GEAR Solutions

Your Resource for Machines, Services, and Tooling for the Gear Industry

ISSUE FOCUS

Gear Shaping | Gear Hobbing

GEAR TOOTH STRENGTH ANALYSIS OF HIGH PRESSURE ANGLE CYLINDRICAL GEARS

COMPANY PROFILE

WOLVERINE BROACH CO. INC.

JUNE 2018
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GEAR SOLUTIONS MAGAZINE
GEAR TOOTH STRENGTH ANALYSIS OF HIGH PRESSURE ANGLE CYLINDRICAL GEARS
JUNE 2018

Achieving Increased Profits and Response Times with Modular Vacuum, Atmosphere Furnaces

"Initially, what appealed to us about this Ipsen equipment was its general purposefulness ... We wanted a low-cost, off-the-shelf-type solution that would allow us the flexibility we required – which is what the ATLAS and TITAN® delivered. Now after having performed some pre-training, I would say what stands out the most for both are the ease of use and control of the equipment."

– Continuous Improvement Manager

Customer Story

Reduced lead times and increased flexibility by bringing the majority of heat treatment in-house

Increased process and part versatility with the installation of both atmosphere and vacuum heat-treating systems

Challenge:
The customer was seeing an increase in production demands and volume of parts. While they were relocating their existing facility to a new location, they also needed to find an equipment solution that would help them keep up with the recent influx.

Action:
Expanded their production capabilities by installing a complete ATLAS atmosphere heat-treating system and a TITAN® vacuum furnace at their state-of-the-art manufacturing facility.

Discover this customer's winning outcome:
go.IpsenUSA.com/Customer-Stories

IpsenUSA.com


Power Skiving Days
Rochester, NY, June 20-21
Experience first-hand the enormous productivity and quality benefits of Gleason Power Skiving at our Power Skiving Days. It's a unique opportunity to learn from the experts, see the complete system at work – and discover how this remarkable technology can revolutionize both your soft cutting and fine finishing of hardened gears.
Register at: www.gleason.com/psdays
IMTS2018
N-237000
Total Gear Solutions
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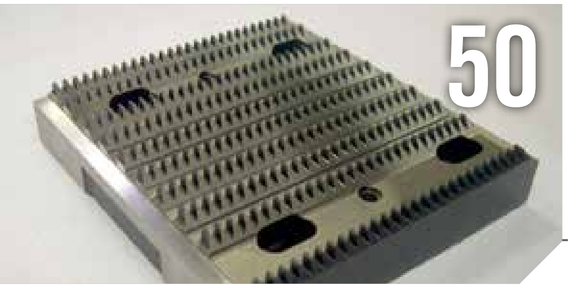
FEATURES



DEPARTMENTS

JUNE 2018 • VOLUME 16, NUMBER 6

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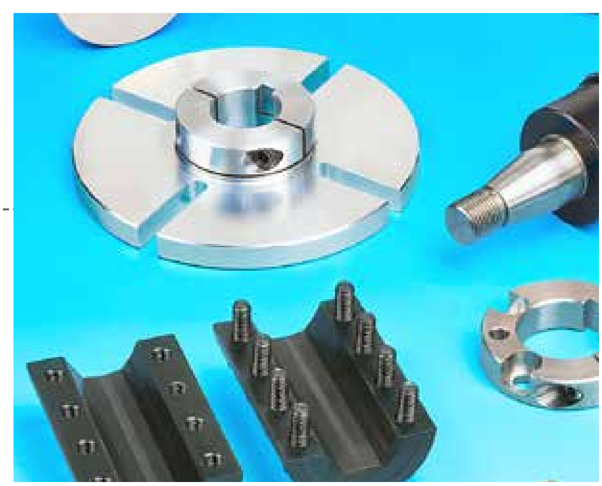
Mazak to spotlight HYBRID multi-tasking in booth at IMTS 2018



RESOURCES

COVER PHOTO: SHUTTERSTOCK

CURTIS DICK

Director of Quality with Riverside Spline and Gear Inc.

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FROM THE EDITOR

Focusing on important industry staples: gear shaping and hobbing

I don't want to steal too much of AGMA's thunder, but I do want to mention that its annual meeting in Naples, Florida, was a great success for the organization. Many of AGMA's members were recognized for what they have done for the industry. It's making some interesting changes to how it wants to continue to help the gear manufacturing industry, including the formation of a new committee on the latest emerging technology.

Make sure you check out the AGMA section in this issue to get the scoop on all the details of what happened at the annual meeting.

Consider the AGMA information just an appetizer to what you'll find in the June issue of *Gear Solutions*.

With a focus on gear shaping and gear hobbing, we're offering up several technical papers that address these important industry staples.

A paper from Dr. Alfonso Fuentes-Aznar and Dr. Ignacio Gonzalez-Perez talks about gear tooth strength analysis of high pressure angle cylindrical gears. Prasmit Kumar Nayak, A. Velayudham, and C. Chandrasekaran share their approach in evaluating the unknown geometry of the high accuracy gears of a CNC machine tool.

Scott MacKenzie, our resident Hot Seat expert, goes into detail on how endothermic atmospheres are used for heat treating.

And Tooth Tips columnist Brian Dengel has written another relatable column. This time it's a primer on worms and worm wheels.

In our company profile, I talk with Wolverine Broach's president and vice president of sales. They have made some impressive strides with broaching and have a recent award to show it.

And last, but not least, I had the pleasure of chatting with Riverside Spline and Gear's director of quality, Curtis Dick. Riverside has recently added several pieces of machinery that will help the company meet its customers' urgent needs.

You'll find that and much more in this issue. I hope you learn something new.

Enjoy, and, as always, thanks for reading!

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The KZF-S collet chuck is especially well suited for clamping gears/workpieces that have an external plane or gear teeth geometries accessible from the outside. (Courtesy: Röhm)

Röhm to feature diverse line-up of workholding solutions at IMTS

At IMTS 2018, set for September 10-15, Röhm Products of America will present a wide range of workholding solutions that lead to higher levels of efficiency in turning, milling, grinding, and drilling applications as well as enable lights-out manufacturing. The workholding specialist will also demonstrate how the company is a single source supplier for chucks, centers, face drivers, rotating workholding, fixtures, palletizing, and robot gripping solutions.

A must-see for visitors to booth #432528 will be a powered external clamping chuck for gear surface face grinding. The KZF-S collet chuck is especially well suited for clamping gears/workpieces that have an external plane or gear teeth geometries accessible from the outside. Additionally, the chuck allows face and ID diameters to be turned or ground concentric to outer gear pitch diameters.

Röhm will also showcase its EASYLOCK clamping system, a zero-point palletization solution that reduces setup times by up to 90 percent. With a standardized interface and level of precision and repeat accuracy of less than 0.005 mm, EASYLOCK can be outfitted with a large range of Röhm's collet chucks, lathe chucks, and vises for full flexibility via its modular design. The clamping system is equally well suited for vertical, horizontal, or multi-axis machining.

MORE INFO www.rohmdonein60.com
www.rohm-products.com

Mazak to spotlight HYBRID multi-tasking in booth at IMTS 2018

At the 2018 International Manufacturing Technology Show (IMTS), Mazak will feature its advanced HYBRID Multi-Tasking technologies in booth #432000 in the West Hall, and 30 of its newest machine tool and automation systems in the South Hall at booth #338300. New to the South Hall booth this year is the Mazak Digital Plaza, a special area for visitors to experience innovations such as SMOOTH Link, the Mazak SmartBox, and other powerful SMOOTH Technology digital solutions.

As manufacturing technology continues its rapid growth, especially in terms of machine tools and digital connectivity/solutions, Mazak has continued to develop solutions that meet the needs of the robust and expanding North American manufacturing sector. At IMTS 2018, Mazak's two booths will offer visitors a glimpse of the future direction in which manufacturing is heading.

"IMTS 2018 comes during our company's 100th anniversary," said Dan Janka, president of Mazak Corporation, "and we look forward to demonstrating how much manufacturing has changed over a century of innovation, as well as where the company will take manufacturing in the next 100 years. Our new second booth has the perfect position to show Mazak's commitment to additive manufacturing and HYBRID Multi-Tasking technology, while our main booth has some of the most technologically advanced innovations our company has ever developed."

Mazak's HYBRID Multi-Tasking series serves as another step toward the realization of true DONE IN ONE® manufacturing. In the new West Hall booth, Mazak will feature new technologies like wire arc additive manufacturing and multi-laser metal deposition. While "multi-tasking" has become increasingly commonplace, these revolutionary HYBRID systems promise to trans-

SEND US YOUR NEWS Companies wishing to submit materials for inclusion in Industry News should contact the editor, Kenneth Carter, at editor@gearsolutions.com. Releases accompanied by color images will be given first consideration.

At IMTS, Mazak will have a special area for visitors to experience innovations such as SMOOTH link, the Mazak SmartBox, and other powerful SMOOTH Technology digital solutions. (Courtesy: Mazak USA)

form manufacturing just as Multi-Tasking once did.

At its South Hall booth, the Digital Plaza will spotlight new SMOOTH Technology enhancements such as SMOOTH Link, a digital connectivity solution that makes remote monitoring as simple as installing a commercial-off-the-shelf wireless network. The company will also demonstrate the user-friendly programming capabilities and processing speed of its MAZATROL SmoothX and MAZATROL SmoothG CNC controls.

In addition to the digital technology on display, the South Hall booth will feature numerous machine tool innovations and new automation solutions.

Mazak will also highlight automation solutions for job shops with new systems such as the Multi-Pallet Pool (MPP), a space-saving palletized system for manufacturers who cannot accommodate a full PALLETECH or MAZATEC SMS system. The company will also demonstrate some of its new machine tool features, including new gear skiving software solutions built into the latest INTEGREX platforms and friction stir welding, a HYBRID Multi-Tasking joining technology.

MORE INFO www.mazakusa.com

Riccardo Rubino joins Star SU as Americas operations manager

Star SU of Hoffman Estates, Illinois, announced the appointment of Riccardo Rubino as its new operations manager for the Americas.

"Riccardo brings operations and supply chain leadership experience from positions held both in the U.S. and Italy," said David Goodfellow, president of Star SU LLC. "He will work closely with me overseeing operations starting with for the Star SU Hoffman Estates and Star SU Federal de Mexico and taking over the quality control for those operations. I am confident in Riccardo's experience in his previous leadership role will help lead our team in continuous growth and enhance operational activities.".

Rubino has spent the last six years building a career surrounding operations, procurement, sales, and product management with Somaschini North America (South Bend, Indiana) and Somaschini Automotive (Bergamo, Italy). He earned a BS and MS in Industrial and Management Engineering while studying in Italy.

Star SU is the go-to-market cooperative partnership of Star Cutter Company of Farmington Hills, Michigan, and SU America, Inc., the U.S. sales and manufacturing unit to SAMP, S.p.A.

Star SU, LLC offers a wide variety of machine tools, precision cutting tools, and services including:

- vertical gear hobbing machines
- chamfering and deburring machines
- gear grinding machines
- gear shaving machines
- tool and cutter grinding machines
- gear hobs and milling cutters
- gear shaper cutters and shaving tools
- scudding® and power skiving tools
- chamfer and deburring tools
- gundrills
- form tools and reamers
- pcd tooling
- cryogenic cutting tools
- carbide blanks and preforms
- tool coatings
- tool life cycle management services

MORE INFO www.star-su.com

Riccardo Rubino spent the last six years building a career surrounding operations, procurement, sales, and product management.

AIMS brings 5-Axis CMM technology to Mexico and Central America

AIMS Metrology named Jose Luis Duarte business development manager for Mexico and Central America. The coordinate measuring machine OEM is expanding its reach in Mexico and the southernmost region of North America to help automotive and aerospace manufacturers eliminate production bottlenecks, boost part quality, and minimize maintenance costs. AIMS builds and assembles its Revolution Series CMMs in the United States and equips the machines with Renishaw 5-axis scanning and touch trigger probes for higher throughput and accuracy.

"Customers are asking for better part quality and shorter delivery schedules," said Duarte. "But manufacturers acknowledge that conventional CMMs are often a choke point. Maintenance is expensive and service support lacking. AIMS CMMs are engineered to boost throughput and improve inspection ratings. Service and support are also critical components for AIMS."

AIMS' laboratory-grade Revolution LM can be fitted for touch or non-contact inspection. Unlike other systems on the market, the LM features Renishaw's REVO 2, the industry's most advanced scanning probe. The precision measuring head and probe system triple productivity, collecting data at a rate of 4,000 points per second. Infinite positioning and 5-axis motion allows users to access complex features while flexible tip sensing enhances accuracy. The SFP2 surface finish probe increases the REVO system's surface finish measurement ability.

For 5-axis touch trigger applications, the LM is also available with Renishaw's PH20 which increases throughput three times faster than traditional indexing heads, offers faster calibration and infinite positioning. Linear motors provide submicron accuracy while eliminating the maintenance and downtime associated with belt and pulley designs. Modus software supports offline programming, true 5-axis measurement programs, full simulation, crash detection, and the capability to leverage large amounts of product information.

The Revolution HB is also built with Renishaw's 5-axis PH20 and is the only mobile 5-axis CMM on the market. A unique undercarriage equipped with one steer and two stationary wheels allows two operators to easily move the unit anywhere on the shop floor. A 110/220 volt outlet eliminates the need for shop air. A polymer-cast base includes built-in vibration resistance and thermal stability. Mechanical bearings add additional protection from the harsh shop floor environment.

AIMS is ISO/IEC 17025:2005 accredited for calibration from the ANSI-ASQ National Accreditation Board. ISO/IEC 17025:2005 covers testing and calibration performed using standard, non-standard and laboratory-developed methods. The company also provides regional customer support and training services.

AIMS was founded in 2009 to equip the industry with the tools to perform accurate, flexible three-dimensional inspection for in-process and post process parts. In 2015, the Dayton, Ohio-based OEM launched its line of Revolution LM and HB series coordinate measuring machines designed and engineered to introduce and bring Renishaw 5-axis measurement technology to the shop floor and the laboratory. AIMS' Revolution line of CMMs are exclusively supported by Renishaw technology through probe heads, touch probes, scanning probes, incremental encoder scale systems, change racks, styli, controls, and Modus software. Faster measuring speeds, enhanced accuracy, higher throughput, and lower cost of ownership make the Revolution series products especially suited for the quality control process demands of efficiency-driven manufacturers and the growing number of smart factories and automated operations. In addition to matching customer requirements with the right turnkey CMM system, AIMS provides installation, service, support, and training. Machine retrofits and refurbished equipment are also available.

MORE INFO www.aimsmetrology.com

Jose Luis Duarte will lead AIMS Metrology's expansion in Mexico and the southernmost region of North America in support of automotive and aerospace manufacturers.

Southern Midwest region strengthened for Toyoda customers

TEKT Toyoda Americas Corporation welcomed ACI Machine Tool Sales, LLC as the latest edition to its distribution network. ACI Machine Tool Sales was founded in 2001 by owner Mark Cox, originally selling and servicing machine tools in its home state of Kentucky. ACI's continuous success has led to a growing team of more than 15 members and expansion into four surrounding states.

The partnership with ACI will facilitate service and sales efforts for Toyoda manufacturing customers in Kentucky, southern Ohio, and southern Indiana. Along with an extensive network of knowledgeable sales personnel, ACI offers customers extended aid out of its Lawrenceburg, Kentucky, technical facility through turnkey engineering solutions and more than 10 machine tool models on show.

MORE INFO www.toyoda.com
www.acimachine.com/toyoda

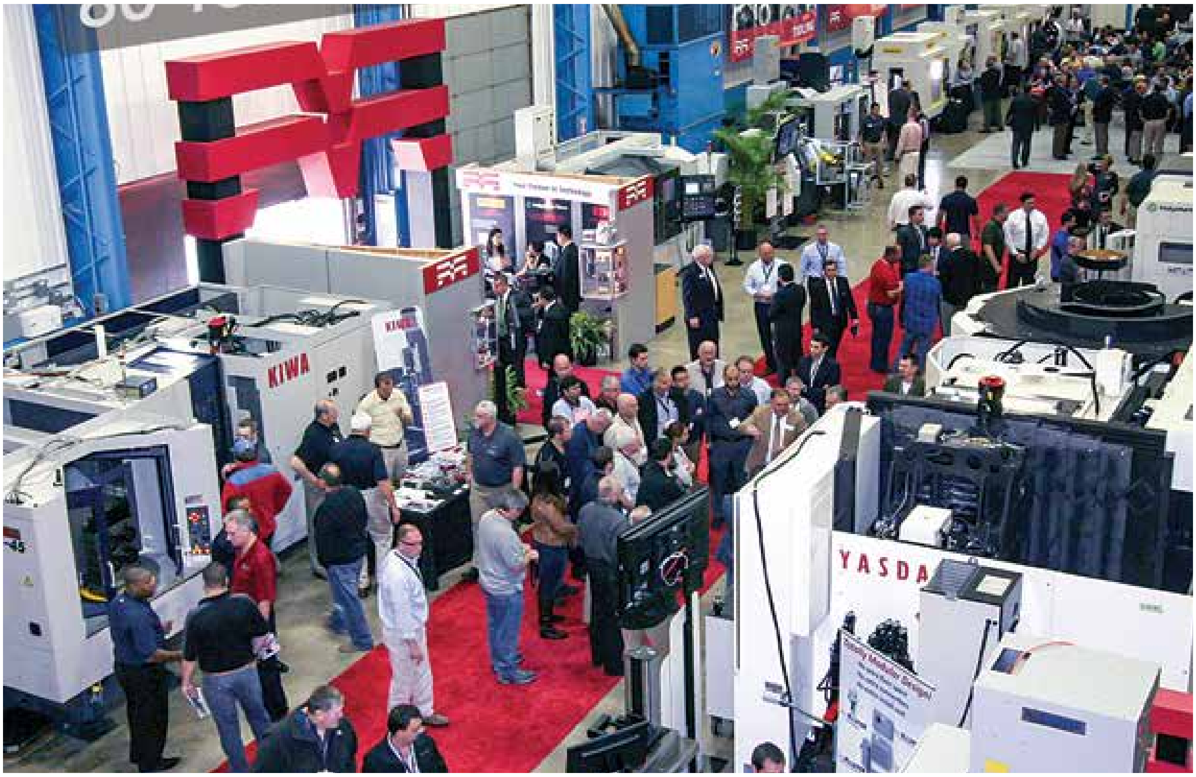
Methods Machine Tools celebrates 60 years serving manufacturers

This year, Methods Machine Tools, Inc., North America's foremost supplier of leading-edge precision machine tools, automation, and additive manufacturing solutions, is celebrating its 60th anniversary. Founded in November of 1958 with three employees and a few refurbished machines, Methods has grown into one of the largest, most innovative, high-precision machine tool suppliers in North America. Methods today has roughly 350 employees, eight sales and technology centers, and more than 35,000 machines installed throughout North America, These range from EDM machines to sophisticated 5-Axis CNC machining centers to state-of-the-art robotics, automation, and 3D printing solutions.

The company's founder, Clement McIver Sr., established principles that have continued to set Methods apart from conventional importers or distributors: "Anyone can sell a machine. But not everyone provides the extra effort that makes a difference on a company's bottom line."

"Staying true to our founder's vision, we have built an excellent reputation in the machine tool industry by closely partnering with machine builders and customers, as well as providing strong application expertise," said Scott McIver, Methods chairman and third-generation owner. "We offer a total service solution from design and applications to engineering, installation, training, and unmatched support, to help manufacturers be more profitable, productive, and competitive."

Methods' product line strategy offers only the most advanced, optimal technology for each machining discipline or class. Machine tool partners include Nakamura-Tome, Yasda, FANUC, KIWA-Japan and, most recently, Niigata Machine. EDM partners include FANUC Wire EDM's and new partner Ocean Technologies Co., Ltd. In addition, Methods 3D, Inc. provides the industry's most advanced 3D printing solutions through 3D Systems and MarkForged. For measurement and inspection solutions,



To commemorate its anniversary, Methods will be hosting open houses, holding technology events, and introducing new product lines throughout the year. (Courtesy: Methods Machine Tools Inc.)

Methods offers Digital Optical Comparators from VISIONx INC.

Demonstrating an unparalleled commitment to quality and reliability, many of Methods' machine manufacturer partnerships have been long term, such as being the exclusive U.S. importer of premier Nakamura-Tome multitasking turning centers for 35 years, and 25 years with FANUC as importer of the world's most popular tapping/ drilling FANUC RoboDrill machining centers and FANUC Wire EDM machines for all of North America. The close, collaborative relationships with Nakamura-Tome and FANUC have provided Methods' customers leading machine technology solutions for decades. In addition, Methods' close attention to applications and dedicated service ensures productive, profitable, customer centric solutions and support.

"We are excited to celebrate our 60th anniversary milestone," said Jerry Rex, president and CEO of Methods. "Our dedicated, experienced team, together with our powerful partnerships, has provided us a strong foundation for serving our customers. We are proud of our heritage and are looking forward to further expand our leading technology solutions in machine tools and automation, including the most proficient ways to apply and support them."

Strategically located across the U.S., Methods Sales and Technology centers complement an extensive, national network of distributors and dealers, offering the latest technology and automation solutions, machines, training, spare parts, and engineering support demanded by manufacturers. In addition, the company has state-of-the-art automation centers in three locations as well as 3D printing labs throughout the U.S.

MORE INFO www.methodsmachine.com

Seco showcases tooling innovations and turnkey services at IMTS 2018

For the 2018 International Manufacturing Technology Show (IMTS), Seco will spotlight the company's innovative new tools and growing range of services at booth #431564 in the West Hall. Additionally, Seco will offer visitors the opportunity to interact with its products and technology via an immersive augmented reality (AR) experience.

Among Seco's exciting new tooling solutions at the show is the Double QuattroMill™ 22, a double-sided version of the company's aggressive line of face milling tools, and the company's newly redesigned Perfomax™ indexable insert drills. Seco's solid tooling display at the show will also include the Feedmax-P drill configuration that incorporates a new coating and geometry specifically for holemaking in steel and cast iron, as well as Niagara Cutter products such as advanced high feed milling tools with grades and geometries designed for the highest possible efficiency even in the toughest materials.

As a one-stop shop for optimizing manufacturing processes, Seco will unveil its new consultancy service, which will complement the company's existing well-known services like STEP training and SecoPoint inventory management. The consultancy will use an extensive evaluation process that examines every aspect of a company's operations to identify all of the factors affecting its bottom line. Visitors will be among the first to learn more about this new service and how it will give manufacturers the opportunity for truly comprehensive process optimization.

DOUBLE QUATTROMILL 22

Seco's new Double QuattroMill 22 face mill for roughing and semi-finishing delivers the next level of performance with its free cutting geometry. Its innovative insert placement reduces cutting forces, leading to workpiece stability, improved tool life and maximum productivity. The Double QuattroMill 22 is ideally suited for applications in a wider range of part materials than ever before, including steel and cast iron as well as 15-5 stainless steel and super alloy materials such as titanium and Inconel®.

FEEDMAX-P

The new Seco Feedmax-P drill gives manufacturers the potential to significantly boost holemaking performance beyond that of current drilling technology for ISO P (steel) and cast-iron workpiece materials. The solid carbide Feedmax-P drills can increase drilling productivity by up to 35 percent while also providing longer tool life due to the combination of the drill's new geometry and advanced TiAlN coating. Together with the drill's strong point geometry, cutting speeds of 623 feet/min are possible in 4140 alloy steel without sacrificing tool life.

Seco offers the Feedmax-P in diameters ranging from 0.078" to 0.787" (2 mm to 20 mm). All drills come standard with through-the-tool coolant channels to ensure maximum performance.

Custom versions such as intermediate sizes and chamfer and step drills are available upon request.

PERFOMAX

A drill body that will stand the test of time, the newly redesigned Seco Perfomax indexable insert drill offers exceptional productivity and longer tool life.

The newly redesigned Seco Perfomax indexable insert drill offers exceptional productivity and longer tool life. (Courtesy: Seco)

Featuring higher drilling parameters as well as exceptional chip control and evacuation, the drill's flutes have improved helix angles along with smoother chip flute exits and Seco's engineered wave pattern, which minimizes contact between chips and flute surfaces.

Furthermore, for up to 140 percent longer drill body tool life, Seco laser hardens the fronts of Perfomax's flutes. A hardness of HRC 60 allows the drill to withstand chip erosion for much longer periods of time.

Perfomax drill bodies are available in diameters ranging 0.594" to 2.375" (15 mm to 59 mm); and in most spindle interfaces.

MZN AND MBZ HIGH FEED MILLING CUTTERS

Niagara Cutter high feed MZN410R and MZN510R AlTiN-coated solid carbide end mills bring high wear resistance and superior performance to applications that involve machining mold and die components from hardened steel, cast iron or nickel based super alloy workpiece materials.

Niagara Cutter's line of high feed milling tools also includes the MBZ tools, ball end mills designed for the rough and finish milling of contours and complex shapes for mold and die steels.

Overall, when used in high feed milling operations, these cutters reduce machining time and costs by allowing use of one tool for a wide range of operations, maximizing material removal rates and allowing close-to-profile pocketing of 90-degree walls.

The technique also minimizes semi-finishing operations to further increase machining efficiency.

MORE INFO www.secotools.com

Whittemore Company adds cutting tool manufacturer to portfolio

The Whittemore Co. has added the cutting tool brands of Precision Twist Drill, Dormer, Pramet and Union Butterfield to its already broad portfolio of products it represents.

These brands are manufactured by Dormer Pramet, which has North American Headquarters in Elgin, Illinois. The company has a history in America dating back to its founding in 1952 as Precision Twist Drill in suburban Chicago. While the Precision Twist Drill brand has developed a focus on HSS drills, the company has added other brands to complete its manufacturing portfolio including Union Butterfield for HSS taps, Dormer for high-performance drills, and Pramet for a complete indexable line.

Today, Dormer Pramet is a one-stop manufacturer for round and indexable cutting tools for milling, drilling, hole-making, and turning.

Russ Reinhart, national sales manager for Dormer Pramet, said, "We are very pleased to welcome The Whittemore Co. to our team. We have a passion for cutting tools and see great value in partnering with others who have a similar passion. Our team members work hard to grow business and ensure the needs of our distributors and end users are met."

Dave Zaval, president of Whittemore, said, "Dormer Pramet and its long-standing heritage of exceptional cutting tool brands align with our company's strategic direction. Together, I am confident that we will provide robust solutions to our customers' metalworking needs. We are excited to enter our next phase of growth with Dormer Pramet on our team."

MORE INFO Whittemore-inc.com

Big Kaiser Precision Tooling names marketing communications manager

Big Kaiser Precision Tooling has named Gillian Campbell as its marketing communications manager. She will oversee the company's marketing efforts.

"Gillian is an experienced marketing professional with a background in manufacturing and metrology. I'm confident Gillian will be a good fit for Big Kaiser and round out the talented group we already have in place to help us drive marketing and sales activity," said Jack Burley, vice president of sales and engineering.

Campbell brings more than 20 years of experience in content strategy to the role. She has worked on the marketing teams for several manufacturers – most recently at a precision metrology company. She also previously served as editor of Quality magazine at a time when the publishing industry was

Gillian Campbell

going through a digital transformation.

"I'm excited about to the opportunity to lead the marketing team at Big Kaiser and continue to increase the company's visibility in the industry," Campbell said.

MORE INFO www.us.bigkaiser.com

JTEKT Toyoda Americas signs Phillips Corporation to distribution network

JTEKT Toyoda Americas Corporation has announced the addition of Phillips Corporation to their distribution network. Phillips' full-service, 45-person sales force and 98-person service team will support Toyoda customers in Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, Arkansas, and the Florida Panhandle.

Having technical showrooms in five of the eight southeastern states served, Phillips stands by its mission to be the best resource in manufacturing technology for Toyoda CNC owners. For more than 50 years, the company has built a dedicated fleet of expert staff vested in continuous improvement of high performance results on a localized level. In addition to carrying JTEKT Toyoda America's entire line of CNC machines (horizontal and vertical machining centers, bridge-type mills, turning centers, grinding machines, and automation solutions), Phillips offers engineering and application support. JTEKT Toyoda Americas looks forward to working with the entire team at Phillips Corporation throughout their new endeavors carrying Toyoda and Takisawa Taiwan machining centers.

MORE INFO www.phillipscorp.com
www.toyoda.com

Liftomatic powered transporter makes drum handling easy

Liftomatic Material Handling, Inc., an industry-leading material handling equipment manufacturer, recently introduced the Ergo-PWPL-750 powered drum handling transport.

The Ergo-PWPL-750™ is a completely self-contained, powered drum handling transport that engages, lifts, lowers, and moves all steel, plastic, and fiber drums. The unit incorporates power drive forward and reverse, as well as power lift and lower features for moving drums quickly and safely in plants, warehouses, and laboratories. Varying weight capacities are available between 650 and 1,000 pounds. As part of Liftomatic's Ergo-Matic® line, the unit is equipped with a fully programmable set of controls for easy operator adjustment.

Additional features include regenerative braking, available in straddle leg or fully counterbalanced versions, as well as EE and spark resistant ratings. All Ergo-Matic® models incorporate Liftomatic's exclusive Parrot-Beak® clamping mechanism, which allows the operator to safely and securely grip the drum lip throughout the pick-up and release process.

Liftomatic Material Handling, Inc. is an acknowledged leader in the design and manufacture of drum handling equipment. Headquartered in Buffalo Grove, Illinois, Liftomatic maintains manufacturing, engineering and sales facilities around the globe. Liftomatic sells products in more than 40 countries and to more than 400 of the Fortune 500 companies.

MORE INFO www.liftomatic.com

Brian Papke inducted into Northern Kentucky Business Hall of Fame

Brian Papke, chairman of manufacturing technology leader Mazak Corporation, has been inducted into the Northern Kentucky Business Hall of Fame. He accepted the award in April at the Metropolitan Club in Covington, Kentucky, where he delivered remarks that credited Mazak's customers and its employees for the company's decades of success across North America.

"Our customers are not just customers,

they are friends, and the majority of our employees are homegrown," Papke said. "We have all worked together over the years to create wonderful opportunities for families, the local community, and all of the areas our customers call home."

Under Papke's direction, Mazak has strived to give back to its customers and the manufacturing industry through its contributions to the state's economic growth and its establishment of a successful model for manufacturing excellence. He also oversaw the Kentucky plant as it became an 800,000-square-foot campus and significant regional employer. Today, the Kentucky facility serves as a proof of concept for the Mazak iSMART Factory™ model in addition to acting as the staging ground for some of the industry's most advanced manufacturing systems, including innovative full 5-axis, Multi-Tasking and HYBRID Multi-Tasking machines.

Of course, Papke has also served the state and the manufacturing industry by working to meet the needs of his company's customers since he joined the company in 1987. "One of Brian's greatest traits is that he listens," said Paul Hemmer, president of Paul Hemmer Company, a local leading construction company that often works with Mazak. "He listens to his staff and he listens to his customers." And armed with that information, Papke and the team at Mazak have developed revolutionary ideas that have helped propel U.S. manufacturing into the 21st century.

Today, North American manufacturers in all types of industries use the Mazak iSMART Factory model, which the company established to better serve its customers and help deliver the advanced technology for which the company has become known. It is this technology that has helped Mazak customers maintain their competitiveness and success to keep work and jobs from going offshore, one of Papke's personal goals for the industry he has helped to lead for decades.

Commissioned by NKY Magazine in partnership with the Northern Kentucky Chamber of Commerce, the Northern Kentucky Business Hall of Fame celebrates Northern Kentucky's heritage of business accomplishments. The award honors men and women who have made a lasting contribution to the community in economic, cultural and civic endeavors.

MORE INFO www.mazakusa.com

Brian Papke, chairman of Mazak Corporation, gives his acceptance speech after receiving the Northern Kentucky Hall of Fame award. (Courtesy: Cincy Magazine)

American Gear Manufacturers Association

Mary Ellen Doran
AGMA Director of Emerging Technology

New AGMA committee offers the latest on emerging technology

Whether you call it Industry 4.0, the next industrial revolution, or smart manufacturing, it is here, and it will have an impact on you and your company. There has been a seismic shift in our culture brought on by the increased availability of affordable high-speed computing power. It has allowed for the creation of new technologies. We can feel it even in our daily lives. In our businesses, we see it in new tools such as generative design, digital twin, preventive maintenance, supply chain management, and new material discoveries at the nano-level — pushing on manufacturing from all sides.

The AGMA Emerging Technology Committee (ETC) recognizes the new pressures faced by members and is working to help make sense of the deluge of information. The committee, with the direction of the Board of Directors, has spent its first six months focused on four specific areas: the Industrial Internet of Things (IoT), metal 3D printing, robotics & automation, and new materials. The goal of the committee is to identify, investigate, and inform AGMA members of Emerging Technologies that may disrupt or significantly make an impact on our industry, as well as to equip our members with the information they need to succeed in this environment. After gaining a better understanding of each of these areas, we have been working to create informational pieces providing a roadmap on how to implement these technologies into our members' business plans and onto factory floors. The ETC wants to be the microscope into understanding these technologies.

The ETC is focused both on understanding and implementing new technology and how AGMA members can gain new business from these technologies. Robotics is an excellent example. In just the last couple of years, the barriers for bringing automation into a plant have significantly decreased — it is no longer the case that robots are only used in automobile assembly lines or multi-billion-dollar corporations. Technologies are now available for use across the manufacturing sector. As a result, there will be a natural increase in the production of robots. The ETC is pursuing ways to help members identify opportunities in the supply chain for this new level of production and maximize production capability of their factory floors through automation.

The ETC will seek out best practices and use cases for AGMA members. The committee was able to have some early successes last year with the creation of the first Emerging Technology Pavilion at Gear Expo, which led to finding more experts to present on our four topics of focus at AGMA events. We have provided expert presenters for members for their on-site education events, and most recently, I moderated the robotics panel discussion at the 2018 AGMA/ABMA Annual Meeting in Naples, Florida. We are working on roundtable discussions for the upcoming SRN, and the committee will assist with a presentation at the FTM. The ETC will continue to provide member access to experts in emerging technologies.

The ETC provides information from the news each week in multiple areas. On Tuesdays, we issue the Gear Industry Update, a weekly overview of the important articles of interest to our members. Many emerging technology news items are included in this e-newsletter every Wednesday in the Tech Deck on the AGMA website, where we present the most relevant developments from the four AGMA ETC focus areas. You may sign up to receive the newsletter on the AGMA home page and visit the emerging technology section of the AGMA website to learn more.

In coming months, you can look forward to seeing more information from the ETC. We are working to provide a report on the current state of gear research and production by metal 3D printing and additive/subtractive processes. We are gathering information on materials research and how high-speed computing is being used to create materials and increase efficiency in traditional material development. We are monitoring current research and will bring you information on developments in light weighting, strength, new alloys, and new discoveries. The committee has 13 members from within the AGMA membership and is chaired by Brian Schultz, president of Great Lakes Industry. We are soliciting support from experts to sit on Technical Advisory Groups (T.A.G.s) for each of the four focus areas.

From smart factories and smart products to predictive maintenance and generative design, AGMA will help you navigate technology, security, and supply chain implications for your company, your products, and your end users. I encourage you to stay informed with us and even join the ETC if you are interested.

Membership in the AGMA Emerging Technology Committee is available for all AGMA member companies. Please contact Mary Ellen Doran at *doran@agma.org* for more information.

AGMA/ABMA annual meeting was a great success

AGMA board of directors

The 2018 AGMA/ABMA annual meeting was a great success on many levels. There were 264 attendees at this year's meeting, and 23 of them were first-timers.

The AGMA Foundation Golf Tournament raised more than $8,500 for future scholarships. The First Annual Cornhole Tournament provided a new, fun way to network. Members got a chance to talk, relax, and enjoy a little friendly competition in the sun. Photos from the week are available to those who attended. Please contact brinkley@agma.org to receive the link.

And, what a speaker lineup! From international trade breakdowns to motivational speeches, members were presented with all facets of the industry and business. Some of the presentations are available for download on the annual meeting webpage.

Thank you for making this annual meeting a memorable experience. We look forward to seeing everyone again next year in Scottsdale, Arizona.

AGMA GIVES TWO LIFETIME ACHIEVEMENT AWARDS

AGMA presented David Goodfellow, president of Star SU and Sam Haines, CFO and chairman of Gear Motions, with the AGMA Lifetime Achievement award. This award is presented to someone who has demonstrated dedication and leadership for the advancement of the gear industry and AGMA, exemplified superior vision and exceptional knowledge that has been shared with colleagues, and achieved admiration and respect of peers. For full press releases, please visit: www.agma.org/resources/newsroom/press-releases/

Maeve McGoff

Benjamin Sheen

AGMA ANNOUNCES NEXT GENERATION AWARDS

AGMA announced two recipients for this year's Next Generation Award. Maeve McGoff, sales & marketing coordinator at Cincinnati Gearing Systems and Benjamin Sheen with Eaton-Vehicle, won the award, and the announcement was made during the annual meeting in Naples.

This award is presented to someone who, while early in their career, is an emerging contributor, innovator, and leader in the gear industry. A Next Generation award recipient demonstrates

Linda and Bipin Doshi donated $100,000.

Jack Masseth received AGMA's Chairman's Award

hard work and acts as a role model for others while having a positive impact on AGMA.

AGMA FOUNDATION RECEIVES DONATION TO ENDOW NEW SCHOLARSHIP

The AGMA Foundation received a $100,000 donation from Linda and Bipin Doshi, formerly of Schafer Industries. The announcement to endow a scholarship award through the AGMA Foundation was made to members at the 2018 AGMA/ABMA Annual Meeting. The $100,000 donation is the largest single gift received in the AGMA Foundation's 22-year history. The Doshis have been active leaders with AGMA and AGMA Foundation boards for many years.

AGMA PRESENTS CHAIRMAN'S AWARD AT ANNUAL MEETING

AGMA presented Jack Masseth of Meritor, Inc., with the AGMA Chairman's Award during the AGMA/ABMA annual meeting in Naples, Florida. This award is presented to a recipient that has contributed greatly to the gear industry and has gone above and beyond the call of duty to support innovation and advancement through AGMA.

Upcoming Courses

INTERNATIONAL COURSE WITH TOUR! GEAR MANUFACTURING AND INSPECTION

July 10-12, 2018 | Ontario, Canada

Learn key factors in the inspection process that lead to better design of gears. Develop a broad understanding of the methods used to manufacture and inspect gears. Discover how the resulting information can be applied and interpreted in the design process.

This course is accompanied by a tour of a gear manufacturer. The tour for 2018 will be at Ontario Drive and Gear.

BASIC TRAINING FOR GEAR MANUFACTURING

September 11-14, 2018 | Chicago, Illinois

Learn the fundamentals of gear manufacturing in this hands-on course. Gain an understanding of gearing and nomenclature, principles of inspection, gear manufacturing methods, hobbing and shaping. Using manual machines, develop a deeper breadth of perspective and understanding of the process and physics of making a gear as well as the ability to apply this knowledge in working with CNC equipment commonly in use.

FUNDAMENTALS OF WORM & CROSSED AXIAL HELICAL GEARING

September 20-21, 2018 | Alexandria, Virginia (Come to AGMA Headquarters!)

Provides an introduction and emphasizes the differences between parallel (the experience base) axis and worm and crossed axis helical gears. Describe the basics of worm and crossed axis helical gears, their fundamental design principals, application guidelines and recommendations, lubrication requirement, a discussion of accuracy and quality, and summarize with a brief review of common failure modes.

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

CALENDAR OF EVENTS

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

JUNE

June 15 — Sound & Vibration Committee — WebEx
June 20 — Helical Gear Rating Committee — WebEx
June 26 — Nomenclature Committee — WebEx
June 26–27 — Plastics Committee Meeting —Detroit, Michigan
June 28 — Gear Accuracy Committee Meeting — WebEx
June 29 — Computer Programming Committee — WebEx

JULY

July 10 — Wind Turbine Gear Committee — WebEx
July 10–12 — Gear Manufacturing and Inspection — West Waterloo, Ontario, Canada
July 13 — Emerging Technology Committee Meeting — WebEx
July 17 — Helical Gear Rating Committee — WebEx
July 19 — Lubrication Committee Meeting — WebEx
July 20 — Sound & Vibration Committee — WebEx
July 31 — Fine-Pitch Gearing Committee Meeting — WebEx

AUGUST

August 10 — Emerging Technology Committee Meeting — WebEx

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E. BUDDY DAMM
STEEL SOLUTION SCIENTIEST • • TIMKENSTEEL CORPORATION

Increasing gear set power density

High-strength, high-toughness steels can be used to increase power density while addressing critical components of gear set design.

Increasing the power density of your gear sets allows you to develop durable gear sets with an existing design but higher horsepower and torque capabilities or with the same capacity, but reduced gear size and mass for light weighting.

Increasing power density can be achieved by addressing three critical components of gear set design: geometry, surface finish, and metallurgy. By modifying geometry, one can avoid stress concentrations arising from geometric factors. Improving surface finish through grinding, honing, or super finishing improves resistance to root-bending fatigue, pitting fatigue, and scuffing damage. The metallurgical tactics include the use of clean steels as discussed in last month's Materials Matter column, removal of intergranular oxidation formed during heat treatment by grinding, shot peening gear roots to generate compressive residual stresses, and optimization of case depth and heat treatment.

This Materials Matter column focuses on employing affordable higher strength steels in order to increase fatigue strength, wear resistance, and resistance to bending overload damage. One of the tremendous advantages steels have over other materials is the broad range of strengths they can achieve by changing the chemistry and heat-treatment process. Finding stronger steels than those typically used for gears is not too difficult. What is challenging is getting significantly stronger steels that exhibit sufficient toughness to avoid brittle or ductile overload fractures or early fatigue failures in gear sets subjected to high loads and/or transient loads. The classical trade-off in all materials is that increasing strength nearly always results in reduced toughness, but with careful design and processing, steels can achieve significant strength improvement and still display excellent toughness properties.

To assess fatigue strength and toughness, one needs only to look for commonly available data on steel properties. An engineering approximation can be made that the fatigue strength is conservatively estimated to be 50 percent of the ultimate tensile strength. And, the most common method to assess toughness is the Charpy V-notch impact toughness test. Figure 2 shows the range of estimated fatigue strengths and impact toughness combinations achievable by common gear steels (8620, 4320, 4820, 9310, 3310) and compares that to some available, patent-pending, high-strength, high-toughness gear steels. In some cases, a 50 percent increase in fatigue strength can be achieved with good, and sometimes even better, toughness than the more common gear steels.

It is worthwhile to take a moment to consider how higher strength steels further drive the need for clean steels. The AGMA Metallurgy and Materials committee has been revising the "AGMA Information Sheet 923 — Metallurgical Specifications for Steel Gearing." The addition of a grade 4 steel for gearing has been proposed, which includes, among other details, more precise and design-relevant metrics for steel cleanness as described in the January 2017 featured article "Gear Design Relevant Steel Cleanness Metrics," and in April 2017's "Steel Cleanness and Why Measurement Matters," May 2017's "Industry Standards for Steel Cleanness," and June 2017's

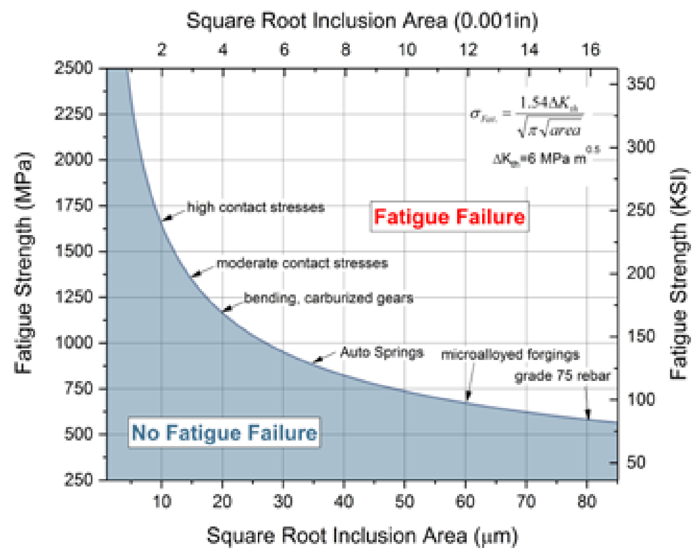

Figure 1: Fatigue limit predicted from linear elastic fracture mechanics approaches described in extensive work by Murakami and colleagues assessing the effect of small flaws such as inclusions on fatigue strength.

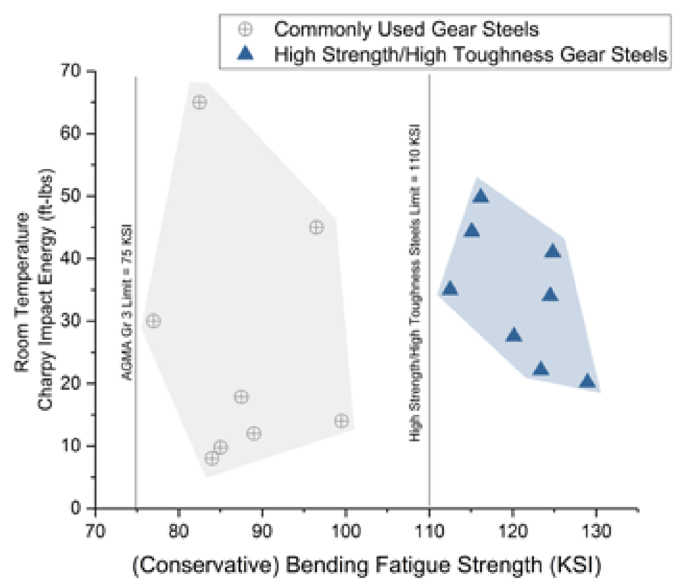

Figure 2: Area charts demonstrating the range of fatigue strength and Charpy impact energy (toughness) combinations achieved with typical (8620, 3310, 4820, 4620, 9310) gear steels (grey shading) and affordable, patent pending, high strength, high toughness steels for gears (blue shading). The vertical lines represent the fatigue strength used to compare these two alloy types below.

One of the tremendous advantages steels have over other materials is the broad range of strengths they can achieve by changing the chemistry and heat-treatment process.

"Power Density; Why Clean Steel Matter" Materials Matter articles. Figure 1 describes the relationship between inclusion size and steel fatigue strength based on the extensive work of Murakami and colleagues, wherein they found that fatigue strength was related to the square root area of an inclusion perpendicular to the principal stress direction as described by Equation 1. As steel strength is increased and gears are subjected to higher loads, the critical flaw size that limits the fatigue strength goes down. As our industry adopts higher strength steels to improve the capacity of advanced gear sets, having clean steels becomes increasingly important.

$$\sigma_{fatigue} = \frac{1.54\Delta K_{th}}{\sqrt{\pi\sqrt{area}}}$$

EQUATION 1

Where ΔK_{th} is the threshold, or minimum stress intensity required for fatigue crack growth and $\sqrt{area}$ represents the square root area of an inclusion-assessed perpendicular to the principal stress.

In order to assess the magnitude of the potential for either light weighting or increased power throughput, one needs to assess the effects of traditional versus high-strength, high-toughness gear steels on gear set design. The Technical Resource "ANSI/AGMA 2001-D04, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth" provides a framework and the equations necessary to make such estimates. In table 4 of this AGMA resource, the allowable bending stress for grade 3 gears is listed at 75 KSI. This value also is shown as the AGMA limit in Figure 1. The allowable limit for high-strength, high-toughness steels also is shown in Figure 1 at 110 KSI. In each case, for traditional and for high-strength, high-toughness gear steels, the actual fatigue capacity may be measurably higher than these conservative limits and will be further dependent on the steel grade and heat-treatment processes selected. For the sake of illustration, the bending stress fatigue limits of 75 KSI and 110 KSI were selected for further calculations.

A generic pinion and gear set was conceived, and the calculations for this gear set were built in a spreadsheet in order to assess the magnitude of potential benefits.

Figures 3 and 4 show the results of these calculations. The switch from commonly used gear steels to high-strength, high-toughness gear steels can result in a 45-percent horsepower increase in an increased through-put initiative or a 30-percent weight reduction in a light weighting initiative. When you need to design your gear sets to go beyond typical gear performance expectations, high-strength, high-toughness gear steels can help get you there. Collaboration between gear designers and materials designers will continue to drive improvements in our industry.

Editor's note: This article originally appeared in the August 2017 issue of Gear Solutions magazine.

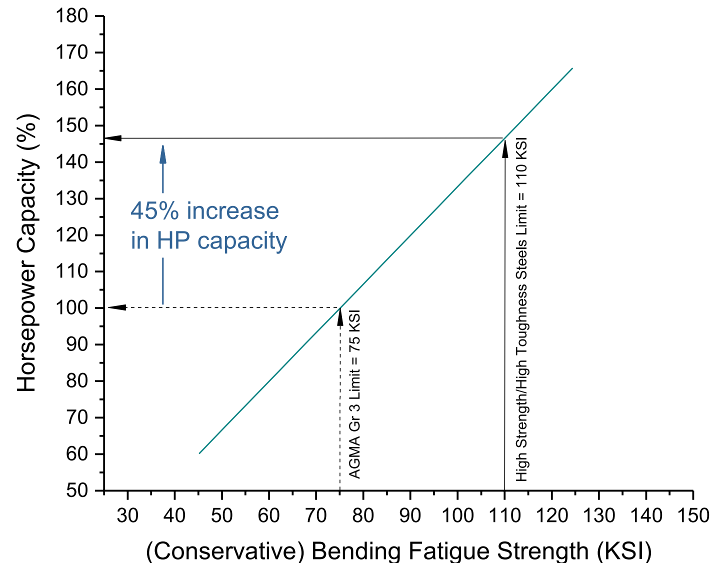

Figure 3: Assuming an increase in fatigue strength from 75 to 110 KSI results in a 45-percent increase in gear set horsepower capacity. Relative horsepower capacity (as a percentage) as a function of the bending fatigue strength calculated per the AGMA 2001-D04 technical resource.

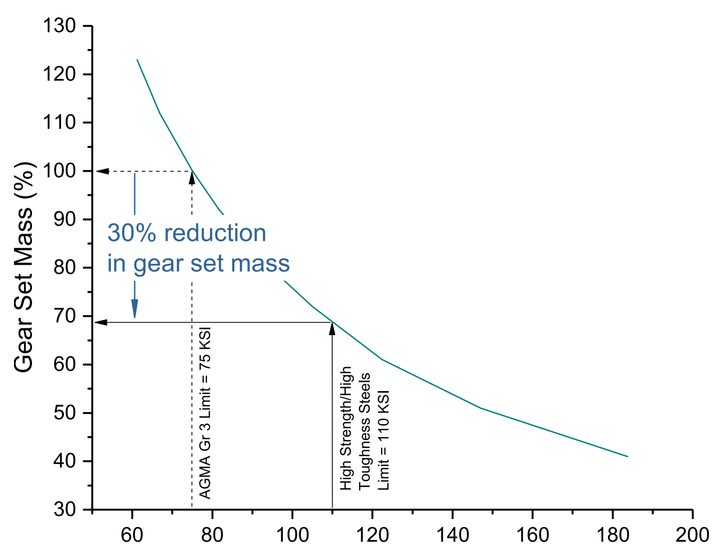

Figure 4: Assuming an increase in fatigue strength from 75 to 110 KSI results in a 30-percent reduction in gear set mass. Relative gear set mass (as a percentage) as a function of the bending fatigue strength calculated per the AGMA 2001-D04 technical resource.

ABOUT THE AUTHOR

E. Buddy Damm is a scientist–advanced steel solutions at TimkenSteel Corporation. He is responsible for developing new or improved products for the company's customers and new or improved processes for its manufacturing operations. His responsibilities include technical leadership for TimkenSteel's high-strength, high-toughness steels innovation platform and corrosion-resistant steels innovation platform. Damm holds a bachelor's degree in metallurgical engineering from Michigan Technological University and a master's and a doctorate degree in material science and engineering from Colorado School of Mines. He can be reached at e.buddy.damm@timkensteel.com. Learn more at www.timkensteel.com.

BRIAN DENGEL
GENERAL MANAGER • KHK-USA

Worms and worm wheels – a primer

Worm gear pairs are an excellent design choice when you need to reduce speeds and change the directions of your motion, and they have many other applications as well.

First published in 1973, the novel *How to Eat Fried Worms* by Thomas Rockwell tells the story of Billy and his desire to win a bet by eating a worm a day for 15 days. Although the thought of eating worms is not something most of us would consider doing, Billy finds a way to ingest a nightcrawler each day. Much like this children's story, most mechanical engineers know about worms, but are not comfortable designing them into their systems.

Worm pairs or worm drives are interchangeable terms for a set of mechanical components that consist of a worm and a worm wheel. The worm is the drive mechanism in this set and has a shape like that of a screw. The worm has several critical dimensions which define how it will function in the set. The critical values are the outside diameter of the worm, the lead angle of the threads, the direction of the threads, and the number of starts of the threads. For the worm shown, the thread direction is clockwise; this corresponds to a right-hand thread. Although available in both left-hand and right-hand threads, the right-hand thread is the most common choice. This worm also has two starts to the threads. This is important in determining the reduction ratio of the pair.

Worm drive

Worm wheel

The worm wheel, also known as the worm gear, is simplistically a helical gear that matches the pitch, pressure angle, and helix angle of the worm. The significant difference between a worm gear and a helical gear is the throat. This is an indent in the tooth form that allows the worm to be properly seated with the centerline of the worm wheel. The speed ratio of a worm gear pair is determined by the number of teeth on the worm wheel and the number of thread starts on the worm. For worms with a single thread, very high-speed ratios can be developed. Since the speed ratio is the ratio of the number of teeth to the number of thread starts, it is possible to change the reduction ratio by replacing the worm pair with another set which is produced with additional starts. With the addition of more thread starts, the helix angle needs to increase if the center distance is to remain the same.

There are several types of worm gear pairs. The set detailed above is known as a single enveloping set. It is designated as such because there is only one set of threads on the worm that engage the teeth on the worm wheel. Because the worm pair is a friction drive and one set of threads repeatedly engages the worm gear, the material of the worm needs to be significantly harder than that of the wheel. For this reason, worms are typically produced from steel and worm wheels are typically produced from bronze alloys. It is common to harden and grind worms specifically when they are going to be used under high load or operating at high speeds such as inside a reduction drive gearbox.

Another type of worm gear set is the double enveloping pair. In this set, the worm is not straight but has a concave tooth shape which matches the curvature of the worm wheel. This permits more of the threads of the worm to engage with the worm wheel. This additional contact allows for greater torque transmission.

A third type of worm gear set is the duplex pair. This type of worm pair uses a single enveloping worm which has a variable pitch across its length. As the pitch profile changes, the tooth form is increased, and the backlash is decreased. Using this type of worm gear pair, a near-zero backlash worm gear assembly can be produced (Figure 1).

Other variations of worm gearing that have been developed to reduce backlash include the use of a spring loaded, split worm (known as the Ott worm), or the use of spring loaded windows in the worm gear.

Worm gear pairs are friction drive mechanisms. As such, they require lubrication to remove the heat built up by friction. Due to the limits of most lubricating fluids, the input speed of the worm needs to be less than 1800 rpm. At higher speeds, most lubricants do not have the ability to pull the heat from the mesh and will froth inside the gearbox. In most cases, open worm gearing should be lubricated with recirculating splash lubrication. However, when enclosed in a housing, the suggestions in Figure 2 should be followed.

Due to the friction, some designers will choose a worm gear pair to act as a brake to prohibit reversing motion in their mechanism. This idea develops from the concept that a worm gear pair becomes self-locking when the lead angle is small and the coefficient of friction between the materials is high. Although not an absolute, when the lead angle of a worm gear pair is less than 4 degrees and the coefficient of friction is greater than 0.07, a worm gear pair will self-lock.

Since worm gears have a lead angle, they do produce thrust loads. These thrust loads vary on the direction of rotation of the worm and

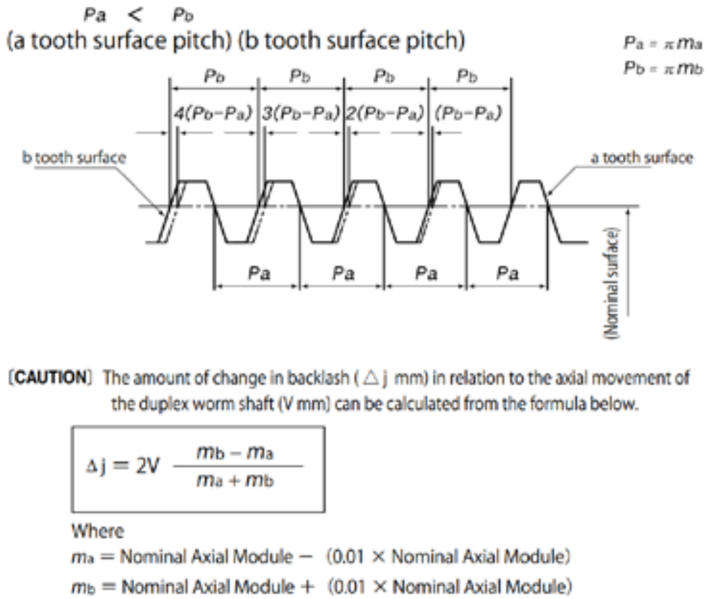

Figure 1: Worm gear backlash calculations.

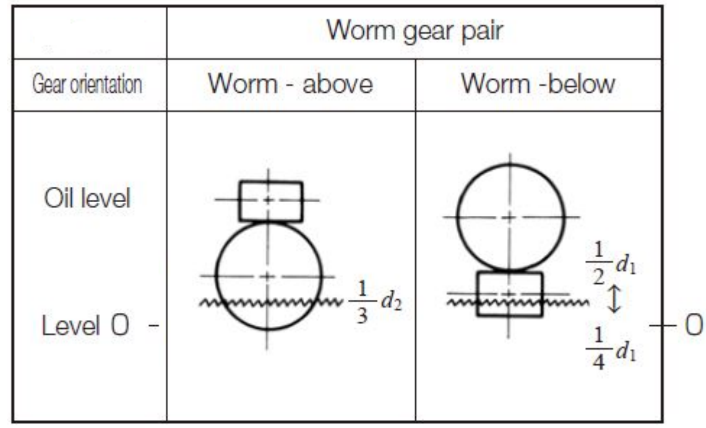

Figure 2: Worm gear lubrication when enclosed in a housing.

the direction of the threads. A right-hand worm will pull the worm wheel toward itself if operated clockwise and will push the worm wheel away from itself if operated counter-clockwise. A left-hand worm will act in the exact opposite manner.

Worm gear pairs are an excellent design choice when you need to reduce speeds and change the directions of your motion. They are available in infinite ratios by changing the number of teeth on the worm wheel and, by changing the lead angle, you can adjust for almost any center distance. I don't recall what Billy did with his $50 for eating all 15 worms, but I do know I won't be taking up that challenge any time soon.

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SENIOR RESEARCH SCIENTIST–METALLURGY • HOUGHTON INTERNATIONAL INC.

Endothermic atmospheres used for heat treating

Why keeping CO content of a furnace must be stable at a value of 20 percent is critical for accurate carbon control of the endothermic atmosphere.

During heat treatment, the part experiences different temperature regimes (Figure 1). Atmospheres are used in heat treating to protect the part from scaling at the elevated temperatures used during austenitizing. The atmospheres range from simple wrapping the part in stainless steel or tantalum foil for small tool room parts, to protective atmospheres containing inert or protective gases.

On an industrial scale, these protective gases are usually mixtures of carbon monoxide (CO), hydrogen (H_2), nitrogen (N_2), carbon dioxide (CO_2), and trace amounts of water vapor. These gases are produced using either endothermic generators with natural gas or propane as the carbon source, or injection directly in the furnace using nitrogen and methanol mixtures. In this article, we are going to discuss the formation of endothermic atmospheres for the protection of parts during austenitization.

Endothermic atmospheres are commonly used during the heat treatment of steel. It is used as a carrier gas for atmosphere additions for carburizing or carbonitriding. Using an endothermic generator, either natural gas or propane is used. If nitrogen-methanol is injected in the furnace, then methanol is the carbon source. The predominant reactions for producing endothermic gas are:

Natural Gas:

$$2CH_4 + O_2 \leftrightarrow 2CO + 4H_2$$

Propane:

$$C_3H_8 + \frac{1}{2}O_2 \leftrightarrow 3CO + 4H_2$$

Methanol:

$$2CH_3OH \leftrightarrow 2CO + 4H_2$$

All of these methods produce an atmosphere containing CO and H_2. Nitrogen appears because it is either from the atmosphere in the case of endothermic generators, or as a carrier gas in the case of nitrogen-methanol atmospheres. The nominal composition of the gas produced using these methods are shown in Table 1. The difference in the amount of CO produced using the different methods is very important, as this value is used to determine the carbon potential in the carbon controller.

For atmosphere generators, air and the hydrocarbon are mixed and introduced into a retort. For nitrogen-methanol, the nitrogen and methanol are injected directly into the furnace. For endothermic generators, the air:gas ratio for natural gas is typically 2.8 - 3.1 (theoretical 2.4:1), while for a generator using propane, the air:gas ratio is 7.5 - 8.1 (theoretical 7.2:1). The difference between the theoretical vales and those typically used in the shop are associated with reaction kinetics. For nitrogen-methanol, the mixture is a bit more difficult as methanol is a liquid. To obtain the proper atmosphere, the total volume will be 40% nitrogen. One gallon of methanol dissociates to form 240 standard cubic feet of CO and H_2, so for 1,000 SCF of atmosphere needed for a furnace, then 400 standard cubic feet of nitrogen is required, and 600 standard cubic feet of CO and H_2 are required. Therefore, 2.5 gallons per hour (600 SCF needed/240 SCF per gallon CH_3OH = 2.5 gallons per hour) are needed.

Gas Species	Formula	Natural Gas	Propane	Nitrogen-Methanol
Carbon Monoxide	CO	20%	23%	20%
Hydrogen	H_2	40%	31%	40%
Carbon Dioxide	CO_2	0.30%	0.30%	0.30%
Water Vapor	H_2O	<0.1%	<0.1%	<0.1%
Methane	CH_4	<0.1%	-	-
Propane	C_3H_8	-	<0.1%	-
Nitrogen	N_2	40%	46%	40%

Table 1: Typical gas compositions from different hydrocarbons used for generating endothermic atmospheres.

ENDOTHERMIC GENERATORS

The endothermic generator, regardless whether used with natural gas or propane, consists of several important parts: the retort; catalyst; heating method (gas or electric); insulation; shell, gas-safety equipment; and temperature control. Automated gas control is often added (and recommended).

An endothermic atmosphere generator (Figure 2) is operated at very high temperatures, typically 1,950°F (1,065°C) for natural gas, and 2,050°F (1,120°C) for propane generators. To handle these elevated temperatures, a high temperature, heat resisting alloy like HT is used. The retort is supported by a flange, and allowed to grow in the vertical direction. A schematic of a small generator is shown in Figure 3.

Inside the retort is the catalyst. This catalyst is often 1-inch cubes of alumina impregnated with nickel. Magnesia (MgO) cubes impreg-

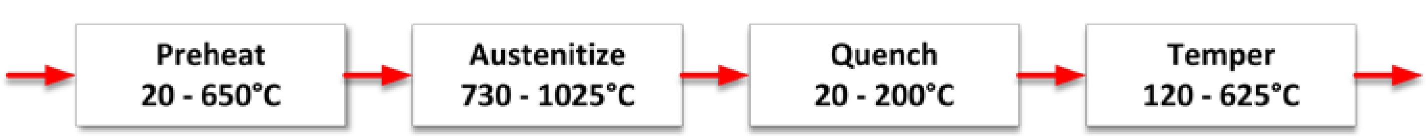

Figure 1: Typical sequence for heat treating, including carburizing.

The advantage of an oxygen probe, is that it is accurate and fast. A direct read-out of the carbon potential of the atmosphere is common. The probe has a high temperature range suitable for high temperature carburizing. Little maintenance is required.

Figure 2: Three retort endothermic generator used to produce endothermic atmospheres. (Courtesy: Surface Combustion, Inc., Maumee, Ohio.)

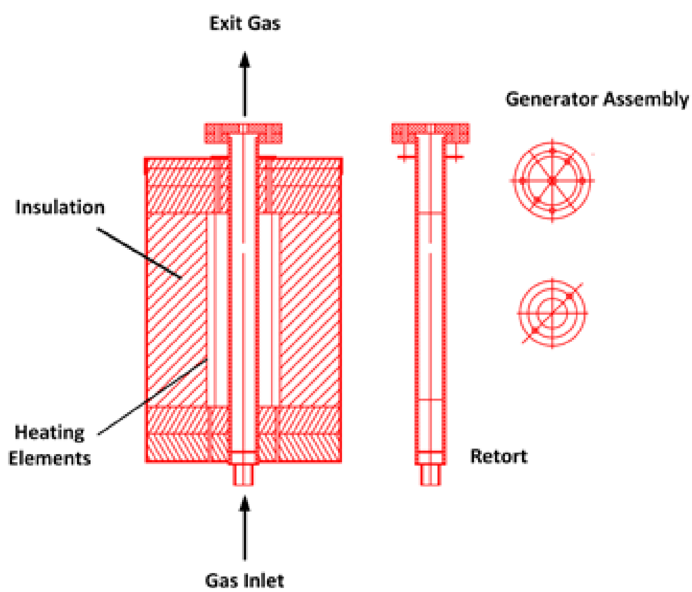

Figure 3: Schematic representation of an endothermic generator showing general assembly. Piping or flame safety equipment is not shown.

nated with nickel are often used with propane as the MgO resists heat better than alumina. Sometimes 1-inch spheres, impregnated with nickel are used, as the spheres offer a greater surface area. Nickel acts as the catalyst to improve the kinetics of the natural gas or propane reaction to form CO and H_2. Plain refractory cubes are generally placed at the air/gas mixture entrance to delay the reaction and preheat the gas to the operating temperature. Once at the operating temperature, the gas reacts with air to form the desired atmosphere composition.

Once the gas has reached the operating temperature and has reacted, the gas exits the generator, where it is immediately passed through a heat exchanger to fix the composition of the gas, and to prevent the formation of soot in the temperature range of 1,300°F to 900°F (700°C - 500°C). Soot forms by the "carbon reversal" reaction $CO \rightarrow C + CO_2$, in which soot is formed from the reaction of carbon monoxide to form carbon dioxide. These heat exchangers can either be water-cool, or air-cooled. Modern practice is to use air-cooled heat exchangers.

The retort is either heated using gas or electric heating elements. Radiant tubes are used for natural gas, and are hung vertically to reduce distortion, and to allow the thermal expansion of the radiant tubes. Electric heating elements can also be used. Typical temperature control equipment, consisting of thermocouples for process temperature, excess temperature control thermocouple, process controllers, excess temperature instrument and data logging equipment are usually included.

If the retort is heated by natural gas, additional control equipment consisting of fire safety equipment (manual shut-off valve or MSOV, fire-eyes and high- and low-pressure switches) are generally required for safe gas operation. The gas supply is shut off (tripping the MSOV) in the event of any malfunction such as:

- Excess retort temperature.
- High gas pressure.
- Low gas pressure.
- No pilot detected.
- Low retort temperature.

Similar gas safety equipment is used on the gas train supplying the retort with gas, separate from the temperature control gas supply.

ATMOSPHERE CONTROL OF GENERATED GAS

The equilibrium composition of the gas depends on the water gas reaction:

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

This means that there are four gas species that can be used for proper control of the atmosphere. Practically, there are really only two reactions available for control:

$$CO + \frac{1}{2}O_2 \Leftrightarrow CO_2$$

$$H_2O \Leftrightarrow H_2 + \frac{1}{2}O_2$$

These two reactions are combined into the water gas reaction above. From these last two reactions, that means that we can control the furnace atmosphere by monitoring and controlling either the water vapor in the atmosphere or by controlling the carbon dioxide.

Dew point is often used to control the carbon content of atmosphere generators or furnaces. However, the use of dew point instruments has waned with the implantation of more modern control methods such as carbon probes and infrared analyzers. The relationship of dew point to the percentage of carbon is shown in Figure 4. One thing to remember, is that these charts are only valid with a 20 percent CO. Other charts need to be calculated or developed for CO concentrations at values other than 20 percent CO. The classical

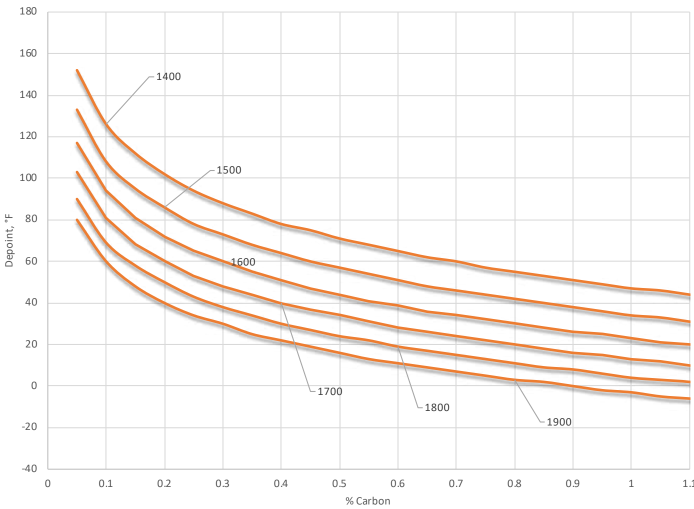

Figure 4: Relationship of dew point to the carbon potential. These values are correct with a 20 percent CO concentration.

dew point instrument is the ALNOR Dewpointer (Figure 5) — these instruments are commonly found in the heat treat shop. They are still in use today.

The amount of carbon dioxide present in the atmosphere is also used. This is often done using infrared analyzers. These often are called three gas analyzers. The advantage of three gas analyzers, is that the three gases measured are CO, CO_2, and CH_4. This enables the user to optimize the generator (or nitrogen-methanol system) setting to first achieve a 20 percent CO. Once that is accomplished, the charts and graphs indicating various carbon potential relationships will accurately indicate carbon potential as a function of either dew point or carbon dioxide.

The infrared gas analyzer operates by measuring the absorption of infrared light through the gas sample. The gases CO, CO_2, and CH4 absorb light at specific wavelengths. A detector measures the energy present at the wavelength of interest and compares it to the reference condition of no absorption. A typical modern infrared analyzer is shown in Figure 6.

The relationship between the carbon potential and carbon dioxide is shown in Figure 7. Again, it is important to reiterate, that these graphs are only valid with 20 percent CO in the atmosphere. Use of other values of CO in the furnace or generator atmosphere will produce erroneous results. One of the most recently developed methods for controlling furnace atmospheres is the oxygen or carbon probe. In this method, the carbon potential is related to the oxygen partial pressure associated with the reversible reaction:

Figure 5: Classic ALNOR Dewpointer used to control carbon potential by the use of water vapor.

$$CO \Leftrightarrow \frac{1}{2}O_2 + CO_2$$

$$K_{eq} = \frac{p_{CO}}{p_{O_2}^{\frac{1}{2}} p_{CO_2}}$$

$$\%C \approx \frac{1}{\sqrt{p_{O_2}}}$$

In other words, the carbon potential of the atmosphere is inversely related to the square root of the partial pressure of oxygen. This again assumes that the CO content of the atmosphere is constant and at approximately 20 percent (23 percent for propane-generated atmospheres).

An oxygen probe or carbon probe consists of platinum electrodes separated by an yttrium-doped zirconia tube. The probe is inserted into the furnace or generator. An air supply of approximately 0.5 CFH of air is supplied to the probe as a reference. The differential oxygen partial pressure between the furnace atmosphere and the reference atmosphere sets up a voltage across the probe. By measuring this small voltage (measured in millivolts), the carbon potential can be determined. Thus, the furnace

Figure 6: Modern multi-gas infrared analyzer. (Image of Ultramat 23 courtesy: Siemens Corporation.)

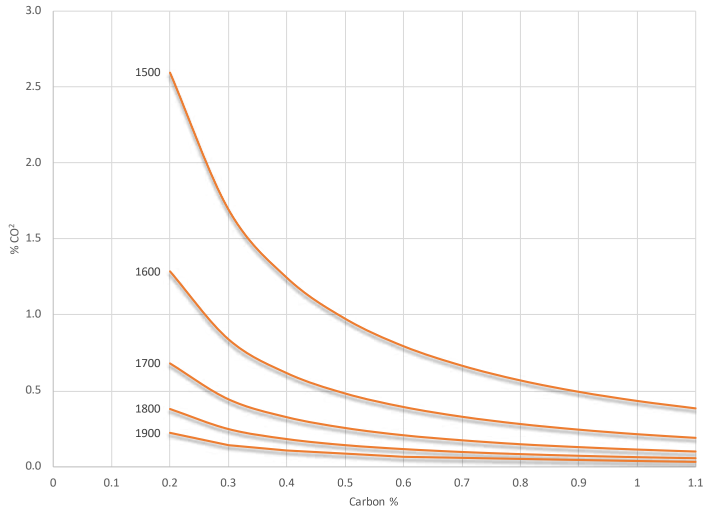

Figure 7: Relationship between CO_2 and carbon potential.

atmosphere carbon potential can be controlled by air and natural gas additions by monitoring the voltage potential across the probe. In modern instruments, this is done internally using microprocessors. In many ways, it operates in a similar fashion to the O2 sensor in a car for proper combustion.

The advantage of an oxygen probe, is that it is accurate and fast. A direct read-out of the carbon potential of the atmosphere is common. The probe has a high temperature range suitable for high temperature carburizing. Little maintenance is required.

The primary disadvantage of the oxygen probe is that it assumes a fixed CO content (typically either 20 percent for natural gas or 23 percent for propane). If the CO content is not at this fixed value, then the readings obtained by the probe are erroneous. The oxygen probe is also a ceramic tube and prone to thermal or mechanical shock. It must be routinely replaced at roughly yearly intervals, depending on the application. Heavy carburizing can shorten the life of the probe. However, the accuracy, ease of use and lack of maintenance, generally outweigh the disadvantages.

CONCLUSION

In this article, we have discussed the production of endothermic atmospheres used in the hardening of steel. We also discussed the control of the carbon potential of the associated furnace or generated atmosphere. Probably the most important takeaway from this discussion, is that the CO content of the furnace must be stable at a value of 20 percent (or 23 percent for propane generators) for accurate carbon control of the endothermic atmosphere. The use of a portable infrared gas analyzer can make troubleshooting of atmosphere problems much simpler and more accurate. Should you have any questions regarding this article, please contact the writer.

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GEAR TOOTH STRENGTH ANALYSIS OF HIGH PRESSURE ANGLE CYLINDRICAL GEARS

High pressure angle gears are not expected to show better mechanical behavior in high power transmissions than gears with conventional designs.

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

The gear tooth strength of high pressure angle gears is studied and compared with that of conventional pressure angle gears. The comparison is carried out regarding contact pressure, contact and bending stresses, and the loaded function of transmission errors. The gear geometric models are generated by the computerized simulation of the manufacturing process, and the corresponding finite element models consider a large number of contact positions along two cycles of meshing. In this way, the load sharing between different pairs of contacting teeth is considered, and the evolution of contact pressure, and contact and bending stresses all over the cycle of meshing are obtained. In general, high pressure angle spur and helical gears do not show a better behavior regarding contact pressure, contact stresses, and bending stresses than spur and helical gears with traditional pressure angle of 25 degrees. Based on the obtained results, high pressure angle gears are not expected to show better mechanical behavior in high power transmissions than gears with conventional designs. The results gathered from the finite element analysis are not in agreement with the improvement on the pitting and bending behavior of the gears that were anticipated by using analytical models as provided by international standards.

1: INTRODUCTION

The use of lower pressure angles in cylindrical gears has been decreasing over recent decades in favor of using higher pressure angles. Nowadays, it is uncommon to find new designs of cylindrical gear drives considering a pressure angle of 14.5 degrees because it is broadly accepted that gears with higher pressure angles yield better mechanical behavior regarding contact and bending stresses. Therefore, new designs of cylindrical gears consider pressure angles of either 20 degrees or 25 degrees.

The design of cylindrical gear drives with high pressure angles has attracted the attention of researchers in the past. In [1, 2], the results of a study to determine the feasibility of using high pressure angle gears in aeronautics and space applications were presented. The NASA GRC Spur Gear Test Facility was used for that purpose. Pressure angles of 20, 25, and 35 degrees were considered in three different designs of spur gears. The face width and center distance were deemed to be constant. However, the test specimens had a different number of teeth and different modules. The conclusions of this study mentioned that high pressure angle spur gears running at high speed provided performance with similar bending and contact stresses over more traditional gear pressure angles. Also, it was stated that high pressure angle gears appeared to be better suited to the low-speed, high load, and grease-lubricated conditions.

In [3], a method for specifying gear teeth with higher pressure angles was presented. The idea of this work was to achieve higher bending and surface contact strength or, in other words, to reduce bending and surface contact stresses by using the highest as possible pressure angle. Miller's work [3] was directed to isolate the influence of the pressure angle on the results so that he kept the number of teeth and module of all designs as constant. The proposed method in [3] allowed for the determination of proper high-pressure angles for which the gear met conditions on the desired top land, contact ratio, or hob tip radius. Four designs were evaluated having the traditional 25-degree pressure angle, and three other designs having pressure angles of 33.5, 35, and 36 degrees. In the mentioned work, all data and stress calculations were performed using the AGMA GRS 3.1.7 Gear Rating Suite program. The application of high pressure angle gearing in low speeds, coarse pitch, and lower quality level was mentioned in [3] as typical applications for these gears. It was suggested that an alternative FEA (Finite Element Analysis) should be performed on the gear teeth and the results compared with those published in the mentioned work. Miller's work inspired the research work presented in this paper.

In [4], it is stated that the lower the pressure angle, the higher the surface compressive and bending stresses become. In that work, high pressure angle gears are referred to as not as quiet as low pressure angle gears. The main reason is that the tooth deflection under load is very small for high pressure angle gears. Noise is generated when the load is transferred from one tooth to another upon impact [4]. Again, high pressure angle gears are considered to have a higher power density and are recommended for high horsepower transmissions [4].

The design of high pressure angle gears is challenging because of the obtained geometry for the gear teeth. The pointing of the gear teeth on the one hand and having enough tip edge radius for the cutting tools on the other hand are limiting factors for gear designs considering high pressure angles. To avoid those problems, asymmetric gears were proposed as a solution to increase the load capacity of gear drives while reducing their weight and dimensions [5]. In [6], the results of the comparison of several designs of asymmetric gear drives were presented. The application of high pressure angles, not only for the driving side of the gear teeth as traditionally is done but also for the coast side of the teeth was investigated. In that work, it was mentioned that the maximum contact stresses and contact pressures on the gear teeth depend only on the pressure angle of the contacting side (driving side) of the gear drive, no matter what the pressure angle of the coast side is. It was mentioned that bending stresses were reduced when higher pressure angles are used, not only for the coast side as stated in other works [7, 8] but also for the driving side.

This paper is intended to answer the following research question: Can we extend and recommend the use of pressure angles of 30 degrees or higher in symmetric gears to improve the mechanical behavior of cylindrical gear drives? The methodology to carry out this research work is based on the application of finite element analysis on models comprising of five pairs of contacting teeth, considering a very fine mesh on the contacting surfaces. Not only one point of contact will be considered for the analysis but the evolution of contact and bending stresses, contact pressure, and loaded function of transmission errors along two complete cycles of meshing will be investigated. This perspective will provide a unique overview of the mechanical behavior of high pressure angle gear drives and will be fundamental to provide further recommendations for the use of gears with high pressure angles.

2: METHODOLOGY OF EVALUATION OF THE MECHANICAL BEHAVIOR OF CYLINDRICAL GEARS

The mechanical behavior of gear drives can be evaluated by using analytical and pseudo-empirical methods as provided by international standards (AGMA — American Gear Manufacturers Association, or ISO — International Organization for Standardization) or numerical methods as the finite element method. AGMA and ISO provide a methodology to evaluate the contact and bending stresses, and with them, the safety factors against the risk of failure of the gear drive by pitting or bending are calculated. On the other side, using the finite element method, the contact and bending stresses on the gear tooth can be determined, as well as the contact pressure, contact deformations, and tooth deflections that are taken into consideration for the determination of the loaded function of transmission errors.

Many researchers refer to contact stresses in technical publications, but many times, there is no mention to what they consider as contact stresses. Frequently, Von Mises stresses on the contact area, contact pressure, or the minimum principal stress are considered indicators of the contact stress, but they may sometimes yield to different conclusions.

Regarding Von Mises stresses as an indicator of contact stress, due to the fact that maximum Von Mises stresses occur underneath the contacting surfaces, they are difficult to capture in a finite element analysis due to the need of using a large number of finite elements under the surface in the finite element mesh. Those finite element meshes would be extremely costly for computation. Instead, the maximum value of contact pressure has been found not being so sensitive to the finite element mesh used for computations, and it is recommended as the main indicator of contact stresses for comparison between different gear designs. Besides, either the AGMA or ISO methodologies use contact pressure (Hertz pressure) as the basis for their calculations (see Section 3).

Regarding bending stresses, Von Mises stresses may be affected by some contact positions where the load is shared between two pairs of teeth and the traction due to the bending of a given tooth is low in comparison with the compression in the same fillet area due to the bending of the previous tooth. Also, contacts near the form diameter may influence the Von Mises stresses on the fillet area. For this reason, the maximum principal stress in the fillet area (the largest tensile stress) is considered for comparison of bending stresses among different gear designs.

3: AGMA'S APPROACH FOR THE EVALUATION OF CONTACT AND BENDING STRESSES

The American Gears Manufacturers Association (AGMA) has developed and disseminated methodologies to design and analyze gear drives during the last hundred years. AGMA started in 1916 to create standards that define gear types, tooth sizes, tolerances, and in general, to set up methodologies to contribute to making gears safer and interchangeable even if manufactured in different locations or by different companies. The method presented in the AGMA 2101-D04 standard [9], Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth, has been used in this work to assess the performance of high pressure angle gears according to analytical methods. The AGMA 2101-D04 standard is the metric edition of AGMA 2001-D04. It provides the formulas for rating the pitting resistance and bending strength of spur and helical involute gear teeth.

The pitting resistance is considered a function of the Hertzian contact (compressive) stress, and for that, the well-known model of contact between two cylinders is used as a basic model. The contact stress number σ_H for cylindrical gear teeth according to AGMA [9] is given by:

$$\sigma_H = Z_E \sqrt{F_t K_o K_v K_s \frac{K_H}{d_{w1} b} \frac{Z_R}{Z_I}}$$

where

Z_E is the elastic coefficient,

F_t is the transmitted tangential load,

K_o is the overload factor,

K_v is the dynamic factor,

K_s is the size factor,

K_H is the load distribution factor,

Z_R is the surface condition factor for pitting resistance,

b is the net face width of narrowest member,

Z_I is the geometry factor, and

d_{w1} is the operating pitch diameter of the pinion.

The contact point in which the contact stress number is determined is considered through the geometry factor Z_I. For spur and low axial contact ratio helical gears, the geometry factor Z_I is calculated considering the radius of curvature of pinion and gear for contact at the lowest point of single tooth contact (LPSTC) for the pinion. For conventional helical gears, the geometry factor Z_I is calculated considering the radii of curvature of pinion and gear for contact at the mean radius or middle radius of the working profile of the pinion [10].

The effective allowable number $\sigma_{HP_{eff}}$ is obtained as a function of the allowable contact stress number of the material, σ_{HP}, modified by the stress cycle factor for pitting resistance, Z_N, the hardness ration for pitting resistance, Z_W, the temperature factor, Y_θ, and the reliability factor, Y_Z. The formula for the effective allowable stress number $\sigma_{HP_{\mathrm{eff}}}$ is:

$$\sigma_{HP_{eff}} = \sigma_{HP} \frac{Z_N}{Y_\theta} \frac{Z_W}{Y_Z}$$

The bending resistance is based on a model that considers a cantilever plate and the tensile stresses obtained on the side of application of the load. When we extrapolate it to gears, the bending model gives the tensile stress in the fillet area of the driving side of the gear teeth. The bending stress number σ_F in a gear tooth is given by:

$$\sigma_F = F_t K_o K_v K_s \frac{1}{b\, m_t} \frac{K_H K_B}{Y_J}$$

where

K_B is the rim thickness factor,

Y_J is the geometry factor for bending strength, and

m_t is the transverse metric module in millimeters.

The effective allowable bending stress number $\sigma_{HP_{\mathrm{eff}}}$, depends on the allowable bending stress number of the material σ_{HP}, modified by the stress cycle factor for bending strength, Y_N, the temperature factor, Y_θ, and the reliability factor, Y_Z, similar to the case of contact stress. The formula to calculate the effective allowable stress number $\sigma_{HP_{\mathrm{eff}}}$ is:

$$\sigma_{FP_{eff}} = \sigma_{FP} \frac{Y_N}{Y_\theta Y_Z}$$

4: FINITE ELEMENT ANALYSIS

Before the application of finite element analysis, tooth contact analysis (TCA) has to be performed to obtain the angular positions of pinion and gear along one or two cycles of meshing. A general-purpose algorithm for simulation of meshing and contact of pinion and gear tooth surfaces is used. This algorithm is based on a numerical method that takes into account the position of the tooth surfaces and minimizes the distance until contact is achieved [11]. The algorithm assumes rigid body behavior and has been extended to two cycles of meshing in [12]. It is valid for linear, point, or edge contacts. A grid of 61 × 61 points on each gear tooth surface, a total of three pairs of tooth surfaces, and a virtual compound thickness of 0.0065 mm have been considered here for determination of contact patterns and functions of unloaded transmission errors.

Finite element models are built automatically from the gear tooth surfaces and following a procedure that is extensively illustrated in [13]. Node coordinates are determined on the gear tooth surfaces as a function of the chosen numbers of nodes in longitudinal, profile, and fillet directions. The finite element model considers five pairs of teeth to keep the boundary conditions, represented by a rigid surface, far enough from the contact areas. A reference node on the axis of the pinion (respectively, the gear) controls the body motion of the rigid surface. Whereas the rigid surface of the gear is held at rest at each contact position by blocking its reference node, a torque about the pinion axis is applied to the reference node of the pinion rigid surface.

A model as the one shown in Figure 1 has been considered for the analysis. Sixty-one contact positions distributed along two cycles of meshing are investigated to capture every detail of the evolution of contact and bending stresses all over two cycles of meshing.

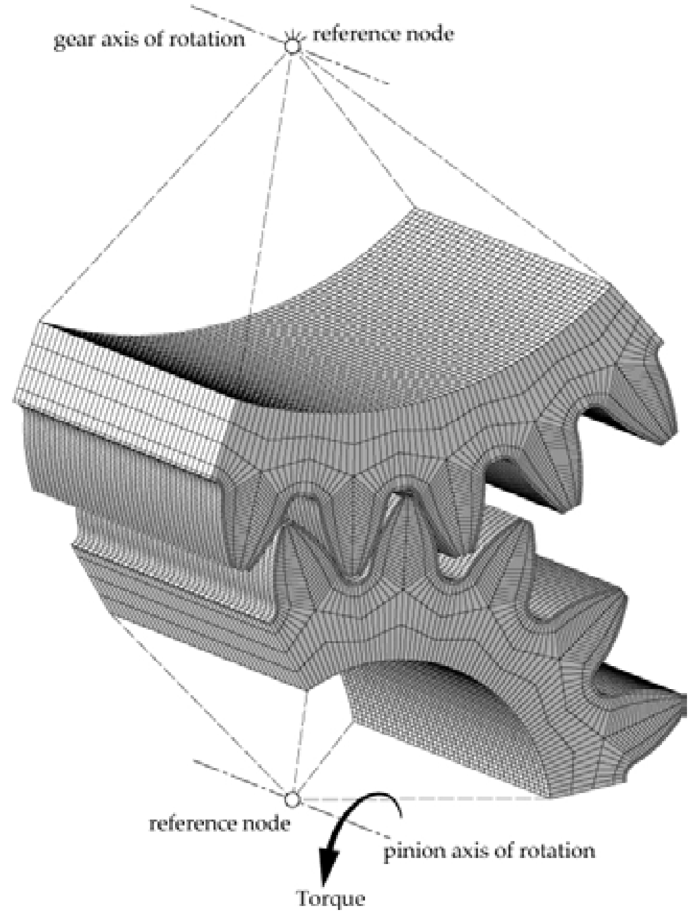


Figure 1: Finite element model with five pairs of teeth having a uniform layer of finite element conforming the contacting surfaces of the gears.

5: COMPARISON OF THE MECHANICAL BEHAVIOR OF CYLINDRICAL SPUR GEARS WITH HIGH PRESSURE ANGLES

Three cylindrical gear sets with different pressure angles are analyzed and compared regarding contact and bending stresses, as well as the loaded function of transmission errors. Figure 2 shows the gear tooth geometry of the evaluated gear sets. Table 1 provides the general design parameters of the evaluated spur gear sets. For all cases, the center distance and number of teeth of pinion and gear are kept constant. The addendum and dedendum coefficients of the generating rack cutters are adjusted to avoid pointing of the gear teeth for all cases. The root radius coefficient is also chosen to allow for a suitable geometry of the generating tool. The profile shift coefficients for each gear set were selected for optimal specific sliding.

The most important derived parameters of the evaluated gear sets are shown in Table 2. The transverse contact ratio decreases as the pressure angle increases, as shown in Table 2.

The rating of the three designs presented in Table 1 is performed according to the AGMA 2101-D04 standard. A torque of 900 Nm is applied to the pinion of the gear set. A speed of 1 rpm is considered to neglect the dynamic effects on the gear performance. Most of the factors of influence on the contact and bending stress numbers have been taken into account equal to 1.0, to isolate the effect of the geometry on the stresses (see Table 3). The stress cycle factor for all cases of design corresponds to a service life of 20,000 hours.

Table 3 shows the factors of influence and main parameters affecting the calculation of the contact and bending stress numbers according to AGMA 2101-D04. Steel, grade 2, carburized and hardened, having an allowable contact stress number of 1,550 MPa

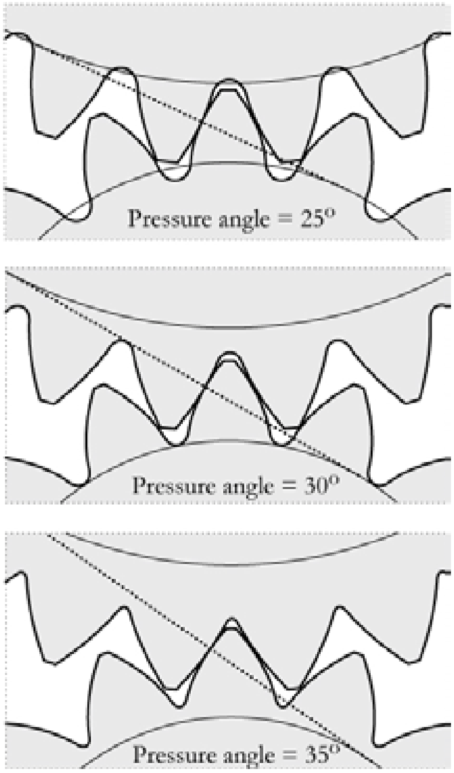


Figure 2: Gear tooth geometry of the evaluated spur gear sets. Table 1 – General design parameters of spur gear sets.

and an allowable bending stress number of 450.0 MPa was selected for the calculations of the safety factors.]

Table 4 shows the safety factors for pitting and bending according to AGMA 2101-D04 for the three designs of spur gear sets. According to the standard, the pressure angle improves both the safety factor for pitting and that for bending. As shown in Table 4, the maximum contact stress for a spur gear drive with 30-degree pressure angle is reduced 4.38 percent with respect to a similar design having a pressure angle of 25 degrees. Bending stresses are also reduced 12.4 percent for the design having a pressure angle of 30 degrees. For the design with the higher-pressure angle (35 degrees), the contact stresses are reduced by 7.30 percent with respect to the design having the pressure angle of 25 degrees. The corresponding bending stresses are reduced by 25.6 percent for the design having a pressure angle of 35 degrees. Generally speaking, and based on the results obtained, by increasing the pressure angle as much as geometrically is possible, the safety factor for pitting and bending is improved, so that the transmissible power can be increased accordingly.

Regarding the results obtained from the application of the finite element method, Figure 3 shows the evolution of the

	GEAR SET 1 (PA25)		GEAR SET 2 (PA30)		GEAR SET 3 (PA35)	
PARAMETER	PINION	GEAR	PINION	GEAR	PINION	GEAR
Number of teeth, N	16	29	16	29	16	29
Module, m [mm]	4.0		4.0		4.0	
Helix angle, β [deg.]	0.0		0.0		0.0	
Center distance, C [mm]	90.0		90.0		90.0	
Pressure angle, α [deg.]	25.0		30.0		35.0	
Profile shift coefficient, x	0.1845	−0.1845	0.1229	−0.1229	0.0757	−0.0757
Addendum coefficient, h_a	1.00	1.00	0.95	0.95	0.85	0.85
Dedendum coefficient, h_f	1.25	1.25	1.15	1.15	1.05	1.05
Root radius coefficient, ρ_f	0.317	0.317	0.21	0.21	0.09	0.09
Face width, b [mm]	50.0	50.0	50.0	50.0	50.0	50.0

Table 1: General design parameters of spur gear sets.

	GEAR SET 1 (PA25)		GEAR SET 2 (PA30)		GEAR SET 3 (PA35)	
PARAMETER	PINION	GEAR	PINION	GEAR	PINION	GEAR
Transverse contact ratio	1.403		1.248		1.072	
Operating pitch diameter, d_w [mm]	64	116	64	116	64	116
Root diameter [mm]	55.476	104.524	55.784	105.816	55.806	106.594
Specific sliding at the tip [mm]	0.621	0.621	0.492	0.492	0.377	0.377
Specific sliding at the root [mm]	−1.641	−1.641	−0.969	−0.969	−0.605	−0.605
Base pitch [mm]	11.389		10.883		10.294	

Table 2: Derived geometric parameters of evaluated spur gear sets.

PARAMETER	GEAR SET 1 (PA25)	GEAR SET 2 (PA30)	GEAR SET 3 (PA35)
Nominal circumferential force, F_t [N]	28125.00	28125.00	28125.00
Radial force, F_r [N]	13114.90	16238.00	19693.30
Geometry factor, Z_I	0.112	0.122	0.130
Elastic coefficient, Z_E [N/mm^2]$^{0.5}$	190.20	190.20	190.20
Overload factor, K_o	1.0	1.0	1.0
Load distribution factor, K_H	1.0	1.0	1.0
Dynamic factor, K_v	1.0	1.0	1.0
Size factor, K_s	1.0	1.0	1.0
Temperature factor, Y_θ	1.0	1.0	1.0
Reliability factor, Y_Z	1.0	1.0	1.0
Surface condition factor, Z_R	1.0	1.0	1.0
Hardness ratio factor, Z_W	1.0	1.0	1.0
Stress cycle factors, $Z_N - Y_N$	1.126 − 1.16	1.126 − 1.16	1.126 − 1.16

Table 3: Factors of influence on the calculation of the contact and bending stress numbers according to AGMA 2101-D04.

PARAMETER	GEAR SET 1 (PA25)	GEAR SET 2 (PA30)	GEAR SET 3 (PA35)
Contact stress number, σ_H [N/mm^2]	1684.89	1611.05	1561.97
Allowable contact stress number, σ_{HP} [N/mm^2]	1550.00	1550.00	1550.00
Effective allowable contact stress number, $\sigma_{HP_{\text{eff}}}$ [N/mm^2]	1745.30	1745.30	1745.30
Safety factor (pitting), S_H	1.036	1.08	1.12
Bending stress number, σ_F [N/mm^2]	320.36	280.71	238.28
Allowable bending stress number, σ_{FP} [N/mm^2]	450.00	450.00	450.00
Effective allowable bending stress number, $\sigma_{FP_{\text{eff}}}$ [N/mm^2]	522.00	522.00	522.00
Safety factor (bending), S_F	1.63	1.86	2.19

Table 4: Safety factors for pitting and bending according to AGMA 2101-D04.

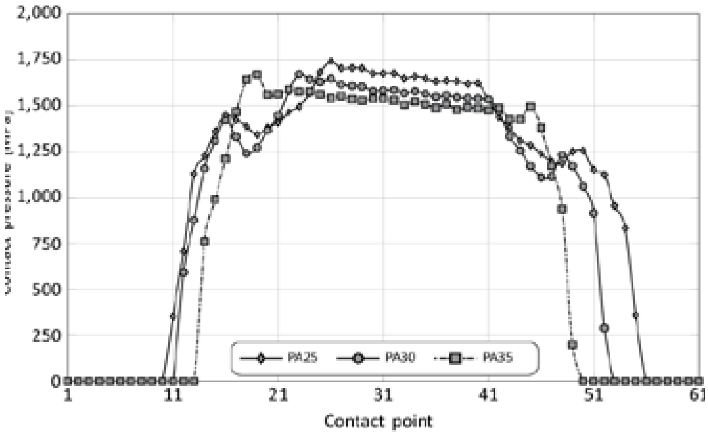


Figure 3: Evolution of the maximum contact pressure on the surfaces of the middle pair of contacting teeth.

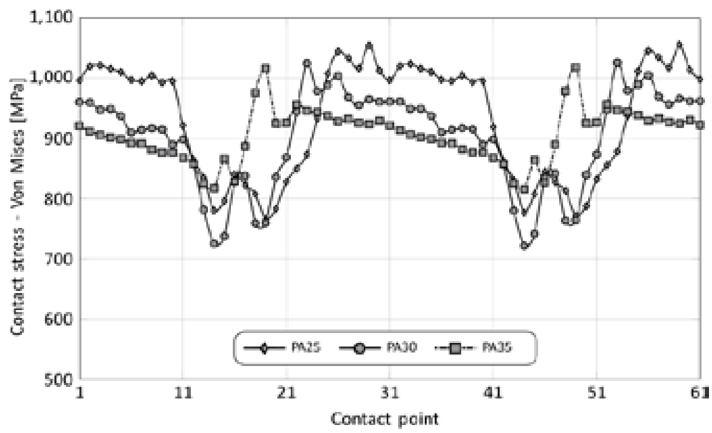


Figure 4: Evolution of the maximum Von Mises stress on the contacting surfaces of the pinion.

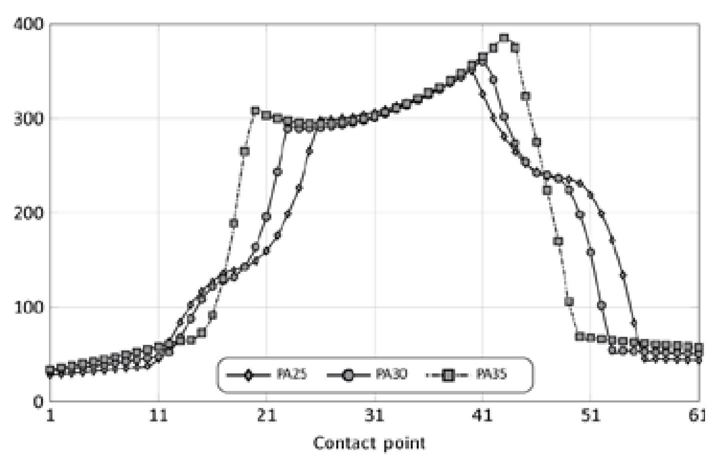


Figure 5: Evolution of maximum principal stress (larger tension) at the fillet area of the pinion teeth.

maximum contact pressure along 61 contact positions distributed in two cycles of meshing. The contact pressure is obtained at the middle tooth of a total of five teeth of the pinion model. It is observed, for each case of design, that the maximum contact pressure occurred, certainly, at the LPSTC point. A minor reduction of contact pressure is observed from the design with 25 degrees to the design with 35 degrees as AGMA 2104-D04 predicts. The reduction of the transverse contact ratio for high pressure angle gears is also noted on the shorter portion along the sixty-one contact positions for which a gear tooth is in contact under pressure (see Figure 3).

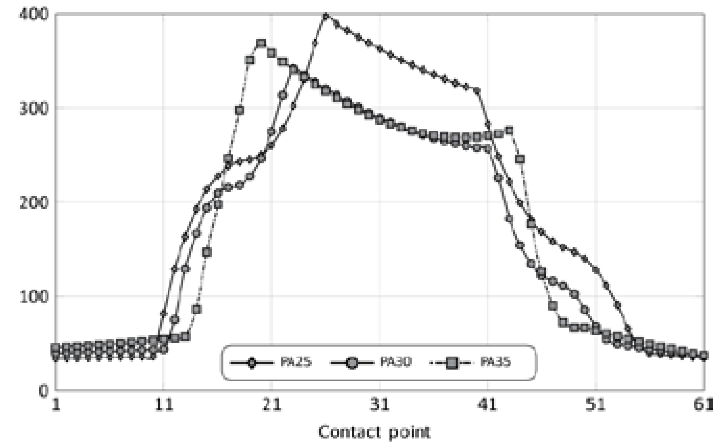


Figure 6: Evolution of maximum principal stress (larger tension) at the fillet area of the gear teeth.

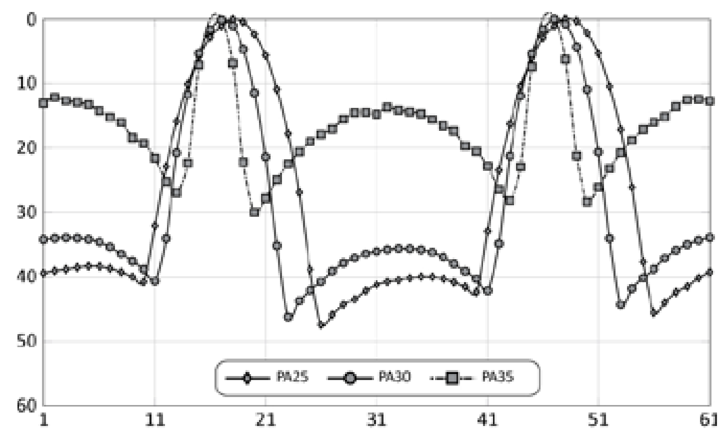


Figure 7: Loaded function of transmission errors for spur gears with different pressure angles.

Figure 4 shows the evolution of maximum Von Mises stress on the contacting surfaces of the pinion teeth. The highest value of Von Mises stress occurs underneath the contacting surfaces, as Hertz theory predicts. Considering the applied finite element model as a reference for comparison without further judging the accuracy of the obtained results (since a higher amount of finite elements would be required to get a better estimation of the real Von Mises stresses), Figure 4 shows the same tendency on the evolution of the maximum Von Mises stresses on the contacting surfaces of the pinion, experiencing the highest value at the LPSTC. A slight reduction of the contact stresses is also observed for the design with higher pressure angles, and it is in agreement with the results obtained for the contact pressure and predicted by the analytical method.

Regarding bending stresses, Figure 5 shows the evolution of the maximum principal stress at the pinion fillet during 61 contact positions. The maximum value occurs at the highest point of single tooth contact (HPSTC), as AGMA predicts. However, the results of maximum stresses and relative comparison are different from those obtained through the application of the analytical model. In fact, an increment of the maximum principal stress is observed as the pressure angle increases. It is clearly seen in Figure 5 how the portion of meshing for single tooth contact is increased as the pressure angle increases. Although the maximum bending stress is well predicted by the analytical model for the pressure angle of 25 degrees, it also predicts that the bending stresses should be decreasing, but on the contrary, in Figure 5, it is observed that the maximum principal stress is increasing for the pinion as the pressure angle increases.

Figure 6 shows the evolution of the maximum principal stress at the fillet area of the middle tooth of the gear for the three cases of design. Although some reduction of bending stresses is obtained for the design with 30 degrees at the fillets of the gear teeth, design with 35 degrees shows an increment on the maximum bending stress with respect to the previous case. Therefore, the idea that higher pressure angles will reduce bending stresses cannot be generalized. One of the main influences on the bending stresses for the evaluated cases is the different values of the root radius coefficient used for each design.

Figure 7 shows the loaded function of transmission errors for the three cases of design evaluated in this work. The maximum peak-to-peak value of transmission errors is decreasing when the pressure angle increases. The Discrete Fourier Transform (DFT) of these functions should be evaluated before drawing final conclusions in terms of noise and vibration excitation.

6: COMPARISON OF THE MECHANICAL BEHAVIOR OF CYLINDRICAL HELICAL GEARS WITH HIGH PRESSURE ANGLES

Most of the published literature regarding the application of high pressure angle cylindrical gears has dealt with spur gears. Not much work has been found related to the design of high pressure angle helical gears. In this section, three designs of helical gears with pressure angles of 25 degrees, 30 degrees, and 35 degrees will be compared regarding contact and bending stresses, and loaded functions of transmission errors. Table 5 shows the general design parameters for the helical gear designs, which were chosen similar to those of the previously analyzed designs of spur gear sets. A helix angle of 20 degrees was chosen for all designs.

Table 6 shows the most important derived geometric parameters of the evaluated helical gear sets. The transverse contact ratio, the overlap ratio, and the total contact ratio have been shown for reference.

Table 7 shows the most important factors of influence on the calculation of the contact and bending stress numbers. Any factor of influence not listed in Table 7 was kept equal to those shown in Table 3.

Table 8 shows the safety factors for pitting and bending according to AGMA 2101-D04 for the three designs of helical gear sets. The analytical model does not predict any benefits on the increment of the pressure angle for helical gears. Actually, the safety factor for the case of higher pressure angle is lower than that for the designs with lower pressure

	GEAR SET 1 (PA25)		GEAR SET 2 (PA30)		GEAR SET 3 (PA35)	
PARAMETER	PINION	GEAR	PINION	GEAR	PINION	GEAR
Number of teeth, N	16	29	16	29	16	29
Module, m [mm]	4.0		4.0		4.0	
Helix angle, β [deg.]	20.0		20.0		20.0	
Hand of helix	Right	Left	Right	Left	Right	Left
Center distance, C [mm]	95.776		95.776		95.776	
Pressure angle, α [deg.]	25.0		30.0		35.0	
Profile shift coefficient, x	0.1599	−0.1599	0.1064	−0.1064	0.0657	−0.0657
Addendum coefficient, h_a	1.00	1.00	0.95	0.95	0.85	0.85
Dedendum coefficient, h_f	1.25	1.25	1.15	1.15	1.05	1.05
Root radius coefficient, ρ_f	0.317	0.317	0.21	0.21	0.09	0.09
Face width, b [mm]	50.0	50.0	50.0	50.0	50.0	50.0

Table 5: General design parameters of helical gear sets.

	GEAR SET 1 (PA25)		GEAR SET 2 (PA30)		GEAR SET 3 (PA35)	
PARAMETER	PINION	GEAR	PINION	GEAR	PINION	GEAR
Transverse contact ratio	1.299		1.158		0.999	
Overlap ratio	1.361		1.361		1.361	
Total contact ratio	2.660		2.519		2.360	
Operating pitch diameter, d_w [mm]	68.107	123.445	68.107	123.445	68.107	123.445
Root diameter, d_f [mm]	59.386	112.166	59.759	113.393	60.233	114.519
Specific sliding at the tip [mm]	0.565	0.565	0.444	0.444	0.338	0.338
Specific sliding at the root [mm]	−1.299	−1.299	−0.798	−0.798	−0.511	−0.511
Base pitch [mm]	11.979		11.394		10.723	

Table 6: Derived geometric parameters of evaluated helical gear sets.

PARAMETER	GEAR SET 1 (PA25)	GEAR SET 2 (PA30)	GEAR SET 3 (PA35)
Nominal circumferential force, F_t [N]	26428.9	26428.9	26428.9
Radial force, F_r [N]	13114.9	16238.0	19693.3
Axial force, F_a [N]	9619.3	9619.3	9619.3
Geometry factor (pitting), Z_I	0.171	0.171	0.162
Geometry factor (bending), Y_J	0.580	0.700	0.899
Elastic coefficient, Z_E [N/mm^2]$^{0.5}$	190.20	190.20	190.20

Table 7: Factors of influence on the calculation of the contact and bending stress numbers for helical gear sets according to AGMA 2101-D04.

PARAMETER	GEAR SET 1 (PA25)	GEAR SET 2 (PA30)	GEAR SET 3 (PA35)
Contact stress number, σ_H[N/mm^2]	1282.46	1280.53	1316.14
Allowable contact stress number, σ_{HP}[N/mm^2]	1550.00	1550.00	1550.00
Effective allowable contact stress number, $\sigma_{HP_{eff}}$ [N/mm^2]	1745.00	1745.00	1745.00
Safety factor (pitting), S_H	1.36	1.36	1.33
Bending stress number, σ_F [N/mm^2]	214.15	177.35	138.02
Allowable bending stress number, σ_{FP} [N/mm^2]	450.00	450.00	450.00
Effective allowable bending stress number, $\sigma_{FP_{eff}}$ [N/mm^2]	522.00	522.00	522.00
Safety factor (bending), S_F	2.44	2.94	3.78

Table 8: Safety factors for pitting and bending for helical gear sets according to AGMA 2101-D04.

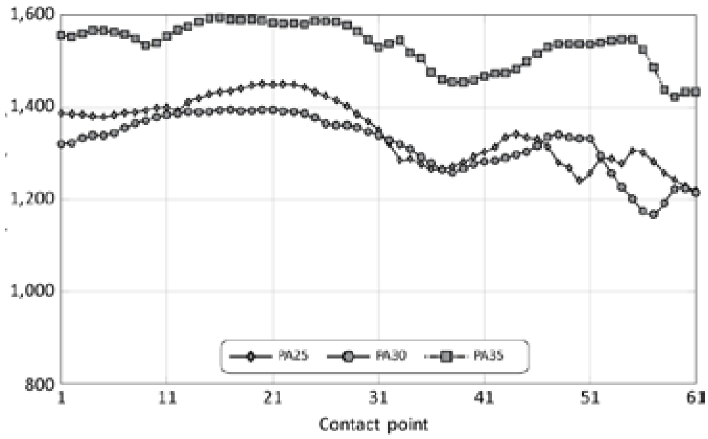


Figure 8: Evolution of the maximum contact pressure on the contact surfaces of the middle pair of contacting teeth.

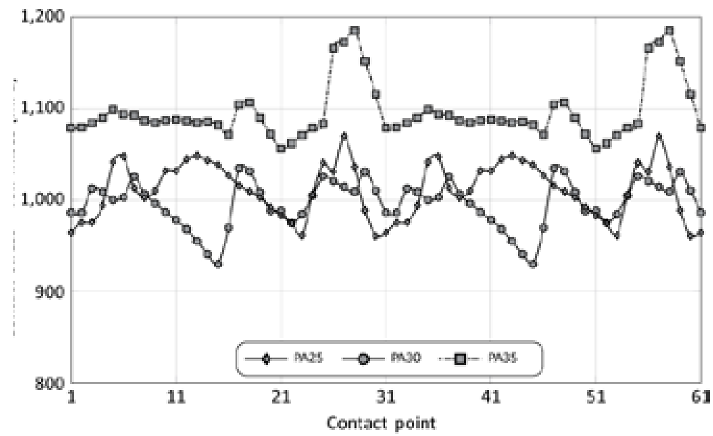


Figure 9: Evolution of the maximum Von Mises stress on the contacting surfaces of the pinion.

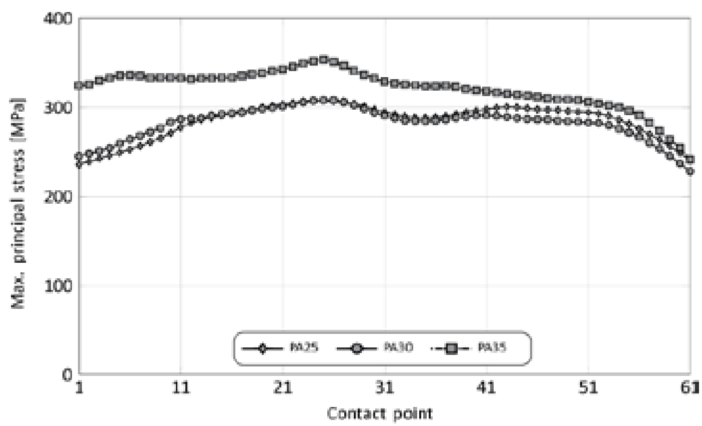


Figure 10: Evolution of maximum principal stress (bending stress) at the fillet surface of one tooth of the pinion.

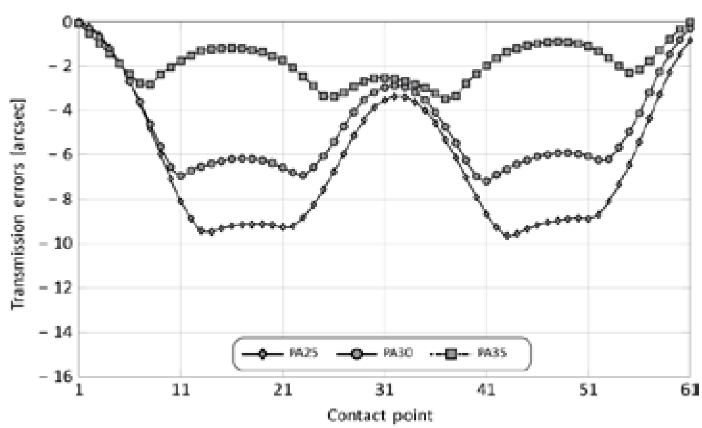


Figure 11: Loaded function of transmission errors for helical gears with different pressure angles.

angles. However, there is a substantial improvement on the safety factor for bending in designs with higher pressure angles according to the analytical model.

Figure 8 shows the evolution of the contact pressure (CPRESS in Abaqus) for the middle pair of contact teeth. It corresponds with the third tooth in a model of five pairs of teeth. Pressure angle of 30 degrees yields slightly lower maximum contact pressure than the reference design with a pressure angle of 25 degrees. As shown in Figure 8, the design with the pressure angle of 35 degrees shows a substantial increment on the contact pressure, which is not entirely predicted by the analytical model for the determination of the contact stress number.

Figure 9 shows the evolution of the maximum Von Mises stress on the contacting surfaces of the pinion, no matter in which tooth it appears. Notice that the evolution is a periodic function as expected, due to the evaluation of two cycles of meshing. The design with the higher-pressure angle of helical gears shows the higher Von Mises stresses, also in agreement with Figure 8, which shows higher values of contact pressure for that design. Designs with 25 and 30 degrees of pressure angle show similar maximum levels of contact stresses. In general, as shown in Figures 8 and 9, no advantages are observed for using high pressure angles in helical gear drives in terms of contact stresses and contact pressure on the gear tooth surfaces.

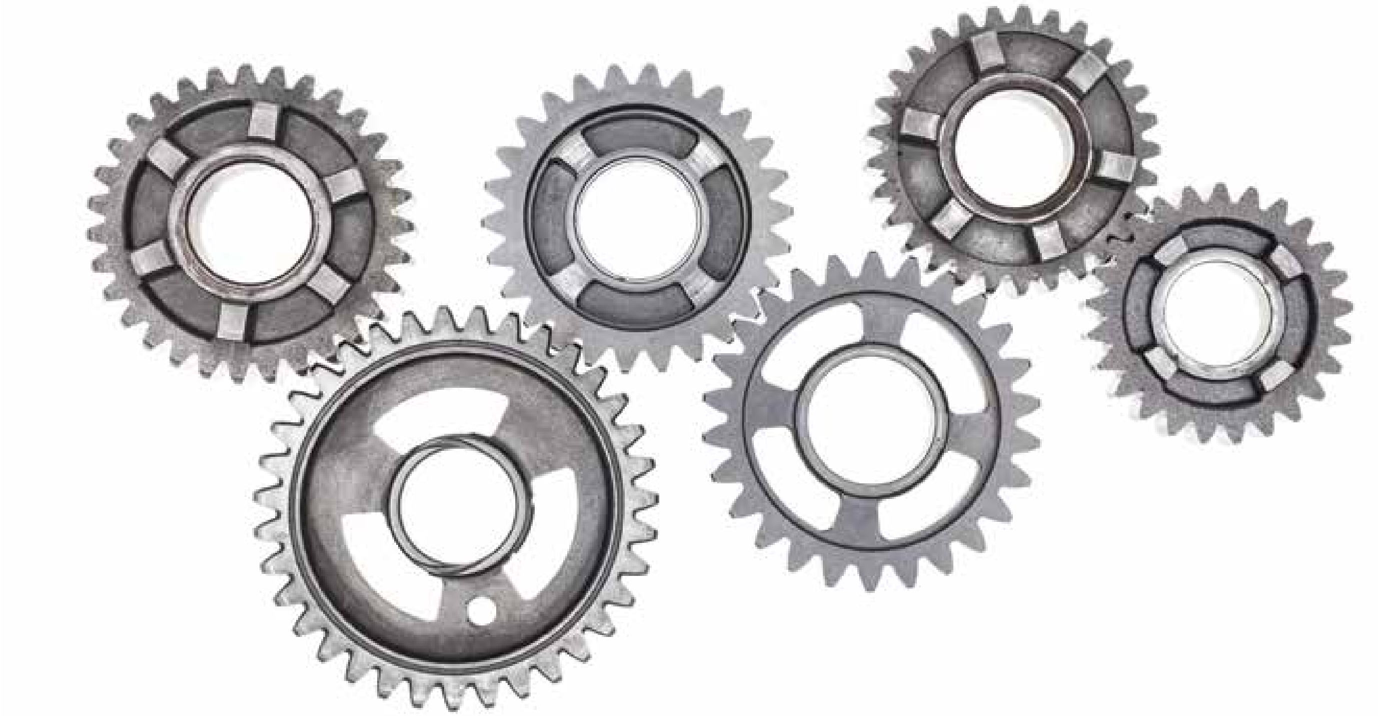
Figure 10 shows the evolution of the maximum principal stress (larger tensile stress) at the fillet surface of one tooth of the pinion. The maximum bending stress for higher pressure angle gears, contrary to what is predicted by the analytical models, is higher for the design with 35 degrees of pressure angle. Designs of 25 and 30 degrees yield similar levels of maximum principal stresses at the fillet. No advantage is observed for the design with higher pressure angles in terms of bending stresses. Therefore, not only has the safety factor not increased, but according to the finite element method, it has been reduced due to higher values of bending stresses. The analytical model to calculate the bending stress seems not to capture the increment of stresses due to larger stress concentration factors in designs with higher pressure angles, where small root radius coefficients are used.

Figure 11 shows the loaded function of transmission errors for helical gears with different pressure angles. It can be observed that the peak-to-peak maximum transmission errors are lower for the design with higher pressure angles. Noise and vibration excited by transmission errors might be lower for high pressure angle helical gear designs. However, the difference is slight and might not be noticeable. In Figure 11, it can be observed that the loaded function of transmission errors is not exactly periodic near the initial and final contact points. This is a characteristic of finite element models with boundary conditions slightly affecting the obtained results. The use of finite element models of seven pairs of contacting teeth for helical gears would improve the periodicity of the loaded function of transmission errors. However, it is not expected that different results would be obtained by using those models.

7: CONCLUSIONS

Based on the results obtained in this work, the following conclusions can be drawn:

- High pressure angle spur gears show a minor reduction in con-



tact stresses and contact pressure. The maximum values for both contact stresses and the contact pressure are obtained at the lowest point of single tooth contact, as considered by the analytical methods.

◗ Maximum bending stresses for spur gears with a high-pressure angle might not only be reduced, but in some cases, might be increased. An example of design in which the maximum bending stresses at the pinion fillet increased was shown. The influence of small root radius coefficients on bending stresses for high pressure angle gears should be further evaluated.

◗ High pressure angle helical gears yield higher maximum contact pressure, higher maximum Von Mises contact stress, and higher maximum principal stresses at the fillet area. No advantage was found for using or recommending high pressure angle helical gears. Only the loaded function of transmission errors showed a peak-to-peak value smaller than that obtained for designs with lower pressure angle helical gears.

◗ Whereas the analytical models yielded lower bending and contact stresses for the designs with higher pressure angles, the numerical analysis of stresses by the finite element method applied to two cycles of meshing yielded higher values of stresses. The causes of this difference should be further investigated and incorporated into the rating methods.

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EVALUATING THE UNKNOWN GEOMETRY OF HIGH ACCURACY GEARING

Finding the addendum modification coefficient using the base tangent length (BTL) method is found to be useful for gear parameter evaluation of an unknown gear.

By PRASMIT KUMAR NAYAK, A. VELAYUDHAM and C. CHANDRASEKARAN

Evaluation of geometry of used and broken gear is a seldom practice followed in the fields such as maintenance repair and recycling. Although gear calculations and main parameters are standardized, this task can be complicated, especially when there is no information about mating gear and gearbox assembly, change in the accuracy of used gears due to heavy wear, and sometimes the gear geometry probably is non-standard. Such situation calls for effective and accurate methods of gear profile geometry evaluation. Different methods like reverse engineering, iterative process, and analytical methods are being followed in gear industries.

Apart from these, a diverse number of CNC gear generative testing equipment and coordinate measuring machines are available in the industry to inspect the gears using fully automated gear measurement cycles. But in these advanced gear-measuring machines, the profile of the tooth can be checked and compared with a flank topography reference, and by means of a trial-and error procedure, it is possible to obtain an approximate geometry of the analyzed gears [Kumar, 2014]. Moreover, some advanced measurement machines have incorporated special programs for measuring gears with unknown parameters and determining some important data of the basic gear geometry [Grimsley, 2003]. Unfortunately, these machines are costly and often inaccessible to the company or factory involved with gear remanufacturing. Because of this, several researchers [Innocenti, 2007; Belarifi et al, 2008; and Schultz, 2010] have proposed alternative procedures to determine the unknown gear geometry.

Gear modifications are carried out by different means and each would influence different parameters.

Gonzalez et al, 2016, have proposed a procedure to obtain the fundamental gear parameters using conventional measurement tools. In their approach, it is assumed that the involute surface of the flank of a cylindrical gear can give information about the basic gear tooth data needed to determine the unknown gear geometry. Jadhav and Sandooja, 2012, have adopted a step wise analytical approach to find out the basic gear parameters for an unknown gear pair, which eliminated frequent trial and errors, iterations, and complex measurements. Alshennawy, 2014, has adopted a machine vision system coupled with CCD camera as a reverse-engineering tool for developing gear spare parts. Suitable algorithms have been developed for extracting and inspecting the mechanical component. Data have been extracted from the image and used to construct a 3D model and 2D drawing. It has been observed that the detecting of straight lines, holes, and circles are faster and more reliable. However, the accuracy of extracted data from the images are very important for reproducing the component. Charles D. Schultz, 2010, has brought out a methodology for the reliable measurement, evaluation, re-design, and manufacture of replacement parts for gear boxes and industrial machinery.

In the estimation of gear tooth geometry, profile shift/modification factor is an imaginary parameter used to represent the thickness of gear tooth. Negative profile shift leads to smaller tooth thickness and tip diameter and positive profile shift corresponds to the larger tooth thickness and tip diameter. It is to be noted that profile shift, real tooth thickness, and real tip diameter may not match precisely, due to various design and technological considerations. Therefore final drawings of spare parts must contain tooth thickness and tip diameter based on direct measurements and calculations of meshing quality (interference, undercut, overlap, minimum tooth thickness at the tip circle of a gear, etc.).

Of the above methods, the analytical method is more accurate, scientific, and does not involve complex measurements and iterations. Hence, the main focus of this paper is to investigate the used and broken spur gear of a CNC machining center spindle gearbox and estimate the basic gear parameters using standard measuring instruments followed by the use of analytical gear equations as given in DIN 3960 and graphical construction. Typically, the evaluation of gears used in the old gearbox of a CNC machining center, implies challenges to the engineers, since the gears used would be of higher accuracy, and the backlash would be minimum. In general CNC machine tool manufacturers use modified gears.

Gear modifications are carried out by different means and each would influence different parameters. Both the gear and pinion can be provided positive or negative correction. Gears are usually modified to avoid undercutting or to maintain a desired center distance in a gear box. In addition to that, the gear and pinion are now positively corrected to achieve several beneficial effects. These positively corrected gears have better strength at the root and the flank of the tooth. Due to positive correction, the tooth thickness at the root increases, thereby resulting in greater load carrying capacity. In case of a corrected profile, the active profiles formed from the involute curve are generated from the same base circle, but this time a different portion of the curve, which is farther away from the base circle. The main advantage of these gears with an involute profile is that even at an extended center distance, it continues to follow the law of conjugate action and continues to transform uniform angular velocity ratio.

In another type of correction, the mating pair of gears receives equal correction factors, but these two factors are algebraically of opposite signs. Normally, the pinion and gear are provided with positive and negative correction, respectively. In this case, the center distance remains unaltered, it remains the same. Thicker pinion teeth are ensured, and the gear tooth also does not become significantly weak. This correction is used in the case where the reduction ratio is very large.

DESCRIPTION OF COMPONENT

There was a requirement to reverse engineer, reproduce, and replace a broken gear component of an old gearbox of a typical horizontal CNC machining center. A schematic of the gear pair is illustrated in Figure 1. The machine was manufactured in 1983 and no spare was available as the machine tool manufacturer closed down the company, thus necessitating the proposed study. The center distance between axis of the gear broken and the axis of the mating gear is 205, ±0.036 mm as shown in Figure 1.

The photographic view of the broken gear is shown in Figure 2.The basic data of the gear pair are measured using standard measuring instruments as seen in Table 1. The common data that can be directly measured are number of teeth, tip diameter, and root diameter for both the gear and pinion. The base tangent length across a fixed number of teeth (number of teeth to be obtained using DIN 3960) was measured using a flange micrometer.

The module of an unknown gear cannot be measured directly. It can be derived from base tangent length. In the case of a corrected gear, the profile modification factor is to be derived. This factor is found out from the measured base tangent length. It is also related to the center distance between the gear pair. An alternative method is also adopted to find the profile modification from the tip diameter of the gear and the pinion.

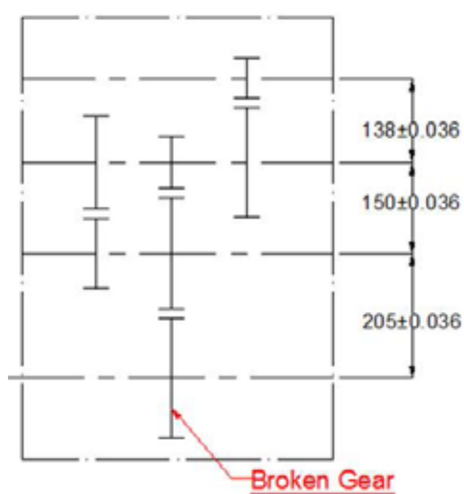

Figure 1: Schematic of gearbox.

METHODOLOGY OF GEAR GEOMETRY EVALUATION

The procedure for finding out the profile modification factor and other data is illustrated in Figure 3, with reference to DIN 3960.

MODULE

The module is an important parameter in defining the size of a gear tooth. It cannot be measured directly from the gear but can be calculated using equations of base tangent length. As per DIN 3960, the expression for finding the base tangent length is mentioned in equation (1) and (2). Using these two equations, the expressions for the module can be obtained as equation (3) and (4). Further, equations (3) and (4) are combined, and a single equation (7) is derived to find out the standard module. Pressure angle is also an unknown parameter. The standard pressure angles and the measured base tangent lengths are substituted in equation (7), and the nearest standard module is derived.

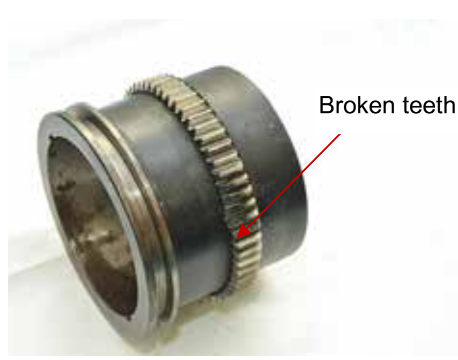

Figure 2: Photographic view of broken gear.

$$W_{k1} = m\,cos\alpha[(k - 0.5)\,\pi + Z_1 inv\alpha] + 2\,X_1 m\,sin\alpha \quad \text{Equation 1}$$

$$W_{k2} = m\,cos\alpha[(k - 0.5)\,\pi + Z_2 inv\alpha] + 2\,X_2 m\,sin\alpha \quad \text{Equation 2}$$

where,

W_{k1} – Actual base tangent length of gear over k_1 no. of teeth

W_{k2} – Actual base tangent length of pinion over k_2 no. of teeth

$$m_1 = \frac{W_{k1} - W_{k1-1}}{\pi cos\alpha} \quad \text{Equation 3}$$

$$m_2 = \frac{W_{k2} - W_{k2-1}}{\pi\,cos\alpha} \quad \text{Equation 4}$$

$$m_1{}^2 = \left(\frac{W_{k1} - W_{k1-1}}{\pi cos\alpha}\right)^2 \quad \text{Equation 5}$$

Assume $m = \frac{m_1^2}{m_2}$ **Equation 6**

Then

$$m = \frac{(W_{k1} - W_{k1-1})^2}{(W_{k2} - W_{k2-1})\,\pi cos\alpha} \quad \text{Equation 7}$$

From Table 2, it is observed that for pressure angle of 20 degrees, the difference between calculated and standard modules is minimum. Hence, it is verified that the pressure angle and the module of both gear and pinion are 20 degrees and 3.5 mm respectively.

ADDENDUM MODIFICATION COEFFICIENT

After finding the values of the pressure angle and module, pitch circle diameters are calculated using standard formula. The center distance is equal to half of the sum of reference diameters. From the calculations, it is found that the center distance is 199.5 mm. If it is less or more than the measured value, there is a positive or negative correction on either or both the gear and pinion. In the case of positive correction, gears are pulled apart by an amount 'X_1+X_2' times module. In this condition, a higher amount of backlash usually results. Therefore, to minimize the backlash, the gear pairs are brought closer to an intermediate value (center distance modification coefficients, '*y*' to get a new center distance.)

For the modified gear pair, the center distance is equal to the sum of pitch circle radii of gear and pinion and the sum of the center distance modification coefficient times the module. The center distance coefficient '*y*,' working pressure angle (αw), and the sum of modification coefficients, X_1+X_2 (theoretical value) are calculated using equations (8) to (10) as per DIN 3960.

To derive the modification coefficient, different methodologies are available. But, since the study involves remanufacturing of

Parameter	Gear	Pinion
No. of teeth Z	59	55
Base tangent length (mm) W_k	Across 8 teeth - 82.73	Across 7 teeth - 71.41
	Across 9 teeth - 93.06	Across 8 teeth - 81.76
Tip Diameter (mm) d_a	219.35	201.6
Root Diameter (mm) d_r	203.6	186
Diameter over pin (Ø 7mm) d_r	223.36	207.61
Centre distance (mm) a_w	205	

Table 1: Data measured from gear pair.

Serial No.	Pressure angle 'α'in degree	Module 'm' mm	Difference (calculated and standard module)
1	17.5	3.4410	0.0590
2	20	3.4924	0.0076
3	22.5	3.5521	0.0521

Table 2: It is here observed that for pressure angle of 20°, the difference between calculated and standard modules is minimum.

Base Tangent length		
	Measured value	Modification co-efficient
Gear (across 9 teeth)	W_{k1} =93.06	$X_1 = 0.9728$
Pinion (across 8 teeth)	W_{k2} =81.76	$X_2 = 0.6509$

Table 3: Calculation of modification coefficient based on BTL.

Tip diameter		
	Measured value	Modification co-efficient
Gear	$d_{a1} = 219.35$	$X_1 = 0.9714$
Pinion	$d_{a2} = 201.6$	$X_2 = 0.7356$

Table 4: Calculation of modification coefficient based on tip diameter.

1	2	3A	3B	Difference	
	Measured value	Calculated value over pins			
		Using Coefficients Table 3	Using Coefficients Table 4	(2) and (3A)	(2) and (3B).
Gear	223.360	223.864	223.845	$\Delta_{x1G} = 0.504$	$\Delta_{x2G} = 0.485$
Pinion	207.610	207.921	208.452	$\Delta_{x1P} = 0.311$	$\Delta_{x2P} = 0.842$
Sum of differences				0.815	1.327

Table 5: Values obtained for verification using pin over diameter.

a used one, it is proposed to follow the methods that use the measurement of an existing component. In this study, measured base tangent length (BTL) and tip diameter have been used for finding the coefficients, and pin over diameter was used for verification.

$$y = \frac{a_w}{m} - \frac{Z_1+Z_2}{2} \quad \text{Equation 8}$$

$$\alpha_w = \cos^{-1}\left(\frac{\cos\alpha}{\frac{2y}{Z_1+Z_2}+1}\right) \quad \text{Equation 9}$$

$$X_1 + X_2 = \frac{(inv\alpha_w - inv\alpha)}{2\tan\alpha}(Z_1 + Z_2) \quad \text{Equation 10}$$

ADDENDUM MODIFICATION COEFFICIENT USING THE BTL METHOD

Using the equations (1) and (2), modification coefficients (X_1, X_2) are obtained from the measured BTL value. The measured BTL values and calculated values of modification coefficients (X_1, X_2) are given in Table 3.*

ADDENDUM MODIFICATION COEFFICIENT USING THE TIP DIAMETER METHOD

Using equations (11) and (12), modification coefficients (X_1, X_2) are obtained from the measured tip diameter value. The measured tip diameter values and calculated values of modification coefficients (X_1, X_2) are given in Table 4.

$$d_{a1} = Z_1 m + (1 + y - X_2)m \quad \text{Equation 11}$$

$$d_{a2} = Z_2 m + (1 + y - X_1)m \quad \text{Equation 12}$$

VALIDATION OF ADDENDUM MODIFICATION COEFFICIENT

The modification coefficients obtained from the two different methodologies are verified through another method called diameter of the gear and pinion over the recommended roller pin diameter. The measured value and the calculated value are compared. The calculated values are obtained by using equations (13) to (22) and tabulated in Table 5.

$$S_1 = \frac{\pi m}{2} + 2X_1 m \tan\alpha \quad \text{Equation 13}$$

$$S_2 = \frac{\pi m}{2} + 2X_2 m \tan\alpha \quad \text{Equation 14}$$

$$inv\alpha_1 = \frac{d_r}{d_{b1}} + inv\alpha + \frac{S_1}{d_1} - \frac{\pi}{Z_1} \quad \text{Equation 15}$$

$$inv\alpha_2 = \frac{d_r}{d_{b2}} + inv\alpha + \frac{S_2}{d_2} - \frac{\pi}{Z_2} \quad \text{Equation 16}$$

$$d_{p1} = mZ_1\frac{\cos\alpha}{\cos\alpha_1} \quad \text{Equation 17}$$

$$d_{p2} = mZ_1\frac{\cos\alpha}{\cos\alpha_2} \quad \text{Equation 18}$$

$$d'_{p1} = d_1\cos\left(\frac{90}{Z_1}\right) \quad \text{Equation 19}$$

$$d'_{p2} = d_2\cos\left(\frac{90}{Z_2}\right) \quad \text{Equation 20}$$

$$M_{a1} = d'_{p1} + d_R \quad \text{Equation 21}$$

$$M_{a2} = d'_{p2} + d_R \quad \text{Equation 22}$$

RESULTS AND DISCUSSION

From Table 5, it can be seen that the sum of the differences Δ_{xG} and Δ_{xP} are minimum in the case of Δ_{x1G} and Δ_{x1P}. Thus the profile modification coefficients obtained through the BTL method are closer to the measured value.

The gear and pinion with the above obtained modification coefficients are brought closer by, i.e. 0.1829 mm, to achieve minimum backlash of 0.03 mm, which is equal to DIN Class 5 accuracy standard value that is required for a high accuracy CNC machine tool gearbox and maintaining the center distance of gear pair.

CONCLUSION

From the approach of evaluating unknown geometry of high accuracy gear the following conclusions can be drawn:

- A relation between module and pressure angle was established, which is applicable for both the gear and pinion. The different standard value of pressure angles is assumed and the corresponding module was obtained from the relation. The obtained value of the

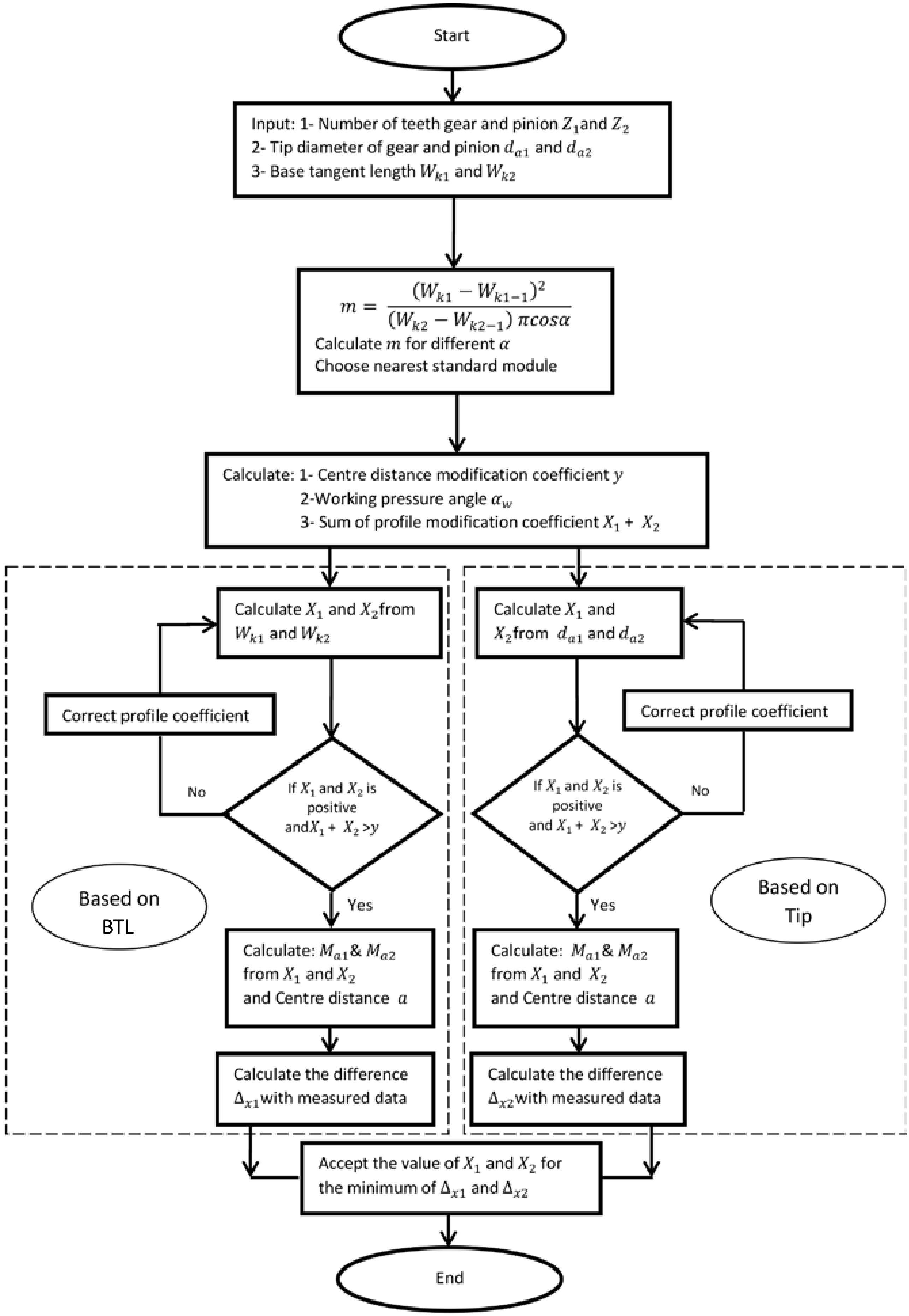

Figure 3: Gear data calculation steps.

module and the standard value of the module were compared. The actual value of the module was ascertained where the difference is found to be minimum.

- The method of finding the addendum modification coefficient using the BTL and tip diameter methods and verification using pin over diameter is found to be useful for gear parameter evaluation of an unknown gear.
- The BTL method is observed to be better for finding the addendum modification coefficient for the gear pair based on the minima obtained between the calculated and measured values of pin over diameter.
- The amount by which the gear pair is to be brought closer to obtain the desired backlash as per DIN class accuracy can be derived using the above methodology.

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NOTATIONS

Z_1 – Number teeth on gear

Z_2 – Number teeth on pinion

m – Module of gear and pinion

X_1 – Modification on gear

X_2 – Modification on pinion

α – Pressure angle

α_w – Working pressure angle

d_1 – Pitch circle diameter of gear

d_2 – Pitch circle diameter of pinion

d_{b1} – Base circle diameter of gear

d_{b2} – Base circle diameter of pinion

$d_{\alpha 1}$ – Tip circle diameter of gear

$d_{\alpha 2}$ – Tip circle diameter of pinion

d_{r1} – Root circle diameter of gear

d_{r2} – Root circle diameter of pinion

W_{k1} – Actual base tangent length of gear

W_{k2} – Actual base tangent length of pinion

a – Standard center distance between the gear and pinion

a_w – Modified center distance between the gear and pinion

y – Center distance modification coefficient

d_g – Measuring pin diameter

S_1 – Gear tooth thickness for the corrected gear

S_2 – Gear tooth thickness for the corrected pinion

d_p – Distance between the pin for the even number of teeth

d'_1 –Distance between the pin for the odd number of teeth

M_a – Diameter over pin

α_1 – Pressure angle of the involute profile at the pin center for gear

α_2 – Pressure angle of the involute profile at the pin center for pinion

Δ_{xG} – Difference between the measured and calculated value of pin over diameter on gear

Δ_{xP} – Difference between the measured and calculated value of pin over diameter on pinion

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DRIVING GEAR DEVELOPMENT

500CB's closed-loop system corrects for blade movement during automatic clamp screw torqueing and provides 'intelligent' feedback for more precise truing.

Gleason technologies help SEW Eurodrive meet global demand for compact, quiet, and very high-efficiency spiral bevel gear units.

By **UWE GAISER**

Ask Chuck Chandler, plant manager at SEW Eurodrive USA in Lyman, South Carolina, about the range of applications for the spiral bevel gear units produced there, and his response is simple: the world. The ultra-modern 385,000-square-foot facility, winner of Plant Engineering Magazine's Top Plant Award in 2007, is running three shifts a day, six days a week, and busting at the seams to keep pace with record demand from SEW Eurodrive Assembly Centers around the world. But if you think these production challenges keep Chandler up at night, guess again.

"We've never been more productive or efficient," he said. "And we have some of the latest Gleason technologies helping us get there. It's a good problem to have."

GRINDING FOR MORE PRECISION

Ten Gleason Phoenix bevel gear cutting machines, including four of Gleason's latest generation of 280CX machines, produce all of the spiral bevel gear sets used in SEW Eurodrive's popular K Series of right-angle gear units. The K Series is an industry workhorse, renowned for delivering 96 percent efficiency and very quiet, wear-free performance across a 200 Nm to 50,000 Nm torque range. These gears are heat-treated and then lapped and tested on Gleason HTL TurboLapper and HTT TurboTester machines. But with the introduction in 2004 of a new family of servo gear units, designed for very high precision applications where positioning tolerances are often measured in microns, Chandler and his team recognized that lapping these gears as a hard finishing process wasn't going to be good enough.

The 280G eliminates pipes, wiring, and clutter from the work area so that swarf containment and evacuation is extremely efficient. Quick-change coolant headers speed setup and ensure optimum coolant delivery.

"The spiral bevel gearsets in these servo gear units must be produced with very tight tolerances and operate backlash-free, so we opted to finish grind them," Chandler said. "Plus, by grinding gears and pinions independent of each other rather than having to lap them as mated sets, we have the added flexibility of finishing gears or pinions in the optimum lot sizes and on demand."

Early on, SEW Eurodrive relied on Gleason and its Phoenix 280G Bevel Gear Grinding Machines to grind the gearsets at Gleason.

"We didn't initially have the volumes or, frankly, the grinding expertise, to justify a grinding machine purchase," Chandler said. "Outsourcing to Gleason gave us a chance to learn about the process and see firsthand how well the 280G performed, so when the time came, we bought one right off the floor at IMTS 2014."

PROVEN PHOENIX PERFORMANCE

Today, this 280G is helping meet the world's growing appetite for SEW Eurodrive's servo gear units and performing so well that Chandler and his team are looking at a second machine and more opportunities to apply grinding, whether for noise reduction or to squeeze more torque out of a smaller gearset. The machine's exceptional reliability has come as no surprise to Chandler, since the 280G is built on the same platform as his tried-and-true Phoenix 280CX cutting machines. It also features an exceptionally well-designed work area for swarf containment and evacuation. This is critical for ensuring fast, accurate bevel gear grinding, as well as helping to minimize the time-consuming and expensive maintenance challenges of swarf accumulation and contamination.

Virtually all of the usual wires, piping, and even the door rails have been moved out of the work area and put behind guarding, so swarf is easily contained and falls free for collection by the coolant chute positioned directly below the work area. In addition, the 280G is equipped with an integrated dressing unit with a unique telescoping design that enables it to extend into the work area for dressing, and then fully retract flush with guarding during the grinding cycle.

But what Chandler also appreciates now is just how productive the 280G is.

"We're producing 24 different gears and pinions in the servo gear family, and once you set it up for a part for the first time, replicating that same part setup downstream is very fast and easy," Chandler said.

He attributes some of this setup speed to the color-coded sets of quick-change coolant headers that allow the operator to easily optimize the flow of coolant for each part, critically important in order to avoid surface defects and achieve the desired surface finish and flank form accuracy.

The machine is also equipped with a quick-change grinding wheel spindle design, as well as a work spindle that allows conventional arbors to be installed to, and removed from, the front of the machine. All of these setup tasks are performed by the operator without tools. Non-productive time is further reduced through use of an automatic stock divider, mounted in close proximity to the work spindle, that operates simultaneously with wheel dressing.

Load/unload automation is easily integrated with the 280G, further reducing non-productive time.

EASILY AUTOMATED FOR MORE EFFICIENCY

As one would expect, SEW Eurodrive makes extensive use of automation. Robotic load/unload is used on 90 percent of the gear cutting machines and was easy to integrate on the 280G.

"Our studies show that manual load/unload is, at best, about 72 percent efficient, which means a machine will be waiting a lot," Chandler said. "On the 280G, we use the robot to not only load and unload the machine, but also to hold the part for cleaning and pick and place the part at laser etching and palletizing."

AUTOMATING CUTTER BUILD

Perhaps the only productivity stone left unturned at the Lyman plant, until recently, was in the tool room, where as many as 25 cutter systems are built every three-shift day to meet the needs of 12 bevel gear cutting machines. True, tool room operators make good use of two highly productive Gleason BPG Blade Grinding Machines and a GBX Blade Inspection System to quickly and efficiently sharpen and inspect all the carbide stick blades used in these Gleason Pentac or older Gleason Tri-Ac face hobbing cutter systems. But much of the operators' time was spent building, truing, and inspecting the cutter heads, a process that, according to Chandler, took upwards of 90 minutes per head and could result in costly blade misalignments and blade chipping despite the expertise of the technicians. So, it's not surprising that, 18 months ago, Chandler took advantage of the opportunity to make his tool room the first beta site for Gleason's new 500CB Cutter Build Machine.

"It's inevitable that building, truing and inspecting cutter heads manually will result in the occasional blade misalignment, but even one is too many," Chandler said. "This can cause a chipped blade downstream, and drastically reducing tool life as a result. Now, with the Gleason 500CB, all of those manual steps are performed automatically and with greater precision and repeatability by the machine. A process that once took 1½ hours now can be done in 30 minutes or less, and we're no longer worried about misalignments and chipping blades. Plus, we've freed up our tool room people so they can be productive while the 500CB is doing its thing."

LESS WORK, BETTER RESULTS

The new Gleason 500CB Cutter Build Inspection Machine is the first of its kind to fully automate most of the critical steps in the cutter build and truing process. Its predecessor, the Gleason CB machine has, for years, been a solid workhorse in tool rooms worldwide and succeeded in lifting some of the burden from the operator's shoulders

Ten Gleason Phoenix bevel gear cutting machines, including four of Gleason's latest generation of 280CX machines, produce all of the spiral bevel gear sets used in SEW Eurodrive's popular K Series of right-angle gear units.

SEW Eurodrive was the beta site for Gleason's first 500CB machine. Today, the machine is reducing cutter build times from the 90 minutes needed previously to less than 30 minutes.

The new Gleason 500CB Cutter Build Inspection Machine is the first of its kind to fully automate most of the critical steps in the cutter build and truing process.

by automating a few of the critical steps in the build sequence. But the 500CB goes much further than the original CB.

Now, after cutter build data is input, all the operator does is load the cutter head, position the build carriage, and load the blades into their respective slots. Next step? Press GO and walk away, with 30 minutes or so of time now available for other tasks. Now, all the other steps that have taken so much time and been so dependent on the operator and his expertise are performed automatically by the 500CB. Blades are positioned in their slots, clamp screws precision-torqued, and blade axial and radial position measured. As this process unfolds, the 500CB actually learns from the measurement feedback it receives, and loosens, tightens, and measures blades again as needed — just as the technician would do — until blades are trued to their optimum radial and axial position down to ±2 microns if needed. It's an adaptive process, too, with the 500CB learning from every build to optimize future builds. Once the operator has loaded the cutter head, positioned the build carriage, and loaded the blades, he's free to perform other tasks while the 500CB completes the build, truing, and inspection operations.

If the operator chooses to, he can view a screen on the machine's CRT charting every blade's position and runout in real time. And, at any point in the process, start to finish, the operator can use the intuitive operator interface with software "wizards" to guide him through every step of setup and operation.

According to Chandler, the 500CB's impressive functionality isn't limited to just a few cutter systems types or sizes either. It can be easily applied to both newer Pentac cutter systems and the older Tri-Ac cutter heads still in use, as well as the wide range of cutter head diameters running on SEW Eurodrive's cutting machines, from as small as 70 mm (2.75") to as large as 533 mm (21").

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SERVICING THE ENTIRE PROCESS

A rack and pinion shaver broach tool. (Courtesy: Wolverine Broach)

Wolverine Broach Co. Inc. has developed a reputation for craftsmanship, design, engineering, and support services.

By KENNETH CARTER, Gear Solutions editor

Broaching can be quite the competitive arena in the manufacturing world, so it's imperative for a company to take those extra steps to bring customers to its door.

At Wolverine Broach Co Inc., company President Bernard J. Aude Jr. prides himself in that ability.

"We're considered a small organization, which allows us to fly under the radar and exceed our customer's expectations compared to our larger competitors," he said. "The quality of our tool will sell itself, yet due to the lack of broaching knowledge in the industry, you also have to service the entire process."

With their quality and customer-service ability, Wolverine Broach has established itself as a critical and key supplier over the entire broaching industry.

RACK AND PINION LEADER

Wolverine Broach has been a leader in the steering, or rack-and-pinion discipline, and has supplied products to companies throughout the years that supply to General Motors, Ford, Chrysler, ZF (TRW), and transplant companies that have invested in or relocated to North America.

"We produce a vast majority of the rack-and-pinion broaches in the North American market," Bernard Aude said. "It is the strength in our ability to quickly problem solve a tool design and offer product support that sets us apart from the competition."

Part of what makes Wolverine so accomplished is the company's attention to detail, according to Matthew Aude, vice president of sales.

"First and foremost, we listen to our customer to better understand what they are currently having concerns with, which allows us to react more efficiently to provide a solution," he said. "As Bernie previously stated, we do have that flexibility as a smaller organization where we can re-appropriate capacity in order to meet a customer's demand very quickly."

PREFERRED SUPPLIER

As witnessed in its market share in the rack-and-pinion broaches, Wolverine has become a preferred and valued supplier at a number of additional end users.

"It's similar to a single source opportunity which many companies have tended to shy away from," Bernard Aude said. "Our primary industries are aircraft and automotive, since the larger production volumes go hand-in-hand with the broaching application. And we've also been at it for quite a while."

Some of the products and services Wolverine Broach offers include pot broaches, keyways, aircraft broaches, steering rack broaches, quadrant broaches, hexagon tools, straight spline broaches, involute spline broaches, square and rectangular broaches, D and Double D broaches, and more.

That quality of service has made some of Wolverine's customers take extra notice.

"I've worked with Wolverine Broach through endless new programs and retool projects," said one customer. "I've come to realize that working with Wolverine has proven to be one less variable to stress over when starting up a new product component line. The level of quality and support they provide during and after is what most end users strive to obtain."

"With broaching, it's becoming an unknown art, which is unfortunate because of how competitive it can be to other processes."

Wolverine Broach's excellence was most recently recognized by Pratt & Whitney with an award for superior quality for the 2017 calendar year. According to the Audes, it is a difficult award to achieve in just four years.

"To accomplish this feat at the Pratt & Whitney, Connecticut, location in such a limited time is difficult to do," Bernard Aude said. "So, we have moved very quickly into a position of tops in quality."

Of all the turbine disc broaching operations, Pratt & Whitney has one of the most stringent tool acceptance procedures in the entire industry, according to the Audes.

"Working with Wolverine is a great experience," said Jose Acosta with Pratt & Whitney. "Their focus on process improvement, cost reduction, and on-time delivery, along with a great service, makes Wolverine a good supplier to work with."

SATELLITE LOCATION

Wolverine also has a satellite location in Alcoa, Tennessee, that primarily serves the Southeastern region and can quicken the turnaround for the company's services.

A Blohm 412 CNC surface grinder. (Courtesy: Wolverine Broach)

"This site was established 20 years ago with the idea that we were going to more quickly respond to a target customer," Bernard Aude said. "That has set us apart. We can turn tools around in a regrind state in less than a week, and that's door to door, sometimes including coating. Give us a tool one week; it's going to be back to them the next week."

"It reduces their inventory or float demands, so it reduces their costs," Matthew Aude added. "If a customer has a broach company that is servicing them from afar, those tools are then transported via truck or even air, which cripples lead time. So, localization has a direct impact on inventory control which is a key component in reducing their tooling costs."

A Blohm 408 CNC surface grinder. (Courtesy: Wolverine Broach)

46 YEARS OF SERVICE

After accumulating more than 25 years of broaching experience, Bernard Aude Sr. decided to start his own broach company. He created Wolverine Broach Co., Inc. in July of 1972. It moved into a new facility in Harrison Township, Michigan, in 1981 and has been at that address ever since.

Bernard Aude Jr. started working at Wolverine Broach in 1972 after earning an engineering degree from the University of Michigan. He also opened Wolverine Production & Engineering in 1982. With this addition, Wolverine Broach was able to provide a full spectrum of broaching services from tool manufacturing to the production broaching process. As mentioned previously, the establishment of the satellite facility, Wolverine Broach Co., Inc. S.E. Division in Alcoa, Tennessee, was another idea developed by Bernard Aude Jr. to meet specific demands.

Those years of experience are what the Audes and their team use to meet their customers' needs head on. Wolverine is an American-owned company with three gen-

Wolverine Broach receives the broach supplier award from Pratt & Whitney. From left: Matt Aude, Bernie Aude, Jose Acosta, Dave Parent, and Ryan Kimball. (Courtesy: Wolverine Broach)

erations of the Aude family involved in its operations.

TRAINING THE CUSTOMER

"With broaching, it's becoming an unknown art, which is unfortunate because of how competitive it can be to other processes," Matthew Aude said. "The incoming engineers in our industry won't know what broaching is until they get to the plant, and it is assigned to them."

In the past, seminars were often offered at the IMTS and AGMA trade shows by the larger companies and machine builders to teach engineers about the advantages with broaching, but those seminars aren't offered with the same frequency, according to Matthew Aude.

"Our larger competitors no longer offer the instructional classes as ownership has transferred from domestic to foreign and priorities shift," he said. "We've actually been working with a number of end users to try and start re-teaching the young engineers and operators what broaching is. This is essential for our long-term survival."

Wolverine has been setting up preventative maintenance and operator training seminars over the past 18 months with great success. The company has provided these seminars in hopes of enabling customers and increasing the overall product knowledge, so it helps the industry as a whole.

EYE ON THE FUTURE

As Wolverine Broach continues to provide quality broaches to a myriad of industries, Bernard Aude said it will explore additional avenues as technology challenges the business, such as fully electric cars with reduced mechanical back up.

"We are always trying to reinvent ourselves with long-term opportunities" he said. "We have invested a substantial amount of capital back into the company over the past three years and have an annual plan for the next five years, at a minimum, to expand our vision."

Even though there are CNC machines in the broach industry, broaching doesn't necessarily get easier, according to Matthew Aude. And that's why the skilled and experienced labor becomes important.

"Unfortunately, it's not as simple as pushing a button and a finished broach tool is then taken from the machine," he said.

The complexity in a broach still requires a high degree of skilled labor, even with the CNC capabilities.

"Most of our employees have been with us for 25-plus years," Matthew Aude said. "It's an older employee base, but by the same token, they're very knowledgeable, dependable, and they take pride in what they do."

MORE INFO wolverinebroach.com

Stafford custom shaft collars and couplings can be manufactured to precise design requirements from a wide range of materials in a variety of configurations. (Courtesy: Stafford Manufacturing Corp.)

Clamping shaft collars, rigid couplings permit precision alignment

Stafford Manufacturing Corp. of Wilmington, Massachusetts, has introduced a full line of shaft collars, mounting collars, and sleeve couplings that provide highly accurate working surfaces and mar-free clamping.

Custom-designed shaft collars and rigid couplings that solve specific mechanical drive or packaging system and conveyor component compatibility issues are available. Stafford custom shaft collars and couplings can be manufactured to precise design requirements from a wide range of materials in a variety of configurations with special bore features such as hex, square, or round shapes and keyways including hinges and threads. Exterior modifications can include flats, slots, knurls, laser etching, tapped through-holes, flanges, cams, target inserts, levers, and related parts to meet OEM specifications.

Supplied in prototype through production quantities, Stafford custom shaft collars and couplings can be machined from alloy steels, stainless alloys, titanium, aluminum with anodizing in bright colors, brass, bronze, Delrin®, and other materials. Sizes can range from 1/8" to 12" I.D. with dimensional tolerances of less than 0.001" and less than 0.001" T.I.R. concentricity, depending upon configuration. 3-D models can be provided for proof-of-concept testing.

Stafford Accu-Clamp™ Shaft Collars feature an integral clamp on one side while leaving the other flat and perpendicular within 0.001" TIR to permit mounting next to precision bearings, sprockets, and gears. For mounting components, Accu-Mount™ and Accu-Flange™ collars have a centering hub with predrilled and tapped holes on their flat side and flange, respectively.

Providing strong, mar-free clamping power, Stafford Accu-Clamp™ Shaft Collars are available made from aluminum, steel, and stainless steel in 0.5" to 2" I.D. sizes. A Precision one-piece sleeve coupling with a rigid center clamp section and the Accu-Clamp™ feature at each end is offered for a distortion-free coupling with a more precise fit and shaft-to shaft concentricity within 0.001" TIR.

Stafford Accu-Clamp™ Shaft Collars and related components are priced according to size and quantity. Price quotations are available upon request and custom modifications can be accommodated.

MORE INFO www.staffordmfg.com

Nord Gear shows high-speed manufacturing at EXPO PACK 2018

Nearly 100 separate conveyors, in-line CT-scan screening machines, multiple infeed lines, four-way sorters, high-speed diverters, spiral power curves and tray sorters — these are just some of the components powered by Nord Drivesystems motors and drives in high-speed material handling, package sorting and luggage handling operations.

NORD is accelerating the speed of manufacturing and material handling as it delivers integrated power technologies to help the world's largest manufacturers, online retailers, warehouses, and airports produce and move products faster, with less energy and more control.

Customization saves time and money. Nord's modular, quick-connect drive systems can be equipped with a variety of common industrial Ethernet communication protocol modules for remote monitoring and control of individual drive units. Plus, Nord can supply the units configured and supplied with required plug connectors for power, photo eyes, sensors, and standard field bus systems to allow for easy installation.

The result: Nord delivers money-saving solutions for tough environments. The high-efficiency drive equipment and integrated technology reduce installation time and cost of operation. Plus, Nord's high-quality equipment and customer support increase uptime and peace of mind.

At EXPO PACK 2018, Nord experts were on hand to discuss integrated drive equipment needs, including:

92.1 Helical-Bevel Gearbox: Nord's 92.1 two-stage helical bevel reducer boasts up to 97 percent gear efficiency. The design using finite element modeling technology with oversized output bearings and extremely accurate construction means extended service life, even under high radial loads. Plus, with flexible mounting and shaft designs, product installation is fast. It's one of the most cost-effective and hassle-free modular gearboxes available.

NORDBLOC.1 Helical In-Line Gear Units: A robust and cost effective in-line gear unit, the NORDBLOC.1 is ideal for a wide range of demanding applications, from the high-speed conveying power needed in warehouse and package handling systems to pumping and mixing food products.

IE4 Permanent Magnetic Synchronous Motors: Like the gearboxes and drives used with new international airport baggage-handling systems, Nord's IE4 Permanent Magnetic Synchronous Motors and VFDs can be pre-configured and delivered with customer-specified power connectors, and photo eye, sensor, and high-speed Ethernet IP plugs needed for easy daisy-chain installation. Because the motor offers best-in-class power density, with energy efficient operation even at partial loads and reduced speeds, it provides extremely low total cost of ownership and predictable load handling.

NORDAC LINK (SK250E Variable Frequency Drive): This is another big piece of the conveying system integration. The NORDAC LINK VFD family offers flexible drive capabilities for virtually any application and supports decentralized installations. NORDAC LINK installation is fast and simple, as is service. Integrated brake management assures wear-free actuation. Direct speed feedback via incremental encoder on the motor generates the highest possible acceleration and guarantees full motor torque throughout the entire speed range. Nord customizes products to provide the specific features and functionality customers need.

LogiDrive integrated solution: Nord's LogiDrive Solution combines the highly efficient gearbox, the permanent magnet IE4 motor, and the versatile NORDAC LINK VFD. With this combination, users can achieve greater energy efficiency while greatly reducing the number of product combinations for an entire system. This solution is available with power ratings between 1.5 and 7.5 HP and available for 50 Hz and 60 Hz power systems. Nord's solution is modular and each of the components can be serviced separately, thereby reducing costs, reducing required variants, minimizing spare part inventory, and increasing uptime.

MORE INFO www.nord.com

Nord's Nordac Link is shown controlling a 92.1 two-stage helical gearbox with IE4 synchronous motor, one of Nord's low-maintenance, high-efficiency drive technology solutions.

The Sandvik CoroChuck 935 delivers fast, rigid, and secure clamping. (Courtesy: Sandvik Coromant)

Hydraulic chuck for turning offers market-leading security

Cutting tool and tooling system specialist Sandvik Coromant has introduced a high-precision hydraulic chuck for turning operations that offers the market's best pull-out security. CoroChuck® 935 has been designed to deliver fast, rigid, and secure clamping, time after time.

With clamping security assured, machine shops can confidently perform demanding turning operations, including those with long overhangs. In fact, CoroChuck® 935 ensures a clamping length of four times the bar diameter. Developed for use on lathes, turning centers and multi-task turn-mill machines, the new hydraulic chuck covers most common machine interfaces.

"The design principal behind the high level of security offered by CoroChuck 935 is based on fulcrum technology," said Åke Axner, global product manager – machine integration at Sandvik Coromant. "A thin, brazed membrane offers an optimized clamping function, whereby expansion creates two distinct clamping points on each side (fulcrums). The concept ensures the clamping force repeats for every use, providing the best possible pull-out resistance and damping performance."

Further benefits of the new chuck include the use of EasyFix™ sleeves to provide the correct center height and help reduce set-up time. EasyFix™ sleeves are a solution for cylindrical boring bars that sees a spring plunger mounted in the sleeve click into a groove on the bar to guarantee the correct center height. The metallic sealing also offers good performance in applications that require high pressure coolant. Moreover, EasyFix™ facilitates excellent cutting action and improved insert life.

CoroChuck® 935 is available in 20 and 25 mm bore sizes (¾ and 1 inch) to suit Coromant Capto®, HSK-A/C/T, cylindrical shank, and VDI machine interfaces. Imperial sizes are available in Coromant Capto and cylindrical shank interfaces.

MORE INFO www.sandvik.coromant.com

United Grinding's new Ewag Profile Line was designed to enhance production efficiency. (Courtesy: United Grinding)

United Grinding transforms insert grinding with Profile Line

United Grinding has unveiled its new Ewag Profile Line, an indexable carbide insert grinding solution. Developed in a partnership between Ewag AG and sister company Walter Maschinenbau GmbH, the Profile Line serves as an extremely efficient grinding center for the advanced processing of highly complex interchangeable insert geometries and interfaces.

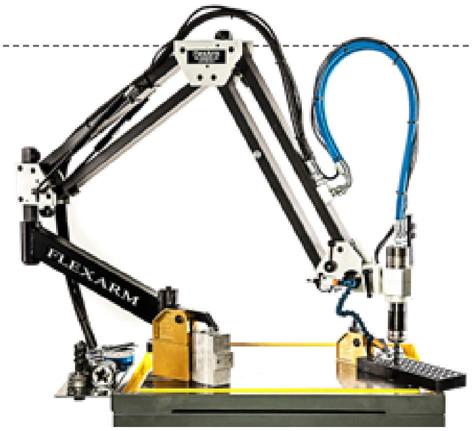
The Profile Line enhances production efficiency with innovative technology such as an intelligent, integrated six-station changer for grinding wheel sets with a coolant supply manifold that selects the optimal wheel to ensure the maximum possible machining volume for sintered insert blanks. The machine integrates both Ewag ProGrind and Walter Helitronic Tool Studio into its FANUC control unit to further expand the range of applications and improve insert geometries.

For unattended, lights-out operations, the Profile Line comes equipped with an integrated six-axis FANUC robot that can easily accommodate customer-specific pallets. A high-resolution CCD-HD vision system is also available for loading grid pallets using magnetic grippers. Cleaning, re-clamping and centering stations can be integrated and adapted to the customer-specific product range.

MORE INFO www.grinding.com

FlexArm to feature all-in-one hydraulic tapping packages at IMTS

At IMTS September 10-15 in Chicago, FlexArm Inc. will feature a mobile tapping package that yields mobility, productivity, and efficiency by allowing operators to tap holes offline while the machining center works on the next part. FlexArm will occupy booths #432115 and #236430. This comprehensive package includes the FlexArm GH-18 tapping arm with a tap capacity of #6 to 5/8", a reach from 17-72 inches, variable speed from 100-420 RPM, 360-degree movement, and a semi-automatic tap lubricator. Additionally, with a caster cart, power pack, tap stand, and five tap holders, this hydraulic tool can be used wherever there is 110V available – with no air needed. With fast set-up times and significantly reduced tap breakage, FlexArm tapping arms are an ideal alternative to tapping holes manually or via CNC.



FlexArm's mobile tapping package allows machining centers to do what they do best – milling, drilling, and boring. (Courtesy: FlexArm)

FlexArm allows machining centers to do what they do best — milling, drilling, and boring. When operators load a machining center and start its cycle, they can use that cycle time to tap previously machined parts with the FlexArm — yielding more productivity per shift. Tap breakage rates are significantly reduced with the FlexArm due to its purpose-centered approach. With a tap breakage rate of 1 per 3,000 holes, versus 1 per 300 holes on a CNC, FlexArm tapping arms can significantly reduce set-up time, cost, and scrap rates.

In addition to the GH-18 model, other hydraulic and pneumatic versions of the FlexArm are available to suit varied tapping requirements. Engineers are available to discuss unique project parameters and offer solutions based on decades of experience. A 30-day free trial period allows FlexArm products to be proven in-plant under actual production conditions. The company stocks an extensive array of tap holders and repair parts in its Wapakoneta, Ohio, factory, for fast shipment, often same day.

FlexArm, headquartered in Wapakoneta, has been manufacturing tapping arms, die grinding arms, torque arms, assembly and part manipulators, and more, since 1984. Hydraulic and pneumatic tapping arms are available with guaranteed precision and dependability. Hydraulic models have a tapping capacity up to 2 inches. It stocks an extensive array of tap holders and repair parts for fast shipment – often same day. All arms and systems include a 3-year warranty. All motors and units are repaired by FlexArm technicians in-house to speed turnaround times.

MORE INFO www.flexarminc.com

MARKET PLACE

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Q&A
INTERVIEW WITH AN INDUSTRY INSIDER

CURTIS DICK
DIRECTOR OF QUALITY •
RIVERSIDE SPLINE AND GEAR INC.

"We consider ourselves North America's job shop. That's kind of our theme. When we say we do quick turnaround, we mean it."

Tell us about Riverside Spline and Gear Inc.'s place in the gear manufacturing industry?

We consider ourselves the industry leader in the job shop arena. We are not afraid of large quantities and do them frequently, but we shine well in the one-off job shop arena. We consider ourselves North America's job shop. That's kind of our theme. We have an average lot size of five or less, and that's uncommon for most gear companies. People are moving more toward mass production of gearing. And it's hard to find someone who has competitive pricing, is high quality, on time, short deliveries in the one-off arena. We are that company. When we say we do quick turnaround, we mean it. We have our own inhouse bar stock, so if you give us an emergency order in the morning, we can have a piece cut off, turned, gear cut, and off to heat treat that evening. That's uncommon.

What achievements have you recently accomplished?

The first and most important at this point is our commitment to quality. We've achieved the requirements of ISO 9001:2015. And this basically assures our customers that we have a commitment to quality, maintaining a quality management system, and a business management system that is driven from the top down supported by Aaron Forest, our president, CEO, and owner. Aaron is involved, daily, in the quoting process, operations, and quality functions. Corrective actions and the understanding of where we can improve are of utmost interest to Aaron.

What equipment have you added to better assist customers' needs?

We've added six machines in the past five months. We are adding two more ID grinders this week and another cut-off saw in a few weeks. This changes pretty much on a monthly basis right now. Our business is booming. We are adding machinery and people in order to meet our commitments to our customers. The largest machine we've added is a Höfler 1500L gear grinder. This Höfler has a 59-inch diameter capacity, a 59-inch stroke, and can grind a shaft up to 99 inches long. We have added a Toshiba VTL and ID grinding to create the blanks large enough to accommodate this machine. Our whole company is focused on our gear grinding. All the machinery that we have in the shop is there to support making a gear blank that is worthy of going on those machines.

Tell us about Riverside's quick turnaround grinding service.

Back in 2006, we broke ground on a new gear grinding center. We used to have old Reishauer grinders. And our customer base was talking about larger gearing and different kinds of gearing that needed more modifications. We realized that we needed to keep it in-house because we couldn't find somebody out there to do that for us. So, we purchased our first Höfler grinder. It was a Rapid 900. Twelve years later, we have five Höfler grinders ranging from 400mm to 1,500mm. They're all equipped with Siemens 850D controllers, and they have onboard checking. These Class 14 (DIN 3) machines run 23 hours a day. We service many industries with between two- and five-day turnaround on gear grinding only. Currently, about 35 percent of our work is gear grind only for other gear companies. So, we have become an extension to their gear grinding capabilities for meeting their customers' needs. We appreciate their trust in our gear grinding capabilities.

What are some of Riverside's proudest moments?

Back in 2013, we had our 50th anniversary. We've come a long way from splining parts for the automotive machinery business and have stayed true to our core values in being a leader in the job shop arena.

Where do you see Riverside in the next 10 to 20 years and its place in the gear industry?

Our future is to grow. We have continuing plans for machinery, manpower, systems, and brick-and-mortar. And we have the space to make that happen.

We strive to continue to be our customers' first choice. Our customers tend to come to us first due to our quick quotes, and shorter lead times, quality, and competitive prices.

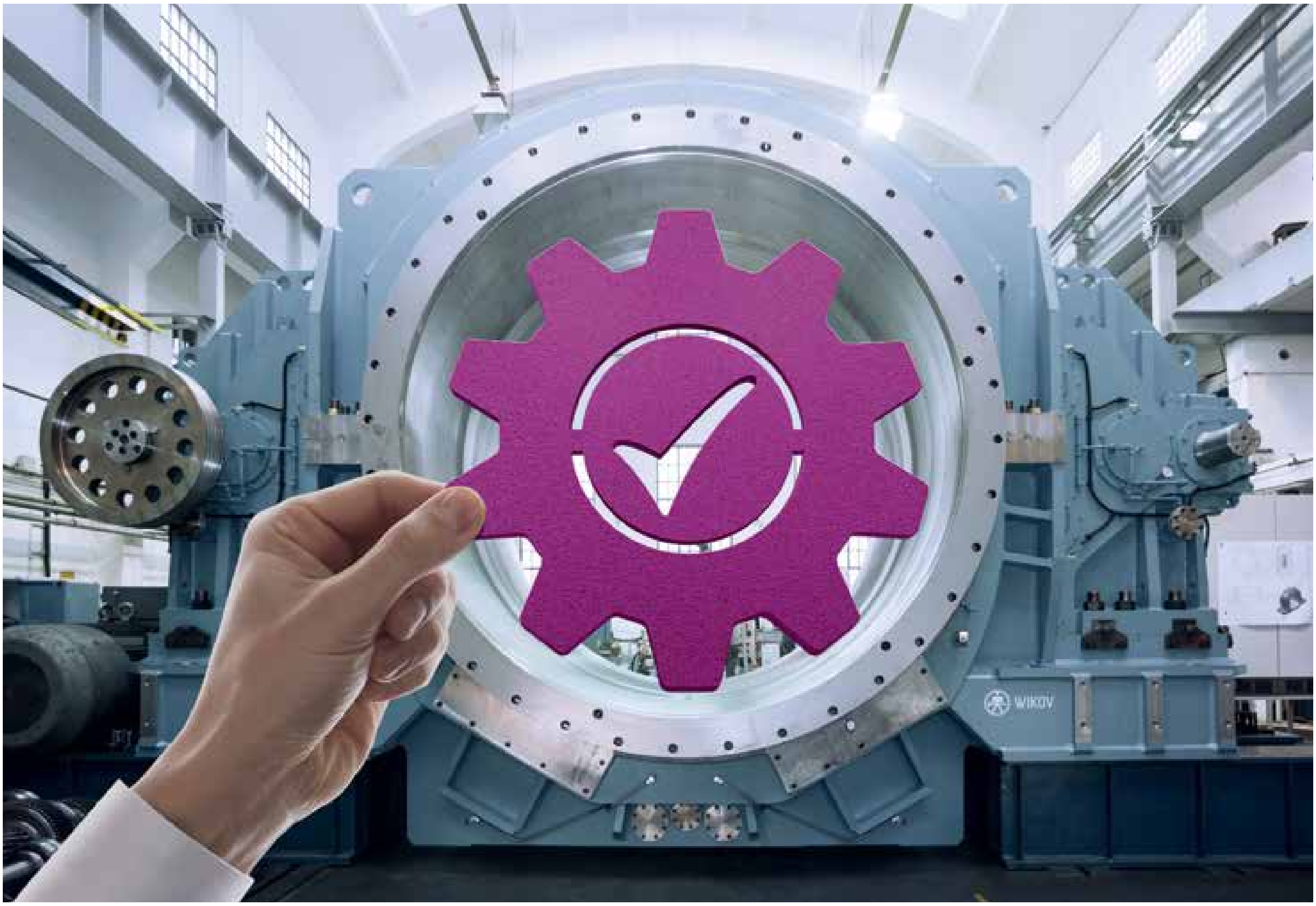
It's easier said than done to be a first choice, of course. We realize it takes a lot of continued commitment, not only in machinery, but in the training of our people. We have a lot of cross training. In the industry today, it is very difficult to find qualified personnel. We often find that home growing is one of the best ways to increase and improve our staff. We find people with good attitude and aptitude, and we grow them in the areas where they excel, and then we stretch them into other areas where they can continue their learning process. This enhances their experience and allows them to grow while contributing to the overall knowledge base of the company. Cross training presents us with the opportunity to move manpower to the work instead of having the work back up in one department. We have a great longevity with our staff. This is greatly important for our future.

We intend to grow the business in four ways:

- Gaining market share with our current customers.
- Adding to our ever-growing customer base.
- Adding machinery and human resources as needed to meet demands.
- Continue to look for adding products and services to the business as we see the opportunities to service our customers better.

In short, we have had a tradition of quality since 1963. We intend to continue this tradition and our tradition of shorter lead times and competitive pricing to meet our customers' product and service needs.

MORE INFO www.splineandgear.com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