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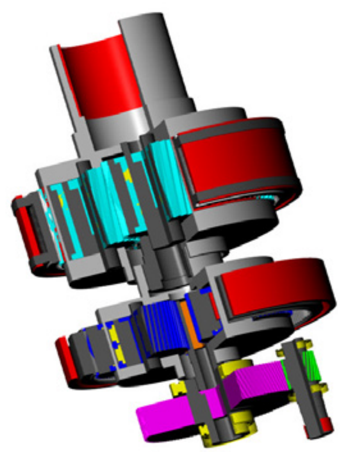

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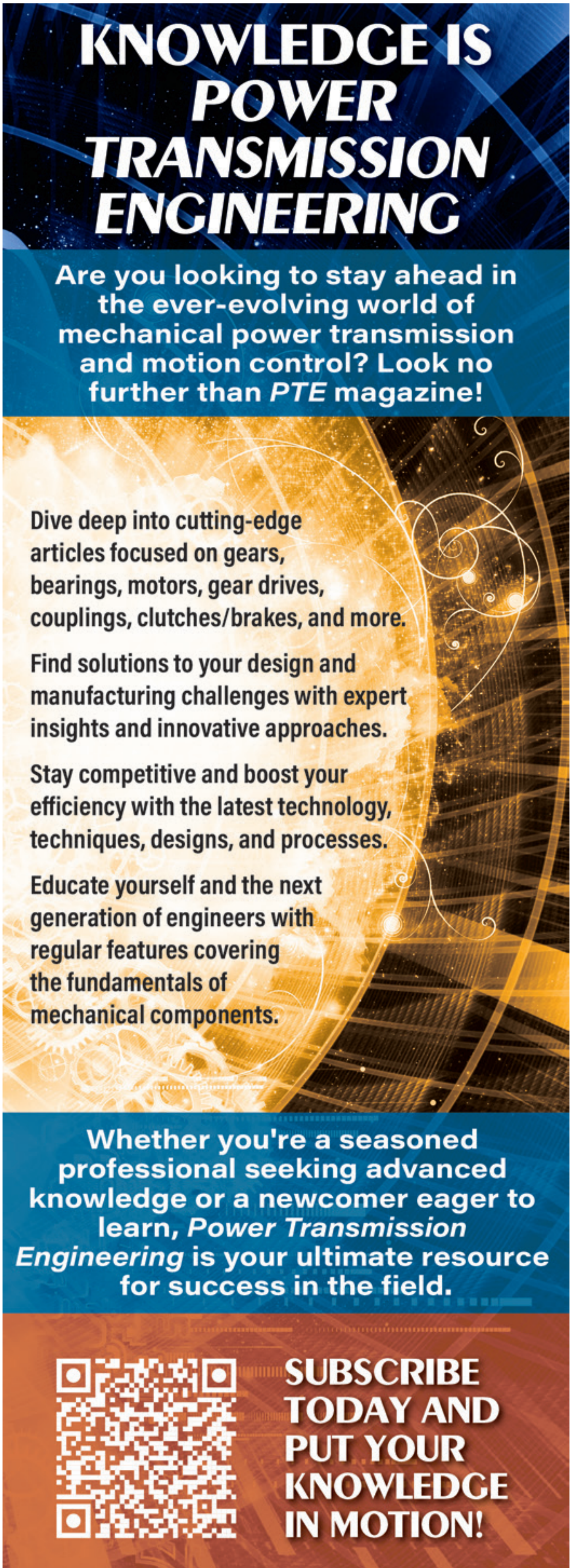


Power Transmission Engineering®

VOL. 18, NO. 5

PTE REVOLUTIONS

AGMA Tackles Electrification Topics

LIFT in Detroit was the perfect host for the AGMA Technical Division to lead a recent meeting on EV standards development. Gear and power transmission engineers who work directly on gearboxes for electric vehicles came together to review current relevant standards and create an information sheet for gears specific to EVs.

powertransmission.com/blogs/1-revolutions/post/9901-agma-tackles-electrification-topics

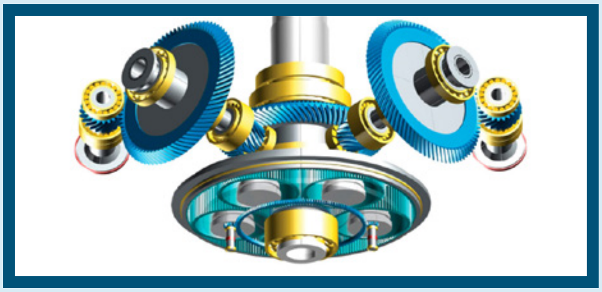
Engineering Legacy: Diamond Chain Company (1890)

The "Engineering Legacy" series gives historical context to mechanical power transmission components featured in PTE. Diamond Chain's products were integral in many historical breakthroughs, including the Wright Brothers' first flying machine, Henry Ford's first automobile, and numerous motorsport champion vehicles.

powertransmission.com/blogs/1-revolutions/post/9884-engineering-legacy-diamond-chain-company-1890

AS SEEN IN *GEAR TECHNOLOGY*

Flexible Planet Pins for High Torque Epicyclic Gears



For wind turbine main gearboxes (MGBs) with about 1 MW or higher power, gearbox designs with multiple power paths are used. They handle several mega-Newton-meter of torque economically. This paper describes experiences using planetary gears where "Flexpins" are used to improve the load sharing between the individual planets—representing the multitude of power paths—and along the planet's face width.

geartechnology.com/articles/30672-flexible-planet-pins-for-high-torque-epicyclic-gears-experience-with-design-manufacturing-and-application

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Stop By and See Us

We're in the middle of industrial trade show season, and our team has been traveling to various events around the country to uncover the most relevant new technology related to power transmission and motion control. But we're not done yet. In fact, I'd like to call your attention to two upcoming events that are of particular note.

We are exhibiting in Booth #2152 at the upcoming Turbomachinery and Pump Symposia at the George R. Brown Convention Center in Houston, August 20–22. TPS combines a robust technical conference with an exhibition of suppliers, offering a forum for the exchange of ideas between rotating equipment engineers and technicians worldwide, especially in industries like turbomachinery, pump, oil & gas, petrochemical, power, aerospace, chemical and water.

The TPS technical program is hand-selected by advisory committees made up of key industry players and led by highly respected practitioners and leaders in their fields. Topics cover maintenance, reliability, troubleshooting, instruction on emerging designs, technology, and best practices that include case studies with real-world relevance on problems solved and lessons learned.

The TPS exhibit hall will include a wide variety of suppliers, including manufacturers of gears, bearings, motors, pumps, couplings and other components specifically designed for high-speed rotating equipment.

For more information about TPS, see their ad on page 17 or visit *tps.tamu.edu*.

We are also excited to be participating in IMTS, which takes place September 8–15 at McCormick Place in Chicago. Our booth (#237314) is located in the Gear Pavilion, where you will find all the major manufacturers of gear manufacturing equipment, software, cutting tools and more.

In addition to gear manufacturing technology, IMTS also includes hundreds of suppliers of components and systems related to machine and factory automation, including controls, linear motion, bearings, servomotors, conveyors, speed reducers, maintenance tools and much more. If you work in a factory, or if you design machinery for manufacturing, IMTS has something for you. For a sneak preview of some of those exhibits, please see Senior Editor Matt Jaster's article on page 18.

For more information about IMTS, visit *imts.com*.

We hope to see as many of you as possible at these events. I encourage you to stop by to chat with our editors, renew your subscription and learn more about the American Gear Manufacturers Association.

If you can't make it to either event, I strongly encourage you to make sure your subscription is up to date. Go to *powertransmission.com/subscriptions* to fill out the quick and easy form. Over the next several issues, we'll be writing about the latest technology, applications and solutions presented at these shows.

PTE

Randy Stott
Publisher & Editor-in-Chief

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BODINE ELECTRIC COMPANY

Introduces New Brushless DC Hypoid Gearmotors

Bodine Electric Company introduces 12 new brushless DC hollow shaft gearmotors with hypoid gearing. These type 42B-25H2 and 42B-30H3 geared motors combine a new brushless DC, 130 VDC motor with two hypoid gearheads. When used with a brushless DC speed control, these gearmotors deliver maintenance-free performance with high starting torque and linear speed-torque characteristics. They are ideal for industrial automation equipment that demands quiet operation, high-torque density, and a wide speed range.

Quiet, Efficient Performance

These new BLDC (electronically commutated) hypoid gearmotors are designed to be high-performance, maintenance-free alternatives to gearmotors with standard worm gearing. The gearmotors are available with gear ratios from 5:1 to 240:1, provide up to 2,370 lb-in (268 Nm) of continuous torque, and speeds of up to 400 rpm. The unique hypoid gearheads are permanently lubricated and feature hardened steel gears for long-life and quiet operation. They can be face-mounted in any orientation via four tapped holes or through-bolts.

Driven by a maintenance-free, totally enclosed non-ventilated (TENV), 1/2 hp (368 watts), brushless DC (130 VDC) motor, the type 42B-25H2 and 42B-30H3 gearmotors are ideal for applications that require continuous operation and minimal downtime. These new brushless DC motors feature a built-in 256 PPR, magnetic encoder with commutation track, and are rated IP-66 for protection from dust and water. They are terminated with two built-in watertight connectors (power and signals).

Hollow Shaft Design

The new type 42B-25H2 (1 in. bore) and 42B-30H3 (1.25 in. bore) hollow shaft gearmotors optimize mounting space, simplify installation, and reduce the number of required parts. They can be connected directly to the driven load eliminating costly shaft couplings and mounting hardware that can be unsafe, bulky, and present alignment issues. These hollow shaft gearmotors offer left- or right-hand face mounts for maximum application flexibility.

Gearmotor/Motor Accessories

Bodine offers various accessories including a base/foot mounting bracket for each gearhead, shaft kits, and a shaft cover kit for the non-extension shaft side of the gearhead.

Availability

Bodine's new type 42B-25H2 and 42B-30H3 gearmotors and accessories are available through Bodine's extensive distributor network or from the Bodine website. Custom options are available to qualified OEMs. Typical OEM modifications include factory-installed mounting hardware or junction boxes, special drive shafts, or wire harnesses.

bodine-electric.com

PBC LINEAR

Expands MTB Belt-Driven Linear Actuator Series

PBC Linear has expanded its MTB Series of Belt-Driven Linear Actuators line with the MTB 105.

Engineered with precision and versatility in mind, the MTB 105 is specifically designed to integrate into multi-axis medium- to large-sized Cartesian Gantry systems, providing robust support for medium to high payloads. Its fully enclosed design ensures reliability even in contaminant-prone environments, making it an ideal choice for a wide range of applications. Precision extrusions for each aluminum actuator body ensure all sides and bottom surfaces are flat and perpendicular giving accurate installations.

Key features of the MTB 105 High-Speed Belt-Driven Linear Actuator include:

- Fully enclosed actuator with stainless steel magnetically coupled band strip seal to assist in keeping actuator enclosed while carriage is in motion.
- High acceleration, speed, and rigidity.
- Long travel length.
- Low friction, noise, and vibration.
- Anodized aluminum corrosion-resistant body and carriage.
- Urethane steel corded reinforced belt to handle high loads.
- Adjustable belt tension.
- T-slots for mounting and sensor mounting.
- Various female and male input drive interface options are offered.

"We are excited to introduce the MTB 105 High-Speed Belt-Driven Linear Actuator as the latest addition to our MTB Series product line," said David Dieter, president at PBC Linear. "This actuator shows our commitment to pushing the boundaries of linear motion technology, enabling our customers to achieve new levels of efficiency and performance in their applications."

pbclinear.com

ABB
Launches Next-Generation Robotics Control Platform OmniCore

ABB Robotics has launched OmniCore, an intelligent automation platform that is faster, more precise and more sustainable, to empower, enhance and future-proof businesses.

The OmniCore platform, the result of more than $170 million of investment in next generation robotics, is a step change to a modular and futureproof control architecture that will enable the full integration of AI, sensor, cloud and edge computing systems to create the most advanced and autonomous robotic applications.

"For our customers, automation is a strategic requirement as

they seek greater flexibility, simplicity and efficiency in response to the global megatrends of labor shortages, uncertainty and the need to operate more sustainably," said Sami Atiya, president of ABB's Robotics & Discrete Automation Business Area. "Through our development of advanced mechatronics, AI and vision systems, our robots are more accessible, more capable, more flexible and more mobile than ever. But increasingly they must also work seamlessly together, with us and each other, to take on more tasks in more places. This is why we are launching OmniCore, a new milestone in our 50-year history in robotics; a unique, single control architecture—one platform, and one language that integrates our complete range of leading hardware and software."

OmniCore's motion performance delivers robot path accuracy at a level of less than 0.6 mm, with multiple robots running at high speeds of up to 1,600 mm per second. This opens new automation opportunities in precision areas such as arc welding, mobile phone display assembly, gluing and laser cutting. Overall, OmniCore enables robots to operate up to 25 percent faster and to consume up to 20 percent less energy compared to the previous ABB controller.

OmniCore is built on a scalable, modular control architecture that offers a wide array of functions to create almost any application imaginable, making it suitable for businesses embracing automation in existing and new segments, such as biotechnology and construction, amongst many others. With over 1,000 hardware and software features, customers can design, operate, maintain, and optimize operations easily. This is enabled by software features including ABB's Absolute Accuracy, and PickMaster Twin, as well as hardware options spanning from external axis and vision systems to fieldbuses.

"The OmniCore difference is its ability to manage motion, sensors and application equipment in a single holistic unified system," said Marc Segura, division president ABB Robotics. "OmniCore opens the door to the entire ABB Robotics portfolio of hardware and software, in any combination under a single control platform, offering endless possibilities and more avenues for value creation. For example, OmniCore enables automotive manufacturers to increase production speed, offering tremendous competitive advantage, increasing press tending production from 12 to 15 strokes per minute to produce 900 parts per hour. As we celebrate our 50th anniversary in robotics, we believe that OmniCore offers the potential for many more industry breakthroughs, empowering our customers across all sectors to meet the challenges that lie ahead."

OmniCore is the latest development in ABB Robotics' 50 years of innovation, starting with the world's first microprocessor-controlled robot in 1974, the launch of *RobotStudio* software in 1998 and the acquisition of Sevensense in 2024, to bring industry-leading AI-based navigation technology to its mobile robots.

abb.com

SCHAEFFLER
Presents Extended Product Range for Off-Highway Applications

Schaeffler recently presented its extended product range for off-highway technology at iVT Expo Cologne 2024. The focus was on systems for the electrification and digitalization of mobile agricultural and construction machinery and for materials handling technology. Schaeffler is emphasizing its commitment to sustainability and supporting the transition to a highly efficient and climate-neutral economy in the off-highway sector.

Electromechanical linear actuators were the focal point of Schaeffler's product lineup on display at iVT Expo Cologne. With

the acquisition of Swedish linear motion specialist Ewellix, Schaeffler presented itself as a comprehensive solution provider. At its exhibition booth, Schaeffler showcased intelligent sensor solutions for off-highway equipment, as well as electric motors for traction drives or auxiliary units in off-highway machinery.

Under the Ewellix brand, Schaeffler presented a broad range of efficient solutions for linear motion. Highlights from the fair include Ewellix CASM actuators, a new generation of high-performance electromechanical actuators. They offer an impressive lifting force of up to 15 tons with maximum positioning accuracy. These actuators support flexible and precise lifting and tilting operations, while only requiring a 24 V power source and a standardized analog or CAN bus control system on the machine side.

The Schaeffler LoadSense-PIN enables effective load control. This sensor solution consists of a small steel cylinder that is pressed into a bore in the customer's respective component and measures loads of the surrounding material structure. A strain gauge coated directly onto the cylinder, based on Schaeffler's Sensotect coating technology, records these changes and transfers them in analog form or via a bus system to the machine control system. This allows the measurement of forces and provides information about loads on components like axles or gearboxes as well as on safety-relevant weight distribution when using lifting tools.

As traction drives or auxiliary units in off-highway machinery, electric motors from Schaeffler offer maximum reliability and maintenance-free operation.

These drive solutions with maximized power density of approximately 5.1 kW/kg motor facilitate the forward-looking switch from combustion engines to electric motors in the off-highway machinery segment and make a significant contribution to reducing CO_2 emissions in the sector.

schaeffler.com

NORD
Offers Complete Drive Solution with LogiDrive

LogiDrive complete drive solutions from Nord Drivesystems reduce planning and commissioning efforts through cost-effective, standardized designs engineered to industry standards and application requirements. These solutions are especially well suited for post & parcel, airport, and warehouse logistics as they are specifically aligned with the intralogistics and material handling requirements of these industries.

For each intralogistics area, there are advanced versions utilizing IE5+ synchronous motor technology and basic versions with IE3 asynchronous motors. While LogiDrive advanced drive systems address issues such as energy efficiency, variant reduction, and total cost of ownership (TCO), the basic versions primarily focus on cost efficiency.

Post & parcel and airport industry applications such as baggage handling systems, parcel distribution systems, and parcel sorting systems require reliable drive solutions that keep up with their high material flow and minimize downtimes. Advanced LogiDrive systems with IE5+ permanent magnet synchronous motors deliver high overload capacity and consistent high efficiency over a wide speed range, even at partial load and low speeds. By using IE5+ motors, systems can achieve significant cost reductions, increase operational efficiency, and provide a fast return on investment (ROI).

Both advanced and basic LogiDrive systems feature a compact, modular design with plug and play capabilities for simple installation, commissioning, and maintenance. In combination with IE5+ motors, advanced versions for the post & parcel and airport industries also include a Nordac variable frequency drive and either a Nordbloc.1 helical bevel gear unit or a DuoDrive integrated gear unit. Nordac decentralized variable frequency drives are wall mounted and feature an Ethernet interface, PROFIsafe options for functional safety, and PLC functionality for drive-related functions.

Basic LogiDrive versions offer a flexible gear unit selection with an IE3 asynchronous motor and motor-mounted Nordac variable frequency drive. The Nordac Flex is Nord's most versatile VFD with fully scalable functions configurable to specific requirements, an optional Ethernet interface extendable for each option module, and various functional safety options. These VFDs also deliver high precision regulation with Posicon integrated positioning mode to ensure accurate movement in intralogistics systems.

Like the post & parcel and airport industries, warehouse technology such as chain and roller conveyors, belt and pallet conveyor technology, container conveyor technology, and overhead conveyors also require reliable drives with high system operation. Advanced LogiDrive solutions for these specific applications include Nordbloc.1 helical bevel gear units paired with IE5+ permanent magnet synchronous motors, and either a Nordac On+ variable frequency drive or a Nordac Flex variable frequency drive. This complete solution has a high system efficiency with high overload capacity, a long service life, and low maintenance to effectively power conveyors transporting heavy loads and industrial containers.

Nordac On/On+ variable frequency drives were designed by Nord for the special requirements of horizontal conveyor technology and feature a version for IE3 motors (ON) as well as a version optimized for use with IE5+ synchronous motors (ON+). The series is characterized by an integrated multi-protocol Ethernet interface for easy integration into automation systems with required protocols easily set via drive parameters. They also offer plug and play capability for quick installation and maintenance, integrated functions to improve conveyor efficiency, and full PLC functionality for drive-related functions.

Basic LogiDrive versions for warehousing also utilize Nordac On variable frequency drives for their scalable functionality and dynamic control. In addition to the VFD, the solution includes a Universal SI worm gear unit and an IE3 asynchronous motor. Universal SI worm gear units provide considerable installation space advantages due to their compact design, flexible input and output options, and universal mounting capabilities. Together, these products deliver a cost-optimized, standardized solution capable of reducing system variants.

nord.com

THOMSON INDUSTRIES

Announces New Miniature Ball Screw Sizes

Thomson Industries, Inc. has announced the availability of new German-engineered precision ball screw sizes with US-based distribution and machining that provide best-in-class load capacity in a small footprint. The Thomson miniature metric ball screw line uses a unique multi-start ball return design that maximizes support for higher loads. This design provides precise, smooth and quiet operation for applications requiring high precision and load handling in confined spaces.

"To achieve specified load capacity, designers of laboratory, medical and other space-constrained mechatronics applications must often choose a larger nut, which makes the final equipment larger than it needs to be," said Denise Goldman, senior product manager for ball screws at Thomson. "Thanks to our unique ball return system and precision product manufacturing expertise, we can deliver a smaller assembly with higher load handling capacity."

Using more balls enables higher loads to be supported. Thomson miniature metric ball screws accomplish this with a unique multi-liner return system that maximizes the number of circuits and loaded balls in the nut. A miniature metric system with a multi-liner return system, for example, deploys 168 balls in eight circuits to support 7.6 kN of static load, as compared to a single-liner design, which would use 84 balls in four circuits to support only 4.2 kN. Maximizing the number of balls within a single nut also extends the life of the system by spreading the load across multiple points. Furthermore, the Thomson multi-liner return system floats axially to compensate for misalignment.

Applications

Thomson miniature metric ball screws are ideal for designers who specify linear motion components with minimal space requirements. Common applications include:

- Diagnostic and life science instruments, such as chemistry analyzers
- Test and measurement equipment, such as torque testers
- Fluid pumping, such as medical infusion pumps
- Robotics and pick & place equipment, such as engraving, scanning and printing machines

Availability

New Thomson miniature metric ball screws with the multi-liner ball return system are now available in 8 x 2.5, 8 x 5, 10 x 2, 10 x 3, and 12 x 2-mm diameters. Additional size options are currently under development. Mounting interface options include threaded, flanged or cylindrical.

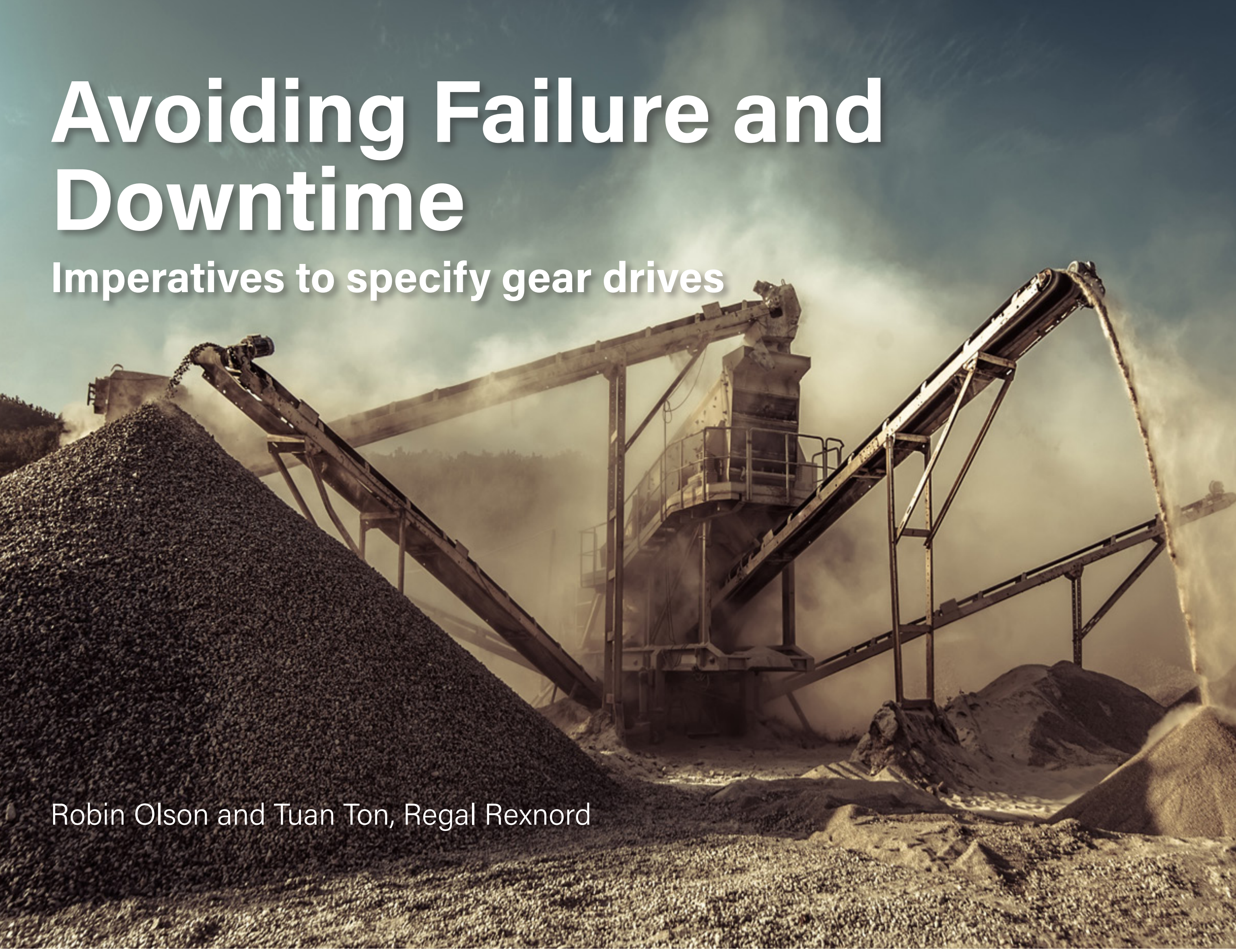
All options feature carbon steel construction, high-performance repeatability (0.05 mm backlash), and ± 52 µm/300 mm standard lead accuracy (T7). Miniature metric ball screws can also be ordered with custom coatings such as thin dense chrome and black oxide coating.

thomsonlinear.com

Avoiding Failure and Downtime

Imperatives to specify gear drives

Robin Olson and Tuan Ton, Regal Rexnord



Regal Rexnord gearing solutions stand up against some of the harshest conditions. However, specifying the correct gear drive is critical to long term lifespan.

Gear drives are fundamental in most processing operations, connecting the prime mover to the driven equipment and ensuring that the system has enough torque to effectively move product. Correctly specifying and selecting the proper gear drives for critical applications leads to reliability, greater uptime and profitability.

Selecting the right gear drive ideally brings together the end user, the system designer and the gear drive manufacturer for success.

The user and the system designer must be familiar with the variables that affect performance and service. Similarly, a gear manufacturer must know for what purpose the drive will be used, the demands to be placed upon it and the nature of the equipment it will be driving.

A number of factors enter into the selection of a gear drive, including:

- Service factor
- Drive rating
- Thermal capacity at the site's ambient conditions
- Speed variation
- Equivalent horsepower
- Drive ratio
- Duty cycle
- External loading on the gear drive's shafts
- Mounting configuration
- Physical size

All must be carefully evaluated to make the right decision. Consider that tooth surfaces showing signs of wear or pitting should be candidates for future preventive maintenance programs. Additionally, fracture of a gear tooth will not only put the gear drive out of service but could possibly do damage to bearings and shafts.

Specifying a Gear Drive—Imperatives

At a minimum, the application loads and configuration must be defined such that a basic gear drive can be selected. The information required is as follows.

AGMA offers standard ratios. Typical manufacturer's deviations between AGMA nominal and exact ratios are ±3 percent for a single reduction gear drive, and ±4 percent for a double reduction.

For applications with variable frequency drives, exact gear ratios become less important. In that case, it is best to select a manufacturer's standard ratio. These will provide lower costs and shorter delivery, with ready availability of off-the-shelf stock spare parts.

Configuration

Gear drives are available in a variety of sizes with various shaft configurations to meet your space requirements. The most popular are parallel shaft, concentric and right angle, with the low-speed shaft either horizontal or vertical. Space should be allowed to access areas such as the lubrication points, the dipstick and the inspection cover.

Service Factor (SF)

Most applications have startup loads, overloads and expectations for life and reliability that cannot be completely captured in the motor loads. The minimum service factor (SF) is a variable that includes the combined effects of stress cycle, reliability and overload factors. It is used to calculate an equivalent horsepower. Application and service duty play an intricate role in determining the proper SF. Appropriate values of SF are determined by field experience. AGMA Standard 6013-B16 (metric 6113-B16) for enclosed speed reducers also contains a listing of applications with their recommended service factors.

A higher SF or larger gear drive size should be selected when peak running loads are substantially greater than normal operating loads. For example, an application that places a torque load on a drive in excess of its rated capacity will inevitably result in distress and, in severe cases, breakage.

Gear drives that are supplied in combination with electric motors may be designated with a service class number such as I, II or III rather than a numerical SF. Class I, II or III are equivalent to SF values of 1.0, 1.41 or 2.0, respectively. Service class and service factor can be used interchangeably. However, numerical designations are preferred because service class does not accommodate intermediate values of SF.

Special consideration for the type of prime mover shall be used as well for determining service factors.

Published service factors are only the minimum recommended for a given application. Some applications require special procedures and may need to be referred to the drive manufacturer. Typical values of SF will not accommodate systems that have serious critical vibrations or repetitive shock loading. The system designer must identify vibratory or shock loading prior to the gear drive selection. These conditions will require changes to be made in the inertia or spring constants of the drive system. Other applications that fall under non-standard selection procedures include a high frequency of starts, reversing service, brake-equipped applications,

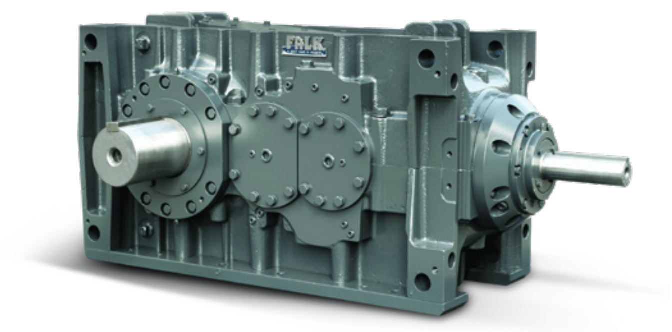
Load and Speed

This is typically the power of the prime mover and its speed. If your motor regularly runs at a lower load than the nameplate, the demand or service horsepower may be used. Gear drives designed and selected in accordance with American Gear Manufacturers Association (AGMA) standards will permit starting and momentary overloads of 200 percent of the unit rating. The unit rating is defined as the maximum power that can be transmitted without exceeding the lowest individual rating of the gearing, housing, shafting, keys, bearings, fasteners and other components of the basic gear drive and auxiliary systems.

Ratio

To arrive at the specific gear ratio required, divide the motor full-load speed by the revolutions per minute (rpm) of the driven equipment. Exact ratios are determined by dividing the actual number of gear teeth by the mating pinion teeth—both of which are whole numbers.

oversize prime movers, and speed variation or multi-speed applications.



The Falk V-Class gear drive offers cooler operating temperatures, optimal power and advanced technology.

Specifying a Gear Drive—Additional Considerations

Speed Variations

Variable speed applications fall into two load categories: constant torque or constant horsepower. Constant torque occurs when load demand varies proportionally with a change in speed. Gear drives are basically constant torque machines requiring no selection modifications. For a constant horsepower application (load demand is constant regardless of speed), the gear drive must be selected for the slowest speed at which the motor will deliver its rated horsepower capacity. This also applies when a mechanical, electrical or hydraulic speed reduction device is used between a gear drive and a constant-speed AC motor. Variable or multispeed applications also require special considerations to provide adequate splash lubrication at the slowest speed without excessive heating or churning at the higher speed. Forced lubrication is also an option to provide adequate lubrication at the slowest speed.

Ambient Temperature and Altitude

Manufacturers' catalogs list thermal horsepower ratings based on an assumed set of standard conditions, e.g., a continuous duty cycle at an ambient temperature of 68°F (20°C) and an altitude of up to 2,460 feet above sea level. For other conditions, the thermal horsepower rating must be multiplied by factors provided by the manufacturer for the specific drive under consideration.

Bearing L10 Expectations

The fatigue life represents the theoretical number of cycles before a product experiences a fatigue failure. The fatigue life of the roller bearings within the gear drive are expressed in terms of L10 hours. In order to increase the time between bearing replacements, the L10 life of the bearings can be specified. It is important to consider that high L10 requirements can force the gear drive selection to a larger drive size or expensive lubrication systems.

Service Costs

The service costs of the gear drive may be a selection criterion. The total cost of ownership of the drive is the initial cost, plus cost of any maintenance required throughout the life of the drive. This includes consideration of useful operating life and spare parts if a marginal selection is made. Some drives have a horizontal split housing that makes them easier to disassemble and reassemble for maintenance of the bearings and gearing.

Rexnord PlanetGear gear drives rugged design are proven to meet the operating challenges of the world's most demanding applications.

Accessory Requirements

Your application may have requirements for a backstop, which prevents reverse rotation. It may also have limitations for water or electrical supply that will affect any cooling or lubrication system selections. These should be specified with the other selection criteria.

In addition to all the above, the application may have additional requirements for corrosion protection, condition monitoring, certifications, dimensional fit, paint, testing, etc. It is best to let the gear drive manufacturer know this prior to receiving the final quote so that any increases in costs and lead times can be considered.

The specifications that are provided to the manufacturer will affect the size and cost of the gear drive that is selected. The best cost will come with a gear drive that uses standard parts and options. For example, allowing flexibility for the use of standard shaft diameters can prevent oversizing the gear drive. If a larger-than-standard maximum ratio is required, switching from a 4-pole motor to a 6-pole motor may prevent the need for multiple gear drives. Generally, the cost will increase as the number of requirements increases. Therefore, it's best to specify the basics and only specify additional requirements if they are absolutely required to successfully run the application.

powertransmission.com/blogs/1-revolutions/post/9824-avoiding-failure-and-downtime

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Next Steps in Automation at IMTS 2024

SPS focuses on collaborative robots, motion control, and data management

Matthew Jaster, Senior Editor

Predictive analytics will be all over IMTS 2024 including the Automation Sector, accelerated by SPS—smart production solutions. Visitors will find a broad range of digital solutions at IMTS 2024 at McCormick Place in Chicago on Sept. 9–14.

IMTS 2024 will feature the new Automation Sector, accelerated by SPS—smart production solutions in the North Building, which features companies specializing in robots, collaborative robots (cobots), motion control, data management, and automation integration. Additionally, exhibits throughout IMTS will demonstrate automated solutions for CNC machining, additive manufacturing, vision systems, metrology, tooling, workholding, abrasive machining, gear generation, parts handling and cleaning, and other manufacturing technologies.

"Automation is omnipresent at IMTS because exhibitors know industry needs automation technologies to leverage worker productivity and boost business profitability," says Peter R. Eelman, chief experience officer, AMT—The Association for Manufacturing Technology, which owns and produces IMTS.

Ian Stringer, vice president of data strategy at AMT, says that "the push toward greater adoption of industrial automation is influenced by an aging workforce and geopolitical uncertainties that have increased defense spending and led to a revitalization of the U.S. supply chain."

Stringer notes that capital intensity (the amount of capital utilized per unit of labor) has surged nearly 12 percent from 2017 to 2023, according to the March 21 economic news release from the Bureau of Labor Statistics. According to Stringer, this figure "is solid evidence" of a significant shift toward more capital-intensive and labor-efficient manufacturing processes facilitated by the automation solutions shown at IMTS 2024.

"From reshoring initiatives and workspace optimization to production capacity and workforce shortages, multiple issues are often at play when companies are looking to invest in automation technology," says Doug Burnside, vice president of North American sales and marketing for Yaskawa Motoman (IMTS Booth #236601). "For smaller companies, collaborative palletizing and welding are two easy options for first steps into automation. The systems deploy rapidly and have user friendly pendants."

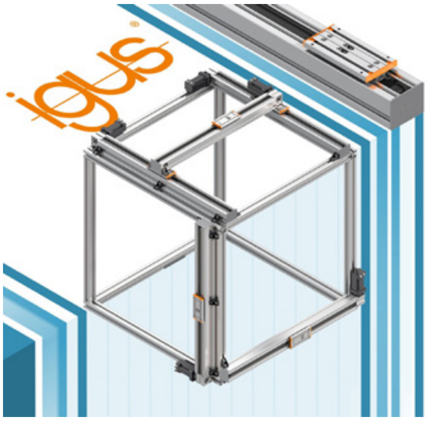
Previews for IMTS 2024

The following is a list of exhibitors in the Automation Sector as well as other areas of IMTS that will be of interest to *PTE* readers.

THK America (Booth #236207) will show how its OMNIedge IoT system combines connected sensors and artificial intelligence to detect part failures before they occur. "We can improve machine operating rates, make maintenance more efficient, and reduce inventory management costs," says John Dykas, marketing and events manager at THK.

Hiwin Corporation (Booth #236124) offers an extensive line of mechanical and electrical motion control components linear and rotary tables and robotic solutions. Visitors will learn more about ball screws, linear guideways, ball splines, crossed roller bearings, strain-wave gearing systems, linear motor components, torque motor components, AC servomotors, drives and controllers and position measurement equipment. They also offer high-performance, single axis and multi-axis ball screw driven and linear motor driven linear motion driven stages and rotary-motion tables. Robotic solutions include articulated and SCARA robots.

Igus (Booth #236557, #236230) has expanded its drive technology range with the new drylin ZLX high-performance toothed belt axis. The compact, robust, and self-lubricating series features an anodized aluminum profile with a completely new geometric design, making it easy to integrate into modular profile systems. With a load capacity of 150N and speeds up to 3m/s, the drylin ZLX is ideal for automated production lines, pick-and-place systems, 3D printers, and more.



The heart of the new toothed belt axis is the linear guide system from the drylin W series, size 16, integrated into a robust, corrosion-resistant, clear anodized profile. Unlike other igus axes, the toothed belt runs inside the profile, giving the axis the appearance of a mechanical engineering profile.

"Classic aluminum profiles have specific dimensions and standards for grooves, which our drylin ZLX meets," says Matt Mowry, drylin product manager at igus. "Using standard slot nuts and connecting elements, combining with other mechanical engineering profiles is easy. This modularity is especially useful for linear robot structures, and the design ensures a cohesive, uniform look."

PBC Linear (Booth #236443) has combined high-quality linear motion components to offer a selection of manual and electric linear actuators. This extensive range of linear actuators are designed to cater to a broad spectrum of industries and applications, providing everything from high precision and load capacity to exceptional durability and environmental resistance. These actuators ensure performance, reliability, and integration ease, whether for a compact medical device or a robust industrial machine.

Collaborative robots (cobots) are a true workforce multiplier and will be demonstrated in conjunction with tooling and workholding, welding, metrology, machining, part handling, and scores of other applications at IMTS. According to Will Healy, global industry leader—welding at Universal Robotics (UR) (Booth #236131), a cobot can arrive on a loading dock in the morning and be assisting with production by noon because cobot providers have "a hyper focus on simplifying the cobot integration experience and improving the cobot operator experience."

A paradigm shift has occurred with cobots. "The breakthrough occurred because of a hyper focus on simplifying integration and improving the cobot operator experience," Healy adds. "At IMTS 2024, conversations will center around how artificial intelligence, 3D vision systems, and cobots combine to pick a wider variety of parts with an unprecedented reliability."

Today, machine operators (not robot programmers) can program and staff multiple pieces of equipment, boosting machine utilization numbers and shortening changeover time between parts. With these factors, shops can now run more parts per machine with overnight runs or lights-out manufacturing, boost shop competitiveness, and help company leaders win new business.

"At IMTS 2024, conversations will center around how artificial intelligence and cobots come together to bring new levels of usability and productivity to the shop floor," adds Healy. "As an example of applications that were challenging to automate in the recent past, we will demonstrate how a UR20e cobot can pick a wider variety of parts with an unprecedented reliability," Healy says.

This advance occurred through a partnership between UR and Siemens (IMTS Booth #133249) that utilizes Siemens' deep learning-based vision software, called *SIMATIC Robot Pick AI*, and Zivid's M130 3D camera.

As manufacturers embrace automation, they also need to explore the transformative power of generative AI. Google Cloud (Booth #236709) delivers AI and machine learning solutions to unlock untapped potential and drive innovation through data-driven insights and intelligent automation. Google Cloud can help IMTS visitors understand where and how to apply AI to product design, research, production, supply chain, customer service, and other manufacturing processes.

While pallet pools provide capability, advanced machine controls ensure accuracy and consistency during unattended runtime. "The TNC7 control will help end users to feel confident in automating their process," says Gisbert Ledvon, vice president of marketing at Heidenhain (Booth #339440). "This year at IMTS, we will demonstrate tool quality and tool life monitoring features using the TNC7's integrated tool table database."

Heidenhain will also demonstrate the TNC7's component monitoring and process monitoring capabilities. Component monitoring can detect events such as tool breakage or excess force on the spindle. Process monitoring captures the data for a sample path and compares subsequent paths to this reference; deviations are graphically displayed, so operators can pinpoint the location.

Additive manufacturing (AM) is inherently an automated process, which is especially helpful to large-scale metal additive technologies such as directed energy deposition (DED), which can replace forgings, castings, and tooling. These products typically come from overseas with lead times of six to 18 months, which AM can shorten to a few months or weeks.

Melanie Lang, co-founder and CEO of Formalloy Technologies (Booth #433018), believes the trend of adding AM equipment to move work in-house is growing and will continue. "The last few years opened our eyes to the instabilities in our supply chain," says Lang. "We can't take delivery times for granted; the true country of origin for our products remains uncertain; and some sources are subject to geopolitical issues. Fortunately, we can apply technology to solve those problems."

Siemens (Booth #133249) will present its extensive machine tool CNC portfolio and digitalization software technology, highlighted by the digital native SINUMERIK ONE control platform for machining applications. Also, using a sports theme of "Speed, Agility and Endurance," aimed at the machine shop on its path to digitalization, Siemens will introduce MACHINUM to the North American market. MACHINUM brings together machine tool controls, digitalization software and machine shop services from Siemens to help manufacturers optimize their production processes, to provide agility for quick adaptation to changing customer requirements and calculated uptime needs, plus enable digitally proven endurance to maximize the productivity of the entire machine shop or production department.

imts.com

PTE

Conveyor Consistency

EV car battery manufacturer finds success with Fenner's Eagle Poly-V belts

Matthew Jaster, Senior Editor

Eagle Poly-V belts helped one of the leading EV battery manufacturers move away from roller chain conveyors, thereby reducing noise and eliminating the downtime, labor, and maintenance expenses associated with chain drives.

A roller chain can handle a lot of weight, but it has some significant downsides. It's noisy and needs regular maintenance. It's expensive, and when it breaks, workers can be injured.

Even its performance is a problem.

"To make it an endless loop, the fit must be loose, which causes a lag between the time the motor starts and when the rollers start to move. Over time, the chain stretches, making positioning less accurate and the conveyor less efficient. To fix it, you either adjust the take-up sprockets or remove a link," said Derek Forney, senior product manager, belting at Fenner Precision Polymers.

Recognizing noise, cost, maintenance, and poor performance concerns, one of the leading EV car battery manufacturers was looking for an alternative for an RS 50 roller chain to drive a one-metric-ton pallet conveyor.

An instrument measures the performance of conveyor rollers driven by Eagle Poly-V belts, which maintain consistent tension and immediately transmit the motor's action to the rollers, unlike traditional roller chains.

The roller conveyor had 76 mm rollers with 56 mm end caps interlocking by 8EPJ536.

A local sales representative suggested redesigning the roller conveyor system to use Fenner Drives' Eagle Poly-V belts. Made from polyurethane, Eagle Poly-V belts are available for all kinds of power transmission applications with designs and reinforcement benefits. By eliminating the roller chain, the battery manufacturer reduced noise and eliminated the downtime, labor, and maintenance costs the chain drive required. Forney said Eagle Poly-V products provide a flexible range of solutions depending on the application requirements.

"Reinforcement options or density, rib count, rib profile, material hardness or temperature range, etc. all play a part in the belt design. While this case is focused on material handling with EV batteries, there's a broader need for customer solutions to solve end user issues including downtime, product performance, and total cost of ownership," he added.

Forney said one of the many advantages of Fenner's belt products is the customization capabilities. "We try to provide custom engineered solutions that are precisely tailored to meet the needs of our customer's applications."

This follows Fenner Drive's philosophy of paying attention to the constant flow of feedback and unique application challenges customers face. They're looking for performance improvements, custom configurations, and material upgrades. Forney reiterated the importance of asking the right questions.

"What equipment are they using and what limitations do they have? For example, what motor capability is there? I attended MODEX this year and we discussed with customers how they look at the application from a total package perspective. We're trying to solve problems, but we're not total system designers. You must understand that full application context. What are some of the things we've seen in the past that might impact their abilities? Do you have restraints on installation that need to be addressed? We have standard belt sizes, but what if the customer has flexibility on center distances? As we look at our belting portfolio, we'll determine how to optimize the materials and the technologies our customers need to achieve the best value," Forney said.

As Fenner works directly with several OEMs, the trick is making sure the engineers are looking at everything involved in the design phase and that they've checked all the appropriate boxes before suggesting or customizing the belt for the application.

In a comprehensive comparison by a leading global logistics company, the Eagle Poly-V belt surpassed Rubber Poly-V belts in performance, showcasing superior durability, less frequent replacements, reduced wear and tear, minimal debris, and lower maintenance needs.

For the EV car battery manufacturer, Forney said an advantage was working with a local sales integrator that provided immediate feedback and helped make sure the Eagle Poly-V product was the correct solution over a roller chain drive.

The Eagle Poly-V belt had a significant reduction in decibels, compared to the roller chain. Unlike the roller chain, the Eagle Poly-V belt maintains consistent tension, transmitting the motor's action immediately to the roller. This provides much more efficient power transmission.

Switching to Poly-V saved the EV plant 10–15 percent in initial build and annual maintenance costs for roller sprockets and pulleys required for chain drives. There was also an overall reduction in total maintenance costs due to less loss of tension and no greasing.

Additionally, the Eagle Poly-V eliminated safety concerns associated with roller chains, especially injuries associated with accidents. A major benefit for EV plants was the elimination of debris within the facility. Chains become corroded when exposed to moisture, dust, and chemicals in the typical industrial environment. Even traditional rubber Poly-V belts generate dust. Unlike rubber Poly-V belts, Eagle Poly-V belts are a clean, dust-free solution that is optimal for these applications.

Rubber Poly-V Belts vs. Eagle Poly-V Belts (A Comparison)

A global leader in logistics and supply chain performed extensive in-house testing to compare Eagle Poly-V belts to rubber Poly-V belts on their roller conveyors. What they found was not only success in the four-month testing period, but the belt continues to run strong over a year later.

Rubber Poly-V Belts:

1. There were 317 rubber Poly-V belts replaced during the four-month testing period.
2. Belt degradation and poor performance caused excessive downtime with both straight and angled rollers.
3. Rubber belts were worn and became lodged around the roller and grooves causing damage and failure to the roller.
4. Debris built up in the roller grooves resulted in the Poly-V tracking off the pulley.
5. Rubber belts require installation with a high belt tension causing damage to some of the belts.

Eagle Poly-V Belts:

1. There were 0 Eagle Poly-V belts replaced during the four-month testing period.
2. Fenner Drives Eagle Poly-V belts have been in the same application with no degradation.
3. Eagle Poly-V has no signs of damage or wear and did not become lodged around the roller and grooves.
4. No belt flaking or debris build up, Eagle Poly-V stayed on track in the groove.
5. Generous tension tolerance resulted in no belt damage during installation.

The EV market is an area Fenner will be targeting now and in the future.

"We have three divisions: Industrial Motion, High-Tech Coated Fabrics, and Air and Fluid Handling, Textiles and Belting and Power Transmission. The question is how can we pivot and focus on the EV market from all three different areas? There's a lot happening in EV and there's a lot of synergy based on what we've been doing internally for years, especially on the belt side. In the short term, we're looking at EV applications in Asia, but as those plants are being set up here in North America, we'll begin to look at several potential opportunities we can leverage in the EV market here," Forney said.

As for the future of belt technology, if MODEX 2024 was an indicator of things to come, the PT market is coming back. The key focus will likely be on sustainable materials, energy reduction, and overall increased performance.

Material handling, packaging, and logistics will continue to be bright spots in belting for years to come.

"There are so many pick and place, automated options in these markets," Forney said. "Timing belts and conveyor belts are rebounding and things are looking very promising from that perspective. Nothing moves without a belt or a drive."

fennerdrives.com/eagle-poly-v/

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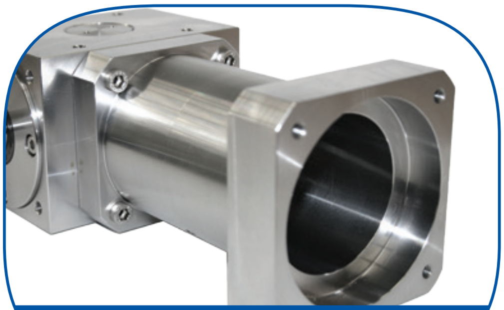

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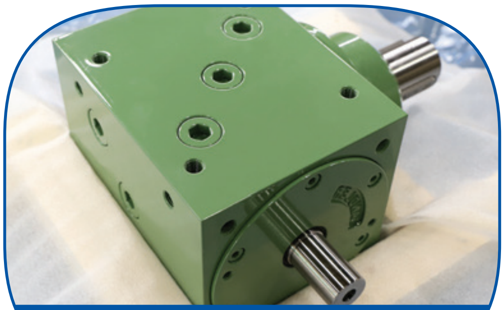

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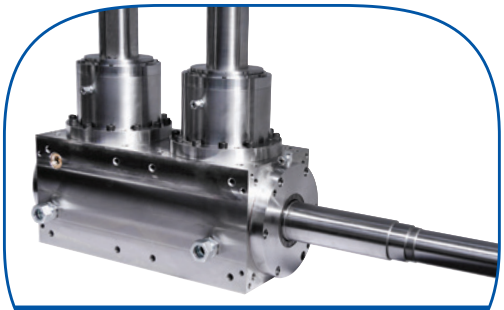

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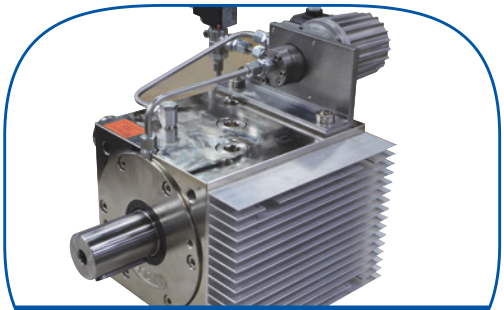

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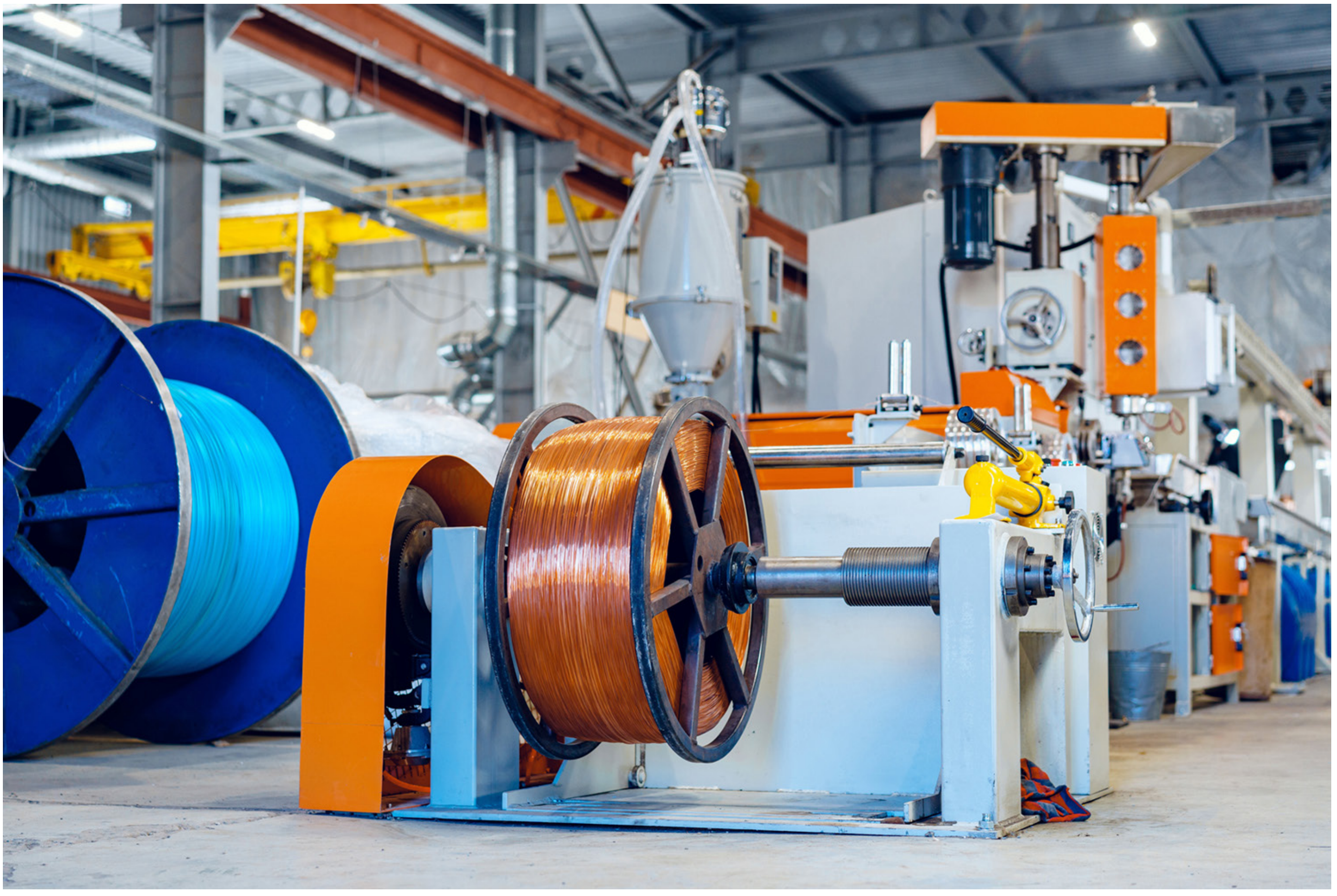
Differential Gearboxes Ensure Wire and Cable Quality and Consistency

A gearbox can offer far more than just speed reduction

Thomas Osygus, Vice President of Sales and Marketing, Redex USA



Demand for specialty wire and cable—fueled in part by data center expansion as well as new charging stations for electric vehicles (EVs)—is in turn creating greater demand for cable production capacity. As you design machines that will satisfy the demand, you'll want to incorporate an effective driving method that controls speed and torque with the highest precision.

Multi-speed gearboxes were once popular for differential applications in many industries—including wire and cable—but they have recently been displaced by new servo drives that provide various benefits. However, differential gearboxes offer far more capability than only speed reduction. In fact, for forming and twisting applications, there's no better solution than a differential gearbox.

This article will explain how a certain class of differentials is designed to deliver high torque and precise control of multiple speeds using smaller motors. With these capabilities, you can solve many motion challenges. Here's an overview of how this class of differentials performs in typical wire and cable manufacturing equipment:

Twisting Applications

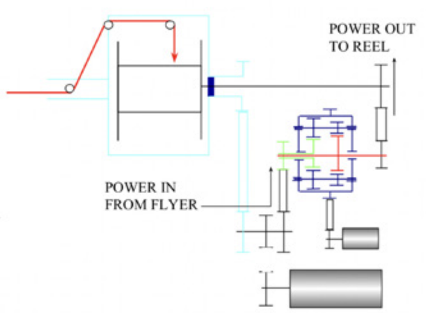
Machines that twist or form wire have one element that holds back (or brakes) the wire, and another element that handles pulling or driving. This situation requires a lot of power—braking power and driving power. In many instances, one motor provides braking power, and another motor does the driving. Each motor must be sized accordingly. However, another approach uses a differential gearbox to provide input power to the wire. This technique is particularly attractive for bunchers and armoring machines.

A typical differential drive on a single twist buncher has two inputs and one output. When the reel rotates, the wire is rewound. A rotating flyer twists the wire without rewinding. When both rotate together, the lay (or pitch) is determined by the following formula:

$$\text{lay} = \frac{\text{wire linear speed}}{\text{flyer rotation speed}}$$

The flyer rotates at a constant speed while paying off the wire. As the wire gathers on the reel, its diameter increases. The reel speed must decrease to achieve a constant linear speed and, ultimately, a uniform lay. Because the speed change occurs dynamically, a machine designer has two options: use two motors—one for each rotating element—or a differential and one motor.

One such differential-based system uses a main motor to drive the flyer and a Redex SR Series planetary gearbox to drive the reel. This system only requires input power for the wire, which is equal to the driving power minus the braking power. The SR Series is also available in an inch bore version, the SA Series.



Because power circulates through the SR differential, the system only requires input power for the wire, which is equal to the driving power minus the braking power.

The SR differential has a unique compound epicyclic gearing design that incorporates two sun gears within the casing along with two gears for each planet axis. Redex's patented assembly process ensures equal load sharing between the planet gears: As planet gear assemblies are added, the torque capacity of the differential increases. The SR unit is designed and constructed to allow power to circulate through the differential so that one element is braking and the other element is driving. Furthermore, there is a large ratio between the drive motor and the driven reel. Therefore, a large change in motor speed affects a small change in reel speed, which makes the speed control and, in turn, the lay, very accurate during winding. The result: lower wire-insulation costs and a better bottom line for your bunching operation.

When an armoring machine winds the metal cover, the wire or cable travels linearly through an aluminum or steel shaft. A coil rotates as forming rolls shape the metal material and wrap it around the wire with accuracy. The forming rolls must lay the material accurately, and the coil needs to provide the right tension to unwind the sheathing material. The consequences of inconsistent twists include poor mechanical stability, failure to meet the application's cable diameter requirements or even noncompliance with international standards. Correct armoring avoids these problems, and a uniform twist depends on precise control of the forming roll's speed relative to the linear speed.

Armoring machines depend on the precise control of the forming roll's speed relative to the linear speed to ensure a uniform twist.

Like the single twist buncher example, a typical armoring machine may incorporate two separate motors to power each rotating element. Each must be sized and will occupy significant space. However, a differential gearbox featuring a compound epicyclic gearing design is more effective and efficient for this application. While the differential must be sized to support the full power, the motors only need to input the power that the cable or wire needs. This means the differential allows a smaller motor to do the same job and, depending on the chosen speed ratio, provides precise speed control.

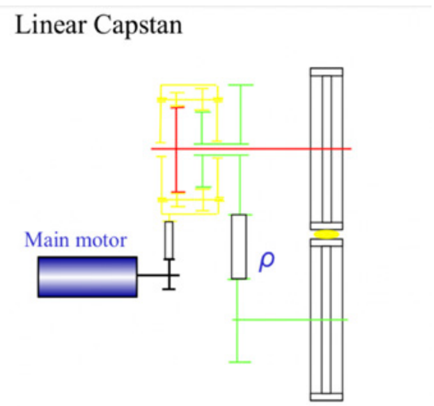
A differential is also ideal for controlling the coil's tension. Although clutches can be fastened directly to the coil, this approach often requires slip rings to activate the clutches and adds maintenance expenses to the assembly.

Tensioning Applications

Whether driving a linear or dual wheel capstan, a requisite balance of torque and speed must be maintained to avoid slipping between the belts and the cable, thus ensuring both product quality and consistency.

"Caterpillar"-type linear capstans employ two belts that rotate at the same speed to pull the product through the processing line at a constant tension. If the capstan's cable tension is unstable, equipment used for extrusion, winding, paying off or other processes down the line will be out of sync, resulting in diminished product quality and possibly costly damage to the capstan itself. Because constant cable tension is essential, the system that drives the belts is critical to maintaining a processing line's precision and, ultimately, delivering a better product. Here's why the right drive system makes a difference in product quality:

You can drive a two-belt system by using a differential or employing a motor with two rigid fixed gear reducers. The gear reducer approach is prone to variations in the belt pulley's diameter, which can cause the two belts to run at different linear speeds. Even the slightest speed differences will cause rubbing and slipping between the belts and the product, which in turn causes the products or the belts to wear. Depending on the application, belt replacement can get expensive.



Using the Redex SR differential with a linear capstan, the input speed defines the sum of the output speeds, and torque equilibrium ensures constant linear speed. The SR also automatically reverses the direction of rotation of the two outputs, thereby providing a reduction from the motor.

In a linear capstan, a differential with one input automatically reverses the direction of rotation between its two outputs and drives the upper and lower belts. This balances the torque between the two outputs and, consequently, balances the speed. If the belt diameters vary, the linear speed remains the same for the top and bottom belt. The result: no slipping and wear for the wire or cable. Taken together, the differential performs three functions in the linear capstan: It ensures a constant linear speed, reduces the speed and reverses the direction of rotation.

For a dual-wheel capstan, the wheels pulling the cable also must have identical torque, but the rotational speed can vary to accommodate diameter differences and maintain a constant linear speed between the wheels. Like a linear capstan, it also requires an effective driving method to maintain the necessary balance of torque and speed to avoid slipping between the belts and the cable.

For dual-wheel capstans, the differential balances torque and speed to ensure a constant linear speed between the capstan and the product, thereby preventing wear on the product or capstan wheels.

The SR differential from Redex USA is well-suited for this type of application, thanks to a compound epicyclic gearing design that incorporates two sun gears within the casing along with two gears for each planet axis. Redex's patented assembly process ensures equal load sharing between the sun gears. It can be installed between the wheels using one input and two outputs. The output speeds can vary slightly to accommodate diameter differences on the capstan wheels. This differential corrects any variations in wheel diameters, eliminates transmission errors and drives the capstan wheels in the same rotational direction. This allows effective linear speed control and ensures precise pulling forces between the capstan wheels.

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> Multispeed gearboxes were once popular for differential applications in many industries—including wire and cable—but they have recently been displaced by new servo drives that provide various benefits. However, differential gearboxes offer far more capability than only speed reduction. In fact, for forming and twisting applications, there's no better solution than a differential gearbox.

Tailor a Differential Gearbox to Meet Your Need

Redex USA has extensive technical expertise and customization capabilities to help you implement the best differential for the job. When you provide our experts with your force and speed requirements along with the pertinent measurements for belts and wheels, we can use that information to help determine a proper differential size as well as help calculate the speed of the motor to establish the differential's gear ratio. Standard options include various timing belts or v-belts for the outer casing as well as coupling options.

High Torque and Speed Control Means Greater Cable Quality

As you design new wire and cable manufacturing equipment to satisfy the growing need for specialty cables in the data center and EV industries, your success will depend on precise torque and speed control throughout your production line. Differential gearboxes deliver high torque output and speed control with exceptional precision, making them ideal for the wire and cable industry's performance and product quality requirements.

Redex SR and SA differentials, with compound epicyclic gearing system and multiple planet trains, offer higher torque capability and a wide range of reduction ratios that ensure the greater precision and speed control that wire and cable production equipment demands. Redex sales engineers can help you determine the appropriate planetary gear reducer for your specialty wire and cable manufacturing application.

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Holistic Assessment of Drive Systems with Gears, Shafts and Bearings Using Measured Torque-Speed Data

Dr. Ulrich Kissling

Introduction

Verification of a drive system should include all main elements of the system, which are gears, bearings, shafts, and depending on the application other parts such as screws, couplings, and connections. Gears are clearly the most complicated parts for verification, but in many cases, a gearbox failure has its origin in a shaft or bearing failure. The subject of this paper is to explain how verification of a drive system based on measured or simulated torque-speed-time data can be handled.

Verification of a gear drive with a reference load/speed can be performed in three ways:

A. Based on a given load and requested lifetime to calculate the corresponding safety factors and compare these factors with a minimum requested safety factor. Such a procedure corresponds to the methods given in most ISO standards (for example in ISO 6336 (Ref. 2) for gears).

B. Based on a given minimum requested safety factors and a requested lifetime to calculate the so-called power rating (or torque rating or transmittable torque). Such a procedure corresponds to the methods given in many AGMA standards (for example in AGMA 2001 [Ref. 4] for gears).

C. Based on a given load and minimum requested safety factors to calculate the achievable lifetime.

These variants are not as different as they appear. One variant can easily be transformed into another depending on the required documented result: Achieved safety factors (per A), transmittable power (per B), or achievable lifetime (per C).

If the load is derived from measured data (such as time-torque-speed information) or a numerical simulation, then the approach is similar. Such information must be converted into a load spectrum, which can be used for gear calculations according to ISO or AGMA ratings, based on the methods described in ISO 6336-6 (Ref. 3). With load spectrums (or 'variable load' termed in ISO), normally variant A is used for verifications, but variant C can also be applied. In this case, the proceeding described in AGMA ratings must be adapted slightly (Ref. 1).

If the load definition is given with variable load, then all elements of a drive system having verification methods, such as gears, which consider material strength depending on the number of load cycles (SN-curves), should make use of this information for an appropriate analysis. For other elements (such as screws and feather keys), which are usually checked by a static analysis, only the most critical bin of a load spectrum (the maximum load) will be used.

In the next sections, the method of how to generate a load spectrum from time-torque-speed data is discussed. The method used depends on the considered machine element, and therefore is quite different for gears, bearings, and shafts.

Then the verification method with variable load will be discussed for the critical elements of drive trains such as gears, bearings, and shafts. Of special interest is the verification of shafts with variable load, because neither ISO nor AGMA have a verification method, only the German FKM guideline has one (Ref. 5).

Generation of Load Spectrums

Time-torque-speed data is usually measured at the input or the output coupling of a drive system. Such data must be modified by a factor (transmission ratio) to get the load at the considered machine element and then further modified depending on the type of the considered element. The tooth of a rotating gear is loaded only when the tooth contact occurs. As a result, a tooth is loaded by a sequence of pulsating loads and is stressed only by a portion of the full load data, whereas shafts and bearings are continuously loaded and get the full load data.

Machine elements stressed by bending are very sensitive to load change. This is the case for gear teeth and shafts, but not bearings. To get all significant cycles with torque changes, the so-called "rainflow" method is used (Refs. 6, 7). Rainflow analysis provides a matrix that shows how often any torque changes happen. For bearings, a much simpler method called "simple count" can be used (Refs. 1, 3). Table 1 gives an overview of the different methods.

Nomenclature

Symbol	Description	Unit
General		
R	Stress ratio	
n	Speed	rpm
T	Torque	Nm
F_t	Nominal tangential load	N
N	Cycle number (over total lifetime)	N
$h.i$	Cycle number of bin i, in %	%
m	Total number of bins in a load spectrum	
i	Load spectrum bin number	
	Symbols for gear calculations	
Y_M	Alternating bending factor, see ISO6336-3 (Ref. 2)	
K_V	Dynamic factor	
$K_{F\beta}$	Face load factor (root stress)	
Symbols for bearing calculations		
L_{hnai}	Service life (load spectrum bin i) in the case of speed n_i and load F_{ri}, F_{ai}	h
Symbols for shaft calculations		
F_{zd}	Axial force in a shaft section	N
M_b	Bending moment in a shaft section	Nm
M_t	Torsional moment in a shaft section	Nm
Q	Transverse force in a shaft section	N
S_{zd}	Axial stress (tension or compression)	N/mm^2
S_b	Bending stress	N/mm^2
T_t	Torsional stress	N/mm^2
T_s	Shear stress	N/mm^2
S_{max}	Maximum stress	N/mm^2
S_{min}	Minimum stress	N/mm^2
S_a	Stress amplitude	N/mm^2
S_m	Mean stress	N/mm^2
k	Exponent of SN-curve	
N_D	Component cycle number at knee point of SN-curve	
S_{a1}	Stress amplitude of the bin with the highest amplitude in the spectrum; per component	N/mm^2
A_{ele}	Distance between fatigue life curve and SN-curve	
K_{BK}	Variable amplitude factor	
S_{WK}, T_{WK}	Component fatigue limit, at knee point of SN-curve, including design factors (notch, etc.)	N/mm^2
$S_{äqu}$	Component equivalent stress amplitude at knee point of SN-curve	
a_{BK}	Degree of utilization	
SY	Safety factor for combined stress	
$SY_{BK,zd}$	Safety factor for axial stress	
$SY_{BK,b}$	Safety factor for bending stress	
$SY_{BK,t}$	Safety factor for torsional stress	
$SY_{BK,s}$	Safety factor for shear stress	
j_D	Minimum safety factor for fatigue strength assessment according FKM	

Verification of:	Load (torque * speed) ≥ 0 (always positive)	Load is ≥ 0 and < 0 (positive and negative)
Gears	▪ Optional: Extract load on a single tooth ▪ Get load spectrum with simple-count method ▪ Load spectrum type A generated	▪ Extract load on a single tooth ▪ Include dynamic factor KV ▪ Perform rainflow algorithm ▪ Get load spectrum from rainflow result ▪ Load spectrum type C generated
Bearings	▪ Load spectrum type A generated	
Shafts	▪ Perform rainflow algorithm ▪ Load spectrum type B generated	

Table 1—Treatment of time-torque-speed data to get a load spectrum.

Depending on the machine element type and the load data (if always positive or positive and negative) different load spectrum types must be generated. See Table 2 for the definition of these types.

Load spectrum type	
A	Load spectrum with torque and speed distribution (extended-counting method)
B	Load spectrum with torque distribution (rainflow algorithm). Contains per bin additional stress ratio factors for shaft calculation. No speed distribution available. All bins of the load spectrum have the mean speed.
C	Load spectrum with torque distribution (rainflow algorithm). Contains per bin additional alternating bending factor YM for gear calculation. No speed distribution available. All bins of the load spectrum have the mean speed.

Table 2—Generated load spectrum types.

Generation of a Load Spectrum for Gear

The tooth of a rotating gear is loaded only when the tooth contact occurs. As a result, a tooth is loaded by a sequence of pulsating loads and is stressed just by a portion of the complete load data (Figure 1).

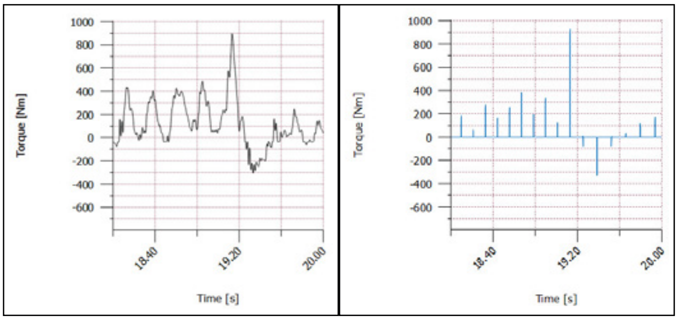


Figure 1—Torque over time in the time series (left). Torque on a specific tooth of the pinion (right).

If the signs of torque and speed in a time series are in such a way that always the same flank is in contact, then the so-called simple-count method can be used. The counting method is also documented in ISO 6336-6, Table 4 (Ref. 3). To obtain the load spectra for fatigue damage calculation, the range of the measured (or calculated) load is divided into bins or classes. If the speed is significantly varying, then for better results speed intervals are also created and each measuring point is sorted into the corresponding category of torque and speed. The number of measuring points is then counted and results in a load spectrum of bins with different torques and speeds (extended simple-counting method), see Figure 2.

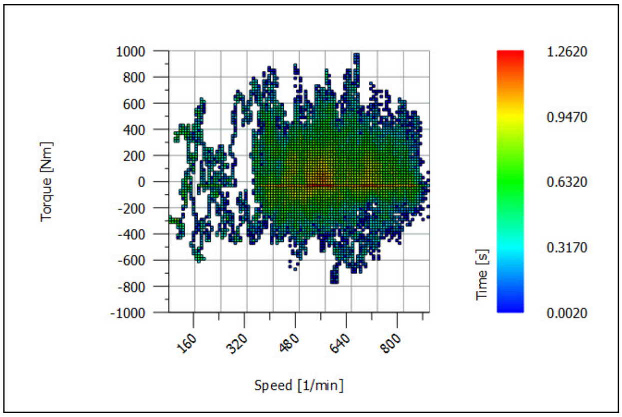


Figure 2—Display of the result of the extended simple-count method, torque-speed distribution with indication of duration in seconds.

If torque and/or speed have alternating signs so that the loaded flank is changing, then the assessment of the Hertzian pressure on the considered tooth flank (left or right) only considers the positive values on this flank. For the bending stress, this simple calculation procedure cannot be applied. The considered tooth root side is subjected to an alternating load, receiving tensile stress with positive torque and compression stress with negative torque. All significant alternating load cases must be extracted from the torque curve through the rainflow-counting algorithm. The result of the algorithm is a half-matrix displaying the count of how often a torque change T_{high}–T_{low} happens (Figure 3).

		T_{low} (Nm)				
		-796.70 -778.60	-778.60 -760.49	-760.49 -742.38	-742.38 -724.28	...
T_{high} (Nm)	-796.70 -778.60	1				
	-778.60 -760.49	0	2			
	-760.49 -742.38	0	0	3		
	-742.38 -724.28	1	4	0	1	
	...	...	...	...	...	...

Figure 3—Extract of a Rainflow half-matrix with 100 bins.

ISO 6336 is designed for the pulsating load on the tooth, meaning the nominal torque and the allowable bending stress numbers are intended for the pulsating load case. In general mechanics, a load case is defined by the stress ratio R (Ref. 5). It is the ratio between the lowest and the highest stress occurring as the stress oscillates during operation. So, for the pulsating load case, the ratio is $R = 0$ (as the stress is oscillating between 0 and σ_{high}).

General definition of the stress ratio R (Ref. 5):

$$R = \sigma_{low} / \sigma_{high} \tag{1}$$

As the bending of a tooth the stress σ_b is proportional to the nominal tangential load F_t; and as F_t is proportional to the torque T, for tooth bending the ratio R can also be expressed as follows:

$$R = F_{tlow} / F_{thigh} = T_{low} / T_{high} \tag{1a}$$

For alternate bending, in ISO 6336-3, annex B (Ref. 2), a rule is given to cover load cases with stress ratios $1 \leqslant R \leqslant 0$ with the alternating bending factor Y_M (see Eq. 1). As the general case of R may be in the range from $-\infty < R \leqslant +1$, the formula for Y_M must be extended as documented in Ref. 1. Then a set of $\{T_{high}, T_{low}\}$ can be converted in $\{T_{high}, Y_{M1}$ and $Y_{M2}\}$ per ISO 6336 nomenclature.

Note that in ISO 6336-3, annex B (Ref. 2), the definition of the stress ratio R appears to be different from Equation 1, but in fact is not. In ISO, the load F_{tlow} is the load applied on the opposed flank (positive value) but creates compressive bending stress (negative) on the considered flank. Furthermore, the compressive stress should be multiplied by 1.2 since the compressive stress on the nonloaded flank is approximately 20% higher than the tensile stress on the loaded flank. The factor 1.2 is used in ISO 6336-3 and can be confirmed with FEM calculations. So, the stress ratio definition according to Equation B.2 in ISO 6336-3 with $R = -1.2 * F_{tlow} / F_{thigh}$ is identical to the definition as used in general mechanics (as above).

Every element of the rainflow half-matrix must be converted in a bin of the duty cycle. To be in accordance with ISO 6336-6, a bin will contain the operating hours per bin, torque, speed and additionally the alternating bending factors Y_{M1}, Y_{M2} for the gear pair. The full procedure (Ref. 1) to convert time-torque-speed data into a duty cycle for gears is complex, see Figure 4.

When torque and/or speed have alternating signs, the rainflow method must be used to catch all significant changes from positive to negative load. The rainflow method will find many load changes occurring during the measured time frame, independent of the speed information. So, the speed information cannot be considered and is lost. Therefore, the mean speed is used in the resulting load spectrum.

Generation of a Load Spectrum for Bearings

Bearing forces depend on the loads applied on the related shaft. The signs of torque and speed applied on the shaft are not relevant for bearing verifications. But speed variation must be considered, so the extended simple-counting method (see Table 2), generating a load spectrum with load and speed distribution, is the appropriate method.

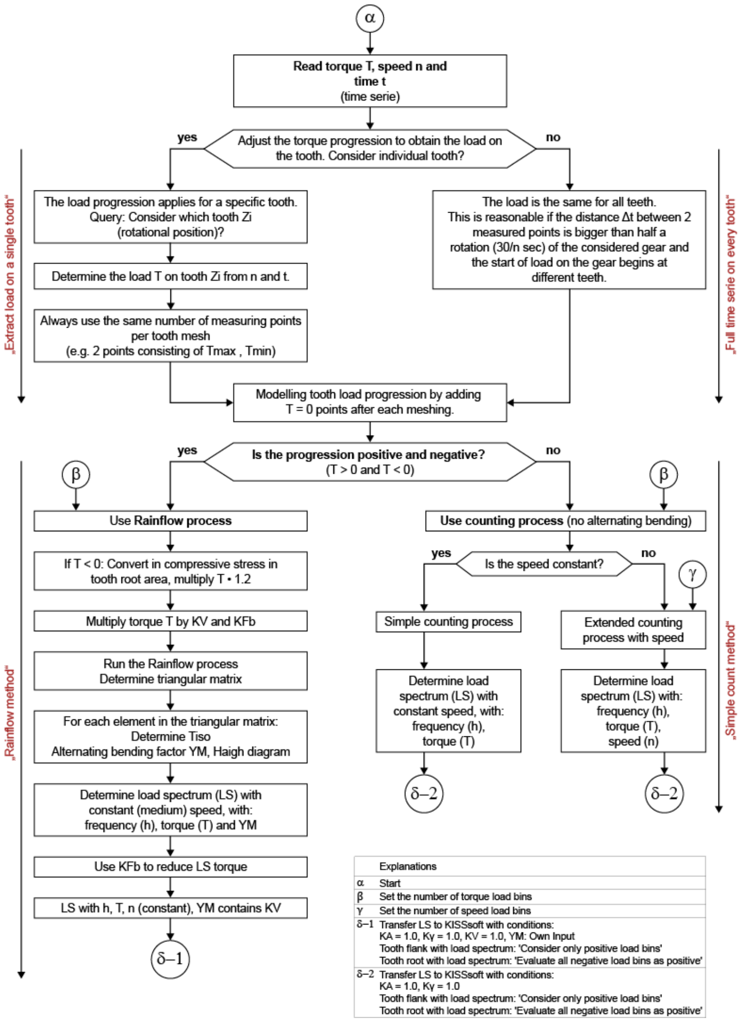
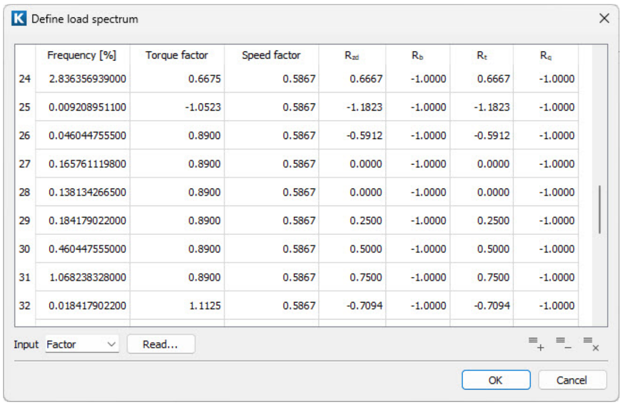


Figure 4—Flowchart to generate a load spectrum for gears from time series data.


Define load spectrum

	Frequency [%]	Torque factor	Speed factor	R_{zd}	R_b	R_t	R_q
24	2.836356939000	0.6675	0.5867	0.6667	-1.0000	0.6667	-1.0000
25	0.009208951100	-1.0523	0.5867	-1.1823	-1.0000	-1.1823	-1.0000
26	0.046044755500	0.8900	0.5867	-0.5912	-1.0000	-0.5912	-1.0000
27	0.165761119800	0.8900	0.5867	0.0000	-1.0000	0.0000	-1.0000
28	0.138134266500	0.8900	0.5867	0.0000	-1.0000	0.0000	-1.0000
29	0.184179022000	0.8900	0.5867	0.2500	-1.0000	0.2500	-1.0000
30	0.460447555000	0.8900	0.5867	0.5000	-1.0000	0.5000	-1.0000
31	1.068238328000	0.8900	0.5867	0.7500	-1.0000	0.7500	-1.0000
32	0.018417902200	1.1125	0.5867	-0.7094	-1.0000	-0.7094	-1.0000

Input Factor Read...

OK Cancel

Figure 6—Load spectrum for shaft verification (extract displaying bin 24 to 32), torque and speed as factors to be multiplied with the nominal values).

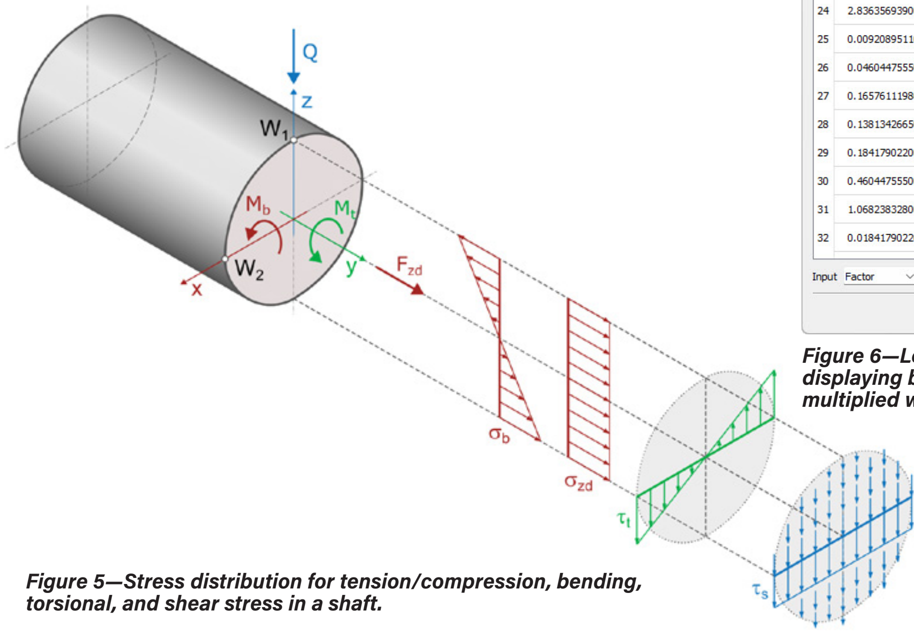


Figure 5—Stress distribution for tension/compression, bending, torsional, and shear stress in a shaft.

Generation of a Load Spectrum for Shafts

Shafts in drive systems are submitted to bending, axial tension/compression, torsion, and shear stresses. A point on the outer diameter of a rotating shaft is submitted to tensile stress in one position and to compression stress when rotated by 180° (Figure 5). Therefore, a rotating shaft with gears submitted to a varying torque - when the torque changes slowly (much slower than the shaft speed)—is basically submitted to alternating bending and shear stress. In contrast, torsional stress is nearly constant, changing much slower according to the changes of the applied torque. In simplified calculations, torsion is often assumed to be pulsating (assuming that the torque is pulsating with every rotation). This assumption is on the safe side, as normally the change in torsion per rotation is much less.

If the real number of torque changes is extracted from time-torque data by the rainflow method, then the torsion stress distribution is more realistic and will provide improved results. The same considerations apply also to axial tension/compression stresses.

The rainflow analysis delivers the upper torque T_{high} and the lower torque T_{low} of a load spectrum bin. For a shaft calculation according to the FKM rule (Ref. 5) the upper torque T_{high} and the stress ratio factor R is used (see Equation 1). Thus, a load spectrum bin must additionally contain the R factors for torsion and axial tension/compression according to Equation 1, and R = -1 for bending and shearing. For further handling of T_{high} and R see the section "Rating of Bearings with a Load Spectrum."

Note that in the shaft section, where bending and torsion stresses are combined, often the bending stress dominates, making the influence of torsion minimal. In such cases, assuming that torsion is pulsating is acceptable. The advantage of this simplification is that shaft and bearing calculations can use the same load spectrum (Type A according to Table 2).

Rating of Machine Elements with a Load Spectrum

The rating of machine elements of a drive system is defined by national or international standards. Generally, a standard provides the calculation methods for the rating with a nominal load. Rules for the consideration of load spectrums are often missing. In this chapter, the methods for the verification of the most critical elements—gears, shaft, and bearings—with a load spectrum are discussed.

Rating of Gears with a Load Spectrum

Part 6 of the ISO6336 standard is the rule for the "Calculation of service life under variable load" (Ref. 3). The method is based on the Palmgren-Miner rule, which is a widely used linear damage accumulation method. The method is "neutral," which means specific factors of the rating method used are not involved. Therefore, this rule can also be used in combination with AGMA ratings (as AGMA 2001 (Ref. 4) and others). AGMA rating methods do not give a rule for nonuniform load, but reference is given to use Miner's rule as presented in ISO/TR 10495 [Chapter 7.2 in Ref. 4]). ISO/TR 10495 was replaced in 2006 by ISO 6336-6.

To also handle cases with bins having negative torque (tooth loaded in the compressive stress domain) the rule for the alternating bending factor Y_M has to be extended (Ref. 1); and for every bin an individual Y_{M1} and Y_{M2} must be used.

Rating of Bearings with a Load Spectrum

A rule for the rating of bearings with load spectrum is not available in an international standard. The calculation procedure is based on the damage accumulation theory developed by A. Palmgren in 1924 and completed by B.F.

Langer (1937) and M. Miner (1945). The formulae are well documented in the literature (Niemann-Winter [Ref. 9]) or in handbooks of bearing manufacturers (Ref. 10).

The main formula for the calculation of the total bearing service life by combining the service life per bin is documented in Equation 2. Service life may include the effect of lubrication and/or the modified reference rating according to ISO 16281 (Ref. 11).

$$L_{hna} = \frac{100}{\frac{h_1}{L_{hna1}} + \frac{h_2}{L_{hna2}} + \cdots + \frac{h_m}{L_{hnam}}} \tag{2}$$

Rating of Shafts with a Load Spectrum

The rating of shafts is not widespread. Until today, no ISO standard is available. Some national standards exist, but they are limited. DIN 743 (Ref. 8) contains indications concerning equivalently damaging stresses. But the only official method, that can cover and complete this task, is the German FKM Guideline (Ref. 5).

It must be noted that the symbols used in the FKM guideline are based on former East German TGL standards and unfortunately quite different from symbols used otherwise in literature, DIN, or ISO standards. All symbols used are listed in the symbol table of this paper.

The FKM Guideline contains variants of the calculation procedure for steel or other materials, as well as welded and nonwelded machine parts, and is therefore quite complex. For shaft verifications, the fatigue strength assessment with nominal stresses must be carried out. In this paper, only the main steps of the calculation with nominal stresses for steel using the method "Miner elementary" with the "equivalent amplitude assessment" rule (Ref. 5) will be summarized.

For shaft verification normally different shaft sections are selected, where a detailed analysis is made. In a section of a shaft, in general, there are different acting stress types: axial stress (tension or compression) S_{zd}, bending stress S_b, torsional stress T_t, and shear stress T_s. Their maximum and minimum values (S_{max}, S_{min} or T_{max}, T_{min}) must be used. With a load spectrum, for every bin of the spectrum, in a determined section of the shaft the maximum loads must be calculated (axial force $F_{zd,max}$, bending moment $M_{b,max}$, torsional moment $M_{t,max}$, and shear force $Q_{,max}$). Then the corresponding maximum stresses (axial $S_{zd,max}$, bending $S_{b,max}$, torsion $T_{t,max}$, shear $T_{s,max}$) are found, using well-known equations (as in AGMA 6001, chapter 4.4, Ref. 13 or in Ref. 5, formula 1.1.1). The minimum stresses can be derived with the ratio factors:

Stress amplitude S_a, mean stress S_m, stress ratio R:

$$\begin{aligned} S_a &= (S_{max} - S_{min}) / 2; \\ S_m &= (S_{max} + S_{min}) / 2; \\ R &= (S_m - S_a) / (S_m + S_a) = S_{min} / S_{max} \end{aligned} \tag{3}$$

The stress distribution in a shaft section is complex and different for the four acting stress types (Figure 5). At a specified point of a shaft section, the resulting stress is a combination of the four stress types, according to the normal stress hypothesis or the von-Mises criterion (Ref. 5). For nonwelded steel von-Mises is preferred. Usually, two points at the position W1 and W2 (Figure 5) of a shaft section are the highest loaded and should be checked.

Verification with nominal stresses consists of a static strength assessment and a fatigue strength assessment. The static strength is checked with the bin of the load spectrum with the highest stresses. So for every bin the resulting combined stress (using the maximum stresses $S_{zd,max}$, $S_{b,max}$, $T_{t,max}$, $T_{s,max}$) is calculated, and the verification is made with the highest value found. According to FKM the static assessment against the tensile stress Rm and against the yield strength R_p must be performed. Additionally in case of higher temperatures, the assessment against the creep strength $R_{m,Tt}$ and against the creep limit $R_{p,Tt}$ is required.

Fatigue Strength Verification

For the fatigue strength, the stress amplitudes (Equation 3) of all bins are relevant, contributing to the damage accumulation. The equivalent amplitude Sequ used in FKM is a constant stress amplitude with an assigned cycle number equal to the knee point of the S-N curve, which is damage-equivalent to the related stress spectrum under consideration of the shape of the S-N curve, the required total number of cycles and the maximum amplitude in the spectrum. The description of the verification proceeding with all formulas would exceed the purpose of this paper. So only some of the important steps will be presented.

For every stress component (axial, bending, torsional, and shear) the same procedure is applied. In the first step, the mean stress value with amplitude (stress $S_{m.i}$ and $S_{a,i}$) of every bin is converted in an equivalent alternating stress with amplitude $S_{aW.i}$ (with $S_{m.i}$ = 0 and $S_{aW.i}$). Then the range of bins must be resorted, such that the first bin has the biggest amplitude ($S_{aW.1}$). In the third step, the variable amplitude factor must be found, using Equation 4 and Equation 5.

The variable amplitude factor K_{BK}, Equation 2.4.39 in FKM (Ref. 5), is

$$K_{BK} = (ND * A_{ele} / N) \text{ ^ } (1/k) \tag{4}$$

with Aele, the distance between fatigue life curve and SN-curve, Eq. 2.4.42 in FKM [5],

$$A_{ele} = \frac{1}{\sum_{i=1}^{m} \frac{h_i}{100} \left(\frac{s_{ai}}{s_{a1}}\right)^k} \tag{5}$$

with k, the exponent of the SN-curve (for steel $k = 5$ for normal stresses and $k = 8$ for shear stresses).

This permits obtaining the equivalent stress amplitude at the knee point of the SN-curve, S_{equ}, FKM Equation 2.4.27 (Ref. 5).

$$S_{equ} = S_{a.1} / K_{BK} \tag{6}$$

For the fatigue strength assessment, depending on the position of the considered shaft section, at locations with shaft shoulders, keyways, etc., the stresses are increased due to local stress concentration. In the FKM (Ref. 5), as in AGMA 6001 (Ref. 13) or DIN 743 (Ref. 8), for the verification the nominal stresses are used (not increased), but the fatigue strength is modified (reduced) by stress concentration factors. As mentioned in AGMA, "since the fatigue strength is largely influenced by physical conditions, environmental conditions, and application conditions as well as material conditions, the basic fatigue strength must be modified (Ref. 13)". In FKM (Ref. 5) all these effects are documented and combined in the so-called "design factor" K_{WK}. So, the component fatigue limit for axial, bending, torsional and shear are reduced by the design factor per component to obtain the effective nominal values of the component fatigue limit S_{WK}, T_{WK}.

In ISO or AGMA ratings, the final result of a verification is the safety factor obtained by division of the permissible stress by the effective stress. The resulting safety S must then be equal to or higher than the minimum requested safety S_{min}. The result obtained by FKM is not a safety factor, but the "degree of utilization." The degree of utilization is just the inverted value of the safety factor. The advantage of the utilization concept is that formulas for the verification with combined stresses are simpler. For this paper, the safety concept is used, and the FKM formulas are adapted accordingly. As a symbol for safety, we use here S_Y, as the symbol S in the FKM guideline is used for nominal stress.

The basic equation for component safety S_Y, equal to the inverted value of the degree of utilization aBK according to FKM Equation 2.6.3 (Ref. 5), for axial, bending, torsional, and shear are:

$$SY_{BK} = 1 / a_{BK} = S_{WK} / S_{equ} \tag{7}$$

So, based on the applied stress and the permissible stress per component, the safety factors obtained are $SY_{BK,zd}$, $SY_{BK,b}$, $SY_{BK,t}$, and $SY_{BK,s}$. For the consideration of the combined stresses in a shaft, these factors are then combined according to the von-Mises criterion (Equation 2.6.7, FKM [Ref. 5]) to obtain the final result.

$$\frac{1}{SY} = \sqrt{\left(\frac{1}{SY_{BK,zd}} + \frac{1}{SY_{BK,b}}\right)^2 + \left(\frac{1}{SY_{BK,t}} + \frac{1}{SY_{BK,S}}\right)^2} \tag{8}$$

In a shaft section, there are two locations where the combined stress may be highest, position W1 and W2 in Figure 5. In point W1, bending and torsion stresses are high, but shear is zero. In W2, shear and torsion stresses are high, but bending is zero. Thus, both positions must be checked to find the lowest safety factor.

The verification of whether the shaft section fulfills the request is then given by:

$$\min\{SY_{W1}, SY_{W2}\} \geq j_D \tag{9}$$

with the requested minimum safety factor j_D for fatigue strength assessment. For cases where the consequences of shaft failure are high, this factor can be assumed to be 1.5.

Verification of Drive Systems

Today the analysis of drive trains is performed with appropriate software such as *KISSdesign* (Ref. 12) which permits modeling the complete drive with all the main elements. Normally the time series is measured at the input or the output coupling. The handling of a time series for a drive train can be made in two different ways.

- The "simple variant," using the same load spectrum for each element of the drive
- The "general variant," generating individual load spectrums for different elements (such as gears, shafts, bearings) and for each stage of the drive

Use of Time Series for Drive Systems with the Simple Variant

A load spectrum of type A (Table 2) must be defined at the input or output of the system, at the location where the time series was measured. This load spectrum is then used across the drive system for all gears, shafts, and bearings. For this scope, it is preferred that torque and speed in the load spectrum are given as factors to be multiplied by the nominal values (see Figure 6). The drive train software will calculate the nominal speed/torque of every single element, and the same load spectrum, if defined with factors, can be used everywhere.

The simple variant can be used with any drive system software permitting the use of load spectrums without any further adjustment. If the torque and speed of the time series are always positive, or if some infrequent negative values can be neglected, then this method is preferred. The results for gears and bearings will be perfect, load spectrum of type A is used. For an accurate shaft verification, always load spectrum of type B should be used, otherwise, the shaft strength will not be accurate. Often shaft strength is not critical. The use of load spectrum type A—and assuming the torsion and shear as pulsating for shaft verification—will produce conservative results (on the safe side). So, if the results are satisfying, there is no need for a more complex analysis.

Use of Time Series for Drive Systems with the General Variant

If time series have positive and negative torques/speeds, then alternating load changes arise, which are very sensitive for strength verifications. For gears load spectrums of type C, for shafts type B, and for bearings type A must be used—meaning for a shaft, a gear, or a bearing calculation, a different load spectrum must be used. To make things even more complicated, the load spectrum for every gear pair must be produced separately. This will be explained in the next section.

The handling of time series with positive and negative torques/speeds in systems is very complex and requires special adaptations in drive-system software. If, for example, the time series is given for the input coupling of the system, then for every gear pair, the ratio r between the input coupling and the pinion of the pair must be known. Then the time series (given for the input coupling) is adapted to the pinion by multiplying the torque by r and reducing the speed by r. This modified time series is then used to generate the load spectrum for the verification of the gears. The same procedure can be repeated for shafts and bearings (see Figure 7).

For shafts and bearings alone it is also possible, and simpler, to generate the load spectrum of type A and type B at the position where the time series is applied. Then the system calculation must be executed twice, once with the load spectrum of type A for all the bearing verifications, and then with type B for the shafts.

Use of Time Series for Drive Systems with Different Gear Sets

As mentioned before, the load spectrum in drive system applications must be produced separately for every gear pair when a time series has positive and negative torques/speeds, because the load on the individual gear tooth must be considered for verifications as explained in Figure 1.

Normally the frequency of torque changing from positive to negative, f_{Torque}, is much smaller than the frequency of pinion speed, f_{Speed}. Let's assume, that f_{Torque} = 0.25 Hz (torque change every four seconds) and that the pinion speed, first stage, is f_{Speed} = 10 Hz (600 rpm). In this case, a tooth of the pinion gets, for four seconds, a positive load 40 times, then one load change, then a negative load 40 times. Thus, the load spectrum will contain 2.4 percent of alternating cycles and the rest will be pulsating cycles.

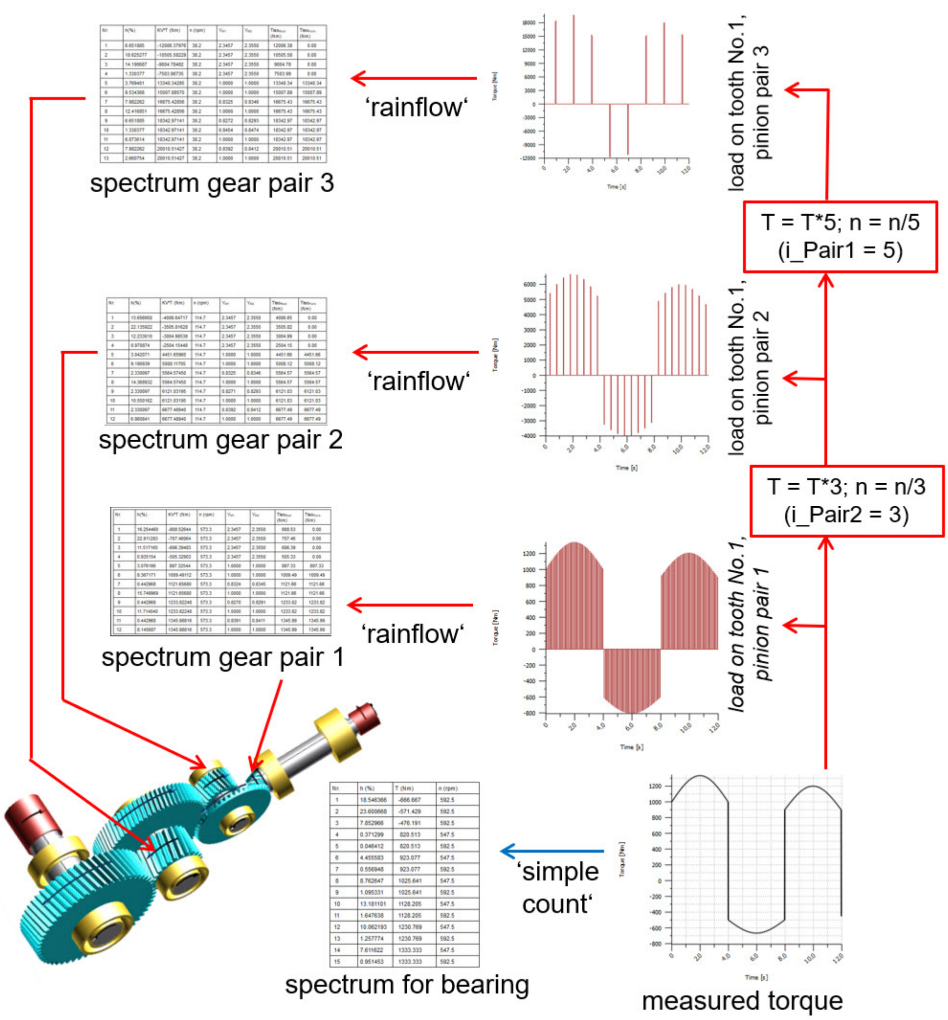


Figure 7—A synthetic time series applied at the input coupling of a three-stage gearbox. The load on an individual tooth of every pinion in the system is extracted from the time series and then converted into a specific load spectrum for every gear stage.

The pinion of the second stage will still get $f_{Torque} = 0.25$ Hz, but due to the reduction of the first stage (let's assume as i = 5), the speed will be $f_{Speed} = 2$ Hz (120 rpm). The tooth of this pinion gets, for four seconds, a positive load only eight times, then one load change, then a negative load eight times. The load spectrum will contain 11.1 percent of alternating cycles and the rest will be pulsating cycles.

As the alternating load cycles are more damaging than pulsating cycles, the load spectrum in the second stage is different and clearly more damaging than the load spectrum of the first stage (Figure 7).

Application of the Method on a Wind Turbine Gearbox

Figure 8 displays just the first 600 seconds of a time series during the power generation phase of a wind turbine. The torque varies significantly between 146 and 1245 kNm, and the speed is low, nearly constant in the range of 7.0 and 8.6 rpm, also called "cut-in speed." As the torque is always positive, a gear tooth is always loaded by pulsating stress. Therefore, the simple-count method is used for the generation of the load spectrum for gear and bearing verification. The resulting torque-speed distribution is displayed in Figure 9. The load spectrum contains bins with different torque and speed values. In drive-system software (Ref. 12) the spectrum is attributed to the input coupling (on the turbine shaft) and then automatically adapted and distributed to all elements of the drive system.

For the verification of the shafts, a specific analysis of the number of cycles with bigger amplitudes is recommended. The torque variation (Figure 8) of the time series is generally low, very few times does a change from high to small torque occur. This is also evident in the resume of events shown by the rainflow half-matrix (Figure 10). Therefore, the shaft is not submitted to many significant torsional stress amplitudes. If, as discussed earlier, the torsional stress was assumed to be pulsating, then the resulting safety would be lower. The use of a rainflow analysis provides a more precise result. The obtained load spectrum (Figure 11) is then applied at the input coupling and used for all shaft verifications. For proper verification, critical sections should be designated in every shaft of the gearbox (at positions with shaft shoulders, keyways, etc.) (see Figure 11). The verification is performed for all sections, and the most critical will be found. In the result overview (Figure 12) for every shaft the static and fatigue strength safety in the most critical section is displayed. This, combined with the bending and pitting safety factors for all gear pairs, provides a good overview of the main strength parameters of the wind turbine.

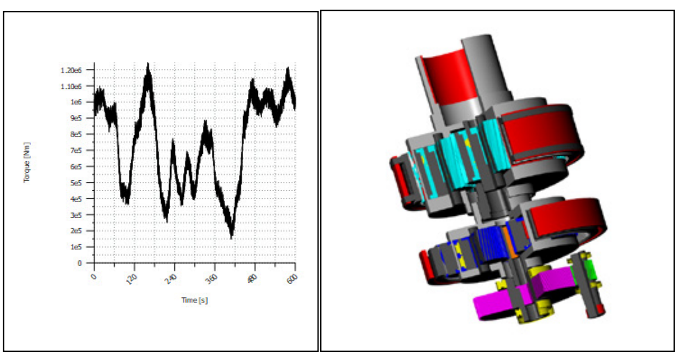
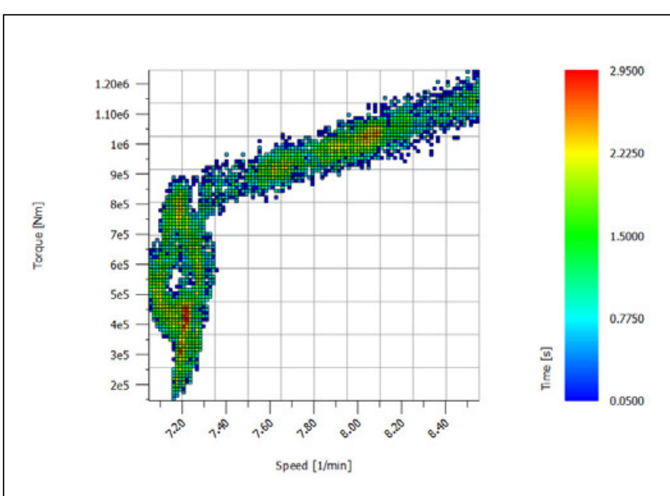


Figure 8—Time series measured during the power generation phase of a wind turbine.

Rainflow half-matrix with 10 bins											
Number of events 266											
	Tmin from:	101	189	277	365	453	541	629	717	805	893 (Nm)
	Tmin to:	189	277	365	453	541	629	717	805	893	982 (Nm)
Tmax from (Nm):	Tmax to (Nm):										
101	189	60									
189	277	6	8								
277	365	1	0	15							
365	453	0	0	6	30						
453	541	2	0	1	5	19					
541	629	0	0	1	1	8	41				
629	717	0	0	1	0	0	5	10			
717	805	0	0	0	0	1	0	7	12		
805	893	0	0	2	0	0	0	2	3	12	
893	982	1	0	0	0	0	0	0	0	1	6

Figure 10—Rainflow half-matrix, most of the 1,512 events (torque changes) found are in the matrix diagonal, where the amplitudes (max-min)/2 are small.



Nr.	h (%)	T (Nm)	n (rpm)
1	0.050000	168551.680	7.2
2	0.216667	190527.360	7.2
3	0.491667	212503.040	7.2
4	0.675000	234478.720	7.2
....	....	....	....
70	1.533333	1135481.600	8.4
71	0.041667	1157457.280	8.0
72	1.216667	1157457.280	8.4
73	0.691667	1179432.960	8.4
74	0.300000	1201408.640	8.4
75	0.133333	1223384.320	8.4
76	0.050000	1245360.000	8.4

Figure 9—Torque display of the result of the simple-count method, torque-speed distribution with an indication of duration in seconds (left) and the spectrum (right).

Conclusion

The method discussed is how torque-speed data given at the input or output coupling of a drive system can be converted into a specific load spectrum for the rating of every gear mesh, bearing, and shaft of the system. The procedure differs for these elements, depending on how the load is operating. A gear tooth is submitted to a pulsating load, so, if the torque never becomes negative, no alternating stress happens. A ball of a bearing always gets a pulsating load, regardless of positive or negative torques. A rotating shaft is always submitted to alternating bending stress, but torsional stress amplitudes normally are small when the torque varies slowly (compared to the rotational speed), so often torsional stress is less damaging.

Therefore, the conversion of time series data into a load spectrum is done with different methods for gears, bearings, and shafts; furthermore, the method must be adapted if the torque is changing from positive to negative.

In the second part of the paper, the method of verification with load spectrums for shaft and bearings is explained. These methods are not yet covered by ISO standards, so the verification of bearings is according to literature and the verification of shafts is according to FKM documentation.

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Nr.	h (%)	T (Nm)	n (rpm)	$R_{Tension/Comp.}$	$R_{Bending}$	$R_{Torsion}$	$R_{Shearing}$
1	0.528751	256454.400	7.5	0.572	-1.000	0.572	-1.000
2	0.594845	256454.400	7.5	0.786	-1.000	0.786	-1.000
3	0.462657	311393.600	7.5	0.471	-1.000	0.471	-1.000
....	....	....	....	....	....	....	....
66	1.057502	1190420.800	7.5	0.862	-1.000	0.862	-1.000
67	1.718440	1190420.800	7.5	0.908	-1.000	0.908	-1.000
68	0.396563	1190420.800	7.5	0.954	-1.000	0.954	-1.000
69	0.066094	1245360.000	7.5	0.118	-1.000	0.118	-1.000
70	0.066094	1245360.000	7.5	0.250	-1.000	0.250	-1.000
71	0.462657	1245360.000	7.5	0.824	-1.000	0.824	-1.000
72	0.396563	1245360.000	7.5	0.868	-1.000	0.868	-1.000

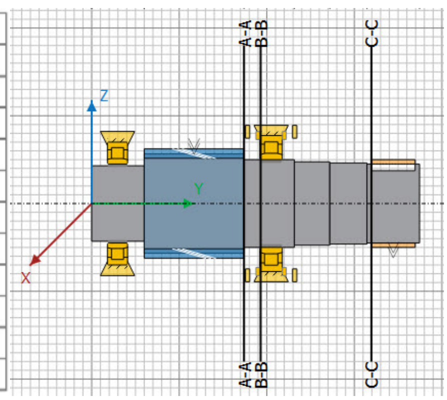

Figure 11—Spectrum for shaft verification (left) and display of the high-speed shaft with an indication of the critical sections (right).

Nominal load calculation	RESULTS	GEARS				
Open module without CA	SF [-]	SH [-]				
Pair1	1.9013	1.0101				
Pair2	1.8589	1.1056				
Pair3	1.977	1.0583				
	RESULTS	SHAFTS			RESULTS	BEARINGS
Open module	SD [-]	SS [-]	max deflection [um]		Lh [h]	S0 [-]
Shaft1	4.1423	4.8658	31.357		6901.2	3.6949
Shaft2	5.5225	7.407	25.822		6282.4	2.2169
Shaft3	3.8083	4.7775	33.801		6358.9	1.8285
Shaft4	4.0946	3.9207	16.467		7665.5	1.834

Figure 12—Overview of the results of verifying the wind turbine.

Dr. Ulrich Kissling, founder and managing director of KISSsoft since 1998, stepped down from his managerial role in July to partially transition to retirement. He studied Machine Engineering at the Swiss Technical University (ETH). As a gear expert, Dr. Kissling participates in different Work Groups of ISO for international standards.

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FVA GMBH

Launches Online Tool for Machine Elements and Standard Calculations

FVA GmbH has released *mechanicus*, an intuitive online calculation tool for machine elements and standard calculations. The new web application is available for free now here and marks a significant milestone in the world of drive technology.

Mechanicus offers engineers, technicians, designers, and students innovative tools to effortlessly perform complex calculations and optimize their processes—from anywhere, with any internet-capable device. With this first version, users can already perform reliable cylindrical gear, notch, and interference fit calculations, as well as dimensioning of rolling bearings and feather keys. New features are continuously being added.

"With *mechanicus*, we want to simplify FVA calculations with an intuitive online tool. Users benefit from proven algorithms and get direct access to the latest research findings that are continuously integrated into the platform" stated Dr.-Ing. Ralf Wuthenow, head of modeling and simulation at FVA GmbH.

Cutting-edge research meets German engineering

From the design of gearbox elements to standard calculations—*mechanicus* covers a wide range of applications and offers users a comprehensive solution for their engineering needs. With a growing range of powerful calculation features, the platform helps users to optimize their designs and develop innovative solutions.

Innovative technology: The platform provides user-friendly access to advanced state-of-the-art calculations. From the design of cylindrical gears to shaft load capacity analysis, *mechanicus* provides a comprehensive solution for drive technology challenges.

Cutting-edge research: As an FVA partner (Forschungsvereinigung Antriebstechnik e. V., the Drive Technology Research Association), *mechanicus* brings the bundled expertise of the FVA expert network directly to the user's desk. With the continuous integration of the latest research findings and projects, users can always take advantage of the latest drive technology knowledge and developments.

Simplicity and efficiency: The web application uses the infrastructure of *FVA-Workbench* gearbox design software and offers a user-friendly interface for modeling and calculating machine elements. Users can even perform calculations on the go or with customers, which increases flexibility and mobility without sacrificing efficiency or accuracy. Default values and a variety of input options make the design of machine elements an intuitive and efficient process.

Tailored solutions: *mechanicus* makes it possible to provide customized local or intranet solutions for corporate customers with minimal effort. This allows companies to perform calculations and simulations that are precisely tailored to their individual requirements and operational processes.

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"Based on our long-term expertise in autonomous driving systems, we are delighted to now also operate successfully on the market as mobility solutions provider," said Alexander Makowski, head of ZF mobility solutions. "In addition, we will leverage the ZF Group's entire expertise in vehicle technology, for example in the electrification of the drivetrain and vehicle motion control. And together with our global aftermarket organization, we will provide state-of-the-art customer service directly on site."

Dr Rafiq Swash, CEO of Aidrivers, added: "We are proud to have won ZF as a global partner with expertise in the field of autonomous driving in a wide range of applications, from passenger cars and commercial vehicles to special vehicles. This is the perfect match for us as a small, innovative solution provider for autonomous driving in ports and logistics areas."

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HECO, Inc.'s annual Reliability, Process, & Maintenance (RPM) Symposium will return to Kalamazoo, Michigan, in 2024. The two-day event focuses on reliability in industrial processes and is scheduled for Oct. 1-2 at The Radisson Plaza Hotel, 100 W. Michigan Ave., Kalamazoo, Michigan, 49007. The conference-style event features industry leaders speaking on topics related to maintenance best practices, electric motor-driven powertrains, Industrial Internet of Things (IIoT) solutions, methods to increase reliability in industrial facilities, and more. HECO and partnering sponsors will present educational breakout sessions designed to provide new techniques and processes for improvement. The sessions are designed for maintenance technicians and professionals within the Midwest, East Coast, and Southern regions of the United States.

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Lego Releases Apollo Lunar Rover Model

Aaron Fagan, Senior Editor

The Lego Technic NASA Apollo Lunar Roving Vehicle—LRV set is a detailed 1:8 scale model of the original moon buggy used by NASA's last three Apollo crews. Comprising 1,913 pieces, this set follows Lego's earlier releases of the *Saturn V* rocket and *Apollo 11* lunar module. The new Lego set will be available in stores on August 1.

According to Lego's website, "Embark on a journey to the moon with this detailed Lego Technic NASA model set for adults. The set includes a displayable model version of the lunar rover module carried by Apollo 17, plus three attachable equipment sets." This set is full of authentic details.

NASA's efforts to extend the distance that astronauts could traverse on the moon led to the development of the Apollo Lunar Roving Vehicle (LRV). The solution was a motorized vehicle, which Boeing developed in collaboration with GM and Goodyear. The LRV enabled *Apollo 17* astronauts Gene Cernan and Harrison Schmitt to venture as far as 4.7 miles from their lunar module, limited only by the distance they could walk back in case of a rover malfunction.

Each wheel of the LRV was powered by its own electric motor. There were four 0.25-hp (200-w) series-wound DC motors, one for each wheel. These motors provided the necessary torque and power to navigate the uneven and rocky lunar surface. Each wheel motor was connected to a harmonic drive gearbox. This type of gearbox offered a high reduction ratio in a compact and lightweight design, which was essential for the weight constraints of lunar missions. The harmonic drive provided precise control and high torque, necessary for overcoming the moon's rugged terrain.

Like the real lunar rover, which needed to fit inside the descent stage of the lunar module, the Lego model's three sections can be removed so that the main chassis can be folded. When stowed, the full-size LRV was just over half its deployed length of 10 ft. The Lego rover can be steered using the same T-shaped hand controller as the original, and it features a suspension system to navigate the rough lunar terrain. Although the Lego model is hand-powered, it is detailed to include the rover's heating and cooling elements, batteries, and other intricate features.

The Lego LRV set also includes pieces specific to at least two of the missions that used the rover. Among the model's features is a collection of moon rocks, including one significantly larger rock representing "Big Muley"—the largest sample brought back by *Apollo 16* astronauts John Young and Charlie Duke. The set also includes the Traverse Gravimeter Experiment, which measured the moon's geological structure as astronauts Eugene Cernan and Harrison Schmitt drove around Taurus-Littrow. Additionally, the map mounted to the LCRU details the actual paths that the *Apollo 17* LRV traversed on its three drives. However, the set does not include a way to convert the map into a makeshift replacement fender, as Cernan and Schmitt had to do on their second outing.

While the set forgoes the fine wire mesh of the high-gain antenna and the rover's mesh tires, the latter are molded to give a mesh-like appearance. This omission can be forgiven, as the training rovers used by astronauts on Earth had to use rubber tires; the mesh could only support the vehicle's weight in the moon's low-gravity environment.

The Lego Technic NASA Apollo Lunar Roving Vehicle—LRV set not only offers a highly detailed model but also pays homage to the remarkable engineering feats achieved during the Apollo missions. This set is a fitting tribute to the ingenuity and determination that took humans to the moon and back.

lego.com/en-us/product/nasa-apollo-lunar-roving-vehicle-lrv-42182

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