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INTEGRATING NON-CONTACT METROLOGY IN THE PROCESS OF ANALYSIS AND SIMULATION OF GEAR DRIVES

The application of non-contact metrology allows a very fast collection of points on the measured gear tooth surfaces with data rates that can be as higher as millions of points per second. This new technology provides a wealth of information on gear geometry.

By Dr. ALFONSO FUENTES-AZNAR and Dr. IGNACIO GONZALEZ-PEREZ

DESIGN FEATURES OF PERFECT GEARS FOR CROSSED-AXES GEAR PAIRS

To improve the accuracy and performance of gears that operate on crossing axes of rotation, gears should be designed so they align to the three fundamental laws of gearing.

By STEPHEN P. RADZEVICH

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HEAT-TREATING GEARS IMPROVES SURFACE DURABILITY

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UNDERSTANDING THE DIFFERENT TYPES OF HEAT TREATING

The most common method of hardening steel involves correct heating, quenching, and tempering — but there are key variables within that process.
Are gears like a box of chocolates?

By the time you read this, Valentine’s Day will be over and done with, and I hope you continue to choose wisely as you pick through that box of chocolates. (No one should ever have to eat that orange jelly thing.)

Gears — as well as life — can be like a box of chocolates sometimes, too. That’s why we have been busy picking and choosing some exciting content to help you figure out exactly what you’re going to get.

Our Focus topics for February are intended to do just that as we shine our spotlight on gear design and gear inspection.

We start out with an interesting article from Dr. Alfonso Fuentes-Aznar and Dr. Ignacio Gonzalez-Perez. In it, they share their expertise on integrating non-contact metrology in the process of analyzing and simulating gear drives. The use of non-contact metrology can collect millions of points on measured gears with speed and accuracy — critical factors when it comes to gear inspection.

In the arena of gear design, frequent contributor Dr. Stephen Radzevich looks at the design features of perfect gears for crossed-axes pairs and how gears should be designed in order to align with the three fundamental laws of gearing.

In addition to articles about gear design and inspection, this month’s issue also showcases some interesting information from our regular columnists.

In Hot Seat, Dr. Scott MacKenzie discusses the different types of heat-treating.

In Tooth Tips, Brian Dengel shares his insights on how heat-treating gears improves their surface durability.

And our newest Materials Matter columnist, Guy Brada, explores AMS specifications and how they can be used to qualify entire heats of steel or individual steel products.

You’ll find all this and more in this month’s Gear Solutions, and the best thing is, these “chocolates” are completely calorie free.

So, enjoy, and, as always, thanks for reading!
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United Tool Supply debuts runout inspection fixtures

United Tool Supply announces its newest product offering, the Roll-A-Matic™, 35 years after the birth of the Unite-A-Matic™. A natural fit for the OEM gauge manufacturer, the Roll-A-Matic fills a void in the inspection world that has been left open.

“We see customers on a regular basis, year-after-year, that all have the same looming problem,” said Curtis Criswell, director of Operations. “They have dozens, if not hundreds, of old runout inspection fixtures that are on their last leg. Having run out of options for spare parts and lengthening the life of their units, multiple companies have turned to us for a solution.”

“Bringing home the same feedback after each trip, we knew had to do something,” he said. “Our in-house design and build team has a track record of knocking each challenge we throw at them out of the park and this was no different.”

The Roll-A-Matic is a flexible PD runout inspection fixture built to accommodate the needs of the customer. United Tool’s design allows for inspection of multiple parts on the same unit with minimal tooling change-over, if any, and the ability to use existing master gears — saving its customers thousands of dollars and shortening lead times by weeks, if not months, to implement new runout fixtures.

A robust design ensures years of use on production floors. With options such as a hand-crank, a servo-driven model, data collection, and SPC, United Tool covers all the bases to be able to customize a solution with a standard product for every customer.

MORE INFO united-tool.com

Raybestos Powertrain receives GM Supplier Quality Excellence Award

The Raybestos Powertrain plant in Sullivan, Indiana, recently was awarded the GM Supplier Quality Excellence Award for outstanding performance during 2017. Quality Manager Jerry Workman traveled to Pontiac, Michigan, in December 2018 to meet with Supplier Quality Engineer Narendra Jagmohan of GM and receive the award. Jagmohan appreciated Raybestos Powertrain’s effort put into each shipment and congratulated the Sullivan plant on the accomplishment.

“Raybestos Powertrain made this possible by having good working relationships with GM, responding to concerns in a timely manner and ensuring that employees understand their responsibilities of efficiently and effectively manufacturing parts,” Workman said.

GM’s stringent criteria for the Supplier Quality Excellence Award includes having zero customer complaints for 12 months and displaying quality performance of less than one defective part per million (PPM). Other metrics used for award-eligibility requirements include being TS16949 certified and QSB or BIQS Level III or higher certified. GM uses an extensive OE supplier scoring system to track manufacturing analytics such as PR/R’s, plant disruptions, and severity scores.

2017 marks the second year in a row that the Raybestos Powertrain Sullivan plant has received the award. It is the fifth consecutive year that one or more facilities within the Gearbox family has been honored to be recognized among this distinguished group of top performing OE suppliers.

“Raybestos Powertrain is pleased to have received the General Motors Supplier Quality Excellence Award for outstanding quality performance,” said Dean Decker, director of operations.

Raybestos Powertrain is a brand of Gearbox Holdings and is a manufacturer and supplier of premium OE and aftermarket automatic transmission parts, providing innovative solutions to domestic and international customers.

MORE INFO raybestospowertrain.com

Klingelnberg presents variety of training courses for 2019

Klingelnberg will continue to support customers in 2019 with comprehensive training and continuing education courses. For more than 10 years, Klingelnberg has been...
offering a wide array of seminars to assist customers in building their employees' skills. Training courses are held primarily in the Zurich Training Center at the Group's headquarters and are designed for a broad target audience. The attached demonstration hall with its wide range of machinery enables practical learning directly on the systems.

Klingelnberg training courses stand apart not only because of the extensive technical expertise they offer but also because of their pleasant learning environment thanks to small groups of no more than eight to ten participants. Participants find the learning experience extremely valuable as a result. And the course content is always tailored to customers' needs and realities. If desired, specific problems are used as training examples and solutions are worked out directly for specific customers — an added benefit beyond pure knowledge transfer.

In various courses, Klingelnberg offers its customers broadly based training and continuing education opportunities in the production technologies of cutting, grinding, lapping, testing, measuring, and blade grinding. These training courses are 70 percent practical in nature. Also highly popular are the technology courses, which present an extensive range of basic and detailed knowledge using a three-stage modular system. These courses are focused on bevel gears and the KIMoS (Klingelnberg Integrated Manufacturing of Spiral Bevel Gears) calculation software. Theory T1 is intended for production planners and anyone just getting started in this area. T2 and T3 are designed for developers who will work with KIMoS.

These four-day seminars are offered in German and English regularly 12 times per year in the Zurich Training Center. Other courses are held on request — and, if desired, on location at the customer’s facility.

MORE INFO klingelnberg.com

Zoller continues capacity for innovation in tool presetting, measuring

Zoller, well known as a leading manufacturer of tool presetting and measuring machines, has developed more and more as a system provider over the past several decades. Some of its offerings include:

“SMILE”
The Zoller “smile” is the universal presetting and measuring machine for standard tools. It's easy to operate, constructed of exclu-
sively high-quality brand name components, comes equipped with all standard measuring functions for professionally presetting and measuring cutting tools, and is suitable for use on the shop floor thanks to its robust, well thought-out design and construction.

The high-precision SK-50 spindle and high-quality optics, combined with leading image processing technology allow for precise measurements, and the ergonomic, single-hand “eQ” operating handle allows for easy maneuvering of the optic carrier. The “smile” has a graphical interface to help guide the user through the “pilot” image processing technology.

Simply put: The Zoller “smile” presetting and measuring machine is a must-have for companies carrying out machining work that are looking for a lasting solution for measuring their standard cutting tools.

“VENTURION”
The Zoller “venturion” is the premium presetting and measuring machine for all kinds of tools. The “venturion” is made from the finest components to ensure Zoller users have a reliable machine to preset and measure all their tools for years to come. Built with Bosch pneumatics, THK guideways, Uhing drives, and Heidenhain glass scales, Zoller knows that quality counts. Fully CNC-drives for both the X and Z axis as well as an autofocusing spindle allow for micron-precise measurements time after time. With Zoller’s “ace” (All Clamping Elements) spindle, users enjoy a changeover accuracy of just 1µ, ensuring consistent measurement results regardless of who is operating the presetter.

Zoller’s intuitive pilot 3.0 software makes measuring even the most complex tool geometries a simple task. The new “eQ” one-hand control handle allows for ergonomic, comfortable maneuvering of the optics carrier. Data transfer is no longer a matter of manual entry into the machine control. With data output, users can send their tool offset information directly to the machine control from the pilot 3.0 software on the “venturion,” minimizing the potential for human-error and thus creating greater process reliability.

The Zoller “venturion” provides faster tool measurement, greater flexibility, safer processes, and the connectivity to prepare your company for Industry 4.0.

**TMS TOOL MANAGEMENT SOLUTIONS**
With Zoller TMS Tool Management Solutions software, users have the ability to have complete control over tooling. A single source database ensures every employee in the company is working from the same tool data. Users can store all critical measurements in the Zoller TMS Tool Management Solutions software, and can create a 3D virtual representation of the actual tool stores down to the compartment. This allows users to track exactly how much of any given item is stored in any cabinet or compartment in your shop.

TMS allows users to build and store setup sheets and access them through the software, showing the precise location of the parts and tools required for jobs. Users can book tools into a specific CNC machine and track where the tools are being used. This allows for total transparency in tooling, which leads to less over-ordering of tools that aren’t needed and more complete control of overall tooling. Tool cost reductions are a significant benefit in adding Zoller’s TMS Tool Management Solutions software to a facility.

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**INDUSTRY NEWS**
SMART CABINETS
The Zoller Smart Cabinets provide the perfect storage solutions for all single components, assemblies, holders, and accessories. Thanks to their connectivity to Zoller TMS Tool Management Solutions software, the Smart Cabinets allow users to precisely track the exact location of any given tool, and to track who checked the tool out, for which machine and too which job, all through the software.

With individually locking compartments, users maintain a high level of accountability and control over tools, and thanks to their modular design, users are able to customize the configuration of each cabinet to your precise specifications.

Manually or electronically locking drawers allows users to choose what works best. The Zoller Smart Cabinets are the best way to control tooling, components, holders, and accessories easily and transparently and significant reduce tool costs.

“CORA”
The Zoller “cora” collaborative robotic assistant supports users in all standard tasks for tool preparation, fully automatically.

Tools can be picked, assembled, clamped, cleaned, and labeled, fully automatically. Thanks to its double gripper, components and tool assemblies can be securely gripped and positioned, either in the tool presetter, Smart Cabinets, or on the tool cart. Thanks to its integration to the Zoller Z.One tool database and TMS Tool Management Solutions, “cora” knows the precise location of assemblies and components. For instance: “cora” can open the “keeper” cabinet, remove an assembled tool, insert it into a presetting and measuring machine, and start the measurement process, simply and quickly with very minimal programming effort. After opening or closing the cabinet, “cora” is swiveled 90° and doesn’t interfere with tool handling.

“POWERSHRINK”
Zoller “powerShrink” is the inductive heat shrinking device for HSS and hard metal tools, with which you can considerably reduce the fitting times in your manufacturing: In max. 10 seconds your tools are heat shrunk, cooled after just 40 further seconds, and are ready for production. The precise time to heat and cool depends on tool diameter.

The Zoller “powerShrink” is easy to use, thanks to a turntable that allows quick and easy exchanging of different holders, and a quick heat-shrinking and cooling process.

The modular design allows for individual adjustments to match specific needs, and users benefit from the high degree of rotation accuracy, long service life and reduced tool expenses.

“TOOLBALANCER”
The latest HSC machines work with high speeds and therefore need precisely balanced tools. The Zoller “toolBalancer” — the high-precision balancing system specifically for tool holders, grinding wheels and rotors — gives users precisely balanced tools, which can be adjusted individually to any requirements, even with future developments, all thanks to its modular design.

This modern balancing system guarantees users a longer, controlled, effective, quick and high-quality production.

This measurably reduces rejection rates, machine downtimes, production costs and lead times.

MORE INFO   zoller.info

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Hexagon strengthens Smart Factory position with Etalon addition

Hexagon AB, a global leader in digital solutions, recently announced the acquisition of Etalon, a provider of equipment calibration solutions. Etalon’s solutions continuously monitor and initiate compensation of machine tools, measuring machines, robots, and structures to ensure the dimensional accuracy of manufactured parts.

Etalon, founded in 2004, employs approximately 25 people with domain expertise in production and metrology technology. Its solutions are used by customers in mechanical engineering, industrial instrumentation, automotive and aerospace technology, and the research sector. Not only does Etalon’s portfolio strengthen Hexagon’s calibration solution offering but also complements its on-machine measurement-solution range, which now incorporates machine tool probes, software, and calibration equipment.

“By joining Hexagon, Etalon gains the scale to strengthen and expand its position in equipment calibration. Moreover, the acquisition is a natural extension of Hexagon’s data-driven smart factory strategy. It is reinforcing our commitment to increase customer value through the convergence of production and metrology and greater process autonomy through machine-controlled operations,” said Hexagon president and CEO Ola Rollén. “We are very pleased to welcome such an innovative team on board and look forward to working together on new solutions for our customers.”

Headquartered in Braunschweig, Germany, with a global network of distribution partners, Etalon will operate within Hexagon’s Manufacturing Intelligence division.

MORE INFO hexagon.com

Heller hires Nick Deaville as sales account manager to reach more markets

Heller Machine Tools L.P. continues to expand its sales team with the hiring of Nick Deaville as sales account manager. Vice President of Sales Steve Pegram is focused on strengthening the company’s sales capabilities. Deaville is a machine tool enthusiast with a background in aerospace and oil & gas machining. He truly understands the demand for quality machines in these markets. Pegram said, “We are excited to have Nick as part of the Heller team.”

Deaville will play a key role not only in increasing Heller’s core business, but also extending Heller’s reach into additional market segments that demand the precision, high quality and highly accurate machining capabilities that Heller machining centers offer. Deaville will be based in Houston to offer local support to our growing customer base in the Southern Midwest region.

From its start in 1894, Heller has become an in-demand machine tool manufacturer because of the quality of the machines and the expertise of the employees. Heller provides engineered solutions that help to

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INDUSTRY NEWS
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MORE INFO  heller-us.com

Hexagon announces Production Software business

Hexagon’s Manufacturing Intelligence division has announced the formation of its Production Software business, comprising Vero Software, FASys, and SPRING Technologies. The move, which sees the three acquisitions adopting Hexagon’s corporate identity, reflects Hexagon’s broadening expertise in the production technology space.

Hexagon acquired Vero Software, a specialist in CAD CAM software, in 2014 and has continued to expand and diversify its offering. The 2017 acquisition of FASys brought tooling and resource management software and shop-floor automation and integration expertise into the portfolio. SPRING Technologies, acquired in 2018, provides CNC simulation technology for G-code verification and workflow optimization. Combining components of this rich portfolio of technology, Hexagon has already used this expertise to develop solutions for reverse engineering and on-machine measurement.

“Over the last five years, our available technology and solutions have evolved considerably from the CAD CAM heritage of Vero,” said Steve Sivitter, CEO of the Production Software business. “We’re increasingly focused on developing product synergies that will help customers improve quality and productivity. Our technology experts from Vero, FASys, and SPRING have been working very closely together for some time, so operating together as a single entity is a natural step for us. We’re all excited at the prospect of what’s possible now creating innovative manufacturing intelligence solutions in the production software space.”

Norbert Hanke, president of Hexagon’s Manufacturing Intelligence division, said, “The formation of the Production Software business complements our design and engineering and metrology businesses, enabling us to build unique solutions for our customers in manufacturing. As we develop this approach further, our experience of leveraging data from all phases of the manufacturing process will help create the Autonomous Connected Ecosystems (ACE) that will enable Smart Factories.”

As a leading metrology and manufacturing solution specialist, Hexagon’s Manufacturing Intelligence division’s expertise in sensing, thinking, and acting — the collection, analysis, and active use of measurement data — gives customers the confidence to increase production speed and accelerate productivity while enhancing product quality.

MORE INFO  hexagonmi.com

Motion Industries promotes Joe Limbaugh to senior vice president

Motion Industries, Inc., a leading distributor of maintenance, repair, and operation replacement parts and a wholly owned subsidiary of Genuine Parts Company, recently announced the promotion of N. Joe Limbaugh to the position of Senior Vice President of Supply Chain, Operations Support and Marketing, effective January 1, 2019. Limbaugh will report directly to the president of Motion Industries.

Limbaugh began his career in 1983 in Bourbonnais, Illinois, in an entry-level position with Berry Bearing Company, which was later acquired by Motion Industries. In 1989, he relocated to Peoria, Illinois, where he continued to achieve higher levels of success working as operations manager, branch manager, and then corporate sales manager. In 2007, Limbaugh accepted the position of vice president general manager of the Birmingham, Alabama, division. He returned to Chicago, Illinois, in 2009 to assume the role of vice president general manager of the Chicago division.

In 2013, Limbaugh was asked to return to Motion’s Birmingham headquarters as vice president of Operations, Distribution, and Properties.

“Joe has a wealth of experience, both in field sales and branch operations, as well as in corporate functions including logistics, distribution, properties and facilities management,” said Randy Breaux, Motion Industries president. “Additionally, Joe’s creative and marketing intelligence makes him uniquely qualified to lead Motion in several disciplines. During the past five years, I have watched Joe master every challenge presented to him. I
am very excited to see Joe take our Supply Chain and Marketing efforts to a new level.”

With annual sales of $5 billion, Motion Industries is a leading industrial parts distributor of bearings, mechanical power transmission, electrical and industrial automation, hydraulic and industrial hose, hydraulic and pneumatic components, industrial products, safety products, and material handling. Through EIS, which joined with Motion Industries to form its Electrical Specialties Group in 2018, the company has broadened its offerings with process materials, production supplies, specialty wire and cable, and value-added fabricated parts for the electrical OEM, motor repair and assembly markets. Combined, total Industrial Group annual sales are approximately $6 billion.

**MORE INFO** motionindustries.com

**Latest MC Machinery technology on display at Houstex 2019**

MC Machinery Systems Inc. will be at HOUSTEX 2019 at booth 2613. From February 26–28, MC Machinery will be at the George R. Brown Convention Center in Houston, Texas, showcasing its advanced machining technologies including the MV2400-ST wire EDM and MCV-1000 machining center.

The MV2400-ST is specifically designed for larger-part production, capable of performing submerged cutting up to 16.5 inches deep. With an annealing length of more than 21 inches, this system can thread the maximum workpiece height both at the start point and through the gap if needed for a broken wire recovery. It also features the new Mitsubishi M800 series control with a 19-inch touchscreen — providing easier user interface than previous models.

The M800 series control uses rotational and tilting functionality while showing job monitoring and important information in a single view. The navigation interface provides smooth and easy job operation time for all expertise levels, allowing production jobs to be completed quickly and accurately.

Additionally, MC Machinery will be showcasing the MCV-1000 machining center. This machine performs well in a wide variety of applications, including but not limited to fixtures, mold bases, and secondary operations. It is a great general-purpose machining center featuring a 12,000-RPM spindle standard and BIG Plus CAT 40 tooling.

As part of the global Mitsubishi Corporation, MC Machinery Systems draws from an extensive global source of support and innovation. HOUSTEX 2019 is the place to learn more about the company, meet local sales representatives and obtain the latest news on the manufacturing industry and technology trends.

**MORE INFO** houstexonline.com

**MC Machine MV 2400ST** is specifically designed for larger-part production, capable of performing submerged cutting up to 16.5 inches deep. (Courtesy: MC Machine)

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AGMA/ABMA Annual Meeting gives members chance to meet face-to-face

In a digital, fast-paced world, it is easy to choose the convenience of online communication over meeting in person. It is proven to be quicker and sometimes easier to email or call to discuss business, but is it really better? While online networking is still a big part of relationship development, it does not hold the same value as meeting your peers and business prospects face-to-face.

According to Hubspot.com, “Nearly 100 percent of people say face-to-face meetings are essential for long-term business relationships.” Not only are you able to shake a person’s hand and read facial expressions, but it allows for a greater sense of trust to develop during the interaction. You are more likely to remember the conversation when you can visualize who you had it with.

The AGMA/ABMA Annual Meeting was specifically designed to assist members in building valuable relationships needed in the gear and bearings industries. This annual event is the place to meet and reconnect with like-minded professionals and suppliers to add value to your business. Join us April 11-13 in Scottsdale, Arizona, and let the networking begin.

The Annual Meeting not only provides you a with a way to exchange ideas and develop new business connections with your peers, but you are provided with all the industry experts in one place. Instead of traveling to three difference conferences, you are able to hear about the latest economic trends, tariffs, technology, workforce development, and blockchain to name a few. This unparalleled conference schedule will make coming to the Annual Meeting the best investment you make all year.

Some business presentations include:
- Carey Lohrenz, First Female F-14 Fighter Pilot, U.S. Navy: Lessons In Leadership.
- Nate Bolin, Partner, Drinker, Biddle & Reath, LLP: Surviving the Trade Tornado: Recent Developments and Prospects for the Year Ahead.
- Jim Meil, Principal, Industry Analysis, ACT Research: U.S. Economy and Business Outlook — Can it Take a Licking and Keep on Ticking?
- Jack Shaw, Executive Director, American Blockchain Council: The Blockchain Transformation of Procurement and Supply Chain Management.

There are many reasons to attend the 2019 AGMA/ABMA Annual Meeting. One of the most important aspects of this meeting is that it was made for you by you. Our Annual Meeting Committee members are gear and bearing industry professionals and suppliers. They know what is important to cover and have guided the associations to make an event that is right for you. We look forward to seeing you in Scottsdale April 11-13. To register for this event, visit: www.agma.org or www.americanbearings.org.

THANK YOU TO THE AGMA/ABMA COMMITTEE
- David Goodfellow, Star SU, LLC, chairman.

AGMA PARTICIPANTS
- Jim Bregi, Doppler Gear Company.
- Dean Burrows, Gear Motions Inc.
- John Cross, ASI Technologies.
- Dave Long, Chalmers, Kubecck Inc.
- Mike McKernin, Circle Gear and Machine Company.
- Anne Miner, Machine Tool Builders.
- Greg Schulte, Bonfiglioli USA.

ABMA PARTICIPANTS
- Jeff Manzagol, NN Inc.
- Tony Richey, Specialty Steel Treating Inc.
NATE BOLIN  
Partner, Drinker, Biddle & Reath, LLP

SURVIVING THE TRADE TORNADO: RECENT DEVELOPMENTS AND PROSPECTS FOR THE YEAR AHEAD  
Last year was anything but quiet on the trade front, and companies continue to face a range of challenging issues under the rapidly changing U.S. trade laws. This presentation will survey recent major changes in those laws — from Section 301 and 232 tariffs to U.S.-China trade tensions, antidumping, and countervailing duties, the U.S.-Mexico-Canada Agreement, and bilateral trade negotiations with Japan, the EU, and other countries — and how they may affect you. We will also discuss strategies for surviving and even thriving in this landscape and what the prospects are for the remainder of 2019.

CHANDRA BROWN  
Executive Director, DMDII

EVERY PART BETTER THAN THE LAST: A VISION FOR U.S. MANUFACTURING  
The opportunities presented by digital transformation are great but are too often impeded by a lack of vision, actionable plans, business cases, resources, know-how, cyber assurance, and other factors. U.S. manufacturers are faced with an urgent challenge to seize this opportunity and make wise technology investments, while not being distracted by any and every technological fad. The Digital Manufacturing and Design Innovation Institute’s (DMDII) Executive Director, Chandra Brown, will talk about building real-time adaptive factory capabilities into existing and new processes, protecting our growing digital advantage and investing in the people and systems needed to realize a vision of “Every Part Better than the Last.”

CAREY LOHERNZ  
First Female F-14 Fighter Pilot, U.S. Navy

LESSONS IN LEADERSHIP  
As the first female F-14 fighter pilot in the U.S. Navy, Carey “Vixen” Lohrenz knows what it takes to win in one of the highest pressure, extreme environments imaginable. In 1994, when Lohrenz was deployed to the U.S.S. Abraham Lincoln, there were fewer than five female aviators on a ship of 5,000 male crew members. Facing uncharted waters in an intensely male-dominated environment, Lohrenz learned vital lessons in leadership that followed her into the corporate world. The most successful leaders share a common foundation of principles used from the flight deck to the front office. The greatest leaders from all corners of the world know how to inspire, use good judgment, take initiative, and make powerful decisions — with integrity. In this keynote, Lohrenz shares the fundamentals that helped her win in the cockpit at Mach 2 and can help your team win in business.

JIM MEIL  
Principal, Industry Analysis, ACT Research

U.S. ECONOMY AND BUSINESS OUTLOOK — CAN IT TAKE A LICKING AND KEEP ON TICKING?  
When the AGMA/ABMA Annual Meeting convenes in April 2019, the U.S. economy is likely to be in record-setting territory for business cycle expansion length. Having started in June 2009, it will be celebrating a 10th birthday in just two months and will be the longest span in the post-World War II period without a recession. But the path hasn’t always been easy, and 2019 may not be a slam dunk. Tariffs, regulations, dysfunctionality in the D.C. Beltway, a slowdown in China and Europe, plus rising interest rates could put growth in jeopardy. Most of the businesses served by AGMA/ABMA members are highly sensitive to the economic cycle. Insights into the pace of the economy and particularly its duration are critical for effective business planning. Jim Meil’s analysis has helped meeting attendees determine the momentum of the domestic economy, and the direction of interest rates, capital spending, manufacturing activity, international economic strength, and business confidence, all key to members, suppliers, and customers.

ALBERTO MOEL  
VP, Strategy and Partnerships, VEO Robotics

THE END OF FEAR: HOW COLLABORATIVE INDUSTRIAL ROBOTS WILL CHANGE DURABLE GOODS MANUFACTURING  
Increasing mass-customization and shorter product cycles intensifies the need to integrate human ingenuity and flexibility with the strength, precision, and speed of robots and machines in manufacturing. But because automation can be dangerous to humans, humans and robots are currently kept apart by cages and other safety devices. Although there have been advances in the development of collaborative robots, these robots sacrifice performance for safety. Alberto Moel will provide insight into how Veo Robotics is developing solutions that allow traditional industrial robots to understand where they are in a work cell, identify workpieces and the humans working around them, and take safe and effective actions when interacting with humans.

PANEL  
Stan Shoun, President of Ranken Technical College; Dr. David Girzadas, Dean of College to Careers at Richard J. Daley College; Kimberly Jones, State Director, Illinois, U.S. Department of Labor; Franco Dutto, VP Human Resources, Compliance and Sustainability at Tsubaki Nakashima

PANEL DISCUSSION: PRACTICAL SOLUTIONS FOR MEETING THE CHALLENGES OF TOMORROW’S WORKFORCE  
Finding, training, and nurturing the workforce of tomorrow is the single largest threat facing all manufacturers, no matter what size or product scope. According to Deloitte and the Manufacturing Institute, over the next decade, we can expect nearly 3.5 million manufacturing jobs will be needed, and 2 million are expected to go unfilled due to the skills gap. Join education and labor experts from Ranken Technical College, Daley College, the U.S. Department of Labor, and Tsubaki Nakashima for this panel that will share pragmatic and successful strategies being deployed at the technical school and industry levels to secure employees. You will learn how to work with local schools, organizations, and extend your reach into your communities to find the right employees for your company. Get all the tools you need to grow the future of manufacturing at every level.
THE BLOCKCHAIN TRANSFORMATION OF PROCUREMENT AND SUPPLY CHAIN MANAGEMENT

The world will change more in the next five to 10 years than it has in the past 50. And perhaps no technology will drive that change more than Blockchain. It will affect every organization in every industry — just as the internet has. Executives are becoming aware that Blockchain is important, but it is still not well understood by most. The enabling technology underlying the digital currency Bitcoin, Blockchain lets people and businesses have trustworthy interactions without requiring costly third-party intermediaries. They can create and maintain cryptographically secure, completely immutable, totally verifiable records of transactions, ownership of assets, authentication of identity, exchange of digital currencies, and smart contracts. Smart contracts are created using computer code on a Blockchain rather than written language. Jack Shaw will help attendees make sense of Blockchain and how it can be used in a manufacturing setting. He will discuss how Blockchain technologies extend the concept of digital transformation beyond individual process and specific geographical locations. They enable the digital transformation of entire business and social ecosystems. This means a radical transformation of how all aspects of procurement and supply chain management will work in the near future.

JACK ULRICH
Global Futurist, Speaker & Author

BUSINESS AS UNUSUAL
As Yogi Berra once famously said, “The future ain’t what it used to be.” He was right. In fact, the future is going to be downright unusual. This begs the obvious question: How do you prepare for an uncertain and unpredictable future? The answer is that you and your organization must think and act in unorthodox ways. In this unconventional keynote presentation, Jack Ulrich helps his audience unlearn the barriers holding them back, so they can unlock new levels of creativity and innovation. He concludes by guiding participants through a series of tangible actions that will unleash their ability to create their own future and, in the process, achieve uncommon levels of success.

Special Networking Events at Annual Meeting

FIRST TIMERS’ RECEPTION
If this is your first time attending the Annual Meeting, please let us know by clicking the First Timer box on the registration form. This will grant you access to the First Timers Reception on April 11, which is open to only first-time attendees and their spouses and guests. This wonderful reception is where you will be paired with an Annual Meeting veteran who will contact you prior to the reception to answer any questions you might have.

This invitation-only event offers first-time attendees an intimate gathering place to meet other first timers and AGMA and ABMA leadership. We look forward to welcoming you to the community!

WELCOME RECEPTION
So much of the Annual Meeting revolves around networking and the opportunities to reconnect with friends and colleagues while making new acquaintances. This year’s reception is on the resort’s Northern Sky Terrace overlooking picturesque mountain views and local scenery. Join us for a cocktail to kick off the first networking event of the 2019 Annual Meeting.

GOLFING FOR SCHOLARS!
String and Mulligan Sales will benefit AGMA Foundation Scholarship Fund.

Golf beginners, experts, and everything in between are welcome to join the annual Golf Tournament at The Westin Kierland Golf Club. To follow the new tournament style developed in 2018, the players will be divided into three teams to compete in larger groups. This will generate some healthy competition and provide a more exciting pace of play. Each team will be divided into foursomes and play the “best ball” format. The difference is that you earn points as a team as opposed to points earned for each stroke. The scoring is done by hole rather than cumulative score for each round to accommodate the wide range of handicaps and skill levels.

CORNHOLE TOURNAMENT
Back by popular demand, join us for a fun and competitive afternoon of the popular tailgate game. Grab a teammate, design your uniforms, and get ready to compete in our second annual tournament. If bean bag tossing is not your thing, spectators and cheerleaders are welcome to join in for refreshments and sideline games. Prizes will be given for both skill and team spirit, so bring your A-game!

CASINO NIGHT
Annual Meeting attendees have hit the jackpot with this year’s theme-night reception. Join us for a fun and glamorous Casino Night featuring a variety of table games, Las Vegas style entertainment, and fabulous food and drinks. Players will be given game currency for open play and additional currency will be available for purchase with proceeds benefiting the AGMA Foundation. Shake, rattle, and roll your way over to this unforgettable event!

CLOSING DINNER
As we wrap up another successful Annual Meeting, the Closing Dinner is your final opportunity to spend time with old and new friends to recognize some outstanding members of the AGMA and ABMA community during our annual awards ceremony. Dinner guests will leave inspired by our motivating speaker Carey Lohrenz, the first female F-14 Tomcat fighter pilot in the U.S. Navy!
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.

| February 12 — Helical Gear Rating Committee Meeting — WebEx
| February 13 — Nomenclature Committee Meeting — WebEx
| February 26 — Metallurgy and Materials Committee Meeting — WebEx
| February 28 — Helical Enclosed Drives High Speed Units Committee — WebEx

| March 5 — Gear Accuracy Committee Meeting — WebEx
| March 7–8 — Working Group 2 — AGMA Headquarters
| March 12 — Metallurgy and Materials Committee Meeting — WebEx
| March 13 — Spline Committee Meeting — WebEx
| March 14 — Wind Turbine Gear Committee — WebEx
| March 21 — Lubrication Committee — WebEx
| March 25 — Fine Pitch Gearing Committee — WebEx
| March 26 — Helical Gear Rating Committee Meeting — WebEx
| March 27 — Nomenclature Committee Meeting — WebEx

| April 8 — Fine Pitch Gearing Committee — WebEx
| April 9 — Lubrication Committee — WebEx
| April 11–13 — Annual Meeting — Scottsdale, Arizona
| April 16 — Gear Accuracy Committee Meeting — WebEx
| April 23 — Helical Gear Rating Committee Meeting — WebEx
| April 30 — Metallurgy and Materials Committee Meeting — WebEx

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**GENERAL REQUESTS**: webmaster@agma.org  |  **MEMBERSHIP QUESTIONS**: membership@agma.org  |  **TRADE SHOW INFORMATION**: blackford@agma.org

**TECHNICAL/STANDARDS INFORMATION**: tech@agma.org  |  **AGMA FOUNDATION**: foundation@agma.org
"The most decisive aspect when buying our 2\textsuperscript{nd} ZP15 KAPP NILES machine is the advantage of a kinematic capability that allows us to work much bigger diameters than having to purchase a larger and higher priced machine. Since we’re already running on a ZP15, we knew that we can count on the KAPP Technologies team for support whenever needed. The KAPP applications engineers are particularly responsive to our needs and their knowledgeable service team keeps our machines in top shape with their annual maintenance."

- Jerry Capone
Shop Operations Manager with Umbra Group

Umbra Group provides motion solutions and components or systems for Aerospace, Power, and Industrial high-tech markets. They just purchased their 2\textsuperscript{nd} ZP15 machine from KAPP NILES.
Clever sampling techniques highlight AMS aircraft quality testing

AMS 23XX specs can qualify entire heats of steel or individual steel products to comply with ‘aircraft quality’ cleanliness requirements. In this edition of Materials Matter, we review the sampling and test piece production required for the AMS aircraft quality (AQ) testing methods specified in AMS 2300, 2301, 2303, and 2304. While each of these standards has variations in the quality levels and testing sensitivity, the overall sampling methodology and test sample geometry requirements are essentially the same for all four specifications.

The AMS 23XX specifications can be used to qualify entire “heats” of steel or individual steel products to comply with “aircraft quality” cleanliness requirements. Once a heat is tested and qualified, any products produced from the qualified heat do not require additional sampling or testing. For this reason, many parts manufacturers will purchase raw material (ingots, blooms, or billets) that is supplied, tested, and qualified to the applicable AMS 23XX specification.

The specific heat lot sampling requirements for top-poured, bottom-poured, or strand-cast heats are specific to the cast steel production process used. In general, for ingot cast material, samples are specified to be taken from material near the top and near the bottom location of each individual ingot. These top and bottom location samples will qualify the material for the entire ingot. When multiple ingots are cast in a heat, normally three ingots are sampled, again using samples taken at the ingot top and bottom locations. Strand-cast heats require samples to be taken from the first, middle, and back of up to two strands produced from a given heat of steel. The test results of all samples and tests from a heat are averaged and a final frequency (F) and severity (S) rating is produced that becomes the AMS 23XX rating.

Interesting aspects of these AQ testing methods are the clever sampling techniques used to produce the test samples that enable inspection of the entire cross-section of the parent material quality. There are two different sampling techniques that can be used, depending on the size of the starting material, that both enable qualification of the material as AQ.

Perhaps the most straightforward sample to understand is the stepped cylindrical, whereby a full-cross section of a round bar (>1.5 inches diameter) or flat-plate material (>1 inch thick) is machined with five equal steps. Smaller cross-section bars or plates require fewer step downs and all the details tabulated within the specifications. Each of the five steps represents the parent material at progressively increasing distance from the outer surface. The machined surface finish must be very fine, and the specifica-

The samples are “hand-forged” using an open-die hammer to produce a straight cylinder forging where the outer diameter of the sample represents material from the surface, mid-radius, to center location.

The stepped sample is typically used for material where the material size enables machining and easy handling of a sample for testing. Typically, sections less than about five inches may use a stepped sample.

In larger sections, typically greater than six inches up to the largest ingots being qualified, a different approach is used. A straight cylindrical or rectangular sample from a quarter section of the parent material can be produced by simply cutting a quarter section, machining to the required surface finish and tested. In large sections a full quarter section of the parent material is sampled and is then re-forged to produce a more manageable cylindrical sample size. The resulting straight cylinder must have a
length of five inches and a diameter up to four inches. Following this approach, the outer diameter of the resulting cylinder continuously represents material from the outer diameter through the mid-radius to the centerline of the parent material. Following the forging process, the sample is then finish machined and inspected using fluorescent magnetic particle inspection to reveal the non-metallic inclusions. The indications are measured, and the size and quantities are recorded. More details on the magnetic particle inspection, recording, and reporting will be discussed in next month’s Materials Matter column.

To see the sample preparation and testing first hand, I had the opportunity to visit Solmet Technologies Inc. in Canton, Ohio. Solmet has been providing AMS Aircraft Quality testing services for 30 years and has tested nearly 400,000 samples. The company receives material from many different steel producers that submit material for testing and certification to the AMS specifications. The quarter sections are torch cut from the incoming material and then heated in a forge furnace. Next, the samples are “hand-forged” using an open-die hammer to produce a straight cylinder forging where the outer diameter of the sample represents material from the surface, mid-radius, to center location.

In next month’s installment of Materials Matter, we will review the fluorescent magnetic particle inspection, indication measurement, and reporting methodology required for the AMS 23XX Aircraft Quality specifications.

**About the Author**

Guy Brada is a metallurgical engineer with more than 25 years in the steel industry. He received his Bachelor’s and Master’s degrees in Metallurgical and Materials Engineering from the Colorado School of Mines. During his career, he has worked in steelmaking, the heavy forging industry, at an independent metallurgical test laboratory, and at a commercial heat treater. He has authored seven steelmaking and steel product patents. Currently he is technical sales service manager for Ellwood City Forge the open-die forging division of the Ellwood Group.
A common question asked of gear manufacturers by their potential customer is, “Is this gear strong enough for my application?” Without qualifiers, this question is ambiguous at best. The world record for deadlift is 536 kilograms (1,181 pounds). Does this make the record holder strong enough? Could he hold this weight for 10 minutes? How about for an hour? A gear needs to be able to withstand the applied torque of the desired service life of the gear. As such, the bending strength AND the surface durability need to be considered in order to answer the heretofore mentioned strength question.

All metals have a bending strength that is significantly stronger than their surface durability or bearing strength. To improve that surface durability and thereby improve the life of a gear, the gear can be heat-treated. There are several methods for heat-treating a gear.

Flame hardening (Figure 1) is a common method for heat-treating gear teeth. It involves using a torch to heat specific areas of a gear, typically the gear teeth, to improve the surface durability. When applied manually, this method is prone to unsatisfactory results as the time spent heating each area will be different, the distance from which the flame is applied will vary and these two variations will cause different surface hardness across the gear. Even when the process is automated to remove these variations, the gear will still experience some dimensional distortion that will typically reduce the gear quality by one grade.

Induction hardening (Figure 2) is another common heat-treating method for gearing. In this process, the gear is surrounded by a coil. The coil is energized, thus creating alternating magnetic fields. These fields in turn generate eddy currents which heat the gear. This method is a fairly accurate way to harden all of the gear teeth to the same hardness and depth. However, it takes some skill and practice to determine the time that each individual gear configuration needs to obtain the desired hardness for a specific material. One of the drawbacks with induction hardening is that the areas immediately next to the gear teeth are also partially hardened. This limits the rework of areas near the teeth, after heat treating.

A third method for heat-treating gearing is to carburize the gear (Figure 3 and Figure 4). Carburization is the process of placing the gear into an oven with added carbon and heating the oven to several hundred degrees Celsius for an extended period of time. This process allows the added carbon to penetrate into the molecular structure of the gear. This added carbon causes a skin of hardened material (also known as a case) to form on the outermost layer of the gear.

This case makes the gear unable to be re-machined after heat-treating unless carbide tooling or wire EDM methods are employed. As such, it is desirable to perform all machining operations prior to carburization. Similar to induction hardening, great skill is needed to obtain the desired results when carburizing.

The newest method of heat-treating is laser hardening (Figures 5 a and b). This method, as the name suggests, uses light energy to rapidly heat small sections of a gear. It has several advantages over all other methods of heat treating. The first advantage is that it can be used in very small areas and does not affect nearby areas. Additionally, since it is operated by a CNC, the amount of energy applied to each section is identical and the hardness depth can be limited. Since the pulse of light is applied very quickly, the gear does not have an opportunity to heat up and therefore, there is no degradation in gear quality.

All heat-treating methods increase the surface durability, but some also reduce the bending strength as the material becomes brittle after heat-treating. Some examples of the benefits of heat-treating are as follows:

- Module 2, 15 tooth, 1045 carbon steel spur gear with a 20mm face width, has an allowable bending strength torque of 29.6 Nm and a surface durability of 1.48 Nm. When induction hardened to HRc 45-55, the allowable bending strength torque remains at 29.6 Nm,
but the surface durability increases to 10.5 Nm. This is a 9x increase in surface durability.

**B:** Module 2, 25 tooth, 1045 carbon steel spur gear with a 20mm face width, has an allowable bending strength torque of 63.3 Nm and a surface durability of 4.64 Nm. When induction hardened to HRc 45-55, the allowable bending strength torque decreases to 52.7 Nm, but the surface durability increases to 27.0 Nm. This is a 5.8x increase in surface durability and a 16 percent decrease in bending strength.

**C:** Module 2, 40 tooth, 1045 carbon steel spur gear with a 20mm face width, has an allowable bending strength torque of 118 Nm and a surface durability of 12.5 Nm. When induction hardened to HRc 45-55, the allowable bending strength torque decreases to 98.3 Nm, but the surface durability increases to 72.1 Nm. This is a 5.7x increase in surface durability and a 17 percent decrease in bending strength.

**D:** Module 2, 1045 carbon steel gear rack with a 20mm face width, has an allowable bending strength of 3830 N and a surface durability of 775 N. When induction hardened to HRc 45-55, the allowable bending strength torque decreases to 3480 N, but the surface durability increases to 2000 N. This is a 2.5x increase in surface durability and a 9 percent decrease in bending strength. However, if laser hardened to HRc 55-65, the bending strength remains 3830 N and the surface durability increases to 1730 N. This is a 2.2x increase in surface durability without any of the distortion or decrease in bending strength that occurs with other methods.

These are some of the many ways that you can heat-treat a gear to improve the surface durability. Each method has its advantages and disadvantages, but laser hardening is the most economical method for small batch hardening.

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**ABOUT THE AUTHOR**

Brian Dengel is general manager of KHK-USA, which is based in Mineola, New York. Go online to www.khkgears.us
Understanding the different types of heat treating

The most common method of hardening steel involves correct heating, quenching, and tempering — but there are key variables within that process.

In the last article, we discussed many different types of annealing, and the reduction of distortion by application of stress relief annealing. In this article, we are going to discuss the primary methods of hardening steel.

QUENCH AND TEMPERING

The most common method of hardening steel in industry today consists of heating the steel component to the austenitizing temperature; quenching in a suitable quenchant; and tempering to the desired hardness. This is shown schematically in Figure 1.

In this example, the part is austenitized, and then quenched in a quenchant fast enough that the surface and center of the part miss the “nose” of the TTT curve and is completely through-hardened. The slowest possible quench to achieve through-hardening corresponds to the quench rate sufficient to just miss the “nose” of the TTT curve. Slower quench rates than the minimum will result in the formation of non-martensitic transformation products of ferrite, pearlite, and bainite. It should be noted that the TTT curve has no bearing on the tempering reaction.

This is the most common type of heat treating of steels and is applicable to a wide variety of heat treatments of all type of components, including aerospace, automotive, and agricultural parts. For most applications, the austenitizing temperature is approximately 25-30 degrees C above the Ac3 temperature. After properly soaking at temperature, the part is then quenched rapidly into brine, water, polymer, or oil. The quenchant is generally less than 80 degrees C for oil and at ambient temperature for the water-based quenchants (water, brine, and polymer). The part remains in the quench until it is at approximately the temperature of the quenchant. The part is then removed from the quenchant and immediately tempered. If the part is not tempered immediately (usually within 90 minutes of quenching), the part may be prone to quench cracking. This type of heat treatment is prone to distortion and residual stresses. To minimize distortion and residual stresses, the quenchant is selected to achieve properties and minimize distortion.

MARTEMPERING

Martempering is a specialized process that is only used when distortion and high residual stresses are an issue. In this process, parts are quenched from the austenitizing temperature into hot oil or molten salt at the approximate martensite start temperature (100-200 degrees C). The part is held at the oil temperature until the surface and center temperatures of the part are nearly the same. Once the center of the part has reached the quenchant temperature, the part is removed from the quenchant and allowed to cool in any convenient manner (usually air cooling). This prevents the formation of thermal stresses due to unequal cooling between the center and surface (Figure 2).
If complete hardening is to occur, the austenite must cool sufficiently fast to prevent the center cooling rate to miss the “nose” of the TTT diagram. Since the TTT diagram shows the martensite start temperature, $M_s$, the TTT diagram is useful for selecting the optimal quenching temperature, and estimating the time the part must be held at temperature to prevent the formation of bainite.

Martempering is most likely used for parts that have been carburized. The carburized case of the part has a greater carbon content than the core. Since the case has a greater carbon content, the $M_s$ temperature is lower in the case than in the core. The part is quenched into oil or molten salt at temperatures just above the $M_s$ temperature of the carburized case. This means that the core will often transform earlier than the case, resulting in the beneficial compressive residual stresses at the surface of carburized parts.

Alloy steels are generally more amenable to martempering. For the most part, any steel that can be oil quenched can be martempered. Steels that have a high carbon equivalent (CE) that are prone to quench cracking are often martempered to avoid cracking. In this case, the Carbon Equivalent is defined as [1]:

$$CE = \frac{%C}{16} + \frac{%Mn}{23} + \frac{%Si}{34} + \frac{%Cr}{11} + \frac{%Ni}{19} + \frac{%Mo}{12} + \frac{%V}{6}$$

Another equation for the Carbon Equivalent is [2]:

$$CE = \frac{%C}{5} + \frac{%Mn}{5} + \frac{%Mo}{10} + \frac{%Cr}{10} + \frac{%Ni}{10}$$

In each case, quenching cracking was determined to be a problem if the Carbon Equivalent (CE) > 0.52 percent. If the Carbon Equivalent of the steel is greater than 0.50 percent, then the steel is a good candidate for martempering. Table 1 shows the carbon equivalent for some common steels.

In the commonly heat-treated alloys in Table 1, only AISI 8630 and AISI 4130 are not prone to quench cracking. AISI 1045 is heat-treated by martempering and by quench and temper. It often is dependent on the geometry of the part, or the tendency toward distortion, on whether AISI 1045 is quench and tempered or martempered. Thin sections are the most likely to be martempered due to the low hardenability of AISI 1045.

Martempering is especially appropriate for carburized parts (especially bearings, gears, and shafts) where the parts are more costly to fabricate and are made to closer dimensions [3]. This is illustrated in Figure 3, where the distortion is shown as a function of martempering temperature [4].

The limitations of section thickness must also be considered for suitability for martempering. With a given severity of quench, there is a limit in section thickness where the steel will no longer harden fully or transform to martensite. However, depending on the

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<th>%Mn</th>
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<th>%Cr</th>
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Table 1: Common alloys, and their martensite start temperatures, and carbon equivalents.
application, it may be acceptable for the center of the part not to be completely transformed to martensite. Often times it is acceptable that the core hardness is less than the surface hardness. If this is the case, then the size for martempering can be increased. The effect of the resulting mixed microstructure on the mechanical properties would have to be evaluated for each application.

AUSTEMPERING

Austempering is an isothermal process to achieve a solely bainitic structure. This is accomplished by heating the part within the austenite range and then quenching the part into a bath of hot oil or molten salt held at a constant temperature of 260-400 degrees C (above the Ms temperature of the alloy). The part is then allowed to transform isothermally to achieve a bainitic structure and allowed to cool in a convenient manner, usually in air. This process is illustrated in Figure 4.

The advantages of austempering are:
- Increased ductility or notch toughness.
- Reduced distortion.
- Shortened overall cycle time.

For true austempering, the part must be cooled so that the center and surface of the part miss the nose of the TTT curve.

The selection of a steel for austempering is primarily based on the TTT curve of the alloy. There are three important considerations for the application of a given steel for austempering:
- The location of the nose of the TTT curve and the time needed to bypass the nose; and
- The time required to achieve complete transformation to bainite; and
- The temperature of the start of martensite transformation, Ms.

Carbon steels are generally unsuitable for austempering because the time to bypass the nose of the TTT curve is very short. Medium carbon alloy steels such as 5140 are well-suited to austempering because the nose of the TTT curve is sufficiently to the right, that it is possible to bypass the nose without forming pearlite. A completely bainitic structure is achieved within one to 10 minutes at 315-400 degrees C. Nodular ductile iron is a common application for austempering, as it improves wear resistance and provides an impact-resistance microstructure.

The maximum section thickness is important in determining the slowest quench rate that will miss the nose of the TTT curve. Because of this limitation, very high hardenability steels are needed to achieve a fully bainitic microstructure in sections greater than 13 mm. When it is permissible to have some pearlite present in the microstructure, the allowable section thickness can be increased.

Because of the section-size limitation, the range of austempering applications are usually limited to parts fabricated from small diameter bars, or strips with thin cross-section.

Austempering can be substituted for normal martempering or quench and temper operations, provided the alloy has sufficient hardenability and thin cross section. Improved toughness and ductility can result along with reduced distortion. Depending on the application, process costs may be less than normal quench and temper operations, because tempering is not required after austempering.

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INTEGRATING NON-CONTACT METROLOGY IN THE PROCESS OF ANALYSIS AND SIMULATION OF GEAR DRIVES
The application of non-contact metrology allows a very fast collection of points on the measured gear-tooth surfaces with data rates that can be as high as millions of points per second — this new technology provides a wealth of information on gear geometry.

By Dr. ALFONSO FUENTES-AZNAR and Dr. IGNACIO GONZALEZ-PEREZ

Speed and accuracy are critical factors for gear inspection. The faster the inspection process, the larger number of gear units can be inspected. The accuracy of the inspection process also plays a fundamental role to identify any possible defect in the production line and before the gearbox is assembled and further tested.

The technology of non-contact metrology of gear drives has been developed during the last decade and it is currently available to be integrated, not only in the process of inspection of gears, as primarily intended, but in the process of analysis and simulation of gear drives as proposed here. This technology has come to stay and to change not only the way in which gear inspection and quality assessment of gears are performed, but to contribute to the process of reverse engineering of gear geometry, noise-root-cause analysis, or to serve as a reference for the determination of the baseline stress information for further gear design optimization as proposed in this paper.

The actual machines for non-contact metrology of gear drives allow for a fast measurement with high precision of all types of gear geometries, including that of the most complex shapes and gear types as hypoid and spiral bevel gears. This technology enables surface point clouds to be acquired at rates as large as 120,000 points per second taking, for example, only five minutes to have all tooth surfaces of a medium size gear inspected. The high-density acquisition of points with a point pitch of 20 µm enables not only the most accurate analysis of surface geometries but also reveals the smallest imperfections on the gear tooth surfaces such as machining traces and resulting surface waviness that will cause undesired vibrations or high frequency noise.

In this paper, a preliminary overview of the possibilities of integration of non-contact metrology in the process of analysis and simulation of gear drives will be provided. For that, two similar gears, with same macro-geometry characteristics and henceforth referred to as Gear A and Gear B, will be simulated based on their corresponding point clouds obtained by a non-contact metrology machine. Unfortunately, the gear quality was not known and no further information apart from the point clouds was disclosed for this work. Along the following sections, the process that has been followed to model the gears from the corresponding point clouds and the results obtained from the tooth contact analysis during their mesh with a common master (theoretical) gear will be presented. Finite element analysis will also be performed for both gears and the obtained results in terms of contact pressure and bending stresses shown.

REGENERATING THE ACTIVE TOOTH SURFACES

The active tooth surfaces of a gear tooth are those parts of the tooth surface that may come into contact with the mating gear tooth surfaces and therefore they are the parts of the tooth surface wherein the contact pattern is obtained.

Figure 1 shows a raw representation of the point cloud of the left side of gear tooth #1 of Gear A as obtained with a non-contact metrology machine. The cloud surface consists in more than 500,000 points for each side of the gear tooth surface. The mathematical processing of this point cloud for its integration in the process of analysis and simulation of the gear drive is computationally challenging. No information of the inspected gear was provided. The number of teeth and the hand of helix were obtained from the simple inspection of the set of point clouds for
all teeth of the gear. A custom-made module has been developed within IGD – Integrated Gear Design – software for the processing of point clouds obtained by non-contact metrology machines. Point cloud data consist in a list of coordinates x, y, and z of all the points.

Figure 2 represents the radial projection of the left side of the gear tooth surface on a plane containing the axis of rotation of the gear. The radial projection is a representation of the axial coordinate of the gear tooth surface, usually the coordinate z of the points, in the X-axis, and the radius of each point of the point cloud in \( \sqrt{x^2 + y^2} \) the Y-axis. It represents the 2D boundaries of the gear tooth surfaces. From the radial projection, the face-width and addendum radius of the inspected gear can be obtained. Moreover, the root radius can be also roughly determined and therefore, with this information, the module of the gear will be estimated as proposed in Section 4.

From Figure 2 and using the radial projection of the point cloud as reference, the intended face width is obtained to be 29.00mm, although for simulation purposes, the point cloud will be limited to a face width of 27.3652 mm. Those points near the edges of the surface will reduce the accuracy of the regenerated gear tooth surfaces and therefore they will be discarded.

In order to clean up those points near the edges of the surfaces, the boundaries of the active tooth surface and fillet will be considered on the radial projection of the tooth surface. Figure 2 shows the five limiting boundaries of the active surface and fillet portion of the tooth surface. The active surface of the tooth is limited by the top, bottom, front, and back boundaries. The fillet will be limited by the bottom, root, front and back boundaries, as shown in Figure 2. Points outside these boundaries are discarded. Using the intersection points of the boundaries, a theoretical regular grid is depicted on the radial projection of the gear tooth surface (see Figure 3). A switch button allows the user to transition between the 3D view and the radial projection of the gear tooth surface (2D view) at any time. The theoretical regular grid has to become an actual best-fit regular grid on the point cloud. The high density of the obtained point cloud allows the actual grid to be kept very close to the theoretical regular grid. This is necessary to obtain the best-fit NURBS surface to the point cloud. NURBS (Non-Uniform Rational B-Splines) are very appropriate to regenerate gear tooth surfaces from point clouds because this form of analytical surface allows partial derivatives to be obtained with respect to two surface parameters. Once the surfaces are regenerated by NURBS, these surfaces can be further used within the algorithms of tooth contact analysis or finite element modeling.

Figure 3 shows different densities for the theoretical and actual regular grid on the radial projection of the gear tooth surfaces. The theoretical regular grid is represented in blue color and the actual regular grid is represented overlaid in red color. As shown, the actual regular fit matches very well the target theoretical grid. Figure 3(a) considers a regular grid of 15 x 10 points (15 points in longitudinal direction and 10 points in profile direction) whereas Figure 3(b) shows a regular grid 30 x 20 points and Figure 3(c) shows a regular grid of 50 x 30 points. The chosen regular grid has to be defined only one time and it is kept for the analysis of the point cloud corresponding to any tooth of the gear or side of the gear tooth surfaces. The effect of the grid size on the results of tooth contact analysis and finite element analysis will be shown later in this paper.

The use of an efficient algorithm to find the nearest neighbor point to each theoretical regular grid node is very important mainly when dealing with data structures larger than half a million points. The authors' approach is based on the use of a kd-tree, a data structure for storing a finite set of points from a k-dimensional space [1], and invented by Jon Bentley in the 1970s.

Once the regular grid based on actual points of the point cloud
is defined, a NURBS surface is created from the regular grid of 3D point coordinates. NURBS is one of the most employed surface fitting models, because it provides a standard representation of curves and surfaces [2] and it is widely supported by modern standards such as OpenGL and IGES, which are used for graphics and geometric data exchange [3]. In addition, the NURBS surface model has stability, flexibility, local modification properties and is robust to noise. However, the NURBS surface model needs the input data points mapped on a regular grid structure. Because point clouds from non-contact metrology machines are high density point clouds, obtaining regular grid structures is relatively straightforward independently of the grid size chosen.

Figure 4 shows the NURBS surface obtained from one of the regular grids shown in Figure 3 and represented together with the defining point cloud. The NURB surface interpolates the point clouds accurately. The same process described above has to be followed to regenerate the right side of the gear active tooth surface from the corresponding point cloud.

**REGENERATION OF THE FILLET**

The fillet is regenerated using Hermite curves. The application of Hermite curves in fillet gear modeling allows for the design of smooth curves based on a small number of user-controlled parameters, usually the initial and final tangent directions and weights of the curve [4]. The initial and final tangent directions are considered as known. The initial tangent direction can be obtained as the tangent to the NURBS active surface along the boundary separating it from the fillet. This boundary, although is unknown, has to be tentatively defined by the user (see the set-up boundaries in Figure 2). The final tangent direction is considered tangent to the root circle of the gear and therefore it is known (see Figure 5). The initial and tangent weights are obtained by an optimization process to minimize the deviations between the regenerated fillet surface based on Hermite curves and the point cloud.

Figure 6 shows the point clouds used for regeneration of gear tooth surface prior to the application of the described approach (left) and after the gear tooth surfaces are regenerated and the 3D model of the gear obtained.

**TOOTH CONTACT ANALYSIS**

After regeneration of the gear tooth surfaces from the point clouds, tooth contact analysis can be applied. The goal of the application of tooth contact analysis is to verify the contact pattern on the gear tooth surfaces, discover the existence of micro-geometry modifications, and evaluate the unloaded function of transmission errors. Three different regular grids have been used to regenerate the gear tooth surfaces: (i) a regular grid of 15 x 10 points as shown in Figure 3(a), (ii) a regular grid of 30 x 20 points as shown in Figure 3(b), and (iii) a regular grid of 50 x 30 points as shown in Figure 3(c).

Figure 7 shows the comparison of the contact patterns obtained when considering the mesh of Gear A (left) and Gear B (right) with a master gear of 34 teeth. The density of the grid to regenerate the gear tooth surfaces is of 15 points in longitudinal direction and 10 points in profile direction. Figure 7 shows a clear difference between the quality of the gear tooth surfaces of Gear A and Gear B. Gear A shows a regular contact pattern and the contact area is extended over the whole gear tooth surface. However, for Gear B, certain deviations make the contact pattern not cover completely the active surface of the gear tooth. There is also a clear difference in the peak-to-peak level of transmission errors in favor of Gear A as the gear with better quality.

Figure 8 shows the comparison of the contact patterns for Gear A and Gear B.
Figure 7: Contact pattern and function of transmission errors for Gear A (left) and Gear B (right) in mesh with a master gear and regenerated by using a regular grid of 15 x 10 points.

Figure 8: Contact pattern and function of transmission errors for Gear A (left) and Gear B (right) in mesh with a master gear and regenerated by using a regular grid of 30 x 20 points.

Figure 9: Contact pattern and function of transmission errors for Gear A (left) and Gear B (right) in mesh with a master gear and regenerated by using a regular grid of 50 x 30 points.

Figure 10: Discrete Fourier Transform (DFT) of the function of transmission errors. Left column represents Gear A and right column represents Gear B. From top to bottom: grid 15 x 10, grid 30 x 20, and grid 50 x 30.

Figure 11: Illustration of additional functions d1 to d4 used to adjust the boundaries of the reverse engineered geometry (theoretical geometry).

(left) and Gear B (right) in mesh with a master gear when a grid density of 30 x 20 points is used for regeneration of gear tooth surfaces. The function of transmission errors is very sensitive to the grid density used for reconstruction of NURBS surfaces from the point cloud. However, from a general point of view, the better quality of Gear A is also observed, not only with regards to the contact pattern but also considering the peak-to-peak values of the function of transmission errors.

Finally, Figure 9 shows similar results when a grid of 50 x 30 points is used for reconstruction of the gear tooth surfaces. Again, comparing the results obtained by considering similar grid densities, the claim that the quality of Gear A is better than Gear B is again consistent with the obtained results.

It is widely accepted that the amplitude spectrum of the function of transmission errors will excite vibrations in the gear drive that will be radiated as noise, so that for lower amplitude spectrum of the function of transmission errors, lower excitation of vibrations will occur, and therefore, lower gear whine noise might be expected [3]. Figure 10 shows the amplitude spectrum of the functions of transmission errors shown above in Figures 7, 8, and 9 for Gears A and B considering various densities of the regular grid used for regeneration of gear tooth surfaces. A speed of 2000 rpm has been considered for the pinion and therefore the meshing frequency for a gear of 20 teeth is of 666.67 Hz.

Gear A shows systematically lower amplitude spectrum of the function of transmission errors and therefore Gear A is expected to radiate lower levels of noise and vibration. The values of the amplitudes are highly sensitive to the density of the grid used for regeneration of gear tooth surfaces from point clouds but the comparison between Gear A and Gear B considering same densities of the regular grid will consistently yield same conclusion: Gear A will radiate less noise and vibration than Gear B.

REVERSE ENGINEERING OF GEAR GEOMETRY

Noncontact metrology allows reverse engineering of gear geometry to be performed fast and accurately. No matter what the number of design parameters is, an optimization algorithm that minimizes the deviation between a theoretical geometry and the regenerated surfaces from point clouds will give us the closest geometry to the point cloud in few seconds. An approach for reverse engineering of gear parameters and gear tooth proportions of helical gears has been developed and the obtained results shown below.

The preliminary known geometric parameters are:
- **Number of teeth**: 20 teeth (from direct inspection of the data).
- **Hand of helix**: Right (from direct inspection of the data).
- **Tentative normal module**: 3 mm. The tentative normal module is obtained using the addendum and root radius shown in Figure 2. Considering that a standard tooth geometry has a whole depth equal to 2.25 times the module, the tentative normal module of the gear shown in Figure 2 can be obtained as follows:

\[
m_n \sim \frac{r_{\text{addendum}} - r_{\text{root}}}{2.25} = \frac{34.91 - 27.90}{2.25} = 3.1156 \Rightarrow 3.0 \text{ mm}
\]

The following seven variables have been used for the process of reverse engineering:
- Pressure angle.
- Helix angle.
- Face width.
- Addendum coefficient.
- Dedendum coefficient.
- Profile shift coefficient.
- Edge radius coefficient.

Not all the variables considered are needed for the reverse engineering of the helical gear geometry. For example, the face width could be considered as known but it was considered as a variable here to test the automatic adjustment of the limits of the to-be-obtained geometry to those of the objective geometry. This is particularly important to reverse engineer the geometry of bevel gears. The objective function to be minimized consists of the sum of the squared value of the surface
deviations between a theoretical and the objective geometry on a grid of points on the contacting surfaces plus four additional distances $d_1$ to $d_4$ to adjust the boundaries of the surfaces in the radial projection (2D) of the tooth surfaces, as shown in Figure 11. With it, the addendum and dedendum coefficients as well as the face width of the helical gear are obtained.

Table 1 shows the results of the process of reverse engineering of the helical gear geometry. The initial value of each parameter used in the search, the minimum and maximum values that were allowed for each variable and the computed values are shown. The Levenberg-Marquardt algorithm (LM) with a trust-region strategy has been applied here. It consists of an iterative algorithm used in nonlinearly bound-constrained and unconstrained optimization problems in which the objective function is formulated in terms of least-squares. The LM algorithm belongs to the family of second derivative unconstrained methods and constitutes an improvement of Newton’s method for nonlinear least-squares problems [5].

Based on the obtained results shown in Table 1, there is no doubt that the intended pressure angle was 20.0 degrees, the intended helix angle was of 20 degrees, and the gear was manufactured with a positive profile shift coefficient of 0.054615. The value of the edge radius coefficient shown in Table 1 converges to the lower minimum value because the boundaries of the fillet surface and not the deviations all over the fillet surface were included into the objective function being minimized. Deviations from the fillet surface should be included into the optimization algorithm to get a better approximation of the edge radius coefficient. Also, the obtained values for the face width and the addendum coefficient are influenced by the boundary drawn by the user and shown in Figure 2. Those values can be adjusted to match the desired values if the gear is to be replaced by a new manufactured gear. Moreover, it is clear from the obtained results shown in Table 1 that the gear was generated with a long dedendum coefficient of 1.4. Additional design parameters can be added to the outlined reverse engineering process of helical gears if needed to match any micro-geometry modification or specific manufacturing processes.

Figure 12 shows the comparison of the reverse engineered helical gear geometry and the objective geometry regenerated from a point cloud.

Table 1: Results of reverse engineering of the helical gear geometry.

<table>
<thead>
<tr>
<th>Gear Parameter</th>
<th>Initial Value</th>
<th>Min/Max Values</th>
<th>Computed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure angle, $\alpha$</td>
<td>22.5°</td>
<td>19.5° / 25.5°</td>
<td>0.349029 rad [19.997°]</td>
</tr>
<tr>
<td>Helix angle, $\beta$</td>
<td>22.5°</td>
<td>10.0° / 10.6°</td>
<td>0.349060 rad [19.999°]</td>
</tr>
<tr>
<td>Face width, $z_f$</td>
<td>20.0 mm</td>
<td>20.0 mm / 40.0 mm</td>
<td>27.342657 mm</td>
</tr>
<tr>
<td>Addendum coefficient</td>
<td>1.0</td>
<td>0.5 / 1.5</td>
<td>0.914994</td>
</tr>
<tr>
<td>Dedendum coefficient</td>
<td>1.0</td>
<td>0.5 / 1.5</td>
<td>1.587717</td>
</tr>
<tr>
<td>Profile shift coefficient, $x$</td>
<td>0.0</td>
<td>-1.0 / 1.0</td>
<td>0.054615</td>
</tr>
<tr>
<td>Root radius coefficient, $r$</td>
<td>0.25</td>
<td>0.15 / 0.40</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Figure 13: Finite element model of a helical gear set with five pairs of contacting teeth.

Figure 14: Contact pressure representation on the pinion tooth surfaces for three different contact positions: contact point 1 (left), contact point 21 (center), and contact point 41 (right).

Figure 12: Geometry comparison between the obtained helical geometry and the objective geometry regenerated from a point cloud.
FINITE ELEMENT ANALYSIS

Finite element models comprising five pairs of contacting teeth were considered for finite element analysis. The solver of ABAQUS computer program was used to perform the analysis. The models were generated automatically from the Integrated Gear Design (IGD) software and therefore all nodes on the finite element mesh are obtained as points of the gear tooth surface, avoiding the loss of accuracy when the finite element models are built with intermediate CAD models. The model size consists of 190,800 elements and 224,666 nodes. Figure 13 shows one of the finite element models that have been used for the analyses. Three-dimensional solid elements of type C3D8I [6] have been used, being hexahedral first order elements enhanced by incompatible deformation modes in order to improve their bending behavior [6]. The pinion and gear materials are defined as steel with elastic modulus of 210 GPa and Poisson ratio of 0.3.

A torque of 350 Nm has been applied to the pinion of the gear set for all cases investigated. Firstly, the finite element analysis of the reverse engineered pinion from point clouds in mesh with a master gear of 34 teeth will be performed with and without considering tip relief. The results obtained will be labeled as “Master” and “Master TR” for the case without tip relief and with tip relief, respectively. The contacting surfaces of these gears are theoretical, and the maximum stresses obtained can be considered as reference level for the considered geometry. The application of tip relief in helical gears can improve gear performance by preventing contact near the leading edge of the teeth throughout a cycle of meshing. In helical gears, contact at the tip of the tooth is maintained almost throughout the entire cycle of meshing, making tip relief modifications particularly important for this type of gear. The results that will be shown below will consider the contact pressure and maximum bending stress on the middle tooth of the pinion (Teeth #3) of the finite element model of 5 pairs of contacting teeth along 41 contact positions covering two cycles of meshing of the gear set.

Figure 14 shows the patterns of contact pressure on the pinion tooth surfaces for three different contact positions: 1, 21, and 41. The contact line crosses the top edge boundary of the gear tooth surfaces of Teeth #3 from contact point 23 until contact point 41, and therefore the effect of edge contact is clearly seen in the following figures showing the evolution of the contact pressure.

Figures 15, 16, and 17 show the evolution of maximum contact pressure (left) and the maximum bending stress (right) for the middle tooth of the finite element model (Teeth #3) for a reverse engineered master pinion without tip relief (Master), reverse engineered master pinion with tip relief (Master TR), regenerated Gear A, and regenerated Gear B, for different regular grid sizes varying from 15 x 10 points for Figure 15, 30 x 20 points for Figure 16, and 50 x 30 points for Figure 17.

From Figures 15 to 17, notice that the maximum bending stresses are not sensitive to the grid size considered for definition of the regenerated tooth surfaces of Gears A and B. Gear B consistently shows higher bending stresses than Gear A. It is also worth it to notice that the master pinion with tip relief shows higher bending stresses than the master pinion without tip relief. However, application of tip relief is essential for reducing the maximum contact stresses and contact pressure. The results obtained for the maximum contact pressure for all sizes of the regular grid are very sensitive to the size of the regular grid, and the results show high fluctuations along the 41 contact positions due to the augmented influence of the surface deviations on contact pressure and contact stresses obtained by the finite element method.

From the point of view of contact pressure and bending stresses, Gear A shows lower levels of contact pressures and bending stresses. Although contact pressure is very sensitive to the grid size used for surface regeneration, the bending stresses are very consistent across all grid sizes.

CONCLUSIONS AND FUTURE PERSPECTIVE

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

- The analysis and simulation of gear drives using regenerated gear tooth surfaces from point clouds is fast and may become a valuable tool to evaluate the mechanical performance of different versions or different batches of gears.
- Regular grids of equal sizes should be used to compare the mechanical behavior of gears when their surfaces are regenerated from point clouds. The function of transmission errors, the amplitude spectrum of the function of transmission errors and the maximum contact pressure are very sensitive to the size of the regular grid used for the regeneration of the contacting surfaces.
- Increasing the number of points used for the regular grid that defines the best fit NURBS surface does not yield better results than grids of lower number of nodes. If the regular grid is too dense, the NURBS surface amplifies certain irregularities of the gear tooth surfaces and does not contribute to obtain better results from TCA.
Finite element models created by regenerated gear tooth surfaces from point clouds yield highly oscillating results in terms of contact pressure on the active surfaces of the gears. However, the maximum bending stress can be evaluated effectively, and its maximum value does not depend on the grid size used for regeneration of the gear tooth surfaces. This information is very valuable to be used as a baseline for further improvement and optimization of existing gear drives.

The presented approach for integration of non-contact metrology in the process of analysis and simulation of gear drives has shown promising results and provides added value for the virtual testing and simulation of gear drives. However, further research work has to be carried out to improve the results of simulation. Filtering and denoising the point clouds have been shown necessary before the gear tooth surfaces are regenerated using the presented approach.

Non-contact metrology provides a wealth of data to perform very accurate reverse engineering of geometric parameters of gear drives.

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DESIGN FEATURES OF PERFECT GEARS FOR CROSSED-AXES GEAR PAIRS
To improve the accuracy and performance of gears that operate on crossing axes of rotation, gears should be designed so they align to the three fundamental laws of gearing.

By STEPHEN P. RADZEVICH

Gearings that operate on crossing axes of rotation of a gear and a mating pinion have been known for centuries. Common sense and accumulated practical experience are the two foundations for the adopted practice of designing gears in ancient times. Such a practice was permissible as the input and output rotations at that time were low, and the power being transmitting was also low: The gears were driven by animals, water flow, wind flow, and so forth.

Because the input and output rotations are permanently rising and the transmitting power is rising as well, the tolerances for the gear accuracy are getting tighter.

Nowadays, gears cannot be designed based only on common sense along with the tremendous experience accumulated by the industry. The insufficiency of such an approach is evident because poorly engineered gears vibrate when operating, producing excessive noise. To reduce noise and vibration and to increase the power density, gears need to be lapped and to get paired when manufacturing.

INTRODUCTION

Gear pairs with crossing axes of rotation of a gear and a mating pinion (Figure 1) are discussed in this article. Gearings of this kind are extensively used, first of all, in the automotive industry, but they are used in other industries as well. High power density of crossed-axes gear pairs (or just $C_a$ — gearings, for simplicity), low noise excitation, and low vibration generation, are among the requirements of prime importance for perfect gearing have to comply with. To achieve these goals, gears for $C_a$ — gearings have to be properly designed, accurately manufactured, and correctly assembled in the housing. If designed, manufactured, and assembled properly, crossed-axes gearings feature line contact between the tooth flanks of a gear, $G$, and a mating pinion, $P$. Perfect gearings that operate on crossing axes of rotation of a gear and a mating pinion, and those featuring line contact between the tooth flanks, were proposed (in 2008) by Dr. S. Radzevich [1]. Gearing of this particular kind is commonly referred to as “$R$ — gearing.” Due to the line contact between the tooth flanks, $R$ — gearing features the highest possible power density and are nearly-noiseless.

1. REQUIREMENTS TO PERFECT GEAR DESIGN

When designing gears for perfect $C_a$ — gearings, the gears have to align with three fundamental laws of gearing:

The first fundamental law of gearing. This requires a proper contact of a gear tooth flank, $G$, and a mating pinion tooth flank, $P$. The “Shishkov equation of contact” (Figure 2):

$$n_g \cdot V_\Sigma = 0$$

is commonly used to describe analytically this law of
gearing (Prof. V.A. Shishkov, 1948 [2, 3]). Here it is designated: \( n_g \) and is the unit vector of a common perpendicular at a point of contact of the tooth flanks, \( \mathcal{G} \) and \( \varphi \); and \( V_g \) is the linear velocity vector of the resultant relative motion of the tooth flanks, \( \mathcal{G} \) and \( \varphi \).

The “Shishkov equation of contact, \( n_g \cdot V_g = 0 \) has been known to proficient gear people since 1948, therefore there is no need to discuss this equation here in more detail.

**The second fundamental law of gearing.**
To fulfill this law of gearing at every point of the line of contact, a straight line along the common perpendicular vector, \( n_g \), must intersect the axis of instant rotation, \( P_{in} \), of the tooth flanks, \( \mathcal{G} \) and \( \varphi \). The “equation of conjugacy” (Figure 3):

\[
p_{in} \times V_m \cdot n_g = 0
\]

is proposed by Prof. S.P. Radzevich (2017) [1] to describe analytically this law of gearing. Here it is designated (Figure 3): \( p_{in} \) and is the unit vector along the axis of instant rotation, \( p_{g,i} \) (as the angular velocity vector, \( \omega_{g,i} \) is also along the axis of instant rotation, the unit vector, \( p_{in} \), can be substituted with the vector, \( \omega_{g,i} \)), \( V_m \) is the linear velocity vector along an instant line of action, \( L_{A_{inst}} \), through the point of interest, \( m \). In addition, the condition \( n_{pl} \cdot n_g = 0 \) has to be fulfilled (here, \( n_{pl} \) is the unit normal vector to the axis of instant rotation, \( P_{in} \), the vector, \( n_{pl} \), is located within the plane of action, \( P_{A} \), of the gear pair).

In the simplest case of perfect \( P_{a} \) gearing, the second fundamental law of gearing reduces to conjugate action law, known as “CES — theorem of parallel-axes gearing” (where “CES” stands for “Camus-Euler-Savary theorem of parallel-axes gearing”).

**The third fundamental law of gearing.** In order to meet this law of gearing, the angular base pitch of a gear, \( \varphi_{h,g} \), must be equal to the operating base pitch of the gear pair, \( \varphi_{h,op} \), and the angular base pitch of a mating pinion, \( \varphi_{h,p} \), also must be equal to the operating base pitch of the gear pair, \( \varphi_{h,op} \) (Prof. S.P. Radzevich, 2008, [1]). The third fundamental law of gearing is analytically expressed by a set of two equations (Figure 4):

\[
\begin{align*}
\varphi_{b,g} &= \varphi_{b,op} \\
\varphi_{b,p} &= \varphi_{b,op}
\end{align*}
\]

or simply as \( \varphi_{b,g} = \varphi_{b,p} = \varphi_{b,op} \).

In 2008, the concept of the “operating base pitch, \( \varphi_{h,op} \) of a gear pair” was introduced by Prof. S.P. Radzevich [1]. The proposed concept is specified for all three possible kinds of gearings, that is, for: (a) \( P_{a} \) — gearings, (b) \( I_{a} \) — gearings, and (c) \( C_{a} \) — gearings [1].

Only in perfect \( P_{a} \) — gearing, all three base pitches, that is, \( P_{b,g} \), \( P_{b,p} \), and \( P_{b,op} \), are linear design parameters, as the line of contact, \( LC_{des} \) (and the plane of action, \( PA \)) travels straight when the gears rotate.

In order to succeed designing perfect \( C_{a} \) — gearings, fulfillment of all three fundamental laws of gearing is a must.

**2. Design principles of perfect involute gears (with parallel axes of the gears rotation)**

The design of spur and helical gears for \( P_{a} \) — gearing is investigated to the best possible extent, while \( C_{a} \) — gearings, as well as \( I_{a} \) — gearings, are investigated more poorly. With that said, it makes sense to briefly outline the design principles of perfect involute parallel-axes gearing and then to consider how these design principles work (or have to work) in a case of crossing axes of the rotation of two gears. Finding and discussing commonalities between \( C_{a} \) — gearings and \( P_{a} \) — gearing is helpful to understand the core of the kinematics and the geometry of \( C_{a} \) — gearings. All the design principles for \( I_{a} \) — gearings then can be derived from the case for \( C_{a} \) — gearings, assuming the center-distance of a zero length.

Consider a schematic of \( P_{a} \) — gearing that is specified by the gears rotations, \( \omega_{g} \) and \( \omega_{p} \), a center-distance, \( C \), and a transverse pressure angle, \( \phi_{t} \) (Figure 5). The axis of rotation of the gear, \( O_{g} \), and that of the pinion, \( O_{p} \), are parallel to each other and are at a center-distance, \( C \), apart from one another. The plane of action, \( PA \), in external parallel-axes gear pair, is a plane that forms the transverse pressure angle, \( \phi_{t} \), with the plane through the axes \( O_{g} \) and \( O_{p} \).

The base cylinder of a diameter \( d_{b,g} \) is associated with the gear. Similarly, the base cylinder of a diameter \( d_{b,p} \) is associated with the pinion (recall the “pulley-and-belt” equivalence of the \( P_{a} \) — gearing).
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FORMERLY GEAR EXPO
The plane of action is considered as a zero thickness film that is unwrapping from the base cylinder of the gear, and is wrapping onto the base cylinder of the pinion, or vice versa. In such a motion, the plane of action, PA, travels with a linear velocity, \( v_{lc} \). Magnitude, \( v_{lc} \), of the linear velocity, \( v_{lc} \), is timed with the rotations, \( \omega_g \) and \( \omega_p \), to ensure rolling with no slippage of the plane of action, PA, over the base cylinders of the gear and the pinion.

Let us consider two neighboring lines of contact as illustrated in Figure 5.

In a reference system associated with the plane of action, PA, a desirable line of contact, \( LC_{des} \), of the \( i - \) th pair of teeth of the gear and the pinion can be specified by position vector, \( r_{LCi} \), point of the line \( LC_{des} \). When the gears rotate, the line of contact, \( LC_{des} \), travels in relation to a reference system associated with the gear. For analytical description of the transition from the first reference system to the second one, an operator of the resultant coordinate system transformation, \( R_{Ps}^{PA} (PA \mapsto g) \), is commonly used (go to [1] on details of coordinate system transformation). Therefore, a gear tooth flank, \( \gamma_g \), can be construed as a locus of consecutive positions of the line of contact, \( LC_{des} \), in its motion in relation to the reference system of the gear. Having the expressions for \( r_{LCi} \) and \( R_{Ps}^{PA} (PA \mapsto g) \) determined, the gear tooth flank, \( \gamma_g \), can be expressed by position vector of point, \( r_{Ps}^{PA} \):

\[ r_{Ps}^{PA} = R_{Ps}^{PA} (PA \mapsto g) \cdot r_{LCi} \]

A desirable line of contact, \( LC_{des}^{i+1} \), of the adjacent \((i+1)-\) th pair of teeth of the gear and the pinion is parallel to the straight line, \( LC_{des}^{i} \), and also is located within the plane of action, PA.

Measured in a common transverse section of the gear pair, the distance, \( d_{b.p} \), between two adjacent desirable lines of contact, \( LC_{des}^{i} \) and \( LC_{des}^{i+1} \), is referred to as the “operating base pitch” of the gear pair.

The operating base pitch of a gear pair is a calculated design parameter of a gear pair. It cannot be measured directly in a gear pair. In a “perfect” parallel-axes gearing, the operating base pitch of a gear pair is equal to: \( p_{b.op} = \pi d_{bg} / N_g = \pi d_{bg} / N_p \). Here, \( d_{bg} \) is the gear base diameter, and \( N_g \) is the gear tooth count.

Note that “operating base pitch” in perfect parallel-axes gear pair is introduced “prior to (!!!)” a gear and a mating pinion tooth flanks, \( \gamma_g \) and \( \gamma_c \), are generated.

In cases of parallel-axes gearing, the identities \( p_{bg} = p_{b.op} \) and \( p_{hp} = p_{b.op} \) (or simply \( p_{bg} = p_{hp} = p_{b.op} \)) are met only for “perfect gearing,” that is, for involute gearing. For any and all types of non-involute gearings, the identity cannot be fulfilled, and, moreover, base pitch of the gear and the pinion cannot be specified in non-involute gearings, while the operating base pitch of the gear pair can be easily calculated.

It is proven that involute tooth profiles can be generated according to one of two ways, that is, (a) by the considered above tracing method, and by (b) generating method as an envelope to consecutive positions of a basic rack (not considered here).

### 3. Design Features of Perfect Gears With Crossing Axes of Gear Rotation

Having refreshed our memory on generation of tooth flanks of gears for perfect \( p_{bg} \) — gearing (that is clear for proficient gear experts), let’s follow that same routing and generate tooth flanks of gears for perfect \( p_{ca} \) — gearings that are not as clear for many of us.
At the beginning, a configuration of the axes of rotation, \( O_g \) and \( O_p \), of a gear and a mating pinion has to be specified. For this purpose, the center-distance, \( C \), and the crossing angle, \( \Sigma \), of the gear’s axes have to be known. Then, the gear ratio, \( u \) (that is, \( u = \omega_g/\omega_p \)), and the transverse pressure angle, \( \phi_t \), must be also given. Having all these parameters determined, one can construct the plane of action, \( PA \), for a \( C_a - \) gear pair. The plane of action, \( PA \), is a plane through the axis of instant rotation, \( P_{in} \), that forms the transverse pressure angle, \( \phi_t \), with a perpendicular to the center-line, \( \ell \).

Point of intersection of the center-line, \( \ell \), by the axis of instant rotation, \( P_{in} \), is the plane-of-action apex, and is designated as \( Ap \). Similarly, the points of intersection of the center-line, \( \ell \), by the axes of rotation, \( O_g \) and \( O_p \) of the gear and the mating pinion, are the gear, \( Ap_g \) and the pinion, \( Ap_p \), base cone apexes, correspondingly.

All these design parameters are illustrated in Figure 6.

A circular-arc line of contact, \( LC \), between a gear and a mating pinion tooth flanks, \( \varphi \) and \( \psi \), in a perfect crossed-axes gear pair is shown in Figure 7 as an example. Lines of contact of other geometries are also possible.

In a reference system associated with the plane of action, \( PA \), a desirable line of contact, \( LC \), can be specified by position vector, \( r_{lc} \), of point of the line \( LC \). When the gears rotate, the line of contact, \( LC \), travels in relation to a reference system associated with the gear. For the purpose of analytical description of the transition from the first reference system to the second one, an operator of the resultant coordinate system transformation, \( \text{Rs}^{ca}(PA \mapsto g) \), is commonly used. (Details on coordinate system transformation to the best possible extent are discussed in [1], and in a few more advanced sources.) Therefore, a gear tooth flank, \( \varphi \), can be viewed as a locus of consecutive positions of the line of contact, \( LC \), in its motion in relation to the reference system of the gear. Having the expressions for \( r_g \) and \( \text{Rs}^{ca}(PA \mapsto g) \) determined, the gear tooth flank, \( \varphi \), can be expressed by position vector, \( r_{g}^{ca} \), of point:

\[
 r_{g}^{ca} = \text{Rs}^{ca}(PA \mapsto g) \cdot r_c
\]

Tooth flank of a gear, \( \varphi \), for perfect \( C_a - \) gearings with line contact between tooth flanks of a gear and a mating pinion, is specified by Equation 5. The tooth flanks generated this way fulfill both the condition of contact, as well as the condition of conjugacy of the interacting tooth flanks.

A plane of action, \( PA \), in a crossed-axes gear pair is shown in Figure 8. Every two desired lines of contact, \( LC \), are at an equal angular distance, \( \phi_{pa} \), from one another. This angular distance is referred to as the “angular operating base pitch, \( \phi_{bpa} \)” in a crossed-axes gear pair. As all desired lines of contact, \( LC \), are spaced equally, the generated gear tooth flanks feature an angular base pitch of a constant value.

Ultimately, if the gears are designed in compliance with the proposed approach, they can be engaged in perfect crossed-axes mesh with line contact between the tooth flanks.

### 4. INCONSISTENCIES IN CROSSED-AXES GEARINGS OF NOWADAYS DESIGN

Almost all inconsistencies in gearings of today’s design that feature crossing axes of rotation of a gear and a mating pinion are due to specific features of the tooth flanks’ generation. Because of this, only approximate gears can be generated in conventional gear machining processes.

Conventional principle of the gear tooth flank, \( \varphi \), generation in crossed-axes gearing is illustrated in Figure 9. In the machining process, a gear to be machined is engaged in mesh with a crowned face gear with straight-sided teeth (round basic rack). Such a schematic is not applicable for finish-cutting of gears for perfect \( C_a - \) gearings, as not all of three fundamental laws of gearing are fulfilled in the gear machining process.

The condition of contact of the gear and the crowned face gear with straight-sided teeth is fulfilled in most cases of gear machining.

The condition of conjugacy of the gear and the crowned face gear with straight-sided teeth is violated, as the common perpendicular to the gear and the mating pinion tooth flanks, \( \varphi \) and \( \psi \), does not intersect the axis of instant rotation, \( P_{in} \), at every instant of time. This is illustrated in Figure 10. All today’s technologies of cutting/finishing bevel gears for \( C_a - \) gearings are developed on the premise of a crowned face gear with straight-sided teeth. No accurate gears
for \( C_a \) — gearings can be produced this way.

The just-mentioned violation of the condition of conjugacy means that a crowned face gear with straight-sided teeth cannot be used for finishing gears for perfect gearings. A basic rack of a more complex geometry can be used for this purpose. However, neither gear-cutting tools, nor bevel-gear generators of modern design fit the basic rack of a complex geometry, that is, the basic rack of this type is impractical.

The angular base pitches, \( \varphi_{bg} \) and \( \varphi_{bp} \), not only don’t equal to an operating base pitch of the gear pair, \( \varphi_{bop} \), but they (that is the angular base pitches \( \varphi_{bg} \) and \( \varphi_{bp} \)) cannot be constructed for approximate \( C_a \) — gearings.

Therefore, if the gears are generated by a crown gear (by the basic rack) with straight-sided teeth, they cannot be engaged in a perfect crossed-axes mesh with line contact between the tooth flanks.

5. A FEW COMPLEMENTARY COMMENTS

As it is impossible to discuss all the design features of crossed-axes gear pairs in a single article, a few more important considerations are noted:

- Precision gears for perfect crossed-axes gear pairs designed in compliance to the discussed approach and then manufactured to the blueprint feature better performance.
- No lapping process is required for finishing the gears. The gears simply can be finish-cut or ground on conventional bevel gear generators/grinders.
- The gears do not need to be paired. The gears become self-replaceable: There is no need to replace an entire gear pair. In necessary, only one broken bevel gear is replaced by a new one.
- In production of gears for \( C_a \) — gearings, multiple-axes NC machines can be used for machining gears themselves, electrodes for EDM, dies for net-forging, and tools for extruding plastic gears.
- Even gears with a few teeth (12 and fewer) can be designed and manufactured precisely (with conjugate tooth flanks and with the angular base pitches equal to operating base pitch of the gear pair).
- The derived equations for a gear and a mating pinion tooth flank can be used for the purposes of gear inspection as the reference surfaces. This makes the gear inspection procedure more reliable.
- When assembling gear drives, no shift-in and no shift-out for the adjustment of the gears are permissible, as all three apexes: \( A_g \), \( A_p \), and \( A_{pa} \), must be snapped together. This can be ensured when the gears are designed, manufactured, inspected, and put together in the gear housing.
- The \( C_a \) — gearings can be used at the first stage of a long gear train [where the input rotation is high, and the input torque is low (here a low axial thrust acts against bearings)], and not at the last stage, where the axial thrust is high. Conventional, and alternative arrangements of gear pairs in a gear drive become possible (as illustrated in Figure 11) if the gears are produced in compliance to the three fundamental laws of gearing. Huge and heavy roller bearings in the first case (Figure 11a) can be replaced with light and small roller bearings as illustrated in the second case (Figure 11b).
- Gears for \( I_a \) — gearings, and for \( C_a \) — gearings, are not identical to one another (the angular base pitch, and so forth). Therefore, gears designed and manufactured for \( C_a \) — gearings cannot be used in \( I_a \) — gearings, and vice versa.
- As the theory of gearing evolves, the term “perfect/precision hypoid gearing” with line contact between the tooth flanks will become more common in all industries.

An intensive research in the field of crossed-axes gearings (and of intersected-axes gearings, as a reduced case of \( C_a \) — gearings) on the premise of the scientific theory of gearing has started just a decade ago [1].
CONCLUSION
In today’s practice of design and manufacture of gears for crossed-axes gear pairs (hypoid gears in particular) no attention is paid to:
(a) the compliance of the designed gears to the conjugate action law (that is commonly referred to as the main law of gearing),
(b) to equality of the gear base pitch to the operating base pitch of the gear pair,
(c) proper axial location of the gears, and a few others to be mentioned. When designing gears, as well as when the gears are inspected and manufactured, all these important gear design parameters are simply ignored by all the gear designers/manufacturers (including the world leaders in production gears for precision crossed-axes gear pairs).

To improve the accuracy and performance of gears that operate on intersected axes of rotation, it is recommended to design the gears so they are aligned to the three fundamental laws of gearing discussed in the article.

When machining (and especially when finishing) gears for $C_u$ — gearings, the parameters of the kinematics and of the geometry of the machining process and the cutting tool have to follow the three fundamental laws of gearing.

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A probe used for aerospace. (Photos courtesy: Marposs)
Marposs has become a global leader for the supply of high-precision equipment for inspection, measurement, and control in the production environment.

By KENNETH CARTER, Gear Solutions editor

In order to maintain its position as a world leader in the field of high-precision equipment for measurement, Marposs always looks for the right blend between experience and innovation.

“Our mission is mainly to provide high-precision metrology equipment for machine control and part inspection in the shop floor environment,” said Matteo Zoin, senior manager, head of new market development for Marposs North America.

Marposs’ primary customers are industries such as machine tool, automotive, aerospace, and many others, where the company has a hand in supplying applications, gaging and testing equipment and components that work with, for instance, engines, transmission, glass, injectors, bearings, electrical motors, and much more, according to Zoin.

More and more of Marposs’ business has been diversified across all markets in the last few years, he said.

PRECISION WORK

The company makes equipment capable of measuring to the thousandth of a millimeter and more; what makes that claim unique is that it can perform this task in a workshop environment along the production lines and on any machine tool, instead of in a metrology lab, according to Zoin.

“For machine tools performing operations such as grinding, cutting, forming, stamping, we provide a variety of measurements,” he said. “We do part measurement, tooth control, and process monitoring.”

For gaging and testing systems, Marposs does inline gaging, offline gaging, non-destructive tests, assembly and tests, such as leak tests, according to Zoin.

This is part of Marposs’ production-line integrity tests that use non-invasive methodologies including non-destructive eddy current testing that verifies surface faults such as cracks, porosity, blow holes, inclusions, and stripping; and leak testing that verifies the presence of a leak in a component or device.

“The technologies involved with all of these products are different, and it depends also on the application,” he said. “That’s why we say, ‘Marposs is one partner for many solutions,’ because we can offer different solutions to solve the same and different problems.”

Those custom requests are often based on what the customer is ultimately looking for, according to Zoin.

“What are their needs? What are the requests of the customer?” he said. “I’m not just talking in terms of budget, but more in terms of streamlining their operations.”

FOUR DIVISIONS

Marposs is made up of four divisions: one for standard products, another for special applications, one for machine tools, and R&D.

The after-sales department has more than 300 service engineers worldwide, according to Zoin.

“They are local experts, so they speak the customers’ language,” he said. “We are able to provide immediate quality assistance everywhere in the world. For example, we may work on a project in the U.S. for use here, or it may be shipped in another country. We are able to follow the shipment anywhere.”

About 92 percent of Marposs’ production is outside of the company’s headquarters in Italy; however, the company has a direct subsidiary presence in 25 different countries with more than 80 locations. The main sales and productive centers are in the company’s main markets: U.S., Germany, China, Japan, and Italy, according to Zoin.

Another part of Marposs’ success is its continuous presence in research and development.

“At the company level, we invest 8 percent of our total sales revenue into R&D to develop new products,” Zoin said. “This is really important for us.”

All of Marposs’ gaging solutions (mechanical, air-electronic, contact-electronic, optical) have their origins in the company’s Research and Development Center, as well as the as-yet-to-be-developed technologies that will eventually replace the current ones, according to Zoin.
AFTER-SALES SERVICE

All that dovetails into Marposs’ after-sales service.

“This is always our strong point: the fact that, with our worldwide presence, we are able to support our customers everywhere,” Zoin said.

Part of Marposs’ flexible and innovative solutions is its non-contact gaging using opto-electronics, according to Zoin, which allows for risk-free, fast, non-invasive measuring.

“We have this innovative optical system, the Optoflash, that has a flexible way to measure any type of part that comes with a different size,” he said. “They are really fast. The Optoflash is going to perform the measurement and really save a lot of time. The device comes ready with measurement software inside, and that software is able also to produce the different analyses across the statistical process control.”

“We have software that also controls the approach of our measurement contacts to the surface of the gears’ teeth because, with this type of system, you are always taking care of the fact that any time you come in contact with a surface, you have to be careful to avoid any damages like a scratch,” he said.

Other products in Marposs’ arsenal, specifically developed for transmissions, include the M62 Flex.

The M62 Flex is a manual use bench gage for the inspection of traditional toothing parameters of gears capable of measuring different parts within a flexible range of applicability. The M62 Flex can be used in the shop floor environment for monitoring the quality of gears during the manufacturing process, thus complementing the already broad M62 family dedicated to gear inspection.

“After machining stages, for example, we can measure inner and outer diameters, perpendicularities, flatness, runout, total runout, concentricity, parallelism; so all the most requested dimensional and geometric features,” Zoin said. “We have other types of offline gages like the M63 (mainly for gears and bushings-like parts) and the M67 (for shafts), which are other manually used bench gages for the transmission shop.”

Marposs is constantly looking for ways to find solutions to streamline its customers’ operations, according to Zoin.

“We always act as a pioneer in any of our markets,” he said. “We always look to develop solutions to streamline our customer opera-

tions with the right blend between experience and innovation.”

FOUNDED IN 1952

Marposs has come a long way since its start in 1952 by founder Mario Possati. Now the company headquarters in Bentivoglio, Italy, consists of three factories encompassing 38,000 square meters, all side-by-side, which house R&D, design, production, marketing, as well as education and training.

“The product manufacturing center develops what we call a standard product, and the application manufacturing center produces more customized solutions and applications systems that would be integrated in customers’ facilities, like a manufacturing product line,” Zoin said.

Over the last several years, Marposs has been acquiring other companies to help with that philosophy, including 18 different companies since 2000.

“When we find a company that is going to complement and create a synergy with our solutions, we usually acquire it,” Zoin said.

And Zoin said he expects that type of synergy to continue as Marposs looks toward the future.

“We will achieve our goal to diversify, to adapt our solutions to the market’s needs, and also the customers’ needs because our goal is always to meet and exceed the customer’s expectations,” he said. “For sure, we are going to grow more and more, like we are doing, for example, expanding our sales operations on the West Coast and in other countries.”

Zoin especially sees this for the gear industry.

“For the gears, there is no difference than in other markets,” he said. “We are trying to perform and achieve what is requested and then do the best that we can while adopting new technology. I strongly believe that the automatic visual inspection for dimensional check of surface quality or assembly completeness will be the key for the future.”

MORE INFO

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All Metals & Forge Group offers open die forgings, seamless rolled rings

Forged gear shapes are offered in ferrous and non-ferrous metals. (All Metals & Forge Group)

All Metals & Forge Group produces forged gear shapes for single hub, double hub, and other near net shapes for finish machining into several different shapes. All parts are rough machined and 100 percent UT tested (ASTM388).

Forged gear shapes and alloys:
- Spur Gears.
- Helical Gears.
- Bevel Gears.
- Hypoid Gears.
- Worm Gears.
- Spiroid Gears.
- Torsoing Gears.

These forged gear shapes are offered in ferrous and non-ferrous metals including carbon steel, alloy steel, stainless steel, titanium, nickel, aluminum, and tool steel.

All Metals & Forge Group, as an ISO 9001:2015 and AS9100D registered forging manufacturer, has a vast inventory (300 alloys & grades) on the floor that will aid in the quickest deliveries, high quality, and extremely competitive products.

MORE INFO  steelforge.com

Michigan Metrology short course looks at surface texture, tribology

Michigan Metrology, experts in solving problems related to surface roughness, wear, texture, and finish, will be hosting a surface metrology and tribology short course on April 11-12, 2019.

Michigan Metrology's Don Cohen, PhD will be leading the two-day short course in Livonia, Michigan. Dr. Cohen is one of the country's foremost experts in surface roughness and its effects. The course's topics will include:
- Roughness, waviness, and form.
- Instruments for measuring texture.
- Filtering surface texture measurements.
- Surface texture parameters.
- Wear.
- Friction.
- Sealing.
- Surface energy.
- Data analysis.
- Specifying surface texture.

The workshop is designed for scientists, engineers, and technicians working in the fields of automotive, aerospace, materials, polymers, and others.

Those interested in the short course can learn more and download the registration form, at www.michmet.com/classes.htm.

In 1994, Dr. Cohen established Michigan Metrology to help engineers and scientists solve problems related to “squeaks, leaks, friction, wear, appearance, adhesion, and other issues” using 3D Surface MicroTexture Measurement and Analysis.

Before forming Michigan Metrology, Dr. Cohen was V.P. of Engineering at WYKO Corporation (now part of Bruker Corporation), developing surface metrology instrumentation.

He served as vice chairman/chairman of the ANSI/ASME B46.1 Surface Texture Standards committee from 2000-2011 and is past chairman of the STLE-Detroit section. He holds a B.S./M.S. in Physics and a Ph.D. in Optical Sciences.

Since 1994, Michigan Metrology has been providing high-volume inspection services and solving problems related to
surface roughness, wear, texture, finish, flatness, and more. Using advanced 3D surface roughness measurement and analysis techniques, state-of-the-art equipment, and expert understanding of 3D surface metrology, the company has helped thousands of clients with solutions for surface development, manufacturing process issues and product warranty concerns.

MORE INFO michmet.com

Helios announces new representation of Yunil Machine Tools

Helios Gear Products, LLC (formerly Koepfer America, LLC) announces its new long-term representation agreement with YG Tech Co., Ltd., owner of the Yunil and Hera machine tool brands. Helios will provide all North American sales, service, and technical support for these gear manufacturing products. As never before, gear manufacturers of all sizes now have access to these globally competitive machines with complete sales, service, training, and application support.

Adam Gimpert, business manager of Helios Gear Products, said, “This partnership allows us to expand our product offerings and remain competitive in the global marketplace. We are always looking for ways to provide more value to our customers, so they are better positioned to efficiently produce profitable gears.”

In partnership with YG Tech, Helios offers a full range of hobbing solutions for gears up to 39” outside diameter. For small gears, the Hera 30 provides horizontal “micro” hobbing with unified automation systems for parts up to 1.575” outside diameter. The Hera 90 aligns with Helios’s legacy customers by offering a horizontal hobbing machine with a unified gantry automation system for parts up to 3.937” diameter. The Hera line continues with a range of vertical hobbing solutions, including the Hera models 150, 200, 350, 500, and 1000. These machines are a welcomed addition to the Helios portfolio of gear manufacturing solutions.

Nearly all parallel-axis gear manufacturers will want to discover the benefits of the Helios Hera series of hobbing solutions. These machines offer contemporary dialogue programming, flexible automation systems, and options such as integrated deburring workstations.

MORE INFO heliosgearproducts.com

Seco expands UNJ/MJ range with precision threading inserts

With the introduction of 13 new full-profile threading inserts, Seco Tools now offers a full range of UNJ and MJ thread profiles for both external and internal applications. Shops that need to generate high-precision threads in stainless steels and heat-resistant nickel-based and titanium alloys will benefit from the extremely tight-tolerance profiles of
these inserts. Manufacturers, especially those in the aerospace sector, can now extend tool life while eliminating process inconsistency and profile inaccuracy with these new inserts that are part of an all-encompassing range of threading solutions from Seco.

Hazardous, tangled curly chips can stall threading production, but the new inserts pair with Seco holders featuring the company’s Jetstream Tooling® high-pressure directed coolant technology that keeps the cutting zone clear. To guide and steer chips in specific directions away from the cutting zone, these holders deliver a concentrated high-pressure, high-velocity jet of coolant directly to the ideal position close to the cutting edge.

Threading titanium and similar materials produces tough chips that decrease tool life. With the improved chip control of Jetstream Tooling, shops can use 30 percent to 60 percent higher cutting speeds without compromising thread surface quality.

UNJ thread profiles produce inch threads; MJ profiles handle the corresponding metric versions.

Seco Tools is a leading global provider of metal cutting solutions for milling, stationary tools, hole-making, and tooling systems. For more than 80 years, the company has provided the technologies, processes and support that manufacturers depend on for maximum productivity and profitability.

Seco Tools now offers a full range of UNJ and MJ thread profiles for both external and internal applications. (Courtesy: Seco)

Achieve maximum machining stability with Big Kaiser

The importance of stability across the metalworking industry cannot be overstated — it affects everything from profitability to employee safety. Big Kaiser, a global leader in premium high-precision tooling systems and solutions for the metalworking industries, has developed the UNILOCK Stabilizer System. This modular system provides lateral support for tall parts during machining, welding or assembly processes and allows for the transfer of loads down to the table or base.

Big Kaiser’s zero-point, UNILOCK stabilizer system can easily adjust to any new part — making machining more efficient and cost-effective. (Courtesy: Big Kaiser)
If there’s a need to back off feeds and speeds to achieve finishes, there’s a good chance a part is not completely stable. One option to increase stability is to add an extra point of contact by using a temporary locating feature or weld tabs and brackets. However, Big Kaiser’s zero-point, UNILOCK stabilizer system can easily adjust to any new part — making machining more efficient and cost-effective.

In place of modifying parts by moving them from machine to machine — introducing the chance for error — this stabilizer system can easily adjust to each new part. The system attaches to the worktable and the side of the workpiece to provide lateral support. This is important because as the workpiece gets taller and further away from the table, there are cutting forces pushing against it and the stabilizer helps to offset them.

The UNILOK Stabilizer System also makes sense for more mobile parts of odd shapes and sizes. No matter the part, they are easy to adjust within one job, or in the case that jobs are changing in and out rapidly. What’s more, integrating it into existing setups is quick. The system stacks easily and uses a wide variety of gripping forms.

MORE INFO
us.bigkaiser.com

New family of Seco end mills makes easy work of tough materials

Shops that struggle to maximize end-mill tool life when machining tough materials can now achieve 25 to 40 percent longer life with new Jabro®-Solid2 JS750 end mills from Seco Tools. Designed specifically for the aerospace sector, the new JS754 and JS755 tools provide cost-effective high performance to tackle that industry’s challenging materials, including ISO M (stainless steel) and S (heat-resistant superalloys and titanium).

The JS754 and JS755 cutter geometries optimize conventional side milling, roughing and slotting, as well as advanced roughing and dynamic milling operations. Instead of struggling with chip formation, the smooth peripheral rake faces and strong radius design of these cutters evacuate chips efficiently while maintaining a true radius form. To avoid slow or unreliable cutting when interpolating or ramping for pocket machining, increased front back tapers enhance speed and reliability.

The broad range of JS754 and JS755 variations and features ensures the highest cutting performance. Shops can match tool to application with various lengths, OD neck reduction sizes and corner radii, as well as chip splitters and through-coolant options.

Range overview (all dimensions metric)

JS754: 4-flute side roughing, side finishing and slotting, APMXS=2+DC+OD.
- 3-25 chamfer and radii offer RE0.2 0.5 1.0 1.5 2.0 3.0 4.0 6.0, normal length.
- 6-20 chamfer ICC through coolant, normal length.

JS754: 4-flute side roughing, side finishing, APMXS=3.5 – 4+DC + OD.
- 10 and ø12 chamfer including chip splitters, normal length.

JS755: 5-flute high volume side rough and side finishing, APMXS=2+DC + OD.
- 6-25 chamfer and radii offer RE0.5 1.0 2.0 3.0 4.0 6.0, long length.
- 10-20 chamfer including chip splitters, long length (advanced roughing).
2.0 3.0 6.0, normal length.

**JS754** and **JS755**: 5-flute high volume side roughing, side finishing, APMX=3.5 - 4+DC + OD.
- 6-25 chamfer and radii offer RE0.2 0.5 1.0 2.0 3.0 4.0 6.0, long length.
- 10-20 chamfer including chip splitters, long length (advanced roughing).

Seco Tools is a leading global provider of metal cutting solutions for milling, stationary tools, holemaking, and tooling systems. For more than 80 years, the company has provided the technologies, processes, and support that manufacturers depend on for maximum productivity and profitability.

**MORE INFO**  secotools.com

### New Jet Coolant Nut by Big Kaiser available for improved surface finish

Big Kaiser, a global leader in premium high-precision tooling systems and solutions for the metalworking industries, announces the MEGA Micro Coolant Nut, a developed solution to provide precise coolant supply to micro cutting tools applications at high speeds.

Achieving efficient coolant delivery has become an important feature to have across the industry. Without precision coolant, chip jamming may be a problem, causing machine stoppages, service call outs, increased tool wear and poor surface finish. As spindle speeds continue to increase though, getting the coolant to the cutting tip has become more challenging.

Exclusively for MEGA Micro Chuck 6S, the MEGA Micro Coolant Nut is an ideal design for high-speed micro machining up to Ø6 mm. By using it instead of a standard nut, tool lifetime is increased by about 35 percent and better cutting performance is achieved for milling applications.

The MEGA Micro Coolant Nut is a continuation of Big Kaiser’s efforts to drive coolant toward the cutting edge and help to maintain process security. For coolant through drills, Big Kaiser offers the MEGA Micro Perfect Seal Nut.

If coolant is required, it should be optimized to maximize its true potential.

**MORE INFO**  bigkaiser.com
Seco Steadyline® tooling additions deepen turning capabilities

Seco Tools has expanded its long-reach turning and boring solutions with additions to its Steadyline® vibration-damping turning/boring bars and their respective heads.

The new additions include 1.00” (25 mm) diameter Steadyline bars, GL25 turning heads, and 4.00” (100 mm) diameter Steadyline bars, along with a range of rough and fine boring heads for Steadyline bars. Where conventional solutions fail, Steadyline delivers accuracy and confidence in long overhang operations, reducing spindle stress, increasing metal-removal rates, creating smooth surface finishes, and extending tool life.

Steadyline turning bars use the most-effective passive damping system in the industry for easy turning and boring operations to depths up to 10xD in small and large holes. A dynamic passive system acts as anti-resonance inside the holder’s body as a damped mass counter vibrates against the first vibration. Working together with the Steadyline damping system, the short, compact GL heads maximize vibration absorption, making it possible to use extended lengths without tool chatter or work interruptions.

With Steadyline, users can exchange turning and boring tool heads quickly and effortlessly using the unique Seco GL connection. The GL connection mounts heads to Steadyline bars quickly and firmly, with centering accuracy and repeatability of 5 microns and 180° head orientation capability if required.

The 1.00” (25 mm) diameter bars with GL25 workpiece-side connection for 6xD, 8xD and 10xD reaches include carbide-reinforced bars for the deepest tool overhang challenges, along with Seco-Capto™, HSK-T/A and cylindrical shank machine-side interfaces.

The 16 new GL25 turning heads target applications including general turning, recessing and back boring with DN..11, CC..09, DC..07, DC..11, TC..11 and VB..11 inserts.

Larger 4.00” (100 mm) diameter bars accommodate existing GL50 turning heads and incorporate Jetstream Tooling® high-pressure coolant technology through BA-to-GL50 adapters.

Boring heads with BA060 and BA080 machine-side connections allow for rough and fine boring at diameters from 2.60” to 4.53” (66 mm to 115 mm).

MORE INFO
secotools.com

Steadyline delivers accuracy and confidence in long overhang operations. (Courtesy: Seco Tools)
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What are your responsibilities with Mazak?
I work in applications engineering. We work with customers to basically size a machine or select a machine appropriate for their application. We help customers generally with machine operation, programming, sometimes setups, and there are times where a customer would purchase, say, a turnkey, which is where we would basically design the manufacturing solution. One of the components is machine tool, and we’ll work with tooling vendors on tool selection, and also the fixture vendors for fixture selection if fixtures are involved, and then we will develop a machining solution for their particular part.

What’s an auto gear package, and why is it important to gearing?
From the outside, a machine with Mazak’s AG (auto gear) function looks like a standard INTEGREX machine, but with that capability, it becomes a Mazak HYBRID Multi-Tasking System. However, there are some mechanical and software enhancements that allow it to perform in such a manner that it can cut high, accurate gears and splines.

How is Mazak incorporating auto gear packaging in its machines?
The auto gear package uses MAZATROL, a programming software that resides on all Mazak controls, and it’s a conversational-based programming system. What it does is it allows the users to input information. Basically, the control is going to ask you, “What do you want to do? Do you want to drill holes, mill slots, what not?” So, the user would enter in information, geometry, a number of features, and where the features are located, and a program will be automatically generated.

Moving on to the manufacturing gear programming, the user can input data similar to a dedicated gear machine. For example, it’ll ask the user how many gear teeth, the pressure angle, the helix angle, the root radius, and so forth, and the machine will automatically create a program to cut that specific part.

What else makes auto gearing unique?
The machine is capable of not just cutting gears. It can be equipped with a second spindle and a lower turret, so it can be used really for anything that you can fit inside the machine and that you can grip on. You can cut components that would go inside the gearbox, such as shafts and other type of components like levers and so forth, or you can cut parts that aren’t even gear-related.

It’s a very versatile machine. We took the INTEGREX, which is already a versatile multi-tasking machine on its own, and we added this additional capability to cut gears.

What’s been the response from the gear industry so far with this technology?
We get a lot of interest. We see customers that basically farm all their gearing out. So, they’re interested in perhaps purchasing a machine like this where they can dabble in gear-cutting, even though they’re not dedicated to gear-cutting.

How do you think this auto gearing will affect the future of the gear industry?
It opens the doors to customers that maybe normally wouldn’t get into gearing, because they don’t have either the money or perhaps maybe the personnel to buy a dedicated gear-cutting machine — for example, someone who is pretty savvy at milling. Those are good candidates for running this type of a machine tool. We employ three different modules of software on an AG machine. The first one is Mazak’s SMOOTH Gear Hobbing, where you’re using a standard hobbing cutter that’s used on any other hobbing machine. There’s nothing special about the hob cutter. We can use that type of tool to cut OD gears and splines.

The second module is SMOOTH Gear Skiving. Much like hobbing, we use the standard skiving tool. And that tool can cut both OD and ID gears and splines, but with straight and helical. Last is SMOOTH Gear Milling, which allows the user to use everyday ball-nose, end mills, and bull-nose cutters — like a non-special tool — to cut a gear tooth. We use milling strategies to machine the involute form of the gear tooth.

Is the machine easy to learn to operate?
It’s a full five-axis machine tool. It’s capable of simple, two-axis turning up to your high-end five-axis milling. We see the people who learn the fastest would be people with a milling background.

I think if you’re just talking just simple gears and splines, the programming of hobbing and skiving is fairly straightforward. The controls handle all of the, what I’ll call “fancy math.”

If you give it an rpm, the machine can figure out what the ratio needs to be between the tool and the part. And so, the control does a lot of the work.
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