REDUCING TOOL WEAR IN SPIRAL BEVEL GEAR MACHINING WITH THE FINITE ELEMENT METHOD

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REDUCING TOOL WEAR IN SPIRAL BEVEL GEAR MACHINING WITH THE FINITE ELEMENT METHOD

This virtual design approach uses real-world cutting tool geometry, automatically generated gear blanks, and known process kinematics to simulate the cutting process.

By FANG HOU, YANTAO ZHANG, SYED WASIF, PETE MATTSON, and KERRY MARUSICH

MOUNTING DISTANCE OF INTERSECTED-AXES GEARING

To favorably configure bevel gears in intersected-axes gearing, the mounting distance must be one of the most important design parameters.

By STEPHEN P. RADZEVICH

TESTS TO PREDICT PLASTIC GEARS LIFETIME

Experimental tensile fatigue data can be used to predict plastic gear life and the polyamide-based polymer loaded with glass fibers can be used for the metal replacement of gears used in applications with high power.

By DAVIDE ALBIERO and RAFFAELE MAZZARELLA

BRINGING THEORY TO REALITY

COMPANY PROFILE  FVA Software and Service’s expert team of mechanical engineers and software developers enable its customers to develop and implement individual transmission models, complex calculations, and programming tasks.

By KENNETH CARTER
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ROUGHNESS MEASUREMENT TIPS: 2- VS. 5-MICRON

Depending on operating conditions and the flank surface being measured, there are times a 2-micron tip can measure a significant difference compared to a 5-micron radius tip.

INTERNAL RING GEARS – DESIGN AND CONSIDERATIONS

When using internal ring gears, you can develop a gear system with a high reduction ratio in a compact space — but there are considerations.

COST, CLEANLINESS, CARBON FOOTPRINT AFFECT QUENCHANT

Weighing the application of vegetable-based quenchants for heat-treating applications.

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.
Happy holidays from Gear Solutions!

The holidays are in full swing, and it looks like it’s about time to put 2019 in the books. But as we enter 2020 and beyond, let this note not only serve as a season’s greeting, but also as a promise that Gear Solutions will continue to keep our readers’ needs at the forefront. We will explore ways to enhance our products with the ultimate goal to getting the best and latest information about the gear manufacturing industry in your hands — whether that be virtually or literally — just as we did this year and in many years past.

It already seems like a lifetime ago, but it was only in October that we were all in Detroit for the inaugural Motion + Power Technology Expo. Our Gear Solutions family enjoyed meeting new friends and reconnecting with old ones. It was the perfect place to learn and share some amazing accomplishments for the industry.

Gear Solutions helped celebrate the occasion by giving away some amazing Stor-Loc tool boxes to three lucky attendees.

Those winners were:
- Michael Ash with Ilmor.
- Keith Blanke with Cone Drive.
- Katie Kabel with Mitsubishi Heavy Industries.

Congratulations, and I hope you enjoy this incredible addition to your workshop. We hope to see you soon at the next industry event.

But before we give a final farewell to 2019, make sure you take some time to discover this month’s issue of Gear Solutions, which has quite a bit to take in.

December’s focus is on bevel gears and plastic gears, and we have a trio of fascinating articles that go into great detail about some of these staples of the gear industry.

With that in mind, Fang Hou and his associates at Third Wave Systems share their insights on reducing tool wear in spiral bevel gear machining with the finite element method.

Frequent contributor Stephen Radzevich dives into understanding the mounting distance in intersected-axes gearing.

And Davide Albiero and Raffaele Mazzarella with Stagnoli take a look at experimental tests to predict the lifetime of plastic gears.

You’ll find that and much more in our December issue. And keep in mind that we are always looking for interesting and educational editorial content, so if you have a technical paper or other gear-related articles you’d like to see published, please contact me. I’d love to hear from you and be given the opportunity to share your unique knowledge with our readers.

Happy holidays from all of us at Gear Solutions, and, as always, thanks for reading!

KENNETH CARTER, editor
editor@gearsolutions.com
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C-B Gear & Machine hires Frank Irey as general manager

Frank Irey has joined C-B Gear as its general manager to help lead the company to the next level of manufacturing excellence. Irey has more than 34 years in the gear and gearbox manufacturing industry, successfully leading businesses in the commercial, automotive, and aerospace markets. Irey’s background in gear and gearbox design will help guide the business in making advances in manufacturing technologies. Irey will implement new internal practices and programs at C-B Gears as it expands to new customer markets and to improve overall business presence.

C-B Gear has been providing quality products and services at competitive pricing since 1952. The company produces large precision OEM gearing to customer specifications in many industries. It also has in-house aftermarket gearbox repair capabilities restoring old, damaged gearboxes to full OEM specifications. C-B Gear services industrial markets such as petrochemical, refining, oil and gas, power, asphalt, cement, pulp and paper, steel and others.

MORE INFO www.cbgear.com

Chiron Group opens digital machine tool plant for new machine series

Chiron Group celebrated the official opening of its new Precision Factory with a large number of guests from industry and politics. The building was constructed specially for the assembly of new machine series which combine productivity and precision in an unprecedented way. Optimized assembly and logistics processes in the plant will also ensure shorter delivery times.

With a maximum annual production capacity of 400 high-precision machining centers, the nearly 150,000-square-foot Chiron Precision Factory in Neuhausen, Germany, is the most modern machine factory in Europe. Costing more than $38 million and completed in just 15 months, the greenfield building is the largest single investment in almost 100 years of Chiron’s corporate history.

Dr. Markus Flik, chairman of the board of management of Chiron, said, “The combination of productivity and maximum precision is what makes our new machine series so unique – and unique machines need a unique factory.”

In planning and equipping the new factory, IT experts and production planners sought to maximize digitalization of the machine production process in order to achieve high productivity and traceable assembly quality. The plant layout is designed for optimal material flow with logistics spine for all flows of people and materials; centralized final assemblies, technical offices and logistics areas; and central order picking for machines and systems.

The plant operation was also designed to be paperless. “The digital assembly folders and logistics bookings are important milestones on the road to a paperless factory,” a company spokesman said. A pick-by-light system helps the order picker to access stored parts quickly and securely.

For testing and quality assurance purposes and as a reference point, the delivery state of the machines is documented through what the company refers to as a digital fingerprint which contains all data related to each machine.

Also, the Chiron Precision Factory makes an important contribution toward climate protection: waste heat produced by the following the official opening ceremony for the Chiron Precision Factory, the guests had an opportunity to discover its highlights. (Courtesy: Chiron Group)
machines during test runs is used to heat the factory. In fact, the plant environment is controlled through a Smart Factory cockpit for managing air-conditioning, lighting, and camera systems.

The new central logistics department at the Neuhausen plant combines the Chiron Precision Factory with the existing assembly halls to form an integrated Chiron campus. The large and future-oriented project was successfully completed without delays or budget overruns, the company said.

The Chiron Group, headquartered in Tuttlingen, Germany, is a global company specializing in CNC vertical milling and turning machining centers, as well as turnkey manufacturing solutions. The Group has a global presence, with production and development sites, sales and service subsidiaries, and sales agencies worldwide.

MORE INFO  www.chironamerica.us

Exact Metrology’s website offers a wealth of information

Exact Metrology, a leading metrology services provider, offers information on 3D scanning services, CT scanning, metrology equipment, and software solutions on its website.

The company’s 3D scanning includes inspection scanning, CT scanning, reverse engineering, long-range scanning, and scan to CAD.

CT scanning (computed tomography) is used in aerospace, archeology, automotive, castings, die cast, electronics, food, molds, personal products, and plastics. Confident in its ability to obtain 3D views from inside a part, Exact Metrology issued a GOM CT challenge. It invited users to send scanned data they’ve obtained from other technologies. If the results obtained from GOM CT weren’t superior, the company would send the user $100 with no strings attached. In addition, Exact Metrology is a representative and seller in North America of Procon X-ray GmbH, a German developer of x-ray inspection equipment for industrial applications and university/scientific research.

Besides GOM and Procon, Exact Metrology features various leading manufacturers such as: Artec 3D, Geomagic Capture, Hexagon, InspecVision Planar, Leica Geosystems, Leica HDS, Polyrix, Raytech, and Surfacer.

Along with its equipment, Exact Metrology offers several software options to complement its offering. This includes Artec Studio, Leica Geosystems Cyclone, Hexagon, Geomagic, GOM Inspect, Polyworks, Volume Graphics and 3D Reshaper.

MORE INFO  www.exactmetrology.com

Exact Metrology, a leading metrology services provider, offers information on 3D scanning services, CT scanning, metrology equipment, and software solutions on its website. (Courtesy: Exact Metrology)
Gear Motions announces personnel changes at its Nixon Gear Division

Gear Motions, a leading precision gear manufacturer, has promoted Brittany McVea Dankiw to manufacturing engineer, and hired Kris Gardner as customer service/purchasing coordinator at its Nixon Gear Division in Syracuse, New York.

Dankiw has been at Nixon Gear for nearly five years, previously serving as customer service/purchasing coordinator before being promoted to manufacturing engineer.

Her engineering education includes a B.E. in mechanical engineering and a U.S. Coast Guard 3rd Assistant Engineer license from SUNY Maritime. She gained experience working in the ship’s engine room and developed skills in troubleshooting and problem solving. Dankiw’s previous work experience includes testing and design engineering for gears and gearboxes. She is furthering her training to become more proficient in the areas of gear and manufacturing engineering. As manufacturing engineer, Dankiw will help to improve processes and productivity in all areas of manufacturing, including streamlining and reducing waste.

Kris Gardner was hired to fill the role of customer service/purchasing coordinator.

Gardner brings many years of experience to his new role. He earned a B.S. in business management from SUNY Oswego in 2015, and most recently held a purchasing position as a contract administrator for government contracts. He also has experience in warehouse operations management and as a machine/heavy equipment operator at Novelis in Oswego, New York.

Gear Motions, Inc. is an employee-owned company, with gear manufacturing facilities in Syracuse and Buffalo, New York. Specialists in precision ground gears, the company manufactures custom cut and ground gears for OEMs all around the world. Products include precision ground helical gears, spur gears, pump gears, bevel gears and worm gears, as well as multiple types of sprockets, timing pulleys, shafts and splines.

MORE INFO www.gearmotions.com

Hexagon Leitz Reference BX CMM speeds blade and glass measurement

Hexagon’s Manufacturing Intelligence division launched the Leitz Reference BX coordinate measuring machine (CMM) designed for blade and glass manufacturers. The specialized system combines leading-edge technologies to accurately capture detailed measurement data across the entire surface of a freeform shape, while dramatically reducing cycle time. The CMM’s optical white light sensor performs well on matte and reflective surfaces, including glass and polished metal. Its fixed scan probe maintains the high precision needed for critical alignment on the root of turbine and fan blades, and also measures inclined fir tree or dovetail root surfaces, which are not easily accessed by an optical sensor.

The Leitz Reference BX CMM’s integrated
rotary table and sensor exchange interface help to reduce cycle time even further by providing accessibility to a part’s surfaces without moving the part, and reducing inspection delays caused by manually exchanging sensors. The system’s combination of an optical white light sensor and fixed scanning probe enables accessibility of hard-to-reach-features such as the curvature of edging on glass, or the profile of a fan blade, while maintaining precision for tight tolerance sections such as the blade root. The CMM’s data capture, speed, and flexibility are all enhanced by its integrated rotary table, horizontal sensor alignment, and 4-axis scanning delivering a cycle time reduction of up to 50 percent.

“Manufacturers today are leveraging new and innovative materials for their designs and freeform components, such as carbon fiber in the aerospace sector or 3D glass in the consumer electronics industry,” said Lukas Kaps, product manager for the ultra-high accuracy CMM line for Hexagon’s Manufacturing Intelligence division. “The Leitz Reference BX is the only CMM in the marketplace that addresses the inspection challenges evolving from these exciting trends and advancements. This sophisticated measurement system delivers a complete solution for complex surfaces like the curvature of a smartphone screen or intricate components such as fan and turbine blades.”

MORE INFO  www.hexagon.com

Gasbarre supplies cold isostatic press to supplier in metalworking industry

Gasbarre recently manufactured and commissioned dry-bag cold isostatic press to a leading German manufacturer of end mills, drills, tool holders, and wear-resistant components for the metalworking industry. The press was designed with the ability to form components of up to 450 mm in length and 3,000 bar (43,500 psi) pressure (Monostatic 400 Series III) for the pressing of tungsten carbide powder into rod, sleeve, and bar preforms. Gasbarre used an advanced forming system that converts hydraulic primary pressure to high pressure forming fluid with an integrated one-shot pressure intensifier for pressure curve control and optimum cycle rate. An HMI/PLC/Motion Control package was used for parameter access, control and monitoring, or all machine aspects. While capacity need driven by growth in the automotive, aerospace, and energy sectors made the acquisition necessary, the manufacturer chose Gasbarre because of their experience. Gasbarre has provided support of the Simac line of presses and continues to produce quality isostatic equipment with continuous enhancements, which provided the confidence necessary to stay with Gasbarre for their seventh Gasbarre/Simac press.

Located in DuBois, Pennsylvania, Gasbarre Powder Compaction Solutions (press & automation) has been designing, manufacturing, and servicing a full line of powder compaction equipment and services for more than 40 years. Gasbarre’s product offering includes mechanical, hydraulic and electric uniaxial presses as well as dry-bag isostatic presses for high-volume and lab type of environments. For unmatched support, Gasbarre provides a full line of replacement parts and auxiliary equipment which consists of customized

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and fluidized mold filling systems, powder handling, and automation, which includes palletizing, weighing, and scanning from the press as well as furnace unloading systems. Gasbarre continues to service and support Simac and PTX-Pentronix brand equipment.

MORE INFO www.gasbarre.com

MC Machinery Systems, Adira partner to provide press brake line

MC Machinery Systems, Inc., a subsidiary of Mitsubishi Corporation, and Adira, a Portuguese manufacturer, part of Sonae Capital portfolio, have formed a sales and service partnership to deliver quality press brakes throughout North America from 100 through 2,000-plus ton capacity machines.

Adira was established in 1956 in Porto, Portugal, manufacturing a variety of sheet metal working machinery. With more than 162,000 square feet of production space, Adira is capable of producing hundreds of quality machines for export all over the world. Adira’s commitment to innovation and continuous improvement have linked Adira’s engineering department to universities and development institutes (University of Porto, MIT, INEGI, & INESC) in a network to develop and transfer innovations and knowledge.

MC Machinery Systems, Inc. partnered with Adira to offer customers more products at economical prices, while providing an extensive network of service and support. MC Machinery Systems, Inc. is headquartered in Elk Grove Village, Illinois, with offices in California, New Jersey, Texas, North Carolina, Ontario, Canada, and Queretaro, Mexico, with parts inventory in excess of $15 million. MC Machinery is well equipped to support all customers with full sales and technical staff.

“The Adira partnership is exciting because it fills a gap in the press brake offering for MC Machinery,” said David Bray, national press brake product manager. “This offering ranges from simple inexpensive hydraulic press brakes to well-equipped high tonnage customized solutions for our customers who expect a higher level of quality and service.”

The Adira press brake line offers customers the option to purchase a standard solution or customize with additional accessories and options. These hydraulic press brakes range from entry level up through high tonnage machines to meet the needs of a wide range of industries.

MORE INFO www.mcmachinery.com

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Hexagon, University of Rhode Island partner for advanced manufacturing

Hexagon’s Manufacturing Intelligence division has formed a collaborative partnership with the University of Rhode Island College of Engineering. Hexagon will provide manufacturing technologies to enable a rich research environment for undergraduate and graduate programs focused on advanced manufacturing.

In October, URI opened its new 190,000-square-foot, six-story Fascitelli Center for Advanced Engineering. The new facility will strengthen the college’s global leadership in engineering education. The work conducted there will build on research in the areas of clean energy, nanotechnology, robotics, cybersecurity, water for the world, biomedical technology, smart cities, and sensors and instrumentation. Hexagon, a multinational company with the North American headquarters of its Manufacturing Intelligence division in Rhode Island, has supported engineering students with an internship program and study abroad assistance.

Hexagon’s Manufacturing Intelligence division is a long-time supporter of URI’s International Engineering Program that combines engineering, foreign language, and study abroad to prepare students for 21st century careers. Many of the company’s employees are URI graduates. Taking the partnership to a new level, Hexagon will provide the facility with state-of-the-industry metrology systems, applications software for both measurement and computer-aided manufacturing (CAM), as well as sophisticated simulation software tools for design engineering.

“The University is grateful for Hexagon’s continuing investment in our engineering programs. Its support is recognition of the strength of our faculty, their areas of research and the importance of educating and training the next generation of scientists and engineers,” said URI President David M. Dooley.

“Early on, Hexagon recognized that URI’s International Engineering Program was an important local asset for building our workforce with graduates with technical knowledge and the skills needed to delve into the international business arena,” said Angus Taylor, president and CEO, Manufacturing Intelligence, North America. “The State’s support and investment in the Fascitelli Center project underlines their commitment to the students and workforce that will drive Rhode Island’s future. We are a willing participant in their mission to shape engineering education and the world through innovation, invention and passion. We are proud that our technology portfolio and Hexagon experts across the global spectrum will support the University’s research and development efforts.”

MORE INFO  www.hexagon.com

Metal Exchange Corporation names Rick Merluzzi CEO

Metal Exchange Corporation (MEC) promoted Rick Merluzzi to chief executive officer of MEC. Mike Lefton, current MEC chairman and CEO, will assume the title of executive chairman. Merluzzi oversees all Metal Exchange Corporation busi-
nesses, including Metal Exchange Trading, Pennex Aluminum Company, Continental Aluminum, and Electro Cycle, Inc. Merluzzi joined Metal Exchange Corporation 15 years ago as president of MEC subsidiary Pennex Aluminum Company, and for the past five years has served as president and chief operating officer of MEC.

“Much of our success at MEC can be attributed to Rick Merluzzi’s outstanding leadership,” said Lefton. “Rick builds high performing teams internally, and creates valued partnerships externally. He is laser-focused on our vision to become an injury-free company, and has a passion for helping all in the MEC family reach their fullest potential. Rick’s actions exemplify the Metal Exchange Dual Bottom Line philosophy, where the safety, well-being, and fulfillment of everyone within MEC are held equal to our financial success. I have extreme confidence in Rick’s ability to continue to lead Metal Exchange Corporation to new heights, as we continue our quest to impact our world and create raving fans.”

“Metal Exchange has an incredible track record of success over its 45-year history. I am humbled and honored to work for this family-owned, people-focused organization, which has a long-term commitment to our industry,” Merluzzi said. “We have grown substantially by focusing on helping our customers achieve success. This impressive growth is a direct result of the hard work and commitment of the many talented people throughout our company who embrace our core values of safety, integrity, respect and drive.”

MORE INFO  www.metalexchangecorp.com

Methods Machine Tools introduces own brand of vertical machining

Methods Machine Tools, Inc., North America’s foremost supplier of leading-edge precision machine tools and automation, has introduced a new line of Methods branded 3-axis vertical and 5-axis bridge type machining centers, all engineered and built to Methods’ highest specifications and quality standards. The Methods machining centers are available in North America, and offer an affordable, accurate, and reliable best-in-class mid-range machining solution.

Methods’ engineering team has ensured that our new branded line meets our customers’ needs and expectations in North America. These machines will provide an ideal value-to-performance solution in the marketplace and complement our full portfolio of leading lines.”

Methods machining centers are made to Methods’ design and engineering standards by Litz Hitech Corp., a reputable, well-established machine tool builder, and are fully backed by Methods’ industry-leading service and support. All Methods machining centers are fully inspected to meet strict quality and design specifications, and also be in compliance with ISO/ASME standards. Laser and ball bar testing ensure performance and accuracy of each machine.

Methods 3-axis vertical machining centers include four initial models – MV 800H, MV 1000H, MV 1100H and MV 1600H – featuring a 15,000 RPM, 30 HP BIG-PLUS 40-taper direct drive spindle with oil-air lubrication and spindle oil chiller, providing power, speed, superior surface finishing, long spindle life, and thermal stability. Rigid box-way construction in the Z-axis using Turcite B ensures exceptional cutting performance and machining accuracy. Turcite B technology was specifically developed to provide machines with superior rigidity, low friction coefficient, reduced vibration, excellent damping characteristics without stick-slip, as well as very high wear resistance for long machine life.

Methods 5-axis machining centers offer an affordable, accurate, and reliable best-in-class mid-range machining solution. Methods MB 650U 5-axis bridge type machining center is designed for the high accuracy, 5-axis simultaneous machining of complex parts and significantly reduces the need for multiple setups. (Courtesy: Methods Machine Tools)

Additional features in the Methods vertical machining centers include thermal compensation using three thermocouples to allow the software to compensate for actual thermal growth. The MV 800H and MV 1000H have robust 1.378-inch (35mm) roller guideways in the X and Y-axis with 2.362 IPM rapid rates. The MV 1100H has a larger structure with 1.77-inch (45 mm) roller guideways in the X and Y-axis with a 1,890 IPM rapid rate, and its Z-axis box ways are more than three inches wider (side-to-side) than the MV 800H and MV 1000H. The MV 1600H is a heavy-duty 41,888-pound machine designed for exceptionally cutting performance on large, diverse, complex parts. The MV 1600H has an impressive 21.85-inch distance between Z-axis box ways (side to side) and offers 2.17-inch (55 mm) roller guideways in the X and Y-axis with 1.417 IPM rapid rates. Automatic tool changers range from 24 tools to 40 tools, depending on the machine.

Methods MB 650U 5-axis bridge type machining center is designed for the high...
accuracy, 5-axis simultaneous machining of complex parts and significantly reduces the need for multiple setups. Equipped with standard linear scales on the X, Y, Z-axes, rotary scales on the B and C-axes, and thermal compensation results in stable, high-precision part production. The MB 650U has a 15,000 RPM, 25 HP BIG-PLUS 40-taper direct drive spindle with oil-air lubrication and spindle oil chiller for long spindle life. This performance package also includes a calibration ball, TCP software, and probe system for setting/calibrating precise tool center point. A laser tool measurement system detects tool wear, damage, and breakage, reducing non-productive time and enabling automated operation.

All Methods machining centers feature FANUC controls, the industry’s benchmark for quality and reliability. Methods’ VMCs have the FANUC 0iMF Control with 10.4-inch LCD screen, manual guide I, AICC II, 2 m/ sec Block Processing Time (BPT) and 200 Block Look Ahead. For the highest level of performance and processing power required for complex 5-axis machining, the MB 650U Bridge Type machining center features the FANUC 31iMB5 Control with 15-inch TFT screen including a data server, manual guide I, AICC II, 1 MB of NC memory, 4ms BPT, 600 Block Look Ahead, collision detection (built in 3D interference check), Fast Package III, Ethernet and 2GB CF card.

“We are confident that our new Methods machining centers will exceed customer expectations for quality, reliability, accuracy, and longevity at a competitive price,” said Jeff Ervay, Methods brand product manager. “To meet the needs of our customers, we are continuing the development of the Methods product line with additional models in the future.”

More Info www.methodsmachine.com

Milltronics names exclusive distributor for Colorado, New Mexico

Milltronics USA has named Foothills Machinery Sales as its exclusive full-service distributor for Colorado and New Mexico.

Founded in 1984, Foothills Machinery Sales is Colorado’s oldest independent dealer of machine tools. Foothills Machinery Sales, in Broomfield, Colorado, is home to knowledgeable sales and service support staffs.

“We’re excited to be representing Milltronics,” said Tim Beer, general manager of Foothills Machinery Sales. “The Milltronics brand is well known for its line of tool room machines that have integrated conversational controllers that make CNC seamless, but they also have a range of CNC machining centers and CNC lathes that offer shops well-built machines at a competitive price. Another big advantage to the Milltronics controller is the G-code visualization screen that helps conversational programmers see the G-code as the program is being created. We’re really proud to offer Milltronics as an option for our customers throughout Colorado and New Mexico,” said Beer.

Foothills Machinery Sales is in charge of sales, service, parts, training, and applications support for Milltronics customers in Colorado and New Mexico. They have industry veterans within the Foothills service, parts, and applications team with in-depth knowledge of machining, tooling, programming, fixturing, and workholding.

“The team at Foothills is top notch,” said
Louie Pavlakos, Milltronics USA general manager. “We know they’re going to help us sell machines throughout Colorado and New Mexico, but even more important, we know they’re going to offer excellent service.”

Milltronics USA has named Foothills Machinery Sales as its exclusive full service distributor for Colorado and New Mexico. Tim Beer, general manager of Foothills Machinery Sales, with the Milltronics MB20 CNC toolroom mill. (Courtesy: Milltronics)

With more than 14,000 machines installed, the company has built its reputation on intuitive controls and well-built machines backed by superior service and support.

Optomec integrates AutoCLAD Vision System into metal 3D printing

Optomec, a leading, privately-held global supplier of production-grade additive manufacturing equipment and software, announced it has integrated the Huffman AutoCLAD vision system with its LENS (a registered trademark of Sandia National Labs) directed energy deposition (DED) metal 3D printing solutions. AutoCLAD is a proprietary integrated vision and software system that generates a custom toolpath for each part prior to processing. Originally developed for the Huffman brand, the system has been used in production extensively by major manufacturers and servicers of aircraft engines and industrial gas turbines to restore worn or damaged components. Adding this capability to the LENS brand of solutions will enable customers to use automated DED for the repair of reactive metals like titanium in a controlled argon atmosphere. It also brings the AutoCLAD technology to hybrid additive manufacturing, combining additive manufacturing and machining capabilities in a single system.

AutoCLAD images the part and then automatically adapts and modifies the toolpath and DED parameters for each individual part based on variations in orientation, dimension, and shape. It not only adjusts the toolpath for variation, but it also adapts laser power to reduce the heat input into thinner areas, which drastically reduces the heat-affected zone (HAZ) of the finished part. Finally, by fine-tuning the toolpath for the individual part, a smaller overbuild is achieved which significantly reduces the final machining time after the additive manufacturing process.

“This latest enhancement combines three important technologies developed by Optomec into a single system. Combining the capabilities of AutoCLAD with Optomec’s industry-leading controlled atmosphere...
technology and hybrid manufacturing solutions enables the processing of reactive metals without oxidation, and allows additive manufacturing and machining in a single system. No other company has this combination, in fact, no one has software like AutoCLAD,” said Mike Dean, marketing director at Optomec. “We see this as a big win for customers who want to use DED for the repair of titanium components as well as anyone doing repetitive part repair in industries such as oil and gas, mining, and tool and die.”

The AutoCLAD system is available immediately as an upgrade for all Optomec LENS systems that use the Siemens 840D controller, which includes the LENS CS 600, CS 800, CS 1500, and MTS 860 machines. Please contact Optomec for pricing.


Nord Gear expands its satellite facility in Charlotte

Nord Gear Corporation, a world leader in drive technology, is in the midst of two large expansion projects as demand for its industrial gear reducers, motors, and variable frequency drives continues to grow. In addition to the previously announced 86,000-square-foot expansion to its U.S. headquarters in Waunakee, Wisconsin, that’s under way, the company is doubling the space of its satellite facility in Charlotte, North Carolina.

Nord opened its Charlotte operations in 1997 and has expanded twice since that time, most recently in 2010.

This latest expansion will see both office and manufacturing spaces roughly double in size as Nord takes over more space in its Nations Ford Business Park location. When renovations are complete next spring, Nord will occupy approximately 37,200 square feet, with 32,000 square feet dedicated to manufacturing.

The expansion of the manufacturing space includes some notable investments in new technology, including an improved paint system, modernized team assembly workstations, expanded warehouse, and higher capacity crane systems. Meanwhile, office workers will benefit from additional cubicles, a new meeting room, expanded breakroom, and a much-improved training room.

Meanwhile, construction at the head-quarters location in Waunakee continues to progress and should be completed by April 2020. The expansion will add 86,000 square feet of office and manufacturing space. Nord employs approximately 425 people in the U.S., with offices in Waunakee, Charlotte, and Corona, California. It is part of the German-based Nord Drivesystems® Group, which employs more than 4,000 employees worldwide.

MORE INFO www.nord.com

Mahr introduces new vision capabilities for Precimar® ICM 100 IP

Mahr Inc., a leading provider of dimensional metrology solutions, today announced the expansion of its proven Precimar® ICM 100 Dial and Digital Indicator Calibrator with image processing, designed for the automated testing of measuring equipment. Existing

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Precimar Optimar 100 devices can also be upgraded with the new vision capabilities.

The ICM 100 is a proven solution for testing dial and digital indicators, test indicators, and dial comparators. The new image processing upgrade now makes working with the measuring instrument safer and faster—a camera automatically records the indicated values of the test indicators and forwards them to a software for processing. The automated procedure saves time and eliminates error-prone readings by the operator. The user also benefits by eliminating eyestrain and muscle fatigue since no interaction is required once the automated calibration process begins.

The hardware and software add-on package provides a cost-efficient way to equip new or existing ICM 100 measuring stations for automated testing. The measuring system including image processing is also available as a complete package under the name Precimar ICM 100 IP.

The new vision capabilities incorporate the fast image processing of a USB 3.0 camera and stable daylight-independent LED illumination, along with secure digital identification and reading of digits. Mahr’s Precimar software for gage calibration controls the measuring device, evaluates the image of the scale or number display of the test object, compares the values with the high accuracy internal reference scale, and automatically completes the process of calibrating the product under test. The software also makes it possible to create and store test certificates.

The easy operation of the ICM 100 with image processing speeds up and facilitates the monitoring of the indicators under test. With auto-recognition of the vision system, more test items and data points will be recorded faster than conventional manual methods. The completely automated inspection system enables the operator to be more productive, completing additional operations while the ICM 100 IP automatically completes the calibration process. This makes indicator inspection much more economical.

Precimar software is preloaded with many standard indicator calibration routines as defined by various national standards including American ASME/ANSI, British, German, French, Japanese and Russian. (Courtesy: Mahr)

Precimar software is preloaded with many standard indicator calibration routines as defined by various national standards including American ASME/ANSI, British, German, French, Japanese and Russian. (Courtesy: Mahr)

Zoller demonstrates latest technology at two-day event

Zoller Inc. hosted its annual Zollerfest in October at its North American Headquarters in Ann Arbor, Michigan.

Zollerfest is an annual technology days and open house event that combines the celebration of the company’s German heritage and its industry-leading technology in presetting, measuring, inspection, tool management, and automation to create a distinctive manufacturing event. More than 100 guests visited Zoller Inc. across the two-day event, coming from a variety of industry segments ranging from aerospace and defense to job shops, with the goal of learning how Zoller solutions could help bring success to their manufacturing process.

Despite the day’s Oktoberfest-inspired décor, Zollerfest is a technology driven event. Zoller’s Industry 4.0 Technology Center houses 39 machines and solutions, including the two latest additions, the Zoller “aralon” and “gemini 2” for crankshaft milling cutter measurement.

These machines significantly increase measurement accuracy and reduce the time spent measuring crankshaft milling cutters, which in some cases can take hours to measure using other methods. With Zoller’s machines, a crankshaft milling cutter can be measured in mere minutes. This was a highlight of Zollerfest throughout the two-day event, and many visitors showed their interest in the benefit of both the gemini 2 and aralon.

There were several keynote presentations at Zollerfest. Georg Maerz, vice president of Zoller Inc., started both days by delivering his presentation, “The Zoller Experience: Driving Success in Global Manufacturing for Over 70 Year.” With the 2019 theme of Zollerfest as ‘Zoller Solutions: Your Key To Success,’ it was a fitting addition to have Jerry Busche, president and CEO of PDQ and Impact CNC follow up on Maerz’s presentation, as he gave a firsthand account of his experiences with Zoller and how PDQ and Impact CNC have experienced great success by using Zoller solutions.

“I had experience with Zoller before and it was amazing when I was using it on the floor,” Busche said. “It was an easy decision for me to buy Zoller. Everyone knows the Zoller name and the world-class product that it is. As customers recognize that you’re using (Zoller) to produce your product, they have a confidence level in your company that you’ll produce a good product.”

In addition to several keynote presentations, Zollerfest featured technical sessions at various stations, discussing subjects ranging from basic tool presetting, to CAM interfaces, to cost per part with Tool Analysis.
Anthony Westfall, TMS technical support engineer at Zoller Inc., demonstrated Zoller’s cost per part feature throughout Zollerfest.

“Cost per part provides a significant benefit for large-scale production facilities,” Westfall said. “We were excited to be able to demonstrate cost per part with tool analysis live at Zollerfest, and it was very well received by our guests.”

More Info www.zoller-usa.com

Tormach unveils new servo-driven CNC product at FABTECH 2019

Tormach, Inc., the industry’s leading supplier of affordable, compact CNC machines, displayed numerous machine tools at the November FABTECH 2019 show.

The company featured its newest CNC mill, the 1100MX. The new MX series are servo-driven versions of the company’s best-selling two mills, the 1100M and 770M, which were introduced in 2018. The new MX series of machines feature an added encoder to the spindle for rigid tapping, a BT-30 spindle, and servos for the X, Y, and Z axes. The servos provide much faster performance with maximum speeds up to 10,000 rpm and feed rates as much as 2.5-3x faster than the M series machines.

The 1100MX on display included the company’s upgraded PathPilot® Operator Control Console. When combined with PathPilot, which provides users with numerous premium features as standard, these machines provide the highest performance and most cost-effective machining solutions on the market.

In addition to the 1100MX CNC Mill, Tormach also featured:

- **PCNC 440 mill:** The company’s benchtop mill that fits all-around capability in a small and affordable package.
- **15L Slant-PRO® lathe:** A CNC slant-bed lathe designed for prototyping and light production.
- **PSG 612 grinder with belt sander attachment:** A compact, 2-axis automatic personal surface grinder for the small metal shop.
- **AF50 Autofeed Bandsaw:** A programmable, affordable, automatic bandsaw priced under $5,500.
- **xsTECH Router:** A new desktop router that is ready-to-run out of the box to cut wood, plastics, and ceramics, and engrave aluminum, brass, and other light metals.
- **PathPilot HUB:** A new, cloud-based, full-
Optomec extends runtimes for 3D-printed electronics

Optomec, a leading, privately-held global supplier of production-grade additive manufacturing equipment and software, announced that its Aerosol Jet® print engine has been upgraded to operate with an uninterrupted 8-hour runtime. The solution enables full shift operation to better meet the needs of current and next-generation electronics manufacturing across a broad range of industries.

“We’ve optimized the mist delivery mechanisms to enable the Aerosol Jet print engine to operate continuously for a full 8-hour shift. This advance, along with Aerosol Jet’s material deposition versatility, make the system ideal for high-volume 3D advanced semiconductor packaging, as well as manufacturing of 3D antenna, sensors, and circuitry. The solution is enabling for a wide range of smart mobile devices, automotive, and medical applications as well as a host of other electronics and wearable products,” said Bryan Hermann, product manager, Aerosol Jet.

The Optomec Aerosol Jet print engine can now run up to 8 hours continuously without operator intervention while maintaining minimal variation in mass output. This directly correlates to high stability for printed line width and line-height as well as the resulting electrical performance (i.e. resistance of conductive traces).

Optomec’s Aerosol Jet technology is offered as a complete production solution enabling 3D printed electronics applications but the print engine can also be sold separately as a scalable solution to be integrated into customers’ own automation solutions. Digital products, such as process recipes, are also available to speed up integration into production.

MORE INFO
www.optomec.com
When announcing that the 2020 AGMA/ABMA Annual Meeting was going to be at Disney's Grand Floridian Resort & Spa, we were met with excitement and child-like energy from our membership. Who doesn't have fond memories of galivanting around the Magic Kingdom, meeting Mickey Mouse and Goofy? But what our members might not understand yet is that the magic really stems from the unparalleled programming and focus on how to inspire growth in their business, in their workforce, and in their connections.

Sure, there will be fun at the private reception at Disney's Animal Kingdom© Theme Park, with exclusive access to rides in Pandora: The World of Avatar. Of course, there will be opportunity to meet new attendees and gain exposure to industry peers at all networking events and at the new Emerging Technology Breakfast. And as usual, guests and spouses will have time to enjoy some hand-picked activities curated just for their enjoyment. We have come to expect all of this at the Annual Meeting; however, we wanted to go one step further.

In order to inspire growth, it is imperative that our general sessions offer the business intelligence and expert speakers our members need. Programming is no longer just about a flashy speaker with some quick wit and no real call to action. AGMA and ABMA pride themselves on offering real value to members, and we hope to expand that in 2020. Walt Disney Parks & Resorts has set the bar when it comes to meeting guest expectations. They have written the manual on customer service, and through the Disney Institute, we will be exposed to some of the fundamentals of leadership, engagement, and service.

Our membership is not a one-size-fits all, and the 2020 Annual Meeting reflects this diversity. Attendees will have access to general sessions that speak on workforce development, economic forecasts, political climate, geopolitical strategy, leadership, and more. These speakers are here to talk about the important issues manufacturers are facing today and will provide great insight into what to expect for the future. This kind of access to information, on such a personal level, is one of the quickest ROIs you will make all year.

Coming to a location like Disney will allow attendees to see first-hand the importance of designing exceptional service and a common purpose for employees. Although it is a fun place with a reputation for theme park rides and movie characters, we know members will gain a great perspective that will help their business grow. The Disney Institute will have a speaker that will address our group directly, tailoring their presentation for our needs. They have worked with numerous companies in the automotive and manufacturing industries, including General Motors, Parker Hannifin, and Volvo, teaching large and small corporations how to inspire employees, nurture their customers, and grow their services.

Make 2020 the year you and your company grow. Attending the AGMA/ABMA Annual Meeting is a great place to catch up with friends and to meet new people who might be instrumental in your business’ success. Manufacturing has experienced a great deal of changes, and it is only going to get more complicated as new technologies emerge, political leaders change, and the next generation comes into the workforce. Let AGMA and ABMA be your guide to help prepare you for what’s to come.

To sign up for the Annual Meeting, go to: www.agma.org/events/agma-abma-annual-meeting

There is still room for sponsorship as well. Please contact Leah Lewis at lewis@agma.org with any questions.
AGMA hosts inaugural Motion + Power Technology Expo

MPT EXPO PROVIDES LARGEST EXHIBIT FLOOR IN AGMA SHOW HISTORY.
The American Gear Manufacturers Association (AGMA) held the first Motion + Power Technology Expo (formerly Gear Expo) in Detroit, Michigan in October. The inaugural event also showcased new partners, the National Fluid Power Association (NFPA)’s Fluid Power Pavilion, and continued the colocation of the show with ASM International’s Heat Treat Conference & Exposition. With 62,700 square feet of exhibits, MPT Expo was the largest tradeshow that AGMA has ever hosted. There were more than 250 companies exhibiting — 50 being first-time exhibitors — bringing the complete power transmission supply chain together.

To read the full press release, please visit: www.agma.org/resources/newsroom/press-releases/agma-hosts-inaugural-motion-power-technology-expo/

The AGMA Fall Technical Meeting was a huge success!

2020 CALL FOR PAPERS IS READY FOR YOUR SUBMISSION
The FTM hosted more than 125 attendees from all over the world. Technical papers were presented on topics varying from electric vehicle transmissions to the performance of new, alternative gear steel. Attendees were able to enjoy the latest research in the industry with some important networking opportunities including the popular Fun & Games Reception! The 2020 Call for papers is up and ready for submission. Visit www.agma.org/2020-call-for-papers/ to see the details.
Last Face-To-Face Courses for 2019!

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.

Did you Know that AGMA Offers On-Site Education?

That’s right, AGMA will bring the quality education right to your building. We offer custom on-site/in-house training that will save you money and time. We understand training can be costly to your bottom line, but it still remains a necessary component for your company to remain on the cutting edge of gear knowledge in order to implement best practices in your workplace. We recognize how important this balance is, and so we work with companies to bring instructors directly to your facilities.

Benefits of On-Site Training

COST SAVINGS
By brining AGMA to your location, you can eliminate the cost of sending your staff to another place. Your organization will:

- Eliminate travel costs.
- Maximize employee training time.
- Increase productivity of your most valuable asset.
- Boost your employee retention program.
- Reduce turnover.

CONVENIENCE
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- Benefit from courses that fit your needs.
- Training in your facility or shop.

RELEVANCE
- Tailor the courses to incorporate examples and content specific to your company’s needs and challenges

SUCCESSION PLANNING
- Reduce the impact of the knowledge gap as new hires start and seasoned workers retire.
- Increase cross-training activities to enhance and diversify the skills of your workforce.

PRIVACY
- Having training at your facility keeps your training needs and proprietary interest private. This provides your team with the ability to speak as freely as needed.

ACCREDITED
AGMA is accredited by the International Association for Continuing Education and Training (IACET). AGMA complies with the ANSI/IACET Standard, which is recognized internationally as a standard of excellence in institutional practices. As a result of this accreditation, AGMA is accredited to issue the IACET CEU.

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’s 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.

AGMA has over 1,000 Twitter followers! Join the conversation @agma
CALCULATOR 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.

December 16 — Wormgearing Committee Meeting — WebEx
December 17 — Plastics Committee Meeting — WebEx
December 18 — Lubrication Committee Meeting — WebEx
December 19 — Nomenclature Committee Meeting — WebEx

January 7 — Helical Gear Rating Committee Meeting — WebEx
January 14 — Metallurgy and Materials Committee Meeting — WebEx
January 21 — Nomenclature Committee Meeting — WebEx
January 23 — Gear Accuracy Committee Meeting — WebEx

February 5 — Bevel Gearing Committee Meeting — WebEx
February 6 — Powder Metallurgy Committee Meeting — WebEx
February 20 — Helical Gear Rating Committee Meeting — WebEx
February 25 — Metallurgy and Materials Committee Meeting — WebEx
February 26 — Plastics Committee Meeting — WebEx

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Roughness measurement tips: 2- vs. 5-micron

Depending on operating conditions and the flank surface being measured, there are times a 2-micron tip can measure a significant difference compared to a 5-micron radius tip.

I’ve written three articles on gear flank roughness measurement for this magazine (Materials Matter; January 2016 and February 2016, and an issue-focus article in January 2019). Those articles gave guidance on the setup and measurement of the roughness parameters (Ra, Rz, Rmr, etc.), the complete roughness diagram needed to specify roughness on a gear drawing (the check mark), and the shop floor contact stylus profilometer. It was a goal of those articles to provide the reader with a basic understanding of roughness and its measurement such that robust and reproducible profilometry of gear flanks could be carried out on the shop floor.

So, how about a follow up article on roughness measurement tips? On the other hand, how about several articles on tips? Wait, you say! If I had done my job properly in my earlier columns, why would you need several articles on roughness tips?

Well, I am not talking about pragmatic shop floor wisdom on roughness or folksy stories on profilometry. I am talking about the contact stylus, specifically the diamond 2- or 5-micron tip stylus. By definition, a 2- or 5-micron tip means the radius of the cone shaped diamond mounted at 90 degrees to the plane of the stylus. See Figure 1 for an example of a 2-micron diamond tip.

This tip is what touches the flank surface being measured and is the most delicate component in what otherwise is a very rugged measurement system. Obviously, a 2-micron tip is much more delicate and costly compared to a 5-micron tip. So, it would be great if ground gear manufacturers could all use 5-micron tips. Fortunately, only for the measurement of surface waviness do you use a “skidless” probe. For the measurement of the R-parameters, you can use a skidded probe. Skidless probes are more fragile than skidded probes. In all examples discussed below, both sizes of styli used the more robust skidded probes. Nevertheless, the 2-micron skidded probe is still very delicate and expensive. It would be advisable to minimize its use on a shop floor.

The later articles in this series on “tips” will discuss the use of profilometer calibration pads and checking the condition of a diamond tip stylus.

2-MICRON VERSUS 5-MICRON TIPS

Today, precision ground gears typically have Ra’s between 0.2 µm to 0.8 µm. Superfinished gears will be even smoother. Therefore, by and large, precision gear flank roughness measurement should use the delicate 2-micron tip. However, there is a little wiggle room here. ISO-3274 notes that for surfaces of Ra > 0.5 µm and < 2 µm, a 5-micron tip can be used without significant differences in the measured results. Similarly, if all parties agree, and it is documented in the check mark diagram or on the gear drawing, the use of a 5-micron tip is acceptable on surfaces of Ra < 0.5 µm, within limits. See below.

Will a 5-micron tip used on a flank of Ra > 0.5 and < 2 µm result in significantly different roughness results compared to a 2-micron tip? In terms of gear performance, will the differences in the measured results equate to a gear performance difference related to, say, lubrication or surface distress? Let us look at the difference in roughness measurement results first and discuss the impact on gear performance second.

ROUGHNESS COMPARISON; Ra 0.3 – 0.4 µm

I was involved in a major study where hundreds of flank measurements were taken on similar precision ground gears using 2- and 5-micron tip styli. The finish specification on the tooth flanks was Ra < 0.5 µm.

All measurements were taken following ISO specifications. Measurements on the gears were taken on identified flanks and multiple roughness measurements per flank. The averaged roughness measurements are shown in Table 1.

Depending on the machining techniques used, I expect ground tooth flank surface roughness will vary 20 percent from one area to the next on a single tooth or from tooth to tooth on a gear, or from gear to gear in a series production run. The variation in the results of Table 1 are indicative of well ground gears with very consistent flank finishes. Regarding performance, these are industrial gears...
operating at steady state loads and speeds. I would predict equal performance in terms of lubrication or surface distress if presented with the roughness results in Table 1.

In this case, the flank roughness ranged for both styli from $Ra > 0.34$ to $< 0.41 \mu m$ and was considered very consistent. There is little difference in the roughness measurement results when using a 5-micron tip versus a 2-micron tip. In addition, no difference in gear performance difference was predicted. Conclusion: Document the stylus type and use the 5-micron tip on these gears.

**SMOOTHER FLANK FINISHES**

What about finishes smoother than $Ra < 0.3 \mu m$? Remember, precision grinding now routinely achieves $Ra \sim 0.15 - 0.25 \mu m$. The temptation would be to push the use of a more durable 5-micron probe in these circumstances. Will there be a significant difference in roughness measurement when using a 2-micron versus a 5-micron tip on such a finely finished surface? How much of a difference will there be, and can it influence gear performance?

In one study of gears targeted for finishes of $Ra < 0.15 \mu m$, an issue arose regarding the measured roughness results of the flanks and the gear performance came into question. Initial testing of the finished gears showed occasional scuffing, which was not predicted, and was unacceptable. The operating conditions were considered high load and high speed.

Gear testing was stopped and the flank finishes were re-measured after it was discovered that some of the gears had been measured for roughness using a 5-micron tip stylus. The roughness results are averaged in Table 2. All measurements were taken following ISO specifications except one profilometer used a 2-micron tip and one used a 5-micron tip.

In the case above, the tip size shows a significant difference in the measured surface roughness. In addition, in testing, the gears were experiencing occasional scuffing. The solution was to remanufacture the gears to the specified $Ra < 0.15 \mu m$ flank finish, using the 2-micron tip to measure flank roughness. The resumption of testing produced acceptable results. In this case, the difference in tip radius was significant in being able to accurately measure the flank roughness and to be able to predict gear performance.

**CONCLUSION**

There is a point in the degree of smoothness where the use of a 2-micron tip can measure a significant difference compared to a 5-micron radius tip. Moreover, under operating conditions such as high speed and high load, this difference can be significant in predicting gear performance. Use of a 2-micron tip is recommended for flank finishes of $Ra < 0.3 \mu m$.

**ABOUT THE AUTHOR**

Mark Michaud, REM Technical Fellow of REM Surface Engineering, is the inventor and pioneer of REM Surface Engineering’s chemically accelerated finishing technology. He has authored numerous patents and technical papers and served a term on the AGMA Board of Directors. He continues to serve as vice chair of the AGMA Aerospace Committee, as a member of the AGMA Wind Turbine Committee and as a shadow delegate on the ISO 61400-4 Wind Turbine Committee. He can be reached at mmichaud@remchem.com.
Internal ring gears – design and considerations

When using internal ring gears, you can develop a gear system with a high reduction ratio in a compact space — but there are considerations regarding the reduction ratio, interference possibilities, and design window dimensions.

When one is under a great deal of stress, they have a choice to either internalize the stress or to express it. Some express it through exercise, some drown their sorrows at the neighborhood pub, and some choose to berate others. In gearing, there are situations when internalizing the gear mesh is desirable. For these applications, we specify ring gears.

Internal gears, ring gears, and internal ring gears are interchangeable terms for the same type of gear. These gears are composed of a cylindrical shape having teeth inside a circular ring. The gear teeth of an internal gear typically mesh with the teeth of a spur gear. Spur gears have a convex-shaped tooth profile and internal gears have reentrant shaped tooth profile; this characteristic is opposite of internal gears. The formulas for calculating the dimensions of internal gears and their interferences are quite different than those of other gearing.

Figure 1 presents the meshing of an internal gear and external gear. Of vital importance are the working pitch diameters ($d_{w1}$, $d_{w2}$) and working pressure angle ($\alpha_w$). They can be derived from center distance ($a$) and equations detailed below.

![Figure 1: The meshing of internal gear and external gear.](image)

Table 1 shows the formulas for calculating the geometry of a profile shifted internal gear and a non-shifted external gear. In this type of gear system, it is common for one or both members to be profile shifted in order to overcome the various interference fits.

If the center distance ($a$) is known, then $x_1$ and $x_2$ can be obtained from the inverse calculations of items 4 thru 8 of Table 1. These inverse formulas are detailed in Table 2.

There are three different types of interference can occur with internal gears: involute interference, trochoid interference, and trimming interference.

1. **Involute interference** (Figure 2) occurs when the distance between the dedendum of the external gear and the addendum of the internal gear is too narrow and the gears cannot mesh properly. It is prevalent when the number of teeth of the external gear is small. Involute interference can be avoided by observing the following cited conditions:

   $$d_{w1} = 2a - \frac{z_1}{z_2}$$

   $$d_{w2} = 2a - \frac{z_1}{z_2}$$

   $$\alpha_w = \cos^{-1} \left( \frac{d_{b2} - d_{b1}}{2a} \right)$$

   Equation 1

   Equation 2

   Equation 3

   Equation 4

   For a standard internal gear, where $\alpha = 20^\circ$, Equation 4 is valid only if the number of teeth is $z_2 > 34$.

2. **Trochoid interference** refers to an interference occurring at the addendum of the external gear and at the dedendum of the internal gear during recess tooth action. This interference is due to the distance between the teeth being too shallow. It tends to happen when the difference between the numbers of teeth of the two gears is small.
### Table 1: The calculations of a profile shifted internal gear and external gear where the module of the gears is 3, the number of teeth on the spur gear is 16, the number of teeth on the internal gear is 24, and the internal gear is profile shifted.

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Symbol</th>
<th>Formula</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Module</td>
<td>$m$</td>
<td>$\frac{16}{3} - \frac{24}{3}$</td>
<td>0.061857</td>
</tr>
<tr>
<td>2</td>
<td>Reference pressure angle</td>
<td>$\alpha$</td>
<td>$2\tan\alpha \left(\frac{x_2 - x_1}{z_2 - z_1}\right) + \text{inv} \alpha$</td>
<td>$20^\circ$</td>
</tr>
<tr>
<td>3</td>
<td>Number of teeth</td>
<td>$z$</td>
<td>$16$</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Profile shift coefficient</td>
<td>$x$</td>
<td>$0$</td>
<td>+0.516</td>
</tr>
</tbody>
</table>

### Table 2: The calculations of the profile shift of an internal gear and external gear when the center distance is known.

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Symbol</th>
<th>Formula</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Center distance</td>
<td>$a$</td>
<td>$\frac{16}{3} - \frac{24}{3}$</td>
<td>13.1683</td>
</tr>
<tr>
<td>2</td>
<td>Center distance modification coefficient $\alpha_{w}$</td>
<td>$y$</td>
<td>$\frac{a}{m} - \frac{z_2 - z_1}{2}$</td>
<td>0.38943</td>
</tr>
<tr>
<td>3</td>
<td>Working pressure angle</td>
<td>$\alpha_{w}$</td>
<td>$\cos^{-1}\left(\frac{2y}{z_2 - z_1} + 1\right)$</td>
<td>$31.0937^\circ$</td>
</tr>
<tr>
<td>4</td>
<td>Difference of profile shift coefficients</td>
<td>$x_2 - x_1$</td>
<td>$\frac{(z_2 - z_1) (\text{inv} \alpha_{w} - \text{inv} \alpha)}{2\tan \alpha}$</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>Profile shift coefficient</td>
<td>$x$</td>
<td>$0$</td>
<td>0.5</td>
</tr>
</tbody>
</table>
The formulas for calculating the dimensions of internal gears and their interferences are quite different than those of other gearing.

Equation 5 presents the condition for avoiding trochoidal interference.

\[ \frac{z_1 - z_2}{z_2} \ \text{inv} \ \alpha_w - \text{inv} \ \alpha_{a2} = \theta_2 \]

\[ \theta_1 = \cos^{-1} \left( \frac{r_{a2} - r_{a1} - a^1}{2ar_{a1}} \right) + \text{inv} \ \alpha_{a1} - \text{inv} \ \alpha_w \]

\[ \theta_2 = \cos^{-1} \left( \frac{a^2 + r_{a1} - r_{a2}}{2ar_{a2}} \right) \]

where \( \alpha_{a1} \) is the pressure angle of the spur gear tooth tip:

\[ \alpha_{a1} = \cos^{-1} \left( \frac{d_{b1}}{d_{a1}} \right) \]

In the meshing of an external gear and a standard internal gear where the pressure angle \( \alpha = 20^\circ \), trochoid interference is avoided if the difference of the number of teeth, \( z_2 - z_1 \), is larger than 9. (Figure 3)

3. Trimming interference occurs in the radial direction in that it prevents the pulling of the gears apart. Thus, the mesh must be assembled by sliding the gears together with an axial motion. It tends to happen when the numbers of teeth of the two gears are very close. Equation 8 indicates how to prevent this type of interference.

\[ \theta_1 = \text{inv} \ \alpha_{a1} - \text{inv} \ \alpha_w \geq \frac{z_1}{z_2} (\theta_2 + \text{inv} \ \alpha_{a2} - \text{inv} \ \alpha_w) \]

\[ \theta_1 = \sin^{-1} \sqrt{1 - \left( \frac{\cos \alpha_{a1}/\cos \alpha_w}{1 - \left( z_2/z_1 \right)^2} \right)^2 - 1} \]

Equation 9

This type of interference can occur in the process of cutting an internal gear with a pinion cutter. Should that happen, there is danger of breaking the tooling.

Table 3 shows the limit for the pinion cutter to prevent trimming interference when cutting a standard internal gear, with pressure angle \( \alpha_0 = 20^\circ \), and no profile shift, i.e., \( x_0 = 0 \).

There will be an involute interference between the internal gear and the pinion cutter if the number of teeth of the pinion cutter ranges from 15 to 22 (\( z_0 = 15 \) to 22).

Table 4 shows the limit for a profile shifted pinion cutter to prevent trimming interference while cutting a standard internal gear. The correction \( x_0 \) is the magnitude of shift, which was assumed to be: \( x_0 = 0.0075 z_0 + 0.05 \).

There will be an involute interference between the internal gear and the pinion cutter if the number of teeth of the pinion cutter ranges from 15 to 19 (\( z_0 = 15 \) to 19).

When using internal ring gears, you can develop a gear system with a high reduction ratio in a compact space. However, there are many considerations regarding the reduction ratio, interference possibilities, and design window dimensions.

ABOUT THE AUTHOR

Brian Dengel is general manager of KHK-USA, which is based in Mineola, New York. Go online to www.khkgears.us
Cost, cleanliness, carbon footprint affect quenchant

Weighing the application of vegetable-based quenchants for heat-treating applications.

Vegetable oils are seeing increased interest as quenchants for steel because of low carbon footprint, a renewable resource, and the ability to reclaim/recycle into bio-fuels. There are many different types of vegetable oils, and considerable research has gone into the viability of these oils for applications in quenching [1] [2] [3].

Vegetable oils are extracted from plant matter, usually seeds. The most common methods are mechanical, chemical, or distillation. Extraction by high pressure CO2 has been investigated. Mechanical means, using a hydraulic press, are the most common, but chemical means using solvents and specific enzymes are also being used. Once the vegetable oils are extracted they are degummed, which removes the phosphatide content common in some crude oils (soybean, sunflower, rapeseed). Often, the free acids present are neutralized by alkali. Using a “winterizing” process, some oils such as sunflower will present an unpleasant turbidity at low temperature. This can be removed by eliminating components such as waxes which solidify at low temperature. Some fat is present in the vegetable oils. This fat is the result of low and high melting temperature fractions. The fractionation process separates both the low temperature and high temperature fractions, in order to obtain a liquid fraction that remains limpid (remains clear) at room temperature. Finally, a hydrogenation process is used to saturate the oil with hydrogen for stability.

Chemically, vegetable oils are triglycerides, as either esters of glycerol or glycerol and fatty acids. A typical structure of a vegetable oil as a glycerol and fatty acid is shown in Figure 1. Typical fatty acids are shown in Figure 2. Typical fatty acid composition of vegetable oils are listed in Table 1.

Mineral oil quenchants are second only to water in use to harden steel. It is used in a wide variety of applications of alloy type and quenching systems. However, mineral oil has poor biodegradability [4]; flammability, and it is not renewable [5]. It produces smoke which can condense and leave a film of oil on machine surfaces. This produces a cleanliness issue as well as an environmental issue.

Multiple advantages apply to vegetable oil-based quenchants. First and foremost, they are readily biodegradable, meaning they are greater than 75 percent biodegradable. As determined by the European CEC Test, the biodegradability of vegetable oil is 80 to 100 percent, in contrast to 10 to 40 percent for mineral oil. These quenchants also possess lower toxico logical hazard potential, as well as high flash and boiling points. Last, but not least, they are a renewable resource with consistent and expandable supply.

Despite these significant advantages, there are concerns with vegetable oil quenchants, including: hydrolytic stability, oxidative instability [6], low-temperature properties, and a narrow viscosity range [7]. Cost is also higher than mineral oil. In order to be a viable alternative, quenchants must have even heat extraction, be stable during use, be usable for a long or indefinite time, be environmentally friendly, and achieve the desired quenching performance.

The physical properties of a typical mineral oil quenchant and a vegetable oil quenchant are shown in Table 2. A comparison of cooling curves are shown in Figure 3 and the specific cooling curve data in tabular form is in Table 3.

For vegetable oils, viscosity is not an absolute guide to thermal stability. The amount of link saturation must be taken into consideration, as the viscosity increases with molecular weight, but decreases with increasing unsaturation.

The flashpoint of a liquid like a quench oil is the lowest temperature at which it can vaporize and ignite in the presence of an ignition source. It is well correlated with the lower flammability limit. As temperature increases, the vapor pressure of the

Table 1. Fatty acid composition of common vegetable oils.

<table>
<thead>
<tr>
<th>OIL</th>
<th>Unsat/Sat</th>
<th>Capric Acid</th>
<th>Lauric Acid</th>
<th>Myristic Acid</th>
<th>Palmitic Acid</th>
<th>Steric Acid</th>
<th>Oleic Acid</th>
<th>Linoleic Acid</th>
<th>Alpha Linoleic Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapeseed (Canola)</td>
<td>15.7</td>
<td>10.0</td>
<td>12:0</td>
<td>14:0</td>
<td>16:0</td>
<td>18:0</td>
<td>18:1</td>
<td>18:2</td>
<td>18:03</td>
</tr>
<tr>
<td>Coconut</td>
<td>0.1</td>
<td>6.0</td>
<td>47.0</td>
<td>18</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>Corn</td>
<td>6.7</td>
<td>11.0</td>
<td>28</td>
<td>58</td>
<td>1</td>
<td>2</td>
<td>28</td>
<td>58</td>
<td>1</td>
</tr>
<tr>
<td>Cottonseed</td>
<td>2.8</td>
<td>11.0</td>
<td>22</td>
<td>39</td>
<td>54</td>
<td>1</td>
<td>54</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>Olive</td>
<td>4.6</td>
<td>13.0</td>
<td>3</td>
<td>71</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>Palm</td>
<td>1</td>
<td>45.0</td>
<td>4</td>
<td>40</td>
<td>10</td>
<td>...</td>
<td>10</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Peanut</td>
<td>4</td>
<td>11.0</td>
<td>2</td>
<td>48</td>
<td>32</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Soybean</td>
<td>5.7</td>
<td>11.0</td>
<td>4</td>
<td>24</td>
<td>54</td>
<td>7</td>
<td>54</td>
<td>7</td>
<td>...</td>
</tr>
</tbody>
</table>

Table 2. Comparison of physical properties of vegetable and mineral oil quenchants.

Figure 1: Typical structure of a vegetable oil.
liquid increases. As this pressure increases, the concentration of the vapor increases. The temperature at which the vapors ignite in the presence of an ignition source is called the flash point. As a general rule-of-thumb, the vapor pressure for most liquids at the flash-point is approximately 4-7 mbar.

The flash point provides information on two different aspects of a quenchant. First, the flash point provides an indication of tendency for fires. Second, it also gives an indication of the vapor pressure, and the amount of fumes present.

The flashpoint of the mineral oil quenchant is approximately 168°C, while the flashpoint of the vegetable oil is approximately 323°C. This shows that the vegetable oil will have a lower tendency for fires and have lower fumes and smoke than the mineral oil.

The cooling curve behavior of the two quenchants, while similar in the maximum cooling rate, shows some distinct differences. The mineral oil quenchant shows a definite vapor phase, with the transition to boiling occurring at approximately 721°C, while vegetable oil shows no vapor phase. Boiling starts immediately upon quenching. Further, the transition from boiling to convection in the mineral oil quenchant shows a much lower transition temperature than the vegetable oil-based quenchant. This would indicate that the vegetable oil would likely have superior or equal properties while producing lower distortion than the incumbent mineral oil. Similar microstructures are obtained with both quenchants (Figure 4).

For vegetable oils, viscosity is not an absolute guide to thermal stability. The amount of link saturation must be taken into consideration, as the viscosity increases with molecular weight, but decreases with increasing unsaturation.
acids present in vegetable oils, the use of the total acid number is misleading. The oxidation processes are similar in both cases, but in the case of vegetable oils, initiation is by fatty acid free radicals instead of hydrocarbon free radicals. In all cases, a varnish or lacquer deposit will form on the parts. In the case of vegetable oils, the deposits are very similar to that formed by burned-on vegetable oil on an overheated pan, and are very difficult to remove. The oxidation resistance of vegetable oils is inferior to that of mineral oils (Figure 5).

Additional problems with vegetable oils are cleaning and removing vegetable oils after quenching. Vegetable oils tend to emulsify, so enhanced splitting formulations are required to fully clean the oil from quenched parts. Removing the last vestiges of oil can be difficult.

Lastly, the last issue with quenching in vegetable oils is the smell. It often smells like French fries cooking, which may become objectionable over time.

CONCLUSIONS

Vegetable oils are a viable quenchant that produces less smoke than a comparable mineral oil quenchant. It has a much higher flash point, which reduces fire hazards. Further, the quenching characteristics are superior to a mineral oil quenchant, yielding equal properties, while improving distortion. It is also a low carbon footprint quenchant, with zero volatile organic content (VOC). It is renewable, and “green.”

On the downside, vegetable oil quenchants are more expensive than equivalent mineral oil quenchants. The price is often dependent on crop success, and competes with food sources. It is also more difficult to clean.

Additional research is needed to improve cleaning of these quenchants, and to improve the short thermal stability of these oils compared to mineral oil. Vegetable oils, once these problems are solved, will be an excellent quenchant, suitable for many heat-treating operations.

Should you have any questions regarding this article, or suggestions for further articles, please contact the author.

REFERENCES

REDUCING TOOL WEAR IN SPIRAL BEVEL GEAR MACHINING WITH THE FINITE ELEMENT METHOD
Due to the complexity of spiral bevel gear machining, the cutting tools can be a significant cost of gear manufacturing. Unlike the price of the material, which is fixed by the market, the cost of tooling and subsequent re-grinding can be lowered through reducing tool wear and increasing tool life. Current methods for making these improvements include costly trial-and-error techniques. These can be expensive, time consuming, and may require use of production equipment, disrupting workflow and product delivery.

This work details an alternative approach to physical testing for predicting and reducing tool wear using the finite element method. This virtual design approach uses real-world cutting tool geometry, automatically generated gear blanks, and known process kinematics to simulate the cutting process. The cutting geometry was scanned with a combination of laser and MRI techniques and then converted into a 3D CAD model for use in modeling. Gear blanks were automatically generated using parametric inputs and material removed to begin simulation mid-process to reduce simulation time. The kinematics for spiral bevel machining were implemented for the non-generating motion and are able to model both face-milling and face-hobbing machining methods. The simulation results included tool temperature and tool stress, which have been shown to be the main drivers in tool wear.

To validate the modeling approach, experimental tests were run for a variety of edge preparations, feeds, and speeds. The experimental results collected included forces, tool wear pictures, and chips. The comparison of the simulated and experimental results found good correlation for forces and between tool wear marks and the temperature and stress contours on the tool. The chip shape was also found to be similar. Based on this comparison, suggestions for reducing tool wear with the modeling approach are made. Additionally, the lessons learned, potential benefits, and pitfalls of this approach to tool wear reduction and future work are summarized.

1 INTRODUCTION

The custom nature of spiral bevel gears and the high cost of cutting tools have continued to put pressure on manufacturers to make timely improvements for reducing the cost of gear machining. However, improvement usually comes at a cost of interruption of production processes to allow for expensive and time-consuming trial-and-error implementations. It is highly desirable for tooling designers and manufacturing engineers to have a virtual machining simulation tool to study the spiral bevel gear machining process including understanding the tool wear, chip formation, and the effect of machining on the work-piece surface.

In this paper, a physics-based finite element model is developed for simulating the spiral bevel gear non-generating process (Formate® process of Gleason Works) for face milling (single indexing) and face hobbing (continuous indexing). The model requires inputs for defining the uncut gear blank, the tool, process parameters, and materials. Then it creates in-cut gear geometry, explicitly meshes gear and cutter, and simulates the complicated kinematic motion between the tool and workpiece. The model is capable of predicting the forces, temperature, chip shape, and stresses during the machining process. In addition, the model allows for setting up the simulation at the beginning, middle, or end of the cutting process, which enables capturing the specific area of interest such as studying a single rotation of the cutting tool or single cutting tooth pattern in high detail while still receiving a solution in a reasonable amount of time.

To ensure the accuracy of simulation solutions, a set of validation experiments were conducted. The experimental data of forces and chips are collected and compared with their simulation counterparts. The experimental tool wear marks are compared with simulation temperature and stress fields to identify a correlation. Suggestions on how to use this finite element model to reduce tool wear are provided.

2 MODELING METHODOLOGY

2.1 FINITE ELEMENT FORMULATIONS

In this study, the finite element solution is obtained by using AdvantEdge software. It is an explicit dynamic, thermo-mechanically coupled finite element modeling package designed specifically for metal cutting [1]. It employs an explicit Lagrangian finite element formulation equipped with advanced material constitutive model, robust contact algorithm, and continuous adaptive meshing capability. The model accounts for dynamic effects, heat conduction, full thermal-mechanical coupling, plasticity in finite deformation and large strain rate, and frictional contact between deformable meshes. A brief description of the finite element formulation is given as follows:

The finite element formulation is derived based on the Lagrangian description of a dynamic equilibrium
equation using the principal of virtual work, which can be expressed by the following weak form:

$$\int_{B_0} P_{n+1} \cdot \nabla_i \eta dV_0 - \int_{B_0} (f_{n+1} - \rho \alpha_{n+1}) \cdot \eta dV_0 - \int_{B_0} t_{n+1} \cdot \eta dS_0 = 0$$  \hspace{1cm} \text{Equation 1}$$

where \( P \) is the first Piola-Kirchhoff stress field, the subscript \( n + 1 \) refers to \((n + 1)\)th time step, \( f \), \( a \), and \( t \) are the body forces, accelerations, and boundary tractions, respectively, \( \rho \) is the mass density on the reference configuration \( B_0 \), \( \eta \) is an admissible virtual displacement field, and \( V_0 \) denotes the deformation gradient.

Upon discretization with finite elements, the governing equation of (1) can be re-written in a matrix form as

$$M_{a_{n+1}} + R_{n+1}^e = R_{n+1}^e$$  \hspace{1cm} \text{Equation 2}$$

where \( M \) is the mass matrix,

$$M_{a_{n+1}} = \int_{B_0} \rho \delta_{ik} N_i N_j dV_0$$  \hspace{1cm} \text{Equation 3}$$

\( R_{n+1}^e \) is the external force array,

$$R_{n+1}^e = \int_{B_0} f_i N_i dV_0 + \int_{\partial B_0} t_i N_i dS_0$$  \hspace{1cm} \text{Equation 4}$$

and \( R_{n+1}^i \) represents the internal force array,

$$R_{n+1}^i = \int_{B_0} P_{ij} N_i dV_0$$  \hspace{1cm} \text{Equation 5}$$

Here \( N_i \) is the shape function.

The explicit time integration method and central difference scheme are used for time discretization

$$d_{n+1} = d_n + \Delta t v_n + \frac{1}{2} \Delta t a_n$$  \hspace{1cm} \text{Equation 6}$$

$$a_{n+1} = M^{-1} (R_{n+1}^e - R_{n+1}^i)$$  \hspace{1cm} \text{Equation 7}$$

$$v_{n+1} = v_n + \frac{1}{2} \Delta t (a_{n+1} + a_n)$$  \hspace{1cm} \text{Equation 8}$$

where \( d \) and \( v \) are displacement and velocity vectors, respectively, and \( \Delta t \) is the time increase from \( n \)th time step to \((n + 1)\)th time step.

Substantial amount of heat is generated during the machining process and has a considerable influence on the mechanical responses. The primary sources of heat are the plastic work in the workpiece and the friction at the tool-chip interface. To get the finite element solution of the thermal effects, the weak form of the first law of thermodynamics in the current configuration \( B_t \) (with the current Neumann boundary \( B_0 \)) is given by

$$\int_{B_t} \rho c \eta \nabla dV + \int_{\partial B_0} h \eta dS = \int_{B_t} q \cdot \nabla \eta dV + \int_{B_t} s \eta dV$$  \hspace{1cm} \text{Equation 9}$$

where \( \rho \) is the current mass density, \( c \) is the heat capacity, \( T \) is the temperature field, \( \eta \) is an admissible virtual temperature field, and \( q \) is the heat flux; \( s \) is the heat rate generated by the plastic work, which can be estimated as

$$s = \beta W$$  \hspace{1cm} \text{Equation 10}$$

where \( W \) is the plastic power density and \( \beta \) is the Taylor-Quinney coefficient [2].

\( h \) is the heat rate generated by the tool-chip interface friction, which can be calculated as

$$h = - t \cdot [v]$$  \hspace{1cm} \text{Equation 11}$$

where \( t \) is the contact traction vector and \([v]\) is the jump in velocity vector across the contact interface.

Applying the finite element discretization and forward Euler algorithm, the thermal time stepping equation is obtained and expressed in a matrix form as

$$T_{n+1} = T_n + \Delta t C^{-1}(Q_n - K_h T_n)$$  \hspace{1cm} \text{Equation 12}$$

where \( T \) is the temperature vector, and \( K \) and \( C \) are the conductivity and heat capacity matrix, respectively. \( Q \) is the vector of sources of heat.

The coupled thermo-mechanical equations are solved by a staggered procedure. The mechanical step is assumed to be isothermal, i.e. temperature is assumed to be constant. The thermal step only deals with the heat generation and temperature change.

Machining involves complicated contact conditions, including the tool-workpiece contact on the tool rake face and relief face, the chip-workpiece contact, which occurs when the chip curls over and touches the workpiece, and the chip-chip contact, which occurs during chip segmentation. A contact algorithm developed by Taylor and Flanagan [3] is employed to model the contact conditions. Two surfaces that come into contact are treated as a pair of master surface (rigid) and slave surface (deformable); the impenetrability of two surfaces is achieved following an explicit predictor-corrector scheme.

To capture fine-scale features developed at the tool-chip interface such as the localized shear bands and to alleviate element distortion for ensuring accuracy of solution, an adaptive meshing technique is used in solving the FEM equations. The adaptive meshing is triggered once the element distortion reaches a critical value. Mesh refinement, improvement, and coarsening are automatically applied. In regions where materials experience plastic deformation, workpiece mesh is refined. On the other hand, the mesh coarsening procedure is applied in regions where plastic deformation is inactive in order to reduce the computation cost.

Since high-speed machining is a high strain, high strain rate, and high temperature operation, AdvantEdge describes the material constitutive behaviors using a power law model in which the material’s flow stress is governed by the following equation:

$$\sigma(\varepsilon_p, \dot{\varepsilon}, T) = g(\varepsilon_p) \times \Gamma(\dot{\varepsilon}) \times \Theta(T)$$  \hspace{1cm} \text{Equation 13}$$

where \( \sigma \) is the flow stress, \( g \) is the strain hardening function, \( T \) is the strain rate sensitivity function, and \( \Theta \) is the thermal softening function. \( \varepsilon_p, \dot{\varepsilon}, \) and \( T \) denote the equivalent plastic strain, plastic strain rate, and temperature, respectively. Flow stress models other than the default power law model, such as the Johnson-Cook model [4], can also be implemented and conveniently interfaced with AdvantEdge using a User Defined Yield Surface (UDYS) capability.

### 2.2 KINEMATICS OF SPIRAL BEVEL GEAR MACHINING

The kinematics for spiral bevel gear machining, including face milling and face hobbing non-generating processes were implemented in AdvantEdge to define the relative positions and motions of the cutter and gear. The method of determining the relative positions of cutter and gear is explained in detail by Stadtfeld [5], which requires input of multiple geometric parameters such as mean cone distance, mean spiral angle, and nominal cutter radius. For face-milling non-generating processes, the gear is fixed during machining. For face-hobbing non-generating motion, the angular velocity of the gear \( \omega_g \) is determined as follows

$$\sigma(\varepsilon_p, \dot{\varepsilon}, T) = g(\varepsilon_p) \times \Gamma(\dot{\varepsilon}) \times \Theta(T)$$  \hspace{1cm} \text{Equation 14}$$

where \( \omega_{ca} \) is the angular velocity of cutter, \( N_c \) is the number of cutter blade groups, and \( N_g \) is the number of gear teeth. Additionally, the feed and starting depth of cut are also required for determining the kinematics of non-generating motion.

The machining kinematics are first used by the AdvantEdge mesh engine in the steps of placing the cutter and creating the in-cut gear geometry. Then, the meshing of the gear and cutter is applied automatically, followed by adding boundary conditions. The simulation is run from the in-cut gear geometry while following the kinematics.
It is worth mentioning that the handedness of cutter and gear was taken into account while determining the machining kinematics in AdvantEdge. Any combinations of cutter and gear handedness can be correctly handled by modifying the positions and rotating directions accordingly.

Figure 1 shows two examples of machining kinematics for different processes and different handedness of the cutter and gear.

3 EXPERIMENTAL VALIDATION

To validate the kinematics and accuracy of the FEM solution for spiral bevel gear machining model, a series of face-milling non-generating tests were carried out. Concurrently with the machining tests, simulations were set up and run for comparison. The validated parameters include force, chip, and tool wear.

3.1 EXPERIMENT SETUP

The validation tests were carried out on a Mori-Seiki NH6300 DCG 5-axis horizontal machining center. A Kistler 9255B table mounted piezoelectric dynamometer was used for measuring forces. Images of chips and tool wear were taken using a Flexbar Optiflex digital microscope. Due to the limitations of the machining center and to ensure high quality data collection, a single-insert cutter is used. Figure 2 shows the setup of the machine test.

The cutting tool material used in the machining test was high speed steel. Two workpiece materials that are commonly used in the gear manufacturing industry were machined — steel X53 and 9310. During the machining test, a flood coolant of a mixture of oil and limited amount of water was used for lubrication, controlling cutting temperature and flushing out chips.

Table 1 shows the feeds and surface speeds used for the validation tests. Nine sets of cutting conditions were studied according to common industry practices, covering high and low surface speeds and feeds.

3.2 FEM SIMULATION SETUP

FEM simulations were set up according to the experiments. Figure 3 shows the whole cutter and a single tooth used in the simulation to reduce the meshing and running time.

The single tooth is imported into AdvantEdge as a STEP file. The simulation was set up through a graphic user interface (GUI) designed specifically for spiral bevel gear machining. Parameters defining the workpiece geometry and machining process were input directly. Tool and workpiece materials were selected from a large material library integrated in AdvantEdge. Parameters relating the initial meshing and adaptive meshing were set according to the geometry size and chip load, respectively.

After the simulation setup, the initial meshes of workpiece and tool at a full-cutting position were automatically generated through the AdvantEdge mesh engine. An example of initial mesh
Figure 3: The whole cutter (left) and a single tooth used for FEM simulation (right).

Figure 4: Examples of the initial mesh (left) and simulation results of temperature contours and time history variation of forces (right).

Figure 5: Comparison of the tangential forces (upper) and radial forces (lower) between experiment and AdvantEdge simulation.
is shown in Figure 4. Meshes on the tooth cutting edge and on the workpiece cutting surfaces are refined to ensure high simulation accuracy. Meshes on other parts of tool and workpiece are coarsened to speed up the computation. The FEM problem was solved using multi-threaded parallel computing methodology. The output results include contours of temperature, stresses, and plastic strain on the workpiece and the tool throughout the simulation, and time histories of global force, torque, and maximum tool temperature. Figure 4 shows a representative simulation of results on the right.

3.3 COMPARISON OF EXPERIMENTS AND SIMULATIONS

The experimental tangential and radial forces were measured by dynamometer to compare with their simulation counterparts. The chips from experiments and simulations were also compared in terms of the chip shape and size. In addition, the tool wear was visually inspected using a digital microscope and compared with the simulation temperature and stress contours to find correlations.

3.3.1 CUTTING FORCES

Figure 5 shows the comparison of forces between experiments and AdvantEdge simulations for steel X53. The simulation was found to accurately capture the expected force variation trends with respect to feed and speed, i.e. cutting forces increase while increasing feed and decrease while increasing speed. Higher feed leads to larger chip load, which causes higher cutting forces. On the other hand, higher cutting speed causes higher cutting temperature, which softens the workpiece material and reduces the cutting forces. The magnitudes also correlate quite well between simulation and experiment. On average, the simulation tangential force deviated from the experimental data by 17.8 percent, while the simulated forces in the radial direction differed from the experiment by 16.4 percent.

It is worth noting that the low-speed tests show a larger discrepancy between experiment and simulation. By analyzing the video and post-machined workpiece, it is believed that this was caused by some sticking condition that is occurring on the machine between the tool and workpiece. This condition is not currently modeled in AdvantEdge.

In addition to the steel X53, another material steel 9310 was also tested. Figure 6 shows the validation of forces with different materials. Apparently, use of different materials does not change the accuracy of the validation test.

3.3.2 CHIP FORMATION

The chips generated during machining test were collected and analyzed. The chip shape between experiments and simulations was compared, and a good similarity was found between the two, as shown in Figure 7.

In addition, the simulation result of plastic strain contour on the chip was checked to identify the locations where significant plastic strain occurs. The large plastic strain can indicate impending material failure and possible chip separation. Figure 8 shows the comparison of high plastic strain area on the chip in experiment and simulation. The simulation was found to accurately predict the plastic strain distribution and the high plastic strain area in the chip.

3.3.3 TOOL WEAR

After the machining test, the cutter tooth was examined using a digital microscope and found to have noticeable tool wear marks on the rake face (crater wear) and flank face (flank wear). The tool wear pictures were then compared with simulation contour results to identify a correlation between tool wear and simulation available outputs. Figure 9 shows the comparison between experimental tool wear marks and simulation temperature and pressure contours. It can be seen that the high temperature area matches the tool wear marks very well. This close correlation between tool wear, high temperature, and high pressure is consistent with the common understanding of tool wear process and is used in building multiple tool wear predictive models [6].

Combining with a tool wear predictive model which is usually a function of tool temperature and tool stress, the finite element simu-
lation tool can be used to predict tool wear during spiral bevel gear machining, which would be beneficial for both tool design and process optimization. For instance, a set of simulations can be set up and run with the design of experiments (DOE) method to study the influence of rake angle, edge preparation, and coating material on the tool stress and temperature fields, and thus the tool wear to get an optimal tool design.

4 CONCLUDING REMARKS
In this study, a physics-based finite element model for simulating spiral bevel gear face-milling and face-hobbing non-generating processes is presented. The model can be used to predict the forces, temperature, chip shape, and stresses during the machining process. These data enable more informed decisions and offer the ability to test a wide range of ideas prior to investing in new cutters or making process changes on the floor. For example, instead of guessing why a cutter fractured, virtual machining simulation allows users to simulate their process conditions to see the areas of high stress and high temperature that indicate tool failure. The accuracy of finite element solutions is validated by a series of simple machining tests. The simulated forces are found to accurately predict trends, and magnitudes are on average within 20 percent of experiment data. Chip shapes are found to be similar between experiments and simulations. The simulation results of temperature and stress fields also are found to be closely correlated to experimental tool wear marks. It is demonstrated that this finite element model will be beneficial for the study of tool wear reduction in spiral bevel gear machining. Users can accelerate the optimization of tool design and machining process for reducing tool wear by coupling the virtual-machining simulation with DOE approach.

In summary, the ability to virtually model the complex cutting process of spiral bevel gear machining has the potential to reduce the cutting cycle time and improve the tool life, which will lower the cost to manufacture gears.

Currently the finite element model focuses on smaller diameter gears that are commonly used in the automotive industry. There are still some improvements necessary to expand the modeling capability to larger size gears and cutters. Other future developments for additional features include the simulation of the generating process in spiral bevel gear machining and adding more gear specific materials.

5 ACKNOWLEDGEMENTS
This study was partially funded by NAVAIR SBIR program award and supported by Meritor, General Motors, Ford, Rolls-Royce and Aero Gear.

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UNDERSTANDING THE MOUNTING DISTANCE: INTERSECTED-AXES GEARING (BEVEL GEARING)
To favorably configure bevel gears in intersected-axes gearing, the mounting distance must be one of the most important design parameters.

By STEPHEN P. RADZEVICH

Mounting distance is one of the most critical design parameters in intersected-axes gearing (in straight bevel gearing, spiral bevel gearing, and so forth). In this article, the mounting distance is discussed with focus on “geometrically-accurate gearing” (that is, with focus on “perfect” gearing). The term “geometrically-accurate gearing” means gearing with zero deviations of the actual values of all the design parameters from their desired values. The disclosed results of the analysis are applicable to bevel gears machined on the bevel gear generators available on the market.

INTRODUCTION
Bevel gearing is extensively used in today’s industry. Gears for bevel gearing have to be manufactured and assembled in a housing in such a way that ensures smooth running and favorable load distribution between the gear teeth. High power density (or, in other words, the “power-to-weight ratio”) in bevel gearing along with quietness when operating is strongly desired. If engineered properly, bevel gears can be installed in the same manner as spur or helical gears and behave and perform just as well. To achieve these goals, certain requirements have to be fulfilled when designing, manufacturing, and assembling bevel gear pairs. Accuracy of the mounting distance is one of the most critical design parameters in this regard.

1 ELEMENTS OF KINEMATICS, AND GEOMETRY IN INTERSECTED-AXES GEARING
The concept of “geometrically-accurate” intersected-axes gearing can be traced back to 1887 when George B. Grant filed an invention disclosure titled Machine for Planing Gear Teeth [1].

A straight bevel gear pair is depicted in Figure 1 as an example. When bevel gearing operates, the gear spins, \( \omega_g \), about its axis of rotation, \( O_g \). The mating pinion spins, \( \omega_p \), about its axis of rotation, \( O_p \). The axes of rotation, \( O_g \) and \( O_p \), intersect one another, and the point of intersection coincides with the plane-of-action apex, \( A_{pa} \) — this is a must for perfect performance of bevel gearing.

A base cone is associated with the gear. The gear base cone apex, \( A_g \), is located within the gear axis of rotation, \( O_g \). Another base cone is associated with the pinion. The pinion base cone apex, \( A_p \), is located within the pinion axis of rotation, \( O_p \). The gear and the pinion must be configured in relation to each other to ensure the apexes, \( A_g \) and \( A_p \), snap together with the plane-of-action apex, \( A_{pa} \). This is a must [2]. Neither axial displacement of the gear nor axial displacement of the pinion is allowed from the position shown in Figure 1. The plane of action, \( PA \), is a plane through the plane-of-action apex, \( A_{pa} \), that is tangential to the base cones of the gear and the mating pinion.

2 MOUNTING DISTANCE
To operate properly, gears in intersected-axes gearing must be properly configured in relation to one another. Mounting distance is a key design parameter that helps keep gears properly configured and is the most important parameter for ensuring correct operation. Mounting distance can be specified as the distance from a locating surface on the back of one gear (most commonly a bearing seat) to the plane-of-action apex, \( A_{pa} \).

Theoretically, in an intersected-axes gear pair, a gear base cone apex, \( A_g \), a mating pinion base cone apex, \( A_p \), and the plane-of-action apex, \( A_{pa} \), must be snapped together, as schematically illustrated in Figure 2a.

In reality, in order to transmit power, gears need to be supported. A gear housing (see Figure 2b) is used for this purpose. The gear housing features a corresponding number of bores that are used to support gear shafts in the housing. A centerline of a bore for the gear shaft is labeled as \( O_{bg} \). Correspondingly, a centerline of a bore for the pinion shaft is designated by \( O_{bp} \). The centerlines, \( O_{bg} \) and \( O_{bp} \), intersect one another at point \( A_{Ap} \). Strong constraints on the configuration of the gear and its mating pinion in the gear housing are
imposed by this point, $A_h$.

The gear must be configured in the gear housing so as to keep the gear axis of rotation, $O_g$, aligned with the axis, $O_{hg}$, in the gear housing (that is, $O_g = O_{hg}$), as illustrated in Figure 2c. The gear base cone apex, $A_g$, must be coincident with the point, $A_h$, of intersection of the centerlines, and (that is, $A_g = A_h$). Then, the rest of the important components — bearings, shims, fasteners, and so forth — are put together so as to keep the gear mounting distance, $MD_g$, to the blueprint. The gear mounting distance, $MD_g$, is measured between the gear back face, and the gear base cone apex, $A_g = A_{pa} = A_h$), as shown in Figure 2d.

Similarly, the pinion must be configured in the gear housing so as to keep the pinion axis of rotation, $O_p$, aligned with the axis, $O_{hp}$, in the gear housing, as illustrated in Figure 2e. The pinion base cone apex, $A_p$, must be coincident with the point, $A_h$, of intersection of the centerlines, $O_{hg}$ and $O_{hp}$ (that is, $A_p = A_h$). Then, the rest of the important components — bearings, shims, fasteners, and so forth — are put together so as to keep the pinion mounting distance, $MD_p$, to the blueprint. The pinion mounting distance, $MD_p$, is measured between the pinion back face and the pinion base cone apex, as shown in Figure 2f.

After the pinion is in position, the tapered roller bearings of the gear assembly are pre-loaded; at the same time, the gear assembly is placed axially in the housing.

Finally, once the gear and the pinion are properly mounted in the gear housing, their axes are aligned to the centerlines of the corresponding bores in the gear housing (that is, $O_g = O_{hg}$, and $O_p = O_{hp}$), and the apexes, $A_g$, $A_p$, and $A_{pa}$, all of them are snapped together with the point of intersection, $A_h$, of the centerlines, $O_{hg}$ and $O_{hp}$, in the gear housing, as schematically illustrated in Figure 2g.

An important conclusion can be drawn up from the above discussion (see Figure 2):

### INTERMEDIATE CONCLUSION

In intersected-axes gearing, NO axial displacements of the gears from the point of intersection, $A_h$, of the centerlines, $O_{hg}$ and $O_{hp}$, in the gear housing are allowed if the gears are designed, manufactured, and assembled properly.

Therefore, it is a wrong practice to adjust for the backlash in intersected-axes gearing by means of “inward-outward” axial displacement of the gears as shown in Figure 3, as recommended in [3], as well as in many other sources.

In precision intersected-axes gearing, it is recommended to inspect the mounting distance at a nominal operating load, as well as the preloaded bearings. Tolerance for the accuracy of the mounting distance is tight.

### 3 MOTIVATION

Consider a geometrically-accurate intersected-axes gear pair ($I_a$ — gear pair). A rotation from a driving member to a driven member in the gear pair is transmitted through a line of contact, $LC$, between the tooth flanks, $\gamma$ and $\gamma'$, of the gear and the mating pinion.

Lines of contact, $LC$, of various geometries are practically used in design of intersected-axes gear pairs. For simplicity, but without
Pinion tooth

(a)

Gear tooth

(b)

Figure 4: Correct (a), and incorrect (b) contact of a gear and a mating pinion tooth flanks, G and P, in a section by the plane of action, PA. The straight line of contact, LC, is designated as ab.

(180° − θ)

Pinion tooth

(a)

Gear tooth

(b)

Figure 5: Unit normal vectors, n_g and n_p, to a gear and a mating pinion tooth flanks, G and P, in cases of correct (a), and incorrect (b) configuration of the mating gears.

In reality, error in mounting distance, ε_g, is always observed. The latter is shown in Figure 6b. In such a scenario, the gear base cone apex, A'_g, does not coincide with the plane-of-action apex, A_pa, as A'_g is displaced axially in relation to A_pa at a distance ε_g. (Here, we are not going into details of the analysis of the gap between the gear base cone and the plane of action.)
the outward displacement, $\varepsilon_g$, is of a positive value. An inward displacement is of a negative value (not shown in Figure 6b).

The performed analysis in Figure 6 allows us to proceed with the derivation of an equation for the calculation of the tolerance for the accuracy of the mounting distance in an intersected-axes gear pair.

### 4.2 Derivation of the Equation for the Calculation of Tolerance for the Accuracy of the Mounting Distance

Consider two teeth in contact intersected by the plane of action, $PA$, as illustrated in Figure 7a. The teeth contact one another along a straight-line segment $ab$. (Here, for simplicity, but without loss of generality, a pair of geometrically-accurate straight bevel gears is considered).

A case of an outward displaced gear is illustrated in Figure 7b. As a result of the displacement, a gap between the teeth is observed. This gap is shown by two straight-line segments, $ab$ and $a^*b^*$, each of which is entirely located on the tooth flanks, $G$ and $P$, of the two interacting teeth.

A schematic for the derivation of a formula for the calculation of a tolerance for the accuracy of the mounting distance is depicted in Figure 7c. It should be stressed from the very beginning that point $b$ within the straight-line segment $ab$ is the closest point to the straight-line segment $a^*b^*$. Therefore, an angle, $\theta_g$, through which the plane of action, $PA$, has to be turned about the axis of rotation $O_{pa}$ depends on the actual distance of point $b$ to the straight-line segment $a^*b^*$.

Assume that the gear is motionless, and the plane of action, $PA$, turns about its axis of rotation, $O_{pa}$, through an angle at which point, $b$, touches the straight-line segment, $A^*_b$. Then, consider a triangle, $A_{pa}A^*_b$. In this triangle, $A_{pa}b = r_{pa} \cdot \varepsilon_g$, $A_{pa}A^*_b = e_g$, and $A^*_b = C_{pa}$.

Law of cosine can be used for the determination of the actual value of the angle, $\theta_g$:

$$\frac{2}{g} = \frac{r_{pa}}{g} + (r_{pa})^2 - 2 \cdot r_{pa} \cdot g \cdot \cos \theta_g \tag{1}$$

Then, either the actual value of the angle, $\theta_g$, can be expressed in terms of the mounting distance error, $\varepsilon_g$, and the design parameters of the gear pair, or a maximum permissible values of the displacement, $\varepsilon_g$, can be expressed in terms of the maximum permissible value of the angle $\theta_g$, and the design parameters of the gear pair:

$$g = \sqrt{\frac{2}{r_{pa}} + (r_{pa})^2 - 2 \cdot r_{pa} \cdot g \cdot \cos \theta_g} \leq \sqrt{\frac{2}{g}} \tag{2}$$

Here, $[\varepsilon_g]$ is the tolerance for the accuracy of the gear axial displacement, $\varepsilon_g$.

$$g = \cos^{-1} \left[ \frac{r_{pa}}{g} + \frac{(r_{pa})^2 - 2 \cdot r_{pa} \cdot g \cdot \cos \theta_g}{2} \right] \leq \sqrt{\frac{2}{g}} \tag{3}$$

An analysis similar to that above can be performed for a mating bevel pinion:

$$p = \sqrt{\frac{2}{r_{pa}} + (r_{pa})^2 - 2 \cdot r_{pa} \cdot p \cdot \cos \theta_g} \leq \sqrt{\frac{2}{p}} \tag{4}$$
Here, \([\varepsilon_p]\) is the tolerance for the accuracy of the pinion axial displacement, \(\varepsilon_p\), and \([\theta_p]\) is the tolerance for the accuracy of the gear angle, \(\theta_p\).

Further, when the gear is fully aligned, the equalities \(\varepsilon = \varepsilon_p\) and \(\theta = \theta_p\) and Equation 5 and Equation 6 can be used for the calculation of tolerance on the mounting distance in the intersected-axes gear pair.

Finally, in a more general case, a bevel gear and a mating bevel pinion are both misaligned. Under such a scenario, either the actual value of the angle \(\theta\) can be expressed in terms of the mounting distance errors, \(\varepsilon_g\) and \(\varepsilon_p\), and the design parameters of the gear pair, or a maximum permissible values of the displacements, \(\varepsilon_g\) and \(\varepsilon_p\), can be expressed in terms of the maximum permissible value of the angle \(\theta\) and the design parameters of the gear pair.

The angle \(\theta\) is the angle that is formed by two perpendiculars, \(n_g\) and \(n_p\), that is, \(\theta = \angle(n_g, n_p)\), constructed at point of edge contact of a gear, \(G\), and a mating pinion, \(P\), tooth flanks, correspondingly: \(n_g\) is the unit normal vector to the gear tooth flank, \(G\), and \(n_p\) the unit normal vector to the pinion tooth flank, \(P\).

For the determination of the tolerances, \([\varepsilon_g]\) and \([\varepsilon_p]\), for the accuracy of the permissible axial displacements, \(\varepsilon_g\) and \(\varepsilon_p\), of the gear and the mating pinion, either one of the tolerances ([\(\varepsilon_g\)] or [\(\varepsilon_p\)]) or a ratio of the tolerances, \([\varepsilon_g]/[\varepsilon_p]\), has to be pre-specified.

The performed analysis reveals that the actual value of the angle, \(\theta\), alters when the gears rotate. The maximum value of the angle, \(\theta\), is observed at the very beginning of the meshing of two gear teeth. As the rotation proceeds, the angle, \(\theta\), reduces to its minimum value. A minimum value of the angle, \(\theta\), is observed within a plane through the axis of instant rotation, \(P_{in}\), perpendicular to the plane of action, \(PA\). Further, the angle, \(\theta\), increases to its maximum value at the very end of the meshing of two gear teeth.

A more detailed analysis is not presented here as the equations are overly complicated.

In addition to the discussed approach, another approach for the calculation of the tolerance for the accuracy of the mounting distance in intersected-axes gearing is developed.

When the displacement \(\varepsilon_g\) (or \(\varepsilon_p\)) is of a negative value, this results in the edge contact occurring at the opposite face of the gear.

5. PERMISSIBLE ALTERATION TO BEVEL GEAR FLANK SURFACE GEOMETRY

As a gear and a mating pinion tooth only interact with one another within the plane of action, \(PA\), the geometry of the tooth flanks, \(G\) and \(P\), allows for a slight modification (a few examples are illustrated in Figure 8) aimed at avoiding edge contact in gearing. The modification is allowed only for lines of intersection of the tooth flanks, \(G\) and \(P\), by the plane of action. Under such a scenario, only the angular base pitch, \(b_{gy}\), of a gear equals to the operating base pitch, \(b_{op}\), of the gear pair (that is, the equality \(b_{gy} = b_{op}\) is valid); and similarly, the angular base pitch, \(b_{py}\), of a mating pinion equals to the operating base pitch, \(b_{op}\), of the gear pair (that is, the equality \(b_{py} = b_{op}\) is valid). No violation of the equalities \(b_{gy} = b_{op}\) and \(b_{py} = b_{op}\) is permissible in precision intersected-axes gearing.

CONCLUSION

A favorable configuration of bevel gears in intersected-axes gearing is discussed in this article. It is stressed that the mounting distance is one of the most important design parameters. In order to have intersected-axes gearing engineered properly, the tolerance for the accuracy of the mounting distance (and the tolerance for the accuracy of the axial displacements of the gears) has to be tight and needs to be calculated. Calculation of the tolerance for the accuracy of the mounting distance in intersected-axes gearing is a challenging problem. No equations for such calculations are in the public domain.

The disclosed approach for the calculation of the tolerance for the accuracy of the mounting distance in intersected-axes gearing is focused on geometrically-accurate bevel gears (that is, on perfect bevel gears). However, it is also valid for the cases of the approximate gear cut in a regular way on gear generators and so forth.

Bevel gears for intersected-axes gearing have to be designed so (see [2]) as to eliminate the necessity of shimming-in/shimming-out when assembling. These gears do not need to be lapped when finishing the tooth flanks. The gears do not need to be paired, as they are interchangeable and can be replaced individually (not as a whole gear set). If designed, machined [4], and assembled properly, no severe contact pattern changes are observed.

Accuracy of the mounting distance has to be inspected on the correct preload on the pinion shaft and gear carrier bearings. The gearbox housing accuracy and stiffness must be assured accordingly. No testing is a must to verify the accuracy of the mounting distance if the gears and the housing are designed, machined, and assembled properly [2].

\(^1\) Edges are considered here as lines of intersection of the tooth flanks of a gear, \(G\), and of two gear faces.

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ABOUT THE AUTHOR

Stephen P. Radzевич, M.S., Ph.D., Dr. (Eng.) Sci., can be reached at 586-292-7209 or radzевич@usa.com.
EXPERIMENTAL TESTS TO PREDICT PLASTIC GEARS’ LIFETIME
Experimental tensile fatigue data can be used to predict plastic gear life and the polyamide-based polymer loaded with glass fibers can be used for the metal replacement of gears used in applications with high power.

By DAVIDE ALBIERO and RAFFAELE MAZZARELLA

One of the major problems of plastic gears is the lack of data about their lifetime. Literature doesn’t contain numerous data on this subject. Even if it reported them, the number of tests, the variables involved, and the test methods are so varied that it would be difficult to compare them with those needed.

This paper presents the results and experimental tests made by Stagnoli on its technopolymer gears to provide design data.

1 INTRODUCTION

By now, the use of plastic gears in applications that require low loads and precision motion transmission is established. The reason for this lies in the fact that plastic gears provide a number of advantages over metal gears: They have less weight, have less inertia, and are quieter than metal. Moreover, they can be used without lubricant and can be used in chemically aggressive environments thanks to their chemical inertia to a large number of substances as well as having low material and manufacturing costs.

The current challenge is to focus more on power transmission applications with high loads, high number of cycles, and high temperatures, which represent the actual limits of plastic gears. In fact, it is known [1–2] that the causes of technopolymer gear failure are: tooth bending breakage, wear, and thermal damage. For this reason, it is important — in addition to taking into account the guidelines of how to design a plastic gear [2] — to focus on critical points mentioned above. Unlike steel gears in which the design is consolidated by the standards guidelines (ISO, DIN, AGM), analytical methods, equations, and data in the literature, the design of plastic ones is more complicated. Gear designers often face a lack of material data that prevents them from using the material to their full capacity. One reason is the complexity of data generation. For example, in the case of S-N flank fatigue, gears need to be tested at different load levels, temperature levels, with different lubrication types, and material pairings. As the choice of gear material and lubrication is broad, an infinite number of material combinations would need to be tested. Moreover, the flank fatigue results might be influenced by the tested gear geometry. So, designing technopolymer gears requires a degree of experience. Many new designs are based on proven concepts of the past. This is certainly true for plastic gears, where at the moment this comparative, best practice method is the safest way to operate.

Starting from this assumption, Stagnoli T.G. decided during these years to characterize its standard gears by making internal tests to provide useful data about the lifetime and breaking loads of its gears. (Table 1)

2 MATERIALS AND METHODS

The plastic material used in tests is a polyamide PA6 filled with 30 percent of glass fiber. Nylon is a thermoplastic material widely used in gear production [3] because it is characterized by a high level of crystal-
In this way the technopolymer gear represents the weak link in the chain. Via two rigid joints, a preset torque is applied on both gears set. Using such a closed-loop system is very beneficial in that the input power is only required to overcome the frictional and hydrodynamic losses of the gears and the frictional losses in the bearings.

The torque and rpm are monitored using a torquemeter and a software.

All tests were run at 300 rpm and 50 Nm of torque in the worst conditions, i.e. without lubrication and 24-hour running. Supported by a previous gear design by KISSsoft, Stagnoli has to choose this torque value to determine mechanical behavior of technopolymer gears to high torque power transmission applications.

The next step was to change the torque, keeping the rpm constant and, subsequently, varying the rpm while keeping the torque constant.

3 EXPERIMENTAL TESTS

In Graph 1, the Wildhaber (chordal distance that takes into account the pitch and thickness of the teeth) is reproduced as a function of the number of cycles the gear has completed. It is measured before the test, in every intermediate step, and just before the break. The graph is an average of three tests conducted under the same conditions on three samples (50 Nm, 300 rpm). The Wildhaber is an indication of the wear of the sample. As you can see, it decreases linearly and dims up until the onset of the break.

In Figure 2, damage morphology is shown. It can clarify how the break occurred. Certainly, the wear has played an important role, but the dominant cause was the high load. The break occurs due to the appearance of tooth-based cracks (as can be seen), which caused the subsequent detachment of tooth.

In Graph 2, the torque versus the number of cycles is shown. As expected, with increasing torque, the lifetime decreases in exponential terms.

In Graph 3, the rpm versus the number of cycles is shown. Increasing the number of revolutions per minute, while keeping constant torque (35 Nm), the duration, in terms of number of cycles,
The cause is to be found in the increase in transmitted speed, which in turn causes an increase in stresses that the teeth undergo. This also leads to an increase in friction between the gears and consequently in the increase in temperature during operation, which becomes the main cause of the break.

Considering this test and the Wildhaber values detected at the beginning and end of the tests, another interesting data set emerges. As can be seen from Table 2 and Graph 4, the percentage of wear that occurs on the sample increases as the number of revolutions per minute increases. From this, we can draw another point of reflection if we consider the whole phenomenon of the breaking on a gear. If the revolution per minute increases, the weight of the wear component plays a more significant role than the role of the fatigue stress component.

In the test carried out at 100 rpm, it can be seen that the break occurred due to fatigue rather than wear.

4 CONCLUSIONS

Experimental tensile fatigue data can be used to predict plastic gear life. Tests carried out by Stagnoli provide useful data in this regard. They point out that the polyamide-based polymer loaded with glass fibers can be used for the metal replacement of gears used in applications with high power; furthermore, they confirmed the results of KISSsoft going beyond expectations both in terms of duration and in terms of maximum transmissible torque. An S-N curve was also provided, emphasizing the fact that, as expected, as the transmitted torque or number of cycles increases, the lifetime decreases. Another interesting aspect was evaluating the upper hand of a phenomenon rather the other responsible for the breaking of the gears.

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Graph 2: Torque versus number of load cycles for gear testing of PA6+30%GF.

Graph 3: Rpm versus number of load cycles for gear testing of PA6+30%GF.

Graph 4: Rpm versus percentage of wear for gear testing of PA6+30%GF.

Table 2: Wildhaber values.

<table>
<thead>
<tr>
<th>rpm</th>
<th>Initial Wildhaber</th>
<th>Final Wildhaber</th>
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<tr>
<td>100</td>
<td>27,65</td>
<td>27,25</td>
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<td>300</td>
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</tr>
<tr>
<td>700</td>
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<td>26,58</td>
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ABOUT THE AUTHORS

Davide Albiero is owner of Stagnoli’s company and head of Technical Department. He graduated from the University of Brescia in Industrial Design. Albiero has been a gear and transmission designer since 2014, with particular expertise in gear molding and plastic gears design. He started the “Stagnoli’s Fatigue Tests Project” on plastic gears in 2015. Raffaele Mazzarella graduated in materials engineering at Salento University where he specialized in technopolymer and composite materials. In April 2016 he began work at Stagnoli T.G in its R&D department where he still plays the role of design and material engineer. He is responsible for the fatigue tests on test benches.
BRINGING THEORY TO REALITY

Wind turbine gearboxes with calculation results for shaft, bearing and gearing.
(Courtesy: FVA)
FVA Software and Service’s expert team of mechanical engineers and software developers enables its customers to develop and implement individual transmission models, complex calculations, and programming tasks.

By KENNETH CARTER, Gear Solutions editor

Describing and creating gears can often be a complex task involving mountains of data and mathematical equations. It can be a daunting, but necessary, endeavor that some manufacturers might struggle with from time to time.

The experts of FVA Software and Service are available to ease that struggle and ensure the proper scientific methods are being implemented, supplying software, the FVA-Workbench, and support that aids customers in designing and simulating gears before they’re physically made.

“We guide them in all the functionalities and theories, which are available to rate a gear,” said Norbert Haefke, managing director of FVA. “In our software, the FVA-Workbench, we use advanced simulation, as well as new and older proven research results to shrink the size of the gear, to increase the power density, to increase the lifetime, as well as the sustainability of their gear. We are getting more and more detailed in the modeling and get more and more detailed information from the customer. We are digging deep with our customer.”

NO JOB IS TOO COMPLEX

FVA is capable of assisting its customers on multiple levels. Basically, no job is too complex for FVA’s staff, according to Haefke. On a basic level, FVA can help with customers who have trouble handling software, whether that be with installation, documentation, or more.

“If they are doing gear design, they often have questions on how to model a gear in a very complex construction,” he said. “They have to ask if the boundary conditions are correct. It could be that the results are, say, realistic, so they want to know how to model their real gear to the software so that the virtual behavior is the same in the physical world.”

But FVA’s advanced technical support allows the company to take a deep dive into the subject to ensure that its customers are succeeding in their gear requirements.

“The next level — and that is very deep — is we are going down to formulas, to theories, to factors, to support our customers and to explain what the base of these calculations are and where they come from,” Haefke said. “Most of our simulation functionalities are based on research work, which were done in the research association Forschungsvereinigung Antriebstechnik e.V. (FVA).” With many of our software components, we have huge amounts of documentation where the basics are documents and formulas from various well-known universities. We support our customers to show them where the results come from, why the theories are described in that way, and what the effects are. That’s our main business. All we are implementing is a result of research work.”

HOST OF RESEARCH AVAILABLE

FVA essentially provides software that includes the formulas and everything else that would allow further research into gear creation, according to Haefke.

What FVA brings to the table is a collaboration of decades of research and expertise that was developed at the best research institutions in Germany. The result is a massive library of research, which guides FVA’s customers to their final product, according to Haefke.

“Sometimes our customers have simple questions, and we enable them to get sophisticated ratings and thus, an optimized gear result,” he said. “But generally, our customers are very educated experts, and in some cases, they want to go very deep into the...
“Sometimes our customers have simple questions, and we enable them to get sophisticated ratings and thus, an optimized gear result. But generally, our customers are very educated experts, and in some cases, they want to go very deep into the theoretical framework.”

Theoretical framework. And they discuss formulas with us or even the physical test methods where the formulas come from. And if we discover that some approach is not proven itself sufficiently, we will start research projects within the research association FVA.

In a nutshell, FVA goes that extra mile so its customers don’t have to, according to Haefke.

SIMPLIFYING THE COMPLEX

“Our motto is that we bring theory to reality,” he said. “In the research work, we have an uncountable amount of theory, but for the daily use, you need a tool that’s very handy, that’s easy to use, that’s very efficient to do ratings and to document your results and to derive your construction from the results. That’s our job: to involve all these complex theories in an easy-to-use tool for daily practice. And we support the use of all this content, which is a part of our software, with training from our special network. That’s an additional service we offer.”

For example, FVA knows many people who are experts in drivetrain design, according to Haefke. And they will offer training for FVA’s customers in order to share their knowledge and educate the younger technicians who are still growing within the industry.

2004 BEGINNINGS

FVA’s foray into software and service assistance began in 2004 when many developments were being done at different universities, according to Haefke.

“They did software coding and developed algorithms for drivetrain simulations. But they were all separated,” he said.

This means that a lot of tools were incompatible with a huge lack of usability. Haefke said that he discovered the concept that would bring all these disparate scientific principles and experts together into one central platform, which eventually became the simulation software FVA-Workbench.

“The template is so we have a common and centralized usability...
strategy,” he said. “We have a centralized model; we have centralized components and attributes, and this is all standardized within the FVA-Workbench as a platform. And, therefore, all the research people are developing small parts, which enhance our overall simulation capabilities.”

**FVA-WORKBENCH SPINOFF**

As the concept grew, it branched off into what is now FVA Software and Services in 2010, according to Haefke.

“We changed the mindset of the industry, because in former times, a lot of the members of this association had access to these separated results from research work, and they weren’t paying anything,” he said. “And then, after we established our business model, they joined us; they support us, and they see that what we do is very valuable to their businesses. And I think that was the major breakthrough to get this success we have today, because we had huge support from the German community, who were willing to finance us, and who is willing to use our services and software.”

From that development, FVA launched a software training department, as well as a consulting department.

And Haefke expects FVA’s services to be just as important as the gear industry continues into the future, as the company maintains its steady growth.

“We have very sophisticated software solutions,” he said. “It’s very unique in the world. Not only in functionality and usability, but also with its vast scientific background where 50 universities in Germany are pushing our development to implement and deliver new results every year. It’s a very powerful ecosystem with a very powerful software department research community in which industry customers are working together. We drive our innovation by ourselves.”

---

**G&E Model 120GH CNC Gear Gasher**
- 150” Diameter – can extend to 8M Diameter
- NEW CONDITION

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**MORE INFO**

fva-service.de
Forest City Gear expands high-precision gear shaping capacity

Forest City Gear has expanded its capacity for the shaping of high precision internal and external gears with the addition of the latest Gleason GP300ES gear shaping machine.

The new GP300ES is the first machine of its kind in North America featuring an increased cutter spindle speed of 1,500 strokes per minute, giving Forest City Gear a significant new capability for the high speed production of precision spur and helical (internal and external) cylindrical gears up to 300 mm in diameter.

The GP300ES is the company’s seventh CNC shaper, all with helical guideless capabilities, making Forest City Gear one of the largest and most productive shaping resource available for contract gear production.

“We are fortunate to be the first company in North America to put this new, faster GP300ES into production,” said Forest City Gear Director of Operations Jared Lyford. “It’s a versatile, highly productive machine that adds valuable throughput for customers seeking faster turn-around and higher quality, particularly for gears that require a unique approach to standard cutting strategies via higher feeds and speeds.”

Since 1955, Roscoe, Illinois, based, family-owned Forest City Gear has been one of the gear industry’s leading sources for the development, manufacture, and inspection of the highest quality gears, for use in applications that range from medical devices to motorcycles, airplanes to automation, even including the Mars Curiosity Rover.

MORE INFO  www.forestcitygear.com

Grieve offers 1,050°F cabinet oven with two drawers

Grieve No. 1049 is a 1,050°F (566°C) cabinet oven with two drawers, currently used for annealing or normalizing processes at the customer’s facility. Workspace dimensions of this oven measure 39” W x 102” D x 51” H, with two drawers rated 250 lbs. loading with 36” wide x 78” deep x 15” high loading area. 800,000 BTU/hour installed in a modulating natural gas burner, while a 10,000 CFM, 7-1/2 HP recirculating blower provides horizontal airflow to the workload. This Grieve oven features 10-inch thick...
insulated walls comprised of 2-inch 2,000°F ceramic blanket and 8 inches of 10 lb/cf density rockwool. Features include a top-mounted heat chamber, aluminized steel exterior, and Type 304, 2B finish stainless steel interior. Additional features include a rear door for access to workspace and heat chamber, exhaust hood over drawers, and motorized dampers on intake and exhaust for accelerated cooling.

The oven includes all safety equipment required by IRI, FM, and National Fire Protection Association Standard 86 for gas-heated equipment, including 1,800 CFM stainless steel powered forced exhauster. It also meets AMS2750, Class 2 (±10F), Type C (survey thermocouple at hottest and coldest location).

Controls on the No. 1049 include a digital indicating temperature controller, two digital shutdown timers, one for burner and one for oven, and a circuit breaker disconnect switch.

MORE INFO www.grieve corp.com

Schunk expands 5-axis power vise with adjustable center

In response to high demand, Schunk has increased its product line of power-amplified 5-axis vises which are now equipped with an adjustable center. The maintenance-free Schunk Kontec KSX-C is now available in four base body lengths (330 mm, 430 mm, 500 mm, and 630 mm) and two heights (174 mm, and 125 mm).

The high-quality 5-axis vises have two jaws, which can be precisely moved by a laser-etched ruler. The clamping forces can be adjusted without tools between 4 kN and 40 kN, and are measured directly on the workpiece. The vise also provides plenty of power for a safe hold even in cases with minimal clamping surfaces. Workpieces are clamped within seconds with the help of 160° quick clamping in a vibration resistant manner and at a high repeat accuracy. Due to clamping by tension, the bending load at the base body is minimized. Moreover, the Jaw guidance system and the arrangement of the clamping mechanism provide for a very rigid and dimensionally stable set-up, and therefore creates the ideal conditions for precise machining of the second side.

The drive and the adjustment mechanism of the 5-axis vise are fully encapsulated, and therefore protected against the ingress of chips, dirt, and coolant. The easy-to-clean design of the vise avoids the accumulation of chips. Therefore, the Kontec KSX-C can be seamlessly integrated into the modular system for highly efficient workpiece clamping from Schunk. The clamping pins of the Schunk VERO-S quick-change pallet system can be used for direct mounting of the base body without
requiring an adapter plate. Combined with the quick-change pallet system, the vise can be exchanged on the machine table within seconds and at maximum repeat accuracy. It can be equipped with standard, aluminum or special 5-axis top jaws, pendulum plates, or with many other standard jaws from the world’s largest range of standard chuck jaws from Schunk.

MORE INFO  www.us.schunk.com

Big Kaiser enhances online access to 2D and 3D tooling data

Big Kaiser, a global leader in premium high-precision tooling systems and solutions for the metalworking industries, has redesigned one of the most popular tools on bigkaiser.com — the manuals, DXF, and STEP (STP) search. The improvements make finding 2D and 3D data and specific product manuals easier. As users type a catalog number into the search field, a drop-down menu will display available DXF, STP, and manuals.

“After gathering feedback from our customers, the tool was completely redesigned for the North American market,” said Alan Miller, engineering manager. “The hope is that making both DXF and STP models available online helps customers’ work a little faster and their day-to-day jobs easier.”

DXF standard allows customers to combine products from multiple companies with unified layer structures. The STP standard keeps things simple for program simulation. DXF access is open to anyone but STP downloads will require a login (application link on download page).

MORE INFO  www.bigkaiser.com

Buehler offers Wilson VH3100 fully automated hardness tester

Buehler, ITW Test & Measurement GmbH showcased the All-in-One VH3100 hardness tester at the HärtereiKongress, the largest expo for the heat treatment industry in Europe. The fully automatic preconfigured VH3100 Vickers/Knoop hardness test system is capable of meeting virtually any requirement in the area of automated micro to macro hardness testing. Buehler is also excited to announce that the All-in-One Wilson VH3100 is available for shipping in industry leading lead times and can be delivered quickly in two to four weeks. Matthias Pascher, hardness product manager at Buehler, said, “Buehler developed the Wilson VH3100 All-in-One hardness tester after seeing that customers wanted a pre-packaged Vickers hardness tester with software. The All-in-One is ideal for production control hardness testing and is easily operated; it includes the advanced DiaMet Enterprise hardness testing software. Many customers at the HärtereiKongress were excited to be able to order the complete unit at once.”

The DiaMet Enterprise software offers mapping, edge detection, scanning, stitching of overview image, CHD calculations, statistics, weld testing, geometric measurement functions, exporting all common file types and barcode scanner interface. It also includes a high-performance personal computer with a 24-inch full HD touch monitor. This VH3100 Vickers hardness test system features a three-position virtual turret with one Vickers indenter and two measurement objectives, an automated X/Y sample stage (110 mm x 140 mm travel range), a bright field overview camera for sample navigation and scanning and a powerful image analysis. A purpose-designed collision protection system helps to avoid accidental damage to the indenters and objectives due to operator errors. The VH3100 hardness testing system provides the ultimate high capacity testing platform capable of performing 150 make...
and measure indents an hour (with 10 seconds dwell time) using the fully automated test program.

The VH3100 with its extensive variety of scales and magnifications excels through maximum flexibility for automated hardness testing to ASTM and ISO no matter whether a quality control production environment or in a test laboratory. It is ideal for more advanced heat treatment processes like the aerospace, automotive, energy, construction and transportation industries that require hardness testing systems to be durable while maintaining precise control during critical test data generation.

The Wilson VH3100 All-in-One is pre-configured with macro and micro ranges, closed loop load cell force control and precision optical measurement system. Other features include:

- Load range: 0.05-10kgf.
- ISO and ASTM certified Vickers indenter.
- 10x and 50x long working distance objective for measurements and navigation.
- Motorized stage 180x180mm stage (travel 110x140mm).
- 5 MP bright field overview camera for sample navigation, scanning, etc.

Optional vises, clamps, sample holders, ISO certified hardness test blocks, and other accessories are not included in the All-in-One and will need to be ordered separately.

MORE INFO  www.buehler.com

New Liebherr machine more than just gear skiving

The constantly rising demands from the markets, such as higher accuracy, more

the secret is out

Introducing the new Scudding® machine, the Profilator S-150, is the high-end alternative to broaching machines for gear production.

The gear skiving machine is a vertical configuration, with the patented Scudding® head design and capable of machining 150mm (5.90”) diameters both internal and external. Equipped with a Heidenhain encoder/resolver assembly and Siemens top-end CNC, this new machine features opposing workpiece and work tool spindles, A6 and HSK standard. With AC servo motor drive on both X and Y axes, this sturdy performer offers a small footprint with BIG production capacity, all at a fraction of the price of a conventional broaching machine.

Call Walter (again, if you asked the secret previously) and he'll tell you all about this game-changing machine tool for the North American gear industry.
effective processes and increased flexibility, require sophisticated machine concepts. For this reason, the new gear skiving machine generation has been equipped, among other things, with a tool changing system integrated in the machine, multimechanical functions, an integrated measurement device for tools, and the option of chamfering during the machining process.

Liebherr-Verzahntechnik GmbH has established targets for the new series of gear skiving machines. With the LK 180/280, a gear skiving machine is launched on the market that enables chamfering during the machining process. “With this machine, you can also produce internal gears with a defined chamfer,” said Dr. Oliver Winkel, head of applied technology at Liebherr-Verzahntechnik GmbH. “This is a world first.”

The advantages are obvious: The 90-degree positioned chamfering device does not influence the cycle time and delivers deburred and chamfered workpieces—an absolute advantage for any customer. “For us as gear specialists, it was important to be able to offer our customers new additional functions,” Winkel said. “Our tool changer can accommodate up to 12 tools for different operations.”

Gear skiving tools for roughing and finishing, drilling, and turning tools allow machining in a single workpiece clamping fixture. This is of particular interest with position-orientated gears, said Thomas Breith, head of product management. “Beyond mass production, we can very clearly see a trend towards the integration of various work steps,” he said. “The aim here is to reduce the set-up times of associated or adjacent machines, as well as the influence on workers.”

If re-clamping is dispensed with, many operations become faster and more reliable. Holes can be drilled, for example, exactly at the position of the gear without the need for a reference point marking or renewed measurement. Particularly on ring gears for planetary gear sets, the reference journal (or reference hole) can be precision turned to match the gear so that one step of the operation can be dispensed with.

“The quality and accuracy of our gears are increasing because they always relate to the reference surfaces,” said Winkel.

Quality is also the main argument for tool measurement in the machine. “The gear skiving machine was developed with a view to the highest precision in all aspects,” said Winkel.

By performing tool measurement in a clamped state in the spindle, a higher process reliability and constant quality are achieved. External tool pre-settings are dispensed with and also the multiple administration of tool data becomes superfluous. This helps to avoid faults and eliminates inefficient procedures.

“Our larger LK 500 gear skiving machine was received very well by the market,” said Breith. “We are extending the portfolio downwards with the new machine because many parts can also be machined on a smaller model. At the same time, we offer a package with additional options such as tool changing system, multimechanical functions, tool measurement and chamfering during the machining process, that doesn’t exist anywhere else and we can promise great interest in it. This small machine leaves almost nothing to be desired and is also of interest to customers who have so far not discovered the benefits of gear skiving for themselves.”

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Liebherr-Verzahntechnik offers the new gear skiving machine generation variably with various table and head variations — in the trusted modular system. The new series is set to cover the maximum workpiece diameters of 80, 180 and 280 in future and will be extended gradually.

The process of gear skiving depends heavily on the tool. “Successful skiving depends on many details and we know our setting screws,” said Arroum Haider, regional sales manager for tools at the Ettlingen factory. “Instead of taking an empirical approach during configuration, we prefer our calculation models that are becoming more and more accurate.”

A deep knowledge of the kinematics of skiving is required.

“This process is not forgiving of inaccuracies or even faults,” he said. “On the contrary: It punishes incredibly, and severely.”

Customers have discovered the procedure for themselves and welcome the manufacture of skiving tools from a single source.

Highlights include:
- Small machine, space-saving and fast.
- Skiving and chamfering in one machine.
- Tool changer integrated in the machine.
- Roughing and finishing tools.
- Additional functions such as turning, drilling, hobbing and measuring.
- Integrated measuring of skiving tools.

The calculation option — crossed helical gear with rack — is available as of the KISSsoft Release 2019 (module ZE7). (Courtesy: KISSsoft)

KISSsoft software offers calculation for crossed helical gear with rack

In vehicles, the transmission from the steering wheel to the wheels is often carried out by a rack and pinion drive. In standard industrial rack and pinion drives, the angle between the pinion axis and the rack is 90°. Due to installation conditions in the vehicle, however, the axis angle between pinion and rack usually has to be adjusted. This results in a crossed helical gear pairing, with the rack having an infinitely large number of teeth.

This calculation option — crossed helical gear with rack — is available as of the KISSsoft Release 2019 (module ZE7).

The theory of calculating a crossed helical gear pair with geometry and strength according to Niemann has been extended for racks. This allows the strength, service life, sliding speeds, and efficiency of such a drive to be determined. In a 3D representation with a skin model, the pairing can be rolled, and the contact pattern can be checked.

Such mechanisms are often used for steering systems, especially in the automotive industry. By entering the coefficient of friction and calculating the sliding speeds as well as the forces, the efficiency of the drive can be calculated and optimized.

More info www.kisssoft.ag

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For information on how you can participate in the GearSolutions.com community storefront, contact chad@gearsolutions.com.

Chad Morrison – associate publisher
800.366.2185 x 202
“Oerlikon Balzers’ primeGear is a consulting process where we map all the nuances of the process and make recommendations for run-out, for speeds, and for feeds.”

What do you do with Oerlikon Balzers?
I’m the Head of Cutting Tools for the Americas. That means that I am responsible for the cutting tools business for North and South America — basically in Canada, Mexico, the U.S., Brazil, Argentina, all places where we are business present with our coating centers.

Tell us about the Oerlikon Balzers’ primeGear, and how it can benefit your customers?
Our primeGear is a successful product already being used in Europe, and we are planning to bring it to the U.S. by the end of 2020, beginning of 2021. It’s strictly for our customers who are machining gears. They would get the benefit of this new consulting process that can improve their performance. We would partner with them on an existing or new process improvement, monitoring their gear cutting processes and verifying the process stability.

If the process is not stable, we would make recommendations to help stabilize the process, because one of the prerequisites of primeGear is to have a stable process. Stable means the controlled run-out, predictable tool life, and tool change pre-established.

Essentially, Oerlikon Balzers’ primeGear is a consulting process where we map all the nuances of the process and make recommendations for maximizing productivity. And, on top of that, we will be applying some new technologies that we have in-house for PVD coatings and pre- and post-surface treatment. Pre- and post-edge treatment is more like optimization of microgeometry on the tool and the tool surface: primeGear is a reliable process to maximize the performance of the gear cutting process, maximizing the tooling coating, and the microgeometry’s performance.

By the end of the consultation, we will be engaged in the customer process, and, if necessary, make recommendations about feeds and speeds, possibly reducing the part cycle time. Another outcome of the consulting process would be a dramatic increase in tool life, which would also help increase productivity, reducing downtime.

This comprehensive consulting analysis can make a big difference because you are using the expertise of someone who knows exactly how that edge of the tool should be, in terms of pre- and post-treatments, plus coating, as well as the overall experience of having a demanding market with extremely high standards, seeking quality and reliability in their processes. We will be able to help our customers to identify a stable application from an unstable one. Additionally, showing them the methodology to improve stability.

Ultimately, this complete service package can help manufacturers achieve savings up to 25 percent or more of the current cycle time.

How will it maximize savings on production costs?
Maximizing cycle time and improving cost savings could come from many different areas. On average, we are talking about 20 to 50 percent more tool life. Imagine how much more time you could have to produce parts instead of replacing tools in the machine. So, downtime is a really important part. Repeatability and reliability mean you have constant performance, and it’s something that many don’t have now.

Adding this post- and pre-treatment with the coating, you will also gain a possible maximized cutting parameter, because if the cutter or the process, in general, is stable, we can check the cutting parameters of our customers’ cutters and suggest improvements based on the coating that has been used. This means that if you’re running faster, then you will be reducing cycle time. We will be saving a lot of time. And time for these customers is critical. This is where the biggest savings are coming.

How does Oerlikon Balzers professional consulting service factor into the primeGear?
It’s imperative for us to have the proper relationship with the customer and create this kind of synergistic consulting service because sometimes customers need help in order to stabilize their processes.

So, we need to understand in detail what’s happening with that customer. To that end, maintaining confidentiality is always a part of our procedures. It’s extremely important that customers understand that we need to know how they are doing what they are doing so we can make the proper recommendations about improvements.

A typical example would involve run-out on some cutters. On hobs, we don’t need to be worried about that. When you are machining ring and pinion gears with stick blades, you have to have a very low radial and axial run-out. So, we need to find the customers who are not following those standards and not understanding the benefits of it, helping them to create a new culture of performance improvement to guarantee that the outcome will be what is expected.

Tell us about Oerlikon Balzers’ high-speed coating solution.
That would be Balinit Altensa. This is one of the best coatings that we have in our portfolio when the subject is gear cutting. There are several different coatings that could be used for gear cutting and Altensa is the No. 1 solution. It’s a solution that could be offered in all Balzers coating centers. Sharing the No. 1 position with Altensa, we also have another excellent coating called Alcrona Pro, which is probably the most versatile coating offered by Balzers.

While Altensa was engineered specifically for gear cutting. Alcrona Pro was developed to be a multi-application coating. I highly recommend it for any kind of application, even if you are not planning to use primeGear. It’s important to have a really reliable coating on your tool. If customers are looking for improvements, something that they could use to improve their performances, Altensa and Alcrona Pro would be the solution.
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2. Input Cutter Data from cutter drawing or box.

3. Cutting speeds and feeds automatically calculated as well as cutter paths.

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For more information visit mitsubishigearcenter.com or contact Sales at 248-669-6136.