ISSUE FOCUS

Motion + Power Technology Expo Preview

FINITE ELEMENT ANALYSIS FOR STRAIN WAVE GEAR TOOTH SURFACES DESIGN AND MODIFICATION

COMPANY PROFILE

JTEKT TOYODA AMERICAS CORPORATION
New gear skiving machine LK 300-500
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APPLICATION OF FINITE ELEMENT ANALYSIS FOR THE STRAIN WAVE GEAR TOOTH SURFACES DESIGN AND MODIFICATION

The gear industry has a well-established gearing theory, design code, and design simulation software to improve gear-transmission performance; however, the lack of similar tools restrains the development of the strain wave gear.

By DR. ZHIYUAN YU AND DR. KWUN-LON TING

METHODS TO DETERMINE FORM DIAMETER ON HOBBED EXTERNAL INVOLUTE GEARS

To assist gear designers to instantly verify the manufacturability of their designs, two methods are presented to calculate the manufactured form diameter given the design parameters of the gear and the hob.

By SHUO “WILL” ZHANG

MACHINES IN STOCK, READY FOR DELIVERY

COMPANY PROFILE For more than 70 years, JTEKT Toyoda Americas Corporation has been a world leader in machine-tool manufacturing that includes its roots in grinding machines to the advanced capabilities of its gear-skiving innovations.

By KENNETH CARTER
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VIBRATORY MEDIA COMPOSITION VS. ATTRITION AND DENSITY

Media content is based on the gear finish desired. High abrasive/low ceramic media leads to higher attrition rate; low abrasive/more ceramic causes less attrition, higher quality Ra surface value.

BRIAN DENGEL

WHAT IS A GEAR ENGINEER?

Skilled engineers design single- and multi-stage gear trains by relying on purpose and application to generate the proper power.

D. SCOTT MACKENZIE

RECLAMATION AND RECYCLING OF QUENCH OIL

The basic process of treating and reusing oil is uncomplicated and leads to cost savings.

American Gear Manufacturers Association

In this section, the premier supporter of gear manufacturing in the United States and beyond shares news of the organization’s activities, upcoming educational and training opportunities, technical meetings and seminars, standards development, and the actions of AGMA councils and committees.

October 2017 — Volume 16, Number 10

Affolter Group: Four generations, 100 years of know-how.

Latest Helios Gear manufacturing solutions to be on display.

NEW PRODUCTS, TRENDS, SERVICES, AND DEVELOPMENTS IN THE GEAR INDUSTRY.

Cover photo: Harmonic Drive LLC

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An expo name change means bigger + better things

No doubt you’ve been hearing about the biggest industry tech show of the year. Gear Solutions has been promoting it for many months now, and we’re all excited that it’s almost here. This year, the former Gear Expo comes with an expansion and a name change: the Motion + Power Technology Expo. It will light up the Cobo Center in Detroit, Michigan, October 15–17. We’re all looking forward to checking out the Expo, as well as the Motor City.

With this year’s expanded show, top manufacturers, suppliers, buyers, and experts in the mechanical- and gear-power, electric-power, and, for the first time, fluid-power industries will be able to connect. No matter your industry, you will gain best practices and new ideas from like-minded colleagues as well as cross-sector collaboration.

Along with this unique opportunity to collaborate, end-users can shop the latest technology, gear products, and services, and compare benefits side-by-side. Prominent exhibitors will conduct demos and host information-rich seminars as well as offer their valuable technical expertise.

I, too, am looking forward to reconnecting with industry experts, officials, and movers and shakers, as well as meeting new friends who are looking for a forum to share their gear knowledge with the industry. That’s what Gear Solutions is for, and I will be at the show to find just the right spot for your subject, whether that’s a submitted article, company profile, or Q&A.

That being said, consider this issue of Gear Solutions a bit of a primer for the MPT Expo with a range of industry news and articles to help get you in the mood for Detroit.

In our Focus section, we present two highly informative articles:

In the first, Dr. Zhiyuan Yu and Dr. Kwun-Lon Ting discuss the application of finite element analysis for the strain wave gear tooth surfaces design and modification.

Next, Shuo Zhang takes on the methods to determine form diameter on hobbed external involute gears.

Additionally, we’ve expanded our monthly Q&A feature to give a shout out to several companies that are exhibiting at the show. Take a look at what they will have on display and be sure and stop by their booths for more information about what they’re offering the gear-manufacturing industry.

So enjoy this MPT Expo preview, and stop by our booth (#4036) and introduce yourself. I’d love to shake your hand and talk about how Gear Solutions can help you share your message.

Thanks for reading!

KENNETH CARTER, editor
editor@gearsolutions.com
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Affolter Group:
Four generations,
100 years of know-how

In 1919, Louis Affolter, the second child of watchmakers Samuel and Marie-Louise Affolter, founded his own company and started to produce gears and pivots for the Swiss watch manufacturers in the area. 100 years later, nine Affolter family members work in the high-tech enterprise Affolter Group and its daughter companies Affolter Technologies and Affolter Pignons.

The 100-year history of the family enterprise was filled with technological innovations. After Louis established the enterprise, the second generation – his sons André, René and Marc – developed the business further and built the first industrial premises. In the third generation, led by Jean-Claude, Michel, and Marc-Alain Affolter, the company underwent a rapid modernization process. Electronics and high-tech equipment helped to improve the production processes.

Based on its innovative power, the Affolter Group expanded, diversified, and grew. In 1980, a mere 15 employees worked on a workspace of 5,400-square-feet. Today, the company has 140 dedicated employees, 15 apprentices, and four buildings with an overall workspace of 86,000 square feet. The fourth generation, led by Grégory and Vincent Affolter, as well as Nicolas Curty, oversees the continued expansion and diversification of the Affolter Group, including the founding of Affolter China in 2013 — a milestone for the enterprise.

The two main business lines of the Affolter Group are the contract manufacturing of gear trains for the gear trains industry and the development, manufacturing, and marketing of machine tools and numerical controls.

Affolter Pignons is specialized on the manufacturing of gear trains for the Swiss watchmaking industry. For 100 years, the company has reinforced its position as a leading expert in the art of force transmission. Through automation, Affolter Pignons was able to realize the mass-production of top-quality, high-precision gear trains.

“In a partnership with Affolter Technologies, we also develop our own machines. Together with our experience and know-how, that enabled us to grow quickly. We aim to continue this growth strategy,” said Grégory Affolter, managing director of Affolter Pignons.

Affolter Technologies specializes in the design, manufacturing, and commissioning of numerical control gear hobbing machines for microtechnology gears. “Through the decades, we were always dedicated to be a technology and innovation leader in the field of micro gear hobbing, aiming to make our customers more productive and efficient,” said Vincent Affolter, managing director of Affolter Technologies. That is why the company invests in R&D.

“Robots, machine learning, in-house designed and developed CNC controls, our own software, Industry 4.0 — we embrace the future,” Vincent Affolter said.

The CNC gear hobbing machines of Affolter Technologies are used for the production of microtechnology gears in markets such as watchmaking, micromechanics, automotive, aircraft, robotics, servo motors and dentistry; 80 percent are being exported into the EU, Asia, and U.S.

MORE INFO  www.affoltergroup.ch
Latest Helios Gear manufacturing solutions to be on display at MPT

Helios Gear Products will demonstrate multiple gear manufacturing solutions at the Motion + Power Technology Expo (MPT Expo) October 15–17. Gear manufacturers of both small and large gears can benefit by visiting Helios’ booth #3213 to see the company’s latest machines and tools for hobbing, deburring, grinding, inspection, and more.

Helios equips manufacturers for profitable gear production with solutions such as the Helios Hera series of CNC gear hobbing machines from YG Tech. Hera machines offer several attractive features: Fanuc or Siemens CNC; high-speed hob heads with automatic retraction during power failure; direct-drive torque motors; friendly dialog programming for easy operating and quick training; re-hobbing (skiving); world-class construction and components; compact footprints. Moreover, Helios Hera hobbers make no compromise on quality while offering manufacturers huge savings.

Helios will show the Hera 90 CNC gear hobbing machine. This machine features a unified, versatile gantry automation system for easy and productive hobbing of spur gears, helical gears, and splines. It also features a high-swivel head for worm and thread milling. Manufacturers of parts up to 90 mm (3.543 in) diameter and 3 module (8.5 DP) should visit the Helios booth to see the machine in action.

Gear manufacturers will also see the Hera 350 CNC gear-hobbing machine. With the series’ same high-quality feature set, the Hera 350 enables profitable vertical hobbing of spur gears, helical gears, and other hobbed profiles. The machine is rated at 6 module (4.3 DP) and 350 mm (13.780 in) diameter for automatic loading (additional capacity is available for manually loaded parts).

On display at the MPT Expo will also be the Helios TM 200-R3 gear deburring machine from Tecnomacchine. This machine deburrs parts up to 200 mm (7.874 in) diameter with high-speed tool spindles. With five workstations and a unified, flexible automation system, the TM 200-R3 offers manufacturers a productive brushing, deburring, and/or chamfering solution that enables consistent quality and reclaimed labor. Manufacturers can visit the Helios booth to see this machine produce deburred parts in as little as every 20 seconds.

Lastly, as part of Helios’s partnership with Kapp Technologies, the PGM 165 gear inspection machine will also be demonstrated. This CNC analytical measuring machine can inspect parts up to 180 mm (7.087 in) diameter using Renishaw 3D probe technology and Penta Gear Metrology software.

In addition to machine tools, Helios offers manufacturers cutting and abrasive tools, including hobs, milling cutters, shaper cutters, generating grinding wheels, form
grinding wheels, bevel gear grinding cups, diamond dressing gears, and more. Gear manufacturers can also benefit from Helios’ services, such as gear cutting tool resharpening and recoating, contract inspection, and application engineering.

Gear manufacturers can ask questions and learn from Helios experts on the spot while viewing machines and tools that enable globally competitive production of gears.

MORE INFO  www.heliosgearproducts.com

Emuge Corp. to highlight workholding capabilities at MPT Expo 2019

Emuge Corp. has announced it will be exhibiting at the Motion + Power Technology Expo at Booth #3307 from October 15-17 in Detroit, Michigan. Among Emuge's broad portfolio of rotary cutting tool solutions, Emuge also designs and builds precision clamping devices for specific customer applications. Emuge's workholding division specializes in providing highly accurate, almost maintenance-free customized solutions for applications from low-volume job shops to high-volume automotive production environments.

Due to its interchangeable clamping element designs, Emuge can adapt its installed precision clamping devices to meet new, evolving customer requirements. Adaptable workholding solutions eliminate the need for an entirely new workholding device, saving cost and streamlining the manufacturing process. Attendees can learn more about these adaptable workholding solutions, and discuss any of their custom clamping application needs at the Emuge booth.

“Our workholding group stays close to our customers to learn about their unique challenges and production environments. Doing so helps us develop the best solutions for their applications,” said David Jones, precision workholding product manager, Emuge Corp.

MORE INFO  www.emuge.com

Leaders in industrial process fluids combine to form Quaker Houghton

Quaker Chemical Corporation and Houghton International have combined to create Quaker Houghton (NYSE: KWR), the global leader in industrial process fluids to the primary metals and metalworking markets. Along with the new name, the company revealed a new logo and brand representing the combined companies. The company will continue to be listed on the
New York Stock Exchange and trade under the “KWR” ticker symbol.

The combined $1.6 billion revenue company employs 4,000 associates serving 15,000 customers worldwide. Quaker was founded in 1918 and Houghton in 1865.

“We are rooted in companies commonly acknowledged as authorities in industrial fluids and valued experts in customer processes,” said Michael F. Barry, chairman, chief executive officer, and president of the new company, who previously served Quaker Chemical in similar capacities. “Our similar cultures and values, combined with the talent and resources we bring to Quaker Houghton, create exciting opportunities to deliver innovative solutions that will help our customers’ operations run even more efficiently and effectively.”

The company’s combined breadth of product and service offerings can be found in end-markets such as aerospace, aluminum, automotive, machinery, can manufacturing, industrial parts manufacturing, mining, offshore, steel, and tube and pipe industries.

With its expanded products and services portfolio, the company expects that cross-selling opportunities will facilitate continued above-market growth. Specific products the company offers include metal cutting and forming fluids, corrosion protection fluids, specialty hydraulic fluids, and steel and aluminum rolling oils. In addition, legacy-Houghton customers will benefit from Quaker’s strength in specialty greases, high-pressure die casting, mining specialties, surface treatment and bio-based lubricants, while legacy-Quaker customers will now have access to Houghton’s heat-treatment quenchants, offshore hydraulic fluids, metal finishing products, and a broader metal removal fluids portfolio.

“Our foundation will be the same customer-intimate operating model that has been key to the success of our customers,” Barry said. “Moving forward together, we will draw upon our rich history and shared expertise to enhance our product and service offerings and continue to deliver value-added service expertise to our customers.”

The combination of Quaker Chemical and Houghton International nearly doubles the size of either company with trailing 12-month revenue as of June 30, 2019, of $1.6 billion. For more information regarding historical financial performance of Quaker, Houghton, and pro forma for the combined company, visit www.quakerhoughton.com.

The company expects to achieve significant cost reductions as a result of the combination and has increased its estimate of cost synergies to $60 million from $45 million. The cost synergies are broad-based and are expected to come from three major areas: Asset Optimization (17 percent), Logistics and Procurement (35 percent), and Operational Efficiencies (48 percent). The cost synergies are expected to be fully realized on a run-rate basis by the end of year two; with about $20 million being achieved in year one, about $45 million in year two, and the full $60 million in year three, reflecting 100 percent achievement as the company exits year two. On a calendar year basis, the cost synergies achieved are estimated to be about $5 million in 2019, about $35 million in 2020, about $50 million in 2021, and $60 million in 2022. The company has used a top consulting firm over the past two years to help with its integration planning efforts and they will continue to assist the company during the integration.

In addition to cost synergies, the company expects that its growth strategy will create additional value over time. Revenue-
based synergies, such as cross-selling, will be an important contributor to growth going forward. The legacy product portfolios of both Quaker and Houghton can now be offered to the combined, complementary customer base, where 14,000 of the 15,000 total customers are unique to one company or the other. The company believes the revenue synergies are achievable and will be significant over time, beginning after year one. In the first year, the company’s focus will be to maintain service levels for its customers and ensure no supply chain disruptions, while successfully executing its integration plans. In year two, the revenue synergies will begin to be visible as the company expects to grow above the market by 2 percent to 4 percent as it has in the past.

The company also expects to continue to grow through acquisitions which remain part of its core growth strategy. In the short term, the company will focus on paying down debt, but will continue to consider smaller acquisitions that can create value. Both Quaker and Houghton have long histories of building value through acquisitions.

MORE INFO www.quakerhoughton.com

New Norton gear-grinding platform includes dual-worm wheels

Norton | Saint-Gobain Abrasives, one of the world’s largest abrasives manufacturers, announced the introduction of its new Norton Xtrimium™ range of gear solutions designed for high-performance gear grinding in extreme, tight tolerance environments. The newly structured portfolio of gear grinding products is specifically designed by category to provide higher profile accuracy, supreme form holding, and burn-free grinding in worm, profile, and bevel applications. Highlighting the new range is an innovative dual-worm wheel design that enables two operations in one grinding wheel, substantially saving time and cost.

“In today’s increasingly stringent industry requirements for higher accuracy and improved surface finishes, our new high performance Xtrimium grinding wheels are engineered to deliver the highest quality gear grinding solutions” said Jim Gaffney, senior product manager.

Norton Xtrimium Dual-Worm Grinding Wheels feature a unique design with a high-performance vitrified bond section for grinding and a fine-grit resin section for polishing the gear teeth, enabling one wheel to perform what traditionally required two wheels. Substantial savings in wheel costs and productivity via the elimination of wheel swapping, can be achieved with the Norton design. In addition, improved surface finishes of Rz = 1.0mm and Rpk = 0.05mm, and reduced harmonics (noise) are realized. The Norton Xtrimium Dual-Worm Grinding wheels can also be adapted to existing machines.

The Norton Xtrimium Gear Grinding Platform also covers the whole range of gear grinding processes and leverages the whole spectrum of Norton grains and bond technologies to match each customer’s requirements, whether with:

- Worm Grinding Wheels featuring micro-structured ceramic grain and providing free cutting action and wheel homogeneity, allowing constant performance throughout the wheel thickness for the life of the wheel. Superior grinding rates and increased form holding without burn are achieved with these worm grinding wheels.
- Profile Grinding Wheels, which are ideal for deep profile gear grinding. The wheels feature high porosity and permeability, create exceptionally high material removal rates, and friction-free grinding.
- Bevel Grinding Wheels featuring a highly porous bevel formation for extremely fast, burn-free cutting.

Norton Xtrimium gear grinding wheels will be highlighted at the Motion + Power Technology Expo booth #2607.

MORE INFO www.nortonabrasives.com

GMTA attends technology days hosted by partner BvL in Germany

GMTA (German Machine Tools of America) recently attended a technology days event held by its partner, BvL, a market leader in parts cleaning technology. The technology days were in May at BvL’s Emsburen, Germany, location. The event was attended by many of BvL’s partners from locations.
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What do you take in your coffee?

Calico coatings earns AS9100D and ISO 9001:2015 certifications

Calico Coatings was founded by racers, for racers and they have been an acknowledged competitor of the performance coatings industry for more than 20 years. Calico has taken initiative in improving their coating process. Calico recently earned another competitive advantage by completing all the necessary requirements to receive both the AS9100D and ISO 9001:2015 certifications.

Calico thoroughly recognizes its customers’ business challenges and partners with them to customize coating solutions that meet their particular needs and exceed their expectations. It became certified in these two quality management processes to demonstrate its commitment to providing the highest level of consistency in their coatings.

The ISO 9001 is an international method that sets certain requirements to achieve quality management. Many organizations use this process to reveal their consistency in providing a product of a certain caliber and standard. Calico’s leadership team puts an emphasis on risk-based thinking to enhance the application of the many selections of coatings.

The AS9100D is specific to aerospace and gives entry to worldwide markets, identification of vulnerabilities in the supply chain.
the OASIS database and compatibility with other quality management systems. In the aerospace industry, safety and reliability are of the utmost importance in meeting the standards of the DOD, NASA, and the FAA. By obtaining the AS9100D certification, Calico is reinforcing its commitment to providing customers with the best possible application of its coatings.

With both of these certifications already in use, Calico is able to increase the quality of its coatings and fulfill needs to many of the industries served.

Calico’s knowledge and expertise in performance coating is continuing to progress in several demanding industries including automotive/motorsports, aerospace, the U.S. military, molds and dies, diesel engine, firearms, and others. In these industries where performance is everything, Calico’s coatings provide the needed edge for outstanding results. Calico’s arsenal of coatings that can withstand extreme pressure, reduce friction and wear include DLC, PVD, PECVD, TiN, ceramic, Teflon®, thermal, non-stick dry film lubricants, and more.

MORE INFO  www.calicoatings.com

Weiler Abrasives to show at FABTECH, celebrate anniversary

Weiler Abrasives, a leading provider of abrasives, power brushes, and maintenance products for surface conditioning, will attend FABTECH 2019 in Chicago, November 11-14, to showcase real-life market displays and its latest product offerings in Booth B33031. The company will also feature its 75th anniversary as a prominent theme throughout the booth, which will include an All-Star wall of product launches from recent years. Among the notable products on the All-Star wall are the new Tiger® Pipeliner Grinding Wheels and Tiger Mech Notching Wheels developed specifically for demanding multi-pass welding applications.

Of special interest at the booth will be the latest abrasive offerings, including the All-Star wall, at booth B33031 at FABTECH 2019. (Courtesy: Weiler)
Weiler Abrasives’ diverse portfolio of 6-inch products, including its performance line of Tiger AO, Tiger Zirc, and Tiger Ceramic cutting and grinding wheels and its robust, industry-leading power wire brushes. The company will soon be expanding its 6-inch flap disc product offering to include Tiger X, Tiger Paw™, Wolverine®, and high-density flap discs and will also showcase these abrasives for visitors.

Small-diameter products for high-speed die grinders will be on display, including the Tiger AO, Tiger Zirc, and Tiger Ceramic 2- to 4-inch diameter cutting and snagging wheels introduced earlier this year as a complement to the Wolverine value wheel offering.

Weiler Abrasives experts will be available to answer product and technical questions at the booth.

MORE INFO  weilerabrasives.com

AMPM Conference seeks technical papers on additive manufacturing

The program committee for the Additive Manufacturing with Powder Metallurgy Conference (AMPM2020) has issued a call for papers and posters covering the latest developments in the fast-growing field of metal additive manufacturing (AM).

The AMPM Conference has grown significantly since its debut in 2014 as the only conference focused on metal AM, and this year there will be an entire extra day of technical sessions. This is only the second time that the AMPM Conference will be held with the co-located World Congress on Powder Metallurgy & Particulate Materials (WorldPM2020), and the International Conference on Tungsten, Refractory & Hardmaterials. All three events will be held in Montréal, Canada, June 27–July 1, 2020, at the Montréal Convention Center.

Technical program co-chairmen Matthieu Brochu, McGill University, and Joseph T. Strauss, HJE Company, Inc., request abstracts covering any aspect of metal AM including:
  • Modeling of Materials, Components and Processes.
  • Design of Components.
  • Particulate Production.
  • Build Processes.
  • Sintering.
  • Post-Build Operations.
  • Materials.
  • Materials Properties.
  • Testing and Evaluation.
  • Applications.
  • Management Issues.

“Metal additive manufacturing has returned the powder metallurgy industry to the technology spotlight and refueled interest in our robust industries,” Strauss said. “The depth of the research presented at AMPM conferences aids in advancing the entire industry.”

All topics related to powder metallurgy and particulate materials should be submitted to WorldPM2020.org and tungsten, refractory & hardmaterials topics to Tungsten2020.org.

All three conferences are sponsored by the Metal Powder Industries Federation, the North American trade association representing the powder metallurgy industry, and its affiliate APMI International.

The abstract submission deadline is November 15, 2019.

MORE INFO  www.ampm2020.org

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**KISSsoft feasibility assessment for power skiving**

As a part of Gleason, there is a strong partner behind the company when it comes to specific manufacturing know-how. For example, KISSsoft can now evaluate the feasibility for power skiving (module ZA8).

Especially in design solutions where there is little room for tool runout (for example, when the shaft shoulder is very close to the pinion), KISSsoft makes it easy to verify if the skive method is well suited for a particular application.

The most important tool parameter, the number of tool teeth, can be determined automatically. Subsequently, a special report with workpiece and tool data can be generated. This report can be transferred to Gleason when required, making the data exchange between the designer and the tool supplier much easier and less error-prone — all within a holistic working process.

Further highlights will be presented in the near future — follow along via KISSsoft News or on Facebook, LinkedIn or YouTube.

**MORE INFO** www.kisssoft.ch

**Metal Injection Molding Conference calls for presentations**

An official call for presentations has been announced for MIM2020, International Conference on Injection Molding of Metals, Ceramics, and Carbides, to be held March 2-4, 2020, in Irvine, California. Potential authors have until October 4, 2019, to submit presentation abstracts on manufacturing innovations and material advancements. All abstracts accepted for presentation require a PowerPoint submission before the conference.

Innovation is responsible for the rapid growth of the powder injection molding industry (metal injection molding, ceramic injection molding, and cemented carbide injection molding), a nearly $2 billion advanced manufacturing industry. MIM2020, sponsored by the Metal Injection Molding Association, a trade association of Metal Powder Industries Federation and its affiliate APMI International, brings together product designers, engineers, end users, manufacturers, researchers, educators, and students for technology transfer.

**MORE INFO** mim2020.org

**NIST and RadTech announce Roadmapping workshop for October**

The National Institute of Standards and Technology (NIST) and RadTech, the nonprofit industry association for UV+EB photopolymer chemistry are partnering to organize Photopolymer Additive Manufacturing Workshop: Roadmapping a Future for Stereolithography, Inkjet, and Beyond, October 29-30, 2019 at NIST in Boulder, Colorado.

This workshop is the first of its kind for photopolymer additive manufacturing and draws on the experience and future plans of end-users, OEMs, resin suppliers, and researchers, to provide critical insights.

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**a sneak peek**

When you visit Motion & Power Technology Expo (aka Gear Expo) in Detroit, be sure you stop at booth 4439 and see GMTA, a leader in gear machine technology, as well as laser joining and parts washing equipment for the industry.

Say hi to Walter Friedrich and ask him, “OK, Walter, what’s the big secret?”

He might tell you.

If you do broaching, you might want to hear his answer.

See you in the Motor City!
FELLOWS 20-8 GEAR SHAPERS
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and perspectives on current capabilities, challenges, priority R&D needs, and future opportunities, especially as additive manufacturing innovation accelerates.

NIST has been instrumental in the growth and development of U.S. technologies and this new push into photopolymer additive manufacturing, led by Dr. Jason Killgore and Dr. Callie Higgins, materials research engineers at NIST. This workshop will build on their ground-breaking additive manufacturing and 3D printing work to bring technology leaders together. The meeting agenda targets the definition of state-of-the-art characterization techniques for resins and printers; determining where additive manufacturing technology is heading; and identifying measurement and standards barriers (opportunities) to achieving technology goals. A NIST facility tour to experience their research and resources is also planned. Please mark your calendars to ensure your organization has a “seat at the table,” as NIST, in partnership with RadTech — The Association for UV+EB Technology will post the meeting agenda and registration details in August.

MORE INFO www.radtech.org

Exact Metrology sets out to prove GOM CT scanner’s strengths. (Courtesy: Exact Metrology)

Exact Metrology offers ‘GOM CT Challenge’ to CT scanner market

Exact Metrology, a leading provider of 3D and CT scanning equipment and metrology services, now offers the GOM CT scanner — the most accurate industrial CT scanner currently on the market. The GOM CT scanner offers the highest accuracy and highest resolution of any 225kV system available and Exact Metrology devised the “GOM CT Challenge” to prove this.

“If a company is considering the purchase of a CT scanner, they can call us and validate the suitability, then send us a part. We’ll scan it and send them the images. If they don’t believe the output is superior to other scanners in the 225kV range, we’ll send them $100 ... no strings attached,” said Steve Young, co-president of Exact Metrology.

MORE INFO www.exactmetrology.com/challenge

KISSsoft Highlights

- Intuitive concept design on system level with KISSdesign
- Rolling bearing calculation with connection to SKF cloud
- Contact pattern of asymmetrical gears
- Crossed helical gear with rack
- Feasibility assessment for „Power Skiving”

Free trial version at www.KISSsoft.com

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Wilson Electronics’ new cellular amplifiers first to offer MTT technology

Wilson Electronics, the industry leader in cellular signal booster technology, recently announced the launch of the new WilsonPro Enterprise 1300/1300R and WilsonPro Enterprise 4300/4300R family of cellular amplifiers. Most notably, the Enterprise 1300/1300R and Enterprise 4300/4300R feature the industry’s first foray into Multi-Tower Targeting (MTT) Technology, using its three outdoor-antenna-port configuration to receive cellular signal from multiple cell towers at the same time. The Enterprise 1300/1300R and Enterprise 4300/4300R are also integrated with WilsonPro Cloud remote functionality — enabling users and integrators to remotely manage, monitor, and adjust their cellular amplifiers and receive real-time updates with any mobile device.

As companies abandon landlines and increasingly rely on mobile phones, the need for strong, reliable cellular connectivity has never been more important. Unfortunately, cellular signal can be blocked by environmental factors such as mountains or trees, as well as building materials such as concrete, steel, brick and even LEED-certified windows.

The Enterprise 1300/1300R and Enterprise 4300/4300R solve this problem through the ability to dedicate separate outdoor antennas to specific carriers. This allows a single amplifier to provide the best possible indoor cell coverage in a multi-tower situation. In situations that don’t require multiple outdoor antennas, the Enterprise 1300/1300R and Enterprise 4300/4300R can use “common mode” to maximize indoor cellular connectivity with a single outdoor antenna.

The Enterprise 1300/1300R cellular amplifier has one indoor antenna port to provide up to 40,000 square feet of indoor coverage — making it a perfect solution for mid-sized buildings including restaurants, retailers, multi-dwelling units, and financial institutions. The Enterprise 4300/4300R’s four indoor antenna ports enable it to cover up to 100,000 square feet of indoor coverage, making it ideal for larger commercial buildings, such as hospitals, hotels, warehouses, office buildings, and more. Both the Enterprise 1300/1300R and Enterprise 4300/4300R help ensure that a building’s residents, employees, and visitors can all enjoy strong, reliable cellular signal — keeping them connected when it matters the most. In addition, the Enterprise 1300 and 4300 family of amplifiers are stackable and scalable. By combining amplifiers, installers can configure cellular coverage for in-building areas up to 1 million square feet — depending on the building’s architecture.

“Typical construction materials for mid-sized and large buildings, such as metal and concrete, are notorious for impeding cell signal,” said Bruce Lancaster, CEO of Wilson Electronics. “The Enterprise 1300/1300R and Enterprise 4300/4300R’s multiple outdoor antenna ports provide best-in-class coverage, offering a comprehensive solution for businesses requiring strong cellular connectivity within their buildings.”
making these powerful amplifiers a natural choice for installers and integrators looking to provide reliable cell signal for buildings up to 100,000 square feet.”

Previously, IT experts and department heads needed to be onsite to diagnose any cellular amplifier issues. Leveraging the Enterprise 1300/1300R and Enterprise 4300/4300R’s enhanced cloud capabilities, integrators and building managers can remotely monitor the amplifiers from any mobile device and be immediately notified of any issues, such as system failure, oscillation, or change in signal strength. This also gives them the ability to troubleshoot remotely when necessary. With this feature, the new Enterprise amplifier line provides IT professionals with the necessary data and numbers needed to further justify return on investment (ROI) on infrastructure spend and manage expectations with employees and leadership.

The Enterprise 1300/1300R and Enterprise 4300/4300R each feature a large 4.3-inch LCD touchscreen, which provides an enhanced user experience. In addition, the “R” model of each cellular amplifier designates a rack-mount configuration, while the non-lettered model indicates a wall-mount setup.

The WilsonPro Enterprise 1300/1300R and Enterprise 4300/4300R are available for purchase through authorized WilsonPro distributors and dealers.

MORE INFO  www.wilsonelectronics.com
            www.wilsonpro.com

KISSsoft sets series of events to share knowledge

In the second half of 2019, KISSsoft is offering numerous opportunities to deepen know-how.

Whether in a regular training course, during which users can explore KISSsoft calculation programs according to the appropriate level of knowledge under the guidance of experts and with practical examples — or in one of the web demos, which provide an understanding of a topic such as KISSdesign (in September), or e-Mobility (in November) in a 45-minute form.

KISSsoft set up four speeches at the International Conference on Gears in Garching, Germany, September 18-20. Under the topic, “High Performance Plastic Gears” it compares the strength evaluation of plastic gears in order to create a new international standard. A second paper discusses the layout of profile modifications for symmetric and asymmetric plastic gears. For manufacturing, there is a lecture on the inclusion of manufacturing decisions in the gear design process. And the fourth presentation deals with the derivation of tooth stiffness of asymmetric gears based on loaded tooth contact analysis.

Finally, all are welcome in Switzerland in October to take part in the KUM International 2019, which will be held in English for the first time. On October 23, KISSsoft will be offering lectures by developers on the innovations in KISSsoft and KISSsys as well as contributions from companies such as CNH, Atlas Copco, SKF, Humbel, and others who use KISSsoft calculation programs in their everyday work. There will be a workshop day on October 24, which will conclude the KISSsoft User Meeting.

MORE INFO  www.kisssoft.ch
Leine Linde’s new ESR sensor better measures equipment strain

Leine Linde’s new ESR digital strain sensor is now available to monitor structural health on equipment where needed. Offered in North America through Heidenhain Corporation, it is coupled with an encoder using the digital interface EnDat, and offers significantly higher signal quality, accuracy, and robustness when compared with conventional strain gauges.

To use, simply mount the ESR sensor on any flat surface where load or mechanical forces apply to a body. This new product is available for use on cranes, conveyor belts, bridges, wind-turbine rotor blades, or wherever a load or force needs to be monitored on a mechanical structure. Similar to all other products manufactured by Leine Linde, the ESR-sensor is suitable for use in exposed conditions and harsh environments.

The ESR series is a fatigue-free measurement concept providing high-resolution digital input into a system of choice. It is based on an optical encoder attached on a mechanical measuring arm which connects to the body being monitored. The applied force on the structure is calculated by the subsequent system measured as a position difference by the encoder.

The material in the measuring arm of the sensor unit can be adapted to match the material of the measured body. The purpose is to create a passive temperature compensation and further increase the overall measurement accuracy for those installations where ambient temperatures are fluctuating.

Simplicity during installation and commissioning was one of the driving factors during the product development, and therefore different mounting accessories are available. The sensor can be tailored for a permanent installation or used in temporary measurement campaigns.

The sensor resolution is 0.025 μɛ (μm/m) and has a measuring range of ±5 000 μɛ. The product enclosure is IP66-rated, which means it is dust proof and has protection against powerful jets of water. It is of use in a temperature range from -40°C to 100°C.

Leine Linde is based in Sweden with exclusive North American distribution through Heidenhain Corporation in Schaumburg, Illinois. Leine Linde is well known for offering high quality, robust encoders and system electronics for industrial applications. These encoders are renowned for their accurate performance, durability and resistance to external impact in heavy-duty operations and harsh environments. Leine Linde has a global presence in more than 100 markets on every continent.

MORE INFO  www.heidenhain.us

Senvol president elected chairman of SME’s AM Community Advisors

Senvol President Zach Simkin has been elected to serve as chairman for SME’s Additive Manufacturing (AM) Community. SME’s AM Technical Community Advisors serve as the primary resource for guidance to SME and its members on AM technologies, including materials, processes, industrial base, and workforce. The primary responsibility of the SME AM Advisory Committee is to advise SME on initiatives, activities, policy, and strategy related to AM.

“AM continues to be a major strategic initiative for SME and a vital emerging sector for manufacturing as a whole,” said Suzy Marzano, product development manager at SME who oversees SME’s Technical Communities. “We’re thrilled at Zach’s selection as chairman for the upcoming year; we appreciate his vision and leadership, and

Zach Simkin
we look forward to working with him and the rest of the AM Community Advisors to help further SME’s leadership position in the industry.”

Community Advisors are chosen based on a combination of active industry contributions, reputation and personal commitment to expand the use of AM. Simkin is currently in the third year of a three-year term as an Advisor, and previously served as Vice Chair before being elected chairman.

The role of SME’s AM Community Advisors is to provide timely and expert guidance to SME on AM activities, initiatives, and content to best serve the AM community. The AM Advisors also serve as “faces of the industry” for SME. The advisors represent various stakeholders within the technical community.

Jennifer Fielding, the outgoing chair of SME’s Additive Manufacturing Community Advisors and Section Chief, Composite Performance and Applications Section at Air Force Research Laboratory, said, “I’ve had the pleasure of working with Zach for several years. He is extremely committed to helping the AM industry advance and is a true thought leader in the industry. Under his stewardship, SME’s AM Advisory Committee will continue to pave the way for the industry’s advancement.”

SME promotes advanced manufacturing technology and develops a skilled workforce. Its member-led Additive Manufacturing Community focuses on the technologies and processes that help conceive, test, improve, and manufacture new products to bring them to market faster and most cost effectively.

Buehler partners with Opti-Tech Scientific for metallographic services

Buehler, an ITW Company, announces a partnership with Opti-Tech Scientific, a Toronto-based leading Canadian supplier of scientific equipment, specializing in optical/digital microscopy, metallography and hardness testing. The partnership provides all involved in materials analysis, metallurgy along with Buehler’s Canadian customers local support for their metallograph-
Opti-Tech offers Buehler’s line of full metallography solutions for sample preparation, materials characterization, and hardness testing. Customers will benefit from a team of proven experts in the industry, local sales support, quick service response, and stocked consumables warehouse in the Toronto area for fast fulfillment with first-rate products and service. Opti-Tech has a distribution center in Toronto to ship throughout the Canadian provinces, as well as a sales office in Vancouver.

According to Benjamin Mangrich, Americas commercial director for Buehler, “We are excited to partner with Opti-Tech, an outstanding distributor with in-depth technical knowledge, experienced service team and impeccable standards. The Opti-Tech team is familiar with Buehler products and the unique requirements of Buehler customers. This partnership is a win-win-win for Buehler, our customers, and Opti-Tech.”

Martin Howells, Opti-Tech’s president said, “We are honored to take on the Buehler line of metallographic and Wilson hardness testing products. As a solution-based company, we promise Buehler customers uncompromising support, a dedicated sales team, knowledgeable application specialists, and expert installation, training, and service. Our team includes seasoned professionals in metallography and we look forward to continuing this legacy throughout Canada.”

MORE INFO  www.opti-tech.ca or www.buehler.com

Motch & Eichele becomes exclusive distributor for AIMS Metrology CMMs

Motch & Eichele is the exclusive distributor for AIMS Metrology’s coordinate measuring machines (CMMs) for the territories of Ohio, Kentucky, and western Pennsylvania. AIMS products will include the laboratory-grade Revolution Series LM equipped with Renishaw’s 5-axis REVO 2 scanning head and SFP2 probe and the Revolution Series HB, the industry’s only mobile 5-axis CMM, built and designed with Renishaw’s PH20 5-axis touch trigger system. Motch & Eichele will also offer AIMS’ Renishaw Equator 300 gauging system for manual and automated applications.

As part of the HEH Group, the Cuyahoga Falls, Ohio, based distributor of machine tools and metrology products will work closely with AIMS to provide installation, calibration, repair, warranty service, and support to fabricators and job shops.

“We value the relationships we have built with our customers and OEMs,” said Motch & Eichele President Willie Eichele. “That is why we represent manufacturers that are committed to providing customers with reliable, accurate, robust equipment that can support today’s smart factories and job shops. We’re also driven by customer service and quick response times whether it’s small fabricator or a large manufacturer. AIMS shares these values and is a respected brand in the CMM marketplace.”

Motch & Eichele has more than 30 years of field experience and knowledge in the machining industry. With the addition of AIMS, the company is expanding its metrology division to help manufacturers reduce scrap and improve parts accuracy. Adam Miller will lead the company’s expansion team. He has 25 years of experience of experience in the metrology industry.

MORE INFO  www.mande.com
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Expanded MPT Expo offers both new and familiar events

The only constant in life is change. The power transmission industry has the potential to see tremendous change over the next decade — with 3D printing, electric drives, new materials, and other innovations advancing manufacturing in new ways. Over the past two years, AGMA's board, committees, and staff have been exploring ways to ensure that the industry and the association are at the forefront of the new technologies, and next month at the Motion + Power Technology Expo, you'll be able to see all of this on display at one time and in one place.

From October 15-17, Detroit will host more than 250 exhibitors at the MPT Expo displaying everything from the latest in machine tools to mechanical and electric drives, materials and forgings to heat treating. New this year, the National Fluid Power Association is a partner with AGMA and ASM International in the expo, bringing 25 fluid-power exhibitors for attendees to explore.

For the first time, AGMA and NFPA are hosting a new conference, showcasing 16 industry leaders in all aspects of power transmission and manufacturing challenges. The MPT Conference allows attendees to focus on either technological concerns such as electrification of trucks, or business needs such as workforce recruitment and supply chain. The topics are wide ranging, covering even blockchain for manufacturing and supply chain issues, in short sessions that get attendees up to speed quickly on a topic and allow plenty of time for discussion with the experts after their presentations.

Beyond the show floor, the inaugural MPT Expo provides attendees with more networking opportunities than ever before. Before the show opens Monday night, everyone is welcome to attend the AGMA Fall Technical Meeting Fun & Games Reception at Punch Bowl Social. Even if you aren’t attending the Fall Technical Meeting, this is a great opportunity to mingle with the best and brightest engineers in the industry, including the 26 presenters at this year’s event and all FTM attendees. On Tuesday night, we continue to the tradition of the on-the-show-floor Welcome Reception, and on Wednesday night, AGMA, NFPA, and ASM have partnered to present “The Heat is On” — a night of networking, food, and entertainment at Waterview Lofts. There are two new networking events this year — one for young professionals on Tuesday night, and a breakfast honoring Women in Manufacturing on Thursday morning. All of these events are designed to help attendees meet new people, interact with experts, and have a bit of fun while in Detroit.

Even while the Motion + Power Technology Expo showcases new technologies and hosts new events, many of the things you’ve come to expect from the former Gear Expo are back as well. On the show floor, the Solutions Center offers free presentations every 30 minutes from exhibitors talking about their latest process and product advancements. Additionally, the AGMA Fall Technical Meeting is again being held in conjunction with the show and will have more than 25 presentations on the latest in gearing and mechanical power transmissions from experts spanning the globe.

While taking in the show floor, there are also many opportunities for education. Twelve education programs from basic to advanced engineering are available during MPT Expo, from gearing experts such as Ray Drago and Mark McVea. For the first time, there are also three seminars from NFPA focusing on fluid power manufacturing for all levels of expertise.

We may have changed the name, but the Motion + Power Technology Expo takes the legacy of Gear Expo’s success and enhances it to embrace the power transmission industry of tomorrow. I hope to see all of you in Detroit next month, so that you, too, can see the best our industry has to offer.
AGMA’s Fall Technical Meeting

Take a deep dive into the gear industry at AGMA’s Fall Technical Meeting. This meeting brings together top researchers from across the globe who will provide the latest information on their peer-reviewed gear industry research. Network with the industry experts, academics, and engineers; ask your burning questions, and see what is in the future of this industry.

SESSION 1: APPLICATION, DESIGN, AND RATING
- Electric Vehicle Transmissions with Hypoid Gearset (19FTM01)
- Misalignment Compensation Splines Design (19FTM02)
- Spline Centering, Piloting, and Toggle: Torsional Stiffness, Shaft Bending, and Centering of Moment Loads (19FTM03)
- Optimal Polymer Gear Design: Metal-to-Plastic Conversion (19FTM04)
- Design of a Double Spiral Bevel Gearset (19FTM05)
- Specific Dynamic Behavior of Planetary Gears (19FTM06)

SESSION 2: EFFICIENCY, LUBRICATION, NOISE, AND VIBRATION
- Phase Management as a Strategy to Reduce Gear Whine in Idler Gear Sets (19FTM07)
- Leveraging the Complementary Strengths of Orbitless and Planetary Drives (19FTM09)
- Reduction of the Tonality of Gear Noise by Application of Topography Scattering for Ground Bevel Gears (19FTM10)
- Computing Gear Sliding Losses (19FTM11)
- Opportunities of Efficiency Improvement by the Use of Hydro Lubricants (19FTM12)

SESSION 3: MATERIALS AND HEAT TREATMENT
- Evaluation of Steel Cleanliness by Extreme Value Statistics and its Correlation with Fatigue Performance (19FTM13)
- Tooth Root Testing of Steels with High Cleanliness (19FTM14)
- 4D High Pressure Gas Quenching: A Leap in Performance vs. Press Quenching (19FTM15)
- Performance and Properties of New, Alternative Gear Steel (19FTM16)
- Material Properties and Tooth Root Bending Strength of Shot Blasted, Case Carburized Gears with Alternative Microstructures (19FTM18)

SESSION 4: MANUFACTURING, INSPECTION, AND QUALITY CONTROL
- Chamfering of Gears — New Innovative Cutting Solutions for Efficient Gear Production (19FTM20)
- Influence of Manufacturing Variations of Spline Couplings on Gear Root and Contact Stress (19FTM21)
- Micro Skiving — (r)evolution of a Known Production Process (19FTM22)
- Rapid and Precise Manufacturing of Special Involute Gears for Prototype Testing (19FTM23)
- A Comparison of Surface Roughness Measurement Methods for Gear Tooth Working Surfaces (19FTM24)

SESSION 5: OPTIMIZATION, GEAR WEAR, AND FAILURE
- Effects of the Load-Dependent Shift of Gear Center Distance on Calculated Load Capacity and Excitation Using Analytical Mesh Stiffness Approach (19FTM25)
- New Standardized Calculation Method of The Tooth Flank Fracture Load Capacity of Bevel and Hypoid Gears (19FTM27)
- Calculated Scuffing Risk: Correlating AGMA 925-A03, AGMA 6011-J14, and Original MAAG Gear Predictions (19FTM28)
- Optimum Carburized and Hardened Case Depth (19FTM29)
- Sizing of Profile Modifications for Asymmetric Gears (19FTM30)
Upcoming AGMA Courses

**Gear Failure Analysis**

November 6-8, 2019 | St. Louis, Missouri

Explore gear-failure analysis in this hands-on seminar where students not only see slides of failed gears but can hold and examine those same field samples close up. Use of a microscope to examine field samples.

This course is taught at Ranken Technical College. A shuttle bus is available each day to transport students to and from the hotel.

**Epicyclic Gear Systems: Application, Design & Analysis**

December 3-5, 2019 | Seattle, Washington

Learn and define the concept of epicyclic gearing, including some basic history and the differences among simple planetary gear systems, compound planetary gear systems, and star-drive gear systems. Cover concepts on the arrangement of the individual components including the carrier, sun, planet, ring, and star gears and the rigid requirements for the system to perform properly. Critical factors such as load sharing among the planet or star gears, sequential loading, equal planet/star spacing, relations among the numbers of teeth on each element, and the calculation of the maximum and optimum number of planet/star gears for a specific system will be covered. Provides an in-depth discussion of the methodology by which noise and vibration may be optimized for such systems and load sharing guidelines for planet load sharing.

**MPT Expo Show Education**

October 15-17, 2019 | Detroit, Michigan

A great way to attend multiple AGMA classes at once is during our tradeshow in Detroit, Michigan, at the Cobo Center. We are offering half-day and full-day courses that will be taught by gear, fluid power, bearings and supply chain management experts. And, when you sign up for a course, you get a free pass to the tradeshow floor.

**Online Education**

Don’t have the ability to come to one of AGMA's fantastic face-to-face courses? We understand that you are busy and that is why we offer online education to meet your schedule. Now you can grow your gear knowledge, get the same quality AGMA education and save money on travel by learning directly at your own computer.

AGMA's online education courses include:

- Gear Failure Analysis.
- Gearbox CSI: Gears Only.
- Detailed Gear Design–Beyond Simple Service Factors.
- Fundamentals of Gearing.
- Hobbing.
- Parallel Gear Inspection.
### CALENDAR OF EVENTS

Whether you're looking for technical education, networking opportunities, or a way for your voice to be heard in the standards process, AGMA has something to offer you. If you would like more information on any of the following events, visit www.agma.org or send an email to events@agma.org.

<table>
<thead>
<tr>
<th>SEPTEMBER</th>
</tr>
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<tbody>
<tr>
<td>September 11 — Bevel Gearing Committee Meeting — <strong>WebEx</strong></td>
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<tr>
<td>September 17 — Powder Metallurgy Committee — <strong>WebEx</strong></td>
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<td>September 24 — Plastics Committee Meeting — <strong>WebEx</strong></td>
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<td>September 25 — Wormgearing Committee Meeting — <strong>WebEx</strong></td>
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<tr>
<th>OCTOBER</th>
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<tr>
<td>October 14-16 — Fall Technical Meeting — <strong>Detroit, Michigan</strong></td>
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<tr>
<td>October 15-17 — Motion + Power Technology Expo — <strong>Detroit, Michigan</strong></td>
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<td>October 17 — Powder Metallurgy Committee — <strong>Detroit, Michigan</strong></td>
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<td>October 22 — Helical Gear Rating Committee Meeting — <strong>WebEx</strong></td>
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<td>October 24 — Metallurgy and Materials Committee Meeting — <strong>WebEx</strong></td>
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<td>October 30 — Nomenclature Committee Meeting — <strong>WebEx</strong></td>
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<td>October 31 — Gear Accuracy Committee — <strong>WebEx</strong></td>
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<table>
<thead>
<tr>
<th>NOVEMBER</th>
</tr>
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<tbody>
<tr>
<td>November 5 — Wormgearing Committee Meeting — <strong>WebEx</strong></td>
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<tr>
<td>November 6 — Plastics Committee — <strong>WebEx</strong></td>
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<tr>
<td>November 21 — Lubrication Committee Meeting — <strong>WebEx</strong></td>
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**General requests:** webmaster@agma.org  |  **Membership questions:** membership@agma.org  |  **AGMA Foundation:** foundation@agma.org

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Vibratory media composition vs. attrition and density

Media content is based on the gear finish desired. High abrasive/low ceramic media leads to higher attrition rate; low abrasive/more ceramic causes less attrition, higher quality Ra surface value.

The third in our multi-part series on vibratory processing of gears is focused on understanding how media of different compositions have varying attrition rates and densities, and why these are important in vibratory finishing of gears.

**VIBRATORY MEDIA COMPOSITION**

Media, the tool in the vibratory bowl used to improve gear tooth Ra surface quality, is commonly a combination of abrasive grit and ceramic binder. The abrasive, typically aluminum oxide, can vary in grit size — such as choosing sandpaper at your local hardware store. The ceramic binder starts out as clay. Media manufacturers will blend abrasive and clay together in different ratios and use abrasives of different grit sizes to generate a myriad of compositions. The compositions vary according to the task at hand and are kiln-fired after extrusion to convert the clay portion of the composition into ceramic. (Remember taking clay in second-grade art class, shaping it into a pot for Father’s Day, and having it fired in a kiln by the art teacher? It is the same principle.)

Since the ceramic is the portion of the media that acts as a binder, as its percentage of the composition decreases vs. the abrasive content, there is less binding capacity in the composition, resulting in a media having a higher attrition rate. The inverse is true as well. Less abrasive, more ceramic binder yields a lower attrition rate.

**WHAT IS ATTRITION RATE?**

Attrition rate is the rate at which media decomposes during the vibratory run. More abrasive media will have a higher attrition rate, but a higher rate of mechanical surface refinement. Abrasive media is good for rapid, gross metal removal but can easily over-radius sharp edges and thin-out tooth flank addendums. Likewise, it will generate substantial swarf (media sludge), which can be a nuisance to handle after part processing. If high abrasive rate media is chosen to generate a short processing cycle, beware that since it decomposes rapidly, if the size and shape chosen were concomitant with part morphology, the rapidly shrinking media can become a lodging issue. Increasing abrasive content typically generates a less dense media in the range of 80 lbs/ft³.

Low abrasive content media have the opposite characteristics. Low abrasive content media typically has a lower concentration of finer-grained abrasives and produce a much higher quality Ra surface value while having a greatly reduced attrition rate. As such, low abrasive content media maintains its form for a longer period of time, reducing the onset of media lodging issues, and produce much less swarf.

Imagine, if you will, a one-inch cube (one inch in length, width, and height). Now, imagine a half-inch cube. Its linear measurements are exactly half those of the one-inch cube because it measures one half-inch in length, width, and height. However, volumetrically, eight half-inch cubes are contained within one one-inch cube. Let us think about this example from a different angle. If the one-inch cube is a piece of media, by the time it attrits to become a half-inch cube it is not one-half its original volume, it is one-eighth its original volume. In other words, attrition decreases media volume as a mathematical function of its cubed root.

**WHY IS THE DENSITY OF THE MEDIA IMPORTANT?**

Remember vibratory media is the tool that is doing work for you in
As the parts roll in the media mass, the most effective amount of force that can be applied to the part is when the tallest column of media possible is present. It is the weight of the media above the part that is allowing the media to bear across the surface of the part and, when abrasive media is being used, to allow the abrasive to polish the tooth-flank surface. The denser the media composition, the more downward force that can be applied.

The biggest crime that can be committed while vibratory processing is to run too shallow a depth of media. When run in this fashion, applied downward force from the weight of the media depth is reduced, as is the polishing efficiency. Regardless of the vibratory bowl being used, the height of the media at bowl mid-channel should be equivalent to the height of the OD rim. Such a set-up maximizes the positive advantage of force applied by the depth and density of the media.

As an illustrative example, consider a submarine running on the ocean’s surface has little applied water pressure on its hull compared to a submarine running at a depth of 500 feet. Run your vibratory bowl as if the parts are that submarine at a depth of 500 feet. Do not skimp on media volume in the machine.

**WHAT IS HIGH DENSITY NON-ABRASIVE MEDIA, AND WHY IS IT USED IN ISF?**

The beauty of the ISF® Process, isotropic superfinishing, is that a completely non-abrasive media having a density of 125 lbs/ft³ can be used. Such media will produce mirror-reflective, < 4μinch Ra surfaces on hardened carbon steels with an Rc hardness > 40. Since the media has no abrasive characteristics, it cannot improve surface quality in the traditional abrasive polishing fashion.

In the ISF Process, a chemical accelerator is added to the bowl. This chemistry is generally a mild acid that reacts with the steel to generate an incredibly soft conversion coating on the part’s surface. The non-abrasive media improves surface quality by wiping, not mechanically abrading, the conversion coating. Since the coating is formed by reacting with the surface of the parts, the top surface of the part is removed simultaneously. On a microscopic level, the media is tens-of-thousands of times larger than part surface asperities. Therefore, the media cannot reach the soft conversion coating between asperities and the asperities are preferentially leveled. The conversion coating formation and wiping continue throughout the processing cycle to generate the final desired Ra value. A high-density media is favored in this process because, at 125 lbs/ft³, it applies more downward force thereby making the wiping activity more efficient.

**ABOUT THE AUTHOR**

William (Bill) P. Nebiolo received a B.A. from The University of Connecticut and an M.S. in environmental sciences from Long Island University. He has been with REM Surface Engineering since 1989 and currently serves as a sales engineer and as REM’s product manager. Since 1978, Nebiolo has been an active member in the National Association for Surface Finishing (NASF) where he has represented the Connecticut chapter as an NASF national delegate and is the 2010, 2014, and 2015 recipient of the NASF National Award of Merit. From 1996 to 2000, he served as one of SME’s Mass Finishing technical training program instructors. He has published and presented dozens of technical papers and is the author of the SME Mass Finishing Training Book. Nebiolo can be reached at bnebiolo@remchem.com.
What is a gear engineer?

Skilled engineers design single- and multi-stage gear trains by relying on purpose and application to generate the proper power.

When you are a young person, perhaps 4 or 5 years old, someone might ask, “What would you like to be when you grow up?” Many children answer, “a police officer” or “a firefighter” or perhaps their favorite superhero. They identify with a particular profession that they have seen and wish to emulate. If you ask them if they want to be an engineer, they most likely will respond with, “and drive a train?” Although gear engineers do design gear trains, their designs don’t usually help with the daily commute.

Gears cannot work singularly to transmit power. At least two or more gears must be meshed to work. This combination of gears in mesh is called a gear train. Some gear trains are single-stage gear trains and others are multi-stage gear trains.

A pair of meshed gears is the most basic form of a single-stage gear train. In a single-stage gear train, which consists of \( z_1 \) and \( z_2 \) numbers of teeth on the driver and driven gears, and their respective rotations, \( n_1 \) and \( n_2 \). The speed ratio is:

\[
i = \frac{z_2}{z_1} = \frac{n_1}{n_2}
\]

Gear trains can be classified by three types, in accordance with the value of the speed ratio \( i \):

- Speed ratio \( i < 1 \), Increasing: \( n_1 < n_2 \)
- Speed ratio \( i = 1 \), Equal speeds: \( n_1 = n_2 \)
- Speed ratio \( i > 1 \), Reducing: \( n_1 > n_2 \)

Figure 1 shows the various forms of single-stage gear trains.

Figure 2: Rack and pinion.

In this particular example arrangement, we have set \( n_2 = n_3 \). Additionally, this two-stage gear train, as detailed in Figure 3, results in Gear 1 rotating in the same direction as Gear 4.

If Gears 2 and 3 have the same number of teeth, then the train is simplified as shown in Figure 4. In this arrangement, Gear 2 is known as an idler, which has no effect on the speed ratio and the resulting speed ratio is:

\[
i = \frac{z_2}{z_1} \times \frac{z_4}{z_3} = \frac{n_1}{n_2} \times \frac{n_3}{n_4}
\]
Table 1 shows the speed ratio calculations for a basic example of the gears shown in Figure 3.

As detailed in the earlier examples, there are many forms of gear trains. Each has a purpose and each application will dictate what style should be selected. However, none will require the use of an air horn when in operation.

<table>
<thead>
<tr>
<th>No.</th>
<th>Term</th>
<th>Symbols</th>
<th>Formula</th>
<th>Calculation Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No. of Teeth (First Gear)</td>
<td>$z_1, z_2$</td>
<td>$i_1 = \frac{z_2}{z_1}$</td>
<td>Pinion: 10, Gear: 24</td>
</tr>
<tr>
<td>2</td>
<td>No. of Teeth (Second Gear)</td>
<td>$z_3, z_4$</td>
<td>$i_2 = \frac{z_4}{z_3}$</td>
<td>Pinion: 12, Gear: 30</td>
</tr>
<tr>
<td>3</td>
<td>RPM (Gear 1)</td>
<td>$n_1$</td>
<td></td>
<td>Pinion: 1200, Gear: -</td>
</tr>
<tr>
<td>4</td>
<td>Speed ratio (First Stage)</td>
<td>$i_1$</td>
<td></td>
<td>Set Value: 2.4</td>
</tr>
<tr>
<td>5</td>
<td>Speed ratio (Second Stage)</td>
<td>$i_2$</td>
<td></td>
<td>Set Value: 2.5</td>
</tr>
<tr>
<td>6</td>
<td>Final speed ratio</td>
<td>$i$</td>
<td>$i = i_1 \times i_2$</td>
<td>Set Value: 6</td>
</tr>
<tr>
<td>7</td>
<td>RPM (Gear 2 and 3)</td>
<td>$n_2$</td>
<td>$n_2 = \frac{n_1}{i_1}$</td>
<td>Pinion: 500</td>
</tr>
<tr>
<td>8</td>
<td>RPM (Gear 4)</td>
<td>$n_4$</td>
<td>$n_4 = \frac{n_1}{i}$</td>
<td></td>
</tr>
</tbody>
</table>

RPM: Revolution per Minute
Set value here stands for the values pre-designated by the designer.

Table 1: Speed ratio of two-stage gear trains.
Reclamation and recycling of quench oil

The basic process of treating and reusing oil is uncomplicated and leads to cost savings.

Because of the cost, many captive and commercial heat treaters are looking at reclaiming or recycling their quench oil as a method of saving money. In many cases, reclamation or recycling of the quench oil can be done, provided that some simple guidelines are followed. However, should these guidelines not be followed, there is a risk of fire, equipment downtime, and personnel injury.

RECLAMATION AND RECYCLING

There is a subtle difference between reclamation and recycling. From the Merriam-Webster Dictionary, the words are defined in the following manner [1][2]:

re·claim 1 a: to recall from wrong or improper conduct 2 a: to rescue from an undesirable state b: to make available for human use by changing natural conditions 3: to obtain from a waste product or by-product: RECOVER 4 a: to demand or obtain the return of b: to regain possession of

re·cycle: 1: to pass again through a series of changes or treatments: as a: to process (as liquid body waste, glass, or cans) in order to regain material for human use 2: to adapt to a new use: 3: to bring back: REUSE 4: to make ready for reuse

Based on these definitions, there are two primary methods for extending the life of quench oil. The first method is based on preventative maintenance of the oil to clean and filter the oil; while the second method reprocesses the oil to make it fit for use, where it would normally be thrown away.

RECLAMATION OF QUENCH OIL

Reclamation of quench oils can be accomplished continuously or in batch. The basic principles are the same, but the steps necessary are slightly different. This means that the oil is filtered on a regular basis, using a high-quality filtration unit. In continuous reclamation, in-line filtration systems are used to remove soot, particulate, and other debris. The use of other types of filtration media, such as Fuller’s Earth (diatomaceous earth) is used to remove deleterious organic acids. Long oil life can result from quality filtering of quench oil.

This reclamation of quench oil can be done in a continuous fashion, on-site. There are two ways of doing this. First, oil can be continually cleaned to prevent the buildup of soot, scale, and oxidation by products. Using high-quality filtration systems, oil can be maintained in a nearly like-new condition.

Filtration of the oil is usually accomplished using a series of increasingly smaller filtration steps, initially 50 microns to remove the larger particles of scale. The filter size is then progressively reduced to approximately 1 micron. This will remove the largest percentage of soot, scale and oxidation precursors. A typical dispersion of particles in quench oil is shown in Figure 1.

This graph clearly illustrates the importance of very fine filtration of oil. In the case of a 20-micron filter, the filter is only removing no more than 5 percent of the particulate present in the oil. It is only until the oil is filtered to less than 3 microns that half the particulate is removed. It is necessary to filter to below 1-2 microns to achieve a truly clean oil.

One misconception that is often cited for not filtering quench oil, is that very fine filtration will remove the additive package. This is absolutely incorrect. Fine filtration will not remove the additive package as the additive package (speed improvers and anti-oxidants) is in solution with the oil. These types of filtration systems are often set up as a “kidney loop” where the filtration system is separate from the system [4].

As an alternative, oil that is resulting in staining can be collected and placed in a large tank located outside the heat-treating facility. Oil can be filtered on-site, or an outside company can be contracted to clean the oil, and return it to the tank for use. The reclaimed oil is then mixed with the new oil — typically 50/50.

Once the reclaimed oil is completed with filtering, it should be tested to verify that the oil is suitable for use. Testing should include comparative cooling curves, total acid number, viscosity, flashpoint, and water. This testing will determine if any additional additive package is needed. If the oil is mixed 50/50, often no additive package is required.

As a general rule, fine filtering can extend the life of the oil up to double the life as well as increase the service interval by up to 50 percent. Additional benefits include improved surface finish with fewer rejected parts.

RECYCLING QUENCH OIL

Recycling quench oil can reduce quench oil consumption by as much as 75 percent. This is accomplished by careful recovery of quench oil from washers and other sources. Usually, the post-quench washer is used to recover the quench oil for reuse. This washer must only be used to clean parts after the quench and must not be contaminated with other coolants or other contaminants. In this process, the oil is recovered from the post-quench wash and segregated to a separate tank. Once a sufficient quantity of oil is gathered (typically 1,500 gallons or more), then it
is cleaned and recycled in a batch process. Figure 2 shows the typical process for recycling quench oil.

Oil from the washer is recovered by skimmers. This means that the oil skimmers must be in good working order, and that the cleaner used will properly split the oil for recovery. The oil must not be emulsified, as this will reduce the efficiency of the recycling process [5] [6].

The oil is segregated to a separate tank farm, typically outside of the facility. Three tanks are usually used: one for new oil, one tank for recycled oil, and finally, a tank for oil to be recycled. In the bulk tank containing oil to be recycled, the oil is allowed to sit for a period of time until full. Any residual water will split out and settle to the bottom of the tank. An initial draining of the tank to eliminate the gross water collection is performed.

An initial filtration (10-20 μm) through blotter paper to remove water remaining is done, and then the oil is passed through secondary filtration, often with multiple passes, being filtered with progressively lower pore size. Typically filtration down to 1μ can be readily accomplished.

A washing step is sometimes performed to neutralize any residual organic acids and to help remove any of the cleaner soap that has made its way into the oil. Buildup of cleaner in the oil can behave as a speed improver, and result in oil that is too fast and oil that can leave inorganic stains on the part. The buildup of the cleaner can be monitored by the use of AA or ICP [4]. Because of this potential buildup of cleaner in the oil, the amount of recycled oil to new oil is typically limited to 50-75 percent.

After filtration, any residual water is removed by centrifugal separation and vacuum dehydration. The oil is heated to 70°C or so under a vacuum. Water, due to its much higher vapor pressure, will be distilled from the oil. This oil is progressively decanted off.

Once the water is removed and the oil has been filtered, it should be properly tested to make sure that it is suitable for continued use. Testing should include cooling curves and water testing to ensure that the water has been removed.

This batch recycling of the oil can either be done in-house or by contracting an outside firm to perform the recycling of the oil. Typically, when contracting out recycling of oil, it can cost upwards of 25-75 percent of the cost of new oil.

**COST SAVINGS**

One common refrain when discussing filtration, reclamation, and recycling of oil is, “We don’t get paid to filter oil — only to heat treat parts.” Proper filtration can increase the life of the oil by nearly double, so that the interval between oil dumps is halved. This means that the purchase of new oil is reduced, and new purchases of oil are extended over a longer period of time.

With recycling of quench oil, the purchase of new oil can be reduced by up to 75 percent or more, with 50 percent the most common. Between proper reclamation of the oil and recycling of oil from the washers, the total oil consumption can be reduced to 25 percent of operations that do not reclaim and recycle. This is oil that is thrown away and hauled off as hazardous waste that could be used to heat-treat parts. It doesn’t cost to reclaim and recycle oil — it pays for itself in reduced consumption, reduced maintenance, and cleaner parts.

**CONCLUSION**

In this short article, I have illustrated the basic process of reclamation and recycling of oil, and the basic cost savings that can be achieved through proper reclamation and recycling process. Should you have any questions regarding this article, or other articles, please contact the author.

**REFERENCES**


**ABOUT THE AUTHOR**

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APPLICATION OF FINITE ELEMENT ANALYSIS FOR THE STRAIN WAVE GEAR TOOTH SURFACES DESIGN AND MODIFICATION
The gear industry has a well-established gearing theory, design code, and design simulation software to improve gear-transmission performance; however, the lack of similar tools restrains the development of the strain wave gear.

By Dr. ZHIYUAN YU and Dr. KWUN-LON TING

This paper represents the application of finite element analysis for the strain wave gear with modified conjugate tooth surfaces. The unmodified tooth profile is designed at a cross section derived from the fundamental kinematic model of the strain wave gear. The conjugation of the tooth profiles has been verified by the plane stress finite element model. Under nominal load condition, the flexspline has elastic deformation compared with its unloaded shape. The flexspline tooth surface is longitudinally crowned to have a localized contact pattern. Such longitudinal crowning amounts are determined from the deformation of the flexspline in order to avoid assembling interference under no load condition. To analyze the contact pattern under nominal load condition, the finite element model of manufactured tooth surfaces with modification is established. The simulation results show that no severe stress edge contact exists for the modified strain wave gear. And the simulation results are compared with experiments of contact pattern for verification.

INTRODUCTION

Strain Wave Gear is a special type of mechanical gearing system that has unique characteristics compared with cycloidal drives or planetary gears. It has three basic components with advantages of compactness, zero backlash, high precision, and high gear ratio from 30:1 to 320:1. It’s the key component for a robotic arm joint. In recent years, the availability of a robotic arm increases substantially due to its important role in automation, so the high-performance strain wave gear is also needed. The gear industry has a well-established gearing theory, design code, and design simulation software to improve gear-transmission performance. However, the lack of similar tools restrains the development of the strain wave gear. The objectives of this research are as follows:

- Build a finite element model of the strain wave gear assembly with crowned tooth profile.
- Use a plane stress finite element model to verify conjugation of the designed tooth profile.
- Study the deformation of the flexspline compliant cup by finite element analysis, which is used to calculate the lengthwise crowning amount for the hobbing process.
- Study the contact pattern of the finite element model and verify the result by using contact pattern experiment.

KINEMATIC MODEL

The three main components of a strain wave gear are the wave generator, flexspline, and circular spline as shown in Figure 1. The wave generator inserts into the open end of the flexspline cup. The flexspline will deform into an elliptical shape at the open end and keep a circular shape at the other end. The open end of the flexspline cup has teeth on the external surface, and the circular spline is a rigid ring gear. The teeth will mesh between the circular spline and flexspline along the major axis of the ellipse, shown as the roller bearings in Figure 1. The strain wave gear has two degrees of freedom, which is analogous to a planetary gear train. The gear ratio can be calculated from

\[
\frac{\omega_F - \omega_W}{\omega_C - \omega_W} = \frac{N_C}{N_F}
\]

Subscript F, W, and C refer to the flexspline, circular spline, and the wave generator, \( \omega \) is the angular velocity of the component, and N is the number of teeth. For a robot arm joint, the wave generator is driven by the servo motor, and the flexspline and circular spline are connected to the fixed link and moving link. The wave generator and fixed link are two inputs, and the output moving link velocity can be calculated from the above equation.

Unlike a planetary gear train, the flexspline is not a rigid body but a compliant cup with elastic deformation [7, 8]. Teeth on the flexspline have variant instantaneous velocities, which are governed by the shape of the wave generator. The motion of a tooth on the flexspline has a radial displacement, u, circumferential displacement, v, and oscillating angle, \( \phi \) [8]. The theoretical conjugate tooth profiles for the flexspline and circular spline are derived from the following procedure as in reference [7]. Design data for the gear is in Table 1.

- Selecting a wave generator shape solves the motion of a tooth on the flexspline with respect to the circular spline.
- Select a double circular tooth profile [9] for the flexspline and calculate coordinates of points on the profile in the flexspline coordinate. Double circular profile will increase the contact ratio under the motion shown in Figure 2.
- Calculate trajectory of the points under the relative motion between the flexspline and circular spline by coordinate transformation.
- Find the envelope of the trajectory point cloud by using the analytical method [7] or graphical method [9].
- The conjugate profiles are assigned to a cross sec-
tion along the longitudinal direction of the teeth.

Figure 2 shows the motion of one tooth on the flexspline with respect to the circular spline. The conjugate designed cross section will have theoretical conjugation between the circular spline and flexspline. In other words, the two profiles will be perfectly tangential to each other during the meshing process.

PLANE STRESS SIMULATION

To verify the conjugation, a plane stress finite element model is developed by the following procedure:

At the conjugate designed cross section, the teeth are modeled and further discretized into sub regions for brick mesh as shown in Figure 3. Finer meshes are used at the contact region and root fillet in order to calculate contact stress and bending stress. Coarser meshes are used at the rest regions to reduce calculation time [10]. A mesh size convergence study has been done for the criteria of deformation.

Contact pairs are defined between the teeth of the flexspline and circular spline. The contact elements are deactivated at the first load step and then reactivated at the second load step after the contact between the wave generator and flexspline are established. This

### Table 1: Circular spline and flexspline design data.

<table>
<thead>
<tr>
<th>Data</th>
<th>Circular spline</th>
<th>Flexspline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth number</td>
<td>182</td>
<td>160</td>
</tr>
<tr>
<td>Face width (mm)</td>
<td>9.0000</td>
<td>8.3000</td>
</tr>
<tr>
<td>Root fillet radii (r_f) (mm)</td>
<td>0.0816</td>
<td>0.1360</td>
</tr>
<tr>
<td>Tip fillet radii (r_t) (mm)</td>
<td>0.0680</td>
<td>0.0270</td>
</tr>
<tr>
<td>Addendum circle diameter (mm)</td>
<td>43.4237</td>
<td>43.4680</td>
</tr>
<tr>
<td>Dedendum circle diameter (mm)</td>
<td>44.2124</td>
<td>42.6470</td>
</tr>
<tr>
<td>Pressure angle (deg)</td>
<td>11.1858</td>
<td>12.5084</td>
</tr>
<tr>
<td>Pitch circle diameter (mm)</td>
<td>43.7330</td>
<td>43.1850</td>
</tr>
<tr>
<td>Module (mm)</td>
<td>0.26995679</td>
<td>0.26990625</td>
</tr>
</tbody>
</table>
element-birth-and-death technique is employed in simulating the addition of layers for additive manufacturing in reference [12]. The contact condition is an augmented Lagrange method with no friction.

Figure 4 is the plane stress model results for the first load step. The initial penetration between the wave generator and flexspline are solved by the contact pair. Though no torque load is added, the stress in the flexspline is caused by its shape change. Its bending stress is only decided by the wave generator shape. The contact between teeth happens at both right and left sides of the flexspline. Furthermore, the teeth in the first quadrant has a right side tooth profile in contact as in Figure 4(a). The teeth in the second quadrant in Figure 4(b) has a left side tooth profile due to the symmetry under no load condition. For each pair of teeth, there is clearance like a rigid gear. However, the strain wave gear will have zero backlash due to the double side contact.

As shown in Figure 4, the profile is tangent to each other at every contact point. Although the plane stress simulation is static with no component moving, the instant shown in Figure 4 represents the input periodic motion of wave generation since the meshing between teeth happens along the entire circumference. The contact ratio of the strain wave gear is as high as 24. If the wave generator rotates clockwise by angle \( \frac{2\pi}{n} \), in which \( n \) is an integer from -12 to 12, it’s equivalent to rotate the whole assembly by the same angle.

The static model shows 24 contact positions of a pair of teeth to verify the conjugation. If the tooth profiles don’t have conjugation, the same 24 pairs of teeth will have extra clearance or interference instead of tangency. Since the contact ratio of the strain wave gear is high, the
static plane stress results show enough contact positions to verify the kinematic conjugation between the tooth profiles.

Figure 5 shows the contact status between teeth when a counterclockwise torque load is applied to the flexspline. In the second quadrant of the flexspline, 15 pair of teeth are in near contact status [11] compared with eight pair of teeth at the opposite side due to the deformation of the flexspline under torque. For the assembly, the deformation will be contributed by the teeth deformation and the compliant cup deformation.

COMPLIANT CUP DEFORMATION

The deformation of the flexspline compliant cup is three dimensional, which will affect the teeth meshing at other cross sections other than the designed cross section. In reference [8], a fully conjugate tooth surface is found from the kinematic model under no load condition. However, this paper will use a different approach to design the modified tooth surface with consideration of lengthwise crowning for the hobbing process.

A cylindrical coordinate is shown in Figure 6(a). The origin of the coordinate is at the center of the rigid end of the compliant cup. The Z-axis is along the longitudinal direction of the cup. The X-axis points to the major axis of the elliptical wave generator. The Y-axis is the angular coordinate. According to the coordinate defined, the deformation of the compliant cup can be broken down into three components. Radial deformation \( u \) along the \( X \) direction, circumferential deformation \( v \) along the \( Y \) direction, and oscillating angular deformation \( \phi \) measured from the \( X \)-positive direction. Components \( u, v, \phi \) are the same as the displacement mentioned in session 2. The deformation can be solved analytically by the given wave generator shape for the points at each cross section’s neutral layer as in reference [8]. They are functions of the cross section’s longitudinal position. In other words, a different cross section along the longitudinal direction has a different deformation. The assumption of the analytical method is that the deformation is totally governed by the wave generator geometry under no load condition. In this paper, finite element model is used to analyze the deformation under any load condition, and teeth meshing will be considered for the next chapter.

As shown in Figure 6(b), the compliant cup will deform into a three-dimensional shape. Figure 6(c) shows the contact pressure between the inner surface of the compliant cup and outside surface of the wave generator. The contact happens at two places: one is toward the rigid end of the cup along the major axis, and the other one is toward the open end of the cup along the minor axis. So, the deformation of the cup is found to be not totally governed by the wave generator shape, but also affected by the contact status between the wave generator and flexspline compliant cup inner surface [8].

Figure 7 shows the major and minor axis’s radial deformation for the compliant cup’s different cross section along longitudinal direction \( Z \). The wave generator has an elliptical shape with a circumference the same as the inner surface of the cup before deformation. The major and minor axis of the wave generator has the designed values comparing with the actual deformed values shown in Figure 7.

Since the contact between the wave generator and the compliant cup is not uniform, the open end of the cup doesn’t have the same shape as the wave generator. Three critical cross sections are defined along the tooth lengthwise direction. At the designed cross section,
We have all heard the phrase WORK SMARTER, NOT HARDER. Makes sense, right? In times of economic uncertainty, it’s SMART to maximize the efficiency of every one of your resources. Workholding technology that allows you to go from O.D. to I.D. to 3-jaw clamping in a matter of seconds without readjustment can maximize the production – and the profits – of your existing machines. Now that is WORKING SMARTER.

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the deviation between the actual major axis radial deformation and designed value is $u_m$. At the heel cross section, the deviation between actual minor axis radial deformation and designed value is $u_h$. At the toe cross section, the deviation between actual major axis radial deformation and designed value is $u_t$. Deviation $u_m$, $u_h$, and $u_t$ will cause interference between the flexspline tooth surface and circular spline tooth surface. So, longitudinal modification is added to the flexspline tooth surface. The crowned amount can be calculated from the compliant cup radial deformation for the three critical cross sections as in Figure 8. The profile has crowned amount $u_m$, $u_h$, and $u_t$ at the three critical cross sections by the plunging motion of the hobbing cutter. The finite element model's deformation result solves $u_m = 19 \mu$m, $u_h = 64 \mu$m, and $u_t = 62 \mu$m for the given strain wave gear.

**LOADED TOOTH CONTACT PATTERN**

The strain wave gear has conjugate tooth profiles at a designed cross section and is further longitudinally crowned. It will be free from interference for assembly. Due to the high contact ratio, periodic motion and the ring shape of the components [7], all the teeth with different polar angle at one given wave generator position will represent one tooth's motion when the wave generator rotates. In other words, one tooth at the given wave generator position will have one contact ellipse. Instead of simulating the rotation of the wave generator, one can overlay the contact ellipse of all the teeth at the instant to have the contact pattern and path of contact for one tooth.

The crowned tooth surface will have a localized contact pattern under no load condition. Under a load condition, the loaded tooth contact pattern is needed to simulate the final contact pattern result, especially due to the flexibility of the compliant cup. The criteria of the contact pattern include the following:

- No high stress edge contact under any load condition.
- The contact pattern spans at least two thirds of the face width.
- Under no load condition, the contact pattern is toward the toe of the tooth surface.
- Under nominal load condition, the contact pattern is shifting to the center of the tooth surface.

Due to the strain wave gear's kinematics, the tooth profile is not involute or cycloid. The relative motion between the flexspline and circular spline as shown in Figure 2 is different from the relative hypocycloidal motion of a pair of rigid internal meshing gears. Involute or cycloid profiles cannot have conjugation under such motion. Instead, in Figure 9, the definition of the tooth profile's three main segments includes the tip circular arc radii $r_1$, root circular arc radii $r_2$, and common tangent straight line $l$. The tip fillet $r_{1f}$ and root fillet $r_{rf}$ will not engage in meshing. The selection of such a profile for the flexspline will lead to a high contact ratio under the relative motion between the flexspline and circular spline. High quality brick meshes as in reference [10] are used for the crowned tooth surfaces. The total nodes number of the model is 1.35 million.

Comparing the radial deformation of the flexspline in Figure 6(b) with Figure 10(a) for no load condition, the max radial deformation is at the major axis of the wave generator with 0.3 percent difference, which verifies the crowned tooth surfaces have no interference between the flexspline and circular spline. Under 20 N·m load condition, the radial deformation is shown in Figure 10(b). The max deformation reduces 11 percent, and the max deformation location shifts from the major axis to the second quadrant as shown in Figure 10(c). Torsional deformation causes the flexspline to be detached from the wave generator as mentioned in reference [13, 14].

Figure 11 shows the loaded tooth contact pattern result under a 20 N·m torque load. Unlike the rigid gear's single oval shape contact pattern, the strain wave gear's contact pattern can be divided into three regions as in Figure 11 and Figure 12. Region I has the highest contact pressure of 94 MPa. The mean point location is at the designed cross section longitudinally. As shown in Figure 12(a), region I has no edge contact. Region II has a max contact pressure of 39 MPa, and it is at the edge of the wave generator as shown in Figure 6(c)'s high contact pressure area. The contact boundary between the wave generator and inner surface of the flexspline causes the shape change of the flexspline teeth, which leads to the higher contact pressure at region II. Region III has a max contact pressure of 77 MPa. Due to the detachment between the flexspline and wave generator, the toe of the flexspline will be in contact with the circular spline. Region III has an edge contact.

However, the max contact pressure is lower than region I. The contact pressure result is for the purpose of comparison of contact pattern marks with experiments, and the contact pressure has not been compared with Hertzian contact stress.

**PROTOTYPING AND TESTING**

Since the strain wave gear has an enclosed ring shape, a gear-marking compound cannot be used to test the contact pattern. The contact
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TOYODA
A finite element model is established for the strain wave gear assembly with a longitudinal crowned tooth surface. The simulation result for the contact pattern has been verified by experiments. The model can be used for future design to shorten the design period.

The shape of the flexible spline is thoroughly studied. The deformation results can be used for calculating the longitudinal crowning amounts.

The contact pressure between the wave generator and inner surface of the flexible spline is found to be not evenly distributed along the longitudinal direction. The deformed shape of the flexible spline compliant cup open end is governed by the wave generator shape and also the contact status.

Plan for future work is as follows:

- Design the wave generator with a compatible shape with the deformed compliant cup inner surface to lower the contact pressure.
- The shape of the wave generator can be optimized similar to the cam profile. The optimal shape might not be an ellipse for the strain wave gear's dynamic performance.
- Conduct a mesh convergence study with criteria of stress and compare contact pressure results with Hertzian contact stress.
- Study how profile crowning will affect transmission error.
- Study how different load and load direction will affect the contact pattern and stiffness of the strain wave gear.

**CONCLUSIONS AND FUTURE WORK**

Based on the performed research and results, the following conclusions can be drawn:

- A finite element model is established for the strain wave gear assembly with a longitudinal crowned tooth surface. The simulation result for the contact pattern has been verified by experiments. The model can be used for future design to shorten the design period.
- The shape of the flexible spline is thoroughly studied. The deformation results can be used for calculating the longitudinal crowning amounts.
- The contact pressure between the wave generator and inner surface of the flexible spline is found to be not evenly distributed along the longitudinal direction. The deformed shape of the flexible spline compliant cup open end is governed by the wave generator shape and also the contact status.
- Under the torsional load, the teeth meshing and the shape of the flexible spline are a coupled problem. The loaded tooth contact pattern analysis for the strain wave gear has solved the problem.
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METHODS TO DETERMINE FORM DIAMETER ON HOBBED EXTERNAL INVOLUTE GEARS
To assist gear designers to instantly verify the manufacturability of their designs, two methods are presented to calculate the manufactured form diameter given the design parameters of the gear and the hob.

By SHUO “WILL” ZHANG

In custom designs of external spur or helical gears, designers generally prefer a lower form diameter for greater transverse contact ratio. A larger root fillet radius and a higher root diameter are also preferred for higher root bending strength. The combination of the above three requirements can render the gear designs unable to be manufactured by hobbing process followed by flank-only finishing processes. To assist gear designers to instantly verify the manufacturability of their designs, two methods are presented in this work to calculate the manufactured form diameter given the design parameters of the gear and the hob. In particular, the second method does not involve iterative calculations or graphical simulations that are adopted by numerous publications and software programs. Instead, a series of empirical formulas are provided for users to directly find the manufactured form diameter using the gear design parameters and hob geometries. Over wide ranges of gear design parameters, the formulas can calculate form diameters with relative errors smaller than 0.1%. Examples of applying the formulas are also presented.

1 INTRODUCTION

For involute gears, form diameter is the diameter of a circle at which the root fillet curve intersects or joins the involute [1]. In most cases, the root fillet curve is one continuous trochoid produced by the tip of the generating cutting tool. In some cases, the root fillet curve can also consist of a trochoid and another involute at a lower pressure angle. Form diameter is also known as true involute form diameter (TIF), or diameter at start of involute (SOI) [2].

Designers of custom external involute gears usually specify a maximum form diameter, which is necessary for the transverse contact ratio of the gear mesh under various conditions. Meanwhile, a higher root diameter and a larger radius of the root fillet are also preferred for higher root bending strength. However, when the above three requirements are specified at the same time, they may cause challenges to the manufacturing of the gear, especially if a notch in fillet caused by the finishing operation is not allowed. If the gear designers can instantly determine whether the specified form diameter can be manufactured along with the specified root fillet radius and root diameter, gear designs that cannot be manufactured can be prevented.

A number of commercial software programs can simulate the manufacturing processes accurately. They usually present a graphical simulation of the generating cutting process, based on the parameters of the gears and cutting tools. However, if the gear design is not created using such programs, it can take additional cost and time to perform the manufacturing simulation with them.

Multiple methods have been presented in prior works to determine the form diameter. Gerpen and Reece presented a method with the simplifying assumption that the form diameter is generated by the end point of the circular tip [3]. Math and Chand presented a method for hobs that have two other straight segments connecting the circular tip and the main cutting flank of the hob [4]. Lian presented a method to determine form diameter of helical or spur, internal and external gears cut by either shaper cutters or hobs [5], if the root fillet consists of only a trochoid generated by the circular tip of cutter, without a secondary involute generated by the transitional straight edge next to the circular tip on the cutter. In addition, all the above methods involve solving a series of equations to determine the form diameter.

This paper presents two methods, A and B, to determine the manufactured form diameters on external helical or spur gears, produced by hobbing process, possibly followed by flank-only finishing process such as shaving or grinding. Method A involves equations to describe three key curves: the trochoid generated by the circular tip of the hob, the primary involute generated by the main cutting flank of the hob, and the secondary involute generated by the transitional straight edge connecting the circular tip and the main cutting flank on the hob. Then the lowest point on the primary involute is determined, which can be intersected by either the trochoid or the secondary involute. Method A involves iterative solving to find the intersection point, similar to previous publications.

Method B consists of a series of empirical formulas, and a flow chart showing how to apply the formulas, to calculate the form diameter without iteration. The formulas are found by regressing a large quantity of examples generated using method A, which consist of form diameters and gear design parameters and hob parameters. Due to the nature of empirical formula, form diameters from method B have relative errors, which are less than 0.1% over wide ranges of input parameters as specified, and are less than 0.05% for common gear designs. Tooth thickness is not needed in either method A or B. Examples of applying both methods are shown.
2 SYMBOL DEFINITIONS

The presented methods apply to external helical or spur gears produced by hobbing process, followed by flank-only finishing process. The methods are presented in section 3.1 and 3.2 assuming the gear is a spur. Section 3.3 discusses how to handle helical gears. An example of a gear tooth is shown in Figure 1.

Table 1: Symbols used in method A.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Terms</th>
<th>Units</th>
<th>First used</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi )</td>
<td>Hob normal pressure angle</td>
<td>rad in A, deg in B</td>
<td>Eq (1)</td>
</tr>
<tr>
<td>( \phi _b )</td>
<td>Hob secondary pressure angle for tip transition</td>
<td>rad in A, deg in B</td>
<td>Eq (A6)</td>
</tr>
<tr>
<td>( r _a )</td>
<td>Hob tip radius</td>
<td>in or mm</td>
<td>Eq (A1)</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>Angle between centerline of ( H ) and starting point ( S ) of involute ( PQ )</td>
<td>rad</td>
<td>Eq (A5)</td>
</tr>
<tr>
<td>( \alpha _2 )</td>
<td>Angle between centerline of ( H ) and starting point ( B ) of involute ( NQ )</td>
<td>rad</td>
<td>Eq (A6)</td>
</tr>
<tr>
<td>( \beta _a )</td>
<td>Helix angle of gear at base circle</td>
<td>rad</td>
<td>Eq (3)</td>
</tr>
<tr>
<td>( \beta _f )</td>
<td>Helix angle of gear at generating pitch circle</td>
<td>rad</td>
<td>Eq (6)</td>
</tr>
<tr>
<td>( \beta _{a0} )</td>
<td>Intermediate-step helix angle of gear at form diameter</td>
<td>rad</td>
<td>Eq (3)</td>
</tr>
<tr>
<td>( \delta _a )</td>
<td>Protruberance</td>
<td>in or mm</td>
<td>Eq (1)</td>
</tr>
<tr>
<td>( \delta _b )</td>
<td>Effective protruberance</td>
<td>in or mm</td>
<td>Eq (1)</td>
</tr>
<tr>
<td>( r _f )</td>
<td>Hobbed root circle radius</td>
<td>in or mm</td>
<td>Eq (A1)</td>
</tr>
<tr>
<td>( r _g )</td>
<td>Generating pitch radius</td>
<td>in or mm</td>
<td>Eq (A1)</td>
</tr>
<tr>
<td>( r _s )</td>
<td>Base circle radius</td>
<td>in or mm</td>
<td>Eq (2)</td>
</tr>
<tr>
<td>( d _{fg} )</td>
<td>Form diameter of gear</td>
<td>in or mm</td>
<td>Figure 1</td>
</tr>
<tr>
<td>( d _{fgx} )</td>
<td>Intermediate-step form diameter of helical gear</td>
<td>in or mm</td>
<td>Eq (6)</td>
</tr>
<tr>
<td>( d _{fsv} )</td>
<td>Form diameter of virtual spur gear</td>
<td>in or mm</td>
<td>Eq (8)</td>
</tr>
<tr>
<td>( \psi _t )</td>
<td>Angle between tangent to trochoid and radius vector ( r _t )</td>
<td>rad</td>
<td>Eq (A2)</td>
</tr>
<tr>
<td>( \theta _a )</td>
<td>Angle between centerline of ( H ) and radius vector ( r _a )</td>
<td>rad</td>
<td>Eq (A1)</td>
</tr>
<tr>
<td>( \theta _b )</td>
<td>Angle between centerline of ( H ) and radius vector ( r _b )</td>
<td>rad</td>
<td>Eq (A4)</td>
</tr>
<tr>
<td>( E )</td>
<td>Center distance between helical gear and its virtual spur gear</td>
<td>in or mm</td>
<td>Eq (7)</td>
</tr>
<tr>
<td>( r _T )</td>
<td>Radial vector from gear center to point ( T )</td>
<td>in or mm</td>
<td>Eq (A1)</td>
</tr>
<tr>
<td>( r _Y )</td>
<td>Radial vector from gear center to point ( Y )</td>
<td>in or mm</td>
<td>Eq (A9)</td>
</tr>
<tr>
<td>( u _s )</td>
<td>Flank finishing stock removal on generating pitch circle</td>
<td>in or mm</td>
<td>Eq (1)</td>
</tr>
<tr>
<td>( Z )</td>
<td>Number of teeth</td>
<td>--</td>
<td>Eq (4)</td>
</tr>
<tr>
<td>( Z _F )</td>
<td>Number of teeth in virtual spur gear</td>
<td>--</td>
<td>Eq (4)</td>
</tr>
</tbody>
</table>

Table 2: Symbols used only in Method B.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Terms</th>
<th>Units</th>
<th>First used</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d , r , C )</td>
<td>Parameters for method B</td>
<td>1</td>
<td>Eq (B1-E5)</td>
</tr>
<tr>
<td>( d _{fg2} )</td>
<td>Form diameter, if produced by the actual hob circular tip</td>
<td>in or mm</td>
<td>Eq (B1)</td>
</tr>
<tr>
<td>( d _{fgcb} )</td>
<td>Form diameter, if produced by sharp hob tip, ( C = 0 )</td>
<td>in or mm</td>
<td>Eq (B1)</td>
</tr>
<tr>
<td>( d _{fgc3} )</td>
<td>Form diameter, if produced by a hob tip with ( C = 0.0005 )</td>
<td>in or mm</td>
<td>Figure 2</td>
</tr>
<tr>
<td>( d _{gb} )</td>
<td>Form diameter of gear, if produced by the secondary straight edge ( NQ ) of the hob</td>
<td>in or mm</td>
<td>Eq (B1)</td>
</tr>
<tr>
<td>( d _{gjk} )</td>
<td>Intermediate variable to determine which segment of the hob produces form diameter</td>
<td>in or mm</td>
<td>Eq (B1)</td>
</tr>
<tr>
<td>( i , j , k , m )</td>
<td>Index numbers to assist locating coefficients in table 4-6</td>
<td>--</td>
<td>Figure 5</td>
</tr>
</tbody>
</table>

Table 3: Description of key points and curves in figures.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Terms</th>
<th>Appears in</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H )</td>
<td>Center point of ( h _0 ) radius</td>
<td>Figure 2</td>
</tr>
<tr>
<td>( H ^* )</td>
<td>Trajectory of point ( H ) during cutting relative to the gear</td>
<td>Figure 3-5</td>
</tr>
<tr>
<td>( M )</td>
<td>Lower endpoint of circular hob tip ( MN )</td>
<td>Figure 3-5</td>
</tr>
<tr>
<td>( N )</td>
<td>Higher endpoint of circular hob tip ( MN )</td>
<td>Figure 2</td>
</tr>
<tr>
<td>( M ^{\prime} )</td>
<td>Trochoid curve generated by circular tip of hob</td>
<td>Figure 3-5</td>
</tr>
<tr>
<td>( P )</td>
<td>Higher endpoint of main cutting flank of hob</td>
<td>Figure 2</td>
</tr>
<tr>
<td>( Q )</td>
<td>Higher endpoint of transitional edge ( NQ )</td>
<td>Figure 2</td>
</tr>
<tr>
<td>( R )</td>
<td>Intersection point of gear centerline and generating pitch circle</td>
<td>Figure 3</td>
</tr>
<tr>
<td>( S )</td>
<td>Starting point of involute ( PQ ) on base circle</td>
<td>Figure 3, 5</td>
</tr>
<tr>
<td>( T )</td>
<td>Any point on ( H ^* )</td>
<td>Figure 4</td>
</tr>
<tr>
<td>( X _{0} )</td>
<td>Intersection of root trochoid ( M N ) and involute ( PQ )</td>
<td>Figure 5</td>
</tr>
<tr>
<td>( X )</td>
<td>Lowest point on primary involute ( PQ ), defines form diameter</td>
<td>Figure 3, 5</td>
</tr>
<tr>
<td>( Y )</td>
<td>One point on ( M ) that corresponds to point ( T )</td>
<td>Figure 4</td>
</tr>
</tbody>
</table>

3 METHODS TO DETERMINE FORM DIAMETER

The presented methods apply to external helical or spur gears produced by hobbing process, followed by flank-only finishing process. The methods are presented in section 3.1 and 3.2 assuming the gear is a spur. Section 3.3 discusses how to handle helical gears. An example of a gear tooth is shown in Figure 1.

The methods assume that the concerned geometries of the hob can be represented by Figure 2. In the normal plane of the hob, a circular tip with radius \( a_0 \) has two endpoints \( M \) and \( N \), and a center point \( H \). A transitional straight edge \( NQ \) is tangent to \( MN \) at point \( N \), and joins main cutting flank \( PQ \) at point \( Q \).

Both methods use the following input variables, which are assumed known to the designers:

- Pertaining to the gear: \( r_f , r_b , Z , \beta _a \)
- Pertaining to the hob: \( \alpha _2 , \beta _a , \beta _f , \beta _{a0} \)

In method A, the pressure angle of NQ, \( \beta _f \), can vary from 0° to \( \beta _a \). In method B, for simplicity purposes, \( \beta _f \) is assumed to be 10°, therefore is not an input variable. If the hob does not have protuberance, \( \beta _0 = 0 \), and \( \beta _f = \beta _a \).

If \( \beta _a \) is the actual protuberance on the hob, the calculated form diameter corresponds to the condition of the gear after hobbing and before finishing. If the form diameter of the gear after flank-only finishing operation is to be calculated, \( \beta _0 \) needs to be replaced with \( \beta _{a0} \) before applying either method:

\[
\delta _{a0} = \delta _0 - u _s \cos \phi
\]  

Equation 1

in which \( u _s \) is the flank-only finishing operation stock removal along the generating pitch circle of the hobbing process.

In custom gear designs, the pressure angle of the gear is not an essential parameter. The same gear can be expressed using various
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pressure angles. Therefore, pressure angle of the gear, normal or transverse, is not an input variable in either method. Normal pressure angle of the hob $\beta$ is important and does not need to equal pressure angle of the gear. Note that the variable $r$ is the generating pitch radius of the gear, which can be found using equation 2 for spur gear:

$$r = \frac{r_b}{\cos \phi} \quad \text{Equation 2}$$

For helical gear, generating pitch radius $r$ can be found by solving equation 3:

$$\frac{r}{r_b} \cos \left( \tan^{-1} \left( \frac{\tan \phi}{1 + \left( \frac{r}{r_b} \tan \beta \right)^2} \right) \right) = 1 \quad \text{Equation 3}$$

### 3.1 METHOD A

In method A, three key curves need to be expressed analytically. The trochoid MN’ generated by the circular tip of the hob is expressed using equation A1-A4 [6], the primary involute PQ’ generated by the main cutting flank of the hob, and the secondary involute NQ’ generated by the transitional straight edge connecting the circular tip and the main cutting flank on the hob. To space the three curves in the correct relations to each other, the angular spacing from centerline of the trochoid MN’ to both involute curves is given in equation A5 and A6.

Then the lowest point X on the primary involute PQ’ is determined, which can be intersected by either the trochoid MN’ or the secondary involute NQ’. Method A involves iterative solving to find the intersection point, similar to previous publications.

During the hobbing process, in the reference frame of the gear, the hob tip center H has a trajectory H’, which is symmetric to its centerline, as shown in Figure 3 and 4. Trochoid curve H can be expressed using variables $\theta_T$ and $r_T$:

$$\theta_T = \tan^{-1} \left[ \frac{r_T^2 - (r_T + \rho_{a0})^2}{r_T^2 + 2 \rho_{a0} \sin \psi_T} \right] \quad \text{Equation A1}$$

The envelope curve MN’ of circular tip MN is an equidistant curve from H’ with a spacing equal to the hob tip radius $\rho_{a0}$. Therefore MN’ can be expressed using equation A2-A4:

$$\psi_T = \tan^{-1} \left[ \frac{r_T (r_T + \rho_{a0}) - r_T^2}{r_T^2 - \rho_{a0}^2} \right] \quad \text{Equation A2}$$

$$r_T = r_T^2 + \rho_{a0}^2 - 2 r_T \rho_{a0} \sin \psi_T \quad \text{Equation A3}$$

$$\theta_T = \theta_T + \cos^{-1} \left( \frac{r_T - \rho_{a0} \sin \psi_T}{r_T} \right) \quad \text{Equation A4}$$

The angle between centerline of H’ and starting point of the involute PQ’ is given by equation A5:

$$a = \frac{(r - r_T) \sin \phi + \rho_{a0} (1 - \sin \phi) - \delta_0}{r_T} - \tan \phi + \phi \quad \text{Equation A5}$$

Similarly, the angle between centerline of H’ and starting point of involute NQ’ is given by equation A6:

$$a_2 = \frac{(r_b / \cos \phi_2 - r_T) \sin \phi_2 + \rho_{a0} (1 - \sin \phi_2)}{r_T} - \tan \phi_2 + \phi_2 \quad \text{Equation A6}$$

There are multiple possibilities of the relative positions of the three curves. Nemcek and Dejl made an in-depth analysis of them [7]. Figure 5 presents two representative conditions, and where the form diameter is in those conditions. To find the lowest point X on the primary involute, it is recommended to first iteratively find the intersection point $X_0$ of the primary involute PQ’ and the root trochoid MN’. Make sure to find the higher one when there are two intersection points. Then determine whether the segment of NQ’ on
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- Spindles
- Hitch Links
- Segments
the outside of MN’ has an intersection point with PQ’. If so, the new intersection point will be higher than X₀ and becomes the lowest point X on the primary involute, as shown in Figure 5(b). If not, X₀ is the lowest point X on the primary involute, as shown in Figure 5(a).

When the iterations are fully converged, form diameter from Method A is very accurate. They have been compared to results from KISSsoft using multiple examples, and almost all visible digits match. See section 4 for example details.

### 3.2 METHOD B

A large quantity of data sets is generated using method A, covering wide ranges of input parameters. Each data set includes input parameters and calculated form diameter. These data are then used in regression to create a series of empirical formulas to directly calculate form diameter from input parameters, without the need to analytically plot multiple curves and use mathematical relations to identify where the lowest point on primary involute is. Method B is believed to be much simpler to adopt.

Due to the nature of empirical formula, form diameters from method B have relative errors, which are generally less than 0.1% over the specified ranges of input parameters, and are less than 0.05% for common gear designs. The accuracy is good enough for most practical use, especially when designers need to verify the manufacturability of specified form diameter, root diameter and hob tip radius.

The 18 equations should be applied in the sequence shown in Figure 6. 135 coefficients \(d_{ijkm}\) are provided in Table 4, which are used to calculate 45 coefficients \(c_{ijk}\), which are later used to calculate 15 coefficients \(b_{ij}\), which are later used to calculate 5 coefficients \(a_i\), which are later used to calculate candidate form diameter \(d_{TIF,C}\). Depending on the input parameters and the logical judgment shown in Figure 6, similar processes may also be needed to find the candidate form diameter when \(C=0.0005\), \(d_{TIF,C5}\), and candidate form diameter when protuberance is zero \(d_{TIF,0}\) and the candidate form diameter if it is produced as the intersection of two involute curves, \(d_{TIF,S}\). Finally, the method will determine which candidate form diameter is the actual form diameter and report it as \(d_{TIF}\). Although method B takes 75 to 178 calculation steps to determine form diameter, all steps are simple and direct.

To have a relative error less than 0.1%, variables \(\varphi, A, B, C\) need to be within the given ranges below:

\[
\begin{align*}
\varphi &: [15°, 30°] \\
A &: [0.01, 0.2] \\
B &: [0, 0.6] \\
C &: [0, 0.005]
\end{align*}
\]

The equations for method B are below:

\[
\begin{align*}
A &= \frac{r - r'}{2r} & \text{Equation B1} \\
B &= \frac{\rho_{ao}}{r - r'} & \text{Equation B2} \\
C &= \frac{\delta_{ao}}{2r} & \text{Equation B3} \\
G &= C + A B \cos \phi \left[ 0.8391 - \tan \left( \frac{90 - \phi}{2} \right) \right] & \text{Equation B4} \\
I f \ \phi > 18, & \ G_C = 0.0065 & \text{Equation B5.1} \\
I f \ \phi \leq 18, & \ G_C = 0.001 \phi - 0.0115 & \text{Equation B5.2} \\
c_{ijk} &= \sum_{m=0}^{2} d_{ijkm} \Phi^m & \text{Equation B6} \\
b_{ij} &= \sum_{k=0}^{2} c_{ijk} C^{k/2}, \text{ except for } i = j = 0 & \text{Equation B7.1} \\
b_{00} &= \sum_{k=0}^{2} c_{00k} C^{k} & \text{Equation B7.2} \\
b_{00} &= \sum_{k=0}^{2} c_{00k} C^{k} & \text{Equation B7.2} \\
a_i &= \sum_{j=0}^{2} b_{ij} B^j & \text{Equation B8} \\
g &= 0.001 \sin \left( \frac{\Phi - 16}{7} \pi \right) e^{-\left[ 25A-\frac{\Phi}{6}+2.76 \right]} & \text{Equation B9} \\
d_{TIF,C} &= 2 r_y (1 + g) \sum_{i=0}^{4} a_i A^i & \text{Equation B10} \\
b_{ij} &= \sum_{k=0}^{3} d_{ijk} \Phi^k & \text{Equation B11}
\end{align*}
\]
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Coefficients used in equation B6 are shown in Table 4.
Coefficients used in equation B11 are shown in Table 5.
Coefficients used in equation B15 are shown in Table 6.

3.3 APPLYING METHOD A & B TO HELICAL GEARS

Method A or B cannot be applied in the transverse plane to accurately determine the form diameter of a helical gear, due to the assumption by both methods that the hob tip is circular. When a hob has a circular tip in its normal plane, the tip has an elliptical cross section.

### Table 4: \( d_{ijk} \) used in equation B6.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( j )</th>
<th>( k )</th>
<th>( d_{ijk} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>i = 4</td>
<td>k = 2</td>
<td>0.050 E+02</td>
<td>-0.954 E+00</td>
</tr>
<tr>
<td>i = 3</td>
<td>k = 2</td>
<td>-0.273 E+02</td>
<td>1.650 E+00</td>
</tr>
<tr>
<td>i = 2</td>
<td>k = 2</td>
<td>1.336 E+01</td>
<td>8.996 E+00</td>
</tr>
<tr>
<td>i = 0</td>
<td>k = 2</td>
<td>8.305 E+01</td>
<td>3.855 E+01</td>
</tr>
</tbody>
</table>

### Table 5: \( d_{ijn} \) used in equation B11.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( j )</th>
<th>( n )</th>
<th>( d_{ijn} )</th>
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</thead>
<tbody>
<tr>
<td>i = 3</td>
<td>j = 2</td>
<td>n = 4</td>
<td>-0.396 E+00</td>
</tr>
<tr>
<td>i = 2</td>
<td>j = 2</td>
<td>n = 4</td>
<td>7.846 E+01</td>
</tr>
<tr>
<td>i = 1</td>
<td>j = 2</td>
<td>n = 4</td>
<td>-1.156 E+01</td>
</tr>
<tr>
<td>i = 0</td>
<td>j = 2</td>
<td>n = 4</td>
<td>2.403 E+00</td>
</tr>
</tbody>
</table>

### Table 6: \( d_{ijk} \) used in equation B15.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( j )</th>
<th>( k )</th>
<th>( d_{ijk} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>i = 4</td>
<td>j = 2</td>
<td>k = 4</td>
<td>-0.604 E+02</td>
</tr>
<tr>
<td>i = 3</td>
<td>j = 2</td>
<td>k = 4</td>
<td>1.336 E+01</td>
</tr>
<tr>
<td>i = 2</td>
<td>j = 2</td>
<td>k = 4</td>
<td>8.996 E+00</td>
</tr>
<tr>
<td>i = 0</td>
<td>j = 2</td>
<td>k = 4</td>
<td>3.855 E+01</td>
</tr>
</tbody>
</table>

\[
\sum_{j=0}^{2} b_{ij} B^j \\
\sum_{i=0}^{5} a_{ij} A^j \\
\sum_{i=0}^{4} h_{ijk} (\psi^{0.05} - 1)^k \\
\sum_{j=0}^{2} g_{ij} G^j \\
d_{TIF,CS} = d_{TIF,CO} + (d_{TIF,CS} - d_{TIF,CO}) \left( \frac{C}{0.0005} \right) \\
g_{ij} = \sum_{k=0}^{4} h_{ijk} (\psi^{0.05} - 1)^k \\
f_i = \sum_{j=0}^{2} g_{ij} G^j \\
d_{TIF,X} = 2 \tau \sum_{i=0}^{2} f_i A^i \\
X = 11.52 \tau_r - 11.71 r + 9.52 \rho_{ao} \\
D_{TIF,X} = \sqrt{(1.9596 r)^2 + X^2} \\
D_{TIF,X} = 1.9596 r \\
\text{Coefficients used in equation B6 are shown in Table 4.} \\
\text{Coefficients used in equation B11 are shown in Table 5.} \\
\text{Coefficients used in equation B15 are shown in Table 6.}

3.3 APPLYING METHOD A & B TO HELICAL GEARS

Method A or B cannot be applied in the transverse plane to accurately determine the form diameter of a helical gear, due to the assumption by both methods that the hob tip is circular. When a hob has a circular tip in its normal plane, the tip has an elliptical cross section.
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Both methods can be applied to helical gears in the normal plane using the concept of virtual spur gear. The generating pitch circles of the helical gear and its virtual spur gear intersect at point R in Figure 3. However, if Equation 4 is used for the number of teeth in the virtual spur gear, the form diameter results can have relative errors greater than 0.1%. A slightly different method to calculate the number of teeth in the virtual spur gear \( Z_V \) is using Equation 5, which provides higher fidelity of the generated root geometry for a wide variety of gear designs. The relative error of helical gear form diameter using Equation 5 and method A is less than 0.01%. The relative error of helical gear form diameter using Equation 5 and method B is mainly from the method itself, which is less than 0.1% if design parameters are in the specified ranges.

\[
Z_{V,I} = \frac{Z}{(\cos \beta_r)^3} \quad \text{Equation 4}
\]

\[
Z_V = \frac{Z}{(\cos \beta_r)^{1.5} \left(\cos \beta_{TIF,I}\right)^{1.4}} \quad \text{Equation 5}
\]

Helix angle at various diameters can be related to base helix angle using equation 6.

\[
\frac{\tan \beta_b}{2r_b} = \frac{\tan \beta_r}{2r} = \frac{\tan \beta_{TIF,I}}{d_{TIF,I}} \quad \text{Equation 6}
\]

The center distance between helical gear and its virtual spur gear is equal to the difference between the generating pitch radius of the two gears:

\[
E = \frac{Z_{V,I}}{Z} r \cos \beta_r - r \quad \text{Equation 7}
\]

In which \( r \) and \( \beta_r \) can be found using equation 3.

After form diameter of the virtual spur gear \( d_{TIF,V} \) is found using either method A or B, center distance adjustment is needed to find form diameter of the actual helical gear using equation 8:

\[
d_{TIF} = d_{TIF,V} - 2E \quad \text{Equation 8}
\]

It is recommended to follow the process shown in Figure 7 to calculate form diameter of a helical gear.

4 EXAMPLES USING METHOD A AND B
Ten examples are created to compare form diameter results from method A, method B to KISSsoft. Each example represents a rather extreme feature of the gear design, as noted in the description, with the hope of covering a wide range of practical gear designs. Ded. factor is equal to \( (r - r_f) \frac{Z \cos \beta_r}{(2r_b)} \).

Graphical representation of the above 10 examples are created using KISSsoft and presented in Figures 8-17. The two circular arcs in Figures 8-17 represent base circle (lower) and form diameter circle (higher).

5 DISCUSSION
Some general conclusions can be made from parametric studies using the methods. With other parameters stay unchanged, larger protuberance, larger hob tip radius, higher root radius, and larger secondary pressure angle tend to cause the main involute to be intersected by the secondary involute rather than the trochoid.

By applying either method multiple times with various protuberances ranging from zero to the actual protuberance, one can construct the shape of the upper portion of the root fillet curve, from form diameter to maximum undercut diameter or base circle diameter, whichever is greater. The shape of the fillet curve can be useful for the design of the tool for finishing operations.

6 CONCLUSIONS AND FUTURE WORK
Two methods are presented to determine form diameter of external helical or spur gears from gear design parameters and hob parameters. Method A can be very accurate but involve some difficulty to apply. With method A, one needs to iteratively find one particular intersection point out of a few intersection points among three curves which are expressed with implicit functions. In comparison, method B is easier to apply, as all equations and steps are direct calculations. Method B has greater relative errors which are acceptable for most practical purposes. One possible use of such methods is that gear designers without access to advanced simulation software can evaluate manufacturability of proposed designs, and correlate achievable contact ratio to root radius and critical section tooth thickness early in the design stage. Other uses of the methods include assisting hob design and performing parametric study of gears and hob parameters, which is time-consuming even with access to advanced simulation software.

For future work, such methods can be expanded to account for internal gears and shaper-cut gears.
<table>
<thead>
<tr>
<th>No.</th>
<th>Z</th>
<th>$\phi$</th>
<th>Ded. factor</th>
<th>$\delta_0$</th>
<th>$\rho_{z0}$</th>
<th>$\rho_r$</th>
<th>Form diameter result, $d_{TIF}$</th>
<th>Method B relative error</th>
<th>Description of example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>22.5</td>
<td>1.3</td>
<td>0.006</td>
<td>0.04</td>
<td>0</td>
<td>4.2305</td>
<td>4.2302</td>
<td>-0.007%</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>30</td>
<td>1.3</td>
<td>0.006</td>
<td>0.04</td>
<td>0</td>
<td>4.1858</td>
<td>4.1855</td>
<td>-0.007%</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>15</td>
<td>1.3</td>
<td>0.006</td>
<td>0.04</td>
<td>0</td>
<td>4.3008</td>
<td>4.3008</td>
<td>-0.019%</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>22.5</td>
<td>1.3</td>
<td>0.0015</td>
<td>0.04</td>
<td>0</td>
<td>1.0548</td>
<td>1.0548</td>
<td>0.000%</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>22.5</td>
<td>0.8</td>
<td>0.006</td>
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<td>0</td>
<td>9.9176</td>
<td>9.9176</td>
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<tr>
<td>6</td>
<td>35</td>
<td>22.5</td>
<td>1.3</td>
<td>0.020</td>
<td>0.04</td>
<td>0</td>
<td>4.3075</td>
<td>4.3076</td>
<td>0.002%</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>22.5</td>
<td>1.3</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>4.1530</td>
<td>4.1530</td>
<td>-0.017%</td>
</tr>
<tr>
<td>8</td>
<td>35</td>
<td>22.5</td>
<td>1.3</td>
<td>0.006</td>
<td>0.08</td>
<td>0</td>
<td>4.2598</td>
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<td>-0.005%</td>
</tr>
<tr>
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<td>35</td>
<td>22.5</td>
<td>1.3</td>
<td>0.006</td>
<td>0</td>
<td>0</td>
<td>4.2053</td>
<td>4.2053</td>
<td>-0.007%</td>
</tr>
<tr>
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<td>0.006</td>
<td>0.04</td>
<td>35</td>
<td>5.1871</td>
<td>5.1872</td>
<td>-0.035%</td>
</tr>
</tbody>
</table>

Table 7: Examples of applying method A and B.
7 ACKNOWLEDGEMENT
The author thanks Jack Tseng, the founder and owner of GearShopPro LLC for the help from himself and his program. The author thanks Star-SU LLC for their input. KISSsoft is used as a benchmark and the tool to generate graphs.

BIBLIOGRAPHY


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Shuo “Will” Zhang is the Advanced R&D Engineer at Dana Off-Highway Lafayette IN (formerly Oerlikon Fairfield). Zhang holds MSME and BSME degrees from Purdue University and a BSME degree from Shanghai Jiaotong University. At his seventh year with Dana, he is responsible for the design and research of off-highway power transmissions and related advanced concepts. His expertise focuses on simulation and validation of the mechanical and thermal durability, efficiency, and NVH of drive products. Zhang is a member of the AGMA Epicyclic Enclosed Drives (Planetary) Committee and Lubrication Committee.
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The FH630SKX1 5-Axis horizontal machining center features a highly rigid spindle with a tilting swivel motion to enable exceptionally efficient machining of large workpieces. (Courtesy: Toyoda)
For more than 70 years, JTEKT Toyoda Americas Corporation has been a world leader in machine-tool manufacturing that includes its roots in grinding machine technology to the advanced capabilities of its gear-skiving innovations.

By KENNETH CARTER, Gear Solutions editor

Necessity may be the mother of invention, but for JTEKT Toyoda Americas Corporation, necessity became the catalyst for innovation.

Toyoda Machinery was born from Toyota Motors when the car company was looking to bring the building of machine tools in-house to make car parts.

“We were making machine tools originally for automotive, but then we obviously began selling our machinery to many other manufacturing companies throughout the world over the intervening decades,” said Michael Rzasa, director of Marketing and Sales Strategy at Toyoda.

Over the course of those many years, Toyoda has continued to make many strides in cutting-edge machinery.

“We were the first to invent a high-speed CNC grinding control in the ‘60s, when we weren’t satisfied with using a machining/chip-cutting CNC controller for grinding operations,” Rzasa said. “Today, we’ve leveraged our history of grinding controls development and machining center technology to come up with state-of-the-art equipment.”

CUTTING-EDGE GEAR SKIVING

Toyoda’s complete line of machines ranges from vertical and horizontal machining centers to grinding machines, bridge and gantry machines to turning centers. Toyoda’s products are developed with the operator in mind and use FANUC and Toyoda controls for ease of use and optimal efficiency.

Toyoda’s gear-skiving machinery is built on a platform of the company’s machining centers, but use Toyoda’s grinding controls. Their extremely high-speed synchronization capability allows them to achieve the industry’s fastest gear-skiving machine operations, according to Rzasa.

Toyoda can take the rotating work spindle, put a workpiece in it and spin that up to 3,000 rpm. Then it can take a skiving cutting tool in the milling spindle and spin that up to 6,000 rpm and, at those speeds, have the cutting tool and the workpiece in perfect synchronization. This is possible due to the Toyoda control system.

“Our gear-skiving technology is really the highlight,” he said. “I believe that we have the best specs for skiving in a couple of ways. Our synchronization capability is higher than anyone else that I’m aware of. There are some competitors out there, but I don’t believe anybody else is able to synchronize at 3,000 and 6,000 rpm like we can. We achieve much faster cycle times.”

MACHINING CENTER COMBINATION

Toyoda’s machines are not just designed for skiving, according to Rzasa. They serve as a machining center combination with a lathe spindle on top of a rotary table. With this setup, a gear profile can be skived, then a tool can be changed out to skive multiple different gear profiles.

“We can also single-point turn using the work spindle,” he said. “We can chamfer; we can deburr; we can mill; we can drill; we can tap; we can engrave — all in a single chucking of the workpiece.”

This functionality offers many benefits to manufacturers, according to Rzasa.

“In the past, you might need to invest in a line of equipment where you would have a lathe and a vertical machining center and a hob and a deburring robot, for example,” he said. “If any one of those machines is ever down, your entire line is down. Now, we can combine all those operations into one multi-purpose skiving machine. And then, if you need to expand your volume, you just add another skiving machine. If one of your machines goes down, you’re still getting capacity out of the line because you have full redundancy on all operations with multiple skiving machines from Toyoda.”

Having all operations performed by one machine also avoids having to re-setup a part, according to Rzasa.

“You’re saving all of that load and unload time,” he said. “And because you’re not re-chucking it over and over and over again, you’re eliminating any concentricity errors because everything’s true to the center line. So, there are a lot of advantages to the skiving technology.”

MASSIVE INVENTORY

With a prime directive of supplying machining centers, cylindrical grinders, turning centers, and gear skiving equipment to manufacturers, Toyoda also sees supporting that equipment as equally important, according to Rzasa.
“We maintain an inventory of over $100 million of machine tools available for immediate delivery,” he said. “And over two-thirds of our staff are in support and engineering roles. We have built our infrastructure not only with machine tools, but also with an extensive inventory of critical spares so that we have parts and service technicians onsite rapidly to keep our production customers operational.”

Toyoda’s dedicated team of engineers are available to create proposals and simulations, and it keeps a gear-skiving machine at its 100,000-square-foot Arlington Heights, Illinois, headquarters facility that’s used for testing, according to Rzasa.

“For example, we just had a customer here who spent 10 days with us doing a battery of performance and tool-life tests in preparation for taking delivery of several machines to their production facility,” he said. “So, they have full confidence in the solution before it ever hits their floor.”

Toyoda also has a huge library of experience dealing with different parts and materials that the company’s staff can rely upon to quickly turn around an estimated cycle time or performance study of a customer’s workpiece, according to Rzasa.

**SERENDIPITOUS PAST**

It’s ironic that Toyoda is now so heavily involved in the gear-manufacturing industry, considering the company was originally not a dedicated gear-manufacturing company.

“Our forte was always machining prismatic parts, and we do have the No. 1 market share in the world for OD CNC cylindrical grinders,” Rzasa said. “We would often grind shafts and other components with gears on them but not actually manufacture the gear itself.”

But with the company’s automotive heritage, combined with a heavy demand from its customer base that expressed frustrations in outdated shaping technology, Toyoda saw opportunity. For example, manufacturing limitations forced parts to be designed with more “manufacturability” in mind, rather than part performance. That need helped Toyoda expand into gear skiving.

“Combining our machining-center technology with our advanced control systems was a logical progression for our R&D division. We’ve been developing the gear-skiving technology for over 10 years in collaboration with automotive OEMs,” Rzasa said. “Our first prototype was built back in 2008 in Japan. Since then, one of our best customers is our own JTEKT company, Torsen, a supplier of differentials to major car manufacturers. They’re able to manufacture these differential gears with no undercut in the gear itself, which was required by older shaping techniques. The part is now lighter weight and performs better.”

**AWARD-WINNING TECH**

Similar needs, such as creating lighter parts in order to create better fuel efficiency, was part of what enabled Toyoda to win the Automotive News’ PACE Award in 2017. The award is given to automotive suppliers for superior innovation, technological advance-
Toyoda’s newly launched GL4i-SWITCH universal grinding machine features an adjustable wheelhead offering the capability to grind as either plain or angle-head. (Courtesy: Toyoda)
over of the hydraulic chuck on the Toyoda, it’s very easy to have one skiving machine handle thousands of part numbers,” he said. “There’s a big advantage with that.”

Toyoda’s 5-axis skiving machines come equipped with 30-, 40-, and 60-tool magazines, where other skiving machines might have only three tools that it can change to, according to Rzasa. Over the next decade, Rzasa expects Toyoda to focus even more on bringing additional 5-axis machining solutions to the market. “We have a new 5-axis machining center, our FH630Xi 5-Axis, which can be equipped with up to a 100-horsepower milling spindle, full synchronous 5-axis capability, automatic pallet changer, and a large tool magazine,” he said.

WHICH CAME FIRST? TOYODA OR TOYOTA?
Despite the slight difference in spelling, Toyoda machinery and Toyota Motors are still tightly involved with one another, according to Rzasa. “While we were an independent company, Toyota Motors was always our largest shareholder, so we’re still heavily tied to them,” he said. “They’re still our No. 1 customer worldwide. There are hundreds of our machines inside Toyota Motors factories.”

Later in its history, Koyo Bearing and other key automotive suppliers merged to form the JTEKT Corporation, which Toyoda is currently a part of, hence the official name of JTEKT Toyoda Americas Corporation.

Fun fact: Toyoda machine tools bear the original spelling of Toyota Motors’ founding family and the current CEO, Akio Toyoda.

FUTURE GOALS
Toyoda’s goals in the coming years also involves becoming more cognizant of the needs of production facilities, including high-performance uptime demands, smaller machine footprint, ease of changeover and re-deployment, and the ability to adjust a part on the fly economically, according to Rzasa. “We’re seeing more and more of that across all industries,” he said. “Because of the pace of development and the technology in design manufacturing and design engineering, people are constantly refining and refining and refining part prints. So, having flexibility in our equipment to keep manufacturing operations up with the pace of design engineering is important to us.”

MPT EXPO
Toyoda will have much of what it can offer the gear-manufacturing industry at this year’s Motion+Power Technology Expo in Detroit, Michigan, October 15-17. “We’re going to have a display on our gear-skiving technology, and we’d be happy to engage with customers about how it might be applied to their manufacturing parts or processes,” Rzasa said. “We’re also going to have on display one of our cylindrical grinders that shares the same control system.”

The vast history of Toyoda’s award-winning technology has made it a go-to for machine shops, both large and small, but it’s the company’s dedication to versatility, along with a massive inventory, that keeps those customers coming back again and again. “Toyoda’s heritage is that you buy one of our machines, and it lasts decades, and it has very little downtime, and you can beat the hell out of it, and it just keeps running,” Rzasa said. “That’s what our philosophy is, so we’re never going to stray from that.”
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The new ACM250F stainless steel grade can be used for chamfering and spot drilling with the C-Cutter Mini or C-Centering Cutter. (Courtesy: Big Kaiser)

The most notable revelation in this study was that the average VMC (Vertical Machining Center), even when it’s in cycle, isn’t cutting 30 percent of the time. Even more revealing is that the real cutting, that other 70 percent, is likely much slower than what’s realistically achievable with today’s technology.

According to Makino, if you factor in all the other time your machine isn’t running, i.e.-setup, workpiece load/unload, cutting tool maintenance, clearing chips, etc., and the typical VMC is working 34 percent of the time. Multiply all those wasted hours by your shop rate, and that’s what non-cutting time is costing you day after day, year after year.

Leading manufacturing innovator of CNC mill spindle optimization products JM Performance Products, Inc. (JMPP: Fairport Harbor, Ohio), takes a look at the goal of increasing cutting time —from the angle of toolholder expansion at the spindle.

Industry wide, a major culprit of the majority of V-flange tooling issues machinists battle with on a daily basis is toolholder expansion. A myriad of production issues arise from this factor including: vibration and chatter, increased run-out, poor finishes, tolerances, repeatability, increased machine and spindle wear and tear, and increased set-up times. The collective impact of these issues is directly related to the number of parts that can be produced efficiently in a given cycle.

The average amount of toolholder expansion industry wide is 3.5/10ths — or 1/7th the width of a human hair. This nominal amount of expansion is enough to inhibit complete toolholder taper-to-spindle contact and reduce tool life significantly. In essence, the lack of contact is equivalent to the motion of a bell clapper in that the holder moves randomly within the spindle. This occurs because once the small end expands, the point of full engagement (or contact) between the toolholder and the spindle reverses from the gage line to the small end. The bottom line is that the toolholder and tool are loose in the spindle.

The fact is that CNC milling using V-Flange tooling is inherently flawed by design. Notably, toolholder expansion occurs at the small end of the holder when a standard retention knob is installed. Extensive testing has proven that a standard retention
A toolholder should make 85 percent to 90 percent taper contact with the spindle for maximum rigidity, with solid contact at the gauge line. Retention knob induced expansion will prevent even dual contact toolholders from properly seating with the spindle. If it doesn’t fit the spindle precisely, a critical “loose-tool” factor occurs that can create the perfect storm for chatter, poor tool/spindle life, and decreased productivity.

Toolholder expansion caused by standard retention knob installation, can reduce the toolholder to spindle contact by 70 percent or more. Carbide tool life is diminished by 50 percent for every 0.0005” distance short of full engagement.

Identifying toolholder expansion can be achieved by simply looking at the wear patterns on the toolholder itself. Wear marks at the small end or at the gauge line, with no wear in between, are a clear indication of toolholder expansion.

JM Performance Products has been spearheading the charge to overcome this “spindle-to-toolholder” relationship production obstacle — by directly addressing the inherent flaw design in V-Flange tooling with their patented “High Torque” or lower-deformation retention knobs. The essential element of the design is a knob that is longer and reaches deeper into the holder’s threaded bore. As a result, all thread engagement occurs in a region of the toolholder where there is correspondingly more material to resist deformation.

Additionally, High Torque knobs feature a precision pilot to increase rigidity and a relief below the flange that forces threads into a deeper cross section of the toolholder. These design elements eliminate the toolholder expansion responsible for costly and ongoing CNC milling and boring issues.

The Makino machining capacity idle time study provided a Cost Calculator profile that illustrated the potential savings of more than $17,000 a year that can be realized by reducing non-cutting time (idle time) by 29.4 percent. Core elements of this savings is realized with new technology, new equipment, and is extrapolated to $350,000 over the course of a five-year lease. The study also highlighted how an additional $5,200 in savings can be recovered by being able to access the tool magazine while the machine is in cycle; and another $10,400 in combined savings resulting from improved chip removal and coolant management, coupled with improved ergonomics.

The results of this calculation spotlight considerably large savings to be realized by upgrading to newer technology and equipment. JM Performance Products takes this...
example to another level by calculating an additional layer of savings that can be achieved based specifically upon improved spindle-to-toolholder contact. The results of this analysis prove as follows based on this simple, real-world equation:

Take 2,000 hours (approximately 1 shift) X $100 shop rate = $200,000 gross production. Then, add a few tangible details to this model: Number of tools: 30 / Monthly tooling cost: $1,000 / Hourly set-up rate: $25.00 / Number of hours per week for set-up: 5.

If you can conservatively affect a 10 percent savings across the board, this is what the realistic breakdown results achieved would look like:

10% savings in tooling = $1,200.
10% increase in production = $20,000.
10% set-up savings = $650.
Total Savings: $21,850.

Even with moderate results of 10 percent, $21,850 represents a significant savings. Of more importance is the fact that it would cost only about $900 one time to realize this savings potential. Beyond the conservative 10 percent barometer set forth in this example, realistic production increases should be 15 percent-40 percent. This would represent savings of $30,000-$80,000 and that doesn’t even factor in a 10 percent-200 percent increase in tool life. Other ancillary savings such as set-up time and maintenance costs should also be absorbed into this equation as well.

Adopting advanced technologies to decrease machining time is paramount to gaining a competitive edge for component manufacturing in vital growth industries such as aerospace, medical, and automotive. In fact, over the past 40 years, CNC machines and the tools used in them have evolved and advanced significantly, as mills are running at faster RPM’s, changing tools in micro-seconds, and have more horsepower.

A machine’s ability to perform well in all of these aspects — power, torque and speed — is especially critical to shops that cut a wide variety of materials. Notably, high speed machining in excess of 20,000 rpm’s is often used when machining components out of exotic alloys and harder metals like titanium and stainless steel.

According to JMPP President John Stoneback, “Tools have become more specific to the materials and processes, with suggested faster speed and feed rate capabilities. The only thing that has not changed is the retention knob. Improper installation, poor spindle maintenance, lack of skilled machinists, and using the wrong tools are part of this equation. Most importantly, the trend toward moving away from standard retention knobs, with their inherent V-Flange deficiencies is vital. Progressively adopting High Torque retention knobs to address this deficit and respond to the growing stresses of today’s manufacturing is paramount to prolonged success.”

More Info www.jmperformanceproducts.com

Exact Metrology now offers Artec Micro 3D scanner

Exact Metrology recently announced the immediate availability of the new Artec Micro 3D scanner. Artec is a world-renowned developer and manufacturer of professional 3D scanners and software. The Artec Micro, an automated, metrology-grade desktop...
The robust construction of the SM 60 demonstrates its design for use in the production environment — right at the point of manufacture — fulfilling the demand for high performance gaging at the point of manufacture, said George Schuetz, director of precision gages at Mahr. “It allows a machinist to easily set up and adapt for new workpieces, while allowing the system to act as either a long-range measuring system or as a very high-performance comparator for sub-micron applications.”

The user is provided the ability to select the best readout for level of performance and application of the measurement. Should versatility be the driving factor, a 25 mm MarCator 1086 or 1087 may be the indicator of choice with its large display or analog-type dial. Having this range allows for measuring a wide range of size parts without having to adjust the system. If higher resolution and performance are required, a Millimar® P2004 LVDT with ±2mm range and C1200 bench amplifier are able to pro-
The new Precimar® SM 60 is an easy-to-use length measurement instrument for fast and precise external measurements on shop floor parts. (Courtesy: Mahr)

provide sub-micron performance at the machining process.

The optional measuring instrument, whether it be a long-range digital indicator or high performance, short-range transducer, is always protected from over range damage by the integrated coupling.

Hardened contact surfaces on both the sensitive and reference contacts ensure long life, even after measuring high volumes of part dimensions. For increased versatility, a family of measuring attachments for the standard contacts is available. These include contacts with radius surfaces, flat-edge contacts, and flat contacts with various diameters, allowing for plain OD checks for adding gage pin wires, OD thread checking and a threaded contact set for adding any of Mahr's standard M 2.5 threaded contacts.

For easy part positioning, an easy-to-adjust support table is positioned up or down for proper part location and then locked into place. Retraction of the sensitive contact is accomplished with a simple retraction lever that is easy to use by right- or left-handed users. Additionally, if simple shaft ODs are a requirement, a floating micro-center support option is available to mount shafts up to 160 mm within the measuring contacts of the Precimar SM 60.

MORE INFO www.mahr.com

Unimove CM500 simplifies overhead handling of materials

Unimove, LLC presents its CM500 vacuum tube lifter for safe and ergonomic handling of bags, boxes, pails, drums, sheet rock, and more. A robust pulley-driven power unit, operated at up to 5,000 rpm, provides the highest lifting capacity in the industry and the ability to effectively handle both porous and non-porous materials. A 5” diameter copolymer RHINO Tube lasts significantly longer than traditional lifting tubes. When coupled with standard stainless-steel components, these proven products provide years of trouble-free service. With a capacity of 140 pounds (non-porous, 110 pounds* porous), automatic balance control, and the ability to accommodate 6-10 moves per minute, the CM500 is ideal for in-plant material handling, warehouse lifting, production line work, and more. The RHINO Tube copolymer construction lasts up to six times longer than traditional lift tube designs with no skewing. This versatile material withstands up to 1 million flex-
Heidenhain supports mastercam to better enable 5-axis machining

In a collaborative effort to best enable 5-axis machining for users with Heidenhain TNC controls and Mastercam® CAD/CAM software, a new collaborate post processor is now available. Called the Heidenhain TNC 5X Mill post processor, CNC Software, Inc., developers of Mastercam software, introduced it recently after coordinating development efforts between the two companies. Collaboration also included beta testers and industry resellers in order to best meet the worldwide demand of providing a consistent, high quality Heidenhain translation post.

All Heidenhain control users who use Mastercam CAD/CAM software can now benefit from this newly developed processor, including those using iTNC 530, TNC 620, and TNC 640 controls.
“Heidenhain is committed to ensuring that our control customers have the tools they need during any 5-axis machining application, and this collaboration post processor is just one example,” said Gisbert Ledvon, Heidenhain TNC business development manager. “We are now experiencing an increased demand in North America for our newest TNC 640 control for high precision 5-axis machine tools, and we want those customers to know that if they have Mastercam software, we are dedicated to providing ongoing translation updates as needed!”

The Heidenhain TNC 5x Mill post processor includes support for the following:

- iTNC 530, TNC 620, and TNC 640 controls.
- PLANE commands (STAY, TURN, MOVE).
- SPATIAL.
- VECTOR.
- EULER.
- TCPM
- TCPM (TNC640).
- M128 (TNC530).

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CNC Thread Grinding

PRECISION GEAR PRODUCTS
(up to AGMA Q14)

GMTA extends its product line, offering baskets, trolleys, lift tables

GMTA, a leader in machine tools and metal fabricating equipment, is adding to its product line. Known for gear cutting and honing, parts washing, special machine tools, tooling, laser welding, surface grinding, deburring machines, multi-spindle lathes, and multi-station vertical machinery, GMTA is now selling baskets, trolleys and lift tables.

Walter Friedrich, GMTA’s president said, “We felt that we needed to have an intermediate step between the machining and cleaning processes.”

Products available include bearing turntables, lift tables, custom carts, and conveyor systems. Lift tables include single-position lift tables, single-position lift and rotate tables, single-position lift and tilt tables, rotate tables, hydraulic-lift tables, air-spring lift tables, and fork-free lift tables for cart access. In addition, custom carts for manufacturing and production operations...
are available. These include 4-wheel carts, 6-wheel carts, low-profile carts, flat-top carts, rotate carts and tilt carts, fork-free carts, and custom-part sequencing carts.

Besides being a link between gear making machines and parts washers, GMTA makes these products available to users in the material handling industry.

NORD extends line of single-stage helical gear units with new sizes

NORD Gear Corporation recently announced the addition of three single-stage gear units to its NORDBLOC.1 line.

The new SK 871.1, SK 971.1, and SK 1071.1 represent the three largest single-stage NORDBLOC gear units manufactured by NORD and provide industry-leading thrust load capacity per case size.

The new products have a power range of 30 to 60 HP, a torque range of 3,540 to 8,850 lb-in. and a ratio range of 1.41 to 8.09:1. With durable UNICASE™ cast iron housing and optimized bearings, they can reliably handle large axial and radial forces and are perfectly suited for pumps, mixers, conveyors, and industrial fans.

Since NORD added single-stage units to the NORDBLOC.1 line in 2017, more than 65 OEMs in the United States have specified the single-stage units for a host of customer applications in food and beverage, oil and gas, and chemical industries. The newly expanded line will enable NORD to capture greater market share by providing a wider selection of configurations at a lower cost than competing gear manufacturers.

“The primary reason for extending the single-stage product line is to provide customers in our target markets a full offering to cover all of their operational requirements,” said Tom Koren, director of engineering at NORD. “By providing single-stage compact gear units that meet the market requirements for speed and torque ratings, customers now can benefit from increased thermal performance, increased bearing ratings and a more compact designs at better price point than our competition.”

GMTA President Walter Friedrich said, “We felt that we needed to have an intermediate step between the machining and cleaning processes.” (Courtesy: GMTA)
With the rollout of the new SK 871.1, SK 971.1, and SK 1071.1, NORD is discontinuing its SK 41E and SK 51E gear units. To ease the transition for existing customers, the new single-stage units come with the choice of two standard output shaft sizes: one to match what the legacy customers are currently using and one to align with market standards.

NORD offers eight single-stage helical gear unit sizes in the NORDBLOC line. Mounted by foot, flange or a combination of both — plus featuring solid shafts with metric or imperial extensions — the line provides customizable, flexible solutions for most high-speed drive applications. Gear units may be ordered with an integral NORD motor or with IEC or NEMA C-face motor adapters.

The new SK 871.1 and SK 971.1 are available now. The SK 1071.1 was slated to launch in late August.

MORE INFO  www.nord.com

ZF Electronic Systems offers Positive-Break Contact Position switches

ZF Electronic Systems recently introduced Steute’s family of Positive-Break Contact Position switches. Units are available with a choice of 10 rotatable (4 x 90°) actuator styles.

Each features a rugged fiberglass-reinforced thermoplastic housing, an operating rate of 1,800 cycles/hour, and compliance to IP65 and cCSAus requirements. Typical applications include packaging, assembly, printing, textile, and woodworking equipment.

These switches are exclusively available in North America from ZF Electronic Systems.

MORE INFO  www.switches-sensors zf.com/us

The newest NORDBLOC.1 single-stage gearmotors extend NORD’s product range to eight sizes, 1.07 to 14:1 gear ratios and 221 to 8,850 lb-in torque. NORD offers multiple output shaft and mounting options.

Consistent Quality
Broad Capability & Capacity
Exceptional People
On-time Delivery

ISO 9001 and TS 16949 registered. Presses up to 8800T and volumes up to 750k/year. Supported by in-house heat treat and an ISO 17025 metallurgical lab.

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Typical switch applications include packaging, assembly, printing, textile, and woodworking equipment. (Courtesy: ZF Electronic Systems)
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To search a complete list of exhibitors by name or product category, visit MotionPowerExpo.com
“Motion + Power is always like a happy family gathering with lots of questions asked, news exchanged, and old friendships rekindled.”

The Motion + Power Technology Expo 2019 is scheduled to hit Detroit, Michigan, October 15-17. The show will bring thousands of industry experts and insiders to the Motor City, where they will be on hand with knowledge to take gear manufacturing and more into 2020 and beyond. Gear Solutions reached out to several exhibitors and asked them to share their plans for M+PT Expo 2019. If you’re going to be at the show, be sure and stop by their booths for more information.

**ADVANCED HEAT TREAT CORP. (AHT)**
**BOOTH #4600**
*Vasko Popovski, PE, Director of Sales and Marketing*

Advanced Heat Treat Corp. is exhibiting at M+P Tech Expo to meet face-to-face with engineers and purchasing professionals about the metallurgy of gears and related components, and how AHT can help them overcome their wear, fatigue, and corrosion challenges. Guests will be able to speak with technical and operations personnel to get the heat treat & metallurgy answers they need now.

**DIABLO FURNACES**
**BOOTH #3407 (M+PT EXPO, MACHINE TOOL BUILDERS) AND BOOTH #1318 (HEAT TREAT EXPO)**
*Bill Gornicki, CEO*

Diablo Furnaces is a new heat-treating OEM poised for growth. Supporting well-known industrial companies with new equipment, Diablo is exhibiting and conveying “Service” by showing our new Utility Van and how it’s an integral part of our company growth. Service is an extension of every aspect from sales, customer relations, installation, and aftermarket, and what better symbol to showcase than our new service vehicle. The expo is the place where connections happen.

**EURO-TECH**
**BOOTH #3209**
*Pat Albers, Marketing Coordinator*

Euro-Tech will feature precision hydraulic expansion arbors and chucks, a workholding solution for high force applications, plus Frenco GmbH spline and gear inspection systems. MyTec Hydraclamp expansion tools are the optimal connecting link between workpiece and machine. Mytec's line of arbors and...
chucks feature accuracy down to 0.0004” (mechanical) or 0.00012” (hydraulic) plus high expansion rates up to 0.010” or greater in a stainless steel construction offering an excellent solution for work-holding where high forces are incurred or auto load applications where high clearance is required. Frenco’s spline gages provide several methods of spline inspection ranging from attribute, to variable and culminating at fully automatic. We will feature hand gages, concentricity gages, and a double flank gear inspection system. Stop by Booth #3209 to check it out!

FOREST CITY GEAR
BOOTH #3418

Jared Lyford, Director of Manufacturing Operations

Visitors to the Forest City Gear booth often arrive armed with drawings and looking for solutions to some of their toughest applications challenges. In many cases, the gears they really need don’t yet exist. Their journey to the right gear for the job often begins right here. So, we take a different approach from many exhibitors at the M+P Tech Expo. We won’t have commodity products on display or demonstrate off-the-shelf solutions. We’ll have plenty of examples of the fine- and medium-pitch precision gears customers throughout the gear industries rely on us to produce.

HAINBUCH AMERICA
BOOTH #3203

Michael Larson, Marketing Director

Clamping solutions for the gear-cutting industry are unique and have special requirements. From our point of view, this is not an ordinary trade show. Attendees come to M+P Tech Expo with a purpose: They are looking for solutions to their gear manufacturing challenges, so be prepared to do business. Highlighting our booth will be the G211 and the MAXXOS mandrels. With our G211, you are relying on a standard segmented mandrel. The rigid and narrow mandrel with optimized tool runout contour is ideal for gear-cutting applications. Three end-stop levels make it possible to use individual workpiece end-stops. The G211 is ideal for gear hobbing, but it can also be used for gear cutting or gear grinding. The new MAXXOS has a hexagonal pyramid shape, perfect for demanding manufacturing.

KAPPS-NILES
BOOTH #3607

Bill Miller, Vice President of Sales and Service

We are exhibiting at MPT Expo to meet our customers and introduce ourselves to new prospects. We’ll introduce our latest KX500FLEX gear grinder with Artificial Intelligence (AI), which calculates and implements corrections for quality assurance both during setup and in production. Our measuring system KNM 5X will be introduced at MPT Expo. The KNM 5X (like the KNM 2X) is equipped with active air damping and thermal comp eliminating tricky measuring task?

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CONTINUED ON PAGE 80
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effects of shop floor conditions. Penta Gear Metrology highlights its functional and analytical gear inspection hardware for shop-floor use, as well as the latest generation evaluation software (PentaSoft). Attendees will also learn the technology of superfinishing gears.

**MITSUBISHI HEAVY INDUSTRIES AMERICA, INC.**
**BOOTH #4418**

Dwight Smith, Vice President

The M+P Tech Expo is the place key decision makers come to find solutions. As a longtime leader in the gear industry, MHIA utilizes the EXPO to develop and maintain relationships with customers and to introduce new products. This year is very exciting, as we will debut our new ZE26C generating gear grinder to the North American market. This innovative machine reduces non-grinding time to increase throughput and productivity while the single table design provides low total cost of ownership. Come see this innovative machine.

**OELHELD U.S. INC.**
**BOOTH #3803**

Stephan Hecht, Executive Vice President

To meet gear-minded friends, customers, prospects, and OEM acquaintances. Motion + Power is always like a happy family gathering with lots of questions asked, news exchanged, and old friendships rekindled; oelheld U.S. Inc., as an innovative and quality-minded supplier to national- and international-operating automotive and specialty-gear manufacturers, will have information material on their best-selling and performing gear-grinding fluids as well as the revolutionary Vomat filtration system at its booth.

**PISELLI ENTERPRISES INC.**
**BOOTH #4500**

Rich Piselli, President

Piselli Enterprises Inc. is exhibiting at the Motion + Power Expo because we want to get back in touch with all the customers we have missed over the years. By starting this new company, it has given us the opportunity to exhibit and put a face with a name, discuss future gear-machine requirements, and talk about the values of their surplus equipment or continued growth and how we can assist. Maybe a simple glass of Scotch, wine, or beer while you rest your feet at the end of a long day. Stop by, and say hello.

**ROTEC TOOLS LTD.**
**BOOTH #3131**

Ivo Straessle, Owner and President

Rotec Tools Ltd. (Mahopac, New York) is displaying the Affolter and Diametal product line at their information booth. Affolter Group has a 100-year history on small gear and pinion manufacturing. Affolter Technologies is manufacturing gear-hobbing machines for small-diameter and small-pitch gears, including spur-, helical-, bevel-, and crown-gears. Diametal is a manufacturer of carbide gear-hobs, including rack-cutters and gear-shaving cutters. Their specialty is fine-pitch hobs.

**SONA BLW**
**BOOTH #3439**

Harriet Tischer, Key Account Manager

Exhibiting our products and capabilities at the M+P Tech Expo is a good way of reaching a large number of key decision makers, gear buyers, and engineers within the automotive, truck, and off-highway industry. The show is a great opportunity to network, build relationships, and to have excellent discussions about the automotive industry, current challenges, and the major changes we are facing, such as electrification and autonomous driving. We are all about gears and their key functional area — the toothing.

**SOUTHERN GEAR**
**BOOTH #4228**

Allan Arch, President

At our booth, attendees will learn why Southern Gear is the go-to source for custom precision gears for industries from aerospace to defense and everything in between since 1957. We look forward to meeting with buyers from industry-leading companies to demonstrate how our skilled workforce with an average tenure of more than a decade, our over-100 modern machines, and our hundreds of thousands of hours of experience making precision gears can work for them to solve their most demanding gear needs.

**UNITED TOOL SUPPLY**
**BOOTH #4614**

Curtis Criswell, Director of Operations

We continually look forward to the M+P Tech Expo to reignite the excitement that comes from working within this industry. The constant buzz and optimism of what’s to come flowing through the expo hall reverberates throughout the attendees and exhibitors alike. We are excited to reconnect with our industry peers, take in what other exhibitors have to offer, and spend a few days introducing new and existing customers to our revamped product line. Our booth will be full of our latest product advancements, in combination with the products that have made our business what it’s been for the last four decades.

**VISIT US AT MOTION + POWER TECHNOLOGY EXPO**

Gear Solutions magazine will be at AGMA’s biannual gear manufacturing and technology show. We hope you’ll stop by our booth (4036) to chat with our staff and to register for our giveaway of a Stor-Loc toolbox. We look forward to seeing you there.
YOU’VE GOT THE PRODUCTS.
YOU’VE GOT THE SERVICES.
NOW, LET US SHARE YOUR STORY.

Gear Solutions wants to make sure the best possible audience knows your company. Through our print, online, and social media presence, our experienced staff can get your message to an industry that wants to know what you can do.

During Motion + Power Technology Expo 2019, stop by Booth #4036 and talk with one of our knowledgeable ad reps to learn more.

GEAR Solutions

Be sure to register for our daily Stor-Loc toolbox giveaway.
The Mitsubishi ZE26C Gear Grinding Machine: **Precision Gears for Precision Systems**

**Optimized** for Electric Vehicles & Robotics

**Greater**
Structural Rigidity

**Shorter**
Non-cutting Time

**Lower**
Running Costs

**Smarter**
Industrial IoT remote monitoring - DIASCOPE

Born from the widely acclaimed ZE-B series, the all new ZE26C has been specifically designed to meet the exacting demands of the electric vehicle and robotics industries.

Featuring increased rigidity of the column, table and grinding wheel head—coupled with revamping of the spindle structure—the ZE26C produces finished gears with enhanced grinding precision and stability. By increasing cutting speed and reducing non-cutting time by roughly 50%, the ZE26C maximizes high-volume production capability and promotes lower running costs. The expanded wheel width provides longer wheel life and supports the use of combination grinding/polishing wheels for improved gear surface finish, making the ZE26C a compact and operationally efficient machine that’s responsive to in-factory needs. To learn more about how the ZE26C has been optimized for the evolving needs of the industry, visit [www.mitsubishigearcenter.com](http://www.mitsubishigearcenter.com) or contact sales at 248-669-6136.