RESIDUAL STRESSES IN CASE HARDENED STEEL GEARS

ISSUE FOCUS
Forging / Casting | Gear Grinding

COMPANY PROFILE
STACE-ALLEN CHUCKS
New gear skiving machine LK 300-500
Machine, tool and process from a single source

In the LK 300 and 500 gear skiving machines, process, tools and machine including tool changer and automation system come from a single source because in skiving the delivery of an integrated solution for the customer is of primary interest. Skiving is especially suited for internal gears of medium size and quantity, as it is much faster than shaping and more economical than broaching. The machine can be operated using the touch-based LHGe@Tec control system.

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RESIDUAL STRESSES IN CASE HARDENED STEEL GEARSGears machined from forged billet and as-received bar develop tensile residual stress in the core of the gear following full heat treatment.

By DAVID EASTON, CHRIS AYLOTT, BRIAN SHAW, and SALAH RAHIMI

CHOOSING THE PROPER GRINDING WHEELExperts with Norton | Saint-Gobain Abrasives discuss the challenges of gear grinding and how advances in technology are improving the efficiency of grinding methods.

By KENNETH CARTER

THE PERFECT CROSSED-AXES GEAR PAIRSGear scientists, engineers, and manufacturers have worked successfully for many decades on finding the optimal flank forms and the optimal non-conjugate flank surface interaction.

By DR. HERMANN J. STADTFELD

CHUCKS, WORKHOLDING, AND MORE

COMPANY PROFILE Although it started out manufacturing precision power chucks, Stace-Allen Chucks has expanded into workholding — designing and manufacturing custom solutions to meet its customers’ demands.

By KENNETH CARTER
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New products, trends, services, and developments in the gear industry.

DON ORTMANN
Operations manager at Iosso Metal Processes

AM ethics celebrating anniversary as metal working exhibition.

Atlanta Gear Works grows field services with new vice president.

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

American Gear Manufacturers Association

BRIAN DENGEL
ACHIEVING ZERO-BACKLASH WORM-GEAR PAIRS
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BACK TO BASICS: MARTEMPERING TO REDUCE DISTORTION
This specialized process is more expensive than normal quenching, but the benefits of reduced distortion and reduction of rework worthwhile.

New products, trends, services, and developments in the gear industry.

RESOURCES
MARKETPLACE
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Forging/casting and gear grinding take the spotlight

Squeezing metal into a mold to forge a gear or pouring hot metal into a mold to cast one are often two sides of a very important coin when it comes to creating gears. That’s why Gear Solutions’ May issue focuses on these important processes of gear manufacturing.

This month’s issue tackles that, as well as gear grinding — another vital part of making sure gears reach their final destination with the detailed specifications required of them.

In our Focus section, we publish a technical paper on the residual stresses in case hardened steel gears. In it, experts David Easton, Chris Aylott, Brian Shaw, and Salah Rahimi discuss how gears machined from forged billet and as-received bar develop tensile residual stress in the core of the gear following full heat-treatment.

On the topic of gear grinding, Josh Fairley and Phil Plaite with Norton | Saint-Gobain participate in a Q&A where they talk about the challenges of gear grinding and how advances in technology are improving the efficiency of grinding methods.

In addition to those articles, a feature from Dr. Hermann J. Stadtfeld with Gleason focuses on why today’s hypoids are the perfect crossed-axes gear pairs.

And an issue of Gear Solutions wouldn’t be complete without the expert advice from our knowledgeable columnists. Each of our contributors always offer interesting information, often conveyed in a unique fashion.

Yes, May is finally here. Schools are about to be out, and the weather — if you live in my neck of the woods — is about to become unbearably hot.

So, grab our latest issue and take it to the pool. It may not keep you cool, but the gear information inside certainly is.

As always, thanks for reading!

KENNETH CARTER, editor
Gear Solutions magazine
editor@gearsolutions.com
(800) 366-2185 x204

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AMB 2020 celebrating anniversary as metal working exhibition

From September 15–19, 2020, the heart of metal working will beat in Stuttgart for the 20th time. Every renowned exhibitor will then present their innovations and further developments for the metal working and processing industry over a period of five days at AMB, International Exhibition for Metal Working.

This platform was created together with the industry in 1982 and has been systematically developed since. AMB set new records in 2018. Never before was so much exhibition space (125,800 square meters) occupied or so many exhibitors (1,553) and visitors (91,016 from 83 countries) recorded at the Stuttgart Trade Fair Center.

"With the new Paul Horn Hall, we took an important step in the Master Plan of Messe Stuttgart in 2018 and also, ultimately, for the further development of AMB – the urgently required increase in the amount of exhibition space," said Ulrich Kromer von Baerle, CEO of Messe Stuttgart. Kromer von Baerle said the results from the last financial year are confirmation that Messe Stuttgart can continue forging ahead with the expansion plans that were announced in the 2025 Master Plan.

The CEO of Messe Stuttgart is again expecting that the trade fair grounds will be fully occupied at AMB 2020.

“The increase in the amount of exhibition space has enabled us to restructure the halls according to topics. This new structure has proved very popular and will therefore only be finely adjusted for 2020," said Kromer von Baerle.

The more than 90,000 expected visitors will find solutions and concepts for future production and will meet existing and potential partners at AMB 2020.

The exhibitors will then showcase all their innovations for metal-cutting machine tools, metal-removing process machine tools, precision tools, measuring systems and quality assurance, robots, workpiece and tool handling, industrial software and engineering, components, assemblies, and accessories. The latest topics will include, for example, digitalization in production, additive manufacturing in metal working, or further developments in e-mobility.

The registration phase for exhibitors has begun and will run until June 30, 2019.

AMB 2020 will be backed by the promotional supporters, i.e. the VDMA Precision Tools Association, the VDMA Software and Digitalization Association, and the German Machine Tool Builders’ Association (VDW).

MORE INFO  www.messe-stuttgart.de/amb

Gear alignment automated with vision application from Radix

Radix Technology Solutions, a division of the AIS Technologies Group, has announced the release of a new vision application at the trade show and conference “Automate 2019” set for May 17-20. This vision application, called Gear Tooth Alignment Analytics, is designed to automate the process of precisely aligning differential pinion and gears.

This configurable vision application inspects individual gear teeth (drive and coast), precisely calculating gear mesh contact patterns. With real-time feedback to the operator, this stand-alone application ensures the achievement of rapid and accurate pinion and gear alignment. Additional data provided by Gear Tooth Alignment Analytics includes length and width of pattern, position along the flank, total contact area, along with other metrics of value to gear analysis. An additional benefit to this product is that it requires only minimal roughing on each gear – a process and material savings of substantial value.

"Radix is well-known for our ability to solve tricky manufacturing problems with clever technologies," said Josh Capogna, VP, product innovation. “This is one more example of our commitment to innovation in intelligent

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.
Headquartered in Windsor, Ontario, Radix Technology Solutions designs and delivers award-winning intelligent manufacturing technology solutions for major North American automotive manufacturers, as well as pharmaceutical, food/beverage, and aerospace manufacturers. Radix offers vision systems, robotics, automation, and software with locations in Windsor and Mississauga, Ontario, Trenton, Michigan, and Montreal, Quebec. Radix Technology Solutions is a division of AIS Technologies Group Inc., part of the AIS group of companies.

MORE INFO  www.aistechgroup.com

Atlanta Gear Works grows field services with new vice president

Atlanta Gear Works has named Bill Hoose to fill its newly created position of vice president of field services.

It is the second newly created position in less than a month at the fast-growing gearbox engineering and repair company.

A trained engineer who has contributed to patents in corrosion-resistant alloys and steam turbines, Hoose was previously vice president of engineering at a competitor, where he was well-known in the power and petrochemical industries.

“We created this position because of a growing demand,” said Atlanta Gear Works CEO Jack Conway. “We can save customers days of downtime by doing troubleshooting and repairs on site. That’s what Bill has done for 30 years.”

Atlanta Gear Works field services include a wide range of field machining, including line boring, hydraulic drilling and boring, and journal repair. Available 24/7, its field services crews have been known to work overnight to get a customer up and running.

“Atlanta Gear Works has a lot of field experience and a reputation in pulp and paper, power, plastics, steel and chemical industries with high-quality innovative solutions and responsive service. The company is growing, with a major plant expansion planned for summer 2019.

MORE INFO  www.atlantagear.com

Exact Metrology now distributes GOM CT scanner in U.S.

Exact Metrology has become a distributor of the GOM CT scanner in the U.S. GOM is an established global company and leader in structured light scanning technologies.

The announcement was made by company co-presidents Steve Young and Dean Solberg. GOM develops, produces, and distributes software, machines, and systems for industrial and automated 3D coordinate measuring technology, 3D computed tomography, as well as 3D testing based on the latest research results and innovative technologies.

The computed tomography scanner GOM CT provides 3D data of internal and external component geometries in exceptionally high resolution. The GOM CT produces the finest details visible throughout the component, simplifying initial sampling, tool correction and inspection tasks during production. It captures complex components including the “inner workings” in a single scanning process, so that the user receives a complete image of the test specimen for form and position analysis or nominal/actual comparisons. The system shows its greatest strengths when digitizing smaller plastic and light metal parts.

To achieve a very high level of detail during component digitization, the components of the GOM CT were perfectly matched to each other: A high-contrast 3k X-ray detector generates a very fine pixel grid (3,008 x 2,512 pixels) and thus lays the foundation for high-precision detection of the measured components. 5-axis kinematics with
integrated centering table makes it easier for the user to position the component optimally in the measuring volume, so that the measurement is always performed with the best possible resolution. An additional plus: Within the measuring volume (diameter: 240mm, height: 400mm) several objects can be measured simultaneously in one scan, further reducing processing times. Thanks to the proven GOM technology the GOM CT ensures high precision and repeatable measurement results.

As with all GOM metrology systems, the control of the device, data acquisition and evaluation are combined in a single software package. This means no further software is required; the chain from recording the raw data to creating the measurement report is greatly simplified.

Exact Metrology will house a GOM CT scanner at their Brookfield, Wisconsin, location. Once there, it will be used for customer demonstrations and educational purposes, as well as contract scanning.

GTI Predictive Technology updates VibePro 24/7 online monitoring

GTI Predictive Technology announces numerous updates to its award-winning VibePro 24/7 online vibration and temperature monitoring — now combined with Route Data Collection — to improve data collection for rotating equipment and bearing health. Updates include advanced alerts from route collected data, superior corporate visibility, advanced report creation, integrated thermal images, and Bluetooth sensor capabilities for hazardous area monitoring.

In addition, the latest version of VibePro 24/7 takes predictive monitoring offerings to the next level by allowing users to easily change assets from route collection to online data collection, clone machines, points, and plant areas, and generate long time waveform for ultrasound display. As always, VibePro 24/7 continues to provide route data...
collection and analysis with wireless online vibration and temperature sensors. GTI Predictive VibePro technology provides superior predictive tools on an iPad platform to monitor nearly any asset. Offering portability, connectivity, and affordability, our products give manufacturers an affordable and fully scalable predictive maintenance solution.

The VibePro 24/7 is the most advanced wireless solution for continuous asset vibration and wear monitoring. An unlimited number of wireless motes are managed by a rugged central base station to acquire data for intelligent trending. All machine data is collected in one place, enhancing route collection. The standard VibePro 24/7 mote contains an advanced 3-axis acceleration and temperature sensor that sets a new standard for frequency bandwidth while maintaining outstanding sensitivity. The VibePro 24/7 hardware is designed for demanding environments and is easy to install, enabling a minimal time investment to implement a complete monitoring solution. An expanded antenna selection makes VibePro 24/7 suited for long-range data collection tasks.

Our VibePro 24/7 solution for route-based data collection and analysis combines the features of our award-winning VibePro8 software and GTI-220 wireless portable sensor – adding a new level of asset condition monitoring. Full vibration data is available for route data and online data on the same analysis software platform. All data from every asset is now available anywhere, anytime in the same platform.

Through the VibePro web app, asset condition, and predictive data are available from any Internet-connected device – anywhere in the world.

 MORE INFO  www.gtipredictive.com

Hexagon hosts second Production Software Users’ Group meeting

Hexagon’s Manufacturing Intelligence division will host the second annual Production Software Users’ Group meeting at HxGN LIVE 2019 June 11-14 in Las Vegas. This year’s programming offers an exclusive look at the latest features in the Production Software product portfolio, focused productivity sessions, customer case studies, and valuable interaction with product specialists from Hexagon’s Production Software business (formerly Vero Software, FASys, and SPRING Technologies). This strategic formation of software complements Hexagon’s design, engineering, and metrology businesses and focuses on creating innovative manufacturing intelligence solutions in the production software space. HxGN LIVE is Hexagon’s four-day digital solutions conference where the physical world converges with the digital.

The Users’ Group meeting offers multiple levels of user education from Hexagon’s top thinkers in keynote presentations to interactive sessions with product experts at the ground level. Conference attendees will have exclusive access to insider roadmaps guiding the development of the production software which includes design and manufacturing process optimization, CNC verification technology, tooling and resource management, and specialized solutions for the tooling, production engineering, and woodworking industries. The program is designed to help users and managers enhance their skills, apply best practices, and ensure their com-
panies leverage the latest technologies and user benefits.

The Production Software Users’ Group meeting will be held June 11-13, and will include productivity workshops, interactive productivity sessions, and new-to-market product unveilings. The three-day program features instructional track sessions covering the latest software upgrades and benefits, as well as Advanced User showcases. Conference attendees will have many opportunities to network with production software specialists and peers in the community. Participants will also have access to the entire HxGN LIVE conference with keynote sessions and The Zone technology expo featuring more than 120,000 square feet of transformative technologies from each of Hexagon’s divisions, partners, and other technology vendors.

The conference kicks off June 11, with two sessions featuring Production Software CEO Steve Sivitter and Regional Director-Americas Nick Spurrett speaking to users about current and future product developments, and how the company’s partnerships translate to greater return on investment for the user community. These sessions will be followed by the late afternoon HxGN LIVE Keynote address by Ola Rollén and reception.

On June 12 and 13, participants will be presented with four solution-specific one-hour sessions on each day for users of CABINET VISION, EDGECAM and SURFCAM. These will include sessions on 2019 product reviews dedicated to using the software latest developments, productivity workshops that will include introductions to new products, and...
advanced user showcases. Customer feedback is a valuable aspect of the event, so each session includes live ask-the-experts opportunities with brand managers and product specialists. The group will also partake in executive-led sessions covering Hexagon’s Manufacturing Intelligence division and its vision for the Smart Factory and the future.

MORE INFO hxgnlive.com

**KISSsoft offers tools for manufacturing multiple gear types**

When grinding helical gears an unwanted production-related twist is generated. This twist can be simulated in advance in the KISSsoft Release 03/2018 (module ZY6), and the influence on the flank contact can be evaluated with contact analysis.

When designing hardened and ground gears, the grinding notch must be taken into account with regard to position and rounding radius in order to avoid stress concentrations. In addition to the ISO 6336 standard and FEM in 2D (module ZA24), KISSsoft also provides evaluation with FEM in 3D (module ZA37). This evaluation is based on the exact load distribution over the tooth width and enables the consideration of crowning and axial misalignments with respect to the load distribution, which results in a much more precise analysis of the stresses over the tooth width.

With the use of protuberance hobs, the grinding notch can be avoided or significantly reduced. The protuberance can be specified in KISSsoft on the reference profile as well as on the tool (hobbing cutter, cutting wheel), and checked in numerous graphics for gear teeth, tools, and production.

MORE INFO www.kisssoft.com

**MarSurf GD Series offers unprecedented measurement options**

Mahr Inc., a leading provider of dimensional metrology solutions, has added the MarSurf GD series for roughness measurements to its new line of surface measuring instruments. MarSurf GD series measuring stations provide unprecedented levels of speed, flexibility and intelligent ease of use, allowing users to improve the manufacturing quality of workpieces with faster throughput and higher accuracy for the broadest range of applications. Developed from the ground up with the leading technology, quality, and

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KISSsoft provides a number of useful tools for gear manufacturing throughout the design process. (Courtesy: KissSoft)
innovation that Mahr is known for, the new MarSurf GD series enable profile and waviness evaluations to be carried out in addition to surface roughness evaluations.

The MarSurf GD series significantly increases the speed of all moving axes to reduce the cycle time of the measurement process, allowing more throughput — which is particularly valuable when used directly in the production environment. The drive units of the MarSurf GD series move the probe with positioning speeds of up to 200 mm/s, making the systems up to 40 times faster than predecessors. All Z-axis columns on the measuring stands of the MarSurf GD series are fully CNC-capable with fast positioning speeds of 50 mm/s, which is up to five times faster than standard Z-axes on the market today.

The MarSurf GD series also offers the ultimate flexibility with available sizes of 140mm and an industry-first 280mm. The 280mm measuring station allows for the measurement of applications that were previously impossible, including larger parts or a series of smaller parts staged together — all on the same machine.

Furthermore, all MarSurf GD series products are equipped with intelligent MarWin,

The MarSurf GD series offers ultimate flexibility with available sizes of 140mm and an industry-first 280mm. (Courtesy: Mahr Inc.)

Easy Roughness software to provide the ultimate ease of use. Many operations can be performed right out of the box, such as creating instructional UIs to guide a user through all the steps of a specific measurement.

“The new MarSurf GD enables manufacturing companies to reach a new dimension in roughness measurements to reliably secure and improve the quality of workpieces in the production environment or lab,” said Pat Nugent, vice president of product management at Mahr. “From a size perspective, there just isn’t anything on the market of its kind, which now enables our customers to measure a whole new range of applications, combined with high speeds that enable a throughput of substantially more parts per hour in a production environment.”

The GD Series features a large mounting plate with 50 mm bore pattern, 60 mm Y adjustment, and Z-axis of 350mm or 600mm. Available with standard probe arm lengths up to 135mm (3x length) for measuring ranges up to 1.5mm vertically, these instruments are also capable of measuring contour features such as radius, angle, or depth within that range. All probe arms feature a quick-change magnetic mount to ensure the fastest change-over time, as well as extra security allowing the probe to “break away” in the event of an accidental collision — protecting both the probe and the system.

The GD series also includes an integrated turret to rotate the probe to 90 degrees for...
transverse measurement and the ability to rotate the probe system 180 degrees to allow “upside down” measurement.

MORE INFO  www.mahr.com

MTB names Warren as its new director of sales and marketing

MTB Machine Tool Builders Inc, the industry leaders in machine tool sales and service, has named K.C. Warren as the company’s new director of sales and marketing. Warren will report directly to the ownership team and is tasked with further developing the company’s rapidly growing position in the machine tool marketplace. He will oversee sales and marketing operations and will be responsible for team leadership, planning and implementing sales, marketing and business development programs, business strategy execution, and product development as well as general management responsibilities. Warren will focus on driving revenues through long-term customer relationships, delivering customized high-value solutions to meet individual customer needs and pursuing new business opportunities that continue to increase MTB’s market share of best-in-class products and services.

Warren comes to MTB with 17 years of executive-level experience, having held technical sales and marketing leadership positions with several companies where he was responsible for building, managing, and leading global sales organizations. Warren is a well-known figure in a variety of industries and markets that include automotive, industrial automation, process control instrumentation, industrial manufacturing and environmental technology. He received national recognition for customer service excellence and has been a key contributor in a number of product innovations and technology advancements that were crucial to each organization’s success.

Warren brings a deep understanding of highly engineered systems and applications allowing him to quickly identify customer needs and provide high value solutions. He brings a proven record of forging relationships with some of the largest companies in the world, working directly with OEMs, integrators, dealers, representatives, distributors, engineering firms, sales partners, reseller accounts, and end-users.

“I am excited to join the dedicated and passionate team at Machine Tool Builders. I’m very fortunate to be joining such a well-respected company that prides itself on best-in-class products and services and achieving absolute customer satisfaction,” Warren said. “I was attracted to MTB given their reputation in the industry. After meeting with ownership, I quickly realized we shared many of the same philosophies, primarily a commitment to serving customers, listening to their needs, and delivering high-value solutions that build positive long-term relationships. “I believe in being proactive to the customer needs, not reactive. That means understanding the applications and processes working together to identify and eliminate issues before they become problems. The goal is to exceed the customer’s expecta-
tions, providing them highest quality products, services and solutions. MTB shares that same passion so it was a perfect fit.”

MTB President Kenneth Flowers said, “We are very excited to welcome K.C. to our team as director of sales and marketing. Our new product and service innovations, coupled with an increasing demand from our customers, led us to look for a new addition to our leadership team, one who also fit with our company philosophy. K.C.’s experience and drive are exactly what we need to introduce our offerings to new markets. I’m confident that K.C. will play a key role in providing and implementing high quality solutions for our clients. Not only will he bring a focus on customer relationship quality to our sales team, but he also possesses a strong sales and marketing background and is very knowledgeable in aspects of business operations. He will be a great resource for our employees, customers and vendors who come into contact with him.”

MTB is a provider of machine-tool technology, systems engineering, and servicing solutions to the machine-tool and gear-manufacturing industry. That includes rebuilding, retrofitting, re-control, maintenance and repair of machines as well as new and used sales along with consulting services.

MORE INFO  www.machinetoolbuilders.com

SCHWING Technologies’ fluidized bed technology aids tool quality

Rolls, extruder screws, and broaching tools are all characterized by a wide variety of stress ranges with specific mechanical properties. In order to set the desired individual characteristics, the corresponding areas must be tempered separately.

For example, the tool surfaces used for power transmission are exposed to greater torsional forces and highly dynamic stresses, so require special toughness. Due to intense wear, other work areas require more strength. A sophisticated technology is required to achieve the correct precise properties in a targeted, safe, and environmentally friendly manner.

“This is exactly what our fluidized bed systems offer,” said heat-treatment expert Andreas Guderjahn from SCHWING Technologies. High-temperature uniformity is their particular advantage. In addition, they offer the best heat-transfer properties and are characterized by particularly homogeneous heat distribution.”

Rolls, extruder screws, and broaching tools can easily be immersed in the fluidized bed with the tool end or shank to be tempered. SCHWING systems ensure consistent quality. Further advantages for customers are the short process times and the flexible loading options. In contrast to the induction process, for example, in which individual inductors must be used, parts of different shapes and dimensions can be processed in one single fluidized bed.

SCHWING systems guarantee the highest temperature accuracy across the workpiece and reproducibility of each individual process.

SSC Werkstofftechnik GmbH, based in Lüdenscheid, benefits from this. The company has been working with fluidized bed systems from SCHWING for several years. Dirk Pritschke is managing director of SSC and particularly appreciates the fact that he can partially temper his customers’ rolls at the...
desired temperature within a very short time.

The systems are indirectly heated by electric heaters and can be used over a wide temperature range, from room temperature to 1,050°C. Fine-grained aluminum oxide is fluidized with compressed air or other gas in a process chamber resulting in a fluidized bed that is not only highly thermally conductive, but also has a special heat capacity due to its mass.

“The rolls can easily be immersed in the fluidized bed. We can then treat them very precisely at the desired temperature. The process can be carried out quickly and the results can be reproduced at any time,” said Pritschke.

Nikola Labs launches VERO equipment monitoring system

Wireless power pioneer Nikola Labs will launch VERO, the perpetually powered equipment health monitoring system. An Industrial Internet of Things (IIoT) solution, VERO is an out-of-the-box system for manufacturers to closely monitor process critical equipment.

Although the VERO platform will most immediately impact the manufacturing industry, Nikola leaders envision a future in which its unique wireless power will be used across industries.

“Think of how wireless Internet revolutionized Internet connectivity. Before, the interface was the Ethernet cord. Then, Wi-Fi created mobility,” said Will Zell, CEO and co-founder of Nikola Labs. “The transition from wired to wireless power delivery is going to have a similar effect; 20 or 30 years from now after the revolution has taken its course, wireless power will be part of our everyday lives.”

Nikola Lab’s proprietary VERO platform is entirely wireless and maintenance free, powered by cells that convert radio frequency energy (RF) into usable direct current (DC) power. The wireless energy conversion technique that powers VERO was developed and patented at The Ohio State University, and is licensed exclusively to Nikola Labs.

Perpetually powered wireless sensors save time for facility managers. Once Vero is installed, data capture and system maintenance are touch-free.
“Battery-powered sensors have a life of one to three years. That’s OK if you have one device, but imagine if you have a thousand. You’d have to hire a full-time maintenance person who walks around doing nothing but replacing batteries. That’s a nightmare,” Zell said. “The whole promise of the Vero system is you can make maintenance more efficient.”

The VERO system can be customized and retrofitted to any size or age production equipment. Once Nikola Labs installs the system, plant technicians have immediate access to the sensors’ data, and that information is translated into real-world recommendations by a live analyst.

The VERO platform allows a manufacturer to shift from a time-based maintenance schedule to a condition-based maintenance schedule. Customers tell Nikola that VERO data is more robust than previous maintenance diagnosis methods.

VERO is subscription-based and includes a free trial period. Custom design of the system, professional installation and lifetime hardware and software upgrades are included.

MORE INFO  www.nikola.tech

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Weiler Abrasives recognized for veterans training campaign

Weiler Abrasives, a leading provider of abrasives, power brushes, and maintenance products for surface conditioning, received the People’s Choice Innovation Impact Award at the 2019 Industrial Supply Association Convention in April. The award, which honors manufacturers who bring innovative products or services to the industrial MROP channel, is in recognition of the “Leading a Warriors Charge” campaign the company launched in May 2018.

The campaign supports Workshops for Warriors, a nonprofit school providing machining and welding training to veterans, wounded warriors, and transitioning service members with the mission to “Rebuild American Manufacturing One Veteran at a Time.”

“We are excited to be recognized by our peers in our efforts to bring awareness about Workshops for Warriors,” said Nate Schmid, director of marketing – Americas, Weiler Abrasives. “It’s taken a lot of hard work to bring the campaign to life, but we are proud to be able to support our veterans as they train to have successful careers in the advanced manufacturing sector. We hope that other manufacturers and industrial distributors will follow in our footsteps.”

The “Leading a Warriors Charge” brand awareness and fundraising campaign includes print and digital advertising, video, distributor showroom displays and promotions, tradeshow signage, and a website where visitors can donate and read about success stories from Workshops for Warriors’ graduates. To date, the campaign has helped raise more than $77,000 for Workshops for Warriors.

As an industry leader and global manufacturer of surface conditioning solutions, Weiler Abrasives Group is dedicated to forging collaborative relationships with customers in diverse markets — metal fabrication, industrial production, and maintenance, repair, and operations — to tackle the toughest cleaning, grinding, cutting, deburring, and finishing challenges.

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INDUSTRY NEWS
Expanded MPT Expo filled with new opportunities and quality programming

According to the Center of Exhibition Industry Research (CEIR), more than 90 percent of tradeshow attendees come to learn about new services and products in their industry, and about 81 percent of the attendees have buying authority. Those are great numbers for any exhibitor at any show. At the inaugural Motion + Power Technology Expo (MPT Expo), the whole premise of bringing the entire power transmission supply chain — mechanical, electric, and fluid power — together is to attract attendees near and far who are looking for the full spectrum of products under one roof. We are making it convenient for your customers to get everything they want.

The statistic I want you to focus on, for now, has to do with time spent at a tradeshow and why having a robust offering of events and education might increase the exhibitor ROI. CEIR gives another great statistic that the average attendee spends 8.3 hours viewing exhibits at a tradeshow. In those hours, we want to give our attendees the latest technology on the show floor, and as much valuable networking and education time as possible, so they’ll keep coming back for more. MPT Expo is more than just a name change; it is a move to make a three-day tradeshow now a three-day experience, and we want to keep people there as long as we can.

AGMA’s tradeshow has a great reputation for high-quality leads and a strong, decade-long relationship with ASM International’s Heat Treat Society and now a new partnership with the National Fluid Power Association (NFPA). In addition, the Fall Technical Meeting has brought in hundreds of engineers from all over the world who are looking for the latest advancements in gear technology and processes. And, finally, education courses have been a crucial element to providing attendees an opportunity to enhance their knowledge while at the show. It has been a priority to make sure that, with MPT Expo, we not only continue offering these programs but that we enhance them with more networking and learning opportunities to keep your customers coming.

That is why you will find some new and exciting events happening in October during MPT Expo. After looking at our attendee base, we decided that we wanted to offer a conference with learning tracks for those end-user customers and other non-engineering attendees that form a significant portion of the show’s attendance base. We wanted to keep up with market trends and make available subject-matter experts in the areas of emerging technology and all things business that might affect manufacturing. That is where the MPT Conference was born. This three-day event, concurrent with the tradeshow, offers attendees the following:

**KNOW YOUR BUSINESS (BUSINESS INTELLIGENCE)**
- Blockchain
- Workforce Development
- Market Trends & Economics
- Contracts & Supply Chain Management

**BE PREPARED FOR THE FUTURE (EMERGING TECHNOLOGY)**
- IIoT
- 3D-Printed Metal
- Robotics
- Electric Drive Technology

With presenters coming from all over the country from companies such as Meritor, Schaeffler, Siemens Gamesa, MTConnect, Machine Metrics, Oxford Economics, FANUC Robotics, Veo Robotics, and IHS Markit, these quick 45-minute sessions are going to be very popular. Not only does this conference offer learning opportunities to an additional group of buyers and attendees, but it provides exhibitors the ability to have their customer come back for three days in a row to conduct business in between sessions.

Lastly, one of the most important deliverables that a tradeshow can offer is time with your customer. Another important statistic from CEIR states that more than 50 percent of expo attendees are there for the first time, and they travel more than 400 miles to be there. That means there is a lot of potential for new business, and you better get to them while they are there face-to-face. That is why we thought it was important to offer more networking opportunities so you can get to know, not only your customers, but other companies in the power-transmission supply chain to build upon your platform.

For the first time, AGMA, NFPA, and ASM International will be hosting two new and different networking events to demonstrate a true commitment to showcasing the diversity within the manufacturing and engineering industries. Keynote speaker Stacey DelVecchio, additive manufacturing product manager at Caterpillar Inc., and the Michigan chapter of Women in Manufacturing will be at the Women in Manufacturing Breakfast that is open to all who...
Upcoming Courses

GEAR FAILURE ANALYSIS
JUNE 12-14, 2019 | ST. LOUIS, MISSOURI
Explore gear-failure analysis in this hands-on seminar where students not only see slides of failed gears but can hold and examine those same field samples close up. Experience the use of a microscope and take your own contact pattern from field samples.

BEVEL-GEAR SYSTEM DESIGN
JULY 10-12, 2019 | OAKLAWN, ILLINOIS
Learn how to design and apply bevel-gear systems from the initial concept through manufacturing and quality control and on to assembly, installation, and maintenance. Engage in a practical hands-on guide to the bevel-gear design, manufacture, quality control, assembly, installation rating, lubrication, and most especially, application.

DETAILED GEAR DESIGN
AUGUST 20-22, 2019 | CLEARWATER BEACH, FLORIDA
Learn how to improve gear designs and gain new insight into concepts presented through illustrations and demonstrations. Explore all factors that go into good gear design from life cycle, load, torque, tooth, optimization, and evaluating consequences.

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

AGMA’s online education courses include:
- Gear Failure Analysis.
- Gearbox CSI: Gears Only.
- Detailed Gear Design—Beyond Simple Service Factors.
- Fundamentals of Gearing.
- Hobbing.
- Parallel Gear Inspection.

MOTION + POWER TECHNOLOGY EXPO IS OPEN FOR REGISTRATION

AGMA and NFPA welcome you to register for the inaugural Motion + Power Technology Expo happening October 15-17 at the Cobo Center in Detroit, Michigan. Finally, there is a show that incorporates all parts of the power-transmission supply chain while providing solutions for manufacturers, suppliers, buyers, and experts in the mechanical, electrical, and power transmission industries.

This three-day event has everything from products, machine tools, services, and technologies across a variety of industries including automotive, material handling, machine-tool manufacturing, agriculture, off-highway, construction, and much more. There are endless networking opportunities, educational sessions, and the AGMA Fall Technical Meeting. Don’t miss your chance to move the future.

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CONTINUED FROM PAGE 19

are exhibiting or attending the MPT Expo. Those who are 35 or younger are encouraged to attend the new Young Professionals Reception so they, as future leaders in their industry, can build their own peer network to help foster future business relationships. We feel these two new opportunities add a dynamic and innovative way to build your networks within all parts of the industry.

These two events, coupled with already popular networking receptions Tuesday and Wednesday evening, provide all at MPT Expo with the ability to conduct business both in their booth and outside of the show floor. This kind of access to customers and business executives will foster the environment that will allow exhibitors to get the best ROI in just three days at the show. We understand tradeshows are a big investment, and we have dedicated our best resources and strategy to making sure the MPT Expo is moving in the direction of our industry. The vision of MPT Expo is creating a dialogue, a collaboration, and securing a future for all our members. Being a part of this is being a part of the future.

MORE INFO

For more information about MPT Expo or to register to attend, please visit: motionpowerexpo.com.
CALÉNDAR 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.

May
- May 14 — Wormgearing Committee Meeting — WebEx
- May 21 — Cutting Tools Committee Meeting — WebEx
- May 22 — Gear Accuracy Committee Meeting — WebEx
- May 23 — Metallurgy and Materials Committee Meeting — WebEx
- May 28 — Helical Gear Rating Committee Meeting — WebEx

June
- June 4 — Aerospace Gearing Committee Meeting — WebEx
- June 5 — Bevel Gearing Committee Meeting — WebEx
- June 11 — Helical Gear Rating Committee Meeting — WebEx
- June 13 — Wormgearing Committee Meeting — WebEx
- June 19 — Helical Enclosed Drives High Speed Units Committee Meeting — WebEx
- June 20 — Helical Enclosed Drives Marine Units Committee — WebEx

July
- July 10 — Helical Enclosed Drives High Speed Units Committee Meeting — WebEx
- July 11 — Metallurgy and Materials Committee Meeting — WebEx
- July 16 — Cutting Tools Committee Meeting — WebEx
- July 16 — Aerospace Gearing Committee Meeting — WebEx
- July 17 — Gear Accuracy Committee Meeting — WebEx

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OK. We can do that!

ZE 800 profile grinding

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Achieving zero-backlash worm-gear pairs

Unique duplex worm gear pairs that minimize backlash in reversing applications.

Life is full of opposing views. If you are heading to the beach, then you want to have the “perfect” beach body. This requires a strict adherence to a healthy diet and a strong gym regimen. After a fun day in the sun, you want to relax with friends over a few beers and some great eats. However, relaxing in this manner will change your beach bod into a Dad bod. With worm gear pairs, there is a similar situation. You design the system to achieve a certain speed reduction, at a particular torque load, but the backlash in the system throws off the repeatability of the mechanism.

The usual method of adjusting the backlash of a worm-gear assembly is to modify the center distance. Once assembled, such adjustment requires a major rework of the gearbox housing. One method for eliminating the backlash is to use a spring-loaded split worm or a spring-loaded split-worm wheel. These two styles of anti-backlash worm gear pairs are limited in their loading due to the limitations of the spring rate. However, the use of duplex worm gears allows the backlash adjustment to be made by axially shifting the worm. This simplifies greatly the assembly and maintenance operations.

Because worm-gear pairs are a friction-drive mechanism, it is critical that the worm has a surface strength (durability) that is greater than that of the worm wheel. When the worm reverses rotation, there is a loss in engagement of the worm-wheel teeth as a result of backlash. When the backlash is minimized by reducing the center distance, there is an increase in wear due to increased contact area.

A duplex worm gear pair consists of a dual-lead worm and a corresponding worm wheel. The dual-lead worm is formed to give a difference between the right tooth surface and left tooth surface so it provides a unique tooth profile in which the tooth thickness varies continuously, corresponding with the lead difference. (Figure 1)

When such a worm and worm gear are set up at a constant assembly distance and the worm is moved in the axial direction, the tooth thickness of the worm in mesh with the worm gear changes, making backlash adjustment possible. The amount of change in backlash ($\Delta j$ mm) in relation to the axial movement of the duplex worm shaft ($V$ mm) can be calculated from the following formula:

$$\Delta j = 2V \frac{m_b - m_a}{m_a + m_b}$$

where

$$m_a = \text{Nominal Axial Module} - (0.01 \times \text{Nominal Axial Module})$$

$$m_b = \text{Nominal Axial Module} + (0.01 \times \text{Nominal Axial Module})$$

When the worm is held with an arrow mark pointing right, the tooth thickness is thinner on the right and thicker on the left. Therefore, moving the worm to the right causes the thicker teeth to come into actual engagement with the worm gear, thereby reducing the backlash. (Figure 2)

The KHK duplex worm is designed so that, for all modules, the backlash reduces by 0.02 millimeters for each 1 millimeter that the worm is shifted. As the worm wheels are produced with a backlash range of -0.045 to +0.045, a 2-millimeter axial adjustment can result in a zero-backlash pair.

These worm-gear pairs are excellent choices for rotary tables, ultra-low backlash gearboxes, and other high accuracy reversing applications.
When there is absolutely no room for error, we deliver extreme accuracy, reliability, and unyielding consistency.

Excellence without exception.
Back to basics: Martempering to reduce distortion

This process is more expensive than normal quenching, but benefits of reduced distortion and reduction of rework make it worthwhile.

In the previous article, we discussed the principle of quench and temper, which is arguably the most common type of steel heat-treating. In this article, we will discuss the principles of martempering.

Martempering [1] is a specialized process that is only used when distortion and high-residual stresses are an issue. In this process, parts are quenched from the austenitizing temperature into hot oil or molten salt at the approximate martensite start temperature (100°-200°C). The part is held at this temperature until the surface and center temperatures of the part are nearly the same. Once the center of the part has reached the quenchant temperature, the part is removed from the quenchant and allowed to cool in any convenient manner (usually air cooling). This prevents the formation of thermal stresses due to unequal cooling between the center and surface (Figure 1) and uniform transformation of austenite to martensite.

If complete hardening is to occur, the austenite must cool sufficiently fast to prevent the center cooling rate to miss the “nose” of the TTT diagram. Since the TTT diagram shows the martensite start temperature, Ms, the TTT diagram is useful for selecting the optimal quenchant temperature, and estimating the time the part must be held at temperature to prevent the formation of bainite.

The primary advantage of martempering is that parts will have lower distortion and reduced residual stress. This is from reduced thermal gradients during quenching and relatively uniform transformation of martensite. Martempering can be accomplished in either oil or molten salt. Typical temperatures for martempering, some through hardening and carburized grades, are shown in Table 1.

As indicated above, the part is held at approximately the martensite start temperature (Ms) for a period of time, to minimize the thermal gradients from center to surface. The maximum time for this thermal hold is dependent on the bainite start time on the TTT diagram. The part is withdrawn from the bath before bainite is allowed to form.

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

Martempering is especially appropriate for bearings, gears, and shafts, where the parts are costlier to fabricate and are made to closer dimensions. This is illustrated in Figure 2, where the distortion is shown as a function of martempering temperature.

The limitations of section thickness must also be considered for suitability for martempering. With a given severity of quench, there is a limit in section thickness, where the steel will no longer harden fully or transform to martensite (Figure 3). However, depending on the application, it may be acceptable for the center of the part not to be completely transformed to martensite. Often times it is acceptable that the core hardness is less than the surface hardness. If this is the case, then the size for martempering can be increased (Figure 4). The effect of the resulting mixed microstructure on the mechanical

Figure 1. Schematic representation of martempering.

Figure 2. Distortion of SAE 52100 bearing races as a function of martempering temperature. [2]

Table 1. Typical martempering temperatures in oil and molten salt [3].
properties would have to be evaluated for each application.

As a general rule, distortion decreases with increasing temperature. This is due to the reduction of thermal gradients during quenching.

A manufacturer of small parts was exhibiting extremely high distortion of SAE 1075 parts. They were martempering the parts at 250°F (121°C) and seeing upwards of 80 percent scrap on certain parts. This led to high rework and material costs. The recommendation was made to increase the martempering temperature. A trial was initiated to increase the martempering temperature up to 176°C (350°F). The results (Figure 5) showed substantial improvement in the percent scrap due to heat treating distortion. Upwards of 80 percent improvement in the scrap generated was achieved [4].

Since martempering uses elevated temperatures of typically 225°-325°F (105°-160°C), the quench oils used must be specially formulated from quality-base stocks and extensive anti-oxidants.

Adequate make-up oil must be added on a routine basis to replenish the additive package present in the quench oils. Because of these temperatures, martempering oil generally has a shorter life than a cold oil. Depending on the application and use (as well as the care and maintenance of the oil), it is not uncommon for martempering oils to be dumped and recharged at 24- to 36-month intervals. Proper care of the oil, including strong filtration, can extend the life of the oil. Generally, the oil is dumped not because of inadequate properties, but due to staining of parts.

CONCLUSIONS
In this short article, we have discussed the benefits of martempering to reduce the distortion and residual stresses of gears, shafting, and bearings. Martempering is a more expensive process than normal quenching, but the benefits of reduced distortion and reduction of rework more than pay for the additional cost.

In the next article, we will discuss the process of austempering. Should you have any questions regarding this, or any other article, please do not hesitate to contact the author.

REFERENCES

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RESIDUAL STRESSES IN CASE HARDENED STEEL GEARS
Aerospace gear components are required to demonstrate excellent load-carrying and endurance characteristics. Case-hardened steels are often used for these parts. During the manufacturing process of case-hardened steel gears, residual stresses are developed. The nature and distribution of these stresses are known to have a significant effect on distortion during heat treatment and machining processes. The fatigue performance of a gear subjected to cyclic loading is also strongly dependent on the nature and magnitude of manufacturing induced residual stresses.

In this work, the development of residual stress during the heat treatment and machining process has been assessed in case-hardened steel alloy spur gears. Gears have been manufactured from two different initial conditions: as-received bar material, and hot-forged billet. A spur-gear geometry was rough-machined prior to full heat treatment, and subsequent surface finishing. The evolution of bulk residual stress distribution within the gears throughout the manufacturing process was measured using the Contour Method. Surface residual stresses, complimentary to contour method, have been measured by X-ray diffraction.

Gears from both manufacturing routes (i.e. machined from forged billet and as-received bar) were found to develop tensile residual stress in the core of the gear following full heat treatment. High compressive stressed regions develop at the carburized case region at the exterior of the gear. The final residual stress magnitude and distribution within the gear was found to be independent of the initial forming process.

INTRODUCTION

Gears are typically subjected to high levels of cyclic loading and stresses in service, and as such are susceptible to fatigue failure [1]. Forging of gears and gear blanks has been shown to have the potential to improve mechanical properties such as impact toughness and fatigue strength [2]. Fatigue of gears is typically initiated at the site of inclusions in the region of the maximum bending stress [1]. Inclusions, or macrosegregations, can be broken down by the forging process and this has the potential to improve fatigue performance. Additionally, forging can influence the flow lines of micro segregations, which can enhance or detrimentally affect fatigue performance depending on orientation [3]. Navas found that the effects of forging on microsegregation structures can remain even after normalizing heat treatment [4]. The effect is heterogeneity in the distributions of hardness and residual stress distribution.

In addition to microstructural features, residual stresses are a dominant factor in the fatigue performance of gear components [5, 6]. Compressive residual stresses can reduce the effective stress experienced in the gear tooth under a tensile applied bending stress. A number of studies have been conducted to investigate the residual stress state of gears. Particular attention is paid to the effect of surface treatments such as peening [7-9], induction hardening [5, 10, 11], and heat treatment [12, 13] on the resulting residual stress state of the gear.

Residual stresses also play a significant role in distortion of gears during manufacture and operation [10, 14, 15]. The forming route, i.e., hot forging, was shown to have an effect on the distortion behavior of the S156 steel considered in this work [16].

It is therefore important to distinguish between the effects of residual stress and the effects that forging can have on the microstructure of a gear steel when considering fatigue performance of a gear. In the current work, gears have been manufactured from two processing routes; machined directly from as-supplied bar stock, and machined from a hot forged “pancake” gear blank. The residual stress evolution from the initial condition through the entire manufacturing process to a fully machined, heat-treated and surface-treated condition has been investigated for both forming routes. The effects of forming route on the fatigue performance of gears shall be presented in a future work.

Residual stresses have been assessed using two methods: X-ray diffraction (XRD) and Contour Method. XRD measurement, in conjunction with electropolishing layer removal, provides residual stress from the surface of the gear tooth to a shallow depth into the part (i.e., near surface). Contour Method provides residual stress magnitudes and distributions across a section of the gear from the tip of the tooth to the inner bore. By adopting two measurement methods, a clear understanding of residual stress evolution during manufacture and the difference in stress states between forming routes can be obtained.

EXPERIMENTAL METHODS

GEAR MANUFACTURE

Gears were manufactured using two manufacturing routes: machined-from-bar stock and machined from a hot-forged pancake. All gears were manufactured...
from S156 martensitic steel with nominal composition shown in Table 1. The S156 steel bar was supplied in the hot extruded, normalized and annealed condition.

Forging was performed at the AFRC using a Schuler AG 2,100-ton screw press. Forging preforms were heated in a protective gas furnace at 1,050°C prior to transfer to the screw press die. A forging reduction of at least 50 percent was implemented to ensure further breakup of macro segregations that can be present in the as-received bar stock.

The forged pancake, and resulting gear profile following machining, is shown in Figure 1. The gear geometry was selected by NUDU to be suitable for single tooth bending fatigue testing (results not presented here). The gear comprises an outer diameter of approximately 120mm, with a 10mm tooth height.

The gears were machined close to the final geometry, with 0.2 mm stock remaining to be removed at the final machining stage. The parts were then heat-treated as shown in Table 2. Gears from both manufacturing route (forged and bar) were heat-treated together to ensure no batch variability. Normalizing and subsequent annealing was performed to relieve residual stresses induced by the forging process. The gears were final machined after completion of the heat-treatment cycle. Shot peening was then applied using a dual-shot process. Finally, superfinishing was conducted to prepare the gears for testing.

### X-RAY DIFFRACTION RESIDUAL STRESS MEASUREMENT

Surface and near-surface residual stresses were measured at NUDU using XRD and electro-chemical polishing layer removal. A Stresstech Xstress 3000 diffractometer was used for all measurements reported. All of the measurements were carried out at mid-facewidth and as close as practicably possible to the 30° tangent point in the root fillet (i.e. the point of maximum bending stress during testing). A 0.8mm aperture size was used. Table 3 details the parameters used for XRD measurements.

The gear tooth was masked leaving the measurement location exposed. Material was removed incrementally using electro-chemical polishing. XRD residual stress measurement was conducted after each material removal stage. Stresses were measured in two principal directions: the direction running across the facewidth (lead), and root to tip direction (profile). The orientation of the measured stress directions can be seen in Figure 5.

### CONTOUR METHOD RESIDUAL STRESS MEASUREMENT

The Contour Method residual stress measurement technique was introduced by Prime [17] as a convenient means of measuring a 2D map of residual stress across an entire section of a part, in the out-of-plane of the cut direction. Based on Bueckner’s superposition principle [18], the original residual stresses in a part can be determined from the elastic strain required to force a cut surface back to plane conditions following electric discharge machine (EDM) cutting (Figure 2).

In a stress-free part, the surface displacement following EDM cutting will be zero. In a stressed component, elastic relaxation of residual stresses causes surface displacements. The cut surface topography is measured using a Coordinate Measuring Machine (CMM). Surface fitting techniques are applied to the measured topography. The surface topography is then applied as boundary conditions in a finite element analysis (FEA) to calculate the original residual stress in the gear.

A multiple step cutting strategy was adopted for the EDM sectioning portion of the Contour Method. In a cylindrical component with a bore, such as the gear considered here, the presence of hoop stresses can cause the part to distort during sectioning. To account for the relaxation of these stresses, an initial “opening” cut is made. A line was scribed parallel to the cutting plane 5mm on either side of the EDM wire path.

After cutting is completed, the clamping is released and the part
is free to move due to stress relaxation. The measured relaxation-induced movement is then combined analytically with the Contour Method results to determine the true stress state [20]. Following the hoop stress release cut, the part is sectioned using cutting/clamping conditions suitable for Contour Method analysis. The location of both cuts is shown in Figure 3.

In this instance, minimal movement was observed during hoop stress release (<0.5mm). Therefore, the Contour Method calculation is taken to be a true representation of the stress state without the requirement for hoop stresses.

The success of a Contour Method residual stress measurement is highly dependent on minimizing bulk movement of the part and development of localized plasticity at the tip of the cut during cutting [21, 22]. A bespoke clamping fixture (Figure 3) was developed to mitigate against bulk movement and localized plasticity developing. EDM cutting was performed using an Agie Charmilles wire EDM with 0.25 mm diameter brass wire. “Skim cut” settings were used to achieve the best possible cut and to minimize errors in the resulting surface topography.

The location chosen for Contour Method analysis was from the tip of the tooth through to the inner bore, with the out-of-plane stresses measured being the hoop component of stress. Although bending fatigue failure of the gears occurs generally at the root, assessing this location by Contour Method is difficult due to the small area of material in the root location. Therefore, to get the highest quality results for purpose of comparison, between manufacturing routes and residual stress evolution throughout the manufacturing process, the tip-inner bore approach was chosen as most appropriate.

Following EDM sectioning, the two cut faces of each gear were measured by Coordinate Measuring Machine (CMM). A Mitutoyo Crystal Apex C CMM was used with a 1mm diameter ruby attached to a Renishaw PH10T probe. A point density of 0.4mm x 0.4mm in the X and Y directions was measured on the cut surfaces.

The measured surface topographies of each of the two cut faces were then analyzed using a series of Matlab codes. The data cloud for each face was cleaned to remove erroneous points, before aligning the two faces. This removes a number of potential error sources by averaging away effects like a non-straight cut. A surface fitting algorithm was then used to evaluate the averaged cut surface. The output of the surface fitting was then used as an input into an FE simulation, where the original residual stresses within the gear are calculated. The data cloud captured by CMM measurement of the sectioned face of a gear is shown in Figure 4.

FEA calculation of residual stress from the measured surface contours was performed using ABAQUS commercial software. A fully elastic model is used (Contour Method is dependent on purely elastic relaxation [17]). The geometry of the sample was modeled as an extrusion of the cut face. Quadratic tetrahedral elements were used with an average element size of 0.4 mm on the cut surface. The model contained approximately 60,000 elements.
RESULTS AND DISCUSSION

XRD RESULTS
The residual stresses as measured by XRD for the forged and machined-from-bar gears are shown in Figure 5. Results for forged gears are shown in red, with bar gears in black. Residual stresses in the profile direction (root to tip) and lead direction (across the face width) are presented. The approximate measurement location is identified by a cross in Figure 5. Depth profiling was achieved using electropolishing and etching, starting in 10μm increments close to the surface, with increment size increasing with depth. This approach provides the richest dataset in the high compressively-stressed region most influential on fatigue performance. Residual stress relaxation and redistribution associated with localized electro-chemical polishing have not been accounted for.

The residual stress measurements in Figure 5 are for gears in the final condition (i.e. case hardened, finish machined, shot peened, superfinished). High compressive stresses are expected due to the processing history. Peak compressive stress of 1,200MPa is found at a depth of 20μm for the forged gear in the lead direction. The peak compressive stress of the machined-from-bar gear was 1,160 MPa at a depth of 40μm (also in the lead direction).

The results show that for both components of residual stress, the peak stress is closer to the surface for the forged gear as opposed to machined-from-bar. This could have an effect on the fatigue performance of the gear under bending loads, depending on the location of typical crack initiation. The difference in residual stress profiles could be explained by variability in the case hardening or surface treatment processes. Alternatively, excessive material stock removal during final machining could cause the shift in peak stress position.

Despite the presence of variability between gears of the two manufacturing routes, the magnitude of the variation is not deemed to be significant. A variation of +/-50 MPa and +/-20μm, for stress and peak stress position respectively, falls within the bounds of measurement uncertainty and batch variability.

CONTOUR METHOD RESULTS
Cross-sectional maps of residual stress for the two gear manufacturing routes (forged and bar) are presented in Figure 6. Residual stress distributions are shown in the initial condition, i.e. machined-from-bar or forging, and final conditions. The final condition of the gear refers to after all manufacturing processes: case hardening, heat treatment, finish machining, shot peening, and super finishing. The surface fitting for the results shown used bivariate splines with 3.5mm knot spacing.

The magnitude of residual stresses is low for both manufacturing routes in the initial condition (Figure 6 (a) and (c)). Maximum out of plane, i.e. hoop, stresses of 100MPa tensile were measured. The supplied bar stock was in the annealed condition so low stresses are expected. The forged pancake cools relatively slowly (air cool) so significant stress gradients are not expected.

The line plots for residual stress from the gear tip to inner bore are shown in Figure 7. Again, it can be seen that the gears from both manufacturing routes exhibit low stress magnitudes in the initial condition. The stress distributions are similar for both routes; no significant difference is observed.

The residual stress magnitudes increase significantly by the time the gears have gone through the full manufacturing process. Case hardening induces compressive residual stress in the case layer (approximately 1.1mm) due to the volumetric change caused by carbon addition. During quenching, the compressive residual stress increases further in the case due to differential gradient in cooling, and also phase transformation. Although annealing and tempering are performed, a significant stress profile remains. The final processes of shot peening and superfinishing induce compressive stress at the gear surface locally (primarily as a result of peening).

From Figure 6, a high tensile core of approximately 400 MPa is exhibited for both the forged and the machined-from-bar gears. The tip of the gear for both manufacturing routes experiences compressive residual stresses in the region of 1,100 MPa. The magnitude of stresses at the gear tip as measured by contour method are comparable with those measured on the surface of the tooth by XRD.

As with the initial condition gears, there is minimal difference observed in residual stress magnitudes and distributions for the final condition gears from both manufacturing routes. Figure 7 shows peak compressive stresses of -1,000 MPa to -1,100 MPa within 1mm of the surface. Within the first 1mm of the surface, Contour Method measurements are susceptible to error due to artefacts introduced during the cutting and clamping process [21]. Uncertainty values are not commonly reported for Contour Method results, however an estimation of 10 percent to 15 percent is regarded as appropriate [23]. The variability between forged and machined-from-bar gears falls within this uncertainty margin.

DISCUSSION
By considering the results of both XRD and Contour Method residual stress measurements, a detailed understanding of the near
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surface and through thickness residual stress state of the forged and machined-from-bar gears has been obtained. The difference in residual stress distributions and magnitudes for gears machined from forgings and those machined-from-bar stock was found to be largely insignificant.

A small variation in the magnitude and location of peak compressive stress in the heat-treated, finish-machined, shot-peened, and super-finished gears was observed for the two manufacturing routes. However, the difference is small enough to be attributed to measurement uncertainty and general processing variability. For future work considering the fatigue performance of the gears, this variation should be re-addressed should the fracture and fatigue behavior vary significantly between the two routes.

The Contour Method results show a severe increase in residual stress throughout the manufacturing process. As residual stresses are self-equilibrating across any given principal plane in a body, achieving the desired high compressive strength (for fatigue purposes) close to the surface will result in tensile stresses redistributed within the part. This has the potential to cause distortion issues during further manufacture of the gear or during operation. This issue is unavoidable. A positive output from this work, however, is that gears from both manufacturing routes exhibit similar bulk residual stress distributions. Therefore, a distortion mitigation strategy already in place for conventional, machined-from-bar gears could be read directly across to forged gears.

**CONCLUSIONS**

- Test gears have been manufactured from S156 case hardened gear steel using two manufacturing processes: machined-from-bar stock, and machined from pancake forgings.
- Residual stresses in the initial condition (following machining) and final condition (following heat treatment and surface finishing) have been measured using Contour Method technique. Residual stresses close to the surface of the gear tooth have been assessed using X-ray diffraction with electro-chemical polishing layer removal.
- The difference in residual stress magnitudes and distributions of near surface (XRD) and through thickness (Contour Method) between the two forming routes (forged, bar) was observed to be insignificant. In the case of variation in fatigue performance or distortion behavior being observed between forged and machined-from-bar S156 gears, factors other than residual stress should be attributed.
- Contour Method residual stress measurements provided a quick and convenient way of observing residual stress evolution through the manufacturing process, and for comparing between forming routes. Although XRD provides data in areas most critical for fatigue performance, Contour Method was found to be suitable for comparison for the purpose intended here.

**ACKNOWLEDGEMENTS**

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CHOOSING THE PROPER GRINDING WHEEL

Norton Xtrimium bevel gear grinding wheel. (Courtesy: Norton | Saint-Gobain)
Experts with Norton | Saint-Gobain Abrasives discuss the challenges of gear grinding and how advances in technology are improving the efficiency of grinding methods.

By KENNETH CARTER, Gear Solutions editor

Methods of gear grinding have changed over the years. As manufacturing standards get tighter, the right machines and abrasives needed to meet specifications have become even more critical. Product Manager Josh Fairley and Senior Application Engineer Phil Plainte with Norton | Saint-Gobain Abrasives share their expertise on how gear grinding — as well as using the correct grinding wheel — plays an important role in gear manufacturing. They also reveal how their company is addressing this essential process.

What changes have you seen in terms of what gear manufacturers need for grinding wheels?

PLAINTE: High-volume automotive manufacturing has made the greatest impact for changing and transforming the way gears are mass produced. Automotive manufacturers are building transmissions with “aircraft quality” gears, which meet the highest quality standards. The newer transmissions are a fraction of the size of the older designs and handle significantly higher torque, horse power, and higher RPMs. The efficiency of these transmissions has increased miles per gallon tenfold. These changes have pushed machine builders and grinding wheel manufacturers to develop products that meet the new requirements.

Gear manufacturers did not always need grinding wheels to provide the final surface finish and form required. They could get by with hobbing and shaving, and on special jobs they might use lapping ring and pinion sets. Aerospace was the first industry to embrace grinding gears, but the aerospace industry was not as cost focused as automotive.

FAIRLEY: Quality standards have increased dramatically over the years for all gear applications. The need to improve efficiency while maintaining high quality and driving down the cost per piece has made choosing the right grinding wheel for the job much more important. Depending on the goals of the gear manufacturer, different grinding wheel specifications are needed to optimize the desired metrics.

What are the most common gear-grinding challenges you see from gear manufacturers? (i.e. higher speeds, burring, finishes etc.?)

FAIRLEY: The most common challenges in gear grinding stem from the strict quality standards and efficiency/flexibility needs of gear manufacturers. Gear manufacturers are looking for very fine finishes and excellent gear geometry results from using their grinding wheels. They are also looking for precise form holding and reduced dimensional variation along with significant cycle time reductions. These quality metrics are more challenging to obtain because of the risk of burning gears. High-grinding area of contact, fine surface finish requirements, and tight form-holding requirements all work against a burn-free grind. Therefore, it is critical to specify the best grinding wheel matrix and grinding parameters for the job.

Another big challenge is operator and engineering knowledge of grinding. Norton | Saint-Gobain offers on-site technical training through our “Norton School of Grinding,” as well as our Precision Customer Seminars in Worcester, Massachusetts. These training classes give gear manufacturers the opportunity to learn grinding theory and ask application specific questions to our grinding experts.

When evaluating a grinding solution for gear manufacture, what are the top five key tips for determining a suitable grinding wheel?

FAIRLEY: 1) Identify the goal and what the key metrics are for the grinding process: If you are looking for high quality, high efficiency, or both, different grinding wheel specifications will get you there. We offer different specifications for each of these performance metrics in order to provide the most optimized solution for the customer, rather than one specification for everything.

2) Know your application: There are different types of gear grinding, and depending on the type, different grinding wheel specifications and sizes should be used.

3) Gear information: To pick the optimal grinding wheel for your gear grinding process, all aspects of the gear should be communicated. The material being ground, the desired surface finish, and profile to hold are all critical to picking the right wheel.

PLAINTE: 4) Coolant delivery and machine characteristics: It is well known how critical coolant is in the gear-grinding process. In an ideal scenario, coolant temperature, flow, targeting, pressure, and filtration are all set up properly. However, if one of these is not at an ideal condition, a modification to the grinding wheel specification or grinding parameters can alleviate those issues.

5) Dressing methodology: The dresser technology, application, and dressing parameters have a huge impact on grinding performance. Different grinding wheel technologies will be optimized depending on the dressing tool and parameters used.

In terms of technology and application support,
what should gear manufacturers expect from their grinding wheels manufacturer/supplier?

PLAINETE: We work with the customer at all levels, from design to manufacture. We have excellent relationships with machine-tool builders and are happy to begin at Day 1 during the gear-grinding application design process. We also get involved when gear manufacturers are faced with challenges and are looking for new ways of producing gears and developing processes.

In what ways is Norton tackling the future of gear grinding?

PLAINETE: Norton | Saint-Gobain is a world leader in the abrasives industry that is focused on engineered material development. A considerable percentage of gross sales is reinvested in R&D. We have six grinding technology centers located throughout the world.

FAIRLEY: Dedication to innovation. Advancements in grain, bond, and engineered porosity, all developed in-house. Norton was the first to develop ceramic, micro-structured grains, changing the game in terms of what grinding processes could achieve. We were the first to develop shaped grains, allowing for unprecedented removal rates. As the gear industry quickly evolved, we too evolved to support the market.

Norton | Saint-Gobain is at the forefront of grinding wheel technology and expertise. We also have a large and diverse team of experienced sales personnel and application support, both locally and globally.

We recently introduced the Norton Xtrimium™ range of gear solutions designed for high-performance gear grinding in extreme, tight tolerance environments. The newly structured portfolio of gear-grinding products is specifically designed by category to provide higher-profile accuracy, supreme form holding, and burn-free grinding in worm, profile, and bevel applications. Highlighting the new range is an innovative dual-worm wheel design that enables two operations in one grinding wheel, substantially saving time and cost.

How is Norton | Saint-Gobain addressing Industry 4.0 initiatives?

FAIRLEY: To address Industry 4.0 initiatives, we have introduced Norton 4Sight process monitoring and diagnostic system, which provides real-time monitoring and improved vision of the machine and operation, as well as in-depth insight into the grinding cycle for optimization and troubleshooting. This also enables customers to work with Norton application engineers remotely to provide real time troubleshooting and optimization. We are also investigating the use of QR coding and RFID technologies in collaboration with customers, to help gear manufacturers achieve their Industry 4.0 goals.

New Norton Xtrimium dual-worm gear grinding innovation allows one wheel to grind and polish. (Courtesy: Norton | Saint-Gobain)
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WHY ARE TODAY’S HYPOIDS THE PERFECT CROSSED-AXES GEAR PAIRS?
Gear scientists, gear engineers, and gear manufacturers have worked successfully for many decades on finding the optimal flank forms and the optimal non-conjugate flank surface interaction.

By Dr. HERMANN J. STADTFELD

In 1924, Ernest Wildhaber, a well-known gear scientist, invented hypoid gearing. Compared to spiral bevel gears, hypoid gears provide an offset that allows lowering of the body of rear wheel drive vehicles by 50mm or more. This is possible because the propeller shaft between engine/transmission and the driving axle is not positioned at the center of the drive axle but is lowered by the offset amount (Figure 1). This allows the vehicle designer to lower the floor of the vehicle and subsequently the entire body by the same amount. Lowering the center of gravity of a passenger car by 50mm reduces the inertia responsible for sideways rolling by more than 10 percent, which provides better vehicle handling and more active safety. The lower body also reduces the CV coefficient for air resistance, providing higher gas mileage. Less than five years after the invention of hypoid gearing, all large automotive manufacturers around the world had converted their passenger cars and trucks to hypoid drive axles with a lower vehicle body.

Ernest Wildhaber emigrated from Switzerland to the U.S. in 1919 and was hired by The Gleason Works as a gear theoretician. Wildhaber received 279 patents, many of which changed the world of gearing. The cylindrical gear tooth profile that is today called Wildhaber-Novikov gearing was invented by Ernest Wildhaber in 1926. Mikhail Novikov, a Russian scientist with no access to western publications, invented the same tooth profile independent from Wildhaber in 1956. The contributions of both scientists are honored today by calling this system Wildhaber-Novikov gears.

Ernest Wildhaber is the father of modern gear theory. His pioneering contributions have been invaluable for the development of today’s gear calculation and manufacturing processes.

NEWS ABOUT HYPOID GEARS?
A recently published article by S.P. Radzevich [1] attempts to explain that hypoid gearsets designed and manufactured today lack good performance and are not perfect but approximate. The article seemingly questions the credibility of many scientists and gear engineers who worked on the theory and its improvement over approximately 100 years. However, reading the article carefully quickly reveals some key misperceptions and false assumptions. This write-up is meant to be a response on behalf of established gear theory and manufacturing.

In the following sections, certain statements and mathematical relationships of the published article are discussed and countering responses are presented and explained. Also, some assumptions about manufacturing and application procedures are discussed and compared to established practices today. The topics of this paper are structured accordingly in:
- The three fundamental laws of gearing.
- Perfect conjugacy.
- Real world applications.
- Transmission design.
- Heat treatment, lapping and grinding.

THE THREE FUNDAMENTAL LAWS OF GEARING
The first fundamental law of gearing quoted in [1]

\[ n_x \cdot V_z = 0 \]

also implies \(|N_1 \times R_1| = i \cdot |N_2 \times R_2|\), where \(i\) is the constant transmission ratio. The three cases in Figure 2 visualize the problem of non-constant ratio and are noncompliant with the first gearing law because of a ratio change from case to case. This problem led Leonard Euler to discover the involute tooth profile. A simplistic mathematical approach teaches that the effective radius vector \(R\) remains unchanged while the contacting point between two mating flanks moves from \(R_{b2}\) to \(R_{b1}\) as shown to the
right in Figure 3 (movement along the line of action).

The line of action in parallel axes cylindrical gearing is a straight line, connecting the two base circles. If the surface normal vectors \( \mathbf{N}_1 \) and \( \mathbf{N}_2 \) are within the line of action, then the vector product \( |\mathbf{N}_1 \times \mathbf{R}_1| \) remains constant during a complete mesh cycle. The consequent application of this principle leads to the construction of an involute, as shown to the right in Figure 3.

The line that forms the tooth surface elements while traveling from position “a” to “f” along the line of engagement (line of action) is always perpendicular to the line of action. This principle implies that a tool, simply with straight cutting edges as shown in Figure 4, can be used to form the complex involute profile. Figure 4 also demonstrates the principle of profile shift while maintaining the first fundamental law of gearing.

The second fundamental law of gearing, which was proposed in 2017, \( p_{ln} \times V_m + n_g = 0 \) [1], is a redundant relationship to the first gearing law and it is limited to cylindrical gears with parallel axes and straight bevel gears without hypoid offset. In this case, it adds nothing to the first gearing law; conjugacy is already given by the relationships required in the first gearing law.

The third fundamental gearing law is quoted in [1] in two different notations. The first notation covers only the special case of ratio = 1:

\[
\varphi_{b.g} = \varphi_{b.p} = \varphi_{b.op}
\]

However, the first notation is incorrect for all cases with different base pitch diameters because the circular pitch and not the angular pitch has to be equal between pinion, gear, and the operating base pitch. The second notation:

\[
P_{b.g} = P_{b.p} = P_{b.op}
\]

is consistent with the requirement of equal circular pitch, but the article makes no mention of the different notations.

**PERFECT CONJUGACY IN STRAIGHT BEVEL GEARSETS**

Bevel gears with intersecting axes is the topic of a series of three papers published between October 2014 and January 2015 [2]. A straight bevel gearset with skew teeth was modeled, and a sample was manufactured. This publication addressed two points: the design of a gearset with low tooth count and the solution for perfect conjugacy. There is no mention in the article that the Coniflex® straight bevel gear system has been used since the 1940s for low tooth count gearsets such as differential gears.

Straight bevel gears such as Gleason Coniflex have tapered depth teeth, where the pitch cones roll on each other and the pitch apexes of pinion and gear match the crossing point of the axes. In the standard case, the face and root cone apexes match the crossing point. In such a standard Coniflex design, the base elements are also cones with cone apexes that match the crossing point of the axes. The involute development in Figure 3 can be applied to an infinite number of normal sections along the face width of a straight bevel gear which allows an involute development similar to that for cylindrical gears. The conical base elements of both members can be connected with a straight line (the line of action) in each section along the face width, whereas the plurality of all lines of action forms a plane (the plane of action).

This principle is shown in Figure 5. The two cones in Figure 5 are base cones of a straight bevel or a spiral bevel gearset. In the right two graphics, the view is directed such that the plane of action appears as a line that is tangential to the two cone-enveloping surfaces. The left side graphic in Figure 5 shows the plane of action three-dimensionally and how it connects the two base elements.

The plane of action cannot be extended beyond its tangential contacting line with the base element as shown incorrectly in Figure 1 in [2] and Figure 6 in [1]. The plane of action only exists where tooth engagement is possible and it is different than the generating gear plane (more specifically explained later).

There is, however, one difference from the true involute of cylin-
drical gears. The rotation of pinion and gear does not occur in the normal plane but in the transverse plane. Because of this difference, the flank profile of straight bevel gears (and all other bevel gear types) is called Octoide. The Octoide is the analog function of an involute, and it provides to bevel gears the same advantages as an involute provides to cylindrical gears. Those advantages are constant ratio, center distance insensitivity, and ease of manufacturing.

Like cylindrical gears, bevel gears also have a trapezoidal generating profile. The straight rack of cylindrical gears becomes a ring, as shown in Figure 6. It is required to establish certain conditions in order to make the ring rack the generating gear for a pinion and a ring gear that will mesh perfectly together with zero transmission error and line contact identical to cylindrical gears. Those conditions are postulated in the kinematic coupling requirements:

- The flank surfaces of the generating gears of the two mating bevel gears are congruent (same shape but mirror images, as given in the example of Figure 6).
- The generating gears of the two mating bevel gears require identical axes of rotation (Top and bottom side of the generating gear in Figure 6 form the same generating gear, which rotates in both cases around the same axis and therefore satisfies condition 2).
- The surface of engagement of pinion and ring gear must be identical to the surface of engagement between pinion and generating gear and also to the one between ring gear and generating gear (without detailed knowledge of the surfaces of engagement, the global condition in Figure 6 seems to satisfy this requirement).

The generating gear principle has to be understood as the ultimate vehicle to form the teeth of two mating gears. The first fundamental law of gearing is fully executed by choosing trapezoidal profiles and by applying the kinematic coupling requirements. Gears are designed and manufactured in order to mesh with each other. What better way to manufacture them by way of a generating gear? The generating gear is represented by the manufacturing machine; it forms the teeth of the gear (at the bottom in Figure 6) while meshing with this gear perfectly. If the pinion is manufactured with the same generating gear but on the opposite side (at the top in Figure 6) and if the generating gear is imagined infinitely thin, then the result is a pinion that perfectly meshes with the gear having zero motion error. It is also given, in such a case, that line contact between the pinion and gear flank surfaces exists along the entire face width. The extraordinary effort shown in [2] to calculate straight bevel gear tooth surfaces that are skew with asymmetric teeth is based on the falsely assumed conjugate requirement. The sample gear pair shown in [2] was manufactured on a machining center with a ball nose endmill in a milling operation likely taking many hours to complete. It is rather simple and straightforward to manufacture a significantly better, perfectly conjugate straight bevel gearset in only a few minutes by using the generating gear method and a standard bevel gear manufacturing machine.

An example straight bevel gearset computer model is shown in Figure 7. The solid model in Figure 7 has been generated by using standard Gleason basic settings, based on the generating gear approach and by applying a standard Coniflex® Plus cutter head as used on Phoenix bevel gear manufacturing machines. The Coniflex straight bevel gear calculation for conjugate contact has to be conducted with a dish angle of 0° and no root angle correction (ΔGammaM = 0°). The dish angle is creating the length crowning and a ΔGammaM creates the profile crowning. With a dish angle of 0° and a ΔGammaM of 0° flank lead lines are straight lines and the profile is a true Octoide (involute equivalent).

A contact analysis of the gearset in Figure 7 is shown in Figure 8. The top of the figure shows the Ease-Offs of left and right flank (called coast and drive side in the graphic). The center of the figure shows the motion transmission errors of the pinion and gear flank pairs. The two bottom graphics are the representation of the tooth contact pattern. The contact pattern graphics are axial
projections of the flank surfaces and the contact lines in the same plane a two-dimensional part print would show the tooth area.

The contact analysis in Figure 8 confirms the full line contact in each roll position (lower graphics) as well as the zero motion error (only numerical static) in the center graphic which indicates an undefined contact path. This means that due to the conjugacy, every point along each contact line is a path of contact point which makes the analysis program pick random points.

The Ease-Off base plane (top graphics in Figure 8) defines the conjugate state of a flank surface pair. Because the Ease-Off graph of the calculated flank pairs matches the presentation plane (base plane) precisely, that is the proof that a conjugate and precisely rolling gearset was the input of this contact analysis calculation.

The above experiment creating a conjugate straight bevel gearset is strictly academic. Conjugacy is the basis of all gearsets manufactured in high volume on dedicated manufacturing machines. A conjugate bevel gearset cannot be used for a power transmission because manufacturing tolerances and load affected deflections as well as material expansions and deformations under high operating temperatures will result in edge contact and high load concentrations. The load concentrations already start with moderate load and cause material damage and considerable noise emission. Although conjugacy is used as a reference for each design, predetermined amounts of length and profile crowning are applied. The right amount of crowning makes a gearset quiet and gives it the required load carrying capacity. The crowning is shown in the Ease-Off graphics with the conjugate reference always being present as the Ease-Off base plane. Several Ease-Off examples of a gearset with length and profile crowning are shown in the proceedings of this paper.

**PERFECT CONJUGACY IN HYPOID GEARSETS**

It begins to become more problematic for hypoid gears. In [1] the pitch elements of crossed axes hypoid gears are drawn as cones. Even though the face cones of hypoid gears and pinions are machined conical, the pitch elements are hyperboloids.

Ernest Wildhaber and Arthur Stewart described their invention of hypoid gearing in 1926 [3]. Boris Shtipelman published in 1978 the relationships and derivations required to understand hypoid gears and their hyperbolic pitch elements [4]. Figure 9 offers a graphical interpretation of the hyperbolic pitch elements and their generator. The pitch surface generator is a line which winds on the surface of a cylinder beginning at the crossing point of the axes, equal to the first contact point of the pinion and gear pitch surfaces. The pitch surface generator is developed by the connecting line between the pinion and gear pitch surfaces by shifting the connecting line along the pinion and gear axes. The connecting line is normal to the pitch elements. Point P is one point of the pitch surface generator. If the division of the vector products of the distances between the axes and point P and their respective axis direction equals the ratio i of the hypoid gearset then one point of the pitch surface generator is found with:

\[
\frac{(n_{up} \times Z_a)}{(P \times n_{og})} = i
\]

Although the pitch elements are hyperbolic and not conical, it is possible to use conical faces for the blanks of pinion and gear. If point P in Figure 9 was chosen at the center of the face width, then line \((n_{up} \times n_{og})\) can be used as a normal vector to define the face angle a blank with straight face cones if the hypoid set was manufactured by face hobbing, which implies parallel depth teeth.

Straight face cones will merely influence the top root clearance of the gearset in the range of 30 to 60 microns. Using straight face cones will not change the form of the pitch surface nor will it influence the base surface. Those functional surfaces are given by the
kinematical relationships and have to be considered when thinking about the shape of the surface of action. No plane of action can exist between two hyperbolic base elements. The correct surface of action is curved and warped, as shown in Figure 10.

The conclusion is that the second fundamental law of gearing according to [1] does not exist and is not related in any way to the conjugacy of gears (as explained and demonstrated in the following section).

CONJUGACY BETWEEN MESHING FLANKS
The term conjugate is used in mathematics for two or more surfaces that contact each other along a line. Since the 1970s, the term conjugate has also been employed in gear technology literature to define the “exact” gear pair which presents a triple plurality of line contact between two gear flanks during the meshing process [5].

DEFINITION OF THE CONJUGATE GEAR PAIR
1: The flanks contact along a line (contact line), which is only limited by the boundaries of the teeth i.e. the working area.
2: The line contact between the flanks exists within the entire area of engagement in every mesh position.
3: Line contact is maintained in the entire area of engagement if pinion and ring gear are rotated by angular increments where: (angular pinion increment) / (angular ring gear increment) = transmission ratio.

The Ease-Off is a three-dimensional graphic of the flank deviations from a conjugate pair. It is calculated by transformation of a pinion flank “into” the gear coordinate system according to the first gearing law, resulting in a virtual gear flank that is conjugate to the actual pinion flank. This conjugate gear flank will then be compared to the present gear flank, where all differences in arc length are plotted point by point in ordinate direction into the Ease-Off graphic.

If both mating bevel gears have conjugate manufacturing data, then the Ease-Off graphic has no deviations in ordinate direction. Also, if the pinion flanks and the gear flanks have spiral angle and pressure angle errors of equal amounts, the Ease-Off graphic will not show any deviation. Although the individual gears are considered incorrect in this case, they will roll conjugate with each other, which subsequently leads to an Ease-Off without any ordinate values. Figure 11 shows the analysis results of a typical conjugate hypoid gearset. The Ease-Off graphics have zero crowning magnitudes in the ordinate direction. The motion graph has, next to some numerical entrance and exit variation, zero motion error. The contact bearings show line contact within the entire working area. The coast side contact ends at a toe root undercut (section ε).

Each spiral bevel and hypoid gearset with uniform tooth depth has a conjugate base design. This applies to all face hobbed and some face milled gearsets. A simple explanation of hypoid gearset conjugacy is possible with a non-generated gear that meshes with a generated pinion. For the calculation and manufacturing process, the hyperbolic pitch elements are calculated for the gear first. Then a suitable blade profile (gear cutter in Figure 12) is chosen and positioned in a face cutter head. The cutter head is positioned to create the desired spiral angle. With this procedure, a non-generated gear can be created by computer simulation and it can be manufactured with a bevel gear cutting machine [6].

A pinion cutter (see Figure 12) is positioned in a mathematical model or in a bevel gear cutting machine such that it represents one tooth of the non-generated gear by rotating around its axis. An additional simultaneous rotation around the pinion generating gear axis results in this pinion cutter becoming the generat-
ing gear of a conjugate pinion. If the pinion is positioned with the same offset that was used to determine the pitch surfaces (Figure 9), then the cutter rotation around the pinion generating gear axis will form a pinion that is perfectly conjugate to the non-generated gear. The tooth contact analysis in Figure 11 has been obtained from such a non-generated hypoid gearset and therefore shows perfect conjugacy.

More complicated is the generation of a conjugate bevel or hypoid gearset with tapered depth teeth (see Figure 13). If the generating gear axes have identical axes of rotation that are perpendicular to the pitch line, the rotating cutter heads and their blades will not follow the root line of a tapered depth tooth. Tilting the cutter head in order to follow the root line would violate the first kinematic coupling requirement for teeth that are congruent to the slots of the mating member. The solution was developed in the 1940s [7].

If the cutting edges are adjusted in the cutting machine such that tooth reference profile and depth is matched at midface, and if an axial motion of the cradle is introduced that guides the blades along the tapered root line while the generating roll progresses along the face width, then the requirements of congruent teeth and slots are fulfilled with the result of perfect conjugacy.

The process configuration and kinematics in Figure 13 is called Duplex Completing. Today, all face-milled and ground spiral bevel and hypoid gears are manufactured with the Duplex Completing process. The axial cradle movement in this process is called Helical Motion and was first introduced with mechanical bevel gear machines in the late 1940s. The Helical Motion of the days of mechanical machines required an additional change gear box which actuated a cam that moved the sliding base during the generation process. Today’s CNC controlled Phoenix® free form machines have the Helical Motion capability automatically by their interpolated axes movement.

WHY IS CONJUGACY NOT DESIRABLE FOR REAL WORLD APPLICATIONS?

In 1926, Ernest Wildhaber [3, 8] was the first to propose applying surface crowning on hypoid gears. Wildhaber acknowledged that the slightest deviations in the gear housing and in the building position, as well as deflections affected by load and heat, will cause edge contact with peak stress levels of a multiple of the allowable values the gearset had been designed for. The conjugate gearset used for the TCA in Figure 11 was repeated with realistic displacement values of 50μm offset, 50μm pinion cone and 30° of shaft angle change. The results in Figure 14 show warped and tilted Ease-Offs and severe edge contact on heel and top. This edge contact will cause noisy operation followed by pittings and tooth fracture.

The theoretically conjugate hypoid set will not fulfill any of the fundamental gearing laws in case of the smallest gearbox inaccuracies or deflections. As mentioned above, already small deflections at moderate loads lead to load concentrations on the edges of conjugate flank pairs and can cause material damage and considerable noise emission. As such, the conjugate gear pair is not suitable for any task in a power transmission.

The introduction of 80μm length crowning and 15μm profile crowning to the conjugate hypoid design delivers the analysis results shown in Figure 15. The crowning makes the gearset insensitive to expected inaccuracies in the gear housing and load and heat affected deflections. Applying the same amounts of shaft displacements then used for the TCA of the conjugate hypoid set in Figure 14 moves the mean point slightly out of the initial position (see Figure 16), but a large contact area within the tooth boundaries is still maintained.

It was demonstrated that the hypoid gearset with length and profile crowning in Figure 15 was developed based on a conjugate design. The first and third fundamental gearing law, mentioned in this paper, applies to the hypoid set in Figure 15 at the mean point roll position, if the load is zero. The first and third fundamental gearing law will apply in the area of contact as the load increases and the Hertzian contact spreads in contact line direction as well as in path of contact direction. This ideal condition can only be
achieved with correct amounts of crowning, adjusted to the operating displacements. It is interesting to mention that a hypoid gearset with crowning will fulfill the first and third fundamental gearing laws even in case of gearbox inaccuracies.

TRANSMISSION ORIENTATIONS

The proposal in [1] to place the hypoid gearset between motor and transmission is not practical. Hypoid gears are not used as simple reducers, but their purpose is to redirect rotation and torque by a certain angle, commonly 90°. In case of hypoids, the second purpose of lowering the center of gravity of a vehicle body has become very important in the automotive and truck industry. The redirection of rotation and torque has to be done at the driving axle of a vehicle. The engine orientation of vehicles with a rear wheel drive is longitudinal. Because engines of cars and trucks are commonly in the front, a longitudinal oriented propeller shaft transmits the engine rotation to the rear drive axle (Figure 17, right side). The transmission, which is located between engine and propeller shaft, needs to have a gear shaft orientation identical to the direction of the engine crankshaft. The hypoid gearset redirects rotation and torque and provides the final reduction at the drive axle. The advantage of this concept is the lower torque in the complex shift or automatic transmission and the high torque only at the ring gear at the drive axle.

A concept as shown in the left side graphic in Figure 17 would require, for example, a chain connection from the transmission output to the drive axle. This solution has low efficiency, causes high noise, provides an unacceptable packaging, and is not very reliable.

IS LAPPING AN ATTEMPT TO MAKE HYPOID GEARS CONJUGATE?

In [1, 2] it is mentioned that lapping of bevel and hypoid gearsets can be omitted if the gear geometry consists of a conjugate design. This reveals a misperception about the reason for lapping (and grinding). Lapping and grinding are hard-finishing operations. The soft manufactured bevel and hypoid gearsets have to be heat-treated, which in the most common case begins with a case carburizing of standard gear steels steel such as AISI 8620 or 16MnCr5. In order to give the low carbon steel a surface hardness in the 60 HRc range, a layer of carbon enrichment below the surface of 0.8 to 1.5mm depth is placed by a diffusion process. After the carburizing a quenching in oil and an additional tempering takes place. The result is a surface hardness that is commonly close to 60HRc and a core hardness in the 30HRc range. Case hardening provides an ideal transition between surface and core hardness that makes gears on the surface hard and wear resistant and in the core ductile. This makes shock loads and certain small plastic deformations tolerable without failure of the gearset. One major side effect of the heat-treatment process is the distortion of the gears that is caused by the carburizing, the re-crystallization of the steel, and the quenching. In order to make a gearset after heat-treatment suitable for power transmissions, for example in cars and trucks, a hard-finishing operation is required. The hard-finishing operation eliminates the heat-treatment distortions hereby providing the flank surfaces with the correct geometry from before the heat-treatment back. In addition, hard-finishing improves the surface finish to a low roughness and waviness, which enhances the hydrodynamic lubrication and reduces noise. Grinding and skiving are the preferred hard-finishing methods, creating a defined surface form that duplicates the original designed surfaces in the single micron range.

In case of face-hobbed bevel and hypoid gearsets, grinding is not possible, because of the epicyclical flank lead function. Skiving can generate epicyclical lead functions, but is not yet accepted for the high production volumes in the automotive and truck industry. This leaves only the lapping process for the hard-finishing of face-hobbed angular gearsets. However, the face-hobbed surface texture and the relative sliding between the flanks of hypoid gears make lapping an ideal alternative. Lapping can remove the surface scale
left from heat-treatment, and it re-matches two mating members by removing some runout and flank form distortions. Lapping can reduce the transmission error in many cases due to the fact that the major material removal is in the center region of the teeth where the tooth contact under light load is expected. In order for the lapping to work well, more crowning than required in the hard-finished gearset is used in the gearset design for the soft cutting. Lapping removes about 30 percent of this crowning, such that the length and profile crowning is just right after the lapping. Soft cutting of parts that are lapped after heat treatment considers a stock allowance of 0.03mm in the pinion and 0.01mm in the gear. If grinding is the hard finishing process (for face milled gearsets) then the design crowning is identical to the desired crowning after hard finishing. Between soft cutting and grinding, a uniform stock allowance of 0.10mm to 0.15mm is applied to the pinion and gear flanks.

### Summary

Conjugacy between the members of straight bevel, spiral bevel, and hypoid gears was only the first step and goes back more than 100 years. Quickly, the early scientists and engineers found out that conjugacy only gives us an important basis, but not a solution for power transmissions. Angular gearsets under load experience deflections that move them away from their theoretical position by half a millimeter and more. Well-designed and manufactured bevel and hypoid gearsets today can live up to those requirements and still maintain a power density that is four times higher than it was 50 years ago.

Transmission errors of 50 to 150 micro-radiant that were normal in the 1970s are in today’s high-power density gearsets only between 5 and 15 micro-radiant. All this was achieved by converting a global length and profile crowning (Figure 18, left) first back to conjugacy (Figure 18, center) and then into a UMC™-optimized selective crowning, which is limited to particular regions of the teeth as shown in the right graphic in Figure 18. It is notable that the flank center of the UMC-optimized Ease-Off is conjugate, and the transmission error is next to zero. In lapping, similar effects as in grinding are achieved by using low inertia spindles with rotational compliance and high-speed torque control (SmartLap™).

The dream of conjugate angular gearsets turned out to be a false objective. Gear scientists, gear engineers, and gear manufacturers worked successfully for many decades on finding the optimal flank forms and the optimal non-conjugate flank surface interaction. The conjugate tooth design is today considered simple compared to a sophisticated higher order surface modulation. There is still room for improvement, but this cannot be achieved by going back to antiquated conjugate designs.

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STACE-ALLEN CHUCKS

CHUCKS, WORKHOLDING, AND MORE

Stace-Allen Chucks has a long and storied history. (Photos courtesy: Stace-Allen Chucks)
Although it started out manufacturing precision power chucks, Stace-Allen Chucks has expanded into workholding – designing and manufacturing custom solutions to meet its customers’ demands.

By KENNETH CARTER, Gear Solutions editor

S

tace-Allen Chucks has been designing and manufacturing chucks for more than 70 years, but the company is so much more than that.

“We are a highly specialized workholding company,” said Phil Grimes, president of Stace-Allen Chucks. “We have an engineering department, and we design specialty workholding. We still do our chucks; we still do our collets, whatever it is that you need, we still do that, but we also design these specifically for the customer. When they have something that’s not round or not balanced, or they need specialty locating or air sensing or any number of special designs, we’ll design and build it specifically for them.”

As the company’s work pertains to the gear industry, Stace-Allen Chucks is heavily involved in workholding applications, specifically the rotative applications where a company would be doing turning on a gear component using a CNC lathe, according to Lucas Emmert, engineering manager at Stace-Allen Chucks.

“For the most part, our focus has been the rotative, subtractive manufacturing side of the industry,” he said.

CHUCKS AND MORE

But the workholding side of the company is only its latest achievement. Chucks are still very much a staple.

“Traditionally, when we’ve done work with gear manufacturers, a lot of times the challenge was always if you could buy an off-the-shelf chuck, you would, but when that off-the-shelf solution doesn’t work, that’s when people would call Stace-Allen,” Emmert said. “We come up with solutions for some of workholding’s most difficult challenges.”

Often times that off-the-shelf approach is a solution, but being able to design and manufacture a product that, in the long run, is better and more efficient is where Stace-Allen shines, according to Emmert.

“We get it all the time,” he said. “If they can just buy something out of a catalog, they will. They don’t call us until it needs to be specially designed from the ground up, or there’s a particular part of the application that the off-the-shelf solution just can’t really handle.”

HELPING CUSTOMERS

Grimes stressed that the company’s specialty is its hands-on ability to help its customers.

“We do the engineering of the workholding, the manufacturing, and the troubleshooting,” he said. “Sometimes you don’t get the right information, and sometimes it’s best to have somebody on site to see how it can be done better, and since we engineer it and make it, we have a better insight on how we can get it to work better when it gets on the machine.”

Although each customer situation can be unique, Emmert said his team of engineers are flexible enough to meet just about any challenge thrown at them.

“We do a lot of work in the automotive industry, and that runs a whole gamut of personalities and even structure types in companies,” he said.

Sometimes a customer will have their entire process mapped out, according to Emmert.

“They’ll know their takt times; they’ll know exactly where they need to grip and locate with full machining parameters,” he said. “I’ve basically got all the data that I need to make my pitch right out of the gate, and then I do that. On the other end of the spectrum, I do have customers that’ll come to me with a part, and they’ll say, ‘I need to turn it into this, but I have no idea how to get there.’ That’s when they really leverage our experience with manufacturing and previous applications, and I’ll work with them to review their part print, GD&T requirements, how it’s coming in, how it’s going out, processes going downstream, cutting tools, I’ve got a lot of knowledge that I can leverage to make a proposal that would really suit their end goal.”

When it comes to that specialty workholding, there is a lot of interaction, according to Emmert.

“It’s a lot of back and forth,” he said. “I don’t get

Matthew Hall sets up a chuck for testing.
the benefit of just being able to have one perfect solution to a job. A lot of times, I have to weigh out different pros and cons. There's a consequential level to every approach, and just figuring out which is going to be the best way to move forward on the project is a big challenge, but it's also why people come to us.”

KEEPING AN EYE ON CHANGES
Part of keeping in step with technological changes involves automation, according to Emmert.
“Something that we've developed that's been really successful is a means of radially orienting components based on their gear form, very accurately, and in a spring-loaded mechanism rather than an automated mechanism,” he said. “It's essentially a snap-in radial orientation device that doesn't leave any marks on the part, and that has been really successful. We've won a bid on a few jobs where we've been able to pitch it, so it's something we've taken some pride in, specifically related to the gear industry. It's probably also worth noting, too, spline and gear profile gripping. We've got a solution where people have stolen the ideas. I'd say that's a pretty good sign you're doing something right.”

IN BUSINESS 70-PLUS YEARS
“Something right” is definitely an understatement for a company with the lengthy history that Stace-Allen Chucks has.
The company was founded in 1946 by Grimes’ grandfather, Joseph Allen, and Allen’s friend, Walter Stace. The idea that sparked the company was for a precision chuck to help with the bombsights on B1 bombers, according to Grimes. Allen asked his wife, Mary, for $400 to buy a lathe and began building the chucks in his garage in Indianapolis, Indiana — three blocks from Stace-Allen Chucks’ current location. Grimes’ mother, Marcia, later took over as company president.
Grimes’ father, Larry, was a rocket scientist who graduated as an engineer from Rose Hulman and worked on the Atlas rocket. He designed, with the help of other engineers, a power chuck that allowed for material to be removed quickly due to the high clamping forces.
“They patented and sold those for 20 or 30 years,” Grimes said. “And from there, when machining got to be more high speed, we started designing specialty collets for people to be able to counteract the centrifugal force. We did that all through the late '80s, early '90s, and now, we are a highly specialized workholding company.”
Stace-Allen Chucks has seen many milestone moments over its history.
Jim Timmons, vice president of sales and a veteran of the company and industry, recently retired in March after 52 years with
Stace-Allen. Timmons was hired in 1967 as a machinist in training by company founder Allen. Timmons learned the trade and the product on the shop floor in the “hands-on method” of the times. He was appointed vice president of sales in 2004. During his time with the company, he has witnessed many changes to the manufacturing industry, including the shift from manual machines to CNC.

Timmons leaves Stace-Allen Chucks a better and more profitable place than when he started.

Emmert said Stace-Allen is constantly pursuing advancements in the manufacturing industry.

“We invented a power-chuck model, which had a 6-to-1 mechanical advantage as compared to the typical wedge chuck that was in the market that only had a 4-to-1,” he said. “When the speeds got even higher, we started making custom collet systems that wrapped right around the customers’ applications. It wasn't just an off-the-shelf collet that might not be the right grip length or the right diameter that the customer would have to customize. We’re always chasing ‘What are the demands of the industry and how can we do just a little bit better than our competition?’

LOOKING TO THE FUTURE
And where automation is concerned, Grimes and his team always have their ears to the ground in search of opportunities to complement industry advances and trends.

“T’d say the big thing is: Everybody’s talking about lights-out running,” Grimes said. “The problem with lights-out running is that you've got to know when the part is in position and when it's in the right position. That’s one of the things we're chasing right now: how to make sure that part is there, if it's seated correctly, and if it is oriented into the workholding properly so the machine knows where it’s at.”

Emmert agreed.

“Automation has been the big buzz word for the past decade now,” he said. “We’re just seeing more and more and more of it — less people, more robots. Having a device that is reliable and responsive is really important these days. They don’t have tool makers like they used to who are just waiting for something to do. They need their devices to continue working reliably.”

As far as what the future holds for Stace-Allen Chucks, Grimes said he sees opportunities as the industry moves more into 3D printing.

“The ability to 3D-print metal is going to be very important to the gear industry,” he said. “Where that leaves us is: There always has to be a finishing process, and if the workholding isn’t there to finish the process, no matter how good your 3D printer is, you’re not going to be able to get the product that you want in the end. As close as they can get in 3D printing, there's still going to have to be a finishing process, and Stace-Allen Chucks should be part of that finishing process.”

GEAR-MANUFACTURING OPPORTUNITIES
Although Stace-Allen Chucks hasn’t had a big presence in the gear industry over the last few years, it’s still very much a part of the company, according to Grimes.

“We kind of floated away, but we’re really looking forward to getting back into the gear industry,” he said. “We think we have some products that could really help some people out, let alone other engineering knowledge of workholding that can solve some problems that people have had.”

Emmert expanded on that by saying Stace-Allen Chucks has been a smaller, fluid-adaptive business.

“We have to keep track of the industry trends, and what we’re seeing is this great wave in the automotive industry that everybody’s been writing about,” he said. “It’s not going away, but it is starting to plateau. For us, we're not going to see a whole lot of new product introductions in the automotive side, and that’s where we really excel: helping customers introduce new products into their facilities. Branching out and knowing we have good solutions for gear applications, we would like to just get more involved in the different areas of the gear industry.”

There are other changes planned for Stace-Allen Chucks as well, and new salesman Ryan Strohm said he is ready to meet new challenges head on.

“We’re all taking full advantage of this transitional period to precipitate big changes internally,” he said. “We’ve got an aggressively ambitious vision for this company that puts us on the front end of the technological cutting edge. In manufacturing, we have 5-axis machining capability coupled with 3D CAM (Computer Aided Manufacturing) software. This allows our engineers to design the best possible solutions, uninhibited by the design limitations of less sophisticated, antiquated machining processes. In research and development, we’re currently testing (both internally and in the field) a variety of new materials, coatings, and treatments to offer longer wear item and chuck lifespans and better performance.

And we’ve got more service and installation technicians than ever before. There’s a new sales and marketing directive at Stace-Allen spearheaded by youth and backed by years of experience. We are rapidly modernizing in manufacturing, research and development, customer service, and engineering through strong goal-oriented organization. Stace-Allen has been rock-solid for a long time, but now, it’s our opportunity to evolve and excel.”

MORE INFO
stace-allen.com
It is no secret that e-mobility is a growing market. A current study by the consulting firm Strategy Analytics predicts the production output of “electric vehicles” will increase to 25 percent of the global market by 2025. It should be noted that the study uses “electric” as an umbrella term that covers all aspects of e-mobility, i.e. hybrids, fuel cell drives, and pure electric vehicles, and that the markets are highly heterogeneous. Heterogeneous markets mean multiple manufacturers, even more models, and diverse drive concepts. In addition, about three quarters of vehicles will continue to have traditional combustion engines. This puts production planners and automotive industry suppliers in a difficult situation: How do you manage this product diversity and increasing production volumes?

For many years, EMAG has been providing answers to these questions with a broad range of production solutions for components used mainly in powertrain applications.

EMAG’s VLC series covers a very broad range of machining technologies: turning, drilling, milling, gear hobbing, hard and soft machining — basically everything that is required to build comprehensive manufacturing lines.

“VLC machines enable us to cover the entire process chain for the manufacturing of transmission components, from blanks to finished parts,” said Peter Loetzner, president and CEO EMAG L.L.C. “Customers benefit from the unified design of our machines — consistent transfer heights and an integrated pick-up automation system that make it easy to connect machines.”

The pick-up automation system, which revolutionized the market almost 30 years ago, is the platform for the success of EMAG machines. Every machine in the VLC series features a parts storage area for raw and finished parts, as well as a working spindle that is automatically loaded and unloaded from this unit. It guarantees minimized non-productive times and high efficiency.

The VLC 200 GT was developed primarily with a focus on transmission gears and was first launched in 2016.

“Because of their large production numbers and high-quality requirements, transmission gears are ideal parts to be machined on the VLC 200 GT,” Loetzner said. “When we analyzed the machining process, we found that we could perform the entire machining process in a single clamping operation.”

To achieve this, EMAG combines the processes of hard turning and grinding. The shoulder and the bore are hard-turned first. Only a few micrometers of material are then left to be removed from the transmission gear. This ensures a much shorter grinding process using aluminum oxide or CBN grinding wheels, which saves costs in two ways: through lower tool costs resulting in a lower unit cost, and through faster cycle times. The machining quality also benefits from the combination of turning and grinding: When there is only a small amount of material remaining to be ground away after turning, the specifications for the grinding wheel can be based more precisely on the end quality required — as a result, surfaces with an average peak-to-valley height Rz of less than 1.6 micrometers can be reliably achieved with the VLC 200 GT.

Transmission gears will continue to be among the most commonly manufactured parts in the automotive industry well beyond the year 2025. However, with the increased electrification of the power train, certain older transmission designs are having a rebirth.

Loetzner said, “We are seeing a trend toward CVT transmissions. This is mainly due to the high efficiency of this design, whose smooth adjustment of the gear ratio without any interruption of the traction force ensures the optimal use of the supplied energy and therefore a low fuel consumption. Applied to hybrid vehicles, this means greater ranges from a single battery charge, enabling for example the fully electric operation in city traffic for an entire day.”

The continuously variable transmission results in especially comfortable driving, and is based on an intelligent design concept that does not use any toothed gears. Instead, power is transmitted via a steel belt or a lamellar chain, which runs around two shafts with conical disks. The quality of the components is extremely important. This is why the precision hard-machining is usually done in a multi-stage process on different turning and grinding machines.

The machining area of the VLC 200 GT
can be configured based on the application. Available options include internal and external spindles, block tool holders, or EMAG’s proven 12-post turret. “The machine’s flexibility allows us to use it for CVT pulley disks, in addition to transmission gears,” Loetzner said.

EMAG has equipped the VLC 200 GT with an external grinding spindle in addition to the tool turret — again, a combination of hard turning and grinding.

“This combination of processes allows us to optimally configure the grinding wheel for the surface of the CVT disk — all the other surfaces and bore holes can be made to the required specs by turning alone,” Loetzner said. This results in lower tool costs and cycle times due to reduced wear on the grinding wheel, which means that it needs to be dressed less often. When it does need dressing, the VLC 200 GT features a separate diamond-coated dressing spindle.

MORE INFO  www.emag.com

Big Kaiser’s twin cutters help minimize tooling and cycle times

Limitations of using milling tools to prepare holes for finishing become apparent as hole depth and volume increase. This is where Big Kaiser’s Series 319SW Twin Cutter boring head showcases its capabilities and can solve the issue along with virtually any other holemaking problem for the range of 0.787-8.000”.

The twin cutter’s ability to take on heavier cuts allows shops to be more efficient. Whether it’s eliminating multiple passes on the same bore or possibly allowing the use of existing smaller tools to create a starting hole, the twin cutter’s boring heads get the job done. Sometimes cast parts have more material to remove than was initially expected. Being able to balance- or step-cut with the same boring head helps minimize tooling and cycle times.

Also offered for the twin cutter boring heads are accessory insert holders to perform auxiliary operations not normally associated with this type of tooling.

Some parts have several bores in line with a blended angle in between. Insert holders with an adjustable insert cartridge allow the bore to be completed while producing the blend angle in one pass, thus eliminating the need for follow-up tooling, such as an angled milling cutter. Back boring holders often eliminate the need for expensive dedicated special tools, and face grooving holders allow plunge cutting versus milling, so the process is much faster and produces a better surface finish.

Any industry using castings or forgings can generally benefit from twin turning. It is designed for heavy-duty rough boring and semi-finishing operations.

MORE INFO  www.bigkaiser.com

FlexCNC introduces new beam line for machining large, long parts

FlexCNC introduces the Beam Line — the latest addition to its lineup of machining centers for large or long parts, such as structural steel beam, in a single set-up. With an open bed design that measures 40-feet by 2-feet, this new model can machine parts up to 40 feet in length. Alternately, the long open bed, coupled with the movable safety light curtain, allows multiple set-ups, so that while the FlexBEAM is machining one part, another can be loaded (or off loaded). This dramatically increases productivity of the machine’s uptime. The open design provides unrestricted access that makes loading and unloading easier and faster. In addition to structural steel beams, FlexBEAM machines are ideal for the machining of long products like tube, or pipe, cutting keyways, and more.

The FlexBEAM has a monoblock welded steel frame with high rigidity and a 5-slot machine bed. It features 3-axis interpolation, scribing, automatic hydraulic workholding, and automatic tool touch-off. In addition, a laser zero detector is standard,
as is 6 x ATC, a hand pendant, and network with ethernet cable.

Standard unit runs on 480V and includes mobile light-curtain safety barriers, frame with chip conveyor and t-slotted table, flood coolant pump and tank, and automatic tool calibrator. The 12” color touch screen is water-resistant and durable enough to provide years of service. Oversized double hung precision linear guideways ensure smooth and precise movement on all axes. All moving parts are self-lubricating on all axes. A programmable servo motor drives the spindle, while a 10-compartment automatic tool change ensures capacity for virtually any application.

Control on the FlexBEAM is simple yet powerful, with conversational and ISO G&M-code programming for versatile 3-axis CNC machining along with an optional fourth axis. Equipped with a color touch screen control, 40 GB of program storage, and 50 programmable zero points, programs can be loaded through USB or through and ethernet connection. Extensive training is provided, both in-plant and on-site.

Headquartered in Wapakoneta, Ohio, FlexCNC and FlexArm have been manufacturing CNC machines as well as tapping arms, die grinding arms, torque arms, assembly and part manipulators, and more, since 1984. They have thousands of customers worldwide, with referrals readily available. They stock an extensive array of tap holders and repair parts for fast shipment – often same day.

MORE INFO  www.flexmachinetools.com

Integrated drive solutions and custom engineering support for intralogistics

At PROMAT 2019, NORD Gear Corporation displayed new drive technology for conveyor and warehousing systems, increasing productivity and return on investment.

NORD showcased its integrated and energy efficient drive solutions for manufacturing and material handling to nearly 45,000 supply chain professionals at the event. The intralogistics industry is one of NORD’s fastest-growing markets. Torsten Schultz, NORD president, said one NORD advantage is its global integration. “Three of the world’s top five material handling suppliers use NORD drive technology, and we have long-term supply agreements with two of the suppliers,” he said. “We support customers and drive systems in 98 countries — wherever their operations are located.”

NORD engineers discussed its complete range of drive solutions for logistics needs, including:

 The LOGIDRIVE® solution delivers inte-
grated drive technologies for manufacturing and warehousing: high efficiency gearboxes, IE4 permanent magnet synchronous motors, and decentralized variable frequency drives (VFDs). In turn, the VFDs and IE4 motors support large speed ranges through gearboxes, to deliver automation for stacker cranes, automated guided vehicles, chain conveyors and roller conveyors, etc. NORD VFDs are capable of operating with all common field bus networks, offer free PLC integration, and provide simple commissioning with plug-in parameter boxes or NORD’s free programming software tool, NORDCON. Efficient operation at partial load and low speeds make LOGIDRIVE the solution for high-volume warehousing, manufacturing and packaging systems.

NORD’s LOGIDRIVE technology is ideal for intralogistics applications. It provides complete drive solution flexibility, increased energy efficiencies, and reduced variants to improve ROI. (Courtesy: NORD)

Hexagon launches dedicated shop floor photogrammetry solution

Hexagon’s Manufacturing Intelligence division launched DPA Industrial, featuring the new C1 Camera in combination with the well-established AICON DPA Series photogrammetry measurement system. Designed to make photogrammetric measurement simple and rugged enough to allow inexpert operation in inhospitable workshop conditions, DPA Industrial is set to establish itself as one of the most accessible high-speed/high-accuracy measurement tools on the market.

The overall DPA Industrial system is a fully portable coordinate measuring system that works over measurement volumes of up to 10 meters diagonal and delivers digital models to an accuracy of within just 10 microns. Full WiFi functionality along with extremely long-life battery operation make DPA Industrial an easy-to-use system.

The Power of One²

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That’s the same objective you have for choosing your gear producer. Circle Gear’s objective is to engage with every customer’s objectives.

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Partnering with QualityReducer to provide Gearbox repair, rebuilding and reverse-engineering.
for measurement directly in the production environment without causing costly production interruptions.

The new C1 camera is a ruggedized DSLR camera unit designed to withstand extremely challenging shop-floor industrial environments. The highly resilient casing also presents an extremely simplified measurement process, with settings adjustment and controls moved behind the scenes to produce an essentially point-and-shoot camera that can be used by inexpert operators to deliver metrology-grade results. The unit features a single button for image capture, along with a viewfinder for controlling field of view.

“In developing DPA Industrial, we were very focused on delivering a simplified user experience that would both protect against operating errors and make the system easy to use with only basic training,” said Andreas Rietdorf, DPA product manager at Hexagon Manufacturing Intelligence. “The DSLR cameras required by this sort of measurement system have always been an expensive and delicate investment, so a solution that delivers a more robust experience fits exactly the needs we’ve heard from users.”

First orders were set to ship in March. Hexagon Manufacturing Intelligence is a leading metrology and manufacturing solution specialist. Hexagon Manufacturing Intelligence is part of Hexagon, a leading global provider of information technologies that drive productivity and quality across geospatial and industrial enterprise applications.

AICON 3D Systems is one of the world’s leading providers of optical camera-based 3D measuring systems. The company, founded in 1990, develops and distributes portable coordinate measuring machines for the fields of inspection and testing including car safety and tube and wire inspection, as well as optical 3D scanners for the measurement of complex surface structures.

Platinum Tooling now represents Henninger speed increasers

Platinum Tooling, the importer of live tools, angle heads, marking tools, Swiss tools, and multiple spindle tools manufactured by various global suppliers, is now importing Henninger speed increasers for North America. The announcement was made by company president Preben Hansen at the company’s headquarters near Chicago.

Henninger is a manufacturer of specialized equipment and precision machine tool accessories. Spindle speeder types including mechanical, air, and electric motor driven styles are available.

These speed increasers help maximize productivity by achieving a higher spindle rpm than is required for certain applications in today’s marketplace. Small diam-
The speeders have automatic tool change capabilities and are modular in design to offer greater flexibility. Henninger also manufactures custom angle heads, live centers, face drivers, and live chucks. In addition, Henninger is the premier manufacturer for center grinding machines.

**MORE INFO**  www.platinumtooling.com

**Henninger products are now offered in North America by Platinum Tooling, effective immediately.**

Broaching tools require rpms that are sometimes not possible to reach with existing machine tools. In addition, they allow for less wear and tear on the machine’s spindle when it is not required to run at its maximum rpm.

Mechanical speeders are available with up to a 1:8 gear ratio and a maximum speed of 50,000 rpm. Air speeders can run continuously at up to 80,000 rpm and high-frequency motor spindles can maintain up to 80,000 rpm with high torque and have variable speed options.

Many of the speeders have automatic tool change capabilities and are modular in design to offer greater flexibility.

**KTR offers torsionally rigid, curved-tooth flange coupling for drives**

With hydrostatic drives in construction and agricultural machines, I. C. engines and hydraulic pumps are directly coupled. Both units are connected by a flange coupling.

This connection has to meet a number of requirements — though primarily it has to transmit the power reliably enabling the machine to perform the pending operations as requested.

BoWex FLE-PAC is a torsionally rigid curved-tooth flange coupling. Its hub is made of steel and the flange toothing of carbon fiber reinforced nylon. This material combination provides the coupling with high dimensional stability even with temperatures up to 130°C allowing for a long and maintenance-free permanent operation thanks to optimized coefficients of friction in the tooth combination.

“Years of experience with applications at customer sites and extensive test series in the KTR test field in Rheine enabled us to determine potentials with this type allowing for an increase of torques of up to 25 percent,” said Dipl.-Ing. Andreas Hücke, product manager for flange couplings in KTR. “Especially the low wear of contacts and the excellent dimensional accuracy of the coupling were decisive for the torque increase. The increased coupling torques definitely result in a bigger performance range with drives up to 800 kW. Thus, the customers will be in a position to use smaller coupling sizes in their machines in the future.”

**MORE INFO**  www.ktr.com

Henninger also manufactures custom angle heads, live centers, face drivers, and live chucks. In addition, Henninger is the premier manufacturer for center grinding machines.

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“Once we get adhesion to the base material, it’s there to stay unless you need us to remove it.”

What’s a typical day like for you at Iosso?
I oversee the production of different departments. We have two departments: One is a production department for larger volume orders, and the other is a hands-on mold and precision department where intricate parts require special handling or where custom work is performed. They can be larger parts like cavities and cores, or smaller intricate components that require special handling, such as plating inside diameters or masking of certain areas where tolerances will not allow any additional dimension change. Throughout the day, I am usually quoting new jobs, answering calls from customers, and scheduling and overseeing the jobs that are in-house being processed. I also oversee the quality control department and chemistry operations.

What does Iosso bring to gear manufacturing?
The unique thing about the Iosso-FE process is that it gives longer wear to the part. We can achieve a Rockwell hardness depending on the base material — anywhere from 72 up to 76 on the C Scale for hardness range. We get one-10th of a millionth of penetration into the base material, which creates a new strong hard surface. For gears, in particular, we extend the life of the part by giving them increased hardness for longer part life, reducing friction, and providing corrosion protection. We have 50 years’ experience in this field and can help consult and design our process into various customers’ unique applications. We are ISO 9001:2015 certified. Our plating process is RoHS compliant and conforms to the requirements of TPCH (Toxics in Packaging Clearinghouse) — all tests provided by an independent laboratory.

What makes Iosso’s coating treatment unique to the gear industry?
We have very sophisticated controls as far as density control, not building up on leading edges. We have such tight controls that we will not build up on these sharp edges. That’s where we differ from other types of platers: very tight controls, no peeling, no flaking, no galling. Once we adhere to the base material, it’s there to stay, unless you need us to remove it. No further operations are needed because we control the tolerance within 0.00005” to meet our customer’s specification. The process is also heat resistant, non-magnetic, static free, and crack free.

What other areas of the industry would Iosso be uniquely suited for?
Other than the gear industry, we do all types of packaging equipment components, mold components, everything from mold-base plates, cores, cavities, core pins, ejector pins, ejector sleeves. There is a wide range of industries we service such as fluid-metering components, medical parts, pipe-cutting equipment, and lock components.

How do you approach a customer when they come to you with a coating challenge?
Our process normally begins with a development order where we would record all process-control information. We would keep all the information on that particular part. It could include pictures, prints, tolerance requirements, and any other information that we get from the customer. Confidentiality agreements, if they’re needed, are signed and submitted back to the customer. We record all the details. Of course, time is money, and in some instances, we may do two or three runs for thickness variations. And we’ll assign a control number to these. The customer can come back and say, “We prefer this particular control number over the other two. So, could you give us a cost on that and what would be involved?” Then we would go from there.

Development order processing is done with our own tooling, and they are usually done in what I referred to earlier as the mold-and-precision department. These would be component parts, maybe five, 10, or 15 pieces, not much larger than that. We process enough parts for the customer to test. Once we establish what is working for the customer, we would quote tooling cost in order to process the largest quantity of parts efficiently for cost effectiveness.

Where do you see the gear industry in the next 10 to 20 years and Iosso’s place in that future?
We process a lot of gears through our facility and are always looking for more business from gear manufacturers that may need us but are not familiar with our unique plating process, which, as I said earlier, is RoHS compliant.

Gear manufacturing will continue to grow. There are so many components that require some type of gear for functionality. We process many gears in our facility, whether it is for hardness or reduced friction and always for the added corrosion protection we deliver to our customers.

What I also see growing is our position on processing zinc die-cast gears. Iosso Metal Processes has a patented plating process engineered and developed by the founder and owner (Richard Iosso) of our great company. We can take a zinc die-cast gear or any component cast from zinc and make it file-hard for wear. This is a highly sought-after process for manufacturers who need the die-cast gear to pass long-term cycle testing for component longevity (part life). We can and do prevail in the hardening of all zinc components. When the volumes are high, zinc die casting of gears can make a huge impact in one’s budget. There are huge cost savings with high-volume die-casting compared to many machining operations that might be needed to produce a gear.

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