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JUNE 2023

GEAR INSPECTION

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TECHNICAL

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Gear cutting tools and services

Star SU offers a wide variety of gear cutting tools and services, including:

- Gear hobs
- Chamfer hobs
- Milling cutters
- Shaper cutters
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- Shaving cutters
- Chamfer and deburring tools
- Rack and saw cutters
- Master gears
- Ring and plug gauges
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Control your tool costs and let Star SU manage your tool room. From new tools to design work to re-sharpening and recoating, we have the equipment and resources to help keep your gear cutting operation running smoothly.

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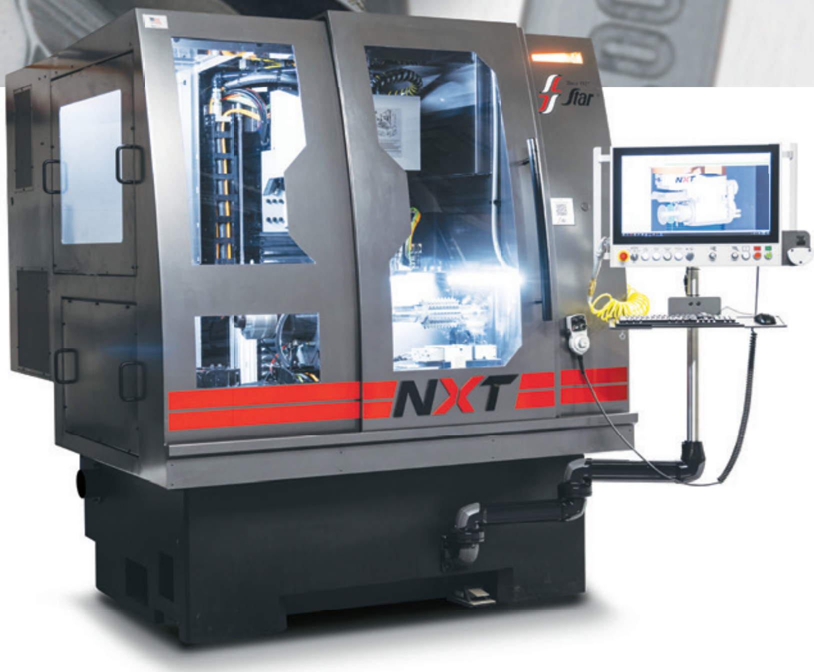

Economical hob sharpening and in-house tool maintenance

The Star NXT linear CNC tool and cutter grinding machine sharpens both straight and spiral gash hob designs up to 8” OD x 10” OAL. With a small footprint and maximized grind zone, the NXT also sharpens disk, shank and helical type shaper cutters, Scudding® cutters, and a wide range of round tools, making it a versatile tool room machine.

FFG Profilator

Gear Cutting Tools
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A Publication of
The American Gear
Manufacturers Association

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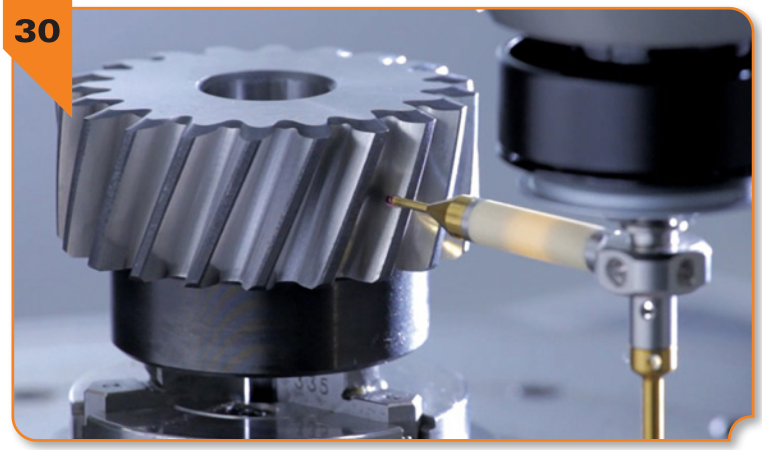

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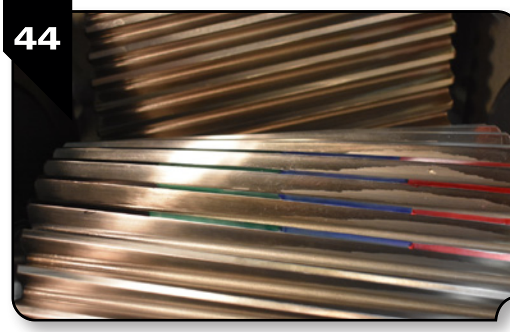

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SynchroFine®

The economical solution for gear hard fine machining

The modular machine for geared drive components

VARIO SPEED DRESSING®
The latest generation of PRÄWEMA SynchroFine® gear honing machines are equipped with so called Vario-SpeedDressing® technology, a dressing process wich works with completely defined cutting edge on the dressing tool Gear Geometries can be adjusted easily via HMI control.

SMART HONING
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FINEST SURFACES
A special oscillation method during the honing process enables surface roughness to be reduced even further, resulting in a further increase in the surface quality of geared components. This allows gearbox manufacturers to minimise friction losses in gear pairs. In addition, there is a less intensive load on the geared gearbox components, which in turn increases their service life.

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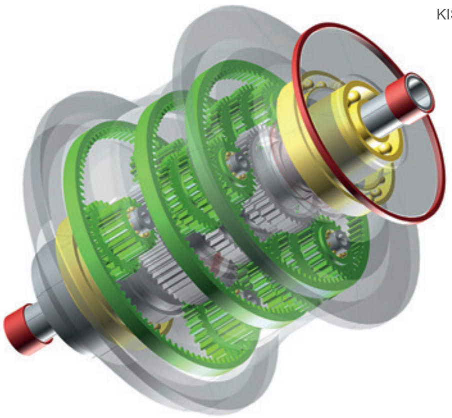

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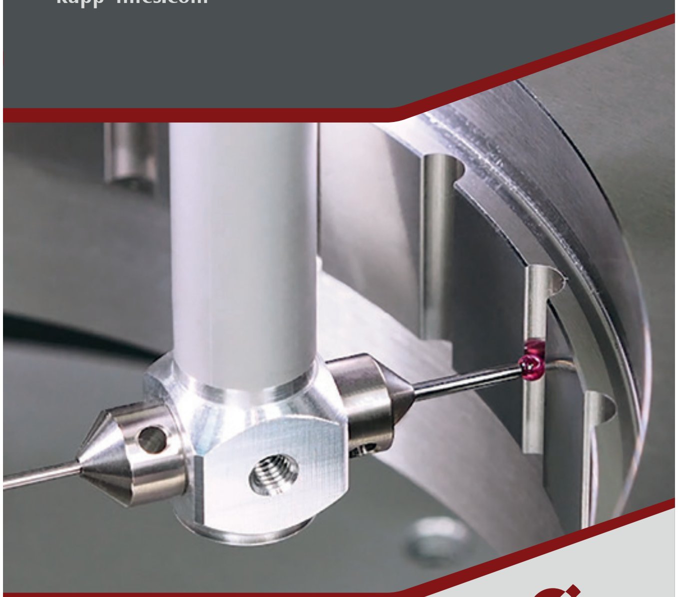

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GT Videos

Kapp Niles Metrology at Control 2023

Kapp Niles Metrology GmbH manufactures measuring machines for the measurement of gears and rotationally symmetrical workpieces. All types of workpieces, from the smallest to the largest, can be measured with the KNM 2X, 4X and 6X machines. Moreover, managing director Gerhard Mohr ranks this innovation as superior to the advantages of the competition. Workpiece types can be changed over in a matter of seconds with the KNM machines. Flexible setup near production offers enormous cost and time savings.

geartechnology.com/media/videos/play/258

Wenzel Offers Gear Inspection with GT Series

The new GT series works with Wenzel's standard controller WPC and is used with completely new software. With the GT series, Wenzel sees an opportunity where gear measuring technology and traditional measuring technology work together: tactile and optical.

geartechnology.com/media/videos/play/259

GT Revolutions

Live from Fort Worth, It's SNL

Just wrapping up three great days (May 17–19) with AGMA members who descended on Fort Worth, Texas, from all corners of the country (and industry!) for the 2023 Strategic Networking and Leadership Forum sponsored by Gleason Corporation, WD Bearings, Blaser Swisslube, and Specialty Steel Treating. Professionals from gear shops and OEMs alike gathered to share their experience and insight about where we are as an industry and where we are going.

geartechnology.com/blogs/4-revolutions/post/30327-live-from-fort-worth-its-snl

AGMA Media
1840 Jarvis Ave.
Elk Grove Village, IL 60007-2440
Phone: 847-437-6604
Fax: 847-437-6618

EDITORIAL

Publisher & Editor-in-Chief
Randy Stott. Vice President Media
stott@agma.org

Senior Editor
Matthew Jaster
jaster@agma.org

Senior Editor
Aaron Fagan
fagan@agma.org

Technical Editors
William (Bill) Bradley. Robert Errichello. John Lange. Joseph Mihelick. Charles D. Schultz. P.E.. Mike Tennutti. Frank Uherek

GRAPHIC DESIGN

Graphic Designer
Jess Oglesby
oglesby@agma.org

ADVERTISING

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

Materials Coordinator
Dorothy Fiandaca
fiandaca@agma.org

CIRCULATION

Circulation Manager
Carol Tratar
tratar@agma.org

MANAGEMENT

President
Matthew E. Croson
croson@agma.org

FOUNDER

Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein *Gear Technology* Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 38 years' worth of technical articles can be found online at *geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

THE GEAR INDUSTRY'S INFORMATION SOURCE
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ARGUS eyes on the grinding process

Reishauer provides unprecedented possibilities to improve your grinding and dressing processes and machine maintenance with the help of our expertise and newly available data science. Process monitoring, optimizing with data analysis, identifying necessary maintenance work in advance, planning efficiently and reducing downtime to a minimum – ARGUS elevates Reishauer services to the next level:

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- Collision monitoring
- Monitoring of machine components
- Web-based process view
- Data analysis
- Process optimization
- Potential zero-defect production

REISHAUER

Gear Grinding Technology

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Start Here

Publisher & Editor-in-Chief
Randy Stott

At first glance, the gear industry might seem like a small industry, easily navigable for someone new to it. But it's only small in terms of the number of people involved. In fact, once you're in it, you quickly realize the gear industry is extremely broad. Not only is the industry global, but it's also enmeshed with every other industry that involves machinery with moving parts—from automotive to aerospace and everything in between. And the people who work in the gear industry have extremely specialized knowledge.

Our organization (both the publication staff and the AGMA at large) produces a lot of information, between the magazines, newsletters, blogs, social media pages, and so on, and we organize a lot of events—everything from specific gear-related education to management-level webinars and in-person events like the very unique upcoming Motion+Power Technology Expo. We publish standards and information sheets, and we convene the technical minds of the gear industry at conferences like the Fall Technical Meeting.

It's easy for a newcomer to be intimidated and to feel like an outsider at first.

If you are new, you should know that you're welcome, and that we're here to help. We've prepared a starting point for you—a list of handy links that gives you a broad overview of the information that's available. We've provided links to help you stay informed, stay connected, learn, conduct business and even contribute.

The "Start Here" page at *geartechnology.com/start-here* is a great place to begin. Sure, you could find all these links if you spent some time digging, but we want to make your life a little easier. We want to help you on your journey from gear industry novice to expert.

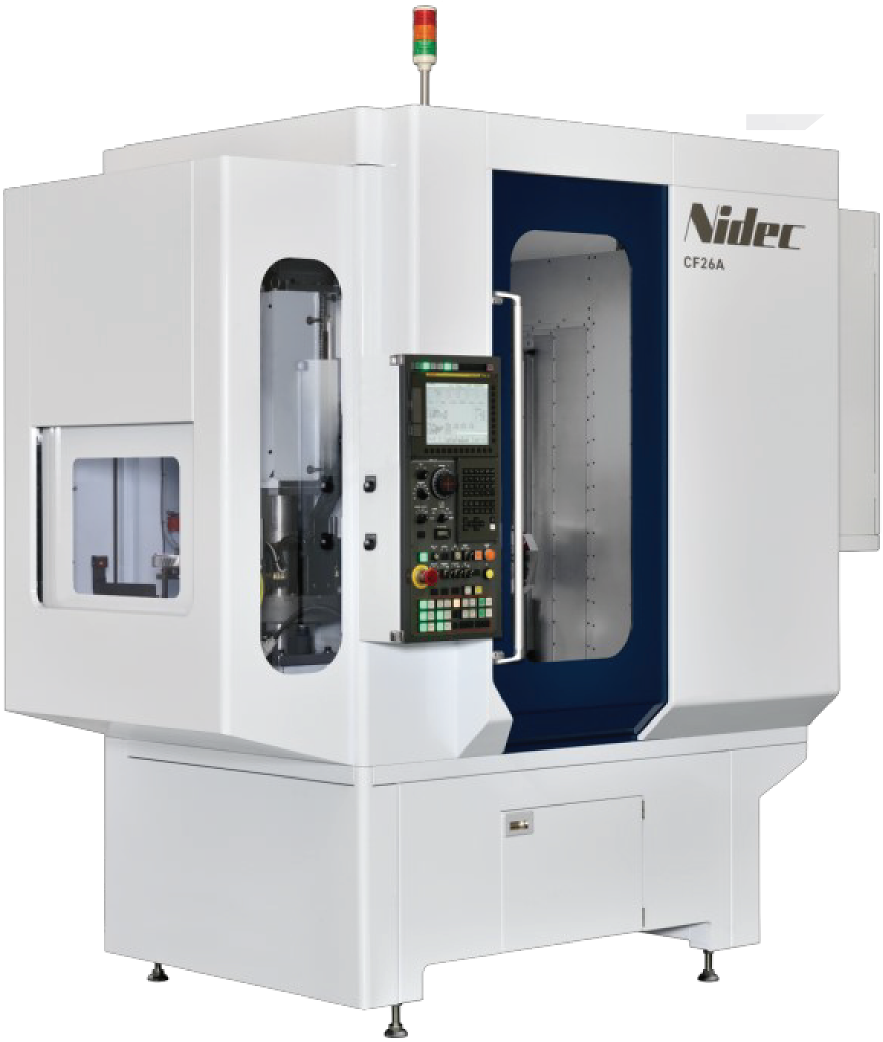
And even if you've been in the industry for awhile, I guarantee you'll be surprised by the amount of information that's available to you and the variety of ways to access it. Sure, we print magazines. But we also produce websites, we blog, we tweet, we create videos, we host webinars, and we collaborate with our audience and our advertisers.

I encourage everyone to visit the "Start Here" page, whether you're brand new or you've spent decades in the industry, because there's something for everyone there.

I'd also like to stress that it's about more than information. Of course, we want to make sure you've subscribed to our magazines and newsletters. But we also want you to join us on social media so you can participate in the conversation. It's about getting involved. All those intimidating gear experts are actually a pretty welcoming bunch, generous in their information sharing and interested in helping lift the industry as a whole through collaboration. So we hope you'll sign up to participate in many of the fantastic networking and learning opportunities our industry has to offer.

CF26A

Gear Chamfering Machine



NEW!
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Removes
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LEGENDARY RELIABILITY

Driving Success in the Gear Industry

By Michael Cinquemani, AGMA Chair and CEO & President, Master Power Transmission

As the American Gear Manufacturers Association (AGMA) enters its 107th year, I am proud to represent our thriving industry as its Chair for 2023–2024.

For the past 37 years, I have been a part of the power transmission industry and I love it! I have been fortunate to lead Master Power Transmission for the last 13 of those 37 years. I look forward to collaborating with our 17 board members and with industry-leading members who deliver value every day. If I don't know you, I want to! I believe strongly in the power of association—our industry binds us together, and our willingness to work together gives us strength both individually and collectively to make a positive impact.

As Chair, I will continue to support our strategic vision of delivering power transmission innovation. AGMA and its members are key drivers of change through our programs, connections and customer focus.

Over the next few years, I am committed to investing in AGMA via new programs, ideas and approaches that can support all AGMA members. Some of the focus areas include:

1. Expanding our technical service capabilities to include more Emerging Technology content. With EV, additive, IIoT and robotics continually evolving, AGMA is playing a significant role in understanding the trends in emerging technology and connecting AGMA members to opportunities, market changes and solutions, while also teaching us how to implement and execute those technologies in our plants and for our customers.

2. Continually looking at investment opportunities in education, technology and events that support members and their work. Education is an important element of this focus, as we all need capable talent. An expanded education offering allows members to be knowledgeable about trends in design, production, operations and many other areas. We will invest in online and face-to-face training that can support our companies.

3. Convening the industry through an expanded role for *Gear Technology* and *Power Transmission Engineering* magazines. AGMA's 35,000 subscribers are leaders in the field across all of our industries we serve. Bringing the leaders together for dialogue, trends discussions and customer insights is a value from which we can all benefit. Leveraging new media and emerging technologies, AGMA will expand the connections that matter under the *GT* and *PTE* brands.

4. Continuing to collaborate with other power transmission trade associations. We believe that working together we can improve how we serve members in common. AGMA will strive to lead the development of an enhanced future state.

5. New ideas on ways we can leverage our reserve funds, the building we own, and the investments we have made in order to benefit the industry. Our focus will always be on adding value to the membership, while creating a self-sustaining business model for the Association.

We have an outstanding staff team that has been guiding AGMA, working collaboratively with more than 400 member volunteers via our business and technical committees. All of this effort has been under the guidance of our Board of Directors. We are moving forward in a dynamic way, and with innovative approaches, and with a spirit of "let's try this" and "let's invest in this" to continually enhance the relevance of what AGMA does and to drive value for AGMA members for the next 50 years and beyond!

It's an exciting time to be part of the power transmission industry, and I look forward to work with our leaders to move AGMA—and the industry we serve—forward.

It's an exciting time to be part of the power transmission industry, and I look forward to work with our leaders to move AGMA—and the industry we serve—forward.

Michael Cinquemani
AGMA Chair and
CEO & President,
Master Power Transmission

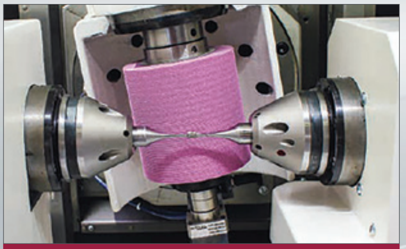
BZ Series Profile and Generating Grinding Machines

FINISH IN FIRST

In the race for more gear grinding speed and precision, who can afford to finish second?

The new generation of German-built Burri Profile and Generating Grinding Machines from Machine Tool Builders packs versatile performance into a series of highly economical platforms. Every model delivers faster chip-to-chip times with generating grinding, automation, and on-board dressing options. For workpieces up to 300 mm in diameter, the BZ300 offers profile grinding as well to produce custom precision gears with special features.

To finish first, start at Machine Tool Builders.


BZ70: Double-spindle design for fast genernative grinding of smaller workpieces.


BZ300: A single platform for profile, generating and worm grinding.


A multitude of on-board dressing options.

Integrated automation to maximize large-scale production.

HAMAI | SMG | TfG TEC for GEARS | BURRI WERKZEUGMASCHINEN | d+p

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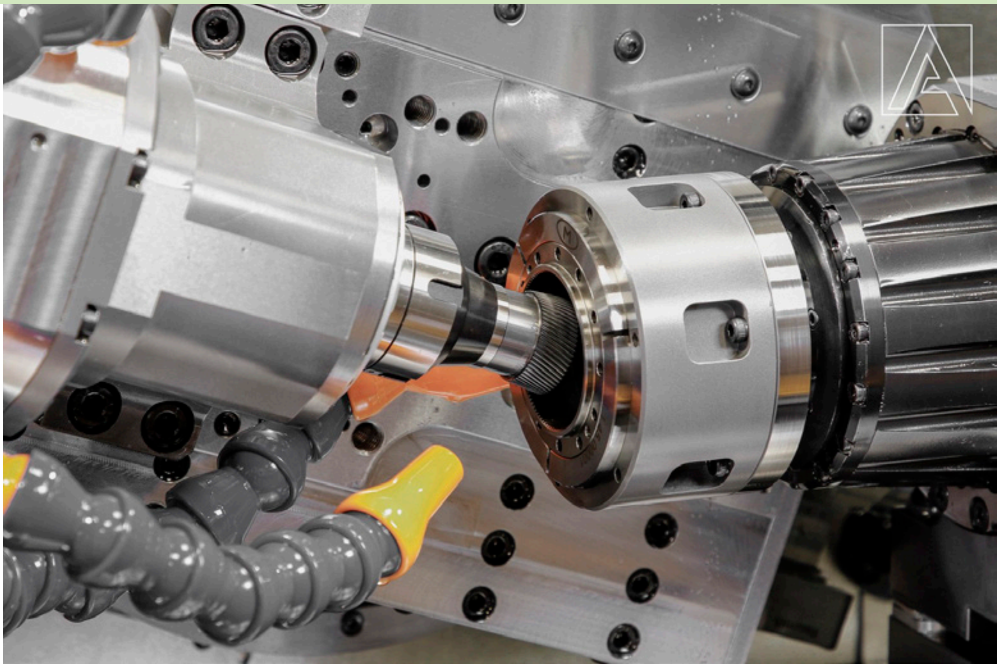
Affolter

OFFERS THE VERSATILE AF160 GEAR HOBBING MACHINE



When developing the AF160, maximum versatility was the key goal of the Engineering Department of the Swiss family enterprise Affolter Group. Vincent Affolter, managing director of the Affolter Group, explains: "The AF160 is designed for high precision manufacturers that need flexibility and efficiency. With its eight axes, sophisticated automation solutions, and an innovative quick-change system, the machine provides exactly that."

Three Gear Cutting Configurations

With the optional quick-change system, machine operators can switch from one configuration to the next in only 30 minutes. In configuration I, both the C axis and the C prime axis are equipped with driven spindles. This setup leads to an increased cutting quality, more torque, and more rigidity. This set-up offers the A axis ±50 degrees swing. "This configuration is ideal for the production of spur, helical, bevel, crowned and face gears", reports Affolter.

With a tailstock on axis C and a spindle on C prime—configuration II—the operator gets more flexibility. The A axis can move from -50 degrees to +115 degrees, making worm milling possible. This configuration can also be used for all gear types mentioned above. In configuration III, the C axis remains empty, and the C prime axis is equipped with a driven spindle. Vincent Affolter: "This configuration is designed for the power skiving of internal gears. The production of face gears is possible, too."

Telescopic Part loader AF72

The part loader AF72 has been specifically designed for the AF160. With its double gripper system for parallel loading and unloading and a telescopic arm, different configurations depending on the volume, product and application can be chosen for an easy and efficient loading of the parts. The AF72 can be equipped with up to five feeding rails, enabling to preload more parts and let the machine work autonomously for more than 24 hours, with a proper configuration. Affolter: "The telescopic arm ensures that the working area in the machine remains clear. The arm retracts after loading the parts, giving the operator a good view of the processes during machining."

Options for maximum flexibility

The AF160 is configurable for any application. Hobbing options include skiving by sensor detection, integrating the deburring process into the gear production with the addition of the AF54 deburring unit, as well as part orientation and part presence control. Different clamping systems, customizable coolant systems, and chip extraction conveyors provide added versatility. User friendliness is key: The state-of-the-art digital CNC Control Pegasus ensures extremely fast regulation and integrates IoT. "The intuitive Pegasus controls all machine axes as well as a multitude of peripherals for various options and automations," underlines Affolter. Programming is simple, intuitive, and user-friendly with a 19-in. touch screen. Data can be shared on the cloud, streamlining after-sales service support and preventive maintenance, and therefore minimizing downtimes. Software updates can be done remotely.

Motion + Power Detroit

The Affolter Group and its US representative Rotec Tools Ltd will be showcasing the innovative Affolter technologies at the Motion + Power trade show in Detroit, from October 17–19, 2023.

affoltergroup.ch

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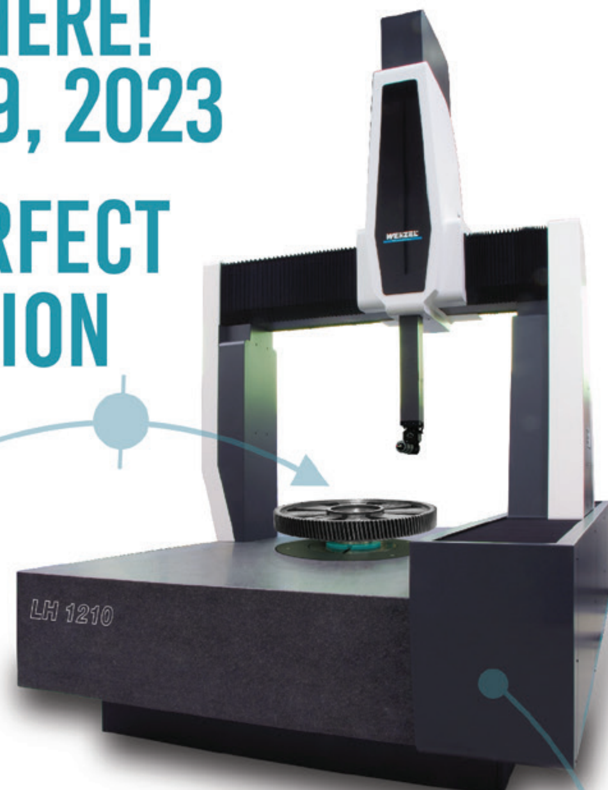
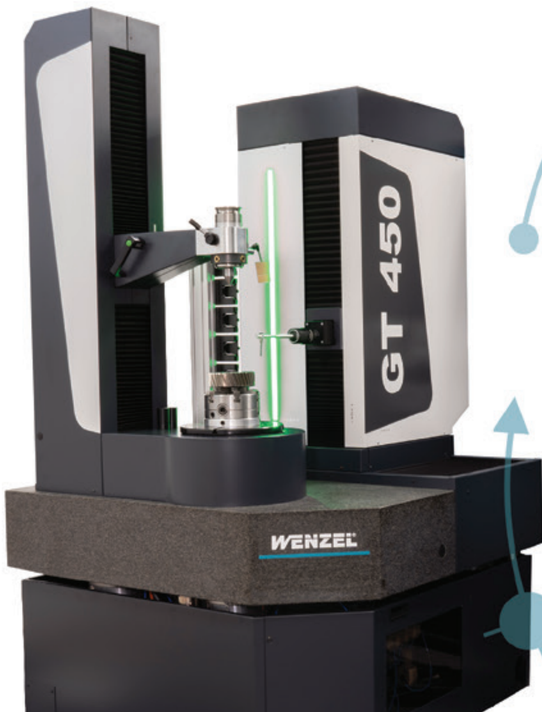


TRADITIONAL CMM



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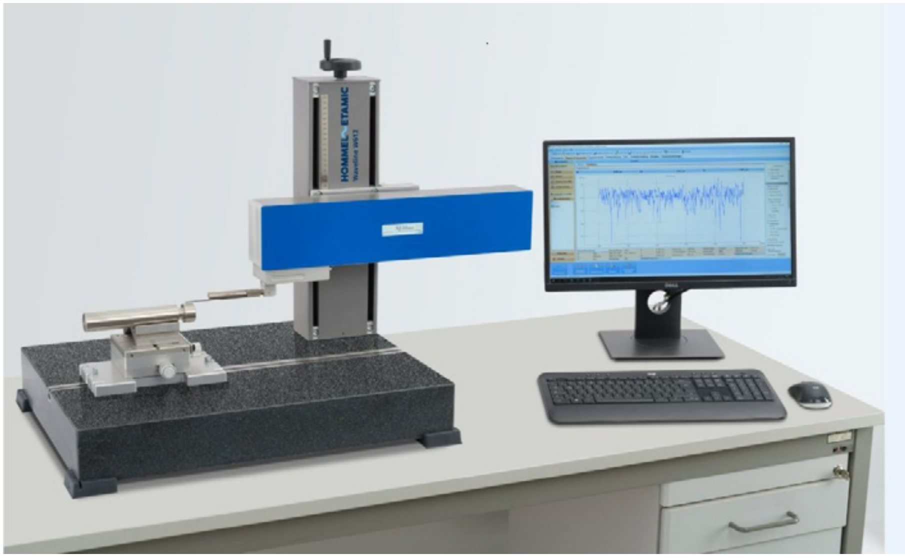


Key benefits include high measurement quality, free access to measuring points, rapid changeover of probe system, automatic probe and probe arm recognition, contour probe arms with RFID chip and Evovis evaluation software with extensive functions.

The new W612 measuring station features a modular probe and system software with the capability to measure a resolution of 1nm with a TKU400 probing system. All Digiscan probe arms utilize a magnetically attached kinematic mounted coupling that enables quick probe system changeover with minimum retooling time due to automatic probe recognition. The Digiscan probe arms are equipped with an RFID chip for simple calibration and automatic configuration.

The system is modular in design with manual height adjustment for precise probe positioning. Modular design enables the upgradation of the roughness measurement system to contour measurement at any later time. The 120 mm traverse unit will move at a speed of 20 mm/s increasing operator productivity. The unit can either be adapted to mount on an existing customer granite base or can be equipped with a new one.

Measuring and evaluation *Evovis* software offers a standardized user interface with easy-to-understand control logic and extensive support functions for tailoring individual measurement applications.

- Modern user interface for safe operation with minimal or no training required
- Individual, free design of test plans and reports with automatic archiving
- All common parameters in accordance with recently published ISO 21920, ISO 4287, other ISO and national standards.

hommel-etamic.com

DMG Mori

LAUNCHES LASERTEC SLM FOR ADDITIVE MANUFACTURING

By launching the new Lasertec 30 SLM US with Adaptive Beam Control—developed and manufactured domestically—DMG Mori delivers a machine to address the rising demands of the US Market.

Breaking the mold of incumbent technology, the machine features several key advancements—Adaptive Beam Control enabling dynamic changes to Laser Power, Laser Speed, and Laser Beam Profile. Noncontact recoating improves the freedom and independence of powder spreading. Best-in-industry production cost using an optional innovative hybrid toolpath strategy that dynamically changes between laser beam profiles using a 1.2 kW laser.

With R&D and manufacturing for Additive Manufacturing in the United States, Japan, and Germany, DMG Mori answers the growing demand for additive technologies in the US market and abroad. This contributes to supply chain resilience and supports export-regulated applications or industries in local markets. The Lasertec 30 SLM US will be the first additive manufacturing product to fulfill this requirement.

DMG has expanded its broad portfolio of conventional manufacturing methods with additive technologies since 2013. The Lasertec DED hybrid and Lasertec SLM models enable highly productive and reliable manufacture of additive metal components within the holistic DMG Mori ecosystem going from metal powder to high-precision finish machining. In the Additive Intelligence consulting unit, DMG Mori also supports beginners and experienced users in fully exploiting the potential of metallic 3D printing. DMG Mori is your partner for the next generation of manufacturing method through continuously developing innovative solutions in additive manufacturing and metal processing.

us.dmgmori.com

Seco Tools

PROPELS MANUFACTURING WITH SMART SOFTWARE AND ACTIONABLE INTELLIGENCE

In the fast, cost-effective, sustainable future, smart software is paving the way to optimized production and improved decision making. Digital technology and smart software have already transformed the machining industry with unprecedented access to actionable data for better results in less time. With a wealth of data generated from production processes of all kinds, shops need to understand how to use that data to their advantage. Now, progressive manufacturers can move toward even greater benefits with software that fulfills the promises of Industry 4.0.

Quick Access to Product Data

Past years have shown the machining industry that sustainable cost containment holds the key to stability and survival, even in turbulent economic times. At the same time, the industry realized it needed faster ways to develop new technologies and tools that can respond to changing circumstances. Smart software is a key to making these developments responsive and effective. In some situations, it can enable manufacturers to optimize machining and production processes by up to 40 percent, eliminating some of the repetitive manual processes.

Nondigitized processes force production personnel to look up product information manually, which wastes time and may not yield accurate results. For example, to reduce routine tasks on the shop floor, with the help of Seco Assistant smartphone app, production personnel can simply scan the product package or the tool. As a result, they can quickly receive relevant product information or calculate cutting data and compare insert geometries and grades from different suppliers.

Smart Ways to Manage Inventories

Thirty to 60 percent of tooling inventory is likely to be uncontrolled, floating

around the shop floor or simply stacked by machines in excess quantities. Smart software, such as the Inventory Management system, can help to tackle this issue in a more cost-effective and secure way.

Apart from physical flexibility, its main benefit lies in monitoring tool and equipment usage and increasing staff accountability. This way, the inventory management systems help to reduce wasted set-up time because of misplaced items and keep track of high-value tools and mission critical items.

Less Human Involvement in CAM Programming

In future, smart machining technologies are likely to allow the feature recognition in components, build quick CAM programming and supply NC codes to machines, saving up to 80 percent of time in the engineering preparation area. Nevertheless, due to the high complexity of some components such as turbine blades and structural parts, human intelligence and technical expertise are still required. Engineering Services from Seco can help with optimization of new or existing complex machining processes and identifying gaps in CAM programming.

"In a factory network, smart software can eliminate unnecessary inventory of materials and tooling for up to a 20 percent reduction in inventory costs," said Janardhan N., engineering services solution manager at Seco Tools. "With processes optimized for efficiency through technology that removes repetitive manual processes from the production line, labor productivity can rise up to 30 percent and machine downtime drop by up to 50 percent."

secotools.com

Marposs

OFFERS COMPACT OPTICAL TOOL SETTER FOR SMALL APPLICATIONS

Marposs has expanded its VTS (visual tool setter) family with the new VTS SF-45 Compact, suited for noncontact, optical measurement of small, complex-shaped tools in constrained working spaces such as micromachining, semiconductor or moldmaking applications. The VTS SF-45 units are installed inside the machine working area to monitor actual tool working conditions without any contact while the tool can rotate at full spindle speed (up to 80k rpm) during data acquisition. Since there is no need to slow the spindle, presetting time can be reduced and measurement accuracy is increased to better eliminate collision hazards.

The VTS SF-45 acquires a variety of tool dimensions in a single instant using the principle of shadow projection where an illuminated objects projects its shadow onto the camera. These measurements include tool length, static and dynamic tool diameter, the tool runout and cutting-edge radius. With a resolution of 0.1 µm, the VTS enables measurement of tools with diameters as small as 10 µm with repeatability of 0.2 µm, providing a higher level of accuracy than touch probes or lasers in small applications.

Additionally, the VTS SF-45 uses a frontal light to analyze the tool surface, displaying the illuminated surface on a PC monitor where the integrity of the cutting edges can be evaluated. The GUI software for VTS simplifies the measuring cycle process and documents the tool history, helping to quickly reveal damage in advance of the machining operation. The software can be fully integrated into Marposs touchscreen PCs (NEMO or Merlin+) or in a standalone version for PCs with Windows or Linux operating systems.

One of the main features of the VTS is its protection system, which enables excellent measurement performance even in the presence of coolant or dust. Pneumatic shutters cover and protect the optical lens when VTS is not working, plus a patented air flow solution rejects chips and coolant drops, keeping the shutter side clean and protecting the optical lens when the shutter is open.

marposs.com

United Grinding

ADDS SEVEN NEW PRODUCTS TO LINEUPS

United Grinding North America recently announced the expansion of their extensive range of grinding and measuring equipment with seven new products being unveiled by three of the company's brands.

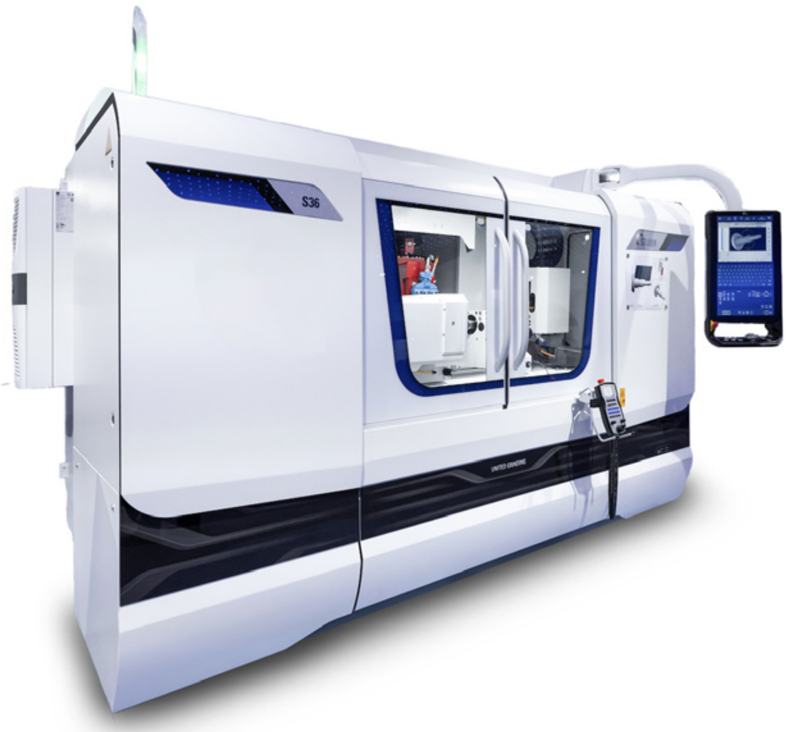
Studer has brought two new cylindrical grinding machines to the North American market with the release of the S100 and S36. The S100 is a universal internal cylindrical grinding machine and the newest member to the "entry-level" family and is a perfect way for job shops to get into cylindrical grinding or upgrade their older grinding machines with the latest technology. The S36 is the newest OD production grinding machine that has a modified wheelhead to accept a large grinding wheel with a diameter of up to 24 in. and a width of nearly 5 in.

Blohm continues its tradition of customer-centric surface and profile grinding innovation with the release of the Planomat XT Essential. This 3-axis grinding machine is Blohm's entry-level offering for job shops who are eyeing CNC grinding but need a more attainable starting point. Blohm is also adding a new option on a powerhouse creep feed grinder: the Profimat XT is now available with a tool changer, enabling the automatic changing of grinding wheels.

Walter is focused on packing more tool grinding functionality into a compact space with the new Helitronic G200 and Helitronic Mini Plus. The Helitronic G200 gives cutting tool makers and contract manufacturers an entry point into the regrinding market and offers an economical solution for the production of small-to-medium-sized tools. If these manufacturers require a higher volume of production of the same-sized tools, the Helitronic Mini Plus is the perfect place to start the conversation. Additionally, the all-new Helicheck Plus now comes with an available 3D sensor, which adds the capabilities of the popular Helicheck 3D model right into the Plus model. The 3D sensor enables this machine to laser-scan a tool and generate a 3D model made up of as many as three million individual points.

"New technologies from our brand companies overseas, paired with recent innovations from our own team here in Miamisburg, are helping our customers realize strong productivity gains and an ability to support a wider array of applications," said Markus Stolmar, president and CEO of United Grinding North America. "Our commitment to bringing the best technology to market is stronger than ever, and I am truly excited for the future."

grinding.com



Jergens Inc.
OFFERS NEW HEAVY DUTY VISE

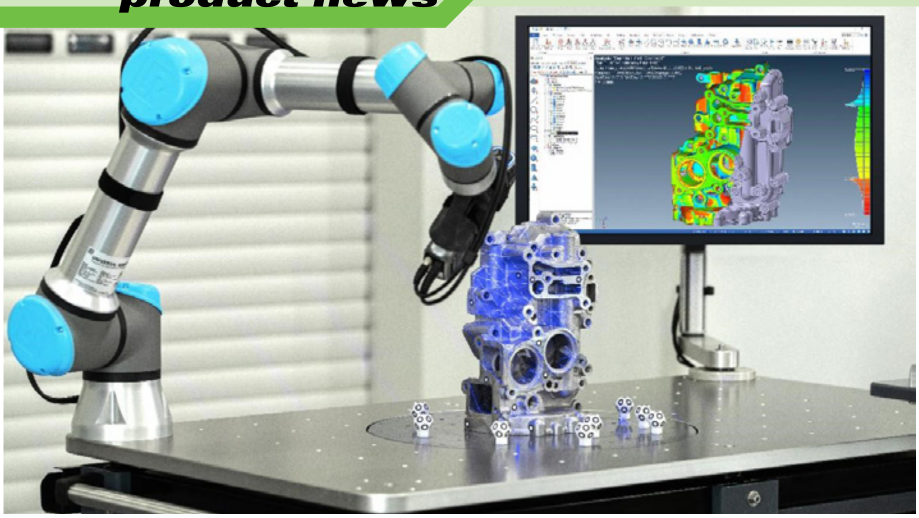
Jergens new 5-in. Heavy Duty Machine Vise ensures secure part holding for general applications across the range of CNC machining, including high production. Designed to a relatively small size and weight, the vise is also more easily moved and relocated, speeding up the time in between change overs and reducing operator fatigue.

"Ergonomics and the physical strain that operators face (during repeated and / or heavy lifting) are important issues that we address", said Joe Farkas, Jergens' national sales manager for workholding solutions. "Advancements in engineering and material strength are key considerations for our product design" Farkas continued.

Hardened and moveable jaw plates combat lifting, which can occur during heavier metal removal applications, to help ensure tolerances of ±.0005 in. Other vise features include the nickel-plated lead screw for long life, needle bearing design that facilitates ease of use even at high clamping force, and a heavy-duty swivel handle to further ease the load for operators. Made in the United States of stress relieved ductile iron (80,000 psi) and flame hardened, the new vise provides very long usable life and predictable performance.

Accessories for the vise include locating key sets, case hardened steel jaw plates, and a Ball Lock fixture plate kit for quick change capability. These engineered plates, available in aluminum or steel, have locating slots and tapped mounting holes machined to accept the vise for easy mounting. As with other Jergens quick change workholding products, users can reduce setup times from minutes to seconds.

jergensinc.com



Verisurf 2024

OFFERS FLEXIBILITY FOR MEASUREMENT APPLICATIONS

Verisurf Software, Inc. with partners IBS Quality GmbH, Blankenhorn GmbH, and Metrology UK Ltd are demonstrating advanced CMM programming and automation features included in Verisurf 2024, the latest release of the popular measurement software for automated quality inspection, reporting, scanning, reverse engineering, tool building, and assembly guidance. The software is powerful, flexible, and easy to use for measurement applications across the manufacturing enterprise.

Verisurf 2024 expands on the software's legacy as the only measurement, reverse engineering, and inspection software built on a full-featured 3D CAD/CAM platform with intelligent Model-Based Definition (MBD). This ensures data integrity and lets users perform metrology workflows in a seamless CAD environment while maintaining model-based digital continuity. Verisurf software is compatible with all CAD file formats, and the Verisurf Device Interface (VDI) communicates with and operates all programmable and portable CMMs for universal CMM programming and inspection compatibility. The software's modular design enables users to quickly shift from reverse engineering to inspection to tool building, efficiently capturing and processing measurement data for practical metrology applications with repeatable process control, across the manufacturing enterprise.

"Verisurf software is under constant development. We work with customers every day to solve measurement challenges with practical solutions. These enhancements are delivered to customers throughout the year as software updates and are also included as part of our annual version release. This keeps us in sync with our customers and on the leading edge of metrology software development," said Nick Merrell, executive vice president of Verisurf Software, Inc.

Verisurf 2024 features many new programming and productivity features designed to improve metrology workflows through automation while maintaining repeatable process control.

verisurf.com

GWJ Technology

ADDS FUNCTIONS TO CALCULATION SOFTWARE

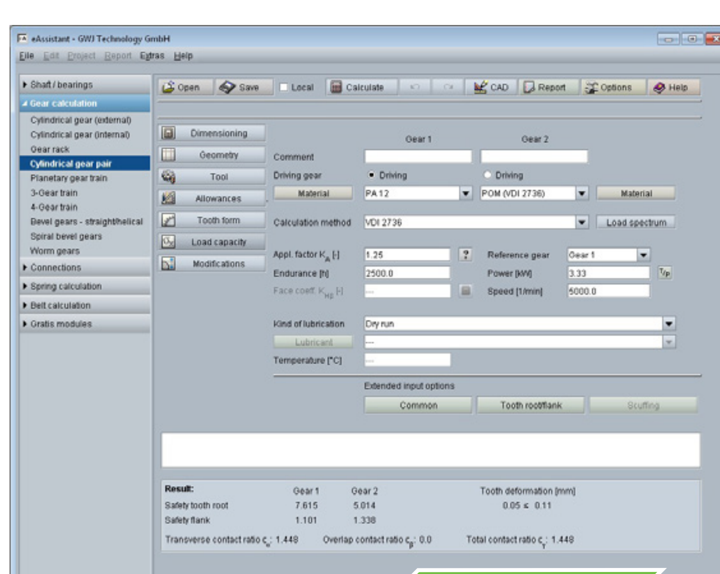
GWJ Technology GmbH, a calculation specialist from Braunschweig, Germany, added new functions to the gear modules of its *eAssistant* web-based calculation software, which has been successful for more than 20 years.

In the latest versions of the "Cylindrical gear pair" and "Planetary gear stage" calculation modules, the old DIN 3961 from 1953 for gear tolerances and tooth space allowances, which has been withdrawn for many years, has been integrated in response to numerous user requests. This makes it much easier for users to recalculate cylindrical gears based on old drawings and is particularly helpful when manufacturing spare parts or updating drawings. In addition to DIN 3961:1953, the tolerance standards DIN 3961, DIN 58405, ISO 1328 and ANSI/AGMA 2015 are available for the calculation of cylindrical gears. Furthermore, the number of decimal places for the input fields can now also be individually configured in the "Cylindrical gear pair" and "Planetary gear stage" modules. For the design dimensioning available in both modules, further options for variant calculation have been implemented, such as "Allow specific sliding > 3 in. or "Allow small geometry errors".

Furthermore, the *eAssistant* module "Cylindrical gear pair" now allows the calculation of the wear load capacity according to VDI 2736 for dry-running plastic/plastic or plastic/metal pairings. In the load capacity calculation according to DIN 3990, method B or ISO 6336, method B, the individual specification of further factors, such as roughness, lubricant, speed, or size factor, is now possible.

With the ISO/TR 6336-30 published in December 2022, eight practical examples for the current ISO 6336:2019 are now available. GWJ uses these examples to verify its calculation modules, which include ISO 6336 or DIN 3990. The comparative calculations carried out in the meantime matched very well with the practical examples of ISO/TR 6336-30. For all 8 examples, the absolute deviation in the calculated safeties is ≤ 0.01.

gwj.de



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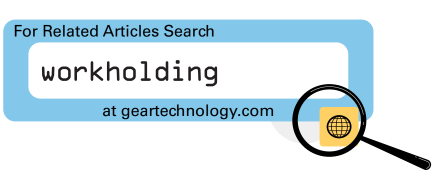
Inspection Workholding: Simply Perfect

Gleason LeCount Adjustable Expanding Mandrels offer a fast, flexible and amazingly simple solution for metrology applications where speed, accuracy and repeatability are paramount

Robert Peyr, Director Product Management, Workholding and Services, Gleason Corporation

Keep it simple. More often than not it turns out to be the best course of action in life and on factory floors. Take, for example, Gleason LeCount Expanding Mandrels. You'll find them in quality labs around the world, delivering reliable, repeatable workholding performance for the inspection of gears and other bore-type workpieces. Quality labs today are at the epicenter of the drive to produce increasingly complex, high-precision parts, while at the same time racing to take time and cost out of the inspection process. Counter-intuitively, perhaps, the best workholding solution to meet these ambitious new inspection requirements turns out not to be something new and more complex—but the simplest solution of all: Gleason LeCount Expanding Mandrels.



Gleason LeCount Expanding Mandrel models accommodate an exceptionally wide range of precision clamping applications, both in the quality lab and on the production floor. Twelve standard models cover workpiece bore sizes ranging from 6.35–177.8 mm (0.25–7.00 in.) in diameter.

Gleason LeCount Expanding Mandrels seem almost tailor-made for the rigorous demands of today's quality labs. They deliver the extreme accuracies required of high precision workpieces with 2.5 microns (0.0025 mm/0.0001 in.) TIR or better. Their simple design makes it easy for a technician with even minimal experience to ensure a precise, repeatable load/unload of the workpiece in a matter of seconds.

Patented Performance

While their patented design has been in existence for more than a decade, the family of Gleason LeCount Expanding Mandrels seems almost tailor-made for the rigorous demands of today's quality labs. First, they're capable of delivering the extreme accuracies required of today's high-precision workpieces: 2.5 microns (0.0025 mm/0.0001 in.) TIR or better. Most importantly, their design makes it a cinch for a technician or machine operator with even minimal experience or training to ensure a precise, repeatable load/unload of the workpiece in a matter of seconds. Finally, an entire family of just 12 standard precision mandrel models spans the widest possible range of workpiece bore sizes—from 6.35 mm to 177.8 mm (0.25 in. to 7.00 in.) in diameter—thus further simplifying operation and reducing workholding investment.

Simple Perfection

Any operator will find that 'getting it right the first time' is a remarkably simple process using this easy-loading mandrel. The patented mandrel design incorporates three parallel expanding jaws that slide uniformly up (expanding) or down (contracting) on inclined guideways. Any workpiece bore size within its range can be accommodated by each mandrel. For example, the popular Type A mandrel, designed for an extra wide range, includes models designed for the most popular bore sizes common to most automotive transmission gears. Models are available to accommodate bore-size clamping ranges of anywhere from 12 mm to 25 mm or greater. Note that the extreme accuracy of the device over this entire adjustable clamping range does not change. It is derived from controlled, precision manufacturing that guarantees concentricity of 0.0025 mm (0.0001 in.) TIR over the entire range of the expansion.

To load, the operator simply lowers the workpiece bore over the jaws, which remain parallel with the bore throughout. The jaws provide three points of centering contact on the bore and act as an internal expanding chuck on any bore within the size range of the mandrel. As the workpiece is lowered, the operator moves a sleeve up along the tapered guideways in the direction of the round, the short end of the mandrel, which acts to expand the jaws and lightly grip the bore. A light tap on this end of the mandrel then further expands the jaws and firmly secures the workpiece without any additional manual tightening or the use of a tool. For unloading, a light tap on the opposite end of the mandrel is all that's needed to release the workpiece.

Expanding the Possibilities

This product's design can be easily adapted to a wide range of applications. The type C model, for example, is very compact, making it ideal for the inspection of a narrower range of dedicated parts. The type H, with its extra-long jaws and narrow expansion range, is well-suited for the requirements of hob inspection. Additionally, the series includes Gleason LeCount Spline Mandrels, since not every part has smooth bores. These mandrels function identically but have the pitch diameter of a splined workpiece ground into the contact edge of the three jaws, with spacing between the jaws adjusted to accommodate the workpiece. They can also be made to contact the major and minor diameters of the workpiece.

The LeCount Type H model, with its extra-long jaws and narrow expansion range, is well-suited for the requirements of hob inspection. Additionally, the series offers spline mandrels, since not every part has smooth bores.

Additionally, the system can be purchased with a dedicated part locator, which allows the operator to position heavier workpieces or dedicated parts more easily in the same, precise, repeatable location each and every time one's loaded.

Type G for the Production Floor

Since they work so well in the lab, why not bring them onto the production floor? Gleason answered this question with the development of the LeCount Production "G" (Grinding) Mandrels, which now bring this highly desirable speed, accuracy, expansion range and robust clamping to the production floor. The G is adapted to the factory floor with, among other design modifications, a sleeve that's sealed from dust, oil, and contamination. They've proven to work exceptionally well in a number of applications, including on lathes and turning centers to help reduce chatter or distortion during heavy metal removal. They are also in use in the production of smaller gears with smooth bores and in gear prototyping work. In these applications, a Gleason workholding fixture can be designed to clamp on the G mandrel itself, which then allows for stronger clamping force and faster changeover times than possible with a conventional workholding solution. Bore sizes range from 17.00–96.00 mm (0.670–3.80 in.) with accuracies and repeatability of 0.005 mm (0.0002 in.) TIR.

Trust, and Verify

Over time, even the best-made workholding will experience some wear and tear. The impact on accuracy and repeatability can be small and measured in microns. Nonetheless, Gleason can help customers to continuously meet and exceed the most stringent quality required of their LeCount Mandrels. With the support of the latest quality assurance equipment Gleason verifies that workholding components meet or exceed customers' requirements. Gleason offers global service and support capabilities, ranging from applications engineering to extensive inventories of high-quality OEM replacement parts, ensuring that Gleason workholding systems are performing at the highest levels—anywhere in the world.

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Corrected Lead Hobs

Understanding their use cases and machine settings

Sanjay Gupta, Director, ESGITools Pvt. Ltd.

During our interactions with customers, we find the common challenge faced by customers about getting incorrect component parameters using corrected lead hobs.

To address the challenge, we will talk about what corrected lead hobs are, why it is necessary to design such hobs, and how to set up the hob on the machine depending upon the type of hobbing machine (manual, semiautomatic CNC, or CNC).

What Is a Corrected Lead Hob

The module and pressure angle of corrected lead hobs are different from the module and pressure angle of the component. If the pressure angle of a hob is less than that of the component, then it is a short lead hob and if the pressure angle is greater, then it is a long lead hob.

Why It Is Necessary to Design Corrected Lead Hobs

When the true involute form (TIF) diameter and fillet radius of a component is not achieved with a standard design, then the pressure angle of the hob is reduced or increased to obtain the correct TIF and fillet radius of the component. This can be explained with the below example.

NORMAL MODULE

COMP DATA		
COMP DWG No.		P05167(0.022.2088.0) 40T
NO OF TEETH		40
NORMAL MODULE		3
NORMAL P.A.		20°
HELIX ANGLE/HAND		23° LH
OUTSIDE DIA		136.540/136.700
ROOT DIA		122.307/122.428
DOP	HOBBING	140.72/140.75
	SHAVING	140.57/140.60
	PIN DIA	6
SHAV. ALL./FLANK		0.032
RAD.CHAMF. SHAV.		0.2 x 40° (MAX.)
TIF DIA REQUIRED		125.450
TIF DIA AT HOBBING		125.94
TIF DIA AT SHAVING		125.48
FILLET RADIUS		1.150 (MIN.)

HOB DATA	
N.MODULE	3
N.PA	20°

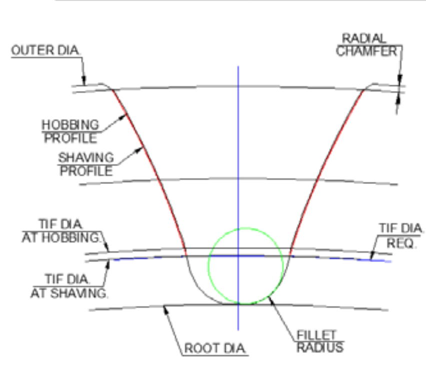

Figure 1—Component generated profile with standard design.

Standard Hob Design

Principally, TIF shaving should be below the required TIF diameter. However, when the hob is designed with the standard method, TIF required and TIF shaving are almost at the same values. Please refer to the component generated profile in Figure 1.

GEN.MODULE

COMP DATA		
COMP DWG No.		P05167(0.022.2088.0) 40T
NO OF TEETH		40
NORMAL MODULE		3
NORMAL P.A.		20°
HELIX ANGLE/HAND		23° LH
OUTSIDE DIA		136.540/136.700
ROOT DIA		122.307/122.428
DOP	HOBBING	140.72/140.75
	SHAVING	140.57/140.60
	PIN DIA	6
SHAV. ALL./FLANK		0.032
RAD.CHAMF. SHAV.		0.2 x 40° (MAX.)
TIF DIA REQUIRED		125.450
TIF DIA AT HOBBING		125.60
TIF DIA AT SHAVING		125.16
FILLET RADIUS		1.150 (MIN.)

HOB DATA	
GEN.MODULE	2.96415
GEN.PA	18°
SETTING ANGLE	20°38'

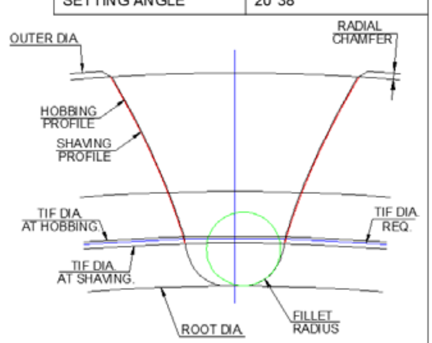

Figure 2—Component generated profile with corrected design.

Corrected Lead Hob Design

To achieve the principal requirement of getting TIF shaving below TIF required, the pressure angle of the hob is reduced from 20 degrees to 18 degrees. Please refer to the component generated profile in Figure 2.

Hence, the corrected lead hobs are necessitated to be designed due to limitations in achieving the component data.

Marking Guidelines on Hobs

Spur Gears

The lead angle is the same as the set angle. Hence, only the lead angle will be marked on the hob (Figure 3).

Helical Gears

The hob set angle is different from the hob lead angle. Though, both the lead angle and set angle are marked on the hob, only the set angle should be referred to for setting the machine (Figure 4).

Machine Settings

Corrected lead type designed hobs bring new challenges at the time of usage like understanding the correct machine settings depending upon the type of gear and machine, considering the wide presence of manual, semiautomatic CNC, and CNC hobbing machines.

Manual Hobbing

Spur Gear

The hob lead angle as marked on the hob is to be manually set on the machine. For example, referring to Figure 3, the value to be manually set on the machine is LA1°18'06".

Helical Gear

Hob set angle (not lead angle) as marked on the hob to be manually set on the machine. For example, referring to Figure 4, the value to be manually set on the machine is SET ANG 20°38'.

Semiautomatic-CNC Hobbing Machines (Hob lead angle set up is manual)

The procedure to set up the angle remains the same as in manual hobbing machines. However, you will find two files for inputting the data, one for component data and another for hob data.

Component Data File

Input original module and original pressure angle (Module 3 and pressure angle 20 degrees as in Figure 1).

Hob Data File

Input corrected module and corrected pressure angle (Module 2.96415 and pressure angle 18 degrees as in Figure 2).

CNC Hobbing Machines (Hob Lead Angle Is Calculated by Machine)

In this case, there is no need to input the lead angle or set angle because it is calculated by the CNC. The operator must ensure to input the values in the component and hob files.

Component Data File

Input the original Module and original pressure angle (Module 3 and pressure angle 20 degrees as in Figure 1).

Hob Data File

Input the corrected module and corrected pressure angle (Module 2.96415 and pressure angle 18 degrees as in Figure 2).

However, the operator must ensure that the hob set angle calculated by the machine is the same as what is marked on the hob.

Since any mistake in machine setting and/or feeding the data will lead to incorrect component parameters, the article will help clarify the necessity to design, how to use corrected lead hobs and understand machine settings based on the type of gear and machine.

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Figure 3—Hob marking for spur gear.

Figure 4—Hob marking for helical gear.

The Future Looks Bright for the Gear Inspection Industry

Empowering quality through deeper precision

Gene Hancz, CMM Product Manager,
Mitutoyo America Corporation

On the surface, it may not seem like the gear inspection industry has changed much over the last few years. Shops still primarily use either machines that are dedicated solely to measuring gears, or multiuse Coordinate Measuring Machines (CMMs). And regardless of which machine they use, software serves as the backbone that supports their many diverse sensors.

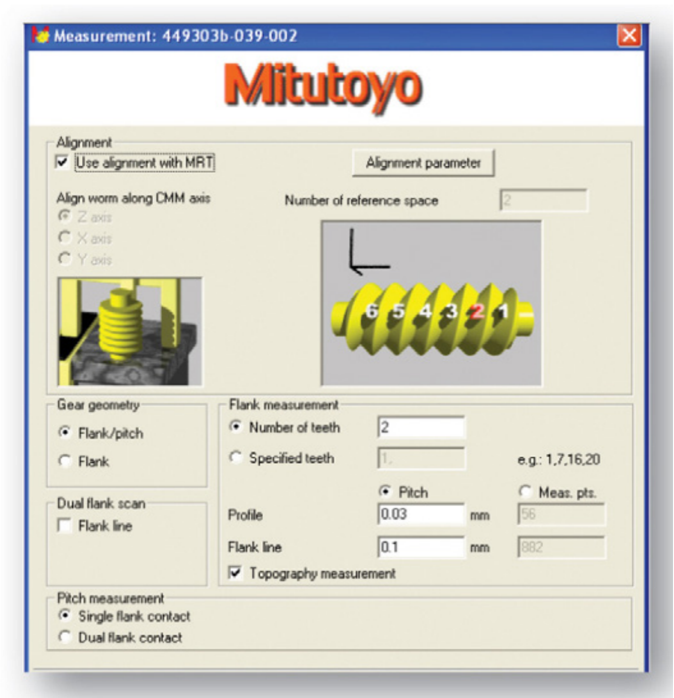
Despite the turbulent economy of the last few years, the gear manufacturing market is expected to grow at a fairly modest CAGR of 5.73 percent through 2026, according to Technavio. As the industry expands, more gear manufacturers are streamlining and automating the inspection process with multisensor CMMs.

But underneath the surface, several exciting and innovative developments are driving the gear inspection industry forward. These bright spots have the potential to transform not only how gear inspection is conducted, but also the tools and processes that companies use as well.

Bright Spot #1: CMMs

While not new, CMMs continue to be a game changer in the industry. Combining multiple gear inspection and measurement tools into a single platform is a highly attractive feature for businesses, and provides several time- and cost-saving benefits:

- **Improved quality:** CMMs help create higher-quality gears by eliminating operator error. Since the engineering CAD model automatically generates the inspection program, the results are clear and unambiguous, nor are they subject to different interpretations by an operator. Additionally, automated optical tools don't touch the gear, ensuring that high-precision measurements can be taken without damaging the gear's precision surface.
- **Improved costs:** High-end, automated, programmable, and dedicated gear-checking equipment can cost hundreds of thousands of dollars. You also need to account for the additional costs of master gears and the artifacts. All told, that equipment can be two or three times more expensive than a multisensor CMM equipped with a rotary table, high-speed scanning probe head and gear measurement software.
- **Improved productivity:** Perhaps the greatest advantage of multisensor CMMs is that they save a significant amount of time since they measure several characteristics faster and more accurately compared to manual methods. And with shops pressed for time more than ever before, this benefit can't be overstated. Whether used for gear checking or regular SATIC geometry, CMMs can provide a 30 percent to 98 percent time savings. The amount of time saved actually grows as the complexity increases. Multiple functions—such as gear parameter inspection, microscopic gear teeth measurement and high-accuracy 3D scanning—can all be done on the same machine. And by using a surface probe, you can check the surface and finish of gear teeth, the internal bore of a gear, as well as the mounting and shaft.



Special CMM software supports measuring different types of worm gears using a touch trigger probe or scanning probe on a CMM.

New technology in CMM probes allow for touch probes to measure gears with high accuracy and repeatability.

Bright Spot #2: Harmonization of Standards

One of the most exciting developments is the increasing harmonization of gear measurement standards across the globe. In the U.S., gear quality standards are set by the American Gear Manufacturers Association (AGMA). However, other countries utilize their own set of standards. For example, Germany relies on the German Institute of Standardization (DIN), while Japan utilizes the Japanese Industrial Standards (JIS), and several other countries have their own standards as well.

Many of these standards are similar, but not quite the same, which can be confusing and frustrating for companies that manufacture or sell gears in multiple countries. If a gear manufacturer is based in the U.S., but also has a facility in Europe, which set of standards should they use? This presents a similar challenge when using gear measuring software. Most software platforms have the major standards built in as selectable options, but knowing which one to use can be challenging.

To solve these challenges, the International Organization for Standardization (ISO) has been pushing for harmonization across the industry, and in recent years has made significant headway. Coordinating among the various standardization bodies—and getting them to agree on common standards—is a complex process. And when you factor in that gear measurement standards can encompass a multitude of different items, it's easy to see why this could take so many years to complete.

While it may still be several years before we're closer to full harmonization, this is an exciting development, both for manufacturers and companies that design measuring equipment and software. For manufacturers, recertifying a single gear or part under multiple standards can be a time-consuming and expensive process—harmonization can minimize effort and cost. For businesses that make measuring equipment or software, this would streamline the process of keeping up with new or updated standards.

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Noncontact laser probes have some advantages to measuring gears and parts of gears, including having great accuracy even though the measurements might take a little longer.

Bright Spot #3: Exciting Equipment Innovation

Several innovations on the equipment side also offer exciting glimpses into the future of the gear measurement industry:

- **Integrating Artificial Intelligence (AI):** It seems like every day there's a new headline about AI transforming some aspect of our lives. Gear measuring is no different. Integrating AI into CAD software has the potential to drastically speed up development time and improve accuracy. This could also free up engineers to focus on more valuable work, which can be especially helpful if the labor shortage continues.
- **Laser sensing in CMMs:** Right now, CMMs and other measuring equipment almost exclusively utilize mechanical sensing. Lasers are useful in some applications, but there are several barriers that make widespread use impractical at the moment. Although they are more accurate, lasers take longer to measure, and they need to be extremely close to the part being measured for the high-accuracy requirements of some gears. In some cases, the size, shape, or dimensions may make it impossible to use lasers. However, advancements in laser technology could make them feasible in a wider range of applications.
- **Imaging cameras:** Using high-resolution cameras can make the gear-measuring process much easier and potentially shrink the equipment's footprint as well. Currently, cameras that can provide adequate detail are often too expensive to be practical, and processing high-resolution images is time-consuming. But as camera technology gets less expensive and computer processing becomes faster, they could prove to be an exciting innovation in the gear measuring industry.

Choosing the Right CMM Is Still Key

Standards harmonization and other technological advancements all offer intriguing new possibilities and point to a bright future. But it's still critical to make sure you have the right inspection equipment and software, which will largely depend on the size, weight, and quality specifications of the gears you produce. Will your gears be under heavy load or subject to intense stresses? Is noise an issue? What kind of materials are they made of?

Answering these questions will help ensure that you have the measuring equipment and software that's best suited for your needs. And having the right tools in place will help ensure that you can respond to the ever-evolving industry.

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The Changing Face of the Off-Highway Drivetrain

Adapting to sustainable products, practices and technologies in the agricultural, construction and mobile equipment markets

Matthew Jaster, Senior Editor

If trade shows are still a major indicator of market growth, the construction and off-highway industries seem to be in a good place in 2023. CONEXPO-CONAGG and IFPE 2023 welcomed more than 139,000 attendees to Las Vegas in March. These visitors were treated to 2,400 exhibitors from 36 countries reaffirming the belief that innovation and sustainability will drive these markets in the coming years.

Bonfiglioli Addresses Electrification Trends

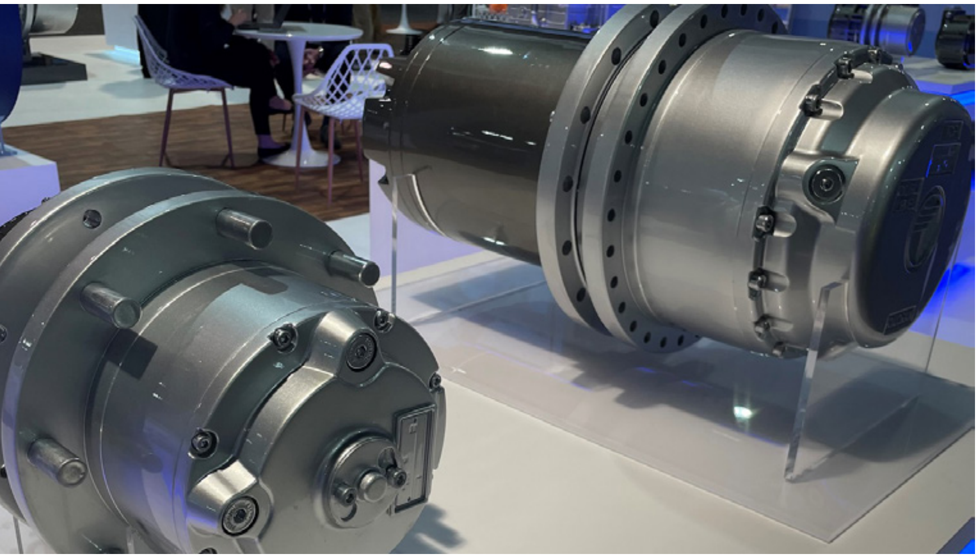
Bonfiglioli is known for a wide variety of planetary gearboxes traditionally driven by hydraulic motors. The paradigm shift is currently the switch from hydraulic to electric mobility and Bonfiglioli is right at the center of some interesting developments in these areas.

"We've invested a large amount of capital into the development of low voltage-high voltage induction and permanent magnet motors that we've interfaced with our high-volume planetary gearboxes," said Kenneth Hartsell, business development manager at Bonfiglioli. "This puts us in a position to offer a very good system solution to the off-highway and construction markets."

Bonfiglioli's electric drives, for example, can be used as travel and swing drives. Hartsell said they are designed in principle like the company's hydraulic models. They have all the technical necessities and properties needed for the switch to electrification.

The electric motor in its robust housing is air-cooled and corresponds to protection class IP67. The core of the drive, the permanent magnet motor itself, is maintenance-free. It is equipped with temperature and speed sensors. A single or multi-stage planetary gear is flanged directly to it, which is defined according to the requirements of the machine manufacturer. Its maintenance intervals are long, and maintenance itself is very easy thanks to the smart design.

"If you're going to mount an electric motor to a gearbox that traditionally had an integrated hydraulic brake, now it's an electric brake and the architecture of the machine has to change to accommodate this," Hartnell added. "A large percentage of our research and development at Bonfiglioli is going towards products to further promote green initiatives, sustainability as well as electrification."



This electric trend is helping in other areas including condition monitoring and maintenance.

"We're seeing major improvements thanks to these wholesale electrification changes across the board. We've developed a condition monitoring system, for example, that is scalable across many different markets giving operators the opportunity to pull data on maintenance intervals, engine oil replacement, etc. We're able to provide so much more information in real-time for our customers today," Hartsell said.

Rental companies that buy hundreds of pieces of equipment are a great example of this. Hartsell said they want a condition monitoring system that allows them to manage the fleet in the most effective way possible.

"Now, while gathering this data, it also helps the manufacturers learn more about what is and isn't working in the field. Do we need new materials? Do we need to make improvements to the gear profiles? Are there things that we must change to enhance serviceability? These are all important questions as we attempt to match our customer's expectations," Hartsell said.

While many are still in 'electrification infancy' so to speak, Hartsell is seeing a two-phase approach to the transition.

"Many OEMs are doing this in a two-phase approach with the first phase being more of an electric-hybrid application where they still have a need to drive hydraulic components to eventually phase two which is the full transition to electrification," he added.

Bonfiglioli displayed many of its electrification products and technologies during IFPE 2023.

The movement towards electric drivetrains and components means a mechatronics approach is needed from an engineering standpoint. There's been a large hiring of electrical engineers at Bonfiglioli to address these market changes.

"We have a great core group of mechanical engineers. At the same time, with the knowledge changing and the skills needed to understand how these mechatronic systems work, you need to have seasoned engineers put training seminars together internally for the sales teams, support teams, etc. as these electrification changes take place in our key markets. The end goal is to be known for our diverse range of electromobility technologies for the construction, off-highway, and heavy industrial markets," Hartsell said.

Hartsell said if IFPE was any indication the future for electrification and e-mobility is very promising. "There's an anticipation that we're turning a corner post-pandemic and these products and technologies will be extremely important to our diverse customer base for years to come."

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Dana Updates Motion and Drive Technologies for Off-Highway Applications

During a press conference at IFPE 2023, Dana executives discussed the expansion of the company's drive production capacity as well as recently repositioning the final assembly of its line of heavy axles for mining and other extreme-duty applications to its Lafayette facility. The realignment helps Dana better address the supply-chain requirements and onshoring of North American OEMs.

These initiatives enhance Dana's reputation in gear engineering, manufacturing, and production. At CONEXPO, Dana showcased its ability to deliver precision-made Fairfield gears and gear drives for industrial and mobile applications as well as its push toward electrification.

"Our goal is to improve the performance, efficiency and durability of conventional and electrified construction vehicles and other off-highway machines," said Jeff Cole, senior director, corporate communications, at Dana during IFPE 2023.

Marcus King, vice president, off-highway global sales, business development, strategy and program management at Dana, said the organization is dedicated to strategic principles supporting its company-wide mission of "Powering Innovation to Move Our World."

"Our vision is to improve our leadership position in both conventional and next generation driveline innovations. Dana is energy source agnostic. This is so important in both the construction and off-highway industries where the adoption of zero emissions can vary from region to region, from market to market, application to application, and even vehicle to vehicle," King said.

This balanced, full system approach was on full display at the Dana booth during IFPE 2023 in Las Vegas.

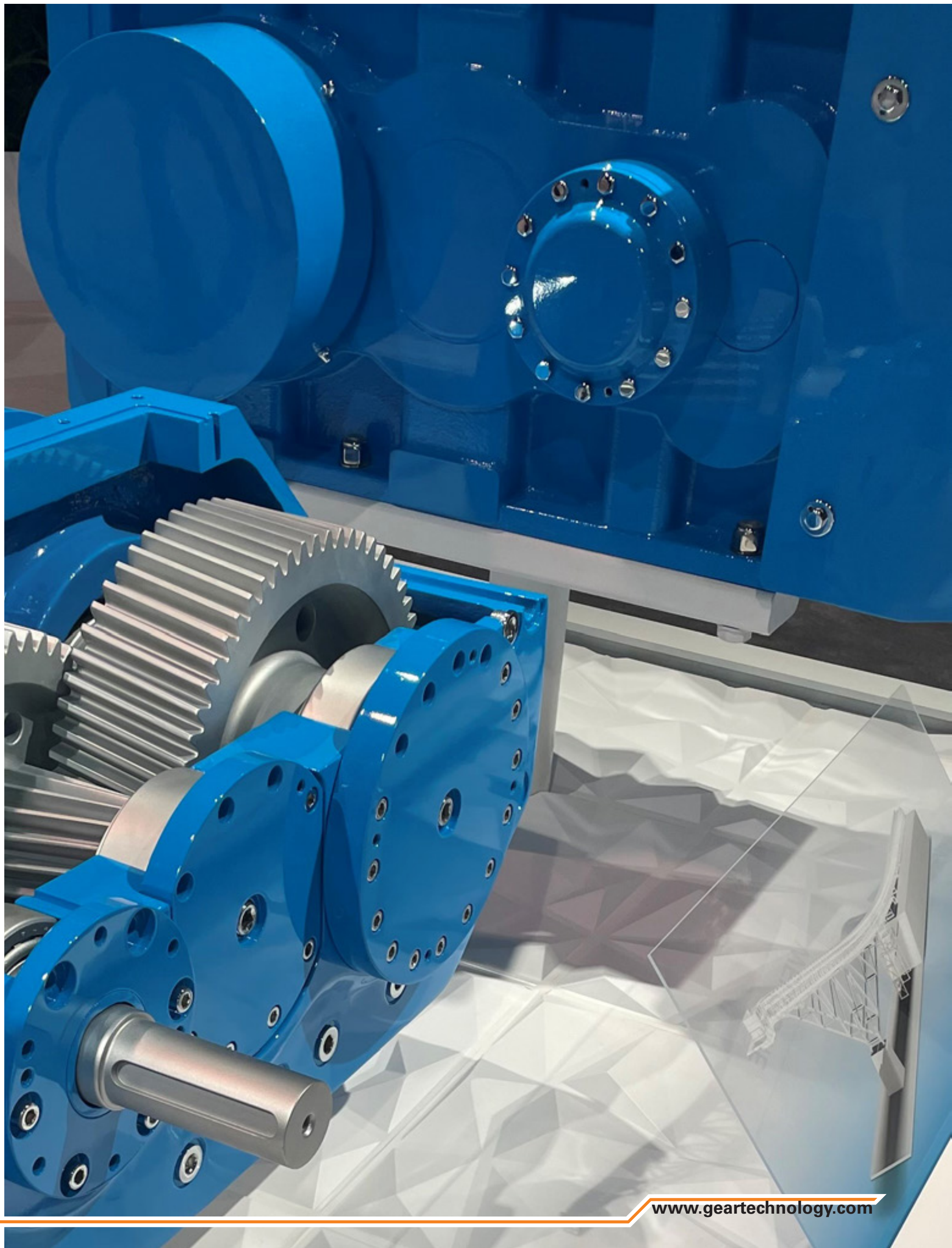
Drive and motion technologies were available for ICE applications and the company continues to expand its offerings in performance and efficiency in these conventional areas. Furthermore, Dana is at the forefront of electric vehicle innovation as well with the e-Transmission and additional e-propulsion systems featured at IFPE.

"Most importantly, we help OEMs minimize development, integration, testing, and manufacturing as they track their paths through this energy transition," King added.

Leveraging Dana's field-proven powershift technology, the eSP502 e-Transmission offers a dual-motor, two-speed design that is built on a flexible platform to enable optimized performance at maximum efficiency in a compact package. The modular approach to the transmission design allows for a single motor solution, as well as an optional power take-off, depending on the specific vehicle requirements.

Delivering high efficiency in a compact package that performs like a conventional powershift transmission, the dual-motor version supports continuous power outputs up to 326 hp (240 kW), while the single-motor configuration is engineered for 187 hp (140 kW) of continuous output.

The eSP502 is equipped with next-generation control software and functional safety readiness, enabling easy installation and smooth integration, and it features a patented clutch design that minimizes clutch drag to maximize efficiency.



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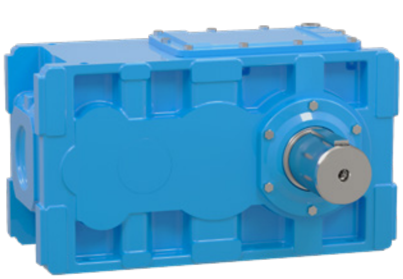


It is equipped with Dana TM4 high-voltage motors of up to 800 V to improve efficiency, reduce total package size, and provide redundancy as needed.

The eSP502 e-Transmission's compact and modular design allows it to be adapted for use in 4x2 or 4x4 vehicle applications with a range of ratio options to support a variety of vehicle types.

Developed for telehandlers lifting to 12,000 lbs. (5,400 kg), Dana's new driveline comes equipped with a compact Spicer 312 dropbox for high-power hydrostatic motors. This new hydrostatic dropbox functions as a continuously variable transmission without torque interruption, delivering enhanced performance with precise maneuvering at low speeds, reduced fuel consumption, and an integrated spring applied hydraulic release parking brake.

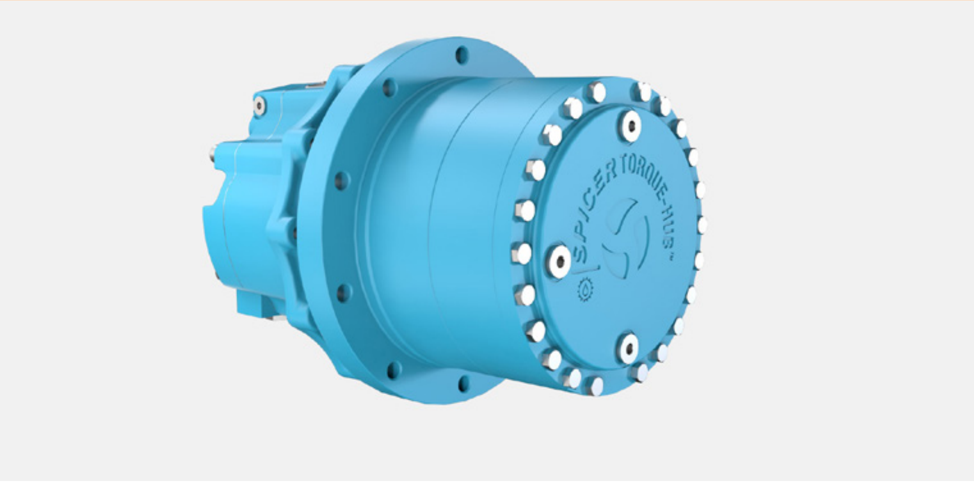
The system includes the field-proven Spicer 222 front and rear heavy-duty axles, which each feature a limited-slip differential and provide the customer with maintenance-free brakes. The complete driveline system is optimized for efficiency as well as noise, vibration, and harshness.

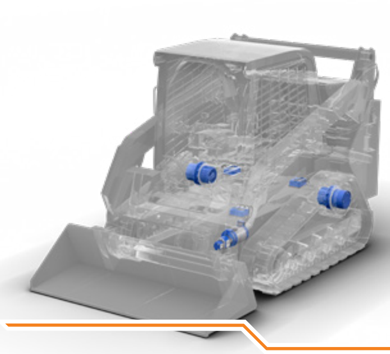
To support the industry's transition to zero-emission vehicles, Dana optimized the axles and driveline system to improve efficiency for a variety of architectures, allowing customers to retain the same driveline solution while choosing between implementing a hydrostatic dropbox or an electrically driven design.

To engage the rapidly increasing interest in CTLs and other tracked equipment in North America, Dana is nearly tripling its annual production of Spicer Torque-Hub track drives within the current footprint of its manufacturing and assembly hub in Lafayette.

Spicer Torque-Hub drives for CTLs offer output torque ratings from 5,000 to 17,000 Nm, delivering increased productivity with maximized motor displacements in a compact package.

dana.com/off-highway





Bosch Rexroth Offers Gearboxes for Electric Motors

The off-highway market is constantly evolving. Mobile working machines are becoming increasingly efficient. At the same time, exhaust gas and noise emissions need to be reduced. Machine manufacturers from all sectors recognize that electric drives are an important building block for a future-viable, sustainable product portfolio.

"We're a strong, growing and thriving business in America. We're investing in our mobile hydraulics partnerships. In North America, we're responsible for our mobile hydraulics, industrial hydraulics and factory automation business which is somewhat unique to Rexroth and allows us to provide solutions to some of our key OEMs in their plants to help them automate and streamline their manufacturing processes," said Greg Gumbs, president and CEO of Bosch Rexroth Americas.

"IFPE is all about our customers," Gumbs said. "We want to earn the right to have our customers love doing business with us. Our booth at IFPE was more than just components, it was about manufacturing solutions."

"A lot of our offerings at Bosch Rexroth are to reduce oil usage in our hydraulic systems, reduce energy consumption, etc.," said Thomas Donato, chief revenue officer, Bosch Rexroth. "You will find custom apps that enables our customers' to utilize these technologies."

Regarding fluid control, Donato said that the boundaries of using software, electronics and electrification are becoming boundless.

"When you look at electrification, it's a new space for many manufacturers in the off-highway and construction markets, and they're looking for a partner with a really strong understanding of how these technologies can be applied on their machines."

In order to support and drive the electrification of off-highway machines, Bosch Rexroth has developed two axle drives designed especially for electric motors.

Bosch Rexroth has developed spur gearboxes which vehicle manufacturers can use to unlock the full potential of new electric motors. The one and two-speed gearboxes are installed in the central section of the vehicle and pool the energy to drive up to two axles with just one motor. The clever integration of essential components is evidence of the wealth of practical know-how that was drawn on throughout the development process.

Technology is allowing customers in the off-highway and construction markets to better monitor oil usage, energy consumption and maintain equipment.

The 1-speed spur gearbox (eGFZ 9100) and the 2-speed shift gearbox (eGFZ 9200) are installed in the central section of the vehicle and therefore open a range of new options compared to previous approaches with individual wheel drives. Both gearboxes enable high power densities to be achieved while simultaneously ensuring noise optimization for high-speed electric motors such as the Rexroth EMS1H and the Bosch SMG, but also for motors of other manufacturers with similar power.

Permanent-magnet synchronous motors are famed for being compact and highly efficient. However, their high rotational speeds present real challenges in terms of noise emissions, temperature, impermeability, and splines. The eGFZ 9100 and the eGFZ 9200 have been specially developed for these applications. They also enable the power to be directed to one or both vehicle's axles. For all-wheel drive, there is also the option to connect or disconnect an axle. A lockable center differential is also provided for permanent all-wheel drive.

When integrating the gearboxes into the installation space available and into the machine concept, Bosch Rexroth drew on the knowledge and experience gained from fulfilling requirements for previous drives. Gearboxes not only have to be compact and reliable but also easy to integrate. While the 1-speed gearbox (eGFZ 9100) can be installed horizontally or vertically depending on the relevant requirements, both Rexroth series feature a plug and drive system. Components such as the heat exchanger and oil pump available in the gearboxes enable both gearboxes to be seamlessly integrated into the existing cooling circuit of the electric drive.

Even the sensors for monitoring functions are already integrated into the gearboxes and can be adapted to suit a wide variety of applications using a range of different options. Machine manufacturers pursue different strategies in terms of voltage supply and battery storage requirements. To ensure that the installation space within the frame of the vehicle can always be optimally utilized, the eGFZ gearboxes with DIN ISO-compliant flange types enable a diverse range of drive solutions to be achieved. These can be executed in two-wheel drive as a U-shape or S-shape gearbox version and in four-wheel drive as a Z-shape version.

Company-wide knowledge of telehandlers, wheeled loaders, and municipal machinery as well as tractors and reach stackers was pooled at the start of the development process to determine which of these drives could be driven electrically and centrally in the future—and with which load collectives. The new eGFZ gearboxes were developed and optimized based on this set of requirements.

Bosch Rexroth now intends to work alongside its customers to determine the best solution for each specific application. The eGFZ 9100 and eGFZ 9200, which are currently being used in different pilot projects, will go into series production in 2022 as part of eLION. Rexroth's platform for the electrification of mobile working machines covers the full range of electric motor-generators, inverters, and accessories as well as tailored gearboxes, hydraulics, and software.

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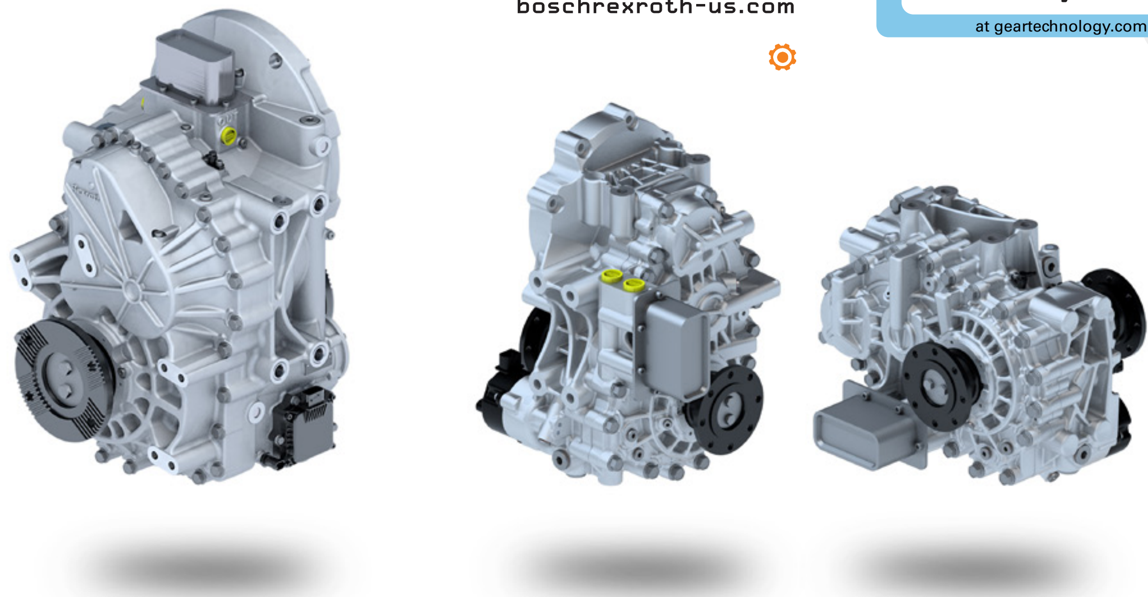

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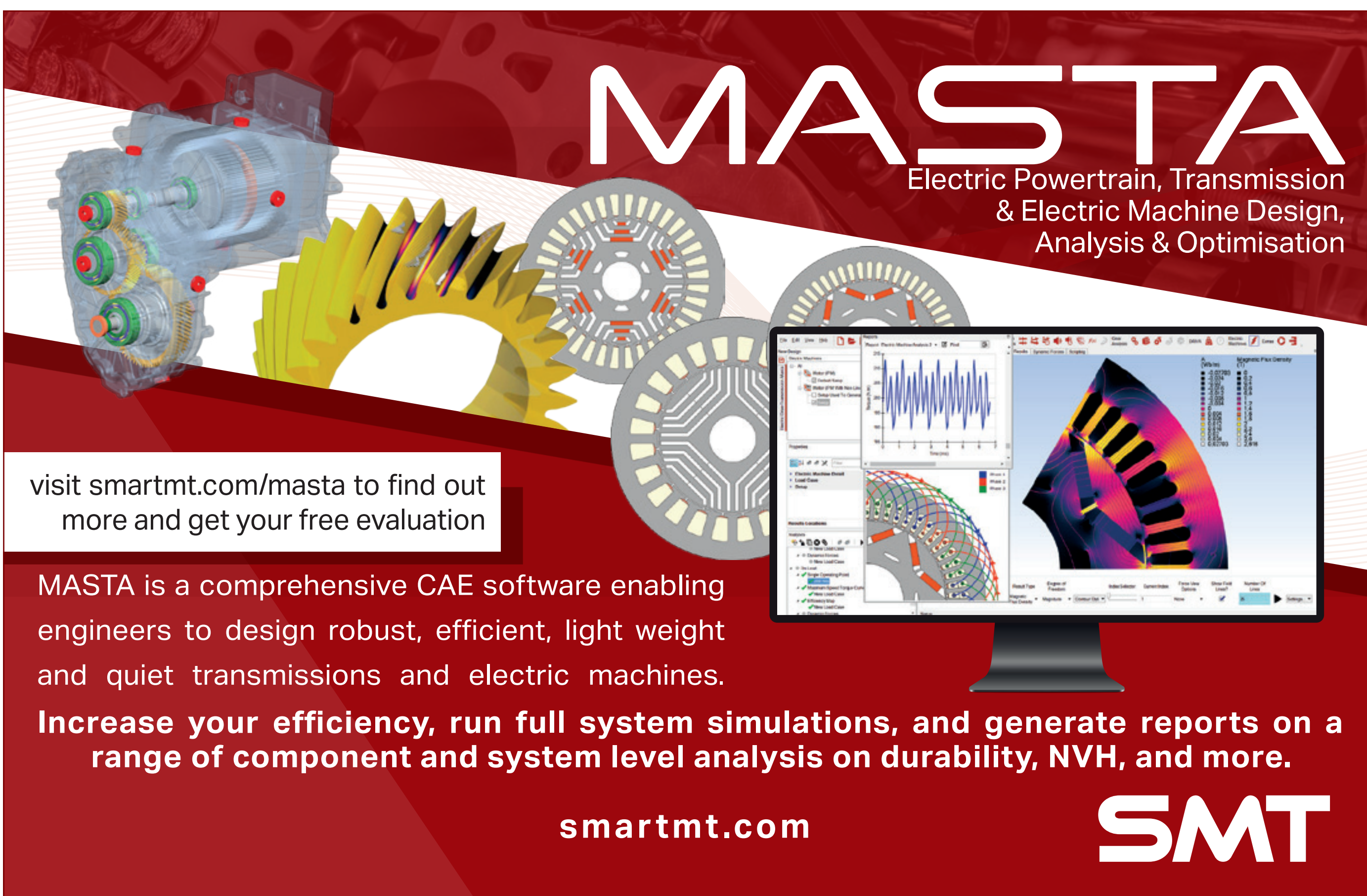

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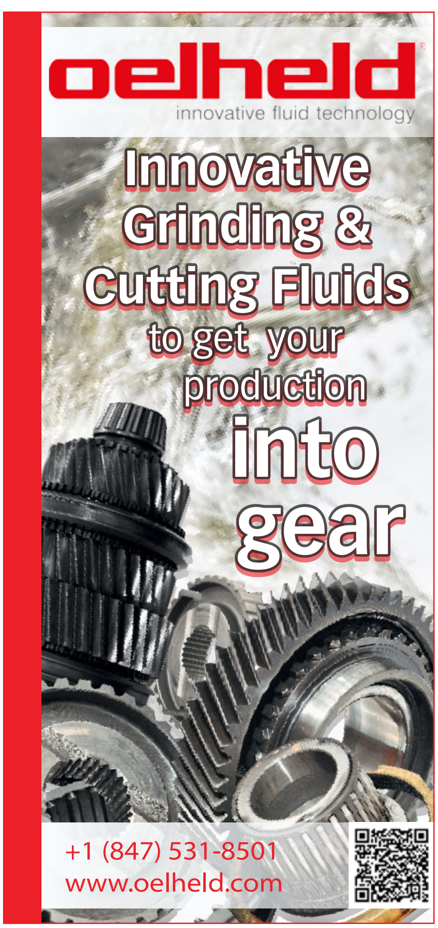
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Two New AGMA Publications

Phillip Olson, Director, AGMA Technical Services

AGMA is pleased to announce the publication of two new documents: ANSI/AGMA 1012-H23, Gear Nomenclature, Definition of Terms with Symbols, written by the AGMA Nomenclature Committee, and AGMA 947-A23, Gear Reducers—Thermal Capacity written by the AGMA Enclosed Drives for Industrial Applications Committee.

ANSI/AGMA 1012-H23

ANSI/AGMA 1012-H23 is one of AGMA's oldest and most fundamental standards. Across 61 pages and 98 figures, it defines gear terms and specifies the symbols for those terms where they exist. Without having standard terms, it would be a nightmare to communicate between vendors, customers, and even within a company. That's why standardizing terms has been an essential task for AGMA since the founding of the association, and the roots of the newly published ANSI/AGMA 1012-H23 can be traced all the way back to 1926 with the publication of AGMA's first nomenclature recommended practice.

Changes in the new revision of the standard include extensive updates of text and figures, edits to better align with ISO gear nomenclature, edits to make the standard metric only, and the elimination of the annexes.

AGMA 947-A23

AGMA 947-A23 is an information sheet, meaning the material in it is still being tested and not yet the industry standard practice. It utilizes an analytical heat balance model to provide a means of calculating the thermal transmittable power of a single- or multiple-stage gear drive lubricated with oil. The calculation is based on standard conditions of 25°C maximum ambient temperature and 95°C maximum oil sump temperature in a large indoor space but provides modifiers for other conditions.

The project to write AGMA 947-A23 began after reviewing two ISO documents on the subject, ISO 14179-1:2001 and ISO 14179-2:2001, and taking parts of both as the starting point for the new document. Major differences from the ISO documents include; Power variables and subsequent equations were converted to Watts. Mesh coefficient of friction calculations are based on ISO 14179-2 and were expanded based on gearing type and to include Hohn's modification. ISO 10300-1 methods were included for calculating mesh coefficient of friction for bevel gears. The oil seal power loss formula was updated based on updated manufacturer information. The gear windage and churning losses clauses were expanded to include the alternate method presented in ISO 14179-2:2001. Bearing windage and churning loss calculations were updated based on updated manufacturer information. The heat dissipation clauses were greatly expanded to include calculations for the heat transfer coefficient under various operating and configuration conditions.

On behalf of the gearing industry, AGMA would like to extend a sincere appreciation for the participation and the valuable contributions of the following experts. In addition, AGMA would like to especially thank the companies of these experts whose foresight and generosity made their participation possible.

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Results of ISO/TS 6336-22 Evaluating Full Contact Zone

Robin Olson, David Talbot, Mark Michaud, Jonathan Keller, and John Amendola, Sr.

ISO/TS 6336-22 (Calculation of load capacity of spur and helical gears—Part 22: Calculation of micropitting load capacity) is the ISO technical specification containing a proposal for a calculation of risk of micropitting in gear sets (Ref. 1). ISO/TS 6336-22 calculates a safety factor against micropitting by comparing the minimum specific lubricant film thickness to the permissible lubricant film thickness. Unfortunately, ISO/TS 6336-22 does not recommend a minimum safety factor. Rather, it is left to the engineer to compare the calculated results to a similar gear application.

The approach has been published since 2010 and the "technical specification" designation of the document means that it contains calculations that are still subject to further development. The next systematic review of the document will require that it either be converted to an international standard or withdrawn. For this reason, it is important to verify that the calculations in ISO/TS 6336-22 reliably predict the risk of micropitting.

As is typical of gear calculation standards, two different methods are presented in ISO/TS 6336-22. The first, Method A, allows the engineer to calculate lubricant film thicknesses using a gear computing program that models the complete contact area of the mesh. In contrast, Method B starts with the assumption that micropitting will start in the region of negative sliding and evaluates the film thickness at specific points along the line of action. ISO/TS 6336-22 recommends both methods should be validated against experience with gear sets in similar application conditions for the calculation of the permissible specific film thickness.

A previous paper, "Case Study of ISO/TS 6336-22 Micropitting Calculation" (Ref. 2), evaluates three cases using the Method B calculations. The first example is an increasing gear set for a compressor, the second is a wind turbine gear set, and the last is the American Gear Manufacturers Association (AGMA) Tribology Test gear set. These examples cover a range of gearing sizes and application conditions. All the gear sets experienced micropitting, providing good examples to verify the computation results. Using Method B, only the AGMA Tribology Test gearing resulted in safety factors that aligned with expectations predicting micropitting.

The results for all three cases were reviewed with members of ISO Working Group 6, who were central to the development of ISO/TS 6336-22. They expressed concern about the use of Method B for Cases 1 and 2. With a pitch line velocity above 80 m/s, Case 1 requires the use of Method A according to the scope of ISO/TS 6336-22. For Case 2, ISO/IEC 61400-4 for wind turbines requires the use of Method A to calculate the minimum specific film thickness. The operating sump temperature for this drive was also scrutinized as wind turbine gearing can run at higher temperatures.

Consequently, the operating conditions and calculation parameters for all three cases were investigated further. That information has been modified for this paper. The results from the previous paper have been updated and are presented here along with the results from Method A. The results from both methods are compared in order to point out the differences. They are also compared to the field results to determine whether ISO/TS 6336-22 Method A reliably indicates micropitting will occur.

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Description of ISO/TS 6336-22

The previous paper contained a detailed description of the methods in ISO/TS 6336-22. A brief refresher is presented here.

In ISO/TS 6336-22, two different methods are presented for the calculations of the minimum specific lubricant film thickness and the permissible specific film thickness. Like other ISO gear calculations, Method A involves the use of testing or detailed calculations to determine critical parameters. Method B is a simplified, analytical method for each. Method B was used in the previous paper.

It is possible to calculate the minimum specific film thickness in the numerator of the safety factor using one method and the permissible specific film thickness in the denominator of the safety factor using the opposite method.

Method B

Method B calculations were conducted using a Mathcad worksheet to follow the equations found in ISO/TS 6336-22.

Minimum specific film thickness

A calculation of the minimum specific film thickness using Method B begins by calculating the film thickness with a Dowson/Higginson analysis along the line of action. This value is modified by a local sliding factor that accounts for regions of negative sliding. The minimum of the specific film thicknesses along the line of action is used to calculate the safety factor.

Permissible specific film thickness

The permissible specific film thickness is determined by conducting standardized testing with gearing that is similar in geometry, quality, and material of the gearing being designed. The gearing is run until the micropitting failure limit is reached. The critical specific film thickness for the test gearing is then calculated with ISO/TS 6336-22 using the load data from the failure stage. This is the permissible specific film thickness. If it is not possible to test with real gears, one may use the failure load stage of the lubricant in standardized tests, such as FVA 54 (Ref. 3), and calculate the minimum specific film thickness using the test gearing.

Method A

Minimum specific film thickness

To determine the minimum specific lubricant film thickness using Method A, the engineer calculates the value with a gear computing program that models the complete contact area of the mesh. The load distribution, sliding velocities, and actual service conditions are considered in this analysis. The results appear as maps of pressures and film thicknesses across the face of the pinion and gear flanks. These are used to calculate the specific lubricant film thickness at each point in the contact zone. It is important to note that the minimum value is used for the safety factor against micropitting.

Permissible specific film thickness

The permissible specific film thickness is determined through testing of real gears in conditions like the application until micropitting just occurs. The test loads and the gear computing program are then used to calculate the film thickness. These tests can also be performed for gear designs and service conditions very similar to the gear set of interest. However, testing such as this can be very costly and may not always be practical if the applications are high load, low speed, with varying operating conditions, and low production volume, or noncritical service. If that is the case, there are options to approximate the permissible specific film thickness from reference gears and FZG lubricant tests. However, each approximation reduces the accuracy of the resulting safety factor.

As recommended in ISO/TS 6336-22, it is important to interpret the micropitting safety factor by comparing it to the performance of similar gearing used in the field under similar operating conditions.

Application of Method A in This Paper

As can be seen in the preceding clauses, a true Method A calculation of the permissible specific film thickness requires that real gearing be tested in a controlled test until micropitting occurs. In Cases 1 and 2, this was not possible given their applications, size, and load conditions. The calculations here were done using Method A for the minimum specific film thickness in the numerator and Method B for the permissible value in the denominator of the safety factor calculation.

Method A Gear Computation Program–*WindowsLDP*

There are several gear computing programs capable of calculating the Hertzian stresses in the contact zone of a gear tooth mesh. This paper uses the *WindowsLDP* (Load Distribution Program) from The Ohio State University to determine the stresses. The remainder of the factors follows the methods of ISO/TS 6336-22 to calculate the minimum specific film thickness.

WindowsLDP is a quasistatic gear design and analysis tool for external and internal spur and helical gear pairs. It employs computationally efficient and accurate semianalytical formulations to compute the load distribution between multiple mating teeth of gears.

The contact pressure distribution is calculated using a parallel-axis gear pair load distribution model (Ref. 4). This model combines:

- The unloaded tooth contact analysis proposed by Singh and Houser (Ref. 5),
- Sources of compliance including tooth bending and shear (Ref. 6),
- Tooth base rotation (Ref. 7) and contact deformation (Ref. 8),
- An initial separation vector including any deviations of the surfaces from perfect involutes (i.e., microgeometry modification).

The load distribution is computed by implementing the modified simplex algorithm proposed by Conry and Seireg (Ref. 9).

WindowsLDP has been validated against testing throughout its development.

Using the predicted load distribution, *WindowsLDP* computes the loaded transmission error, root and contact stress distributions, mesh stiffness functions, and tooth forces. Other design evaluation parameters such as lubricant film thickness and surface temperature can also be computed. Tooth modifications of various forms can be entered interactively or can be read from the tooth surface measurements. The results are presented by an interactive graphical user interface that provides the user the flexibility to process and present them in desired formats.

Case Studies Using Method A

Cases of operating gear sets that experienced micropitting were selected to exercise the ISO/TR 6336-22 document. Because there was concern over the influence of operations and maintenance on micropitting, the authors reviewed lubrication tests, load cases, and operating conditions for each, particularly for Cases 1 and 2. The details of the calculations of these case studies are quite lengthy. The drawings and details of the profile and lead modifications are also proprietary. The authors can provide specific details upon request.

Case 1—High-Speed Compressor Gear Set

Case 1 is a high-speed gear set driving a centrifugal compressor. This set had micropitting on the pinion starting in the dedendum, extending through the pitch line and to the addendum. The micropitting is localized to the drive end of the face width. From experience, this result is predictable due to an increase in tooth contact temperature as the gear mesh load travels through the helical contact pattern.

This gearbox operated for approximately 120,000 hours or 54.6 x 109 cycles. The installation was not located near an area of salt water, high humidity, or subject to significant climatic temperature fluctuations. It operated continuously for four- to five-year periods of time under constant load and speed in an environmentally controlled room. This continuous operation prohibited the absorption of water into the lubricant. After every four to five years of operation, the gearbox was shut down, inspected, and routinely maintained. It was not until approximately 13.5 years of operation that micropitting was detected. At this point, the gear set was exchanged. Prior to this, there was no significant maintenance required.

A picture of the micropitting damage can be seen in Figure 1, with more detail in the previous paper. Other than micropitting, the rest of the gear tooth surface is in very good condition and there are no indications of contact distress or scuffing.

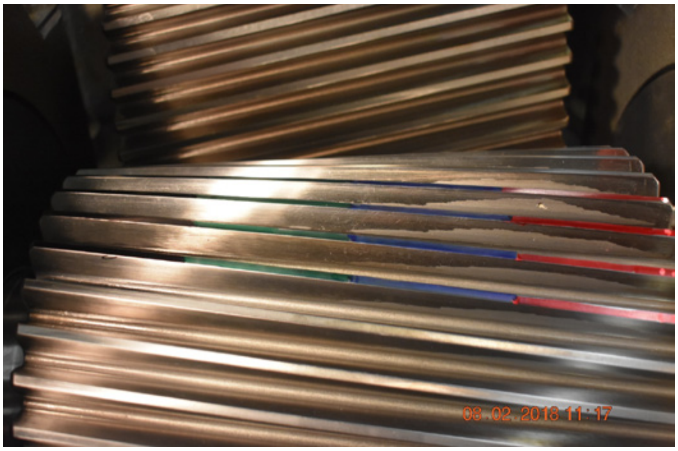

Figure 1—Micropitting on the flank of the pinion teeth. The red zone is closest to the compressor (drive end). The black zone is the motor side. (Photo courtesy of Artec Machine Systems.)

The geometry, loads, and lubricant for this case are summarized in Table 1. The gear teeth have adequate profile and lead modifications for the operating loads.

Dimension	Units	Pinion	Gear
Number of teeth	-	37	163
Ratio	-	4.405	
Center distance	mm	600	
Normal module	mm	5.90	
Face width	mm	280	
Outside diameter	mm	236.30	987.29
Pressure angle	degrees	20.00	
Helix angle	degrees	10.00	
Addendum modification coefficient	-	0.2407	-0.0876
Surface roughness	µm	0.41	0.40
ISO accuracy grade	-	4	4
Material surface hardness	HRC	58-64	58-64
Pinion speed	rpm	7,582.0	
Pinion torque	N-m	12,209.3	
$K_A\ K_v\ K_{H\alpha}\ K_{H\beta}$ product	-	1.4170	
Lubricant	-	Mobil Teresstic AC ISO VG 32	
Inlet lubricant temperature (estimated)	°C	54	
Bulk temperature (for calculations)	°C	82.93/100	

Table 1—Input data for Case 1.

Lubricant Condition

The lubricant used in this gear drive was Mobil Teresstic AC 32. This is an ISO VG 32 rust and oxidation oil. Light lubricants such as this are typically used in compressor-duty gear drives wherein there is a long history of successful use.

After detection of micropitting, a sample of this lubricant was analyzed compositionally using ferrography and comparing it to a sample of new lubricant. The analyses showed:

- No significant deterioration of the lubricant chemical composition,
- No significant water content,
- Improved particle content compared to the new sample indicating excellent filtration.

See Figure 2 for "used" ferrography analysis of the lubricant indicating acceptable operating conditions.

This case is of interest because micropitting has been sporadically seen in similar gear drives operating at pitch line speeds between 73 m/s and 175 m/s. In most cases, micropitting was observed after long years of operation. This gear set was only inspected approximately every four to five years, so it is not certain exactly when the micropitting first occurred.

The gear drives are installed indoors in a heated building. They run at steady loads in continuous operation. The manufacturer reviewed the history of sump temperature and oil analysis for the drives that micropitted. There is no evidence

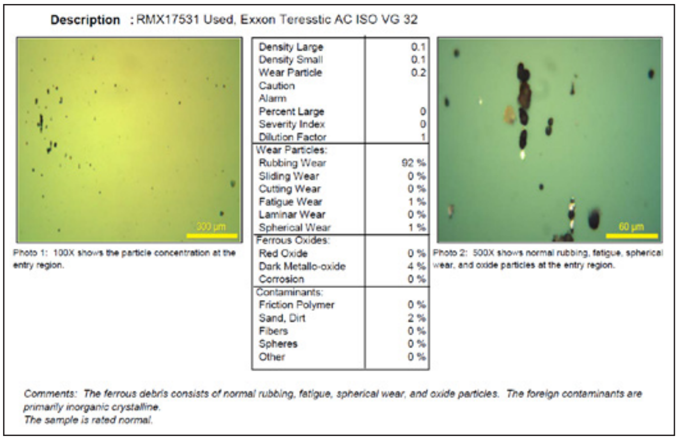

Figure 2—Analytical ferrography of used lubricant. (Photo courtesy of Artec Machine Systems.)

of high temperatures, contaminated lubricant, or nonuniform contact in the gear mesh.

It is interesting to note that Martinaglia's (Ref. 10) testing demonstrates that the zone of highest temperature is located toward the exit end of the tooth face designed with spray ports symmetrically spaced along the spray bars. This result corresponds to the offset pattern in the micropitting seen on this gear set where the tooth flank experienced the highest operating temperatures. We can conclude that the rise in temperature across the face contributed to the onset of micropitting.

In summary, the lubricant and lubrication system for Case 1 performed well throughout the gear set's operation based on the previously mentioned analyses. All data associated with this case's lubricant condition are available upon request.

Calculation Methods for Bulk Temperature and Film Thicknesses

The formulas in ISO/TS 6336-22 were validated with gearing with pitch line velocities between 8 m/s and 60 m/s. Case 1 has a pitch line velocity of 88 m/s. In the previous paper, the Method B calculations arrived at a minimum specific film thickness of 2. While reviewing this example with members of ISO Working Group 6, it was pointed out that the equation for the bulk temperature, θ_M, is not applicable for pitch line velocities above 80 m/s because of significant heat generation from churning and windage that occur at high velocities. Method A is recommended for calculations at pitch line speeds greater than 80 m/s.

A thorough calculation using Method A would model both the contact pressure and bulk temperature across the face of the gear teeth. Unfortunately, *WindowsLDP* does not calculate friction or heat generation within the mesh and creating a model to do so is beyond the time frame for this paper. Instead, we turned to the work of Amendola (Ref. 11) to evaluate the bulk temperature for high-speed gears for scuffing calculations. This work is based on tests conducted by Akazawa (Ref. 12) and Martinaglia (Ref. 10). The result is an equation for bulk temperature that depends on the pitch line velocity for gear sets running at greater than 35 m/s. This equation has been incorporated into AGMA 925-B22 (Ref. 13). Using this equation from AGMA 925, a bulk temperature of 82.93°C resulted and was used in our Method A calculations.

Amendola's previous work (Ref. 14) to correlate MAAG gear predictions to AGMA 925-A03 (Ref. 15) and AGMA 6011-J14 (Ref. 16) uses 100°C for the bulk temperature. To observe the change in the predicted film thickness, 100°C was used for a second set of Method A calculations.

The permissible specific film thickness for Mobil Teresstic AC 32 was calculated using Method B with the geometry of FVA 54 test gears. Unfortunately, no FVA 54 micropitting testing could be found for this lubricant. However, the manufacturer of this gearbox reported that a similar lubricant (Mobil DTE Light, VG 32) used in a similar gearbox was tested and performed to Load Stage 8. Both lubricants have been proven satisfactory in similar applications. Thus, FVA 54 failure Load Stage 8 with 60°C test temperature was used.

Calculation Results

Method A Results

The results using Method A are shown in Table 2.

			θ_M Method	
Name	**Symbol**	**Units**	**Amendola High PLV Calculation**	**MAAG Approx.**
Bulk temperature	θ_M	°C	82.93	100.00
Minimum specific film thickness	λ_{GFmin}	-	1.574	1.149
Permissible specific film thickness	λ_{GFP}	-	0.127	0.127
Safety factor	S_λ	-	12.39	9.04

Table 2—Results using ISO/TS 6336-22, Method A for Case 1.

The pressure distribution and specific film thickness across the contact zone can be seen in Figure 3. The zone of highest pressure and lowest film thickness occurs in the dedendum of the pinion, which corresponds to the location of micropitting. The variation of bulk temperature across the face of the high-speed pinion could not be modeled by *WindowsLDP,* so it does not predict that micropitting will be predominant on the drive end of the face.

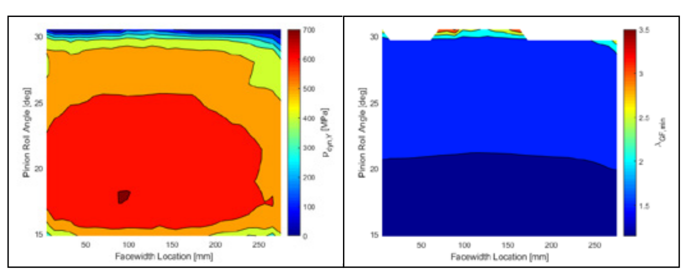

Figure 3—Pressure distribution (left) and specific film thickness (right) across the contact zone for Case 1.

Method B Updated Results

In Table 3, we recalculated the example from the previous paper using Method B for the minimum specific film thickness and bulk temperatures of 82.93°C and 100°C in order to have a closer comparison to the *WindowsLDP* results.

			θ_M Method		
Name	Symbol	Units	ISO/TS 6336-22 Method B (previous paper)	Amendola High PLV Calculation	MAAG Approx.
Bulk temperature	θ_M	°C	60.00	82.93	100.00
Minimum specific film thickness	λ_{GFmin}	-	2.12	1.29	0.95
Permissible specific film thickness	λ_{GFP}	-	0.157	0.127	0.127
Safety factor	S_λ	-	13.48	10.18	7.50

Table 3—Recalculated results using ISO/TS 6336-22, Method B for Case 1.

The Safety Factors

The safety factors that result from all of the calculations—whether using Method A or Method B—are very high. This result occurs when the specific film thickness is much larger than the permissible specific film thickness. However, there are two areas of concern in these calculations:

- The minimum specific film thickness is heavily dependent on the bulk temperature. We did not have a program that can accurately calculate this value. It is also not possible to measure this during the actual operation of the gear drive. We assumed fairly high values for the bulk temperature, but a complete model would contain measured values along the tooth contact, thereby requiring testing with real gears in operating conditions.
- The permissible specific film thickness is based on the assumed performance of Teresstic VG 32 in FVA 54 tests. A more exact value would be derived from standard testing with similar gears. As the permissible value becomes less accurate, the safety factors calculated with ISO/TS 6336-22 are less reliable.
- This gear set operated for billions of stress cycles before surface distress was noted. In such a long life, other applications may be subject to transient torsional, start-up, and shutdown loads that contribute to momentary reductions of film thickness. This gear set was run at even loads without stopping for years. Based on photos of the gear teeth, operational data, and observations, this example appears to have operated under full elastohydrodynamic lubrication (EHL). As such, a lambda greater than one is not a good initial basis for predicting micropitting. Rather, this example suggests that asperity interaction was not a factor in micropitting. Instead, it suggests that micropitting can emerge as a micro-surface Hertzian fatigue phenomenon under full EHL. Only sufficient accumulated stress cycles appear to be needed. Development of a predictive model that incorporates this unique micropitting mechanism is important as gear drive life cycle expectations continue to grow.

Case 2—Wind Turbine Gear Set

Case 2 is a gear set from a 1.5-MW wind turbine at the National Renewable Energy Laboratory (NREL) Flatirons Campus in Colorado. This example is representative of minor micropitting in wind turbine gearing that has operated for five years or more. Micropitting was found in the start of active profile (SAP) of all of the sun pinion teeth. Micropitting and some abrasions were also found higher on the flanks of the sun pinion teeth. The gear set had been installed for just over 8 years. It had produced approximately 6-million kWh of energy in 14,170 hours of grid operation time, representing approximately 8 percent of its minimum design life. Micropitting was noted after just over 6 years of operation, which represents a relatively low number of stress cycles.

Pictures of the micropitting can be seen in Figure 4. The previous paper also contains pictures of the micropitting and details about the gear drive as documented in (Ref. 17). For this paper, all maintenance records were reviewed. In addition, extensive operational data were acquired and analyzed from the turbine's supervisory control and data acquisition (SCADA) system. Reference [18] is publicly available and contains the full documentation for this information.

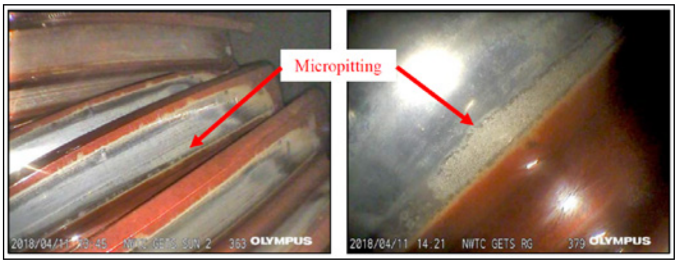

Figure 4—Micropitting on the sun pinion teeth. (Photos by Scott Eatherton, Wind Driven, NREL 61193 and 61194.)

The geometry and lubricant for this case are summarized in Table 4. The gear teeth have adequate profile and lead modifications for the operating loads.

Dimension	Units	Pinion	Gear
Number of teeth	-	27	88
Ratio	-	3.2593	
Center distance	mm	487.51	
Normal module	mm	8.0609	
Face width	mm	200.9	
Outside diameter	mm	247.955	759.079
Pressure angle	degrees	22.5	
Helix angle	degrees	17.584	
Addendum modification coefficient	-	0.0804	0.0804
Surface roughness	µm	0.22	0.55
ISO accuracy grade	-	6	6
Material surface hardness	HRC	59-63	58-62
K_A K_v $K_{H\alpha}$ $K_{H\beta}$ product	-	1.478	
Lubricant	-	Castrol Optigear A320	
Inlet lubricant temperature	°C	50 and 70 (see measured data in Figure 3)	

Table 4—Input data for Case 2.

SCADA Data and Lubricant Analysis

In reviewing the details of the Method B results from the previous paper, questions were raised regarding the gear drive operating temperature and lubricant condition. This gear drive was well-monitored during its operation. To better understand the influence of its application conditions on the presence of micropitting, three different factors were reviewed:

- *Operating temperatures.* Data were available for the temperature of the oil sump for approximately 7.5 years of the 8 years of operation. Oil sump temperatures ranged from 20°C to 66°C, with the densest cluster being between 40°C and 60°C, as shown in Figure 5 [16]. Later measurements on a replacement gearbox showed the temperature of the outer race of the high-speed-shaft bearing, one of the highest operating temperatures in the gearbox, did not exceed 70°C [19]. Based on this, calculations for the sun pinion were performed with a normal oil temperature of 50°C and a worst-case temperature of 70°C.

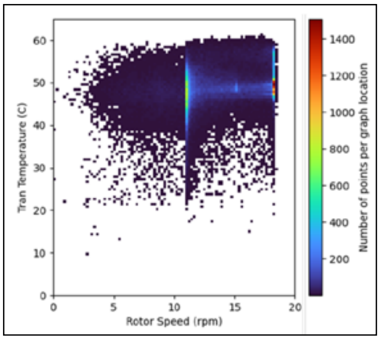

Figure 5—Oil sump temperatures (Ref. 18).

- *Load cases.* Wind turbines operate under varying load conditions. The previous paper applied the mean load condition to calculate the micropitting safety factor. In order to gain an understanding of the running loads that affected the gearing, the operational torque and speed data were mined in both one-second and 10-minute intervals (Ref. 18). The largest amount of time the turbine spent was actually in idle mode, in which the rotor speed is 0–1 rpm and there is no load of the grid operating time, there were high numbers of data points at rotor speeds of 11 rpm (cut-in speed) with loads under 20 percent and 18 rpm (rated speed) at loads ranging from 40 percent to just over 100 percent. An additional collection of points was seen at 13 rpm and relatively light loads under 25 percent. Based on this, it was decided to run calculations at these three load cases summarized in Table 5.

	Units	Original Paper	Cut-In Speed	Intermediate Speed	Rated Speed and Load
Rotor Speed	rpm	18.3	10.91	12.73	18.3
Sun Pinion Speed	rpm	254.17	140.62	164.08	254.17
Sun Pinion Torque	N-m	20,880	3,840	4,080	20,880

Table 5—Load cases for Case 2 calculations.

- *Oil condition.* The NREL report on the gear drive condition [17] mentions that sludge was found in the filter during a late 2017 inspection just prior to removal of the gearbox. In order to determine whether the oil condition influenced the onset of micropitting, especially with respect to water content, the gear drive maintenance records were reviewed. Other than an unexplained brief spike in the water content in 2012, the lubricant condition is normal until the late 2017 inspection. The oil viscosity, particle counts, and water content were otherwise within recommended parameters [18]. From this, it was concluded that the lubricant was well-maintained, resulting in relatively cool, clean, and dry conditions and did not contribute to the micropitting.
- *Castrol Optigear A320 lubricant.* The lubricant supplier was contacted for information related to the lubricant's micropitting resistance. Castrol Optigear A320 has a FVA 54 failure load stage greater than 10 at 60°C and 90°C test temperatures. The permissible specific film thickness of this lubricant was calculated at an oil temperature of 60°C because that provided a more conservative calculation and was representative of the operational data for the wind turbine.

Calculation Results

Method A Results

The results using Method A are shown in Table 6.

At the rated speed and load and an oil temperature of 70°C, the pressure distribution and specific film thickness across the contact zone can be seen in Figure 6. The tooth microgeometry can be seen in the pressure distribution, where low pressure zones are at the root and tip of the pinion tooth. The region of lowest film thickness is located in the dedendum of the pinion between the root clearance and the pitch diameter.

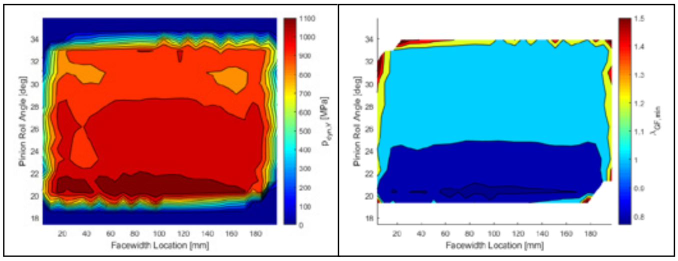

Figure 6—Pressure distribution (left) and specific film thickness (right) across the contact zone for Case 2.

Method B Updated Results

For comparison, Method B calculations were also run using the additional load cases and temperatures. The results are shown in Table 7.

			Load Case					
Name	**Symbol**	**Units**	**Cut-in Speed**		**Intermediate Speed**		**Rated Speed and Load**	
Oil temperature	θ_{oil}	°C	50	70	50	70	50	70
Bulk temperature	θ_M	°C	50.00	70.00	50.00	70.00	50.00	70.00
Minimum specific film thickness	λ_{GFmin}	-	1.742	0.921	1.829	0.964	1.516	0.769
Permissible specific film thickness	λ_{GFP}	-	0.338	0.338	0.338	0.338	0.338	0.338
Safety factor	S_λ	-	5.16	2.73	5.41	2.85	4.48	2.28

Table 6—Results using ISO/TS 6336-22, Method A for Case 2.

Name	Symbol	Units	Load Case					
			Cut-in Speed		Intermediate Speed		Rated Speed and Load	
Oil temperature	θ_{oil}	°C	50	70	50	70	50	70
Bulk temperature	θ_M	°C	50.31	70.32	50.35	70.37	51.70	71.75
Minimum specific film thickness	λ_{GFmin}	-	1.283	0.669	1.412	0.738	1.287	0.695
Permissible specific film thickness	λ_{GFP}	-	0.338	0.338	0.338	0.338	0.338	0.338
Safety factor	S_λ	-	3.80	1.98	4.178	2.18	3.81	2.06

Table 7—Results using ISO/TS 6336-22, Method B for Case 2.

The Safety Factors

The highest load condition for this gear set is at the rated speed. This is also the load case where the lowest safety factors are found. Using Method A, the safety factor is 2.28 with a 70°C oil temperature. However, the gear drive rarely ran with that sump temperature and we would expect the operating safety factor to be closer to 4.48. It is expected that an ISO calculation using Method B will be more conservative than one using Method A. That remains true in this case, with a safety factor of 2.06 when calculated using the 70°C oil temperature.

Guidance in IEC 61400-4

In the last several years, the IEC/ISO joint working group has been revising IEC 61400-4 "Wind turbines - Part 4: Design requires for wind turbine gearboxes" (Ref. 20) to include guidance on the use of ISO/TS 6336-22 for wind turbine gear drives. The calculations in this paper agree with the requirement to use Method A for the calculation of minimum specific film thickness and Method B for the permissible specific film thickness. There is an additional recommendation in IEC 61400-4 to balance the roughness of the pinion and gear teeth for critical gear stages that are not in ISO/TS 6336-22. This gear set does not adhere to that, but neither will many older wind turbine designs.

The draft wind turbine design document also recommends that the safety factor against micropitting should be greater than 2.0 to avoid damage. However, it strongly encourages the engineer to verify the results of the calculation to field experience with similar gear sets and establish a minimum safety factor based on that with values between 1.5 and 2.0. The safety factors calculated for Case 2 approach 2.0 as the oil temperature is raised toward 70°C. However, the gear drive never operated at this temperature. As can be seen in Figure 5, the maximum temperature was 66°C and was between 40°C and 60°C for the majority of the operating time. This is a case where the calculated safety factors should be validated against field experience.

As was noted in "Calculation Results," the gear drive operated at several different load cases based on the wind speed. The load spectra are used to perform a cumulative fatigue damage calculation when wind turbine gearing is evaluated for gear tooth pitting and bending damage. This approach is not possible with micropitting because an S-N curve for micropitting has not yet been established. A calculation in accordance with IEC 61400-4 would be made at the rated speed of the rotor.

Case 3—AGMA Tribology Gear Set

Case 3 is the gearing used in the AGMA Tribology Test Program (Ref. 21). This gearing is similar to FZG "C" gears, but more representative of industrial gears, as they have finer pitch, different tooth counts, and incorporate tip relief and profile modifications to remove interference. They also have axial crowning to increase compressive stress near the center of the face width.

In the previous paper, the micropitting safety factor was calculated with the lubricants that were used in the original tribology test. For this paper, the study performed by Houser (Ref. 22) is referenced. That study was run to test the ISO/TS 6336-22 method by testing with Dexron VI ATF to determine its micropitting load stage. Photos of the micropitted pinion appear in Figure 7.

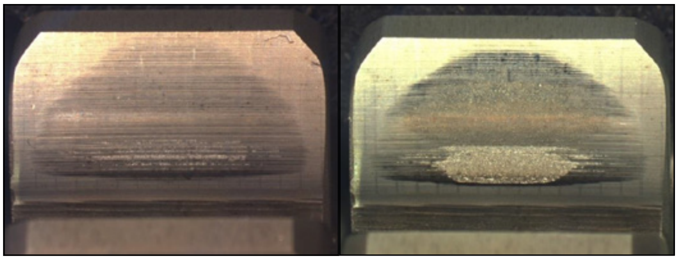

Figure 7—Tooth surfaces of a pinion operated at (left) SKS 9 after 40 hours and (right) SKS 9 after 160 hours. (Photos courtesy of Gearlab at The Ohio State University.)

The calculations with Method B in the last paper resulted in safety factors that were between 1.10 and 1.80, with values decreasing as the load increased. This result is comparable to other calculations of micropitting safety factors that have been reported when micropitting was seen. This paper will compare Method A and Method B calculations with the test results from Houser's study. The calculations were made using the loads for FVA 54 Load Stages 7, 8, 9, and 10 in order to simulate the testing that was performed on the gear set. The geometry and lubricant for this case are summarized in Table 8. The loads appear in Table 9.

Dimension	Units	Pinion	Gear
Number of teeth	-	20	30
Ratio	-	1.50	
Center distance	mm	91.50	
Normal module	mm	3.629	
Face width	mm	13.97	
Outside diameter	mm	82.042	116.716
Pressure angle	degrees	20.00	
Helix angle	degrees	0	
Addendum modification coefficient	-	0.2533	-0.0296
Surface roughness	µm	0.34	0.22
ISO accuracy grade	-	4	5
Material surface hardness	HRC	59-61	59-61
K_A K_v $K_{H\alpha}$ $K_{H\beta}$ product	-	1.0826	
Lubricant	-	Dexron VI ATF	
Inlet lubricant temperature	°C	40 (Measured)	

Table 8—Input data for Case 3.

SKS	Pinion Speed (rpm)	Pinion Torque (N-m)	Nominal Hertzian Contact Stress at Point A (N/mm^2)
7	2,250	132.5	1,048
8	2,250	171.6	1,191
9	2,250	215.6	1,333
10	2,250	265.1	1,476

Table 9—Load cases for Case 3 calculations.

Additional Details/Discussions on This Gear Set

The geometry of this example is very close to the FVA 54 test gears and the loads are those used in the load stages for the FVA 54 test. The permissible specific film thickness that is calculated for the lubricant will be representative of the test gearing. It is expected that the safety factors calculated for this case will be predictive of the micropitting found during the testing.

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Calculations

Method A Calculation Results

The results using Method A are shown in Table 10.

			SKS Load Stage			
Name	**Symbol**	**Units**	**7**	**8**	**9**	**10**
Bulk temperature	θ_M	ºC	53.28	56.58	60.19	64.09
Minimum specific film thickness	λ_{GFmin}	-	0.256	0.224	0.196	0.171
Permissible specific film thickness	λ_{GFP}	-	0.189	0.189	0.189	0.189
Safety factor	S_λ	-	1.35	1.18	1.04	0.90

Table 10—Results using ISO/TS 6336-22, Method A for Case 3.

The pressure distribution and the specific film thickness across the contact zone can be seen for the failure Load Stage 8 loads in Figure 8. The effect of the tooth crowning is clear with the loads centered on the tooth. The influence of the sliding factor on the film thickness is evident in the higher values near the pitch line and lower values near the tooth root.

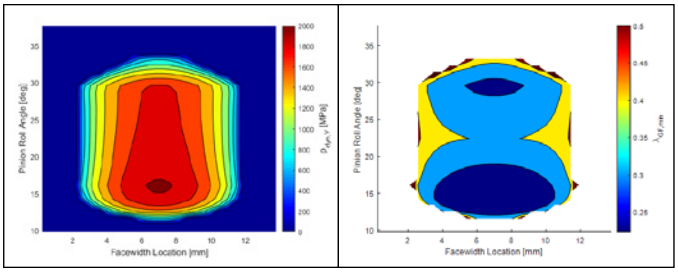

Figure 8—Pressure distribution (left) and specific film thickness (right) across the contact zone for Case 3.

Method B Updated Results

The results of Method B calculations are shown in Table 11.

			SKS Load Stage			
Name	**Symbol**	**Units**	**7**	**8**	**9**	**10**
Bulk temperature	θ_M	ºC	53.58	56.91	60.52	64.47
Minimum specific film thickness	λ_{GFmin}	-	0.319	0.273	0.233	0.200
Permissible specific film thickness	λ_{GFP}	-	0.189	0.189	0.189	0.189
Safety factor	S_λ	-	1.69	1.44	1.23	1.06

Table 11—Results using ISO/TS 6336-22, Method B for Case 3.

The Safety Factors

Using both Method A and Method B, the calculated safety factors are well-aligned to the micropitting seen on the test gears. Significant micropitting was seen between Load Stages 8 and 9 with low values of safety factors at these stages.

Conclusions

The details of the calculations of these case studies are quite lengthy. The drawings and details of the profile and lead modifications are also proprietary. As a result, the authors can provide specific details upon request.

This investigation has reviewed calculations using ISO/TS 6336-22 Method A and Method B, comparing the results against field results. In the process of writing both papers, extensive reviews have been made of geometry, surface roughness, load conditions, and lubricant conditions. These reviews were done to best understand the influences of micropitting on each example and the applicability of the calculations to the results. The following conclusions about the methods can be made.

- *The safety factors calculated using Method A and Method B did not predict micropitting for Cases 1 and 2.* Both cases have high safety factors, but experienced micropitting in application.
- *Permissible specific film thickness.* The permissible specific film thickness is a significant factor in the calculation of a micropitting safety factor. It is important to use a value that is representative of the gear set being evaluated.
  - This value is best when measured from testing of real gear sets in application conditions until they micropit. This is not always practical or possible.
  - If testing with real gears is not possible, a calculation using the results of FVA 54 testing can be used. However, FVA 54 testing is a test of the micropitting resistance of a lubricant using gearing that is designed to micropit. The resulting permissible film thickness will have a degree of uncertainty based on how different the gearing and operating conditions are from the FVA 54 test.
- *Fatigue limits for micropitting.* Case 1 ran at steady load and speed for much longer than what would be the endurance limit for the classic bending or pitting failures. In addition, the condition of the nondamaged flank areas indicates that the gearing operated in a full EHL regime throughout its life. The *WindowsLDP* analysis shows that the entire face of each tooth carried the contact. Despite these good operating conditions, the teeth experienced micropitting after billions of cycles. This outcome leads one to question whether micropitting is solely predicted by film thickness, or whether additional fatigue considerations play a role.
- *Minimum specific film thickness.* Method B is a general calculation model for the minimum specific film thickness. The engineer is advised that a more thorough analysis uses Method A. However, the engineer is left to decide how to determine the pressures and temperatures within the contact zone when using Method A.
- *Influence of surface roughness method.* ISO/TS 6336-22 uses the arithmetic mean roughness value (Ra) to assess the influence of the surface finish on the specific film thicknesses. Recent tribological work has utilized the root-mean-square roughness (Rq) or maximum height of profile (Rz). In order to test whether the use of these parameters would change the results of the calculations, measured values of Rz from the gearing in Case 2 were used to calculate the specific film thickness. Measured values of FVA 54 test gearing were used to calculate the permissible specific film thickness. Specific film thickness decreased when using Rz. The resulting safety factor also decreased, but it is hard to say whether it is more predictive of micropitting. More review is needed on this topic.

			Roughness Method	
Name	Symbol	Units	Ra	Rz
Effective roughness[1]	Ra, Rz	μm	0.385	4.315
Minimum specific film thickness	λ_{GFmin}	-	0.653	0.058
Permissible specific film thickness	λ_{GFP}	-	0.338	0.048
Safety factor	S_λ	-	1.932	1.212

[1] Effective roughness using Ra is the arithmetic mean value. Effective roughness using Rz is the root-mean-square value.

Table 12—Results of using alternate roughness parameters, Case 2, Method B.

In general, the methods in ISO/TS 6336-22 work best when the engineer has complete knowledge of the design, manufacturing, operating conditions, and service life of the gear set and its lubricant. Pinnekamp (Ref. 23) noted that confidence in the safety factor against micropitting relies on the engineer's knowledge of the operating conditions and the quality of their calculations. The safety factor must be compared to the results of the tests with similar gears when there is low confidence in the methods.

Future Work

As the science behind predicting micropitting continues to evolve, some future work is needed for ISO/TS 6336-22. Future development should arrive at safety factors that do not require comparison to similar gearing for interpretation. Additional recommendations are to:

- Continue to develop a method to establish the permissible specific film thickness of the lubricant when testing of real gears is not possible. If results from FVA 54 lubricant tests must be used, it would be helpful to have a method to scale the data to the application geometry and loads.
- Improve the guidance to lead the engineer in the complete use of Method A, including all factors for consideration (e.g., load, temperature, surface topography, etc.).
- Develop a test procedure to evaluate the S-N relationship for micropitting so the impact of accumulated stress cycles can be established when evaluating for the risk of micropitting. Further, developing a predictive model that incorporates this unique micropitting mechanism is important as gear drive life cycle expectations continue to grow.

Acknowledgments

Many thanks to the contributors to this paper:

- *WindowsLDP* data was provided by The Ohio State University.
- Artec Machine Systems provided the geometry and application data for the compressor gear set in Case 1.
- NREL and General Electric Renewables provided geometry and application data for the wind turbine gear set in Case 2.
- REM Surface Engineering provided the surface roughness analyses for all three cases.
- Regal Rexnord provided all support for the Method B calculations and analysis.

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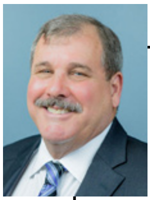
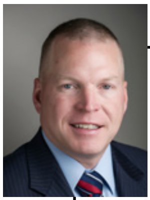
Robin Olson is the director of application engineering in the Engineered Gear group of Regal Rexnord's Motion Control Solutions division. She started her career in gear engineering with the Falk Corporation in 1995 and has held previous roles in engineering software and analysis, sustaining engineering, warranty, test lab, and technical services. She has bachelor's and master's degrees, both in Physics. She has participated in various AGMA Technical Committees since 1995 and is currently a member of the Helical Gear Rating Committee. She has the honor of representing the United States on Working Group 6 of ISO TC 60, covering the topic of Gears.

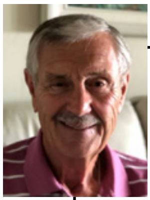
David Talbot is an assistant professor at The Ohio State University Department of Mechanical and Aerospace Engineering. His research focuses on multi-disciplinary power transmission problems within the aerospace, transportation, wind energy, and industrial gearbox industries. His specific research investigations include load distribution modeling of power transmission components, gear, bearing, and power transmission system efficiency modeling and measurement, gear dynamics and vibrations, and gear manufacturing process simulation.



Mark Michaud recently celebrated his 40th year with REM Surface Engineering. Mark is the inventor and pioneer of REM's chemically accelerated finishing technology; currently serving as technical fellow. Mark Michaud is a leading scientist and technical mentor and continues to play a crucial role in the company's future. Mark has authored numerous patents and technical papers and served a term on the AGMA board of directors. Mark continues to serve as vice-chair of the AGMA Aerospace Committee, as a member of the AGMA Wind Turbine Committee, and as a shadow delegate to ISO 614-4 Wind Turbine Committee. He graduated with a bachelor's degree in chemistry from Reed College and an MBA from the University of Hartford.



Jon Keller is the team leader for wind turbine drivetrain technology at NREL. Jon leads projects ranging from the development and verification of new drivetrains with improved performance, power density, and efficiency and to in-depth research investigations of failure modes and improvement in reliability of existing drivetrains often conducted in the dynamometers or field turbines. Prior to joining NREL, Jon worked for the US Army at Redstone Arsenal, AL, for 10 years, where he developed condition monitoring systems for Army rotorcraft to reduce the cost and maintenance burdens while increasing availability and safety. His Ph.D. is in aerospace engineering from Penn State University.



John Amendola, Sr. is an executive officer and chairman of the board of Artec Machine Systems where he has been working for 50 years. Prior employment was with Western Gear, Texaco & Boeing Co. where he operated a full load four square locked torque test stand for helicopter gears. He is currently an active member of AGMA Helical Gear Rating & Lubrication Committees, active chairman of AGMA Enclosed High Speed Units Committee, a member of the US TAG to ISO TC60, and a member of the American Petroleum Institute 613-6 Standards Task Force. John holds a Bachelor of Mechanical Engineering degree from Villanova University and a Master of Science degree in Mechanical Engineering from (NYU) Brooklyn Polytechnic Institute. Amendola is a recipient of the AGMA TDEC Award.

Analytical Determination of Range of Number of Teeth in Generating Non-Involute Tooth Forms Using Fixed Reference Profiles

Igor Zarębski, Jarosław Górniak, Tadeusz Sałaciński, Adam Marciniec, Paul St George

The standard ISO 17396:2017 specifies sizes and tolerances of pulleys for synchronous belt drives. The pulleys feature trapezoidal tooth profiles that can be machined with generating methods (such as hobbing). The profile is different for each pulley diameter. A reference profile, produced by a generating tool (such as a hob), can closely approximate the nominal tooth shape over a range of a number of teeth (Ref. 1).

The reference profiles for involute gears have straight-line sections that shape theoretically correct tooth flanks regardless of the number of teeth on the gear. On the other hand, a unique reference profile corresponds to the number of trapezoidal teeth on a belt pulley. That reference profile can be obtained for each pulley with methods described in Ref. 2, 3, 4. If imported into CAD software, it can be compared with other profiles, which were created for a different number of teeth on the pulleys. Tooth forms generated with fixed reference profiles can be found using the same methods, and the profiles can be compared with each other and against the specifications from the ISO standard. As these comparisons are usually done manually, they may take a significant amount of time and effort.

When a reference profile suitable for generating the subject toothing is obtained, a tool's profile can be derived from it, which may include process-related modifications. In the case of hobbing, these modifications may be necessary for several reasons, including tool-workpiece kinematics of two bodies rotating around skew axes (Ref. 2), and local cutting conditions which change along the cutting edge having an influence on the final shape of the gap being cut. A single tool can typically produce a single reference profile, therefore the act of selecting the reference profile or profiles required for a given task is a very important step in designing the manufacturing process as it has a direct and decisive influence on the costs. The methods based on manual comparisons of profiles in CAD software might not be efficient enough in some cases, so an analytical method needed to be developed to streamline the reference profile development process.

The toothed belt and pulley system known by the designation T, which has been selected as an example within this paper, was developed in the 1950s and standardized first in DIN 7721 (1977) and then in ISO 17396:2014 (Ref. 5). Here, in this case study, we check if a single hob can properly cut T5 profile pulleys with 25 and 30 teeth, and if so—define the range of the number of teeth covered by this hob. Standard tool designs indicate a range from 21 to 36 teeth (Ref. 6), 21 to 50 teeth (Ref. 7), and 21 teeth and more (Ref. 8).

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Pulley Geometry

As the number of teeth to be considered first are 25 and 30, a T5 28-tooth pulley profile has been selected from the ISO 17396:2017 standard, and is shown here (in millimeters):

The specified flank angle tolerance is ±1.5 degrees. If constant gap width at points where straight flank lines end and rounding R0.6 mm begins was maintained, changing the flank angle within that tolerance produces changes of specified gap width 3.345 mm. The magnitude of these changes for each side is of the same order as the gap width tolerance (Figure 1—details drawn red). Furthermore, the specified gap width is dependent also on the tolerance of major diameter ϕ43.695 mm. To address problems resulting from these changes, it has been assumed that nominal values in the middle of respective tolerances will be used within the scope of this paper.

The generating tool could machine the major diameter of the pulley. In such a case the tolerances on the major diameter would limit the possible positions of the generating tool. To keep the generating tool's design as flexible as possible it has been assumed that the major diameter would be machined during the manufacture of the blank, and the generating tool would only machine the tooth gaps.

The tolerance of rounding R0.6 mm is specified two times wider than the tolerance of the major diameter, and the generating tool would machine this rounding. Even when the radius of rounding is kept within that tolerance, as the number of teeth generated on a pulley with a fixed reference profile changes, the radial height of rounding would also change. A generating tool could be designed to achieve a perfect transition of rounding into major diameter for one chosen number of teeth. Since different numbers of teeth are to be generated with that tool, it has been assumed in this paper that the radial height of rounding R0.6 mm (with a nominal value equal to 0.392 mm) must be monitored and maintained within the same tolerance as specified for the radius of rounding (±0.05 mm).

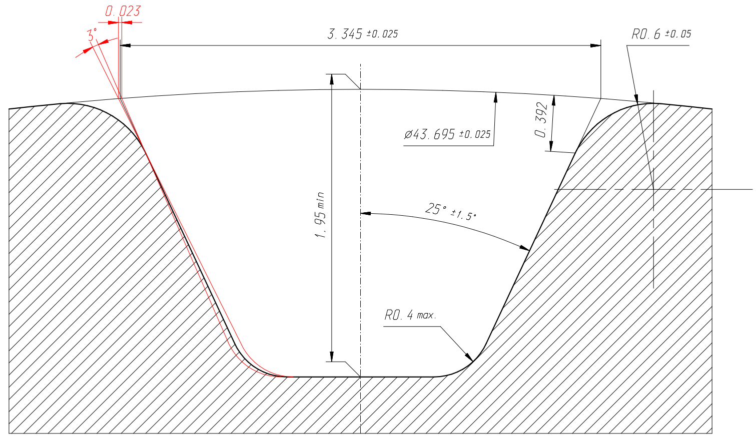

Figure 1—Geometry of a T5 28-tooth pulley.

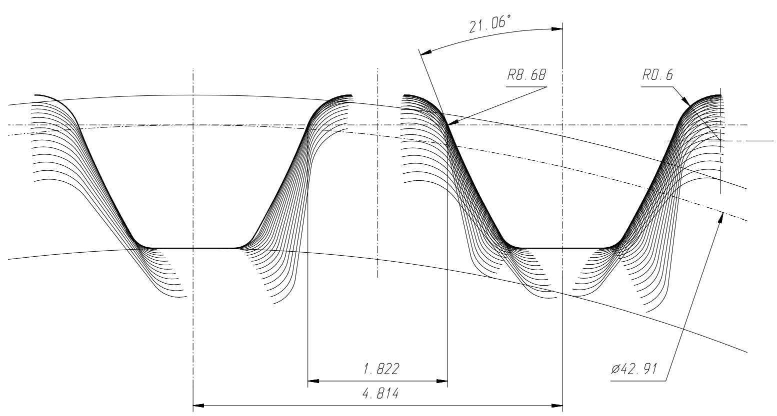

Figure 2—Reference profile of generating tool for a T5 28-tooth pulley.

Reference Profile of Generating Tool

A reference profile of generating tool for a T5 28-tooth pulley has been obtained, using methods described in Refs. 2, 3, 4:

The local curvature of the reference profile at the point where rounding R0.6 ends and generating of flank begins is measured 8.68 mm, and the profile angle at that point is measured 21.06 degrees. When a small section of the profile is isolated, its deviation from a straight line is small enough to assume that it will shape an involute of a circle. In this study, a section with a length of 0.000536 mm (0.0005 mm high) has been used with a deviation from a straight line δ calculated from Equation 1 as 4.1E-09 mm.

$$\delta = R - \sqrt{R^2 - \frac{l^2}{4}} \qquad (1)$$

Calculating Parameters of Pulley Profile

The circular tooth thickness on pitch diameter for a 28-tooth pulley, generated with a reference profile shown on Figure 2, can be measured straight on the profile as no profile shift is required to achieve the required gap width of 3.345 mm. This circular tooth thickness is measured at 1.822 mm. When the number of teeth on the pulley is other than 28, the reference profile would also be different, but since the reference profile for 28 teeth will be used, profile shift needs to be applied to achieve the required gap width.

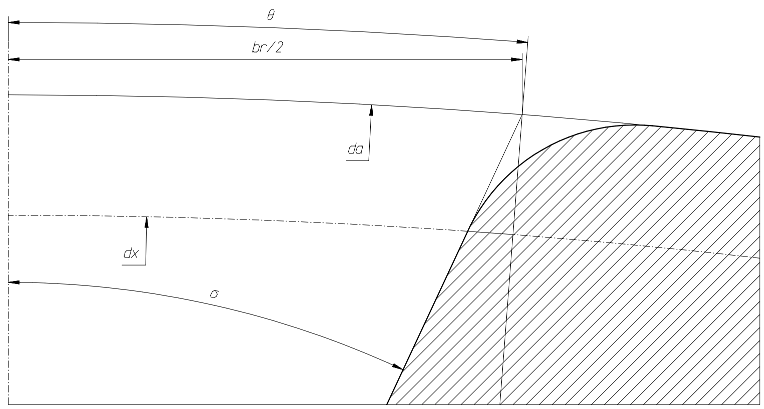

Figure 3—Calculating parameters of pulley profile.

$$\sin\theta = \frac{br}{da} \tag{2}$$

The circular gap width *gr* on diameter *dx* can be approximated from:

$$gr \approx \theta \bullet dx - (da - dx) \bullet \mathrm{tg}(\sigma - \theta) \tag{3}$$

For 28 teeth, br=3.345 mm, da=43.695 mm, dx=42.91 mm and σ=25 degrees, the gr was calculated as 2.992912 mm. The angle θ is expressed in radians. The difference between gr calculated and measured in CAD is 0.0004 mm, which has been assumed to be accurate enough for the purposes of this study.

The calculating procedure begins with setting the number of teeth to be generated on the pulley. A small section on the reference profile, as shown in Figure 2, located where rounding R0.6 ends and flank begins, is generating the pulley's profile at diameter *dx*. For this case study, the diameter *dx* was calculated using proprietary software (*kzz*) developed at Prozamet (Ref. 9). The same program was used for calculating the circular gap width on diameter *dx*, which was then compared with gr calculated from Equation 3. If these two are different, the gap width *br* is not equal to the specified value of 3.345 mm and the reference profile must be shifted to address that. The correct amount of reference profile shift was calculated with a modified Newton method. For a 25-tooth pulley, the calculated reference profile shift was −0.105 mm, and for a 30-tooth pulley it was +0.075 mm. The pulley's profile flank angle σ was calculated from the slope of the generated section (Ref. 10).

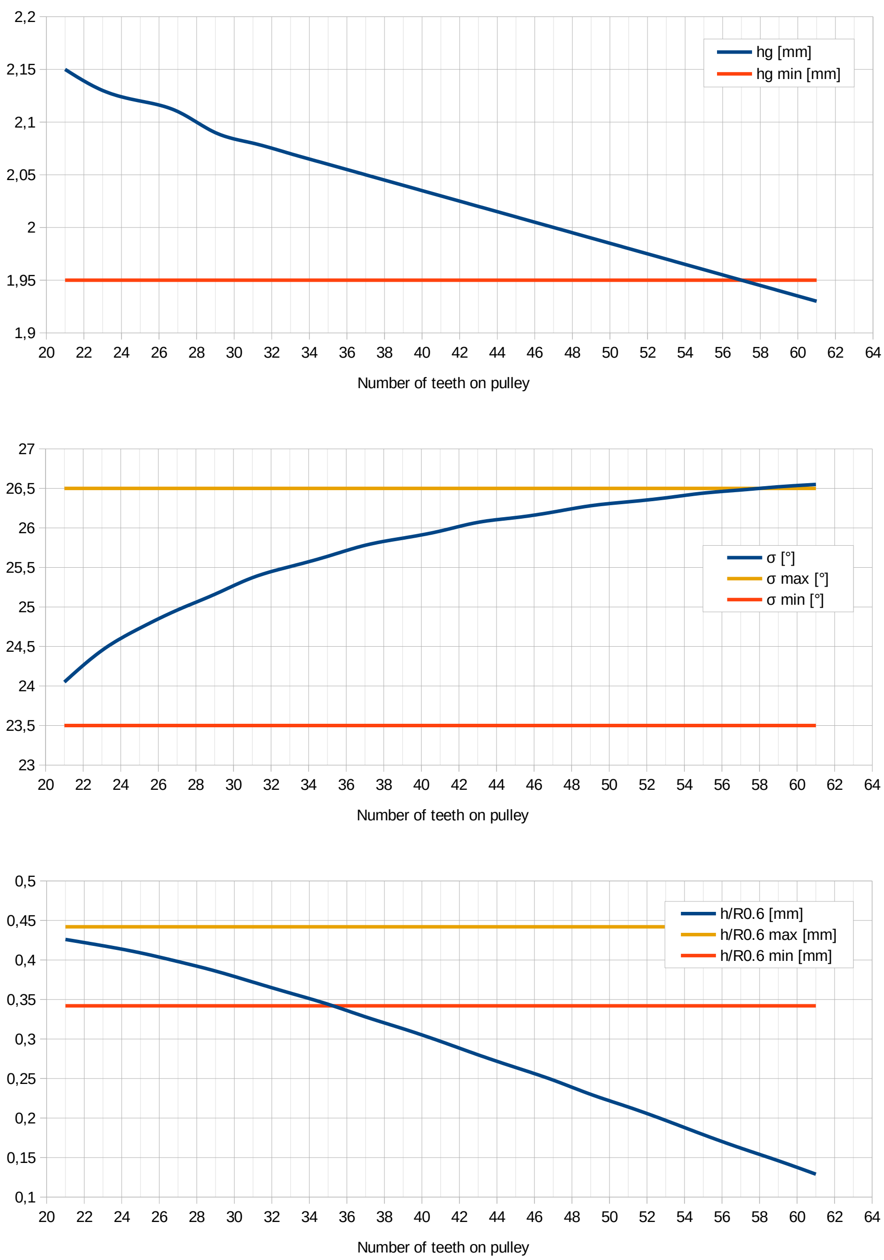

Figure 4—Application range charts.

Pulley Profile Parameters Calculated for 25, 28 and 30 Teeth

Table 1 shows the parameters of pulley profiles calculated for 25, 28, and 30 teeth. The profiles were generated with a reference profile for a 28-tooth pulley (Figure 2).

All parameters are within their respective tolerances—a reference profile for 28 teeth can generate 25 teeth and 30 teeth profiles.

Parameter	Symbol	Nominal value with tolerance	Generated with reference profile for a 28-tooth pulley		
			Number of teeth		
			25	28	30
Major diameter	da	-	38.925 mm	43.695 mm	46.885 mm
Radial height of tooth	hg	1.95 mm min	2.12 mm	2.10 mm	2.09 mm
Flank angle	σ	25°±1°30′	24°44′	25°4′	25°17′
Radial height of rounding R0.6	h/R0.6	0.392±0.05 mm	0.409 mm	0.392 mm	0.378 mm

Table 1—Parameters of pulley profiles calculated for 25, 28, and 30 teeth.

The Range of Application of a T5 28-Tooth Reference Profile in the Generating of Pulleys with Different Numbers of Teeth

The method and criteria described above have been used to determine the range of application of T5 28-tooth reference profile in the generating of pulleys with different numbers of teeth. The smallest number of teeth is 21 because below that a different set of parameters is defined in the ISO standard. The results are shown on the Figure 4 charts.

The factor limiting the range of application is the radial height of rounding R0.6 mm. The 28-tooth reference profile can generate pulleys ranging from 21 to 35 teeth.

Conclusion

In the process of modeling the T5 pulley profiles in accordance with ISO 17396:2017, some definitions in that standard were interpreted to derive applicable validation criteria of the geometrical parameters of profiles. An analytical method for reference profile evaluation was developed to address problems with previously used methods, which were based on manual comparisons of profiles in CAD software. It might be surprising that the critical factor, most severely limiting the application range of a reference profile, turns out to be the radial height of the tooth tip's rounding R0.6 (h/R0.6). Has that limitation been recognized and introduced intentionally, or should a revision of rounding tolerances be considered?

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Dr.-Ing. Igor Zarębski is the director at Prozamet. His main interests are gear calculation methods, including cylindrical gears, straight and spiral bevel gears, hypoid gears, worm gears, non-circular gears, skew-axis and face gears, as well as gear tools - hobs, shaper cutters and milling cutters.

Ing. Jarosław Górniak is the technical director at Prozamet. His main interests are gear manufacturing technology, including gear hobbing, shaping, milling, heat treatment and finishing, as well as gear tools, fixture and workholding design and manufacturing.

Dr. habil.-Ing. Tadeusz Sałaciński is an associate professor at Warsaw University of Technology's Institute of Manufacturing Technologies. His main interests are cylindrical gears, spiral bevel gears, non-circular gears, metrology, statistical process control, production engineering, cutting tool design and manufacturing technology.

Dr. habil.-Ing. Adam Marciniec is an associate professor at the Faculty of Mechanical Engineering and Aeronautics of Rzeszów University of Technology. His main interests are gear geometry calculation and computer-aided modeling, including cylindrical gears, spiral bevel gears, hypoid gears, and worm gears.

Dr. Paul St George is an artist and writer, who strives to bring the inherent beauty of mathematics, science, and gears to a wider audience. His research into technical innovations from the late nineteenth century and his exploration of the aesthetics of mathematically defined shapes and objects, including noncircular gears, developed into a project titled Travelling Curves.

Punch Powertrain Stellantis JVs

START LARGESCALE SERIAL PRODUCTION OF NOVEL HYBRID EDCT

Building on 50 years of expertise in transmission systems, Punch Powertrain has achieved a significant transformation, reorienting towards hybrid and electric systems production. The shift enables the company to contribute to the sustainability of the automotive market in Europe, with a reduced carbon footprint.

Today marks the official opening of the DT2 manufacturing lines in Sint-Truiden, charged with large-scale manufacturing of DT2 key components and sub-systems. This milestone coincides with the capacity increase of the transmission assembly in Metz, marked on April 27th, in the presence of Stellantis CEO, Carlos Tavares. Following a ramp-up phase and ongoing capacity increase, in 2024 the Sint-Truiden site will be equipped to manufacture 600.000 sets of key components for its assembly affiliate in Metz, France, and additional 600.000 key component sets for assembly in Mirafiori (Turin), Italy.

To produce the necessary Stellantis volumes, extensive investment has been made by both joint-venture partners, among others in the installation of state-of-the-art equipment and processes. As the growth spurt is now set in motion, both the Sint-Truiden and Metz plant will benefit from ongoing investments in innovation and training and from upcoming recruitment to expand the workforce towards ramp-up.

In preparation for this milestone, earlier this year the Sint-Truiden site started hiring activities to attract more than 100 technically skilled production workforce. By 2025, over 250 new employees will have joined the local production team. The rise in the workforce is further complemented by investment in training programs for both new and incumbent employees. Within 2023 over 6.000 hours of training will be attended by over 500 people in Sint-Truiden, enabling them to upskill and join the new technology economy.

"We are excited to kick off the serial production of our flagship hybrid transmission," says Jorge Solis, CEO of Punch Powertrain. "Our patented technology enables us to bring sustainable technologies to global markets at affordable cost, taking a leap in the direction of our vision 'Our Powertrains drive a sustainable world'. We are utmost proud to collaborate with Stellantis on this major project and to be one of the main contributors to CO^2 reduction in the vehicles we will equip."

"The production launch we mark today is the result of exemplary teamwork of passionate experts across locations, including Research & Development in Eindhoven and Sint-Truiden, as well as production in Sint-Truiden and Metz" states Michel Becker, CEO of Punch Powertrain PSA e-Transmissions. "Furthermore, we are utmost grateful for the strong collaboration within our intricate supply chain and the unwavering support of the local and national authorities, all of which contributed to our success. We look forward to ramping up the production to full capacity in the next year, bringing a robust and highly compact transmission to our roads."

The DT2 hybrid transmission is one of the most significant technologies to be realized by Punch Powertrain. Alongside Punch Powertrain's EV product suite, it demonstrates the company's transition from conventional (CVTs) to electrified and electric transmission systems and an important step forward in green technology deployable at scale. This hybrid dual-clutch transmission also signifies growth in European and global markets for the company, as with DT2 it is poised to become the largest Tier 1 supplier of hybrid DCTs worldwide by 2025.

As recently announced by Stellantis, the CO^2 emissions-reducing 48 V variant

of the eDCT will be offered within a few weeks on the Peugeot 3008 and 5008, before gradually being fitted to other Stellantis brand vehicles in Europe.

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Forest City Gear

EXPANDS CYLINDRICAL GEAR GRINDING CAPACITY

Forest City Gear has expanded its capacity for the grinding of high-precision internal and external gears with the addition of two Kellenberger K100 cylindrical grinders.

These machines will support the growing capabilities Forest City Gear offers customers with complex OD (outside diameter) and ID (inside diameter) grinding requirements. The first machine is a Universal capacity, with ID capability utilizing 1000mm capacity between centers for longer shafts or deep ID requirements. The Universal machine also has nonround grinding capability, making it ideal for grinding hexagonal and square gears as well as micron accuracy.

The second machine, 600 mm between centers, is focused on cylindrical OD grinding. Both machines are fully equipped with auto part sizing equipment, active and passive flagging, and roll dressing capability.

"With the addition of these two machines, we are looking forward to having the capacity to improve throughout—along with the efficiency advantages that are found with such an upgrade," said Jared Lyford, Director of Operations. "Forest City Gear is dedicated to investing in the best equipment with the most capabilities available, to consistently offer more value to our customers."

forestcitygear.com

West Ohio Tool

EXPANDS OPPORTUNITIES WITH WBE CERTIFICATION

West Ohio Tool, one of America's leading manufacturers of custom-designed carbide, polycrystalline diamond (PCD) and cubic boron nitride (CBN) tooling, continues its growth and market expansion with the acquisition of several certifications that benefit women-owned businesses.

West Ohio Tool is now a certified Women-Owned Business Enterprise (WBE) for the state of Ohio, which expands opportunities in obtaining contracts for goods and services, construction, engineering, IT, professional services and other sectors. The program also provides access to favorable capital financing for growth opportunities such as the company's planned purchase of a new Electrical Discharge Machining (EDM) erosion machine.

Additional women-owned business recognitions are pending that will further increase West Ohio Tool's entry to broader markets. The Women's Business Enterprise National Council (WBENC) and Women-owned Small Business (WOSB) certifications will enhance access to Department of Defense and federal contracting opportunities, which the company expects to finalize this summer.

West Ohio Tool CEO Kaci King has previously established herself as one of Ohio's leading businesswomen. In 2022, "Ohio Business" magazine included King in its "Ohio 500" list, which recognizes the most influential Buckeyes contributing to Ohio's future growth. She has been featured on the cover of WomLEAD magazine and recognized as one of the Top 25 Female Influencers of 2022, then as a Top 5 Female Influencer of 2023. King also served as a panelist for the publication's 2023 "She's Possible" event celebrating female entrepreneurship and achievement. Last fall, West Ohio Tool was a sponsor for Women in Manufacturing's (WiM) National Summit in Atlanta.

Kaci King

Since its inception in 1989, West Ohio Tool has grown from a regional custom tool maker to a national tool manufacturer and service provider for a variety of industrial sectors. In 2022, the company had sales in 28 states, and based on first-quarter 2023 figures, it is on track to have the best year in its 33-year history, King said.

westohiotool.com

EMAG

ANNOUNCES NEW CEO

Dr. Heinz-Jürgen Prokop handed over the CEO position to Markus Clement on April 1, 2023.

"My mandate was to lead EMAG until a long-term and forward-looking appointment is found for this responsible position. Markus Clement and I made contact very early on and discussed future opportunities. A good working relationship quickly developed. With Markus Clement, EMAG is now fortunate to have a CEO who knows the company and its business very well, who has proven with his success in China that he can lead EMAG and whom the employees trust," said Dr. Prokop about the personnel change.

Clement can look back on a successful career in the EMAG Group and has held many positions of responsibility in the group over the past 24 years. He started his career in the service division, where he worked for over six years. This was followed by positions in production management, engineering and customizing including twelve years of experience at EMAG China. Most recently, Clement served as CEO of EMAG China.

"I am looking forward to this new challenge, because EMAG is a great company and I can see many positive development opportunities in the interest of our customers. I am certain that with the new product and technology developments as well as the extremely committed employees, the EMAG Group has the right solutions on offer for the demands of the future in the field of productive precision manufacturing," Clement said.

Dr. Prokop will continue to serve as a consultant on innovation and technology topics. The EMAG Group would like to thank Dr. Prokop for his commitment and dedication during an important phase for the company. The EMAG Group wishes Clement every success in his new, responsible role.

emag.com

Weiler Abrasives

INTRODUCES KEY USER PROGRAM

Weiler Abrasives has expanded the focus of its end-user support programs, broadening its workforce to help end users better meet their surface finishing challenges.

The Key User Program will provide end users in such target markets as foundry, shipbuilding, metal fabrication,

primary metals and precision manufacturing with direct technical expertise and support at their locations. These end users may face challenges related to labor constraints, supply chain issues, productivity, costs and safety. Weiler Abrasives technical specialists and district sales managers are available for on-site assessments, where they will study the entire process and total cost of ownership—not just the abrasive products being used—to deliver solutions.

"Weiler Abrasives aims to be the best partner to our end users and distributors. We work to understand their biggest challenges and then apply our expertise to solve them," says Bill Dwyre, vice president, Global Sales and Marketing. "To that end, we're investing more in people, processes and technology with the ultimate goal of delivering greater value to our end-user customers."

Weiler Abrasives has added staff to support the Key User Program, including two new technical sales managers who bring extensive abrasives knowledge and experience. In addition, John Sockman has been appointed as director of End User Sales to lead and manage the Key User Program.

Among the resources the technical sales managers and district sales managers will offer are three existing Weiler Abrasives programs: the Weiler Consumable Productivity (WCP), the SPOT Safety Training and Weiler Process Solutions (WPS). The WCP program tests and evaluates abrasives to compare product life, reduce cycle times and increase efficiencies. The SPOT program educates end users how to use abrasives safely and effectively, covering proper usage, potential hazards and safety tips. The WPS program focuses on providing industrial grinding and automated deburring solutions to alleviate bottlenecks in high-volume production operations.

Weiler Abrasive's distribution partners will continue to be an important piece of the overall value chain and end-user experience. The Key User Program investments will help distributors bring added value to Weiler Abrasives end users and provide opportunities for mutual business growth.

weilerabrasives.com

Mazak's

DAN JANKA BRINGS A LIFETIME OF MANUFACTURING EXPERIENCE TO AMT CHAIRMAN POSITION

With experience in the manufacturing industry dating back to the age of 13, Mazak President Dan Janka once again has accepted the position of chairman of the board of The Association of Manufacturing Technology (AMT). Janka, an AMT member since 2005, last served as chairman in 2010. He retired from the board in 2013, but remained an active committee member and attended the association's forecasting conferences.

Janka's first exposure to manufacturing came on milling and turning machines in his father's basement hobby machine shop. In high school, Janka opted for a vocational path, attending classes during the first half of each day and working in a machine shop the second half. After graduation, he attended Illinois Valley Community College, where he received an associate degree in mechanical technology.

In the early 1980s, Janka put himself through a four-year college degree program while still running NC machines, welding and performing other tasks at a machine shop. He graduated from Southern Illinois University with a bachelor's degree in industrial engineering and technology. With his combined degrees, Janka originally was hired into the machine tool industry in 1984 as a software systems developer and analyst. In this initial position, he developed post processors for 5 to 11-axis CNC machines, one of which was a composites tape layer machine that produced wings and structures for the US B-2 Bomber.

His extensive manufacturing education and work experience primed Janka for numerous executive positions in the machine tool industry, and in 2016, he became President of Mazak.

The AMT approached Janka in 2021 about accepting the chairman position again. "I was a bit hesitant," said Janka, "mainly because, my position at Mazak is my top priority and main commitment. However, I felt that serving on the AMT board again is a way for Mazak and myself to give back to the industry that I've been in basically my entire life. And, like me, AMT is a steadfast advocate for manufacturing."

According to Janka, the AMT is critical to US industry. They are a staunch promoter of manufacturing and provide critical services, including the best manufacturing market data and information of any association, in addition to their ownership of IMTS, the industry's leading manufacturing and technology show.

Janka added that the AMT also helps drive and accelerate the adoption of new technologies, and with events such as IMTS, it creates an environment in which to promote and display those technologies. Additionally, as a champion of software and digital technology manufacturing solutions, the AMT initially created and funded the development of MT Connect. The protocol now is an industry standard that allows manufacturing assets to communicate with one another on the shop floor to facilitate process monitoring.

"I'm 100 percent behind 'made in the USA,' and manufacturing in this country is my passion," said Janka. "With that, my goal throughout my career has been to help promote and develop the next generation of young engineers and manufacturers. And my position as the AMT chairman is an effective means toward that goal."

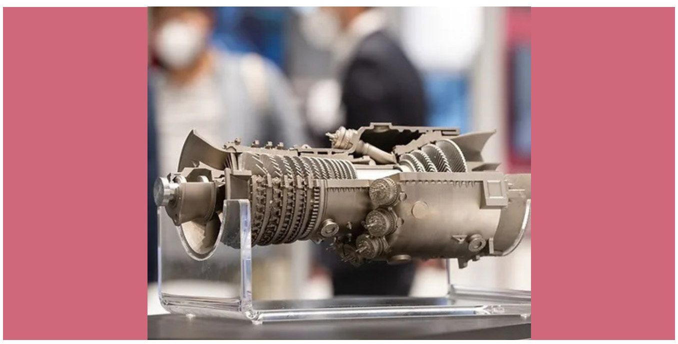
mazakusa.com

July 31–August 3—Reliable Plant 2023

This three-day event (Orlando) offers attendees learning sessions and case studies on the latest industrial lubrication and oil analysis technologies. The comprehensive conference schedule covers every facet of the machinery lubrication industry and includes workshops on topics such as employee performance, lubrication fundamentals, condition-based maintenance, and maintenance planning. Reliable Plant is focused on both entry level and management positions within the lubrication industry including engineers, plant managers, maintenance professionals, safety personnel, planners, quality managers and more.

geartechnology.com/events/5068-reliable-plant-2023

August 28–30—Formnext Forum: Austin 2023



Formnext Forum: Austin is the first in a series of events to drive industrial 3D printing innovation and growth in the Americas. Hosted in one of the world's most tech-forward manufacturing communities, Formnext Forum: Austin, will connect leaders from across the industrial additive manufacturing supply chain. The program includes technical sessions examining design, material, machinery, and applications technology used in additive manufacturing. Topics include application success stories, unique applications, software, design, organizational changes and more. Technical presenters include thought leaders from OEMs, leading additive manufacturing job shops, machinery suppliers and cutting-edge research outfits.

geartechnology.com/events/5074-formnext-forum-austin

September 11–14—Fabtech 2023

Fabtech returns to McCormick Place in Chicago for North America's largest metal forming, fabricating, welding, and finishing trade show. Fabtech provides a convenient 'one-stop shop' venue where you can meet with 1,300+ suppliers, discover innovative solutions, and find the tools to improve productivity and increase profits. There is no better opportunity to network, share knowledge and explore the latest technology. Gain insights into industry trends that will help you prepare for what's ahead, all here in one place. The Fabtech Conference combines 60–90 minutes sessions and workshops covering the latest in advanced fabrication technology, workforce, and management topics. Pick and choose the sessions right for you and build an agenda to provide the key insights and solutions to all your manufacturing and production challenges.

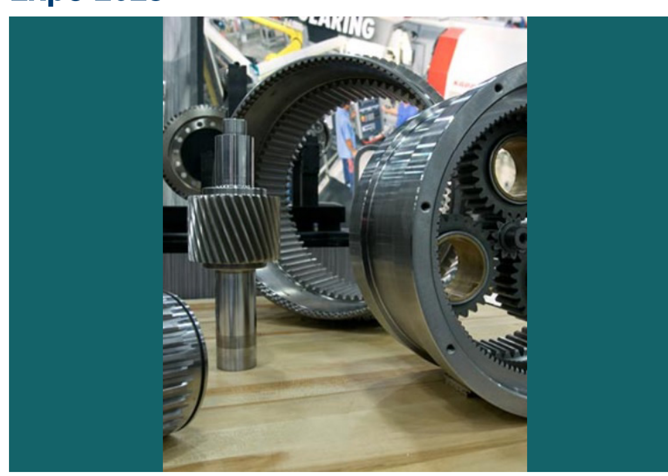
geartechnology.com/events/5075-fabtech-2023

September 18–23—EMO Hannover 2023

The discussions between manufacturing experts at EMO Hannover 2023 will revolve around three main future insights. The future of business will explore Work 4.0, new financing solutions, sales models, and markets. The future of connectivity will delve into the potential of smart production, the IoT and AI. It will be beneficial for smaller companies, as the new technologies create additional perspectives for them. The future of sustainability in production will address the developments related to alternative drives, energy efficiency and, of course, sustainable production. Learn more here:

geartechnology.com/events/5071-emo-hannover-2023

October 17–19—Motion + Power Technology Expo 2023



Produced by AGMA, Motion + Power Technology Expo (Detroit) is a three-day show that connects professionals looking for motion power solutions with manufacturers, suppliers, and buyers. Attendees will find new power transmission parts, materials, and manufacturing processes. Buy, sell, and get business done with organizations in aerospace, automotive, agricultural, energy, construction and more. Hundreds of exhibitors and attendees means MPT Expo is a unique opportunity to find partners that can help fulfill your specific production needs. The show is colocated with Heat Treat 2023 and IMAT 2023.

geartechnology.com/events/5076-motion-power-technology-expo-2023

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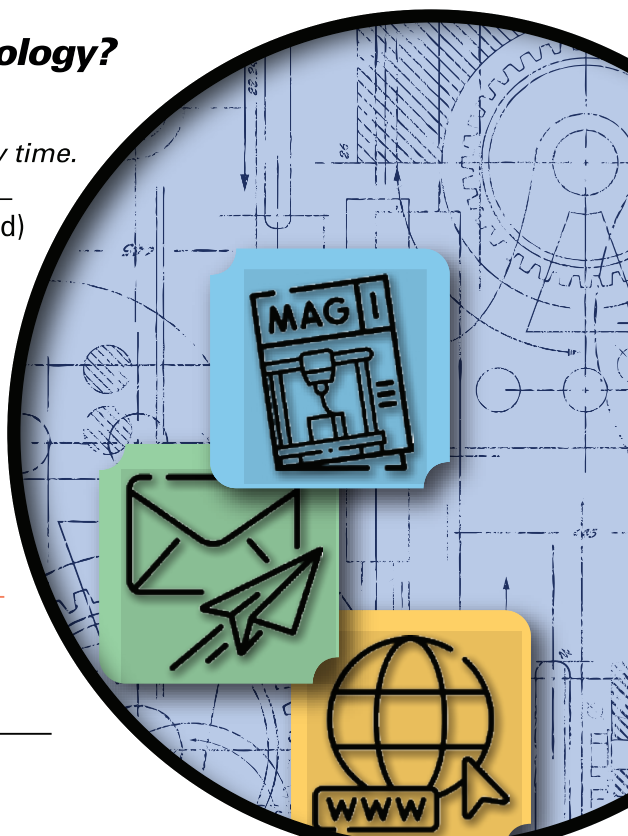

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The Mystery of Diesel Lost at Sea

A new historical novel examines Rudolf Diesel

Aaron Fagan, Senior Editor

Gear Technology readers know diesel—because of the fuel's properties, such as viscosity, lubricity, and combustion characteristics—can influence the design considerations for gears within the diesel engine. Diesel engines are known for their high torque output, especially at low engine speeds. Gears in diesel engines must be designed to handle the higher torque loads and transmit power efficiently without excessive wear or failure. The profiles, size, materials, and overall strength should be appropriately specified to withstand the specific torque and load characteristics of diesel engines.

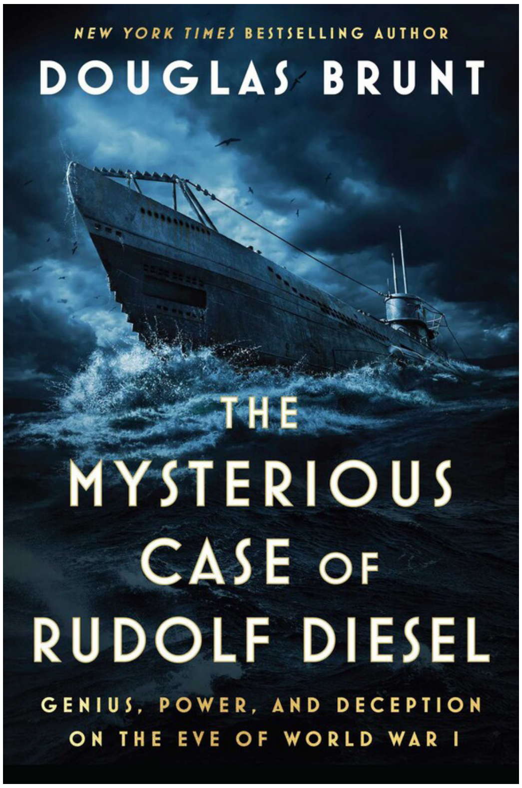
What our readers might not know is on September 30, 1913, *The New York Times* led with a headline that Rudolf Diesel—multimillionaire inventor of the diesel engine and international superstar in the scientific community—had disappeared from the passenger steamship, *Dresden,* crossing from Belgium to England and was presumed dead. In addition to building the world's most prominent ICE, Diesel is credited with inventing—no joke—the ice cube. While living in France and working for Carl von Linde, the pioneer of refrigeration, France awarded Diesel the patent for *carafes frappes transparentes* (bottled clear ice) on September 24, 1881.

At the time of his disappearance, his invention—the diesel engine—was in the process of transforming almost every aspect of industry and transportation around the world. First publicly presented in Kassel, Germany on June 16, 1897; the diesel engine was vastly more efficient than the steam engine. Diesel's initial vision for the engine was to alleviate the appalling working conditions of the Industrial Revolution by offering a new power source that was far more efficient, produced far less pollution, and could burn a range of substances for fuel—including vegetable and nut oils that all countries could produce domestically so as not be beholden to petroleum monopolies.

Fast forward to preparing for this piece, a banner ad appeared above the *New York Times* homepage for a major fuel company that promoted those precise benefits of diesel. Diesel remarked to the American press in 1912 that he would like to see the diesel engine power the entire American railroad system while using only butter for fuel, "If you would kindly lend me the butter."

The contributions of Diesel and his engine are among the most underappreciated of the last hundred years. For example, the *MS Selandia,* "the ship that changed the world," of the Danish East Asiatic Company, begins her maiden voyage on February 22, 1912, considered the most advanced ocean-going diesel motor ship of her time. Not only did the diesel engine enable the submarine in both world wars (the submarine was previously an ineffective vessel without diesel), but it has also powered every train, truck, cargo ship, and piece of heavy equipment throughout the 20th century.

The diesel engine came to prominence at the height of European militarism and the Anglo-German naval arms race. Virtually every Allied naval vessel used in the D-Day invasion had a diesel engine. The engine delivered enormous military advantages, but expertise with the nascent technology was limited to very few engineers. Today, the diesel engine—largely unchanged from Diesel's own original design—continues to power almost every form of transportation in the world.



So, what happened to the man behind the machine? *New York Times* bestselling author and historian Douglas Brunt reopens the hundred-year-old mystery of what became of Rudolf Diesel in his new book *The Mysterious Case of Rudolf Diesel: Genius, Power, and Deception on the Eve of World War 1* (Atria Books, forthcoming September 19, 2023). Though there was an initial storm of media reporting about Rudolf Diesel's disappearance in 1913, this book examines previously unexamined evidence and includes the consultation of police detectives and former members of the OSS (Office of Strategic Services, now known as the CIA) and UK Special Forces. Brunt skillfully weaves history with intrigue while presenting a new theory on Diesel lost at sea.

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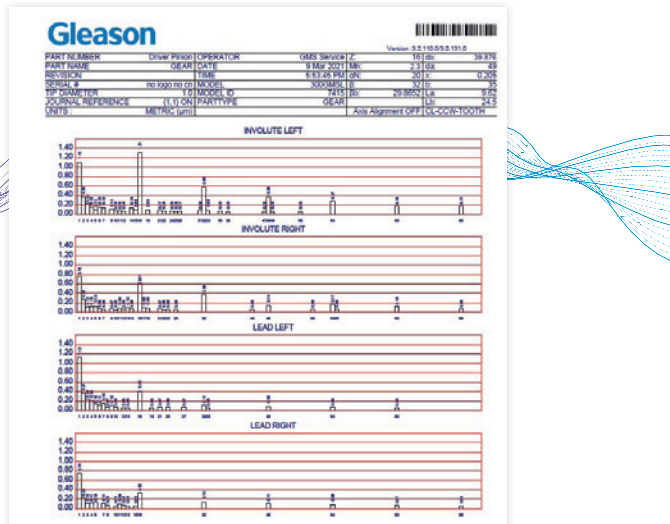

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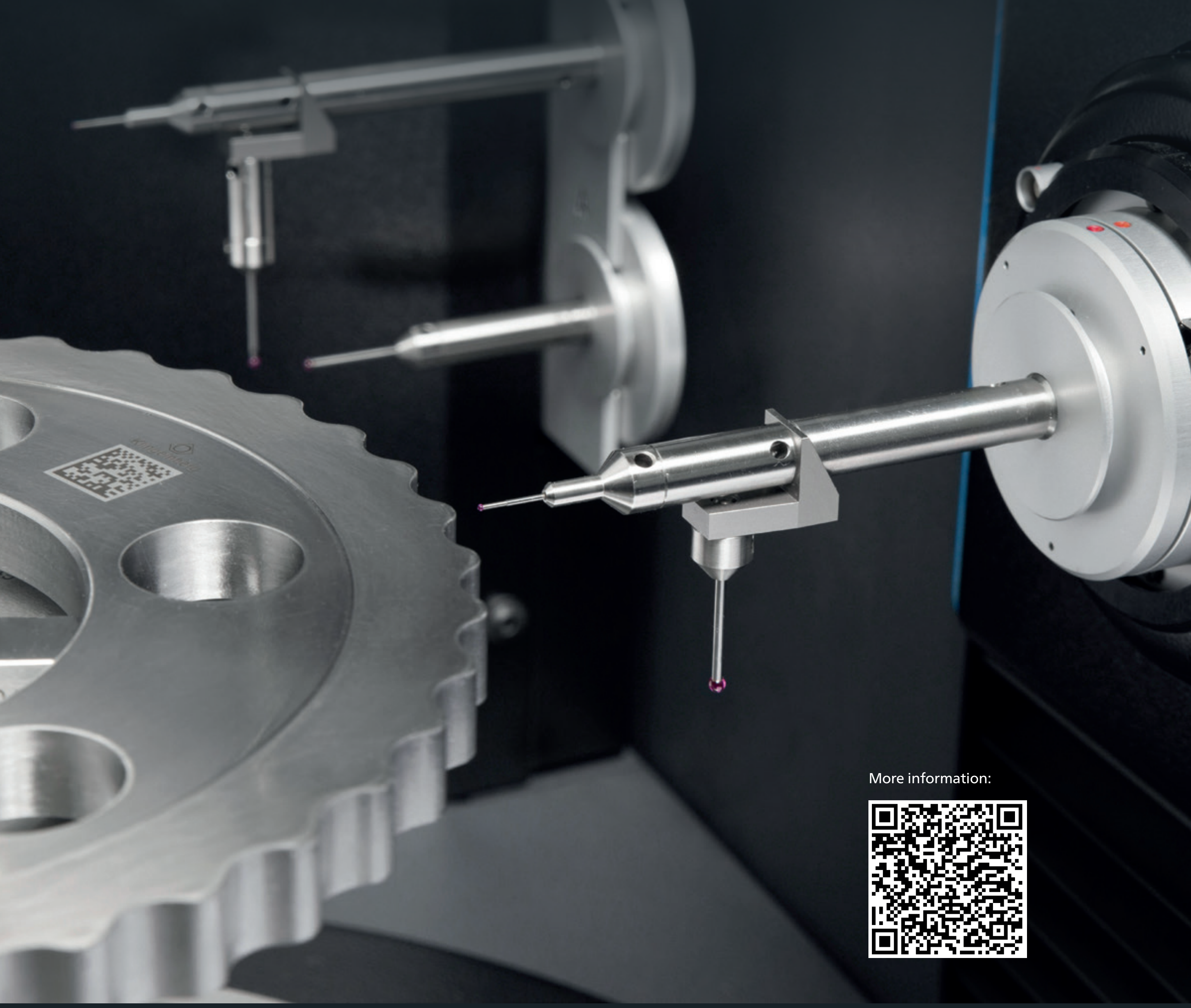

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