from more than 600 leading exhibitors. Each day also offers inspirational keynote sessions and theater presentations to help attendees find the best solutions for their unique business needs. In addition to seeing demos of the latest automation solutions, Automate show attendees can watch keynote sessions highlighting how these technologies solve real-world challenges or participate in small group discussions in the theater sessions covering important topics.

powertransmission.com/events/941-automate-2023

May 24–25—CTI Symposium USA 2023

The CTI Symposium USA (Novi, Mich.) will update attendees on the latest technical developments and applications on automotive transmissions for conventional and alternative drives. Exchange experiences, discuss technologies and strategies with automotive experts from the United States, Asia and Europe. The conference and exhibition provide expert-led plenary and technology sessions as well as expert discussions and product showcases representing the full range from complete drivetrain systems to components and engineering services. CTI drives progress in passenger cars and commercial automotive transportation. Manufacturers and suppliers are actively demonstrating how to keep pace and staying ahead of customer needs, environmental, institutional and economic demands.

powertransmission.com/events/942-cti-symposium-usa-2023

June 24–27—EASA Annual Convention 2023

The Electrical Apparatus Service Association (EASA) will hold its Annual Convention and Exposition from June 24-27 in National Harbor, Maryland. EASA is an international trade organization of more than 1,700 electromechanical sales and service firms in nearly 70 countries. EASA supports companies involved in the service and sale of electric motors, pumps, drives, controls, gearboxes, and other rotating machinery. Highlights include synchronous motors, machine reliability, leadership, sustainability, EASA's 90th birthday bash, motor maintenance, pump repair, supply chain issues and more.

powertransmission.com/events/945-easa-2023-annual-convention

June 27–30—Automatica 2023

Automatica (Munich) is a trade fair for intelligent automation and robotics covers the entire value-added chain: from components to systems; from services to applications—for all manufacturing sectors. It offers an overview of current developments and innovations and thus provides the necessary orientation and investment security. Whether autonomous production, climate protection, supply chain resilience or a shortage of skilled workers: Automatica addresses the major global challenges of our time. To this end, it explores the potential of the key technologies of robotics and automation and offers the greatest possible practical relevance as well as concrete solutions.

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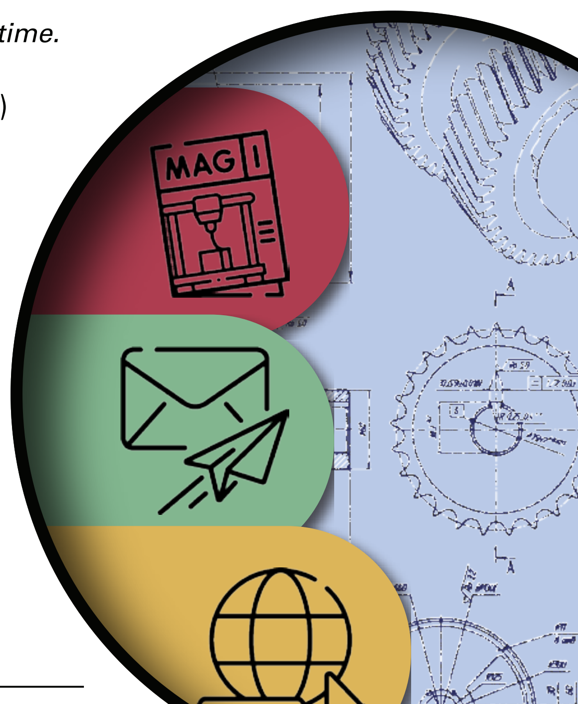

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Academic Accuracy

The Power of Miniature Motors in Lab Automation

Matthew Jaster, Senior Editor

It's called the d2, a small, lightweight, nanoliter microplate dispenser—say that five times fast— used in lab automation to handle a variety of liquids. Created by UK Robotics, the liquid handler was launched in 2022 to shake up the possibilities of moving liquids around the lab on a budget.

The Bolton, U.K., company specializes in providing integrated systems for life science labs and counts both small biotech companies and big pharmaceuticals as essential to helping the tech firm grow.

Most life sciences experiments run in biotech and pharmaceutical companies start with a microplate, a flat plastic plate with small holes (wells) used as test tubes. A 120 mm x 80 mm microplate will have 1,536 wells; this is used to run thousands of experiments using the same volume.

Before lab automation, pipettes were used to move liquids by hand into large tubes; large tubes required large volumes of liquids, which meant the number of experiments was limited. It is essential that the dispensing and fluid volume control are extremely accurate before the experiment.

Miniaturization has existed for a while but usually at a price. The UK Robotics liquid handler, the d2, is small; it is 25 percent smaller than other dispensers and has a lower price point. These factors are hugely important for start-ups or companies with limited lab space and budgets who still need to maintain accuracy.

The d2 uses two Maxon brushless EC 60 flat motors for the arms for the X and Y coordinates. The Z-axis uses the Maxon EC 45 flat with a mile encoder. The motors needed to provide consistency, accuracy, and a smooth torque curve. The sample is delivered through a hole of just 0.1 mm through a dispensing head valve made of polished sapphire and ruby, which is robust enough to allow for cleaning and sterilization without damage. The machine can accurately deliver 40 samples per second. Yes, that's 40 samples per second!

"I know there are lots of cheaper motor manufacturers, but we needed the consistency that Maxon is known for. The accuracy of our product is paramount. When you calibrate for one motor you know it will be the right calibration for the others; you don't want to be calibrating each one every time," said Mike Counsell, UK Robotics founder.

The multitude of possible combinations makes Maxon's EC 60 flat the ideal drive in a wide range of applications. Whether the focus is on high nominal torque, on high-dynamic positioning tasks with superb repetition accuracy, or on robustness and insensitivity against environmental conditions, the options are endless.

The MILE (Maxon's Inductive Little Encoder) is used to make optimal use of the flat motor in high-precision applications and positioning tasks. This tiny inductive rotary encoder operating principle is based on the detection of high-frequency inductivity which generates eddy current in an electrically conducting target. The advantages of a high-frequency inductive method of measurement compared to traditional encoders include the potential for higher speeds, greater robustness, and an insensitivity against interference pulses (PWM controllers or motor magnets, for example).

For UK Robotics, Maxon motors allows the company to provide a plug and play lab automation system small enough to fit on a bench, under an extraction hood or right into an existing automation system. This wouldn't be possible without the power behind some of the tiniest motors and encoders on the market.

maxongroup.us
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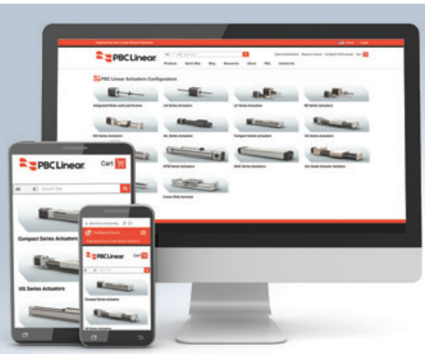

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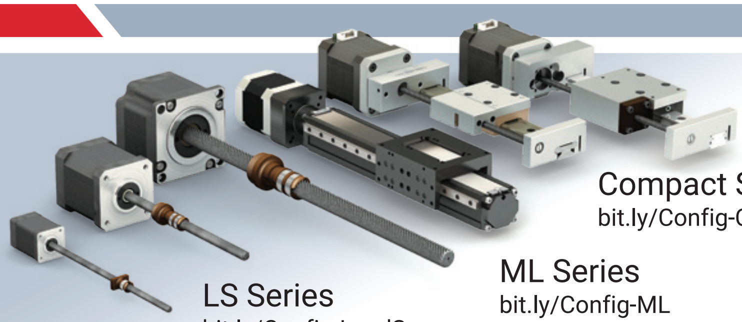

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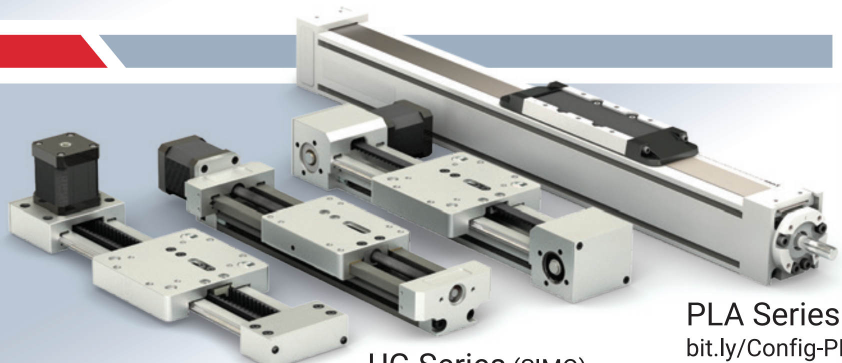

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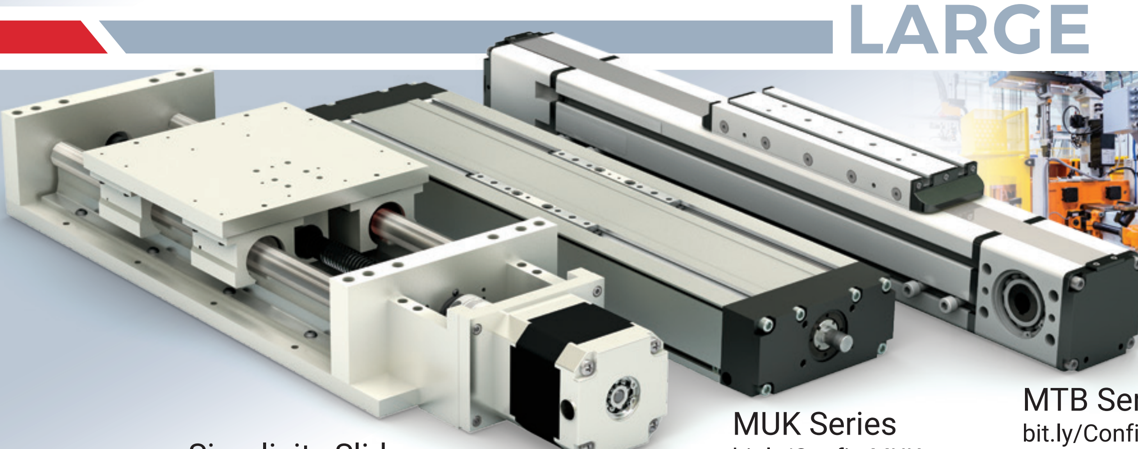

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