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Engineering Showcase 2018

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Power Transmission Engineering

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Cover photo by David Ropinski

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PTE Videos

Siemens Looks at Propulsion Systems

The Siemens propulsion portfolio includes components for the complete drivetrain of various mobility solutions. Pantographs, main transformators, traction converters — as well as motors and traction gear units. Check out the video here: ***www.powertransmission.com/videos/Siemens-Looks-at-Propulsion-Systems-/***

Altra Industrial Motion: TB Woods

Sure-Grip Quick Detachable bushings are easy to install and remove. Split-through flange and taper provide a true clamp on the shaft that is equivalent to a shrink fit. See the video here: ***www.powertransmission.com/videos/Altra-Industrial-Motion:-TB-Woods-/***

Editor's Choice Blog:

One baggage handling system OEM came to greatly appreciate certain features of the Nord Drivesystems products they had chosen to include: encoder connectivity, positioning capability, and plug-in connectors that ensure fast and safe installation and commissioning. Read more online here: ***www.powertransmission.com/blog/nord-drivesystems-optimizes-baggage-handling-system/***

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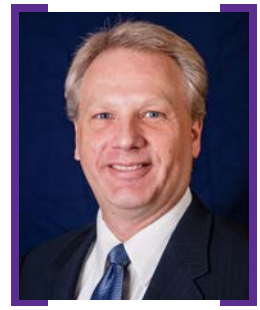
Smarter Machines Need Smarter Components



In this issue's feature article on motion control (p. 16), Senior Editor Matthew Jaster explores some of the leading trends in our industry. The article begins with this simple phrase: "The future of motion control is connectivity."

That about sums it up. Whether you call it Industry 4.0, the Industrial Internet of Things (IIoT) or just plain modern technology, there's no doubt that there's a revolution underway, and it affects just about everything we do.

Dumb components are no longer good enough. They have to talk to their counterparts. They have to talk to us. And we have to listen—which means, in addition to wired components, we also need better, more capable control systems, software and interfaces to enable engineers to make the best use of them.

And all you have to do is flip through the pages of this magazine to see not only that the components, controls and systems are already a big part of industry, but also that they continue to change. Even more importantly, it's clear that the change isn't over. The revolution will continue.

For even more evidence, look no further than our *2018 Engineering Showcase* section (p. 48), where we've highlighted a number of the companies leading the charge.

This issue also features a great case study from Framo Morat and Dunkermotoren (p. 26), who give us a glimpse of the factory of the future with their contribution to the technology of automatic guided vehicles, which seem almost like they should be racing down corridors in front of Darth Vader.

In addition to the cutting edge, we always try to give you a sampling of basics and technical articles on a variety of subjects. In this issue's Baldor Motor Basics, motor guru Edward Cowern wraps up his discussion on hazardous motors and also covers DC drive fundamentals. If you're new to electric motors, or even if you just need a refresher course, the Baldor Basics series is a treasure trove of information. (Baldor Basics began in December 2016 issue and has run continuously since then).

For our coverage of medical devices, Associate Editor Alex Cannella describes how the MedAccred accreditation program has continued to grow, taking on greater significance to suppliers in the medical industry. See his article on page 22.

Continuing the medical theme, we also have a detailed technical article from Bühler Motor about the development of miniature plastic gears for medical devices.(page 36).

We round out the technical content with an in-depth article about a new calculation method for evaluating the efficiency of worm gears.

We are always looking for new contributors, so if you have stories to share, especially as they relate to the continued changing of the technology that affects our industry, please consider sending those stories to us. Send your ideas via e-mail to *wrs@powertransmission.com*.

As always, we hope you find our articles interesting, educational and helpful in your quest to build smarter machines.

FVA

COMMITS TO DEVELOPING STANDARDS FOR GEARBOX DATA WITH SEW EURODRIVE AND SCHAEFFLER

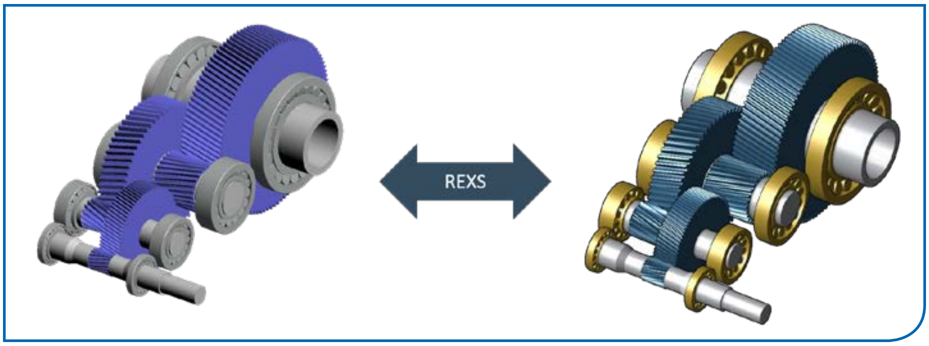


Figure 1 Three-stage parallel shaft gearbox from SEW in *Bearinx* and FVA *Workbench*.

The software landscape in the field of gearbox development, simulation, and production is extremely diverse today. Although these programs perform different tasks, the data they use is largely identical. However, no industry-wide standard has been established for the exchange of gearbox data. This leads to high-cost, high-maintenance custom solutions and duplication of work that can be avoided.

"The goal is to be able to efficiently and effectively use different systems with their own computational focuses, such as *Bearinx*, *SIMPACK*, and *FVA Workbench*," said Dr. Heinrich Bolz, head of calculation and simulation in gearbox development for SEW-Eurodrive.

FVA, the German Research Institute for Drive Technology, is committed to the goal of developing an industry-wide standard for the exchange of gearbox data. The interface will be developed in close cooperation with industry and research under the name REXS (Reusable Engineering EXchange Standard).

REXS defines an industry-wide uniform modelling and nomenclature for the gearbox and its components based on the detailed terminology of 25 of FVA's project committees. With many years of experience and broad roots in industry and research, FVA is in a unique position to develop an industry-wide standard in this area.

For FVA partners SEW Eurodrive and Schaeffler, the focus is primarily on the exchange of gearbox data related to bearing calculation. However, instead of developing another specialized solution, both companies became involved in the FVA "Standardization of Gearbox Modelling," research project, thus laying the foundation for the interface.

Their many years of experience with gearbox software will ensure that the developed concept is applicable for the industrial environment.

"For this purpose, we made a deliberate decision to develop a common standard with FVA, as this approach holds tremendous potential for the future," said Bolz.

The first practical implementation of the REXS interface was the exchange of data between the *FVA Workbench*, Schaeffler's *Bearinx*, and SEW's *Wesilab* software.

The advantages of the REXS interface are clear: it reduces errors during the exchange of data and minimizes the effort required for communication between different programs. Development of a new interface is very labor intensive, therefore, the barriers to creating new links between existing software tools are high. A uniform interface can be used to efficiently implement such links, and to accelerate and improve the product development cycle.

"With REXS, gearbox data can be transferred quickly and reliably. Thus, the interface helps us to optimize our innovation processes," stated Bolz.

"We can greatly reduce the effort for the technical coupling of CAD software tools, and at the same time simplify the IT architecture," added Stephan Evert, leader of CAE application development for research and development processes, methods, and tools at Schaeffler.

In REXS, the components of a gearbox are defined based on common parameters. The REXS specification includes everything necessary to define a gearbox model. Essentially, this includes the machine elements, their attributes, and the relations which are used to define the relationships between machine elements. The simple and generic structure of REXS makes it possible to depict individual components, assemblies, and complex gearbox structures.

The interface has an open architecture, so companies can define their own extensions without affecting the standard. Thus, the interface is suitable for exchanging data between standard programs as well for internal use with custom software solutions.

The first version of the REXS interface was released at the annual FVA Information Conference in November 2017. It is freely available under Creative Commons License (CC-BY-SA) at *www.rexs.info*.

Anyone who is interested can learn more about the interface as well as how they can contribute to its future development. Schaeffler and FVA demonstrated the simple transfer of data between their *Bearinx* and *FVA Workbench* software packages using the REXS 1.0 interface live at their stand at the FVA Information Conference.

"REXS defines a very simple, extensible data structure that was created from its conception as a standard to be distributed via free licensing," Evert said.

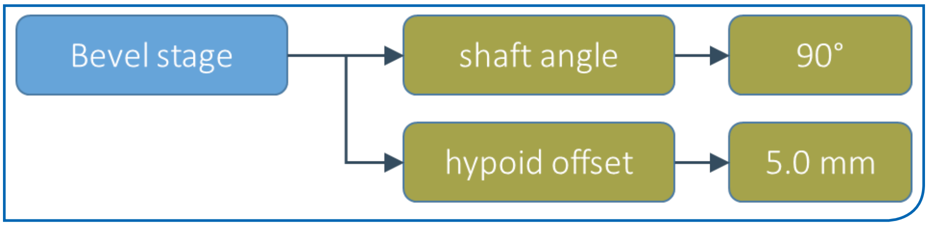


Figure 2 A bevel stage component with shaft angle and hypoid offset attributes.

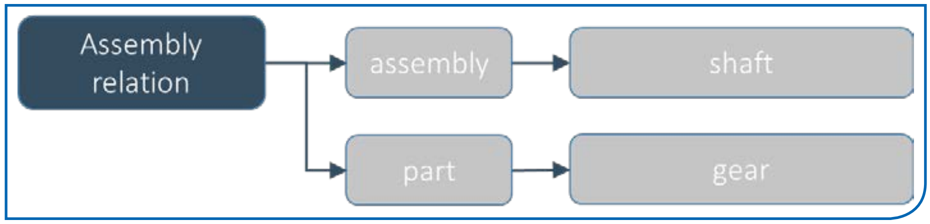


Figure 3 A connection between shaft and gear components via an assembly relation.

Although the current version of the interface is focused on the definition of gearboxes for calculation programs, the possibilities for future development are broad. According to the motto "If you want to achieve great things, you have to set high goals," FVA's vision for REXS is to develop an interface that can be used for all CAE powertrain applications.

"REXS is a real step toward new business models based on digital services, and can be used as a standardized data container for digital twins," said Evert.

The *FVA Workbench* is a platform in which new concepts for the further development of REXS are already being implemented and tested for practical suitability.

From version 5.0, the *FVA Workbench* will always support the latest version of the REXS interface. This will make an important contribution to the efficient exchange of data and provide users with reference software for the implementation of the interface.

"In order to take advantage of digitization, it is essential that data can be exchanged beyond system boundaries. Proprietary data formats do not help, as they increase complexity in the digital world," said Norbert Haefke, managing director of FVA GmbH. "That is why we see the *FVA Workbench* not just as a calculation platform for the community, but also as a common data hub and enabler for digitization in drive technology."

For more information:

FVA GmbH
Phone: +49 69 6603-1663
www.fva-service.de

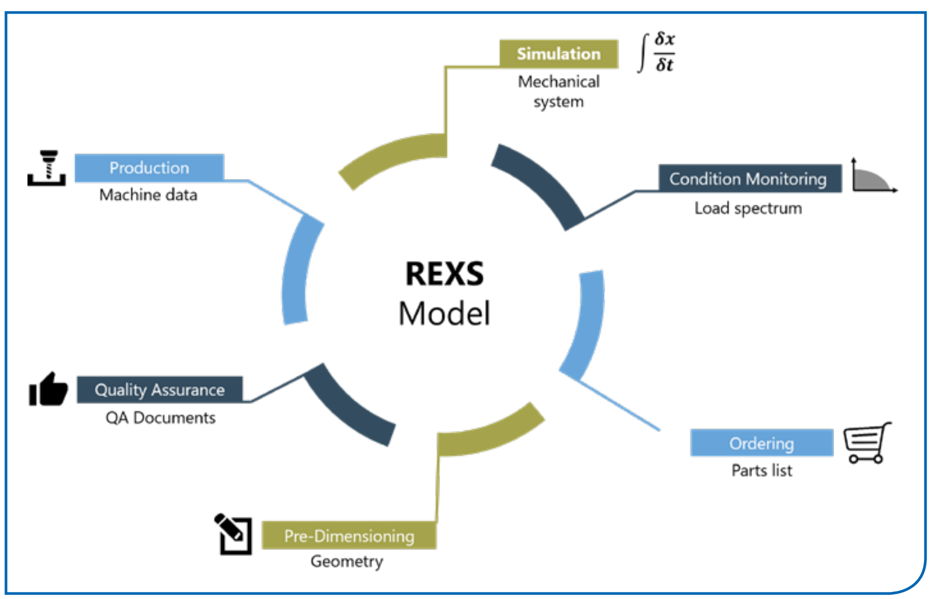
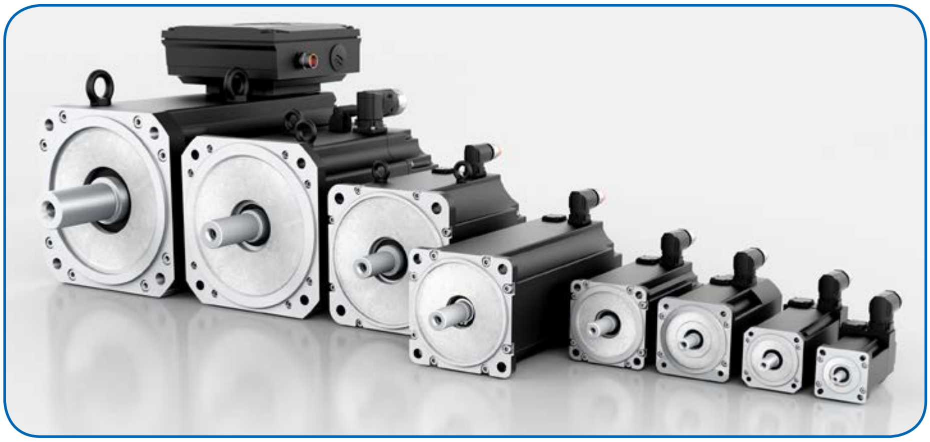


Figure 4 The vision for REXS is a standard interface for all CAE powertrain applications.

B&R Automation

8LS SERVOMOTORS OFFER MAXIMUM TORQUE DENSITY



B&R Automation has taken the next step in development of its 8LS servomotors. Three newly designed size 5 motors in lengths A, B and C fill out the mid-range of the 8LS product line. Compared to their predecessors, they offer more compact dimensions and improved thermal design.

The new 8LS servomotors are highly dynamic and offer a high torque-overload ratio. They are suited for applications such as plastics processing, printing presses and servo pumps. With a flange size of 142 mm, the new motors deliver excellent torque density. Customers profit from more power with smaller space requirements. They can be combined with any of B&R's many gearbox options and shipped as pre-assembled motor-gearbox combinations.

All motors from the 8LS series are offered with an optional digital encoder and optional safety functions. For the majority of speed variants, motors up to size 7 are also available with a single-cable solution that combines the cables for the motor and encoder. This reduces cabling to a minimum and substantially reduces installation costs.

For more information:
B&R Automation
Phone: (770) 772-0400
www.br-automation.com

Thomson Industries

EXPANDS ELECTRAK LINEAR ACTUATOR LINE

Thomson Industries, Inc. has extended the capability of its Electrak HD electromechanical linear actuator line to loads of up to 16 kilonewtons (kN) (3,600 lbs). This new offering delivers heavy load handling capacity comparable to hydraulic technologies but with greater controllability, smaller footprint and low maintenance.

"Hydraulic cylinder users are increasingly converting their hard-to-maintain, hard-to-control systems to low-maintenance electromechanical technology with onboard electronics," said Chad Carlberg, product line manager — Industrial Linear Actuators-Americas at Thomson. "By expanding our popular Electrak HD capacity to 16 kN, we offer clean, compact and smart electromechanical replacement for hydraulic actuators in just about any size application."

Hydraulic systems require integration of many components, including a motor, pump, reservoir and hoses, as well as the cylinders themselves. Any control capability desired, such as position feedback or dynamic braking, requires additional equipment, and the fact that hydraulic systems are prone to leakage adds additional operating and maintenance costs.

Smart electromechanical actuators accomplish all operation and control functions with onboard electronics, dramatically reducing footprint, installation and maintenance costs. Electrak HD actuators simply connect to a power supply and PLC or other control source to bring the benefits of onboard electronics to high load applications for construction and agriculture, material handling, and factory automation.

By expanding from 10 kN (2,250 lbs) to 16 kN and enabling that capability at stroke lengths up to 500 mm (20 in), Thomson has also created a high performance and durable electromechanical actuator with onboard intelligence. It offers a minimum duty cycle of 25 percent among stroke lengths up to 500 mm. For 16 kN loads at those stroke lengths, Thomson also offers speed options up to at least 5 mm/s (0.197"sec).

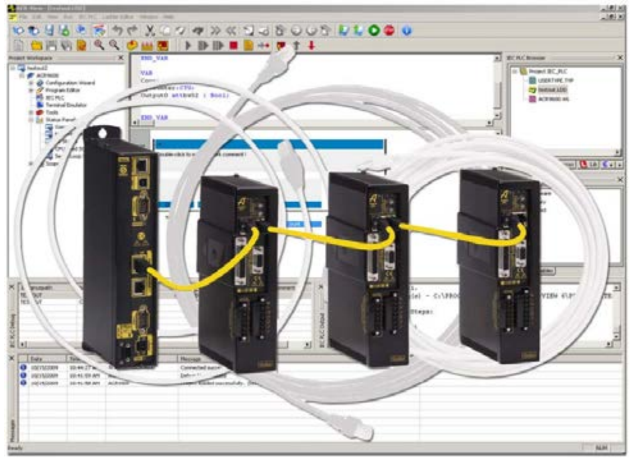
With enhanced functionality provided by an advanced onboard Electrak Modular Control System (EMCS) and its optional functions, the Electrak HD line offers a simpler method of control and communication, which reduces operating costs, requires less space and simplifies setup and installation. Optional out-of-the-box J1939 CAN bus communication enables control and monitoring, while optional low-level switching, end-of-stroke indication output, choice of analog or digital feedback, and a customer control interface provide additional versatility.

For more information:

Thomson Industries, Inc.
Phone: (540) 633-3549
www.thomsonlinear.com

Parker Hannifin

RELEASES ACRVIEW MOTION DEVELOPMENT SOFTWARE



Parker's Electromechanical and Drives Division North America is pleased to announce the release of *ACRView* version 6.4.2, which allows users to develop applications using the Windows 10 operating system from Microsoft. *ACRView* is a code-development tool that assists users of ACR controller and IPA drive products to program, debug, and commission their application. Several features are incorporated to assist both the novice and expert users in developing code. This motion development software is designed to please both existing users with requested new features and new users with an intuitive, step-by-step configuration wizard with up-to-date help files.

ACRView 6.4.2 also supports Windows 7 and 8 and is available for free at the website below:

For more information:
Parker Hannifin
Phone: (800) 272-7537
www.parkermotion.com/scripts/support_downloads.asp#ACRVV

Dana Incorporated

OFFERS AXLE/GEARBOX COMBINATION FOR DRUM ROLLERS

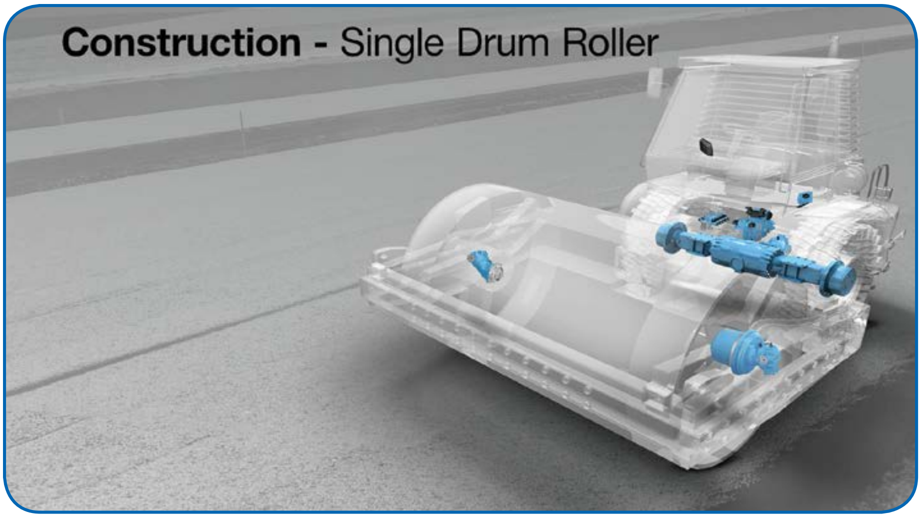
Dana Incorporated has announced a new, optimized axle/gearbox combination for small- and medium-sized single drum rollers that enables original-equipment manufacturers to reduce the package size of motors, pumps, and other hydraulic components.

Dana now offers a solution that includes the Spicer 192 rigid planetary axle, a Brevini CTU Series gearbox, and Brevini SH Series variable displacement hydraulic motors. This combination facilitates the use of an axle with a high reduction ratio, which increases the power available to the rest of the system and allows manufacturers to use more compact hydraulic components while maintaining optimal performance.

"The designs of single drum rollers

are becoming increasingly compact and versatile to provide improved visibility, enhance operator comfort, increase productivity, and accommodate advanced emissions controls and other new systems," said Aziz Aghili, president of Dana Off-Highway Drive and Motion Technologies. "This configuration illustrates the tremendous value Dana can deliver through our unique portfolio that combines Spicer drive systems and Brevini motion systems."

Dana offers a wide range of products for both single and tandem drum roller applications ranging from 4.5 to 23 tonnes (5 to 25 tons), including rigid planetary axles, gearboxes, drum drives, fixed and variable displacement hydraulic motors, vibration motors, gear pumps, piston pumps, valves, and associated electronic controls.



For more information:
Dana Incorporated
Phone: (419) 887-3000
www.dana.com/offhighway

Varvel

OFFERS RS AND RT SERIES WORM GEARBOXES

The Varvel RS and RT series worm gearboxes demonstrate the company's versatility and innovation for a variety of demanding applications.

To optimize costs and avoid the unnecessary use of bronze (a precious and therefore high-cost metal), Varvel began long ago to produce worm wheels made from two components, with bronze used only where really needed.

Varvel's standard worm wheel features a hub normally made from cast iron and a bronze sleeve bearing the teeth that mesh with the worm. This solution produces worm gearboxes that are suitable for most normal applications. In certain areas of industry, however, this standard hub in grey cast iron may not be able to achieve the level of performance required.

Where greater mechanical strength is needed, Varvel offers worm wheels with a hub in spheroidal cast iron, an alloy that offers superior performance to grey cast iron and is therefore better suited to heavy duty use.

In applications in the food industry and in all areas associated with shipbuilding and the marine sector, cast iron hubs are unable to withstand the highly oxidizing operating environment. Food processing machines have to be washed with highly aggressive sanitizing solutions. In addition, the atmosphere on or near the sea is too rich in chlorides for marine applications. To avoid the problem of oxidation in these sectors, Varvel produces worm wheels with a stainless steel hub.

For situations that demand greater mechanical strength, where spheroidal cast iron cannot be used, and for limited production series, Varvel also makes hubs in normalized or hardened and tempered steel.

Worm wheel customization and adaptation options also extend to the bronze sleeve in which the teeth that mesh with the worm are cut. The normal material for this part is leaded bronze, an alloy that remains malleable throughout the fusion process and that therefore reduces production times while improving efficiency. Under normal conditions, leaded bronze gear sleeves satisfy the needs of most common applications.

Here too, however, different circumstances may require customized and specific solutions. Variations in performance can be achieved by changing the bronze alloy from which the sleeve is made. Nickel bronze gear sleeves are used for higher torque transmission, to improve resistance to compression and impact and to combat corrosion. In applications involving larger worm wheels and wherever particularly high loads and stresses lead to violent impacts, aluminum bronze (also kNown as BRAL) sleeves can be used. Gear teeth made from this bronze alloy are less likely to break under the effect of sudden, violent impacts, and therefore guarantee less machine downtime for repairs and replacements.

For more information:
Varvel USA LLC
Phone: (770) 217-4567
www.varvelusa.com

12 Current Trends in Motion Control

Smart Factory solutions hint at machine design potential in 2018

Matthew Jaster, Senior Editor

The future of motion control is connectivity. Conversations continue to revolve around the concept of the smart factory—a plant where manufacturing blends data and production seamlessly and integration is the be-all, end-all to long-term success. While we're not there yet, the concepts, technologies and potential of the smart factory is certainly taking shape in manufacturing today.

For every challenge facing machine builders, the answer will most likely come in the complete optimization and digitalization of products and services. Actuators, servo drives, encoders, servomotors and software provide solutions for a wide range of industrial applications today. These components will be pivotal in driving the technology needed to run the smart factory of the future. Here's how the motion control industry is capitalizing on the latest products and technologies:

1. Creating More Flexible, Modular Machines

Daniel Repp, industry manager, automation at Lenze, believes it's no longer only about connecting drives and transmitting data to subordinate systems, but rather providing software to support the OEM in the development of flexible, modular machines.

This can be as simple as making frequently-used machine functions available as standardized technology modules or adding pre-configured and tested software modules via the application template and adjusting the parameter settings.

"Automation specialists should work the way they are used to—with a basic architecture. The functions are enclosed in the individual modules. The modules are autonomous and can easily be exchanged and tested completely independently. The software toolbox provides standard software modules for positioning, cam profiling, multi-conveyor coordination, and other synchronized motion control tasks, including modules for feeding, unwinding, sealing, cross-sealing and pick and place robotics," Repp said.

Up to 80 percent of machine software engineering requirements are covered by the modules available from Lenze's *FAST* platform.

"This leaves more time for the machine builder to focus on the development of a machine's special performance features. It also allows for a savings on engineering costs while, at the same time, speeding up the machine design process," Repp added.

2. More Servo Module Options

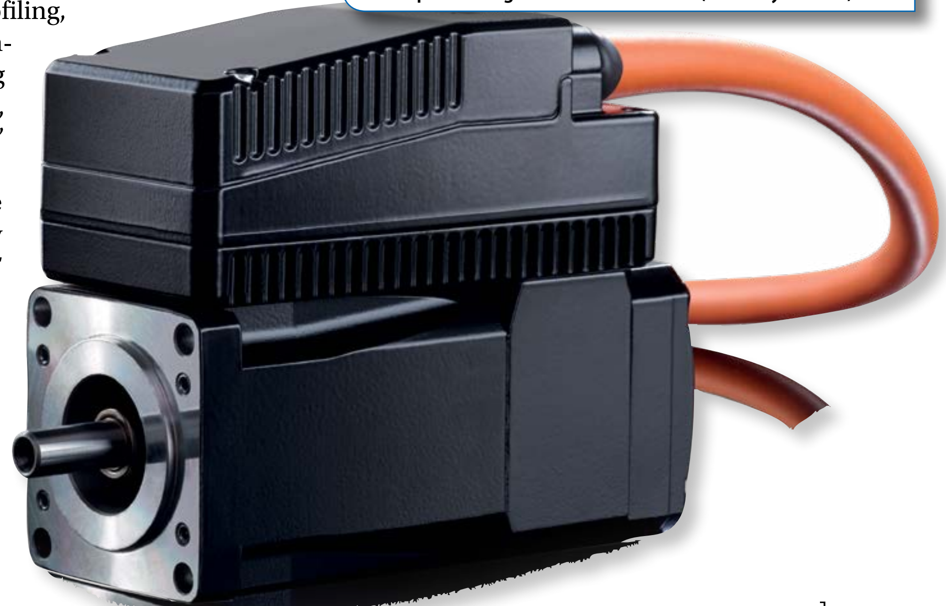
Because the cost of power electronics and motor components are decreasing each year (relative to economic forces), AMK is making an effort to replace more motion on a machine with servo modules. Things that once had to be pneumatic due to costs are now in the range of servo control which gives the OEM the ability to create machines without timers—now they know absolutely where the mechanics of the machine are at all times.

"Because of the power of the digital signal processor (DSP) we are using, we are able now to create motion systems that do not need a centralized controller," said Tom Jensen, general manager at AMK Automation. "This makes the machines we are on actual "machine modules" and makes things like robotic cells, conveyor integration possible in a small cabinet—or likely cabinet free," Jensen said.

3. Ease of Installation

On the installation front, Craig Nelson, senior product manager at Siemens Industry, Inc., said it is now very common to only use a single cable between servomotor and drive on servo systems which reduces the installation time and cable trays—the result is a simple install that increases productivity and efficiency.

"This is made possible by the fact that encoder signals are now sent via serial communication, which, once shielded properly, can be run in the same hybrid cable as the motor power leads and brake leads," Nelson said.



With its new ihXT series, AMK is expanding its AMKASMART decentralized product family to include a full-value servo drive with a power range of 150 to 450 watts. (Courtesy of AMK)

4. Innovations in Remote Diagnostics

Jensen said that remote diagnostics are a focus of every automation company because of the times we live in, but they need to provide an action path for the machine owner to be effective. Therefore, AMK is working on a combined Remote/HMI diagnostic to harmonize the pathway to keeping machines running.

"As an example, automobiles today have enough dashboard (HMI) information that the driver knows what is going on (tire pressure, fuel, oil, etc). What this connectivity provides is the next step in the process–where to find service, gas, oil. What this combination can do for plant machinery is to effect a course of action when an alarm arises (call the right maintenance personnel, but also plants can reduce speeds and cycle machinery based on plant environmental conditions, power input conditions and other external variables keeping the operator and machine efficient even when conditions aren't," Jensen said.

Repp said that Lenze is moving far beyond simple remote maintenance by enabling its customers to be IIoT-ready — a key element for future machine development.

"We find that when IIoT systems communicate with each other, their value is multiplied. This makes interoperability essential and increases the benefits exponentially. As technology segments get closer and grow together through digitalization, these cross-functional innovations become more likely to occur," Repp said.

5. Trusting Engineering Experience

One thing AMK is focused on in the United States is the elimination of templates, according to Jensen. For years the automation industry has focused on templates to hide the complexity of machine programming, with the goal of making training and adoption simpler.

"This strategy only works if the team developing the template can make a template that *every* engineer understands. The strategy therefore has worked well in niche markets (robotics), but has made general automation much more complex (that is why you don't (but could) use a robotic controller on a conveyor cell," Jensen said.

AMK has instead created training and tools based on the fact that the U.S. automation engineers are the best and can handle IEC 1131 programming environments as they are.

"Our bet is that a little more up front training will allow engineers to create great machines well beyond the initial training with support only needed for new forward-looking machine concepts," Jensen said.

6. Staying Connected to the Cloud

Nelson at Siemens Industry, Inc. said that the increased connectivity of servo systems to Ethernet-based communications for control and integration into cloud-based analytics represents a future-proof trend with instant payback as little or no additional costs are typically occurred.

"Built-in Industrial Ethernet interfaces are common for most all servo drives today with some offering connectivity to multiple Industrial Ethernet protocols such as Profinet or EtherNet/IP." Nelson said.

7. Single Software Solutions

Jensen said the question of software is not as simple as pointing at the PC based editor most engineers see, because software exists at every level (in every processor) of the motion system — from the firmware in the motor module through the PC environment.

"AMK has a single software solution based on IEC61131, and our tools in the environment are incredibly effective because of the harmony from the single motion control block at the IEC level to the firmware in the drive. With a handful of function blocks and our integrated tools, we can truly make any machine — quickly and in the OEMs methodology," Jensen added.

Repp said that Lenze has integrated all the safety functionality into their existing programming software tools.

"We offer one programing tool, the Lenze *PLC Designer*, for all programming demands. Whether it's motion or logic programming, or safety implementation — it's all covered by one product," Repp said. "Safety functions are also implemented in our *FAST* automation software modules. This allows the machine builder to follow the modular programming standard not only for the machine application program, but also for the safety part."

8. Factoring in Safety

Machine safety is pivotal in the building process, according to Jensen. Without risk analysis completed for each machine design, the machine will have a hard time being insured making the final sale difficult.

"Technology providers then have to be able to show how to use their systems to eliminate risk conditions in the best way," Jensen said.

As humans are required to interact more frequently with machines — and robots, in particular — machine safety becomes an even higher priority.

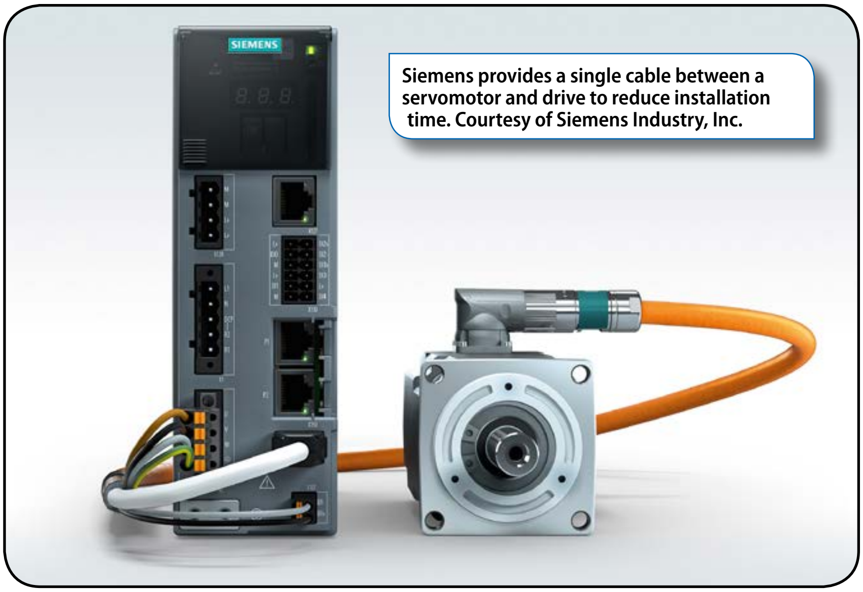
"We have taken this into consideration and integrated the safety functions directly into the different parts of our portfolio — servo inverter, servo motors, controls and engineering tools," Repp said. "Because we understand that these trends are continuously evolving, we offer a safety solution — controller-based and drive-based that provides optimal support to the customer and makes his machine ready for future safety requirements."

9. Adapting to Changes on the Plant Floor

Safety functions for servo systems and the machinery they control are undergoing a radical change on the plant floor. Here, technology is rapidly changing as robots, automated systems and autonomous guided vehicles (AGVs) become the norm.

Nelson believes the time has come to adapt to these changes faster and more efficiently.

"Gone are the cabinets of safety relays and contactors with the proven and flexible adaption to safety integrated drive functions with safety signals now coming from a failsafe protocol over Industrial Ethernet. New safety functions for motion control such as Safe Limited Position, Safe CAM and Safe Torque are game changers for increased safety and productivity today," Nelson said.



Siemens provides a single cable between a servomotor and drive to reduce installation time. Courtesy of Siemens Industry, Inc.

10. Consumer Integration

It's no secret that when it comes to automation and motion control, the industrial community lags behind the consumer market by a wide margin.

"In the near future, the automation industry can expect the continued influx of technologies from the consumer market into their portfolios," said Jensen. "Concepts found in mobile devices and automobiles — Wi-Fi, multiple cameras, etc. — will become inexpensive and developed enough that automation engineers will begin to use them. "

Repp said that consumers love individualized products. Technologies such as web-based car configurators, individualized beverage containers or sport shoes have already proven to be successful in the marketplace.

"The flexibility of a production system for the manufacture of individually customized products is therefore comparable to the Holy Grail of production technology," Repp said. "The advancement of digital technology — like cheap and high-CPU performance, or small and cheap memory — means the long-lasting technological dreams of flexible, autonomous and cost-efficient production systems, are now very close to becoming reality. This is not only true for consumer goods, but also for industrial production."

In short, consumer automation may hold the key for future products and technologies coming to the industrial market with one awfully large caveat — technical solutions take time. An Iphone, Fitbit or pair of running shoes won't come with the security concerns, safety requirements, environmental challenges or power needs found in a pump manufacturing plant or a wind turbine. This is where research and development will be key to reimagining motion control technologies.

"We need to take advantage of apprentice and mentoring programs to integrate and test consumer products with our portfolio to see what is possible," Jensen added. "Ideas like controllerless automation are innovations that have come from this process."

11. A Digital First Approach

Repp is confident that the trend in motion control for the next five years is the digitalization of industrial processes. "To improve the quality of new developments, and reduce development time and costs, many activities will be outsourced into digital processes — a trend that is already occurring. With continued developments of the IIoT and Industry 4.0, machines are becoming more connected. Machine builders will benefit from the optimization of each singular machine, since they can easily be adapted for the whole machine system. Digital twins of machines will help to reduce development time and associated cost. Virtual reality environments will improve the tests and completion of new machines."

12. Learn, Adapt and Innovate

Each new concept on motion control starts with conversations with current customers. How these products and technologies are put to use — and their effectiveness — will determine the course of action for future developments. The feedback received from a servo drive today will influence how these components will be adapted to new industrial applications down the road.

Motion control systems — including controllers, servo drives, rotary and linear servo motors, linear actuators and software — will continue to evolve as long as machine builders, engineers and product specialists continue to strive to make these systems faster and more efficient.

The concept of the smart factory may still lie behind the curtain, but it's slowly and methodically being pulled back to reveal a promising future for manufacturing production. **PTE**

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Back to Basics:
Motion Control or Robotics?

Both concepts overlap in several areas, but there are significant differences between motion control and robotics. This sidebar aims to clear up some of the confusion with some assistance from National Instruments, New York University and Omron Adept Technologies.

National Instruments defines motion control software and hardware as the development of products and technologies that solve a diverse set of application challenges, faster and at a lower cost. These components can be *applied* to robotics, but fall under the motion control umbrella:

Motion Control

- **Application software —** You can use application software to command target positions and motion control profiles.
- **Motion controller** — The motion controller acts as the brain of the system by taking the desired target positions and motion profiles and creating the trajectories for the motors to follow by outputting a ±10 V signal for servo motors, or step and direction pulses for stepper motors.
- **Amplifier or drive** — Amplifiers (also called drives) take the commands from the controller and generate the current required to drive or turn the motor.
- **Motor** — Motors turn electrical energy into mechanical energy and produce the torque required to move to the desired target position.
- **Mechanical elements** — Motors are designed to provide torque to some mechanics. These include linear slides, robotic arms, and special actuators.
- **Feedback device or position sensor** — A position feedback device is not required for some motion control applications (such as controlling stepper motors) but is vital for servo motors. The feedback device, usually a quadrature encoder, senses the motor position and reports the result to the controller, thereby closing the loop to the motion controller.

Looking at Motors in Motion Control Applications

The most common motors in the industrial and embedded space are stepper, brushed, and brushless DC motors, but there are other motor options. Each motor requires individual input signals to spin the motor and transform electrical energy into mechanical energy.

In the broadest sense, motion control helps you use the motor that best meets your application requirements without dealing with all the low-level signaling needed to spin a motor. In addition, motion control provides high-level functions so you can efficiently implement custom applications based on building blocks to create solutions for common tasks like precise positioning, synchronization of multiple axes, and movement with defined velocity, acceleration, and deceleration.

Robotics

According to NYU, the first programmable robot was designed by George Devol, who coined the term Universal Automation. He later shortened this to Unimation, which became the name of the first robot company back in 1962.

Industrial robots gained recognition and rapid growth during the 1980s. During this time period many institutions began introducing programs and courses in robotics. Robotics courses are spread across mechanical engineering, electrical engineering, and computer science departments and they continue to grow today as the focus turns toward mechatronics and big data.

The design and operation of robotic systems includes dynamic system modeling and analysis, feedback control, sensors and signal conditioning, actuators (muscles) and power electronics, hardware/computer interfacing and more.

What Solution Fits Your Application?

A company like Omron Adept Technologies offers both motion control systems as well as existing robotic technologies. Most motion control components can be used in addition to an existing robot or it can be designed as a stand-alone system. Omron has installed more than 30,000 robotic and motion control systems in a variety of industrial applications.

While a customer may be wondering if a motion control or robotic solution would be more appropriate for their automation needs, the truth is that motion control is really a sub-system of robotics. For example, many components in motion control — actuators, motors, etc. — makeup the nucleus of a Selective Compliance Assembly Arm (SCARA) robot. However, you can create an automation system without using robotics with the right engineering experience.

This typically comes down to the engineering support and technical background within an organization. Productivity and efficiency can improve if you have the expertise to combine motion control hardware and software for an automation cell. But, an easier, hassle-free approach may be to incorporate a few robotic units on your plant floor. They are already assembled, easy to setup and offer an immediate turnkey solution.

The answer to motion control or robotics lies in how much time and money you're willing to invest for the requirements of your application. **PTE**

MedAccred Rising to Ubiquity

MedAccred is emulating the Nadcap standard that came before it, and much like its predecessor, is on a sure rise to prominence.

Alex Cannella, Associate Editor

If you want to do business in the aerospace industry, you pretty much need to be Nadcap accredited. It's the ubiquitous gold standard that everyone looks for when they want to buy parts from a supplier, and if you haven't at least heard of it, I can guarantee you're not working in aerospace. What you may not have heard, however, is that PRI, the group that administers Nadcap, was approached by the medical device industry to develop a similar program over the past few years: MedAccred.

The quick and easy way to describe MedAccred is "Nadcap for the medical device industry." For those who aren't familiar with PRI's style of accreditation, however, programs like Nadcap and MedAccred differentiate themselves from other industry certifications by taking a microscope to individual critical manufacturing processes. As the mantra at PRI goes, other certifications are a mile wide and an inch deep, while MedAccred is an inch wide and a mile deep. Instead of looking at your entire facility, a MedAccred audit will focus on a single critical manufacturing process, which could be anything from laser welding to injection molding to brazing, and review that critical process from end to end in painstaking detail.

From the start, the focus has been to make MedAccred the same universally recognized badge of excellence that Nadcap is. PRI's goal with the program is to improve patient safety by addressing final product quality through oversight of the most critical manufacturing processes. And every year that ticks by has been a positive year for the program that has made that goal look like more of a reality. In every metric, MedAccred has been expanding.

The program itself is growing rapidly, expanding the number of critical processes they accredit for. Currently, MedAccred's processes can be broadly separated into six categories: cables and wire harnesses, heat treating, plastics, printed circuit board assembly, sterilization and welding. Within each category, however, are sub-categories, such as with plastics, which PRI currently has divided into critical processes surrounding extrusions such as blow film, tubing and over-jacketing and injection molding processes such as compression molding or micro molding. In all, MedAccred has expanded to cover over 20 different critical processes and sub-processes.

And the industry shows no signs of stopping. Most recently, they added electron beam and fusion welding to that list, and they're currently in the middle of developing accreditations for new critical processes related to the mechanical assembly of plastics, including three sub-processes, the production of printed boards (bare boards), both flexible and rigid, and sterile device packaging, covering three sub-processes. And after that, there's no end to the number of other processes being requested by participating companies that haven't yet received a task group.

"The industry is really excited about the program to improve their final product quality and, most importantly, patient safety. Each year, we're probably going to be adding two or three new critical manufacturing processes to what we accredit," Connie Conboy, director of MedAccred, said.

MedAccred is an audit program that takes an in-depth look at individual, specific critical processes instead of looking at your entire facility.

They're also busier than ever. Last year, MedAccred accredited approximately 30 companies. And according to Conboy, they're currently expecting to perform over 60 audits in 2018, a number that is only growing as more companies apply for an audit in these early months of the year. They've also gotten more global. In 2015, MedAccred performed their first audit off of U.S. soil. Fast forward to today, and they're regularly auditing companies across a dozen countries ranging from Mexico to China to a number of European countries, and pretty soon, India and Israel will be added to that list.

One potential explanation for MedAccred's sudden explosion of audits is that large manufacturers are starting to accredit multiple facilities. Early adopters have been accredited for a few years now, so some of the bigger players in the industry have had a chance to get used to the program in one or two test facilities and are starting to prepare a significant number of their production operations for accreditation. Flex, for example, had three facilities accredited two years ago, then in 2017 doubled that number to six. But that number is expected to jump significantly by the end of this year.

While that might make MedAccred's growing numbers a little less impressive, it's not enough to explain away its expansion entirely. The program is also attracting a larger following, with more companies actively getting involved in MedAccred's taskgroups and requesting new accreditation categories.

If you're worried about passing your audit, there are multiple resources, both within PRI and from other organizations, that you can take advantage of to improve your readiness.

Most notably, the number of subscribers, companies that provide the program's oversight and funding, has doubled to six, with Baxter Healthcare, Medtronic and Boston Scientific Corporation joining the established group of Johnson & Johnson, Stryker and Philips. Stryker in particular has doubled down on MedAccred, beginning to require that future suppliers be accredited for their new product business.

"They are an exceptional group of industry leaders helping to assure that MedAccred has a positive impact on patient safety while expanding the global reach of this vital program," Conboy said.

PRI, of course, hasn't been idle in creating real enthusiasm across the medical device industry. According to Conboy, the organization has been "actively educating and communicating with all companies that might have an interest in the program." They've been doing a significant amount of individual outreach, both at conferences such as FDAnews Medical Device Quality Congress and Medical Device Supplier Quality Conference and by getting in touch with suppliers and OEMs directly.

Most of these direct efforts have been focused on education, both educating outsiders about MedAccred's message and advising accreditation hopefuls on how to best prepare for the audit process.

"We're very open to working with any of the companies that are interested," Conboy said. "If they want us to do a presentation and provide information about the audit criteria, we're very willing to do that, or if they want to learn more, we will even provide specific training."

According to Conboy, MedAccred has regularly trained companies when requested on what the program looks for during an audit and what to expect. Training often takes the form of a webinar, but MedAccred can also arrange to teach suppliers in person.

PRI's training program has very recently started being supplemented by government efforts from the U.S. Department of Commerce, as well. The Department recently set aside money for the MEP (Manufacturing Extension Partnership) program, and as part of that, awarded $1 million for 2018–2019 for a program that's been dubbed "Growth through MedAccred." The program is designed specifically to help accreditation hopefuls get educated on the program and get their U.S.-based production facilities to pass muster during an audit. The program's new funding will allow government specialists to come to suppliers' facilities and help conduct internal audits, as well as assist suppliers with fixing any issues the audit might find.

"There's a wonderful opportunity for U.S. companies that are manufacturing in any of these critical process areas," Conboy said, "...There's quite a bit of opportunity for any company now to gain that support. And this is just the start. We expect that the Department of Commerce through NIST will continue to support programs to help U.S. companies with MedAccred. They're very interested in helping companies in the medical device industry. They want to see U.S. manufacturers be more competitive globally and be able to retain that business. They know that MedAccred is going to be a key to helping them grow their business in the medical device industry."

In general, PRI is seeing a lot of support from the government for MedAccred. In addition to the most recent award of funding, MedAccred also received a show of support from the FDA. After two years of working with PRI, the FDA has recognized the AMS 2750 pyrometry standard for heat treating used in the MedAccred heat treating accreditation requirements. This recognition makes it easier for medical device companies during the pre-market approval phase, since meeting a recognized standard "can support a reasonable assurance of safety and/or effectiveness" in devices, according to the FDA 2007 guidance "Recognition and Use of Consensus Standards." In other words, if you have achieved MedAccred accreditation, you have satisfied the FDA recognized standard for AMS 2750 for heat treating. This is a real benefit for the program, and one of the past few years' developments Conboy personally was most excited about.

"We worked with the FDA for two years on that pyrometry standard," Conboy said. "It's imbedded in our heat treating accreditation, so that standard really helps companies if they have a new product they're introducing and want to use a company that's MedAccred accredited for heat treating, it means they are meeting the AMS 2750 standard...it's a very critical factor to assure the final product quality from that furnace, so the fact that FDA has granted complete recognition of that standard is a huge step forward for the medical device industry…This is a first for the medical industry in heat treating for the FDA to recognize anything."

The FDA has recently recognized the AMS 2750 pyrometry standard, which was a big win for MedAccred.

PRI's first program, Nadcap, has become a ubiquitous presence in the aerospace industry. The mission with MedAccred has always been to focus on improving product quality and patient safety for the medical device industry, just like Nadcap is successfully addressing quality and safety for the aerospace industry. This focus on quality and safety is vital to both industries and as a result the medical device industry believes they should see a similar growth trajectory for the MedAccred program. MedAccred still has a ways to go before it reaches Nadcap's level of scope and acceptance, however. As large as MedAccred may sound already, Nadcap's dictionary of aerospace critical processes dwarfs its successor's, so you can expect that they'll be introducing new accreditations for years to come.

But every year, it looks like more of a sure thing that that's exactly what's going to happen. MedAccred is big, and it's still growing. They're at most major conferences. The FDA has demonstrated strong support for the program. They have the attention of many industry leaders. And according to Conboy, those leaders are increasingly invested in MedAccred's success. Stryker's move to begin requiring future suppliers be accredited for new product business is starting to be echoed by other OEMs in the medical industry, and the number of companies requiring accreditation is likely only going to grow. The question isn't if MedAccred will ever fit in its predecessor's shoes anymore; it's when.

MedAccred's doors are open, not just for those looking to get accredited, but also those who want their voice to be included in the program.

"We're still at the early stages, but there's no question in our minds with the support from leading companies in the medical device industry, their involvement in the program, and the real understanding they have in terms of value of the program, we will continue to show strong growth" Conboy said. "This is something that PRI sees in the years to come will be like Nadcap. And I think most of the leaders in the medical industry see it that way as well."

And eventually, when that goal becomes a reality, it's going to become imperative that you get accredited yourself. With that in mind, the sooner you jump on the bandwagon and start that audit process, the less painful and rushed it's going to be when your OEMs start asking for it.

Or better yet, get involved. Help shape MedAccred yourself. If you're likely going to have to adopt MedAccred in the future anyway, you might as well start having some say in what that program looks like. Whether you're a supplier or an OEM, there are numerous benefits for any companies that want to participate, even if you don't become a subscriber. Feedback from participating companies regularly gets incorporated into MedAccred, including on selecting what critical processes get selected next, and if you get involved with the task groups, there's opportunity to have your voice heard when developing the audit criteria for those processes.

But regardless of if or how you decide to get involved with PRI's program, be sure to keep an eye on them. They're an increasingly relevant presence in the industry, and if they continue on their current trajectory, you'll be forced to pay attention sooner or later. **PTE**

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Mechanical Motion in Tight Spaces

Framo Morat and Dunkermotoren Produce Drive Systems for AGVs

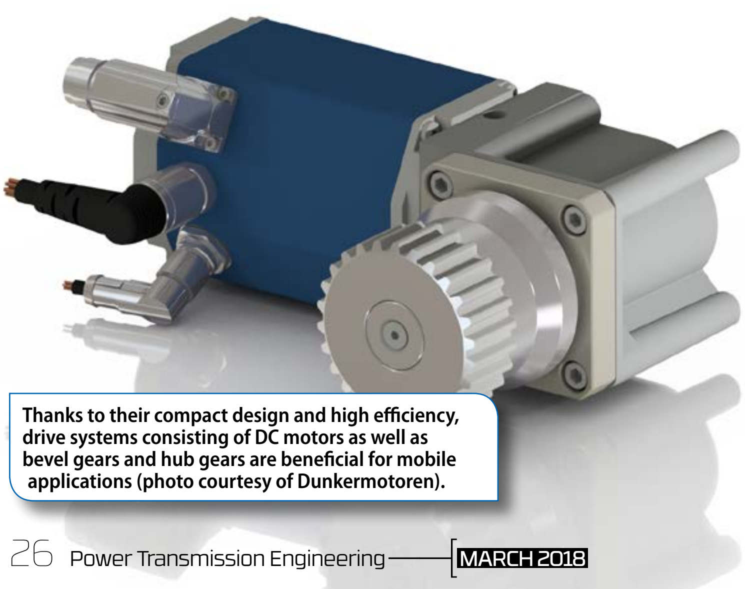

With unattended operation around the clock, driverless transport systems (AGVs) in warehouses, parcel distribution centers and production halls ensure maximum profitability and reliability when distributing goods, packaging materials or components (photo courtesy of Framo Morat).

Driverless transport systems have proven to be extremely economical and productive. For example, they are used to distribute goods that are picked in large storage and freight forwarding halls. The vehicles—often referred to as Automatic Guided Vehicles (AGVs)—are also used to transport individual parts and prefabricated components into processing stations in assembly and production halls. They usually work autonomously, using sophisticated sensor technology to orient themselves within their environment. Their routes and destinations are programmed and stored in a built-in computer, and the electric power for the driving motor is provided by rechargeable batteries carried in the vehicle.

Compact vehicles ensure a long useful life

AGVs are particularly productive and economical if they can complete long distances and operating periods without repeated recharging of their batteries. This places special demands on their design and construction. In particular, the vehicles and components installed therein must be lightweight and compact. Especially, the AGV manufacturers require high power density and energy efficiency from the drive system. As a further problem, the increasingly smaller shuttle vehicles used for distribution systems in warehouses contain little available space for these drives. This means that the standard drive units with axially arranged electric motors and multi-stage spur gears and planetary gears cannot be installed due to their overall length.

In accordance with the requirements of the AGV manufacturers, the gear manufacturer Framo Morat from Eisenbach and the motor manufacturer Dunkermotoren from Bonndorf have developed and implemented a particularly compact DC drive system. The system's hub gears, which were designed by Framo Morat, are a particularly impressive feature.

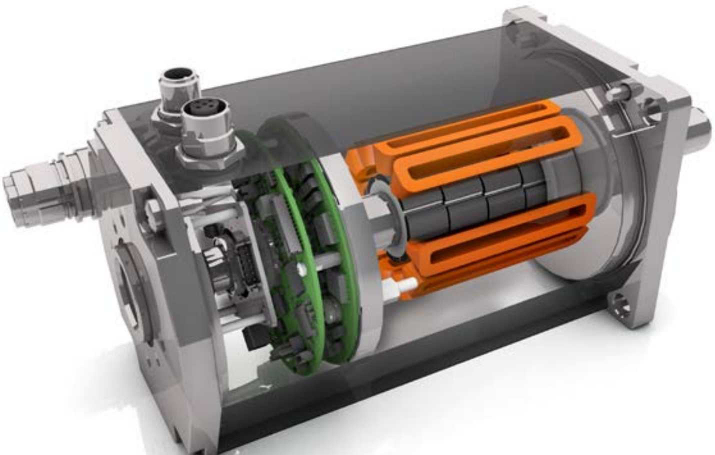

Thanks to their compact design and high efficiency, drive systems consisting of DC motors as well as bevel gears and hub gears are beneficial for mobile applications (photo courtesy of Dunkermotoren).

As Wolfgang Sühling, who is responsible for the development of custom drives explains at Framo Morat, this is the first time that this gearbox design has been used in a drive system for an AGV.

"In addition to its compact dimensions, this gearbox design has further decisive advantages, especially for the wheel and toothed belt drives that are frequently installed in shuttle vehicles," he says. In conventional wheel or belt drives, in which a planetary gear unit or a spur gear unit is used, large radial loads act on the bearings due to the load distribution into the protruding shaft. The bearings installed in the gearbox must be able to withstand this."

However, standard shaft bearings with grooved ball bearings or preloaded tapered roller bearings have some major disadvantages, according to Sühling.

"When ball bearings are arranged closely behind one other, radial loads acting on the protruding shaft end lead to high bearing loads. Due to the bearing clearance in combination with the short bearing spacing, which is dictated by the design limitations, this also results in an inclined position of the output shaft and individual transmission components, for example the planetary carrier. As a result, the gears wear very quickly and the required service life and reliability cannot be guaranteed. In addition, the inclination of the shaft causes increased noise emissions. Although pairs of pre-tensioned tapered roller bearings can easily accommodate larger radial loads, they suffer greater bearing losses than grooved ball bearings, especially in the partial load range. Moreover, they are larger and heavier than grooved ball bearings," explains Sühling. For this reason, the gearbox specialists from the Black Forest looked for an alternative to the usual spur and planetary gearboxes that are flanged to the electric motor.



The electronics integrated into the DC motor enable the drive systems to be networked via different fieldbus systems (photo courtesy of Dunkermotoren).

Compact design easily handles large radial forces

The newly developed hub gears use standard ball bearings to absorb the high radial loads. "The designation of this gearbox design provides an insight into its special design features. The entire gearbox can be accommodated inside a narrow wheel hub," reports Sühling. In this gearbox type, the drive shaft and output shaft are arranged coaxially, one inside the other. The radial forces are distributed almost centrally between the two ball bearings via the hollow shaft. The small clearance between the ball bearings has a positive effect on the bending stiffness of the hollow output shaft, which scarcely bends at all.

A planetary gearbox transmits the torques between the drive and the output shaft. It provides the required transmission ratios for the speeds between the drive and the output side. For the attached electronically controlled DC motors from Dunkermotoren, these are usually between i = 20 and i = 30. And because the planetary carrier is only inclined to an insignificant degree, the gearbox runs extremely quietly.

In order to make the entire drive package particularly compact, a bevel gearbox connects the DC motor to the input shaft of the hub gears. "With this combination, we can achieve the smallest installation space with the maximum energy density," emphasizes Stefan Tröndle, product manager at Dunkermotoren in Bonndorf. "The combination of our brushless, electronically controlled DC motors with over 90 percent efficiency and the very light, low-loss bevel and planetary gearboxes enable us to achieve very high efficiency for the entire drive system and thus high energy efficiency. This innovative drive system plays a decisive role in making the shuttle vehicles particularly cost-effective," adds Tröndle.

Hub gears from Framo Morat prove their value as wheel drives for AGVs due to the advantageous arrangement of both the bearings and the drive and output shafts (photo courtesy of Framo Morat).

Custom modular configuration

The drive units are configured according to the individual requirements of the AGV manufacturers. At the same time, by using their existing modular system, the motor and gearbox manufacturers can ensure short delivery times and economic investments. The two companies can thus combine their standardized, modular components to create the required drive system.

For this purpose, Dunkermotoren provides electronically commutated DC motors from its BG series. Depending on the model, they operate with 10 V to 60 V DC. With a 24 V supply voltage, they can provide a permanent drive power of 1100 W and can reach a maximum of 2600 W for short periods. In addition to models with integrated commutation, versions with built-in speed control or positioning electronics are also available. The integrated electronics allow, for example, complete driving profiles to be stored and retrieved. The CANopen, Profibus or EtherCAT bus systems provide data communication with higher-level controllers. As a modular component, Dunkermotoren offers suitable brakes for the respective motor size. As an option, the motor manufacturer can implement Safe-Torque-Off (STO) via software and the motor control. This ensures safe operation of the drives and helps to avoid hazards for personnel and equipment in critical situations.

The hub gears designed by Framo Morat are based on gear components from the standard gearbox series with nominal output torques of up to 350 Nm. The gearbox manufacturer from Eisenbach customizes the outer contour of the output shaft and the torque support in accordance with the customer's requirements, for example with standard toothing for toothed belts, customer-specific shaft-hub toothing or as a smooth shaft with flange bores for a wheel rim. **PTE**

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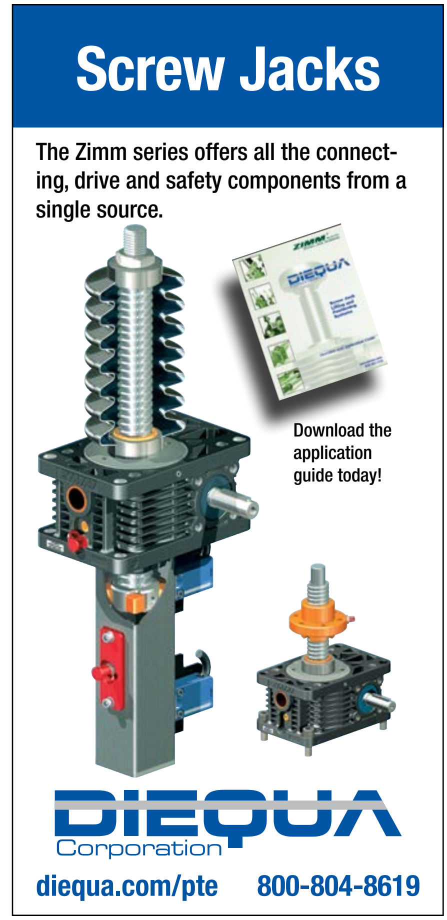
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Baldor Motor Basics — Part 11
Explosion-Proof Motors in Division 2 Areas and DC Drive Fundamentals

Edward Cowern, P.E.

We have found that one of the most confusing things about explosion-proof requirements involves the application of motors in Division 2 areas. To put things in perspective, Division 1 involves areas where hazardous liquids, vapors, gases or hazardous dusts are present a good deal of the time, or even all the time, in the normal course of events.

Division 2 areas are where the hazardous materials are only apt to be in the area if there is a spill, accident, loss of ventilation or some other unusual condition; the treatment of both of these divisions is covered in Article 500 of the National Electric Code (NEC).

Once an area has been identified as being either Division 1 or Division 2, the NEC requires certain types of motors be used in those environments. Division 1 areas always require hazardous location (explosion-proof) motors having the class and group approvals that match the particular hazardous substance in the area. Thus, for Division 1 requirements explosion-proof equipment must be used. On the other hand, if an area has been classified as Division 2, the National Electric Code will frequently allow the use of totally enclosed (or even open drip-proof) motors, provided certain conditions are met. Basically, those conditions relate to there not being any hot surfaces or sparking parts in the motor. For example, sparking parts could be brushes (as found in DC motors), switching devices (such as centrifugal switches used in many single-phase motors), thermostats or thermal overloads normally found in thermally protected motors, or space heaters that might have high surface temperatures.

In essence, what the code is saying is that three-phase induction motors that do not have high- temperature surfaces or sparking parts will not, in normal operation, be likely to ignite the surrounding environment. They can be used because the likelihood of a (spark-producing) failure of the motor occurring at the same time that a spill or accident occurs is so remote it is a very unlikely event.

One way to avoid conflicts on interpretations of what is needed is to "play safe" and use hazardous location motors for both Division 1 and Division 2 requirements. This is a safe but expensive option, and becomes more expensive as motors get larger.

A second choice is to use three-phase TEFC or even open drip-proof motors that meet the non-sparking and no-hot-surfaces requirements for Division 2.

For machinery builders or contractors who want to use the less expensive motors for Division 2 requirements, it is always wise to make your intentions known to the customer in advance. Perhaps the best way to do this would be to notify them by letter, with a statement such as follows:

"Since your stated requirement is Class (*fill in appropriate references*), Group (*fill in appropriate references*), Division 2, it is our intention to supply totally enclosed, fan-cooled, three-phase induction motors in accordance with paragraph (1) of the National Electric Code. If you object to this, please notify us as soon as possible."

By using this type of letter to make your intentions clear, it is much less likely that a dispute over interpretation will develop at a later time.

If you should have any questions regarding this requirement, please refer to the NEC for the appropriate section based on the class, group and division of the requirement.

(1) Paragraph references
For Class I.................................501-8(b)
For Class II ....502-8(b)

When using motors in Division-2 areas with an inverter power supply, refer to comments in the February 2018 issue of *Power Transmission Engineering* (pages 46–47.)

DC Drive Fundamentals

Understanding DC drives. DC motors have been available for nearly 100 years. In fact, the first electric motors were designed and built for operation from direct current (DC) power. Alternating current (AC) motors are now, and will of course remain, the basic prime movers for the fixed speed requirements of industry. Their basic simplicity, dependability and ruggedness make AC motors the natural choice for the vast majority of industrial drive applications.

Then where do DC drives fit into the industrial drive picture of the future?

In order to supply the answer, it is necessary to examine some of the basic characteristics obtainable from DC motors and their associated solid-state controls.

1. Wide speed range
2. Good speed regulation
3. Compact size and lightweight (relative to mechanical variable speed)
4. Ease of control
5. Low maintenance
6. Low cost

In order to realize how a DC drive has the capability to provide the above characteristics, the DC drive has to be analyzed as two elements that make up the package. These two elements are of course the motor and the control. (The "control" is more accurately called the "regulator.")

DC motors. Basic DC motors, as used on nearly all packaged drives, have a very simple performance characteristic — the shaft turns at a speed almost directly proportional to the voltage applied to the armature. Figure 1 shows a typical voltage/speed curve for a motor operating from a 115-volt control.

HP	% MOTOR REGULATION
¼	13.6
⅓	12.9
½	13.3
¾	10.8
1	6.7
1½	8.0
2	7.2
3	4.2
5	2.9
7½	2.3

Table 1 DC drive regulation is generally expressed as a percentage of motor base speed; if control (regulator) lacks capability of responding to and compensating for changing motor loads, regulation of typical motors might be as shown in Table 1.

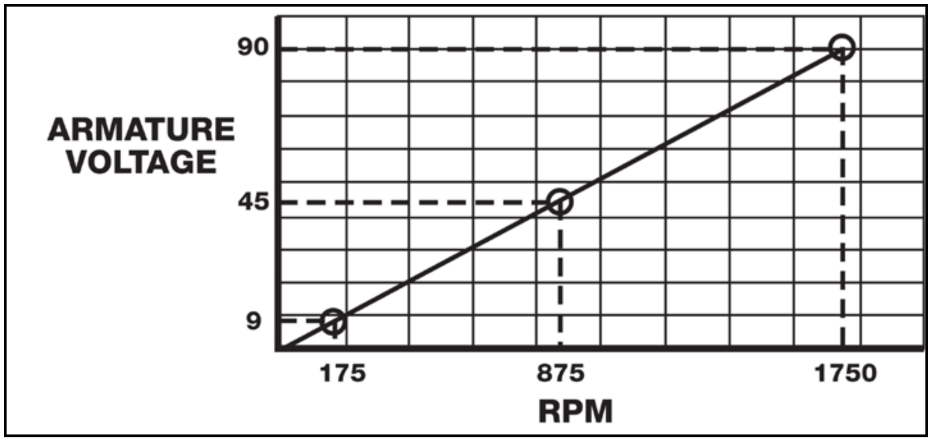

Figure 1 Typical voltage/speed curve for motor operating from 115 volt control.

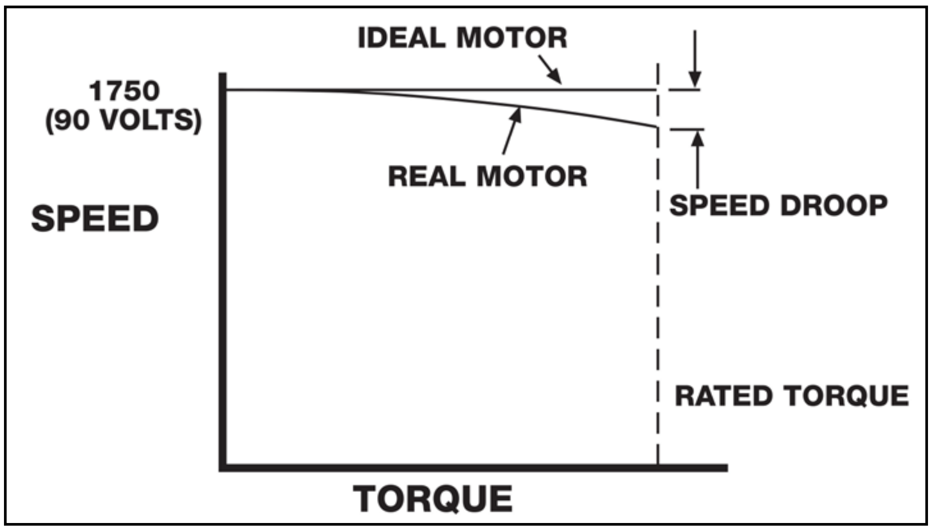

Figure 2 When operated at a fixed, applied voltage with a gradually increasing torque load, DC motors exhibit a speed droop.

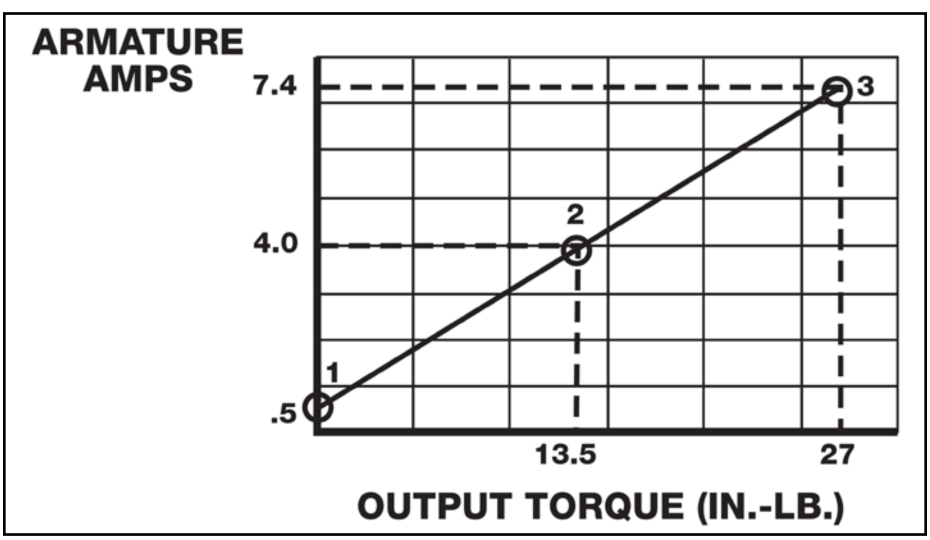

Figure 3 Beyond Point 1 and through Points 2 and 3, the current increases in direct proportion to the torque required by the load.

From the above curve you can see that with 9 volts applied to the armature, this motor would be operating at Point 1 and turn at approximately 1,75 RPM. Similarly, with 45 volts applied the motor would be operating at Point 2 on the curve, or 875 RPM. With 90 volts applied, the motor would reach its full speed of 1,750 RPM at Point 3.

From this example a general statement can be made that DC motors have "no load" characteristics that are nearly a perfect match for the curve indicated in Figure 1. However, when operated at a fixed applied voltage, and with a gradually increasing torque load, they exhibit a speed droop (Fig. 2).

This speed droop is very similar to what would occur if an automobile's accelerator pedal was held in a fixed position with the car running on level ground. Upon starting up an incline, where more driving torque would be needed, the car would slow down to a speed related to the steepness of the hill. In a real situation, the driver would respond by depressing the accelerator pedal to compensate for the speed loss to maintain a nearly constant speed up the incline.

In the DC drive a similar type of "compensation" is employed in the control to assist in maintaining a nearly constant speed under varying load (torque) conditions. The measurement of this tendency to slow down is called "regulation" and is calculated with the following equation:

$$\% \text{ regulation} = \frac{\text{No load speed} - \text{Full load speed}}{\text{No load speed}} \times 100$$

In DC drives the regulation is generally expressed as a percentage of motor base speed.

If the control (regulator) *did not* have the capability of responding to and compensating for changing motor loads, regulation of typical motors might be as shown in Table 1.

One other very important characteristic of a DC motor should be noted.

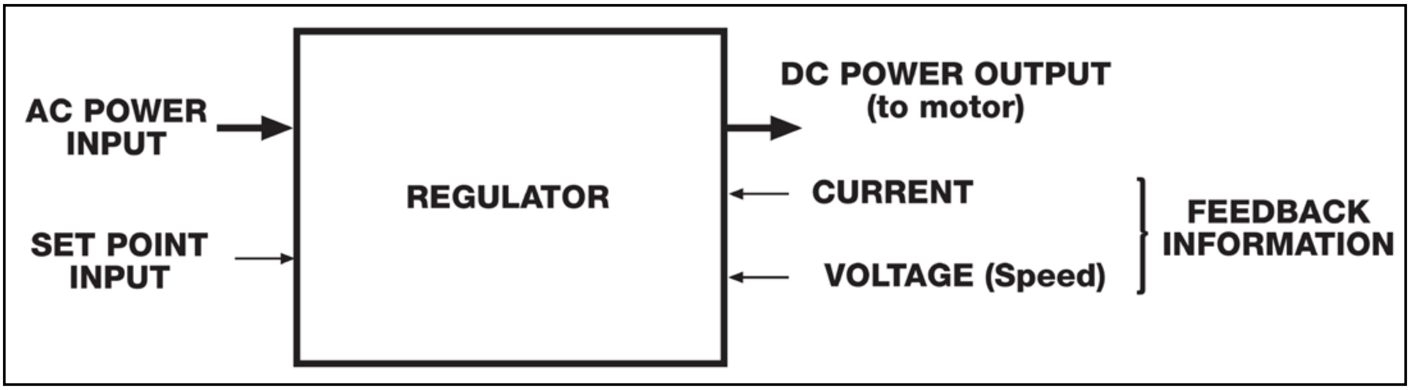

Figure 4 Input signals required to give regulator its capabilities.

Armature amperage is almost directly proportional to output torque — regardless of speed; this characteristic is shown in Figure 3. Point 1 indicates that a small, fixed amount of current is required to turn the motor, even when there is no output torque. This is due to the friction of the bearings, electrical losses in the motor materials, and load imposed by the air in the motor (windage).

Beyond Point 1 through Point 2 and 3, the current increases in direct proportion to the torque required by the load.

From this discussion and Figure 3, a general statement can be made that for PM and shunt wound motors, load torque determines armature amperage.

In summary, two general statements can be made relative to DC motor performance.

1. Motor *speed* is primarily determined by *applied armature voltage*
2. Motor *torque* is controlled by *armature current* (amperes)

Understanding these two concepts of DC motors provides the key to understanding total drive performance.

Regulators (controls). The control provides two basic functions:

1. It *rectifies* AC power, converting it to DC for the DC motor.
2. It *controls* the DC output voltage and amperage in response to various control and feedback signals, thereby regulating the motor's performance, both in speed and torque.

Rectifying function. The basic rectifying function of the control is accomplished by a combination of power semiconductors (silicon-controlled rectifiers and diodes) that make up the "power bridge" assembly.

Regulating function. The regulating function is provided by a relatively simple electronic circuit that monitors a number of inputs and sums these signals to produce a so called "error signal." This error signal is processed and transformed into precisely timed pulses (bursts of electrical energy). These pulses are applied to the gates of the SCRs in the power bridge, thereby regulating the power output to the DC motor.

For most purposes it is not necessary to understand the electronic details of the regulator; however, in order to appreciate the regulator function it is good to understand some of the input signals that are required to give the regulator its capabilities (Fig. 4).

The AC-to-DC power flow is a relatively simple, straight through process with the power being converted from AC to DC by the action of the solid-state power devices that form the power bridge assembly.

The input and feedback signals need to be studied in more detail.

Set point input. In most packaged drives this signal is derived from a closely regulated, fixed- voltage source applied to a potentiometer; 10 volts is a very common reference.

The potentiometer has the capability of accepting the fixed voltage and dividing it down to any value from, for example, 10 to zero volts — depending on where it is set. A 10-volt input to the regulator from the speed adjustment control (potentiometer) corresponds to maximum motor speed; zero volts correspond to zero speed. Similarly, any speed between zero and maximum can be obtained by adjusting the speed control to the appropriate setting.

Speed feedback information. In order to "close the loop" and control motor speed accurately, it is necessary to provide the control with a feedback signal related to motor speed.

The standard method of doing this in a simple control is by monitoring the armature voltage and feeding it back into the regulator for comparison with the input "set point" signal.

When armature voltage becomes high, relative to the set point and established by the speed potentiometer setting, an "error" is detected and the output voltage from the power bridge is reduced to lower the motor's speed back to the "set point." Similarly, when the armature voltage drops, an error of opposite polarity is sensed and the control output voltage is automatically increased in an attempt to re-establish the desired speed.

The "armature voltage feedback system," which is standard in most packaged drives, is generally called a "voltage-regulated drive."

A second and more accurate method of obtaining the motor speed feedback information is called "tachometer feedback." In this case the speed feedback signal is obtained from a motor-mounted tachometer; the output of this tachometer is directly related to the speed of the motor. Using tachometer feedback generally gives a drive improved regulation characteristics. When "tach feedback" is used, the drive is referred to as a "speed-regulated drive." Most controls are capable of being modified to accept tachometer signals for operation in the tachometer feedback mode.

In some newer, high-performance "digital drives" the feedback can come from a motor-mounted encoder that feeds back voltage pulses at a rate related to motor speed. These (counts) are processed digitally, being compared to the "set point," and error signals are produced to regulate the armature voltage and speed.

Current feedback. The second source of feedback information is obtained by monitoring the motor armature current. As discussed previously, this is an accurate indication of the torque required by the load.

The current feedback signal is used for two purposes:

1. As *positive feedback* to eliminate the speed droop that occurs with increased torque load on the motor. It accomplishes this by making a slight corrective increase in armature voltage as the armature current increases.
2. *As negative feedback* with a "threshold-type" of control that limits the current to a value that will protect the power semiconductors from damage. By making this function adjustable, it can be used to control the maximum torque the motor can deliver to the load.

The current limiting action of most controls is adjustable and is usually called "current limit" or "torque limit."

In summary, the regulator accomplishes two basic functions:

1. It converts the alternating current to direct current
2. It regulates the armature voltage and current to control the speed and torque of the DC motor

Typical Adjustments

In addition to the normal external adjustment, such as the speed potentiometer, there are a number of common, internal adjustments that are used on simple, small analog-type SCR drives. Some of these adjustments are:

- Minimum speed
- Maximum speed
- Current limit (torque limit)
- IR compensation
- Acceleration time
- Deceleration time

The following is a description of the function that these individual adjustments serve, and their typical use.

Minimum speed. In most cases, when the control is initially installed the speed potentiometer can be turned down to its lowest point and the output voltage from the control will go to zero, causing the motor to stop. There are many situations where this is not desirable. For example, there are some machines that want to be kept running at a minimum speed and accelerated up to operating speed as necessary. There is also a possibility that an operator may use the speed potentiometer to stop the motor to work on the machine.

This can be a dangerous situation, since the motor has only been brought to a stop by zeroing the input signal voltage. A more desirable situation is when the motor is stopped by opening the circuit to the motor or power to the control using the on/off switch. By adjusting the minimum speed up to some point where the motor continues to run — even with the speed potentiometer set to its lowest point — the operator must shut the control off to stop the motor. This adds a degree of safety into the system. The typical minimum speed adjustment is from 0 to 30% of motor base speed.

Maximum speed. The maximum speed adjustment sets the maximum speed attainable either by raising the input signal to its maximum point or turning the potentiometer to the maximum point. For example, on a typical DC motor the rated speed of the motor might be 1,750 RPM, but the control might be capable of running it up to 1,850 or 1,900 RPM. In some cases it is desirable to limit the motor (and machine speed) to something less than would be available at this maximum setting; the maximum adjustment allows this to be done. By turning the internal potentiometer to a lower point, the maximum output voltage from the control is limited. This limits the maximum speed available from the motor. In typical controls such as Baldor's BC140, the range of adjustment on the maximum speed is from 50 to 110% of motor base speed.

Current limit. One very nice feature of electronic speed controls is that the current going to the motor is constantly monitored by the control. As mentioned previously, the current drawn by the armature of the DC motor is related to the torque that is required by the load. Since this monitoring and control is available, an adjustment is provided in the control that limits the output current to a maximum value.

This function can be used to set a threshold point that will cause the motor to stall rather than putting out an excessive amount of torque. This capability gives the motor/control combination the ability to prevent damage that might otherwise occur if higher values of torque were available. This is handy on machines that might become jammed or otherwise stalled. It can also be used where the control is operating a device such as the center winder, where the important thing becomes *torque* rather than speed. In this case the current limit is set and the speed goes up or down to hold the tension of the material being wound. The current limit is normally factory-set at 150% of the motor's rated current. This allows the motor to produce enough torque to start and accelerate the load, and yet will not let the current (and torque) exceed 150% of its rated value when running. The range of adjustment is typically from 0 to 200% of the motor-rated current.

IR compensation. IR compensation is a method used to adjust for the droop in a motor's speed due to armature resistance. As mentioned previously, IR compensation is positive feedback that causes the control output voltage to rise slightly with increasing output current. This will help stabilize the motor's

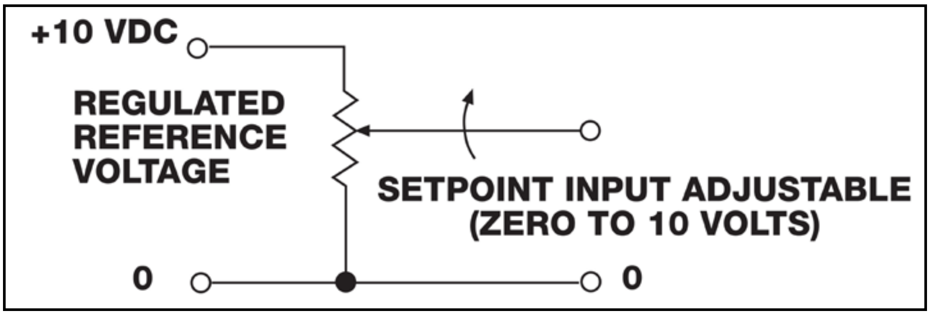

Figure 5 Set point input signal derived from foxed voltage source.

speed from a no-load to full-load condition. If the motor happens to be driving a load where the torque is constant or nearly so, then this adjustment is usually unnecessary. However, if the motor is driving a load with a widely fluctuating torque requirement, and speed regulation is critical, then IR compensation can be adjusted to stabilize the speed from the light load to full load condition. One caution is that when IR compensation is adjusted too high, it results in an increasing speed characteristic. This means that as the load is applied, the motor is actually going to be forced to run faster. When this happens it increases the voltage and current to the motor that, in turn, increases the motor speed further. If this adjustment is set too high, an unstable "hunting" or oscillating condition occurs that is undesirable.

Acceleration time. The acceleration time adjustment performs the function that is indicated by its name. It will extend or shorten the amount of time for the motor to go from zero speed up to the set speed. It also regulates the time it takes to change speeds from one setting (say 50%) to another setting (perhaps 100%). So this setting has the ability to moderate the acceleration rate on the drive.

A couple notes are important: if an acceleration time that is too rapid is called for, "acceleration time" will be overridden by the current limit. Acceleration will only occur at a rate that is allowed by the amount of current the control passes through to the motor. Also important to note is that on most small controls the acceleration time is not linear, meaning that a change of 50 RPM may occur more rapidly when the motor is at low speed than it does when the motor is approaching the set point speed. This is important to know but usually not critical on simple applications where these drives are used.

Deceleration time. This is an adjustment that allows loads to be slowed over an extended period of time. For example, if power is removed from the motor and the load stops in 3 seconds, then the "decel" time adjustment would allow you to increase that time and "power down" the load over a period of 4, 5, 6 or more seconds. Note: On a conventional, simple DC drive it will not allow for the shortening of the time below the "coast to rest" time.

Adjustment summary. The ability to make these six adjustments affords great flexibility to the typical, inexpensive DC drive. In most cases the factory-preset settings are adequate and need not be changed; but on other applications it may be desirable to tailor the characteristics of the control to the specific application.

Many of these adjustments are available in other types of controls, such as variable frequency drives (VFDs). **PTE**

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Design of Plastic Microgear Teeth for Mass Production with High Manufacturing Tolerances for a Medical Device

Jürgen Strüber

Introduction

Microgears (module < 0.2 mm) for prototype mass production have very large production tolerances in comparison with the gearwheel size. The tolerances are of the order of ±1.5% of the nominal size. Fault-free operation, i.e. — flank clearance and sufficient contact ratio — must be ensured over the entire tolerance range. A transverse contact ratio of greater than 1, which represents a conventional design rule, is no longer achievable with such large tolerances. These framework conditions set new requirements for the *design* and also the *evaluation* of microgears.

Here a tolerance-insensitive design is presented, which has a large absolute tooth depth (in mm) *and* a large relative tooth depth (in modules). The modifications made here ensure a smooth start to meshing over the entire tolerance range, even with a transverse contact ratio of less than 1.

Microgears have been available for decades, as, for example, in small wrist-watches. Over the last few years the range of use has grown to include other sectors such as digital cameras, model-building or medical technology. Especially in the latter sector, there is an increasing number of short-lived mass-production products which must be both inexpensive and simultaneously offer very high reliability over the specified product lifetime. Typical examples are blood glucose measuring devices and insulin pumps for diabetics: devices no bigger than a mobile phone house a mechanism that is capable of providing and evaluating measuring strips or extremely precise micropumps driven by microgear motors.

According to VDI 2731 *Microgears Basic Principles* (Ref. 1), the boundary between precision engineering gears and microgears is a module of 0.2 mm. With micro-gearwheels, just as for precision engineering gearwheels, the involute form is the favored tooth shape (Ref. 1). However the tolerance dimensions cannot be reduced to the same extent as the main dimensions, and thus increase relative to the component size, the smaller the gear unit becomes. Plastic injection molding is primarily used as the production process, which intrinsically has relatively wide production tolerances.

Problems and the Resulting Definition of a Task

The production-inherent tolerances of micro-gearwheels in mass production can certainly amount to 1.5% of the nominal dimension. In addition, there are large center distance tolerances due to plastic housings and long tolerance chains. The main requirements of the tolerance design are a tooth flank backlash greater than zero, and sufficient contact ratio over the entire tolerance range.

Figure 1 shows gear meshing according to a conventional design similar to DIN 58400 (Ref. 2), with tolerances typical of a microgear. According to conventional evaluation, the transverse contact ratio must be at least 1 over the tolerance range. For the widest mesh (Fig. 1, right) there is a transverse contact ratio of less than 0.6, with a correspondingly hard impact at the start of meshing. The results are noisy running and severe wear. Consequently a gearwheel design is required that ensures operating reliability — even with large tolerances.

Design of Tolerance-Insensitive Toothing

The following requirements should be adhered to:

- Gear ratio: approx. 2
- Plastic gearwheels and housing parts can be

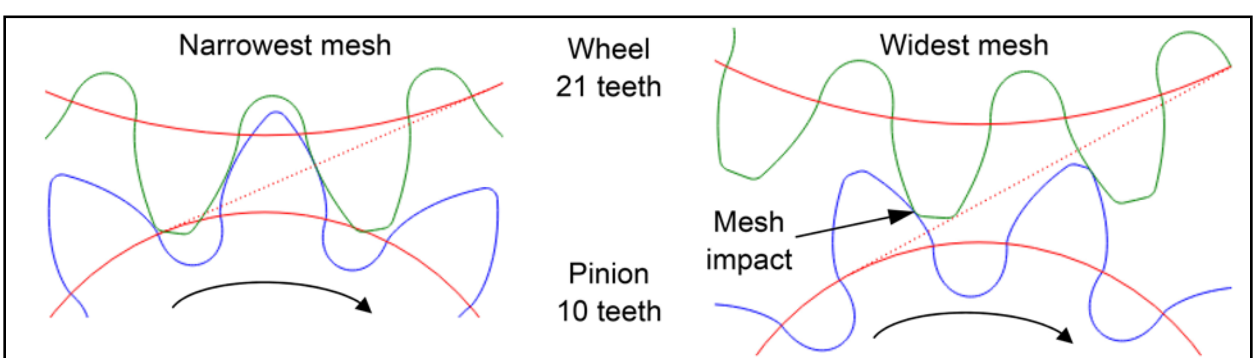

Figure 1 Conventional design, similar to DIN 58400 (Ref. 2).

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

mass-produced using a (micro-) injection molding process
- Tolerances for tip diameters, tooth thickness and center distance, as already presented
- Straight-toothed

A design insensitive to large center distance and gearwheel size tolerances requires a large absolute tooth depth in millimeters; i.e. — a trend towards a large module and a small number of teeth is necessary. With a small number of teeth, the tooth depth relative to the module is limited by undercut and by the tooth tips becoming pointed.

In contrast, the requirement for a sufficient transverse contact ratio requires a large tooth depth or a sufficiently long, involute form relative to the module which, if anything, requires a small module and large number of teeth. Below it is shown how an acceptable absolute tooth depth (in micrometers) and relative tooth depth (in modules) can be achieved. In doing so, large undercut on the pinion cannot be avoided; the mesh must be optimized by modifications.

Step 1: *specification of module and number of teeth.* Multiple calculations have shown that for the design optimized here, the optimum number of teeth-per-pinion is 7. Figure 3 shows a design similar to Figure 1, but with 7 teeth on the pinion.

The transverse contact ratio for the widest mesh is only about 0.8. There is a mesh impact at the start of meshing. The tooth depth on the pinion cannot be further increased due to the tip limit.

Step 2: *increasing tooth depth by complementary toothing.* Complementary toothing represents the state of the art: the tooth thickness of the pinion is increased while maintaining an unchanged tooth flank geometry and by counter-rotating the right and left tooth flanks about the gearwheel center. The intermeshing gearwheel is changed inversely ('complementary'). These measures mean the teeth of the pinion are no longer pointed; therefore the tooth depth can be increased.

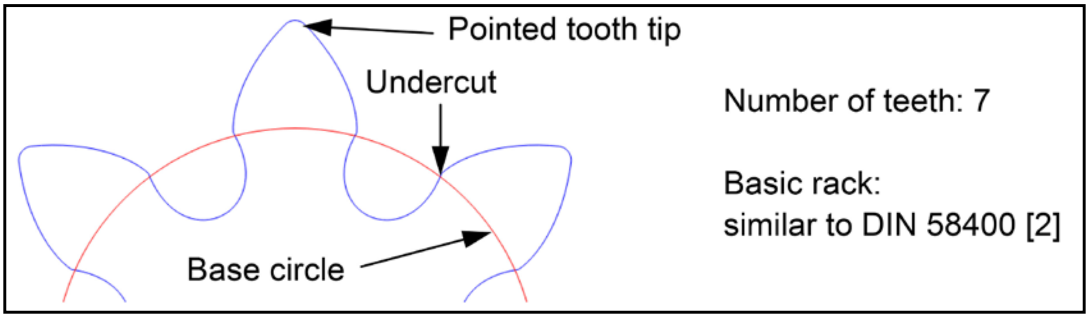

Figure 2 Limited tooth depth with a small number of teeth; pointed tooth tip und undercut.

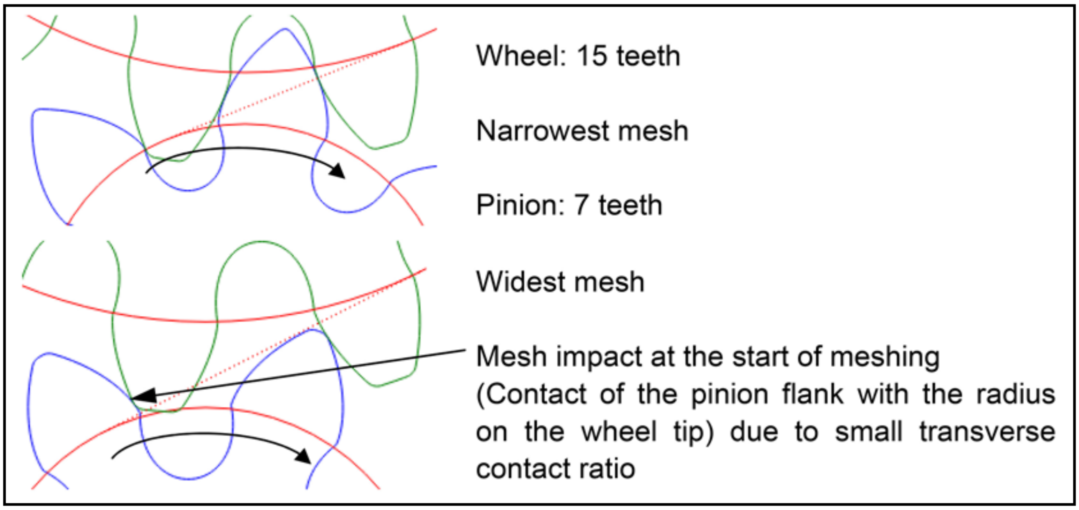

Figure 3 Pinion number of teeth — 7; conventional design — basic rack: similar to DIN 58400 (Ref. 2).

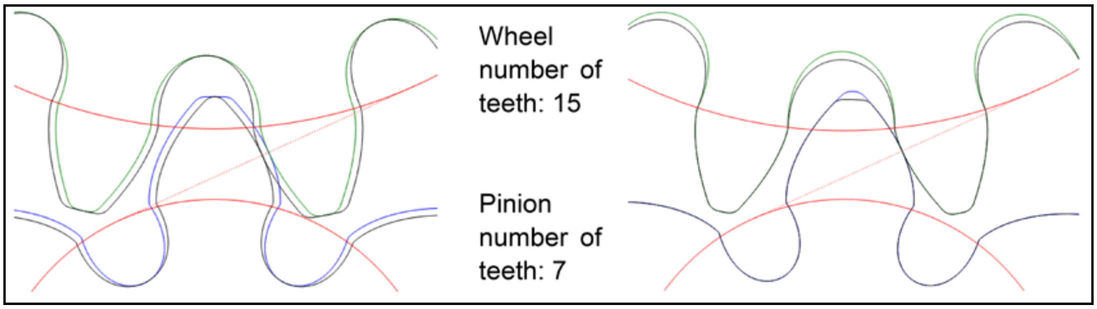

Figure 4 Left — complementary toothing; right — pinion addendum and wheel dedendum increased.

Step 3: *increasing the tooth depth by accepting larger undercut.* The tooth dedendum of the pinion and the tooth addendum of the wheel are increased; increasing of the already present undercut is accepted.

Step 4: *meshing optimization.* At first sight the resultant meshing appears unusual, but definitely practical. Seen graphically, the contact ratio over the tolerance range is not optimal — but acceptable (Fig. 6).

By calculation for the widest tolerance situation, a transverse contact ratio of approximately 0.9 results, which, while again not optimal, is a significant improvement compared with the conventional design (Table 1).

The mesh as shown in Figure 6 still exhibits weak points; if tooth flank wear and pitch errors are considered, then, particularly with narrow meshing, the result may be a hard mesh impact or premature contact.

To prevent this collision the pinion is given root relief that, in comparison with more usual root relief, primarily recesses the dedendum in the area of the root surface or the undercut, and mandatorily only removes a small element from the involute form.

Figure 7 clarifies how this measure prevents a collision before the desired meshing. However, a small part of the involute form is lost, which further reduces the calculated transverse contact ratio for the widest mesh. It is for this reason that it is explained in the following which design and mesh are to be favored.

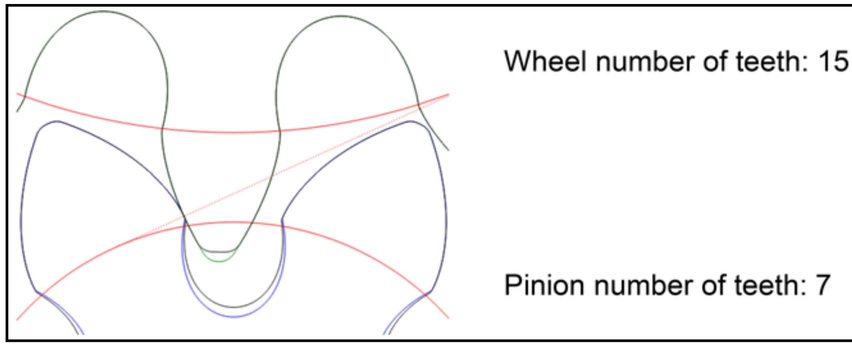

Figure 5 Pinion addendum and wheel dedendum increased.

Table 1 Comparison: calculated transverse contact ratio for the widest mesh

	Basic rack	Calculated transverse contact ratio for the widest mesh
Conventional design according to Figure 1 Pinion 10 teeth, wheel 21 teeth	similar to DIN 58400 [2]	Less than 0.6
Conventional design according to Figure 3 Pinion 7 teeth, wheel 15 teeth	similar to DIN 58400 [2]	approx. 0.8
Increased tooth depth according to Figure 6 Pinion 7 teeth, wheel 15 teeth	special	approx. 0.9

Evaluation and Advantages of the Optimized Design

With the optimized design, meshing takes place smoothly and close to the pitch point. Very similar meshing conditions exist over the entire tolerance range; the pinion involute is shorter than that of the wheel. The whole involute of the pinion engages throughout the entire tolerance range with the

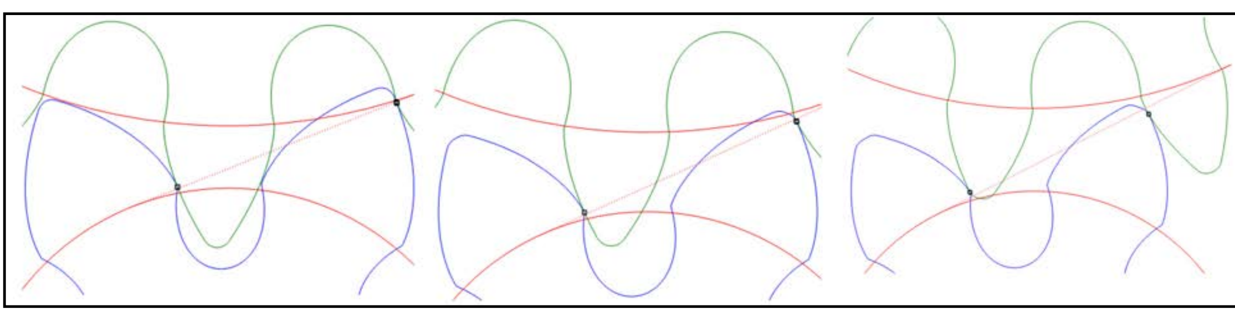

Figure 6 Increased tooth depth according to Figure 5 for narrowest, medium and widest mesh.

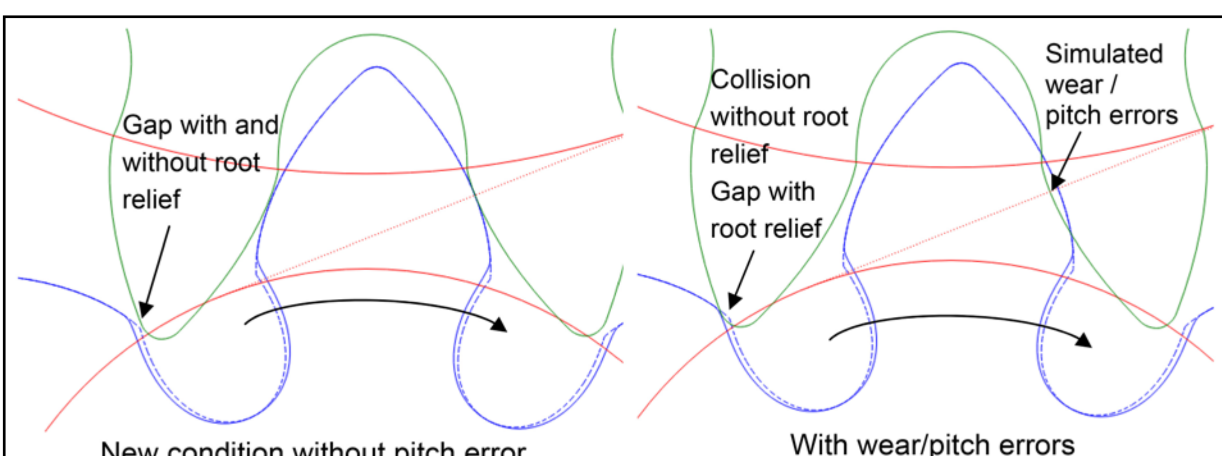

Figure 7 Pinion without root relief (dotted line) and with root relief (solid line) with narrowest tolerance situation.

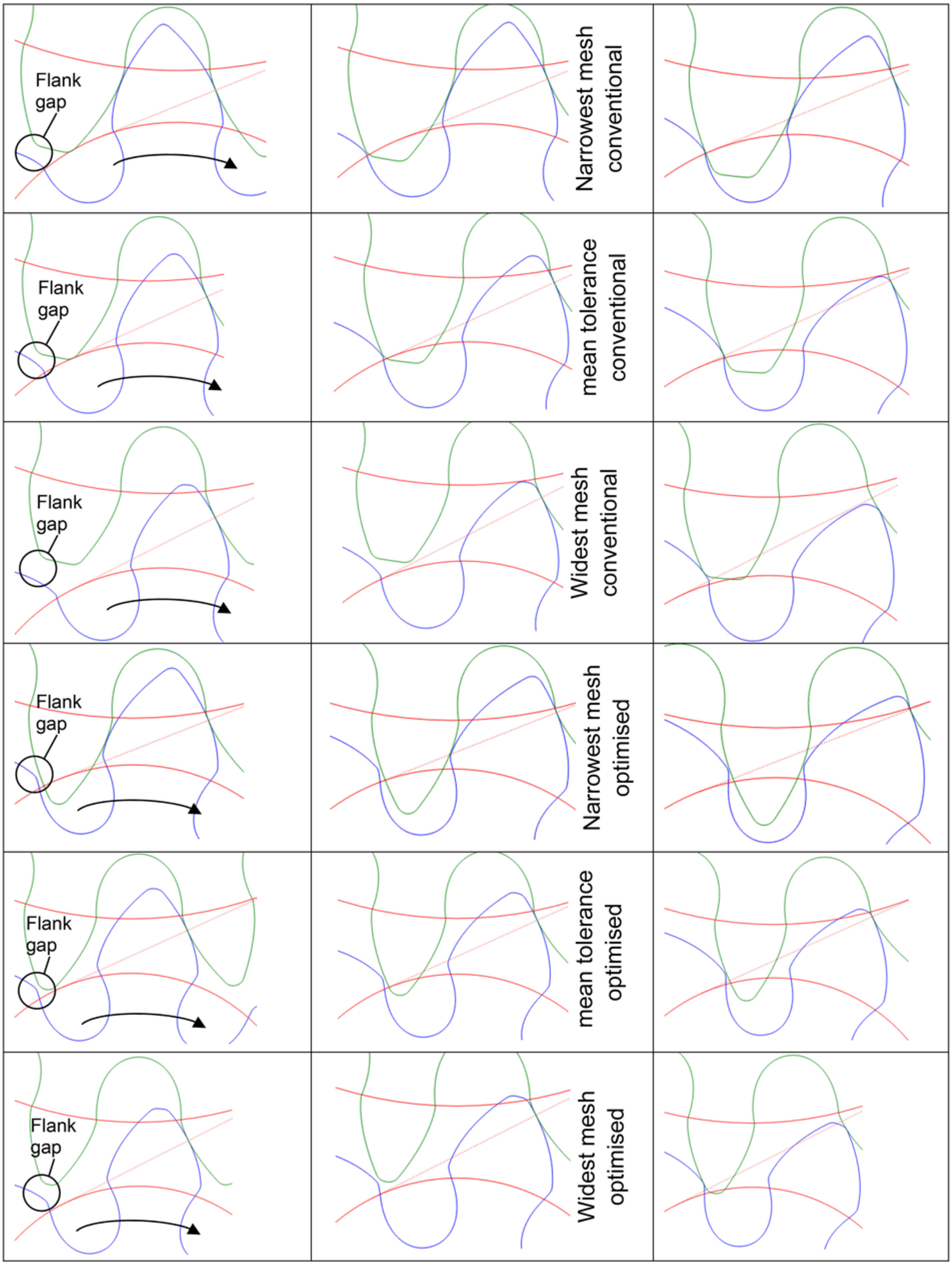

Figure 8 Start of meshing via tolerances: conventional design (Fig. 3, top 3 image rows) and optimized design according to Figure 7 with root relief (bottom 3 image rows); pinion rotation angle between left and right image: 15°.

wheel flank. The involute used by the wheel lies more in the outer, middle or inner area of the involute, dependent on the tolerance situation. The start of meshing takes place over the entire tolerance range below the wheel tooth tip, which ensures a smooth meshing start.

Figure 8 shows that in the optimized design the flank gap decreases in slower fashion and the contact starts later (that is, closer to the pitch point) than with the conventional design. Moreover, with the conventional design there is a meshing impact for the widest mesh because of the overly small transverse contact ratio. With the optimized design the meshing start is smooth, even for the widest mesh, with a transverse contact ratio significantly less than 1. At the conventional design pitch, error and wear can significantly amplify the mesh impact, while with the optimized design the start of meshing is indeed moved, but remains 'smooth' nevertheless. Figure 9 shows the calculated geometric transmission error for the conventional and optimized design—without elastic deformation and without pitch errors. The wide plateaus represent areas in which the involutes are in contact. The downward peaks are those areas between the involute engagements. Therefore the width of the peaks is a measure of how much the transverse contact ratio is less than 1. Indeed, the transmission error (more accurately, the difference between maximum and minimum values subsequently referred to as *Δ* transmission error) for the narrowest and medium mesh for the conventional design is approximately zero; by contrast, the widest tolerance situation is equal to a difference of about 4 µm. For the optimized design there are similar curves for the transmission error for the three tolerance situations. The difference between maximum and

Table 2 Comparison: computed transverse contact ratio and Δ transmission error

		Conventional (Figure 3)	Optimized (Figure 7)
Narrowest mesh	Transverse contact ratio	1.0	0.77
	Δ transmission error [µm]	0	2.0
Mean tolerance	Transverse contact ratio	0.95	0.74
	Δ transmission error [µm]	≈0	2.3
Widest mesh	Transverse contact ratio	0.80	0.71
	Δ transmission error [µm]	4.0	2.7

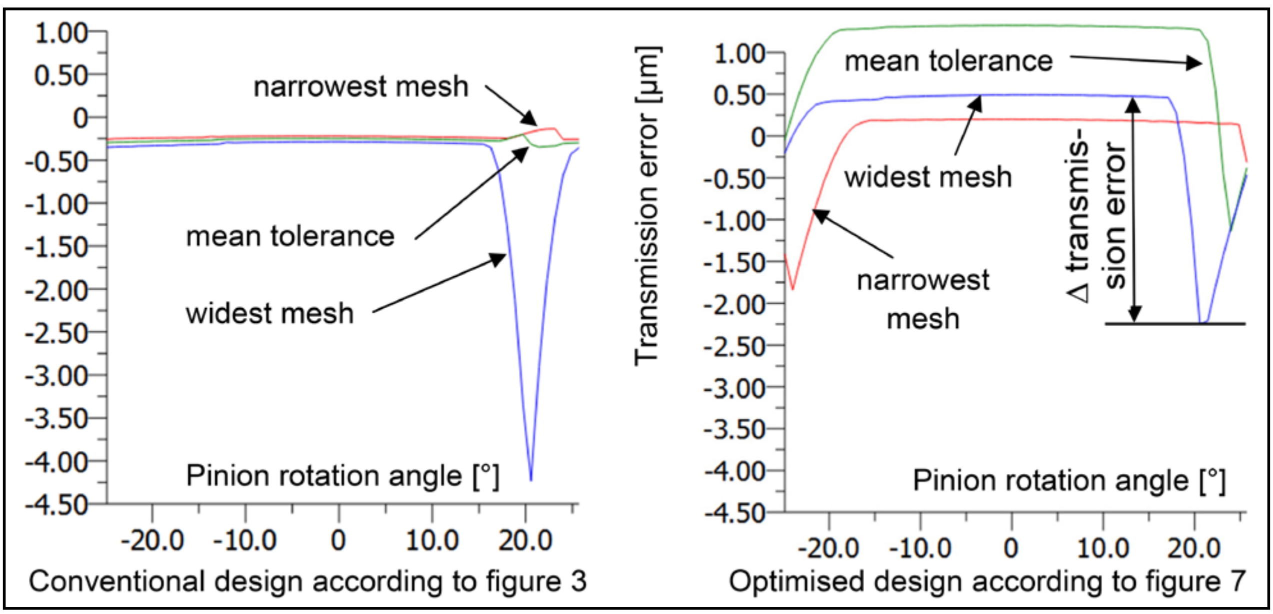

Figure 9 Geometrically caused transmission error (calculated).

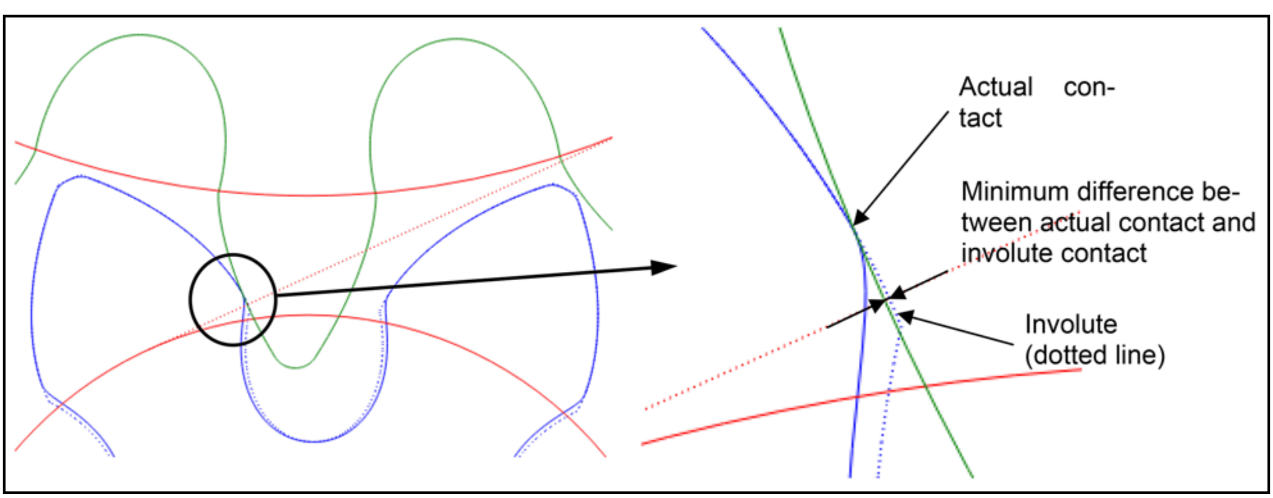

Figure 10 Problem in the calculated transverse contact ratio (e.g.—optimized design according to Fig. 7, mean tolerance).

minimum value is between 2.0 and 2.7 µm, dependent on the tolerance situation. Moreover, the downward peak for the conventional design for the widest mesh is narrower than for the optimized design.

Metaphorically speaking, the transmission error represents for the conventional design a 'narrow, deep pothole,' while for the optimized design it represents a 'wide, flat depression.'

Although a transverse contact ratio greater than 1 over the entire tolerance range is desirable, it is, however, not possible with large tolerances relative to the component size. Also, solely maximizing the transverse contact ratio is not appropriate. Table 2 very clearly indicates for the widest mesh that a smaller transverse contact ratio can even have a smaller transmission error as a consequence.

One reason the value of the computed transverse contact ratio for such toothing systems is to be considered with caution is that, as a result of undercut or root relief, there is from a calculated viewpoint no contact in the area of the involute. The difference between the actual contact and the involute contact may, however, be in the sub-micrometer range, i.e. — negligible in practice.

For evaluation of corresponding optimized toothing systems, it is therefore suggested that less consideration be given to the transverse contact ratio and that most attention be paid to transmission error. Moreover, the mesh, especially the start of the mesh, should be visually considered, which in fact partially results in a somewhat subjective assessment.

Outlook

A design for microgears was presented that ensures uniform operation over a wide tolerance range. Corresponding gears were constructed and found to function well during internal tests and customer trials. Viewed under the microscope, the parts look like 'actual gearwheels' with tooth flank contours that correspond to the figures shown. However when the gearwheels are viewed with the naked eye, the question nevertheless arises — to what extent optimizations in the micrometer range on plastic parts remain solely of an academic nature, and whether (to put it bluntly) triangular teeth with rounded tip and root would not also serve the same purpose. Experience has shown that small, plastic gearwheels are in practice much more tolerant to deviations than would be expected from pure theory.

In the sense of a proof of reliability for demanding medical devices, the theoretical considerations are nevertheless not at all in vain. There are very few standards dealing with microgears; VDI 2731 (Ref. 1) cited at the beginning refers not for nothing to *Microgears: Basic Principles*. Here the state of the art and the differences relative to larger gears in respect to design, production or measuring technology are presented. 'It is intended to provide a basic repository of information, to stimulate discussion, and, in the longer term, expansion,' as explained in Section 1 of VDI 2731 (Ref. 1). However, etched-in-stone design guidelines for, example, basic racks or tolerance values, are not included.

Miniaturization is just beginning. **PTE**

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A New Standardizable Calculation Method to Predict the Efficiency of Worm Gear Drives

Manuel Oehler, Balázs Magyar and Bernd Sauer

Introduction

Within the scope of the research project FVA 729 I "Worm Gear Efficiency," a physically based simulation method for the efficiency of worm gear drives was developed. This method is validated by experiments with different gear sizes and ratios. An extensive parameter study with the use of this simulation program was carried out to specify the magnitude of various influencing variables on the efficiency. The large parameter field for this study was created with design of experiments (DoE) to take into account a wide range of different parameter combinations. Based on the principle of similarity, the method of dimensional analysis was applied to derive an approximation equation for the efficiency in order to make the developed method accessible to broad practice. The derivation of this new, physically based formula using dimensionless influencing parameters is the object of this paper. The resulting tool allows calculation engineers to compare different drivetrain concepts with regard to efficiency. These easy-to-handle formulas can be incorporated into the standard DIN 3996.

Worm gearboxes are characterized by the large gear ratios that can be realized in a single stage, as well as by low-vibration- and low-noise-running behavior, compared to other gear transmissions. These positive properties, however, are associated with a lower efficiency compared to helical gearboxes, due to the high sliding velocities in the tooth engagement resulting from the intersecting axes. In order to be able to design efficient drive solutions, various transmission types and design variants must be comparable with each other in terms of the expected operating efficiency during the design phase. The approximation equations described in the German standard DIN 3996 (Ref. 1) are based on quasi-stationary measurements of gearboxes with a gear ratio of $i = 20.5$ and with a center distance of $a = 100$ mm. The transferability of the existing and partly standardized empirical formulas to other sizes and gear ratios is only possible to a limited extent. For this reason there is a need on the part of industry to expand the field of use of the calculation method in a broad range of sizes and gear ratios. The aim of this work is the development of a physically based simulation method which is verified by experimental results in order to reliably determine the efficiency of worm gear drives. Included in the investigations are various sizes, gear ratios and oil types, as well as stationary and transient operating conditions. The efficiency calculation of worm drives is based on theoretical principles, taking into account the different interactions of the influencing variables. This theoretical work is supplemented by random running trials and tribological investigations that provide input data for the calculations. This results in a physically based simulation model with which worm gearing can be investigated in a variety of ways. The target variables are, among other things, the local and the mean tooth friction coefficients, as well as the gearing and overall efficiency of the gearbox under test. The average gear friction coefficient can also be used to check the transmission for possible self-locking or self-braking.

Tribological Simulation

Magyar studied *ZK*-type cylindrical worm gears as part of his dissertation at the Institute of Machine Elements, Gears and Transmissions (MEGT) with regard to the tribological and dynamic behavior, both experimentally and simultatively (Ref. 2). In his work a calculation model was developed based on the work of Bouché (Ref. 3). Thus, the local tooth friction coefficients and the overall efficiency of worm drives operating in the mixed friction area can be determined by means of the TEHD theory in quasi-stationary operating conditions. The simulation model was verified with own test results. This calculation approach is the starting point of this work.

To calculate the locally variable tooth friction coefficients of worm gears, the theoretical contact lines are determined first (Fig. 1, left). The calculation of the radius of curvature at the points of contact and the discretization of the contacting tooth flanks by rotating rollers follows (Fig. 1, middle). In order to be able to model the kinematic conditions of the worm and worm wheel, the points in the contact zone are modelled with the aid of rotating rollers. Considering the kinematic behavior of the gears, the sliding and sum velocities in every point of the contact lines are calculated. The lubricating gap height is determined under the assumption of a Hertzian pressure distribution (Fig. 1, right).

Knowing the film thickness of the lubricant and using pre-calculated division curves for the load-carrying contact ratio derived from a self-developed software, the rate of boundary lubrication can be calculated for each rotating pair of rollers. The heat conditions in the contact zone are determined in an iterative manner by simultaneously solving the differential equation for Fourier's law of heat conduction and the simplified energy equation of the lubricant. With a known lubricant temperature, the viscosity and the fluid friction force dependent on this viscosity can be calculated for all pairs of rollers. Subsequently, the calculation of the coefficient of mixed

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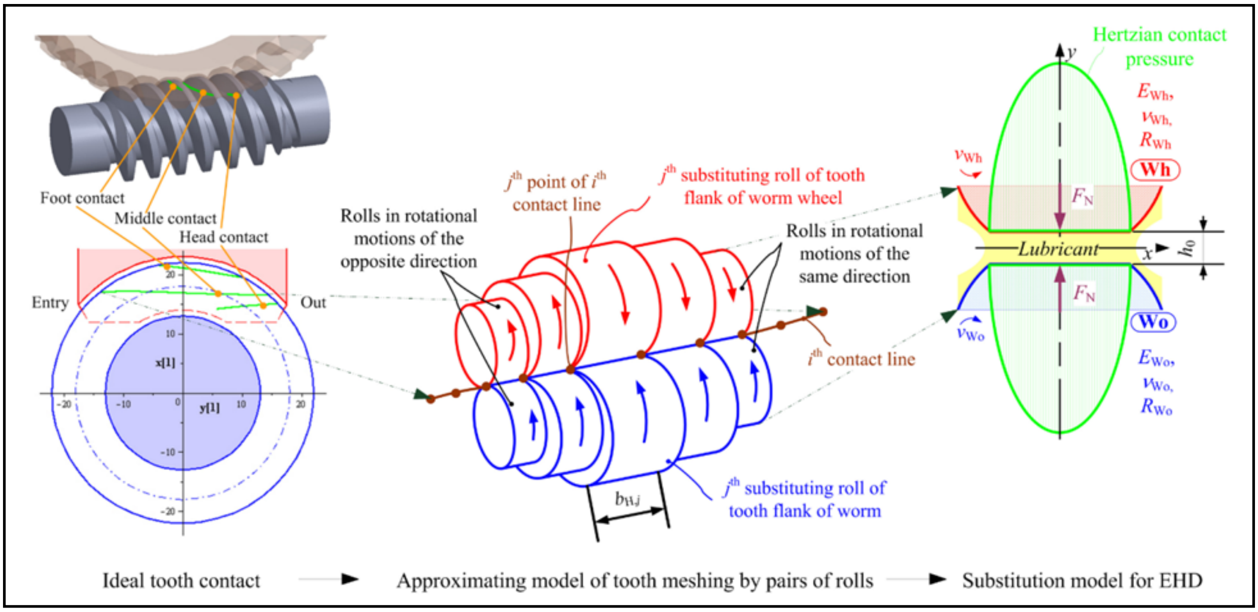

Figure 1 Simplified tribological modeling of the contacting teeth of worm gears (Ref. 2).

friction follows, which corresponds to the local friction coefficient between the gears. A more precise description of the procedure of this method can be found (Ref. 2). According to the knowledge of the local tooth friction coefficients, these can be averaged and thus the total efficiency of the gears η_z and the gear power loss $P_{VZ,P}$ can be calculated.

$$P_{VZ,P} = \frac{T_2 \cdot \omega_1}{u} \cdot \left(\frac{1}{\eta_z} - 1\right) \quad (1)$$

$$\eta_z = \frac{\tan(\gamma_m)}{\tan\left(\gamma_m + \tan^{-1}\left(\frac{\mu_Z}{\cos(\alpha_0)}\right)\right)} \quad (2)$$

Here, T_2 is the output torque on the worm wheel shaft; ω_1 is the angular velocity of the drive shaft; u is the tooth ratio; γ_m is the lead angle of the worm, α_0 is the pressure angle, and μ_Z is the average coefficient of friction. In addition to the tooth friction losses, there are still further sources of loss in the worm gear (Ref. 4).

$$P_V = P_{VZ,P} + P_{VZ,0} + P_{VL} + P_{VD} \quad (3)$$

For the calculation of the additional losses, existing methods, which are state-of-the-art, are used: The calculation of the bearing losses P_{VL} is carried out according to the methods of the bearing manufacturers, the friction in the dynamic seals P_{VD} is carried out according to Engelke's model (Ref. 5) and the churning losses of the gears $P_{VZ,0}$ according to (Ref. 6).

Validation by Experimental Results

For the validation of the tribological simulation software extensive experimental investigations are carried out with worm gear drives of different sizes and gear ratios. In the tests, *ZK*-type worm gears with two different center distances ($a = 40$ and $a = 125$ mm) and two gear ratios ($i = 10$ and $i = 60$) are analyzed. In addition, all tests are carried out with two different types of lubricants. While the smaller worm gearboxes are from serial production, a new drive with $a = 125$ mm is designed especially for research purposes. For all experiments the same kind of materials (worm: 16MnCr5, worm wheel: CuSn12Ni) is used. The worm wheels of the smaller gearboxes are made of CuSn12Ni-GC (continuous casting) and the worm gears of the gearboxes with $a = 125$mm are made of CuSn12Ni-GZ (centrifugal casting). The tests are carried out on the modular MEGT electrical wiring test bench. The basis of this test bench is two asynchronous machines with a maximum power of $P_{max} = 30$ kW.

The test bench for examining the worm gearboxes with a center distance of $a = 125$ mm is designed as shown in Figure 2. Here, the component's drive motor (Eq. 3), output motor (Eq. 13) and test gearbox (Eq. 7) can be seen. In addition to the torques and rotational speeds at the input and output

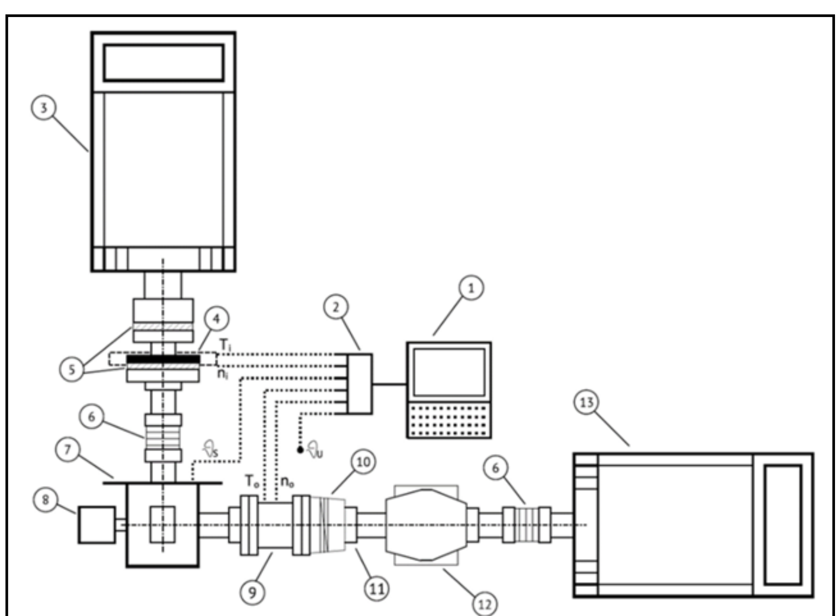
Figure 2 Sketch of the test rig setup for the worm gear drive with $a = 125$ mm.

shaft (Eqs. 4, 9), the temperatures are recorded on several non-moving components. Additionally, the temperature of the rotating worm wheel is transmitted by telemetry via a Bluetooth transmitter (Eq. 8) and receiver. In order to reduce the torque at the output motor (Eq. 13), a planetary gearbox (Eq. 12) is built in the power flow between the latter and the test gearbox (Eq. 7). The test bench for testing the transmissions with a center distance of $a = 40$ mm corresponds largely to the structure described above. Figure 3 shows an example of the validation results for the gearbox with center distance $a = 125$ mm and gear ratio $i = 10$ for lubrication with polyglycol-based oil (PG) of viscosity class ISO VG 460. The comparison between the tribological simulation and the experiments shows very good agreement for both of the examined sizes. The German standard DIN3996 overestimates the efficiency by up to 4%, at an input shaft speed of 1,400 min^{-1}.

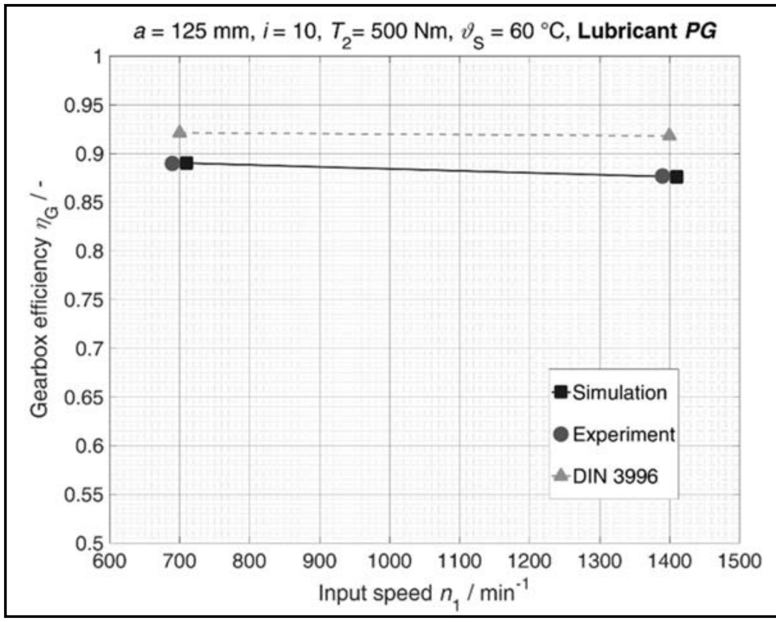

Figure 3 Comparison of gearbox efficiency for a worm gearbox with $a = 125$ mm, $i = 10$, lubrication with polyglycol ISO VG 460 at $\vartheta_S = 60°C$ — as determined by tribo-simulation, experimentation, and DIN 3996 (Ref. 1).

Approximation Equations

To apply the results of the described work in practice, approximation equations for the determination of the gearing efficiency by simple means are derived. In order to be able to find a suitable calculation rule, a detailed parametric study with the validated simulation program is carried out, thus creating a meaningful data basis. Based on this, the interactions between the different input variables and the efficiency of gearing are examined in order to be able to quantitatively describe them. The approximation equations for the determination of the efficiency of worm gear drives are devised under the guideline of finding a standardized — but at the same time physically justified — approach that can be adopted in (Ref. 1). For this reason many calculation bases and characteristic values (mean pressure between the tooth flanks σ_{Hm}, mean sliding speed v_{gm}, mean film thickness $h_{min.m}$, and average sliding distance s_{gm}) are taken from the existing standard (Ref. 1). Since in practice worm gears operate in the mixed friction area, an approach is used for the approximation equations described below, which considers both boundary and fluid friction in order to reproduce the physical circumstances in the mixed friction area.

$$\mu_Z = \psi \cdot \mu_{Gr} + (1 - \psi) \cdot \mu_{Fl} \tag{4}$$

The average friction coefficient in the worm gear unit μ_Z is thus composed of a proportion determined by boundary friction (boundary friction coefficient μ_{Gr}) and a proportion determined by the fluid friction (fluid friction coefficient μ_{Fl}). The division factor between the friction mechanisms is the load-carrying contact ratio ψ. While local tribological quantities are calculated with the tribological simulation from (Refs. 2, 7) in order to be able to determine the coefficient of friction in the mixed friction area, a global approach with average characteristics is selected for the approximation equations. The transfer from local to global values is outlined in Figure 4. Influence variables such as the coefficient of boundary friction μ_{Gr}, the velocities of the tooth flanks v_1 and v_2, the lubricating gap height $h_{min,m}$ and the viscosity of the lubricant η_m are now no longer calculated for single discretization points, but are incorporated as global variables into the tribological consideration of the tooth contact.

The load-carrying contact ratio ψ is calculated using the dimensionless film thickness λ. In order to calculate the dimensionless lubricating gap height λ, the average gap height $h_{min,m}$ is divided by the combined root-mean-squared roughness S_q of both friction partners (worm $S_{q,1}$ and worm gear $S_{q,2}$).

$$\lambda = \frac{h_m}{S_{q,12}} = \frac{h_m}{\sqrt{S_{q,1}^2 + S_{q,2}^2}} \tag{5}$$

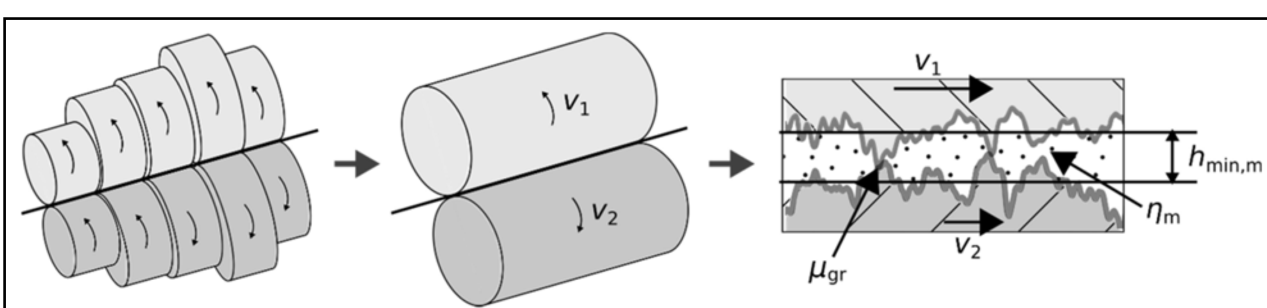

Figure 4 Schematic representation of the procedure for the transfer from local (left) to global tribological parameters (right) through simplification by reduction to a global replacement roller pair (middle) (Ref. 7).

In addition to the dimensionless film thickness λ, the deformation behavior of the two friction partners is decisive for the proportion of boundary friction. With a detailed contact simulation of real-measured surfaces, a relationship between the approximation of the solids and the proportion of the surfaces that are in contact with each other can be calculated. It is found that, in the case of contact calculation with different worn tooth flank surfaces that have been processed by the same manufacturing method, a similar profile exists of the curve describing the load-carrying contact ratio results independently of the root-mean-squared roughness S_q (Fig. 5). This relation can be described according to (Ref. 2) with an equation of the following form:

$$\psi(\lambda) = \exp(a \cdot \lambda^b) \tag{6}$$

The coefficients a and b are determined by means of a curve-fitting method from division curves generated with different surfaces. Figure 5 shows the results of the contact calculation in the form of the division curves for the load-carrying contact ratio and a compensation curve.

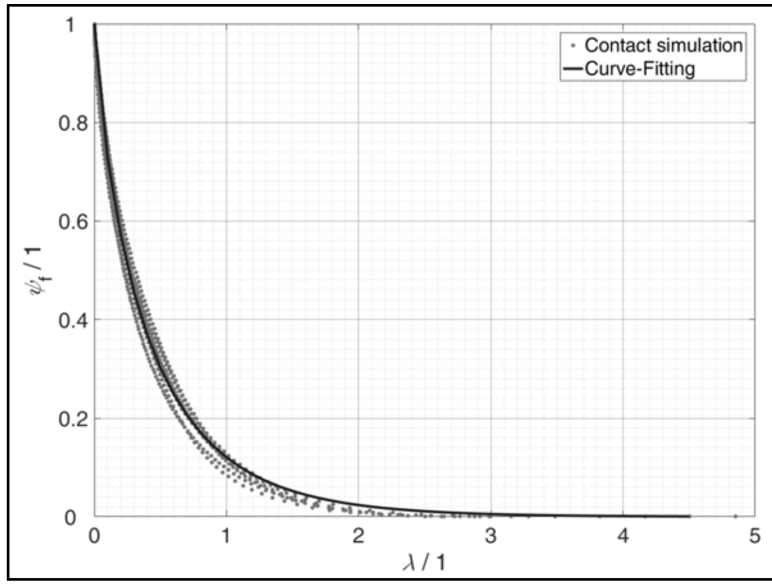

Figure 5 **Multiple dimensionless division curves for the load-carrying contact ratio from contact simulations of different measured tooth flank surfaces and compensation curve through all calculated values.**

The coefficient of boundary friction μ_{Gr} is determined as an integral parameter from friction coefficient measurements at a twin-disc test rig. These measurements are carried out using a combination of materials (steel 16MnCr5 and bronze CuSn12Ni) that are typical for power transmitting worm gear drives and representative surface structures. The additives and the temperature of the lubricant, the pressure between the friction partners, the slide-to-roll ratio (SRR) and the direction of rotation of the disks relative to each other (constant or counter-flow), are decisive influencing variables on the boundary friction coefficient, which is determined at very low hydrodynamic velocities. For the approximate calculation of the coefficient of friction between the gears, an average coefficient of boundary friction is required. The parameters of a simplified equation for the estimation of this mean boundary friction coefficient as a function of the mean pressure σ_{Hm} must be determined separately for each selected lubricant:

$$\mu_{Gr} = c + d \cdot \sigma_{Hm} \tag{7}$$

The fluid friction coefficient μ_{Fl} is determined from the shear stress of the fluid in the lubricating gap. This characteristic is calculated by the shear stress τ_{FL} relative to the mean pressure of the tooth flanks σ_{Hm}.

$$\mu_{Fl} = \frac{\tau_{FL}}{\sigma_{Hm} \cdot (1 - \psi)} \tag{8}$$

The shear stress τ_{Fl} is calculated according to the fluid model of Bair and Winer, taking into account a limiting shear stress of the fluid τ_{lim} (Eq. 9).

$$\tau_{FL} = \tau_{lim} \cdot \left(1 - exp\left(\frac{-\eta_m \cdot v_{gm}}{\tau_{lim} \cdot h_m}\right)\right) \tag{9}$$

In addition to the limiting shear stress of the fluid τ_{lim}, the mean sliding velocity v_{gm} and the mean lubricating film

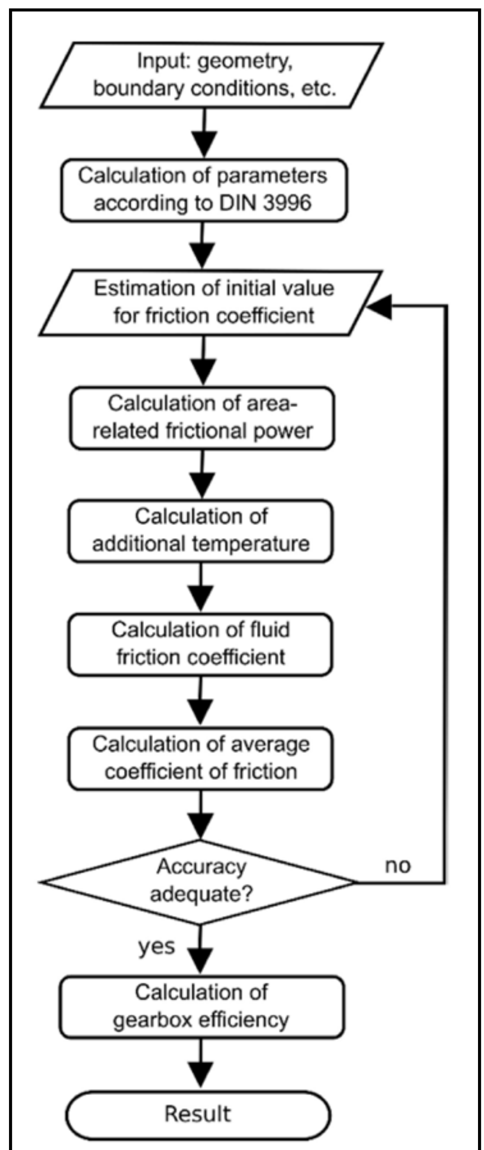

Figure 6 **Flow chart of the iterative procedure.**

thickness $h_{min,m}$, which can be calculated according to (Ref. 1), are also required to calculate the shear stress in the lubrication film. Furthermore, knowledge of the mean dynamic viscosity η_m of the lubricant in the gap is necessary. The viscosity of the fluid depends essentially on pressure and temperature. The mean pressure between the tooth flanks σ_{Hm} will be used as the pressure in the lubricating gap; the temperature in the gap must be calculated from the temperature in the oil sump ϑ_S and the flash temperature ϑ_{flash} due to the heat input caused by the friction in the contact zone. The flash temperature depends on the area-related frictional power and the mean sliding distance s_{gm}, for which the following empirical relationship is used:

$$\vartheta_{flash} = C_{th} \cdot \sqrt{\mu_Z \cdot \sigma_{Hm} \cdot v_{gm} \cdot \sqrt{s_{gm}}} \tag{10}$$

The thermal constant C_{th} was obtained using regression methods from the data base generated by the parameter study and is mainly dependent on the materials of the gears and the type of lubricant. The method for determining the lubricant temperature in the lubricating gap requires an average coefficient of friction, which is simultaneously the target value of the calculations, as an input variable. For this reason an iterative approach is required. This means that a starting value for the average coefficient of friction must be estimated and afterwards iterated until the deviation between the result and the incoming coefficient of friction comes down to a limit value. This approach is outlined in Figure 6 and explained in more detail in (Ref. 7). The presented method for the approximate determination of the average coefficient of friction shows very good overall agreement with the detailed tribological simulation method (Fig. 7).

Here, the coefficient of friction determined by means of the described approximation equations is plotted over the coefficient of friction determined with the tribological simulation. In the range of $\mu_Z > 0.04$, the deviations between the two calculation methods are, for the most part, $\Delta_{\mu Z} < 0.005$. The deviations — particularly with very small coefficients of friction ($\mu_Z < 0.03$) — can be attributed, for example, to the uncertainties in the calculation of the fluid film thickness according to (Ref. 1).

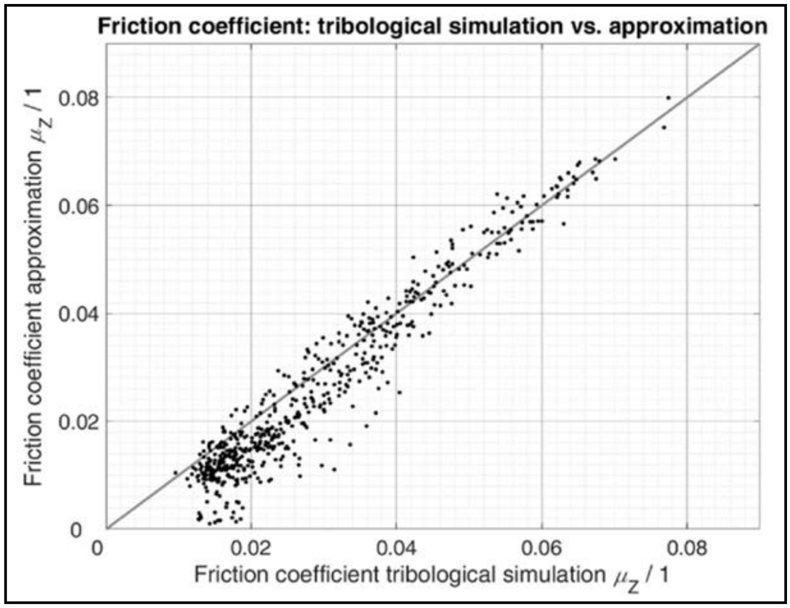

Figure 7 Comparison of the friction coefficient calculated with the tribological simulation and the values determined by approximation equations.

Conclusion

In this work a physically based method for the tribological investigation of worm gears is presented. In order to derive a standardized calculation approach, average values instead of local parameters are used for the tribological considerations — thus greatly reducing the computational effort. A comparison of the tooth friction coefficients calculated using this easy-to-handle method with the more complex, local simulation shows good agreement.

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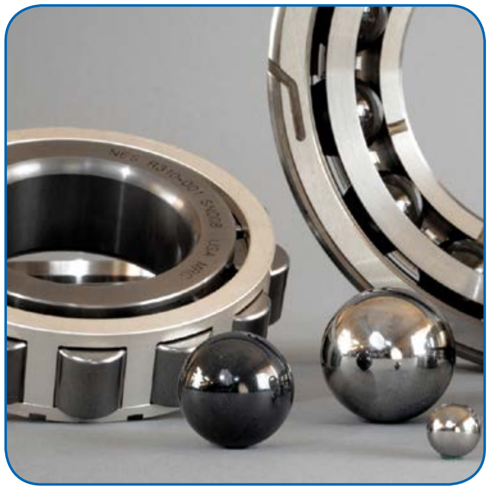
Outside of North America 716-372-6532
Fax: 716-372-1448
Email: sales@nesbearings.com
www.nesbearings.com

Napoleon Engineering Services (NES) specializes in custom bearing manufacturing. We are also the largest independent bearing inspection and bearing testing facility in North America. Our goal is to empower you with specialized bearing solutions related to custom bearing manufacturing and inspection and testing.

Why should NES be your bearing solution?

- Corrosion Resistant
- Temperature Extremes
- Load Extremes
- High Fatigue Life
- High Life Materials
- Cost Effective Solutions
- Bearing Size Range 20–350 mm
- Short Lead Times
- Small Production Runs
- High Precision Capabilities
- Advanced Design Technologies
- Over 100 years combined application experience and engineering knowledge
- Made in America



Custom Bearing Manufacturing

NES's design engineering and manufacturing capabilities provide customers with custom designed bearings without long lead times. Our knowledge and expertise allow us to analyze your application conditions and develop an advanced product that will meet or exceed your needs.

Types of Custom Bearings:

- Deep groove ball bearings
- Angular contact ball bearings
- Double-row self-aligning ball bearings
- Needle roller bearings
- Cylindrical roller bearings

Bearing Inspection & Testing

NES is the creator of inspection & testing programs supporting global bearing sourcing & bearing qualification. NES has been leading OEMs through the global bearing qualification process for 20 years providing technical information through bearing inspection, modeling and testing programs to evaluate bearing design, manufacturing capability, overall quality of workmanship, and the relationship these attributes have on bearing life. No other source has the experience, capacity or capability to service your bearing qualification needs like **NES – the World Leader**.

Industries & Applications

- Aerospace
- Defense
- Oil & Gas
- Power Generation
- Marine
- Industrial
- Transportation
- Gear Drives
- Medical
- Food Processing
- Agriculture
- Pumps/Turbines
- Generators
- Off-Highway
- Certifications
- ISO 9001:2008 Certified
- AS9100C Certified

R+W Coupling Technology

254 Tubeway Drive, Carol Stream, IL 60188
Phone: 630-521-9911
Fax: 630-521-0366
Email: info@rw-america.com
www.rw-america.com

R+W has always stayed in the forefront of breakthrough coupling technology and does its best to exceed customer's requirements and expectations. An ever-expanding product line helps them design the most optimal solution for nearly every application in any industry.

The most recent expansion of the ST product line shows the commitment that this company has to take on new markets and provide more customers with overload protection. A newly updated torque limiter department with its own facility has been created to focus on customization efforts. This line of new industrial safety clutches has undergone vigorous testing not only at the company's R&D center, but also at partnered Universities in Germany including RWTH Aachen and University of Bayreuth. The added models feature new sizes as well as connection methods to provide more options than ever before.

Over the past 25 years, R+W has established itself as a precision couplings expert, and with these new safety coupling additions it plans to expand its expertise into the industrial sector as well. As always, customer's demands are top priority as engineers are ready to assist with customized solutions for complex coupling applications. Find out what the coupling technology leaders can do for you and get the best connection, worldwide.

RW-AMERICA.COM

R+W®
A POPPE + POTTHOFF COMPANY

Schaeffler Group USA Inc.

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Fax: 803-548-8599
Email: info.us@schaeffler.com
www.schaeffler.us

Schaeffler Engineering: Greater Than the Sum of Our Parts

When it comes to bearings, Schaeffler, together with our INA and FAG brands, has always been at the forefront of technological innovation. Industry firsts - such as the development of the needle roller & cage assembly, or the groundbreaking ball grinding machine that is regarded as the foundation of the entire rolling bearing industry - have earned Schaeffler a unique distinction among the world's great bearing companies.

SCHAEFFLER

With nearly 90,000 employees working in approximately 170 locations in over 50 countries, Schaeffler is one of the world's largest technology companies in family ownership.

In addition to rolling bearings for practically any application, linear bearings and guidance systems are also a vital part of Schaeffler's product portfolio. Unrivaled in scope and versatility, Schaeffler's linear product lineup ranges from shafts with linear ball bearings and monorail guidance systems to sophisticated actuators with drives and control systems, plus special coatings and every conceivable accessory.

PWG Differential Roller Screw

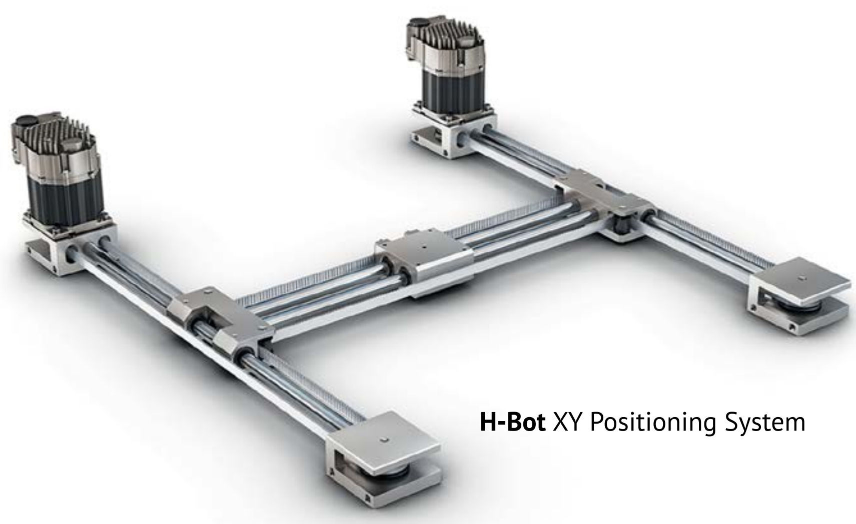
But that's only the start. Schaeffler's linear portfolio is based on a modular concept that goes far beyond mere components. We can design a complete system solution tailored to the customer's specific application - from large gantry robots to intricate circuit board inspection systems. In fact, many of our linear guidance systems started out as solutions to customers' needs! Case in point: Schaeffler's ingenious H-Bot XY positioning system.

Sometimes, of course, a Schaeffler solution comes about because a customer's needs were not being met by the conventional standard. Such is the case with Schaeffler's innovative differential roller screw. Within the pantheon of traditional mechanical/linear drive systems, the screw category has been limited to lead screws, ball screws and roller screws.

Until now, that is.

In response to a customer's request for a solution that better addressed its ambitious price-performance target, Schaeffler recently developed the PWG differential roller screw: a new option that offers the high forces of a traditional roller screw, but at a price point closer to a ball screw.

So while innovative products make up the heart of Schaeffler's offerings to our customers, service represents the soul of what we do. Because when it comes to linear guidance systems, Schaeffler has all the pieces; you only have to supply the puzzle. Together, we'll create the perfect linear solution… yours.



H-Bot XY Positioning System

2018 Engineering Showcase

Zero-Max

13200 Sixth Avenue North, Plymouth, MN 55441-5509
Phone: 763-546-4300
www.zero-max.com

Innovation & Leadership

For over 60 years, Zero-Max, Inc. has created innovative solutions to motion control problems worldwide. With strategic distribution points located throughout the world, Zero-Max can deliver your motion control solution.

The Zero-Max team of application specialists can engineer a solution to meet your motion control requirements. With many years of application experience Zero-Max excels in these areas: • Experienced Practical Application Advice • Responsive to customer needs • Predictable high quality • Fast Delivery • Integrity • High Value • ISO 9001: 2008 certified •Configurable 3D CAD downloads

Zero-Max Primary Product lines include: Shaft Couplings and Torque Limiters for Servomotors, Linear Actuators, Wind Turbines, Printing Presses, Label Printing, Converting Machines, Machine Tools, Test Equipment, Feedback devices, Packaging Machines, Process Equipment, Dynamometers, and other high performance applications.

Variable Speed Mechanical Drives for Agricultural, Printing, Peristaltic Pumps, Food Processing, Pharmaceutical, Packaging, and many other applications.

Overhung Load Adaptors for Timber processing, Brush Clearing, Road Construction, Marine, and other rugged applications that need overhung load protection for hydraulic pumps and motors.

Keyless Locking Bushings for Packaging, Processing, Tooling, Automated Assembly, and applications that would benefit from the unique qualities of these bushings.

Gear Technology

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E-mail: publisher@geartechnology.com
www.geartechnology.com

Gear Technology is where the world turns for information about gears and gear manufacturing. We reach a broad-based audience of gear industry professionals involved with every phase in the life of gears and geared products, from conception to design, from design to manufacturing, from manufacturing to inspection, from inspection to purchase and from purchase to end use.

Our magazine, website and e-mail newsletters are read in more than 60 countries around the world, at huge multinational corporation and small job shops, in high-tech engineering offices and on the factory floor.

If you have an interest in gear design, engineering or manufacturing, you should subscribe at: *www.geartechnology.com/subscribe.htm*

If you have an interest in reaching our audience of gear industry professionals, you should look into our advertising options at: *www.geartechnology.com/adinfo.htm*

Brother Gearmotors

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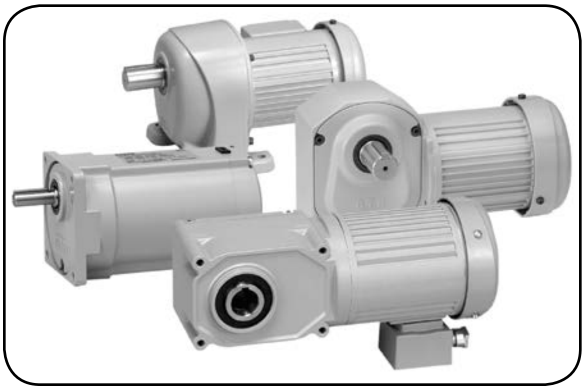
Customer Service: gearmotors@brother.com
Technical Support: gearmotortechnical@brother.com
www.BrotherGearmotors.com

A division of Brother International Corporation, Brother Gearmotors offers a wide range of high-quality, sub-fractional AC gearmotors and reducers in demanding industries such as food & beverage, packaging and material handling. Brother Gearmotors is one of the world's largest fine-pitch gear manufacturers, meeting ever-increasing demands for smaller, lighter, more reliable and energy-efficient power transmission and motion control components.

brother
at your side

Virtually maintenance-free, Brother's ie3 gearmotors are sealed for life with universal mounting options that offer maximum flexibility. ie3 gearmotors feature a hypoid/helical combination that maintains a compact drive package at higher ratios, and also run cooler and with less noise. A key factor in their enhanced durability is Brother's ultralong-lasting e-coat paint.



Among other offerings, the Brother Gearmotors recently introduced a line of Brushless DC gearmotors (BLDC) ideal for environments requiring virtually maintenance-free operation and accurate speed control, as well as operation over a wide speed range. Cost-effective, compact and long-lasting, the brushless gearmotors are especially desirable for settings where brush dust contamination must be avoided, or where brush contact arcing could affect sensitive equipment.

Sesame Motor

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www.sesamemotor.com

Sesame Motor Corporation was founded in 1990 as a manufacturer of motors and gear reducers in Taiwan. Our main products include precision **planetary gearbox**, **gear reducer**, **gear motor** and **AC motor**. SESAME lines of planetary gearbox offer a wide variety of size, precision levels and configurations to satisfy the full range of applications from highly dynamic control to very simple motion profiles. All are competitively priced and provided in industry standard dimensions to help users select the best power transmission solution.

Step forward is the only way to stay ahead in this time of rapidly changes. Sesame Motor well experienced production and engineering teams offer support and quick respond to unique demands and customized requirements. Products are provided to be used in machine tools, industrial robots, semiconductor devices, aerospace industry, medical and rehabilitation equipment, palletizer robots, green energy related industries and precise automation equipment with servo motors.

The clients are also assured of receiving **CE**, **CCC** and **UL** certified products by an **ISO9001** and **ISO14001** certified company.

SESAME®

America Exclusive Agent
DIEQUA
Corporation

The Timken Company

AWARDS 17 SCHOLARSHIPS TO CHILDREN OF EMPLOYEES AROUND THE WORLD

The Timken Company has awarded college scholarships to 17 children of Timken associates in 13 locations around the world today. These scholarships — valued at up to $540,000 over a four-year period — are funded by The Timken Company Charitable and Educational Fund, Inc. Since the program's inception in 1958, it has awarded more than $23 million in scholarships to deserving students.

Chairman John M. Timken, Jr. hosted the recognition event for students and their families at The Timken Company World Headquarters in North Canton, Ohio. Local scholarship finalists attended the event in person, while other finalists and their parents joined via global webcast. "This year marks the 60th anniversary of our scholarship tradition," said Timken. "Throughout the years, our alumni have used their scholarships as an opportunity to make a positive impact on the world through their careers, and I am confident this year's class will go on to do the same."

The $140,000 Henry Timken Scholar Award recognizes the top-ranked applicant. This year's Henry Timken Scholar is Nicholas LaPlant, the son of Scott LaPlant, manager of manufacturing technology at the company's bearing plant in Asheboro, N.C. Nicholas, a senior at Randolph Early College High School, will study biomedical engineering at Duke University. Nicholas aspires to someday be a physician.

The $100,000 Jack Timken Scholar Award was presented to Smriti Suresh, the daughter of Suresh Kumar, head of mobile industries in the company's technology center in Bangalore, India. After graduating from the Indian Institute of Technology in Bombay, Smriti plans to work for a multinational company in the field of data analysis.

Five students received $40,000 scholarships:

- **Natalia Bożek,** the daughter of Anna Bożek, leader — payroll and personnel administration in Sosnowiec, Poland. A senior at Ignacy Jan Paderewski High School No. 10 in Katowice, Natalia plans to study law at Jagiellonian University.
- **Louisa Frank,** the daughter of Sylvia Erdmann, manager — account coordination in Düsseldorf, Germany. When she graduates Carl-Fuhlrott Gymnasium, Louisa plans to study international management at Otto Beisheim School of Management.
- **Alvia Ghazal,** the daughter of Raisul Azhar, operating technician in Jamshedpur, India, is a student at Loyola School. She plans to study psychology at the National University of Singapore.
- **Luke Herman**, the son of Daryl Herman, application engineer at Timken Belts in Springfield, Mo. A senior at Nixa High School, Luke plans to study entrepreneurship and recording arts at Missouri State University.
- **Corrine VanNatta,** the daughter of Christopher VanNatta, manager — HR and global benefits in North Canton, Ohio. After graduating Hoover High School in Canton, Corrine plans to study biomedical engineering at Mount Union, the University of Akron or Case Western Reserve University.

In addition, ten individuals received $10,000 scholarships:

- **Katherine Blauner,** daughter of Brett Blauner, national sales manager — automotive aftermarket in Canton, Ohio. Katherine is a senior at Jackson High School in Massillon. She plans to study finance and accounting at Lehigh University.
- **Davis Graham,** son of Tim Graham, vice president — supply chain in North Canton, Ohio. After graduating from Jackson High School in Massillon, he plans to study chemical and biomolecular engineering or cellular and molecular biology.
- **Ketan Ilu,** son of I. Muralidhar, senior manager — supply chain management in Chennai, India. A student at Maharisi International Residential School, he plans to study engineering at the Indian Institute of Technology upon graduation.
- **Zhongyu Jiang,** son of Karl Jiang, supplier quality development manager — East Asia in Wuxi, China. After he completes high school at Wuxi No. 1, he plans to study environmental engineering at the Tongji University.
- **Parker Johns,** son of Clark Johns, manager — quality assurance in Gaffney, S.C. A senior at Dorman High School, Parker plans to study chemical engineering at Brigham Young University upon graduating.
- **Sarah Johnson,** daughter of James Johnson, plant engineering manager in Honea Path, S.C., is a senior at TL Hanna High School in Anderson. She plans to study aerospace engineering at Virginia Tech.
- **Pauline Koch,** daughter of Jean-Rene Koch, application NVH specialist in Colmar, France. A student at Lycée Ribeaupierre, Pauline plans to study engineering at Lycée Kléber.
- **Chesley McDonald,** son of Steve McDonald, plant manager in Springfield, Mo., is a student at Logan-Rogersville High School. He plans to study economics and applied mathematics at the University of Arkansas or the University of Missouri.

- **Josh Miller,** son of Mark Miller, principal development engineer in North Canton, Ohio, currently attends Tuslaw High School in Massillon. He plans to study computer engineering at Cedarville University.
- **Aashwin Raj,** son of Virendra Prasad, operating technician in Jamshedpur, India, plans to study nuclear physics and engineering at the Massachusetts Institute of Technology upon graduating Arihant Public School in Kota Rajasthan. (*www.timken.com*)

Brother Gearmotors

ANNOUNCES NEW NATIONAL SALES DIRECTOR

Brother Gearmotors has named Dan Lydigsen as national sales director. In this role, Lydigsen will manage all sales team members for Brother Gearmotors throughout the United States and Canada.

During his thirteen-year tenure with Brother's Business Machine Group, Lydigsen accrued an exemplary reputation while rising through the ranks. Most recently, he was director of sales, machine group for the company's direct market reseller channel. Before that, Lydigsen served as key account manager, machine group for OfficeMax.

"Dan's sales success and leadership qualities made him a natural choice to lead our team of talented sales professionals," said Matthew Roberson, vice president of Brother Gearmotors. "Inter-company talent transfer is refreshing and motivating—it helps the entire Brother group grow and develop. It's an exciting time for the company, with several new products, and we're confident that Dan's stewardship will lead to continued market growth for Brother Gearmotors."

Lydigsen earned a B.A. in business administration and anthropology from Illinois Wesleyan University. He is a founding board member of the Sgt. Thomas M. Gilbert Memorial Foundation. A father of two, he resides in St. Charles, Illinois with his wife. (*www.brother-usa.com/gearmotors*)

Sulzer

PUMP FIELD SERVICES HELP MAINTAIN RELIABILITY AND EFFICIENCY

Large pumps, such as those operated in the oil and gas, power generation and water industries perform a crucial role and represent a significant investment by the owner. Safeguarding these assets and maintaining efficiency and reliability are vital for the continued productivity of the application. Very often, when it comes to maintenance, the choice is between the original equipment manufacturer (OEM) or an independent service provider (ISP), but it is possible to have the best of both worlds.

The aftermarket support of large pumping equipment needs to be of the highest standard in order to ensure the availability of the equipment. Ideally this would involve the expertise and engineering knowledge of the OEM combined with the flexibility and wider experience of the independent service provider.

Maintenance, repair and rerating work is preferably completed during planned shutdown periods, but this requires precise planning and efficient execution to deliver each project on time. The ideal world, however, does not account for unplanned events that need to be resolved at the earliest opportunity.

In order to achieve the optimum balance, it is essential to establish clear communication with the customer. Creating a local presence that can deliver a comprehensive range of services and expertise through a single point of contact ensures a transparent repair process and confidence for the plant owner.

Modern pump design and maintenance incorporate advanced levels of engineering that require those involved in the maintenance processes to be properly equipped and trained. As a leading OEM of pumps and pumping solutions, Sulzer has all the necessary design and manufacturing expertise required to repair and rerate large pumps.

In addition, Sulzer provides an independent maintenance service for pumps of almost any description. The service teams that deliver this support are some of the most experienced and well supported in the field, capable of delivering large-scale projects on time. (*www.sulzer.com*)

Dellner Brakes

ACQUIRES PINTSCH BUBENZER

Sweden's Dellner Group with its subsidiary Dellner Brakes has signed an agreement to acquire German industrial braking manufacturer Pintsch Bubenzer in a deal that will pave the way for the companies' rapid global expansion.

This acquisition is being carried out in partnership with investment company Active Ownership Capital and comes just four months after Dellner Brakes acquired U.S. brake and clutch company Gummi USA. It is a significant step in the Swedish company's focused ambition to become the world's leading supplier of brakes and related power transmission products.

Pintsch Bubenzer is a globally leading manufacturer of brakes for harbor container cranes and has around 300 employees. Dellner Brakes and Pintsch Bubenzer will continue to operate both brands from their existing global locations. Furthermore, the enlarged group plans to open several new offices around the world over the next 12 months.

Dellner Brakes CEO Marcus Aberg said: "This acquisition is a strategic decision and marks the start of a new era for our organization. It will facilitate major global expansion for both companies and will also enable us to build the Dellner Brakes and Pintsch Bubenzer brands in the industrial market sector."

Both companies operate globally offering braking products for a range of applications including materials and container handling, industrial automation, ports and shipping, mining, wind energy, oil and gas. Dellner Brakes offers its 'stopping, turning, locking' (STL) system including a world first, patent pending all electric version. Notable products from Pintsch Bubenzer include its new, patented BUEL electro hydraulic thruster. (*www.dellner-brakes.com*)

March 22–23—PTDA Leadership Development Conference San Antonio, Texas. PTDA 2018 Spring Meetings combine governance meetings and the Leadership Development Conference to offer networking opportunities along with powerful education for those looking to enhance their leadership skills and to achieve the goals set forth in the PTDA Strategic Plan. The PTDA Leadership Development Conference is for any up-and-coming leader, including Next Genners or established leaders seeking a skill set refresh. Step up your leadership game, while networking with your power transmission/motion control industry peers in an intimate and relaxed setting. Educational sessions are designed for emerging and seasoned executives who want to build executive leadership skills. Open to all employees of PTDA member companies. For more information, visit *www.ptda.org*.

April 3–6—Basic Training for Gear Manufacturing (Spring) Hilton Oak Lawn, Chicago, Illinois. Learn the fundamentals of gear manufacturing in this hands-on course. Gain an understanding of gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. Utilizing manual machines, attendees will develop a deeper breadth of perspective and understanding of the process and physics of making a gear as well as the ability to apply this knowledge in working with CNC equipment commonly in use. Instructors include Dwight Smith, Peter Grossi and Allen Bird. For more information, visit *www.agma.org*.

April 26–28—AGMA/ABMA Annual Meeting 2018 The 2018 Annual Meeting combines the expert knowledge of the gear and bearing industries with the latest emerging technologies that influence manufacturers and suppliers. More than 300 executives will gather this April to experience the information-packed week full of top-tier speakers. Members will be connected to innovation and opportunities in the industry with potential to strengthen business connections and relationships. Join AGMA & ABMA for an event that is tailored directly for its members to address trends, successes and future possibilities. For more information, visit *www.agma.org*.

April 30–May 3—OTC 2018 Houston, Texas. The Offshore Technology Conference (OTC) is where the world's energy professionals meet to exchange ideas and opinions to advance scientific and technical knowledge for offshore resources and environmental matters. OTC is the largest global event for the oil and gas sector featuring approximately 2,000 exhibitors and attendees from across the globe. The event provides excellent opportunities for global sharing of technology, expertise, products, and best practices. OTC brings together industry leaders, investors, buyers, and entrepreneurs to develop markets and business partnerships. Technical highlights include updates on world-class projects, offshore renewable energy, the digital revolution, safety and risk management and more. For more information, visit *2018.otcnet.org*.

May 6–9—CIM 2018 Convention Vancouver, British Colombia. Founded in 1898, the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) is the leading technical society of professionals in the Canadian Minerals, Metals, Materials and Energy Industries. The CIM Convention and Expo features 450+ companies showcasing the latest in mining equipment, tools, technology, services and products. The event includes plenary sessions intended to bring focus and start dialogue around the conference theme of "Thinking Differently." Leaders from all aspects of mining and some from unexpected tangential sectors are brought together in these thought-provoking discussions. For more information, visit *convention.cim.org*.

May 7–10—AWEA Windpower 2018 Chicago, Illinois. Windpower 2018 is the wind industry's premier North American event with wind energy professionals from all over the world gathering in one place. It's the most effective way for attendees to expand their knowledge base and business network. With competitive pricing and stable policy in place, the wind industry is booming. Now the industry can focus on the future and the other drivers that will propel the industry forward through the 2020s. The program will feature speakers with "disruptive" and innovative ideas that will continue to strengthen wind energy's value proposition and challenge the current way we do business. Attendees will hear about how technology advances will continue to lower LCOE, and learn lessons from other industries that are more mature or have experienced similar rapid growth. They will also receive updates on: state policy support, transmission infrastructure efforts, and emerging and growing offtake trends. For more information, visit *www.awea.org*.

May 7–10—AISTech 2018 Philadelphia, Pennsylvania. This event will feature technologies from all over the world that help steel producers to compete more effectively in today's global market. AISTech 2018 provides perspective on the technology and engineering expertise necessary to power a sustainable steel industry. More than 7,000 people are expected to attend AISTech 2018. Along with over 500 exhibiting companies, AISTech 2018 allows attendees to meet face-to-face with key individuals involved in the production and processing of iron and steel. The comprehensive conference schedule includes topics on metallurgy, safety, material handling, energy, maintenance and reliability, lubrication and more. The Association for Iron & Steel Technology (AIST) is a non-profit organization with 17,500 members from more than 70 countries. For more information, visit *www.aist.org*.

May 7–11—NPE 2018 Orlando, Florida. NPE2018 provides exclusive access to the innovations, people, processes, science and ideas that are shaping the future of plastics. Attendees will build connections, exchange ideas and explore the largest concentration of machinery, tools, technology and professional training available in today's plastic industry. On the show floor, attendees will meet with the 2,000+ of the world's leading plastic manufacturers and suppliers to gather important information and insights on the latest equipment, products and materials for every phase of plastics production. Focus areas include 3D/4D printing, moldmaking, material science, medical parts, processors and more. For more information, visit *www.npe.org*.

The Automated Industrial Community

Hannover Messe 2018 will focus on mobility, integration and collaboration

Matthew Jaster, Senior Editor

"Integrated Industry: Connect & Collaborate" is the theme for Hannover Messe 2018 (April 23–27, 2018) and once again robotics, automation and motion control will play a large role in Germany. Robotic companies, system integrators and providers of gripper systems are breaking new ground in human/machine collaboration.

"The range of Industry 4.0 solutions coming out of the robotics industry at the moment is truly vast," said Arno Reich, global director automation for Hannover Messe. "That is why the robotics and automation showcase is a major attraction for all visitors at Hannover Messe. All areas of the manufacturing industry are improving their production processes and outputs by integrating industrial robots, mobile robots, automated guided vehicle systems and industrial image processing solutions. The applications of these technologies are growing all the time, thanks to innovations like touch-sensitive robotic technologies, pack-and-place solutions and barrier-free, collaborative robots."

Visitors should check out the Robotics, Automation and Vision Application Park in Hall 17 as well as the Automation Forum in Hall 14. The forum lectures will have a dual-focus on R&D and in-factory applications.

Planning on attending the show this year in Hannover? Here are a few booths that will feature products and technologies regularly featured in *PTE*:

Siemens (Hall 9, Stand D35)

The technical prerequisites for the implementation of Industry 4.0 are readily available with the Siemens Digital Enterprise: the connection of the virtual and the real world of production along the entire value chain based on profound industry knowledge and unique expertise in the fields of electrification, automation, and digitalization. At the Siemens booth, attendees will see how the seamless interaction of automation hardware, software, and services is already paying off in many industries and in companies of all sizes. They will learn first-hand how the process and manufacturing industries are already benefiting from digitalization: from customized industry solutions for the simulation of machines and equipment with digital twins, from MindSphere, the open IoT system for more connectivity and data sharing, and from comprehensive cyber security. (*www.siemens.com*)

Schaeffler (Hall 22, Stand D49)

At the Hannover Messe 2018, Schaeffler will be presenting intelligent solution packages for machine monitoring and lubrication, illustrated using reference projects. One such customer is the Perlenbach water supply association, which supplies fresh drinking water to roughly 50,000 residents in seven municipalities of Germany's Eifel region every day. Ensuring fault-free and reliable operation would mean manning and monitoring the association's facilities 24 hours a day, since bearing defects in the centrifugal pumps could cause them to fail and compromise the security of the water supply. Perlenbach therefore decided to utilize a system that would continuously monitor

and lubricate the machinery. In Schaeffler, the water supply association found an expert partner to help implement a predictive maintenance system.

Together with the Concept8 lubricator, the preconfigured SmartQB condition monitoring system ensures fault-free operation. The stand-alone complete solution detects irregularities in electric motors, pumps, fans, and the rolling bearings that all of them contain. The SmartQB identifies the potential cause of failure — whether it's bearing damage, imbalance, friction, a temperature increase, or changes to the vibration pattern — and gives a clear text notification of the findings. The integration of the system, which was developed in partnership with Mitsubishi Electric, into the control room visualization means that maintenance personnel are informed of incipient damage at an early stage and can immediately initiate maintenance measures and procure any replacement parts that might be needed. (*www.schaeffler.com*)

Beckhoff Automation (Hall 9, Stand F06)

Beckhoff provides the foundational technologies and tools needed today to implement Industrie 4.0 concepts and Internet of Things (IoT) connectivity, all via PC-based control. TwinCAT engineering and control software packages are available for the creation of applications such as Big Data, pattern recognition as well as condition or power monitoring, in addition to traditional control tasks—which can sustainably increase production and engineering efficiency as a result.

The Beckhoff AM80xx, AM81xx, AM85xx and AM88xx servomotor series represent robust, durable and high-performance synchronous servomotors, made in Germany. The AM80xx motors are ideal for applications with highest demands on dynamics and performance. The AM88xx series is the equivalent with stainless steel housing and shaft for use under IP 67 or IP 69K conditions. The AM85xx series offers an increased rotor moment of inertia for applications with large loads and high synchronism requirements. The AM81xx motors enable compact drive solutions in combination with the EL7201-0010 servo terminal. All motors of the AM8xxx series require only one motor connecting cable, since the feedback system's encoder information is transmitted digitally via two cores of the motor cable. The One Cable Technology (OCT) leads to a considerable saving in material and reduces installation and engineering costs. (*www.beckhoff.com*)

B&R Automation (Hall 9, Stand D26)

B&R combines state-of-the-art technology with advanced engineering to provide customers in virtually every industry with complete solutions for machine and factory automation, motion control, HMI and integrated safety technology. Here are some highlights from the upcoming Hannover Fair.

HMI Solutions

With mapp View, B&R now offers direct access to the wide world of web technology right from the engineering environment. For the first time, automation engineers have all the tools they need to create powerful and intuitive HMI solutions - and they don't have to know HTML5, CSS and JavaScript do to it. This solution relies 100% on web standards to ensure content can be viewed optimally on any output device or even customized for specific users or user groups. What makes mapp View unique is the way it integrates web technology right into the engineering environment. While mapp View is built on HTML5, CSS3 and JavaScript, automation programmers never need to deal with these languages. All GUI functionality is encapsulated in modular control elements called widgets, which are simply dragged and dropped into place and configured. Since content and layout are separated, designs can be adjusted at any time or even used on other machines. Automation engineers have all the tools they need to create powerful and intuitive HMI solutions.

ACOPOSmotor

The ACOPOSmulti has always been extremely modular, and it was the next logical step to merge inverters with the motor to create 8DI ACOPOSmotor modules that can deliver power directly where it is needed. This allows configurable modules to become easily connected mechatronic devices. It also makes it possible to reduce delivery times, free up valuable floor space and simplify commissioning.

Stainless Steel Motors

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Built for Speed

Japan's Electric Aspark Owl Does 0-to-60 MPH in 1.9 Seconds!

Jack McGuinn, Senior Editor

The feat doesn't compare with breaking the sound barrier for the first time—but try and tell street-legal hyper car enthusiasts that.

We are referring to the fact that on February 11, Japan's Aspark Owl electric hypercar tested at 0–60 mph in 1.9 seconds—a "ridiculous" achievement, as *Top Gear* (*topgear.com*) describes it. For perspective, the Owl outdid familiar, gas-powered beasts such as the Bugatti Chiron (2.3 seconds) and the Lamborghini Aventador (2.7 seconds). Of perhaps greater apples-to-apples, competitive significance, the electric Aspark Owl's 1.9 seconds has easily eclipsed the 0–60 performance of the Tesla Model S P100D (2.28 seconds). Beyond *Top Gear*, the Owl's performance has captured the attention of industry publications *Car and Driver (caranddriver.com)*, *Jalopnik (jalopnik.com)*, *Motor Trends (motortrends.com)*, and—a seemingly less likely source—*Forbes (forbes.com)*.

Then again, perhaps *Forbes'* coverage of the event does in fact make sense, in that much of the magazine's readership is comprised of millionaires and billionaires. You see, the Aspark Owl carries a price tag of *$4.4 million dollars,* and only 50 units will be produced. One wonders what the dreaded "destination fee" could be for such a vehicle; and leasing is probably not an option.

Aspark Co. Ltd., R&D division, announced in early 2014 its intention to produce "the world's fastest accelerating electric car." Just *Google* Aspark Owl and you'll be taken to sites with photos and videos galore; *Facebook* is a likely resource and seems to be the only online source with video showing the Owl's engine. (In fact, the Owl has two engines—one for each axle.) The carmaker—referred to by *Jalopnik* as "a mysterious Japanese company that is primarily a technical consulting firm"—is indeed a bit—*mysterious*.

But check it out at *aspark.com*; there you'll find photos of the car and home movie-looking video of the acceleration test. Speaking of which—unless you've got some skin in the game as an investor or are part of the design-and-build crew—the test is about as exciting as listening to the grass grow. 1.9 seconds? Blink or sneeze—you've missed it.

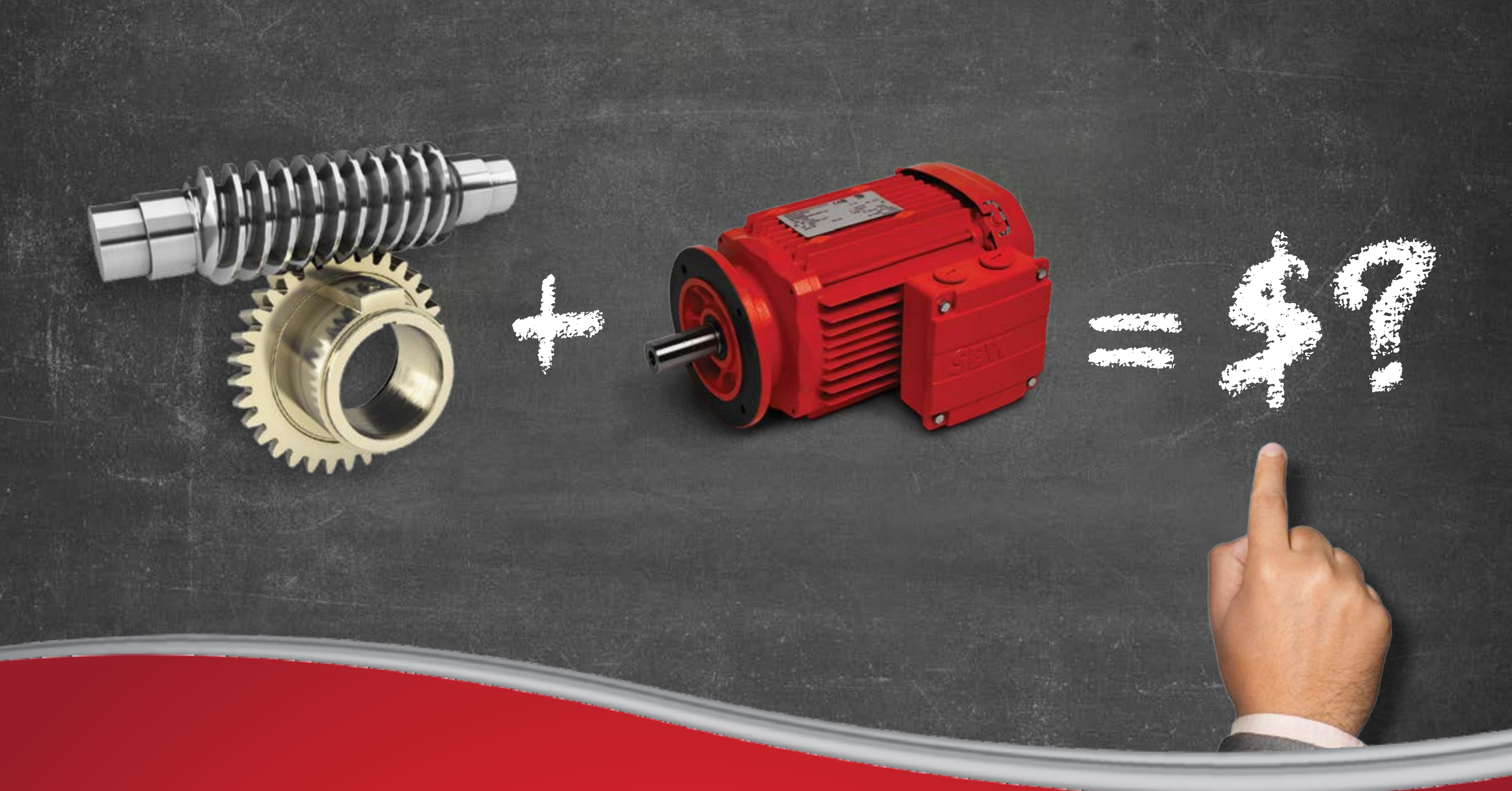
There is also a caveat regarding the 1.9 mark. The Owl was outfitted with what some refer to as non-street-legal Hoosier racing tires to accommodate the Owl's 563 all-wheel lb-ft of torque. Nevertheless, as *Jalopnik's* Bradley Brownell puts it, "A 1.921-second 0–60 is a 1.921-second 0–60." Also pointed out is the fact that most of power used to run the car was provided by "super capacitors" rather than batteries.

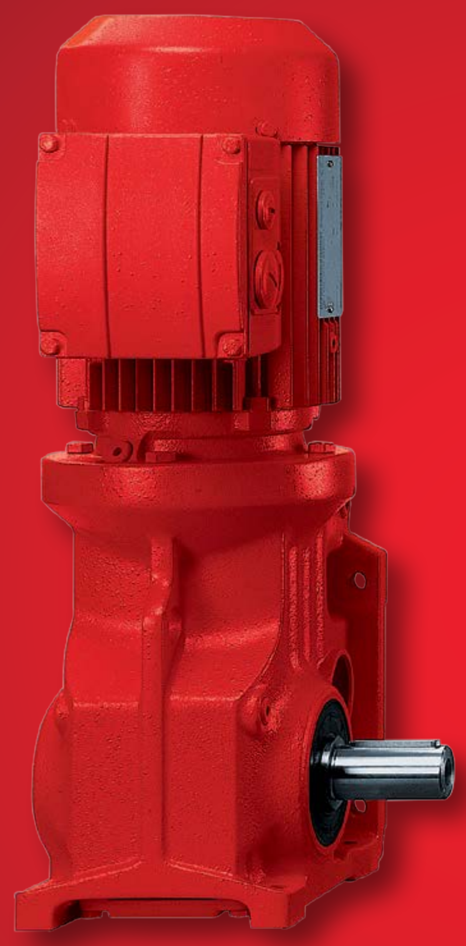
Introduced at the 2017 Frankfurt International Auto Show, the Owl claims 430 hp as well as all that torque, and weighs in at a light-weight 1,900 lbs. Described at *Jalopnik* as having a "space frame wrapped in a carbon fiber body," the car somehow reminds of a cigarette boat on wheels. Upon first sight—it looks a bit batty—as in Batmobile. It's also a mere low-riding 39 inches tall.

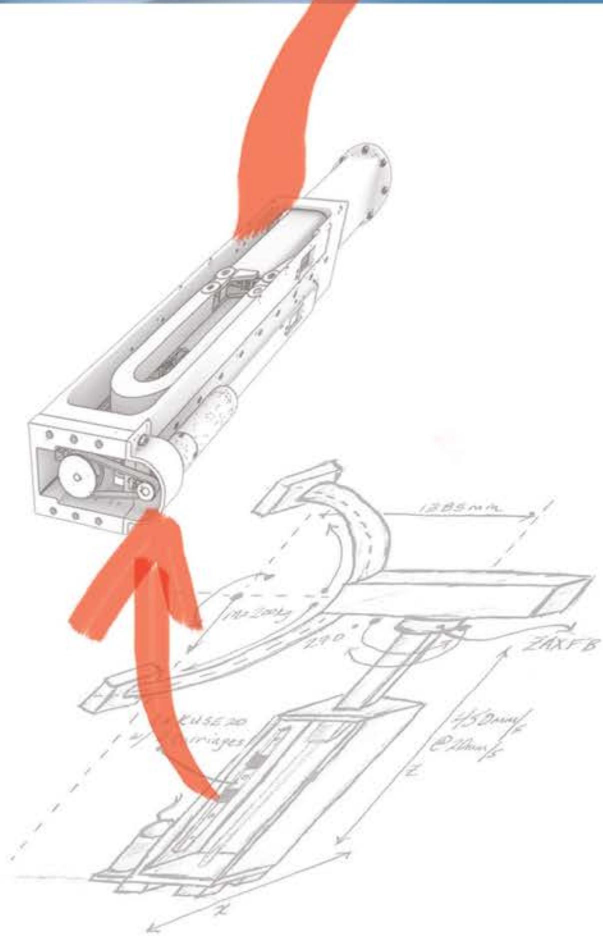
Also, according to *Jalopnik*, "(The Owl team) apparently prioritized weight over range, as the car only promises 93 miles of total driving distance per charge. Between the resulting light curb weight, a 4.44 final-drive ratio, and enormously wide tires to take all that torque (275 section fronts and 335s out back), the recipe for success seems like it might be there." And, the site reports, "The body only weighs 110 pounds—leaving the remaining 1,790 pounds to the chassis, powertrain and drivetrain."

This all sounds sexy and exciting. But a question presents: Who would need a car that does 0–60 in 1.9 seconds? What do or can you do with it? Where, except maybe the Autobahn, can you safely put such a car through its paces without ending up with a fistful of speeding tickets—or worse? Yes, we all have our moments of goosing the speed limit, but that's often because maybe, for example, we're running late for something important. The Owl, says *Jalopnik*, "could soon become the zippiest car you'll ever pull up next to at a stoplight." OK—imagine two cars waiting out a red light—one the Aspark Owl, the other a Ford Focus. Waiting for the green light, are you the one anxiously revving the engine as you prepare to race off in the 0–60-in-1.9-seconds Owl? Or are you the one in the Ford, maybe obliviously listening and seat-dancing to Fleetwood Mac?

Perhaps the answer is that if you can afford to buy one, you can afford to develop your very own proving grounds-type property where you can satisfy your need-for-speed fixation without killing anyone. An expensive hobby for sure, but when money is no obstacle the Aspark Owl should provide many hours of speeding-like-crazy enjoyment. **PTE**







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