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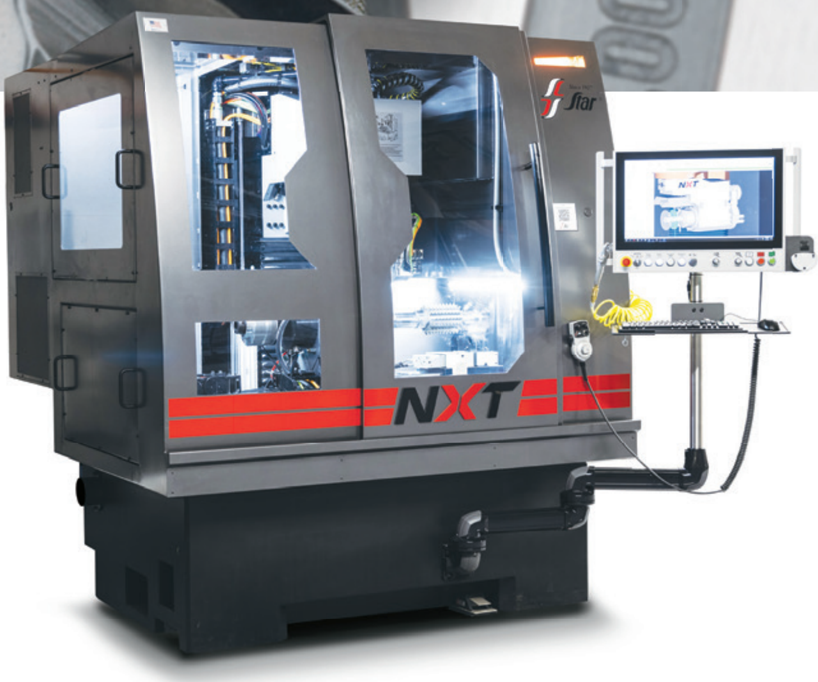
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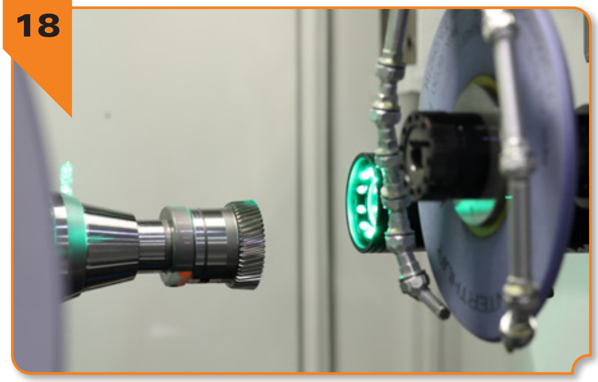

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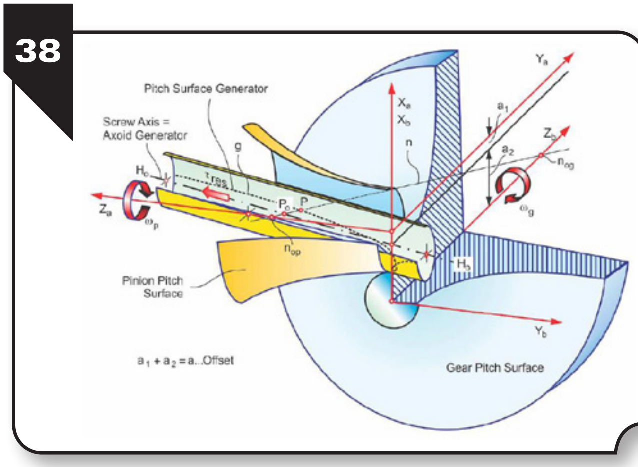

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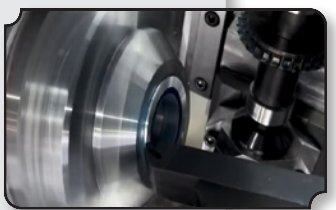
GT Videos

Gleason 100PS Power Skiving

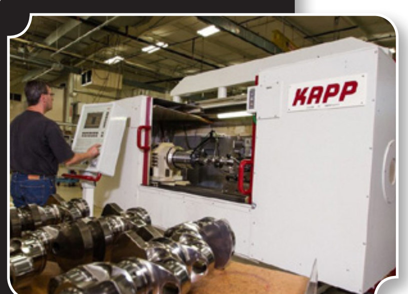


Gear hobbing and power skiving processes can be used on the 100PS, including additional processes like brushing and/or turning operations. Due to the unique flexibility of the 100PS, all gears of a typical e-bike transmission can be produced on a single machine.

geartechnology.com/media/videos/play/256

GT Revolutions

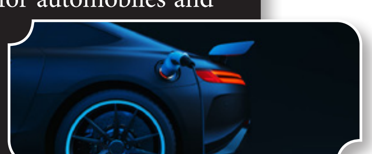
State of the Gear Industry Perspectives: Forest City Gear



State of the Gear Industry Perspectives takes an in-depth look at the challenges and opportunities in gear manufacturing today and in the future. Our seventh installment online is an interview with Kika Young, president, and Jared Lyford, director of manufacturing operations at Forest City Gear (FCG).

geartechnology.com/blogs/4-revolutions/post/30213-state-of-the-gear-industry-perspectives-forest-city-gear

Keeping Up with Manufacturing Changes



The rise of electrification is happening more widely and suddenly than anyone expected, both for automobiles and for other types of electric vehicles (EVs). The global EV landscape is also more competitive than the automotive markets of previous decades, as more manufacturers—large and small—compete for space. How can manufacturers stay ahead of the competition while also overcoming the increasing challenges posed by difficult-to-machine materials, like high-strength steel?

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Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein *Gear Technology* Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 38 years' worth of technical articles can be found online at *geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

THE GEAR INDUSTRY'S INFORMATION SOURCE
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Prepare for Anything

Publisher & Editor-in-Chief
Randy Stott

The presentations at last month's AGMA/ABMA Annual Meeting provided plenty of food for thought. In particular, the topic of artificial intelligence kept coming up. But, as always, attendees wanted to know what's going to happen next with the economy.

Jim Meil, Principal, Industry Analysis for ACT Research, gave his usual analysis of the state of the economy, apologizing at the outset that all of his information, prepared the week before, might already be out of date (the Silicon Valley Bank failure occurred the weekend before the meeting). Meil has been presenting at the annual meeting for a number of years, and his detailed analysis—and dry sense of humor—make his presentation always well anticipated.

This year, of course, the main gist of Meil's talk was whether or not there will be a recession, or even whether or not we're already in one. We're in unusual times, he said, with unprecedented low unemployment at the same time we're experiencing rapid inflation. The Fed has never gone through a sustained period of rate hikes when the country has been at 3.5 percent unemployment, so they're operating without a road map, Meil says. In addition, we've seen repeated shocks to the system over the past several years, including trade wars, COVID and the war in Ukraine, He pointed to softening of demand in things like the Purchasing Managers Report. All of this makes it pretty hard to predict what's going to happen next. When banks start failing, and the federal government is about to reach its debt limit, it could make for a very interesting summer.

So will there be a recession or won't there? At the end of the day, Meil shrugged his shoulders and said, probably yes, a small one, on paper. "But it will be the best recession of most of your careers."

Overall, the mood at the event was extremely positive. Gear manufacturers and suppliers alike were enthusiastic to be together again for only the second meeting since COVID. People are definitely still celebrating the fact that we can all get together in person. From my observations and conversations, not too many were overly concerned about the economy.

The other topic that kept coming up, both in the presentations and in individual discussions, was the importance of beginning to understand artificial intelligence. Much of this has to do with the recent headlines surrounding ChatGPT and other language-learning chatbots that are becoming scary good at what they do. Mostly, people in industry are looking at this as another tool that they can use to make their businesses more efficient. If you haven't done so, you should try it, if for no other reason than so that you know what everyone is talking about.

We live in crazy times, when the only thing that seems certain is that we have not yet reached the pinnacle of craziness. Change is happening on so many fronts that it's hard to know what's going to come next. Like Jim Meil, we just have to shrug our shoulders and give it our best guess.

I say it's time to prepare for anything. In your business, you need to be agile, and to be agile, you need to be informed.

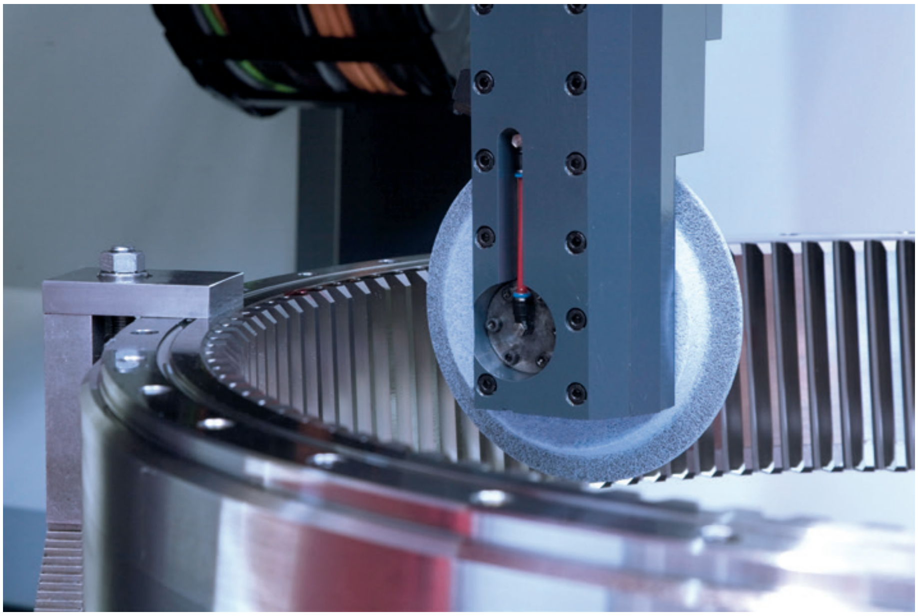
One of the best ways to be informed is to continue reading *Gear Technology*. Every issue we try to bring you information that will help you in the business of gear manufacturing. One of the other ways is to attend industry events. While the AGMA/ABMA Annual Meeting is a members-only event, there are plenty of other opportunities—some coming up soon, like AGMA's Motion+Power Technology Expo, which takes place October 17–19 in Detroit (*motionpowerexpo.com*). The association has a lot planned for the event, and there will be more opportunities to learn and network than you can possibly fit into just three days. You should add it to your calendar now.

It's just one way you can prepare for the next round of craziness.

Krebs & Reidel

OFFER PREMIUM GRINDING WHEELS WITH HIGH PROCESS RELIABILITY

Philipp Bötte, marketing and communication, Krebs & Reidel



Krebs & Riedel is expanding into other sectors where large gears are manufactured with the new Blue Moon TZ premium product range.

Serial production of large gears requires a high level of quality, excellence, and continuity in production. Emphasis is placed on maximum synergy between the grinding machine, the grinding process, and the grinding wheel. After several successful trials on various Klingelnberg Höfler Rapid grinding machines carried out by Krebs & Riedel with customers in their production facilities, Krebs & Riedel has received several large orders for grinding large gears from abroad and has introduced the new premium grinding wheels with high process reliability.

Krebs & Riedel is a manufacturer of grinding wheels for gear grinding in the automotive and EV sector. The family-owned company is also expanding into other sectors where large gears are manufactured with the new Blue Moon TZ premium product range.

In recent years, wind power has been an important factor in reducing CO^2 emissions. Wind turbines are getting bigger and more powerful, while production costs must be reduced. This requires production methods that can produce the gears cost-effectively and in high quality, even with complex flank modifications. Gear sizes in wind power typically range from 800 to 4,000 mm. Some gears can even reach a diameter of 8,000 mm and weigh up to 100 tonnes. The most common size in the field of external gears is 1,200 mm in diameter and ranges from module 12 to module 52. The profile grinding wheels typically have a diameter of 100–450 mm.

Synergy between the grinding machine, the grinding process and a premium grinding wheel is very important. Only a perfectly ground gear geometry ensures optimum power transmission for high wind turbine efficiency and smooth running. Grinding burn must be avoided under any circumstances, because the forces in the gearbox are very high and tooth breakage is very expansive. High-precision gear quality is a matter of course at Klingelnberg and Krebs & Riedel. It increases the service life of the individual gear components and makes a significant contribution to reducing maintenance and production costs. To achieve maximum synergy between the grinding machine and the grinding wheel, Krebs & Riedel optimizes the process with application support at customers sites around the world and offers with the Blue Moon TZ, a new premium grinding wheel with a precision-shaped abrasive grain.

Blue Moon TZ is characterized by a very high cutting performance and a very high material removal rate.

"In some trials, the material removal rate (Q_w) was more than 30 mm^3/mms," said Sigurd De Ridder, senior application engineer at Krebs & Riedel, who conducts trials and process optimization for customers worldwide. "Precision-shaped abrasive grains are state of the art today. Blue Moon TZ is comparable in performance to other precision-shaped abrasive gains on the market. It is self-sharpening, very sharp-edged, microcrystalline and has an elongated trapezoidal shape."

The homogeneous pore structure of Blue Moon TZ contributes to an extreme improvement of the entire cooling system during the grinding process. Due to the open structure, the entire grinding wheel is immediately flooded by the cooling liquid. Even with extreme material removal rate, the chip is transported away from the contact surface. This avoids heat input

Blue Moon TZ is comparable in performance to other precision-shaped abrasive gains on the market. It is self-sharpening, very sharp-edged, microcrystalline and has an elongated trapezoidal shape.

After several successful trials on various Klingelnberg Höfler Rapid grinding machines carried out by Krebs & Riedel with customers in their production facilities, Krebs & Riedel has received several large orders for grinding large gears.

that could lead to thermal damage to the gear.

On average of all tests on Klingelnberg Höfler Rapid 2500 machines, De Ridder had the following grinding results: A cooler grind and a longer tool life, combined with up to 20 percent faster grinding time compared to standard grinding wheels. The longer tool life and higher grinding performance helps to reduce costs while achieving the same, or even better, quality of the gear. On average of all dressing tests, De Ridder achieved the following results: 20 percent longer dressing intervals, 30 percent less infeed, which also leads to a longer tool life of the dressing wheel. Another side effect is that the machines have a lower power consumption after the optimization.

The profile grinding machines of the Rapid series for large workpiece sizes are designed for component diameters up to 8,000 mm. Depending on individual requirements, they are equipped with an extended stroke range (L variant) and are also available in two variants. In addition to the standard configuration, the machine is also available with a small grinding head to accommodate very small grinding wheel diameters of 20–300 mm (K variant).

In all configurations, machines of the Rapid series can be converted from external to internal gears in a very short time by means of optional internal gear grinding arms. In addition, the special arrangement of the machine axes, a thermally stable and almost vibration-free machine bed made of mineral casting, as well as wear-free torque drives in the machine table and the grinding head for 5-axis grinding contribute to the proven precision, consistent quality, and enormous flexibility.

Thanks to the highly flexible grinding head with integrated 3D probe and adjustment of the helix angle during the grinding process, gears can be topologically modified in 1-flank grinding or 2-flank grinding, depending on the permissible deviations. The measurements with the optionally available testing devices ensure a controlled grinding result already during the grinding process.

Serial production of large gears requires many hours of workpiece setup, programming, grinding, dressing and quality control. It is important to use a premium grinding wheel with precision-shaped abrasive grain. The dressing and grinding processes should be perfectly set up on the grinding machine and optimized by application support. The Blue Moon TZ premium grinding wheels have not only proven themselves in the grinding of planetary gears, spur gears and IR outer and inner rings. They have also led to a reduction in production costs when grinding drive shafts, automotive gears, and conveyor screws.

krebs-riedel.com

Mitutoyo America Corporation

RELEASES NEW IDC INDICATORS

Mitutoyo America Corporation, a leading manufacturer of precision metrology instruments and solutions, is proud to announce new versions of the IDC, IDF and IDS series of digimatic indicators and products built around these indicators such as depth and thickness gages.

IDC and IDF series improvements and changes

The IDC and IDF series digimatic indicators have new designs and functions. Improvements include higher resolutions down to 20 µin. / 0.5 µm, a built-in calibration date warning, larger LCD and "analog" bar, and new S1 output (bidirectional communication) which allows settings to be changed through the new *USB ITPak 3.0* software (free and paid versions).

All models with 0.5 in. / 12.7 mm range will now have a metric (M2.5x0.45) stop screw (screw under dust cap). The contact points will remain the same: AGD models = 4-48 UNF contact point, ISO/JIS models = M2.5x0.45 contact point. The tapered, tapped hole for lifting cables has been removed.

Calibration period notification functions

The LCD displays an icon to notify the user when the set calibration time approaches. This facilitates the proper precision management of ID-C/ID-F.

The calibration period notification icon starts blinking at a set time before calibration is due (e.g., one week before the calibration due date). If the deadline is exceeded, the entire screen starts blinking to notify the user.

mitutoyo.com

FVA-Workbench 5.5

OFFERS DETAILED TRANSMISSION CALCULATION RESULTS

The latest version offers a wide range of powerful new features, from a new gear design module, to the influence of the wheel body during a complete rollover, to new display options for 3D images and animation of the gearbox kinematics in reports. With its powerful calculation methods, the *FVA-Workbench* makes it possible to significantly reduce calculation times and quickly achieve optimal gear designs.

A selection of the new features in *FVA-Workbench 8.0:*

- Ovalization of FE components at bearing seats
- FEM influence coefficient method for bevel and hypoid gears

- Audio output of the transmission error for cylindrical and bevel gear stages
- Optional modeling of stiff shafts and wheel bodies in the overall system
- New scripting functions
- Distributed calculations with the *FVA Simulation Hub*

`fva-service.de/en/`

Jergens Inc.

INTRODUCES NEW COMPACT ZERO-POINT SYSTEM (ZPS) MODULES AND PULL STUDS

Jergens now offers two new zero-point-system (ZPS) installation choices for compact, light-duty applications. SP140 and K02 pull studs utilize pneumatics and a mechanical spring in a small package. Together they offer quick-change solutions for vise or gripper jaws, electronic component manufacturing, packaging machines, medical technology, and automation.

SP140, the smallest clamping module on the market, features a threaded body for low profile installation. No external fasteners or clamps are needed for securing in a plate. This allows for flexible mounting options along with the fact that pneumatic pressure can be supplied manifold style through the subplate or through external lines ported into the bottom of the module. The pull studs are offered in Zero Point, timing, and clearance configurations, like larger ZPS systems.

SP140 and K02 are part of the vast ZPS offering which uses either pneumatic or hydraulic modules to fix, position, and clamp all in one step. Additionally, ZPS ensures repeatability of up to 0.0002 in., and reduces cycle times by up to 90 percent. Users quickly and accurately locate and clamp vises or fixtures, or if preferred, attach retention studs to workpieces and then direct mount components for machining or welding, avoiding potential interference from jaws or clamps.

`jergensinc.com`

NUM

OFFERS TOOL GRINDING SOFTWARE TO DENMARK TOOLING COMPANY

TN Vaerktoejsslibning, Denmark's second-largest precision tooling company, is deploying *Numroto*, the programming system for tool grinding from NUM across its entire production floor. The company cites highly successful long-term experience of the software, together with excellent technical support from NUM, as the key reasons for choosing to standardize on *Numroto*.

Founded by Torben Nielsen in 1987—which coincidentally is the same year that *Numroto* was launched—TN Vaerktoejsslibning has grown steadily to become a leading player in the manufacture of special solid carbide tools, with an enviable reputation for the quality and precision of its products. Operating from a modern 2,000 square meters industrial facility in Bjaeverskov, some 30 miles southwest of Copenhagen, the company serves the world market and currently exports about 70 percent of its production.

One of TN Vaerktoejsslibning's prime business advantages is that it handles every aspect of manufacturing and can therefore track the movement of individual tools from initial order through to delivery. The company maintains a large stock of high quality "sub-nanograin carbide" materials in the form of rods with internal cooling channels and solid bars, ranging in diameter from 2 to 70 mm. Using multiple advanced CNC grinding machines, TN Vaerktoejsslibning produces a comprehensive range of standard "TN" brand high-speed end mills, step drills and form cutters, the design, and dimensions of which can be tailored to meet customers' needs for "exactly the right tool for the job."

TN Vaerktoejsslibning also operates advanced in-house tool polishing and coating technology. Tools can optionally be coated both before and after polishing, to extend their service life and to help optimize chip evacuation. The company additionally offers tool regrind and recoat services. Provided that a tool is physically undamaged, it can often be returned to full service after regrinding and possibly recoating, for less than 50 percent of the cost of a new tool.

Every aspect of tool manufacturing at TN Vaerktoejsslibning is extensively automated. The main production hall is equipped with fifteen 5-axis CNC grinding centers, complemented by cylindrical grinding machines. All of these machines are controlled by *Numroto* software and are networked together to help simplify production management and software maintenance. Each machine has a dedicated programming station, enabling part programs to be created while grinding is taking place, and the company is also in the process of expanding its multiuser programming facility, which currently has capacity for seven users.

An interesting facet of TN's operational structure, which is quite possibly a factor behind the company's consistent year-on-year success, is that it

deliberately has a flat hierarchy—there is no design department. Each CNC machine operator is responsible for programming, grinding the tools and fully documenting the process.

According to Torben Nielsen—who is still at the helm of the company, nowadays as TN Vaerktoejsslibning's CEO as well as its owner, "We try to make work as interesting and satisfying as possible for people, and over the years we have built up a dynamic team of highly qualified and committed employees. Another important point is that by standardizing on *Numroto* for the bulk of our CNC machining operations, we benefit immensely from our employees sharing a common pool of expertise and knowledge about state-of-the-art tool production technologies and processes. Many of our more specialist tools are only required in small batch sizes—sometimes just two or three—and yet we aim to supply these to customers within the same nine-day timeframe as our standard tools. To help meet this goal, our operators need fast, simple, and unambiguous machine control facilities—which in turn demand very flexible, accurate and reliable software, with a modern user interface."

TN Vaerktoejsslibning regularly enhances its machining capabilities to meet the changing tool needs of its customers. The company first started using *Numroto* software back in 2002, when it purchased two Deckel S20 CNC grinding machines, which have since been followed by a further 10 Deckel S22 machines. The company's current complement of *Numroto*-controlled CNC grinding machines comprises the 12 Deckel machines, plus a UWS SF40 cylindrical grinder and two Vollmer VGrind 340S machines.

The programming and machining of special tools, which constitute the majority of TN Vaerktoejsslibning's production output, is usually carried out during the day by skilled operators. Larger standard tools are processed at nighttime, using robotic part loaders and unmanned machining centers, but with a high degree of feedback such as in-process measurement and run-out compensation to ensure consistent product quality.

All tools produced by TN undergo thorough inspection prior to shipment. The company's quality assurance facilities include an air-conditioned, positively pressurized measuring room, equipped with a 5-axis CNC measuring machine and other precision optical measuring equipment.

Nielsen adds: "Our experience with *Numroto* has been fantastic. The software is perfect for grinding both simple and highly complex tools and is extremely reliable. It is very easy to work with and the simulation is very precise. In a period of just over 21 years, there have been very few tools that we have been unable to create. Due to our very short delivery times, we rely on good support—and this has always been forthcoming from NUM."

num.com

Sandvik Coromant

OFFERS ALL-DIRECTIONAL Y-AXIS TURNING

Sandvik Coromant has introduced a new method for turning complicated shapes and pockets with a single tool. Y-axis turning offers benefits such as reduced cycle time, improved component surface quality and more stable machining.

Turning has developed immensely in recent years with new innovations, such as all-directional PrimeTurning, nonlinear turning and interpolation turning. "One could say that these advances, together with progressive capabilities in modern machines and CAM software, have paved the way for the new Y-axis turning method," says Staffan Lundström, product manager, turning, at Sandvik Coromant. "And with the tools and method now in place, we look forward to exploring the possibilities this method can present to our customers."

So how does Y-axis turning work? As the name implies, the new method makes use of the Y-axis, and all three axes are used simultaneously when machining. The tool rotates around its own center, the insert is placed for machining in the Y-Z plane and the milling spindle axis interpolates during turning. This allows intricate shapes to be machined with a single tool.

Y-axis turning offers numerous benefits. The ability to machine several features with a single tool reduces cycle time, and no tool changes are required, which minimizes the risk of "blend points," or irregularities between adjacent machined surfaces. The main cutting forces are directed into the machine spindle, thus improving stability and reducing the risk of vibration. A constant entering angle drastically improves chip control and makes it easier to avoid chip jamming.

Two new tools have been developed to support Y-axis turning. The new CoroTurn Prime variant is suitable for shafts, flanges, and components with undercuts. The CoroPlex YT twin-tool, featuring CoroTurn TR profiling inserts and CoroTurn 107 round inserts with rail interface, can favorably be used for components with pockets and cavities.

To summarize, Y-axis turning is a method for simultaneous three-axis turning with interpolation of the milling spindle axis. The new tools can also be used in "static mode" with a locked spindle for flexible two-axis turning with fast insert indexing. The method is suitable for all materials and requires a multitask machine with options to allow interpolation of the milling spindle axis during turning.

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The Secrets to Implementing Lights-Out Machining

Making a whole day productive requires strategy not staffing

Simon Richardson, Product Manager, ANCA

It's little wonder there's more and more interest in the potential of lights-out or unattended production. The benefits seem immediately obvious. Staffing costs fall significantly if you can run equipment unsupervised, or with far fewer operators. Production capacity of the business greatly increases, offering the opportunity to add more customers without the expense of adding new equipment or staff.

It offers enhanced flexibility by allowing you to move longer-running jobs—that don't require supervision—to overnight, ensuring your skilled operators can be fully engaged with jobs where they're needed during working hours.

Another reality that's having a significant impact on the appeal of unattended production is the skills shortage. Finding and retaining skilled operators seems to be becoming more and more difficult, with a high likelihood that it'll be even harder in the future. Any opportunity to maintain the number of operators required and increase productivity can only benefit your business in the long run.

However, moving into lights-out machining can be a challenging transition and isn't as simple as automating a few processes and hoping for the best. There are a multitude of factors to consider and changes that need to be made to ensure your machine shop's ready to run unattended. But the improvements to efficiency and profitability make it an investigation well worth having.

Start Slowly

As attractive as the idea is of your business pumping out a day's worth of production while you're in bed asleep, there's no need to rush into it. If you have multiple machines, don't plan to put all of them into unattended production at once. Take one or two machines as a test case and see how it goes.

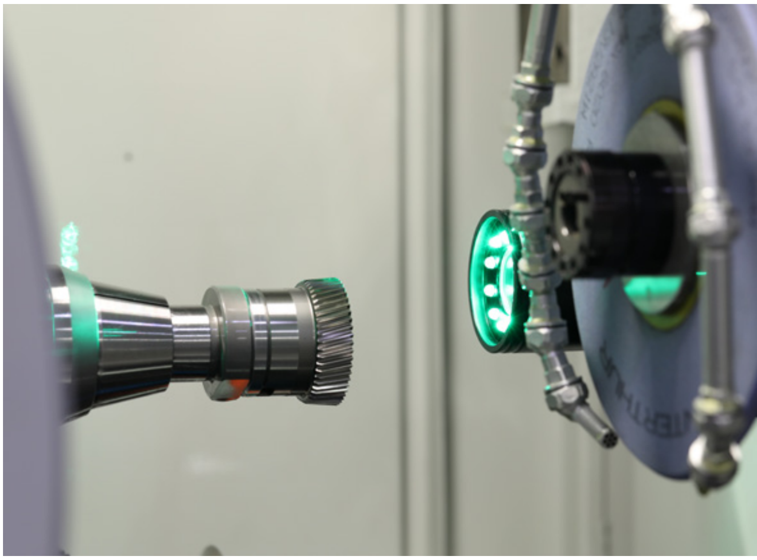
Similarly, don't try and get an entire production line ready in one go. Take incremental steps to test each section of the production process to discover potential issues when they're running unattended. Then, slowly build up to a fully operational production line.

Be Smart About the Jobs You Choose to Run Unattended

Initially, it's wiser to select simpler projects that are less likely to run into problems and need supervisor intervention. And remember, speed is less important than accuracy and reliability in lights-out production. You're not paying the same staff overhead, so if you can ensure greater quality by slowing down the process a little, it's worth it. Similarly, going slightly slower to avoid potential quality problems with your tools makes sense when you're having the machines work unsupervised.

Ideally, you won't run a job overnight, that hasn't been tested with operators present during the day. It's just asking for trouble not to check that everything works before you run it lights-out.

When It Comes to Lights-Out Machining, Preparation Is Key



The iView is a measuring system that evaluates tooling while still in the workholding such as the ANCA GCX Linear skiving machine.

Ensuring a high level of preventative maintenance across every element of the process becomes even more vital if you're

There's more to running lights-out than simply having the automation in place that enables you to achieve it. Other elements of the process need to be up to the task, as well. Consider:

considering moving into lights-out production. Some little quirk of the machine that an operator just handles on the go can become a real problem when unsupervised. So, make certain your staff report even the smallest of issues that might cause problems.

Monitoring, of course, is invaluable. Take ANCA's *REDAX,* for example. This real-time monitoring software not only delivers up-to-date information about every machine on the floor but can send emails and SMS notifications to nominated recipients as needed.

REDAX *offers complete visibility of a machine's status and activity.*

It's also vital that you have the technology in place to guarantee quality control. There's no value in producing tools all night that are defective. A premium in-machine tool measurement system, like ANCA's LaserUltra, can automatically compare the tool with its required geometry and make the necessary compensation to ensure consistency.

- **How reliable are your services to the machines (such as power and air)?**
- **What happens if there's a power outage?**
- **Are your fire suppression systems adequate?**
- **Are your management of coolant and different coolant applications correct?**
- **Are your machines currently monitored remotely and how are operators notified of any issues?**
- **How adequate are your management and access to the correct grinding wheels inside the machine when needed?**

Maybe There's One Light On

It's worth pointing out that unattended production doesn't have to be taken literally. There are certainly benefits to having at least one operator supervising the night shift, even if they end up not having to do anything. Proper automation will ensure you receive a significant increase in productivity for the nominal cost of one wage.

Lights-Out Machining Can Really Move Your Business Forward

Approached deliberately, and with the appropriate planning, the introduction of unattended production can offer huge benefits to your bottom line. And the changes you make to your processes to allow you to embrace it will increase your productivity and profitability both day and night.

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ANCA CNC Machines
Ancon Gear & Instrument Corporation
Ash Gear & Supply
Balance Systems Corporation
Bevel Gears India Pvt. Ltd.
Blaser Swisslube, Inc.
Bomatec International Corp.
Bourn & Koch Inc.
Brelie Gear Co.
Canton Drop Forge
Capstan Atlantic
CGI, Inc.
Cincinnati Gearing Systems
Circle Gear and Machine Company
Cleveland Deburring Machine Company
Closed Loop Recycling
Columbia Gear Corporation
Creative Automation Inc.
Croix Gear
CUMI America Inc.
Curtiss-Wright Surface Technologies
Delta Gear
DixiTech CNC
Dontyne Systems Limited
Doppler Gear Company
DTR Corporation
Dumbarton Tool
DVS Technology America
Elgeti Engineering GmbH
EMAG LLC
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Great Taiwan Gear Ltd.
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What's Happening in Heat Treating?

Acquisitions, retirements and facility expansions highlight start to 2023

Matthew Jaster, Senior Editor

Quality control, EV components, energy consumption and material influences are just a handful of topics being discussed in heat treating today. New heat treat methods and global trends will be the topic of conversation later this year at Heat Treat 2023. Here's a round-up of some stories circulating across key market segments.

Dana's Heat-Treating Capabilities Provide Gears and Gear Drives for Construction, Off-Highway and Agriculture Markets

To engage the rapidly increasing interest in compact track loaders (CTLs) and other tracked equipment in North America, Dana is nearly tripling its annual production of Spicer Torque-Hub track drives within the current footprint of its manufacturing and assembly hub in Lafayette.

Spicer Torque-Hub drives for CTLs offer output torque ratings from 5,000 to 17,000 Nm, delivering increased productivity with maximized motor displacements in a compact package.

Scheduled to start operation in the second quarter of 2023, the expansion includes installing automated assembly processes managed by a full manufacturing execution system, extending already robust lean manufacturing initiatives, and incorporating next-generation quality controls.

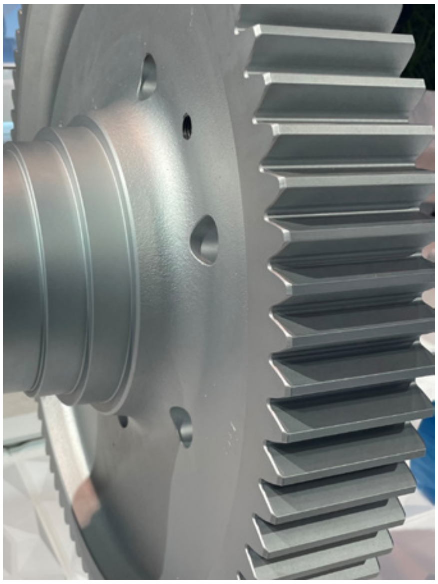
In addition to expanding its drive production capacity, Dana has also recently repositioned the final assembly of its line of heavy axles for mining and other extreme-duty applications to its Lafayette facility. The realignment helps Dana better address the supply-chain requirements and onshoring of North American OEMs.

In-House Heat Treating Facility

At CONEXPO, Dana highlighted its ability to deliver precision-made Fairfield gears and gear drives for industrial and mobile applications. The company's machining and state-of-the-art heat treatment capabilities enable the production of custom-made Fairfield gears up to 6.5 ft. (2 m) in diameter and shafts up to 10 ft. (3 m) in length.

Dana also supports the production of custom-made Fairfield drives produced to industry certifications, ranging from build-to-print services up to end-to-end support encompassing design, manufacturing, metallurgical engineering, and testing.

"Our Lafayette facility serves a dual purpose as a world-class manufacturing facility and as a technical and customer experience center," said Jeroen Decleer, senior vice president, off-highway drive and motion systems at Dana. "Optimally located for many of



our US-based customers, our Spicer Torque-Hub center of excellence features numerous upgrades that will help us further increase customer satisfaction and create value."

dana.com

Bodycote Receives Science-Based Target Initiative Approval for Emissions Targets

Bodycote recently announced its near-term science-based emissions target has been approved by the Science Based Targets initiative (SBTi).

SBTi is an independent global body enabling businesses to set and validate emissions reduction targets in line with the latest climate science and strict criteria. The initiative is a collaboration between CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF) and one of the We Mean Business Coalition commitments.

Science-based targets provide a clearly defined pathway for companies with ambitious climate goals to reduce greenhouse gas emissions, helping prevent the worst impacts of climate change and future-proofing business growth. Targets are considered 'science-based' if they are in line with what the latest climate science deems necessary to meet the goals of the Paris Agreement – limiting global warming to well-below 2°C above pre-industrial levels and pursuing efforts to limit warming to 1.5°C.

Bodycote, with over 165 facilities in 22 countries, commits to reduce its absolute Scopes 1 and 2 greenhouse gas emissions by 28 percent by 2030 from a 2019 base. Scope 1 includes all emissions directly linked and emitted by Bodycote facilities and Scope 2 includes all emissions linked to the Group's purchased inputs, those associated with the purchase of electricity, steam or cooling. Bodycote measures Scope 3 emissions, in line with the SBTi guidelines, but does not report them as SBTi deems the quantum to be immaterial.

Bodycote's services are vital to ensuring the performance and longevity of crucial components in almost every part of the modern world, enabling—amongst many other advantages—longer lifetimes, less machining, less waste and greater fuel efficiency. Both in the products we process and the way we process them Bodycote's services support industry to avoid emissions, commonly referred to as Scope 4. By avoiding emissions from the outset, Bodycote is a major contributor to helping industries to reduce their carbon footprint and help to minimize the adverse impact on the climate.

Commenting on the approval, Bodycote Group Chief Executive, Stephen Haris said, "We are very pleased to achieve approval of our near-term science-based emissions targets. Managing energy and reducing our environmental impact has long been part of our corporate culture. As a company, Bodycote is focused on ethical and sustainable growth, and proud of our commitment to setting an ambitious target. Leading by example, Bodycote demonstrates the positive impacts of carbon reduction for its stakeholders and encourages other businesses to commit to science-based targets."

bodycote.com

Ipsen Repurposes Ceramics Facility for Expanded Hot Zone Production Capacity

Ipsen in Pecatonica, Ill., (formerly Ipsen Ceramics) is being repurposed for vacuum furnace hot zone assembly. The plant is currently undergoing major refurbishments, including new lighting, HVAC, roofing, and other interior and exterior upgrades. The factory, located at 325 John Street, is less than 30 miles from Ipsen's Vacuum Technology Excellence Center in Cherry Valley and will initially employ up to eight material assemblers. Incorporating the Pecatonica location into Ipsen's vacuum furnace production and aftermarket process will provide added benefits to customers.

"Our goal is to reduce delivery times and better control the critical phase of assembly," said Jake Hamid, Ipsen's director and chief operating officer.

In the future, Ipsen is considering other manufacturing activities in Pecatonica to supplement the needs of the Vacuum Technology Excellence Center.

Ipsen is now hiring material assemblers. Benefits include 401k with

company match, medical, dental, and paid vacation time.

ipsenglobal.com/careers

Aalberts Surface Technologies Expands Austempering Capabilities

Aalberts surface technologies recently announced a significant expansion of its austempering capabilities and capacity in Canton, Ohio and Ft. Smith, Ark.

Three atmosphere-to-salt furnaces will be added at the existing facility in Canton. This expands the number of austempering locations in the Aalberts surface technologies US footprint to four. Infrastructure will be engineered in Canton to allow for up to six austempering furnaces in the future. The expansion in Canton will allow Aalberts to better serve customers located in the eastern US and those with product flowing through the area. The austempering and marquenching equipment is anticipated to be online in Q4 2023.

The Aalberts surface technologies austempering facility in Ft. Smith was started in 2018 to bring industry leading capabilities to an underserved market. In response to growing demand in the region, additional capacity will be added at the Ft. Smith plant, with one furnace to be installed in Q3 2023 and another planned for Q4 2024.

The added capacity will allow the company to support current customers' growth plans as well as demand from new entrants into the fast growing

austempered ductile iron market. Additionally, the expanded US footprint creates redundancy that provides customers greater flexibility, risk mitigation, and cost reduction opportunities.

"We are pleased to announce our latest investment in technology to add capacity that meets our customers' growing demand in key markets. The added capacity allows us to maintain our high level of customer service and further strengthens our position as the market leader in austempering and marquenching," says Steve Wyatt, president of Aalberts surface technologies.

aalberts-ht.us

AFC Holcroft Announces Management Changes

William Disler, president and CEO at AFC-Holcroft

William Disler, president and CEO at AFC-Holcroft, has announced that he is stepping down from the company, effective March 30, 2023.

As part of the departure news, the company also announced Tracy Dougherty and Ronald Waligora will share senior leadership responsibility for leading the company. Dougherty, formerly vice president of sales, has been named chief operating officer for sales, applications, marketing and aftermarket sales while Waligora, formerly senior engineering manager, has been named chief operating officer for project management, engineering, manufacturing and field services.

Disler said, "It has been an exciting and rewarding journey with AFC-Holcroft. It is hard to believe it started more than 35 years ago. Over the years I have had a chance to work with many incredible people and have made many friends." He added, "I have every confidence that the new leadership will continue to guide the company in a good direction. We have brought together a stellar team, and I feel good that I am leaving the company in such capable hands, and that this company will continue its long history of excellence into the future. I am very proud of AFC-Holcroft and the people that have always worked so hard to make it such a great company."

Disler started his career at the Holcroft Company in 1987 as an electrical engineer newly graduated from Lawrence Technical University, where he currently sits on the Advisory Board of the College of Engineering. His career included extensive international involvement, including living in Asia for more than two years coordinating furnace co-builds with multiple customers. He began to transition his way into engineering and sales roles, such as Manager of Advanced Controls and Far East Operations Manager, with a growing emphasis on international business, which eventually led to his senior positions at AFC-Holcroft. He traveled throughout more than 25 countries around the world while supporting sales, engineering, and manufacturing activities. After serving as the company's executive vice president starting in 2005, he was named president and CEO of AFC-Holcroft in 2012.

Christian Grosspointner, CEO of Aichelin Group said, "I would like to offer my appreciation to Bill for his dedication to AFC-Holcroft over so many years. And to the new management team, I wish you great success as you lead the company forward."

Disler concluded, "With our new management team in place, I can now take the time to enjoy other private and professional pursuits that I was unable to find time for. I will always support the AFC-Holcroft Team and plan to keep in touch as much as possible with my friends and colleagues. Thanks to everyone; employees, customers, partners, and friends who helped make my time at AFC-Holcroft so gratifying."

afc-holcroft.com

An Early Look at Heat Treat 2023

Heat Treat 2023 is a conference and expo for heat treating professionals, attracting global innovators, researchers, influencers, and decision makers from around the globe. This year's conference and expo will feature:

- Latest research and industry insights with more than 125 technical presentations.
- 2.5 days of face-to-face networking opportunities with approximately 200 heat treat exhibitors/companies.
- Colocation with ASM's Annual Meeting, "International Materials, Applications and Technologies (IMAT)" Conference & Expo, providing Heat Treat attendees with access to 100 materials-related exhibitors and more than 400 additional technical presentations and workshops. Special crossover keynotes and technical sessions are planned!
- Continued co-location with Motion + Power Technology Expo 2023 with access to an additional 300 exhibitors.
- "Basics of Heat Treating" education courses.
- VIP guided industry tour.
- Student/emerging professionals initiatives, including free college student registration, Fluxtrol Student Research Competition and the new ASM Heat Treating Society Strong Bar Student Competition.

Heat Treat 2023 takes place October 17–19, 2023, in Detroit.

youtube.com/watch?v=F3jxNovHNRo

Seco/Vacuum Quench Furnace Supports U.S. Manufacturer

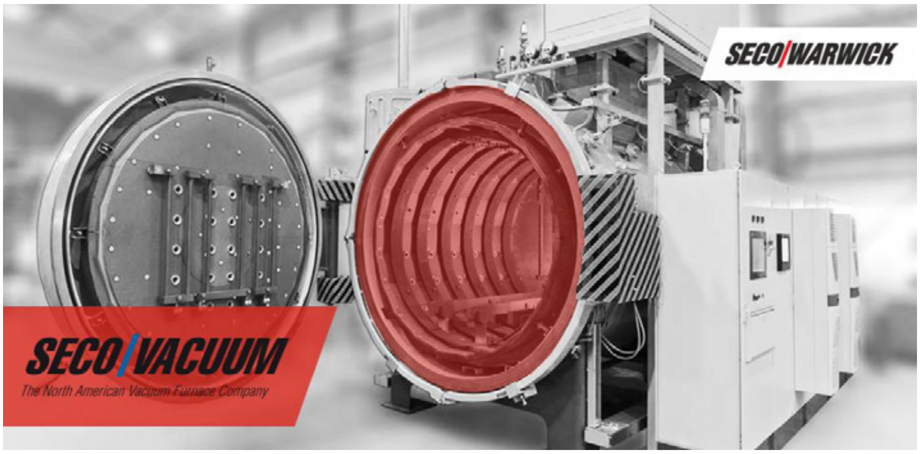
A US-based international manufacturer placed an order for a Vector high-pressure gas quench furnace from Seco/Vacuum, a Seco/Warwick Group company. With this new addition partner will increase its heat treat capability while improving part quality. The new furnace will allow to heat treat larger parts, at higher quantities per cycle, than their existing furnace, all with improved quality control and reliability.

The partner's equipment requires the use of large dies that require precise heat treating. Their current heat treatment setup includes a pair of vacuum furnaces which have some limits compared to the Vector they are about to receive.

New furnace features improve turnaround

The new furnace, a bottom loading Vector vacuum furnace with 6-bar nitrogen gas quench, is 60-in. dia., 72-in. tall, with a three-ton capacity working zone. This is room enough to treat three of their largest dies at once compared to only two per cycle for the old furnace. The furnace is also equipped with convection heating which allows them to run their tempering cycle in the same furnace without having to move parts after hardening, a tremendous time and labor savings.

Three temperature control zones and heating elements in the ceiling and in the bottom ensure temperature uniformity of ±10°F. A 6-bar nitrogen quench system with cooling nozzles located 360 degrees around the load combined with a rotary hearth drive all serve to ensure fast, uniform cooling, minimizing out-of-roundness distortions. The furnace is also equipped with Seco/Warwick's FineCarb



low-pressure carburizing system for future process developments.

All these features and more will allow them to increase production capacity to meet the rising market demand of today and tomorrow.

Positioning for growth

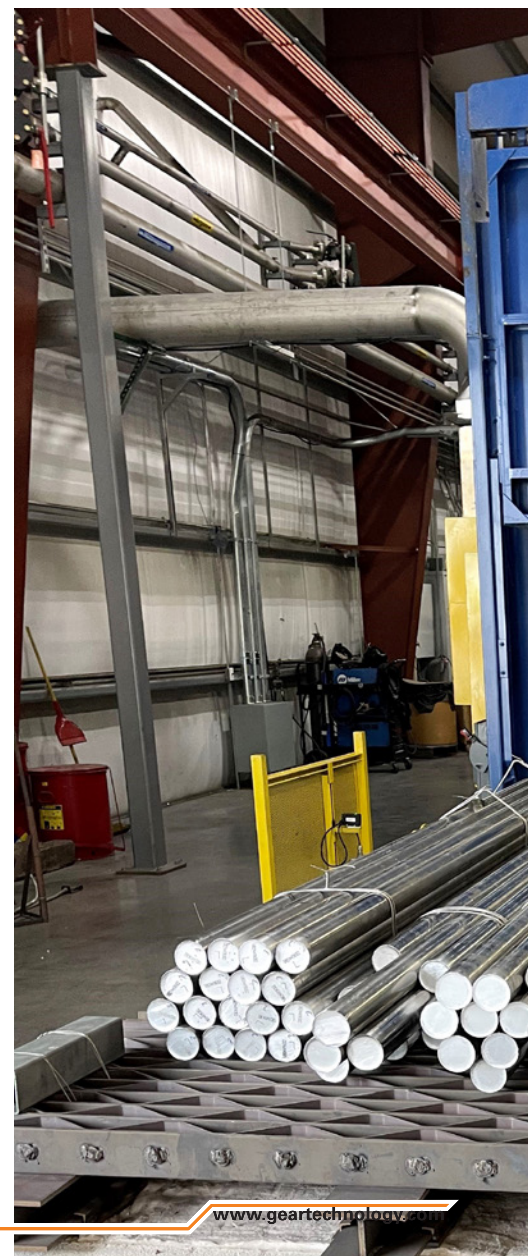
The OEM is seeing a lot more orders for their largest size dies than they used to. The new furnace's vertical configuration and rotary hearth were built specifically to accommodate more of these large dies, allowing them to meet the elevated demand with ease. The new Vector not only has the volume to handle more large dies at once, but also has features that make loading and unloading easier. Seco/Vacuum's intuitive process controls ensure greater heating uniformity than their existing equipment in both convection mode and in vacuum mode.

"We are looking forward to delivering our state-of-the-art furnace, specially configured for their needs, to augment the existing general-purpose furnaces they've utilized for so long. With a wide range of quenching features, they'll have room to grow too, even enabling them to conduct low-pressure carburizing processes if they ever need to," said Peter Zawistowski, managing director of Seco/Vacuum.

Vector: A versatile heat treatment tool

Vector, Seco/Warwick's versatile high-pressure gas quench vacuum furnace, is employed extensively in in-house manufacturing plants across the globe, especially those conducting a wide range of heat treat processes. Whether it's used for hardening tooling or finished parts, low-pressure carburizing (LPC), solution heat treating, annealing or other processes,

secovacusa.com



Solar Atmospheres of California Installs Large Car Bottom Air Furnace

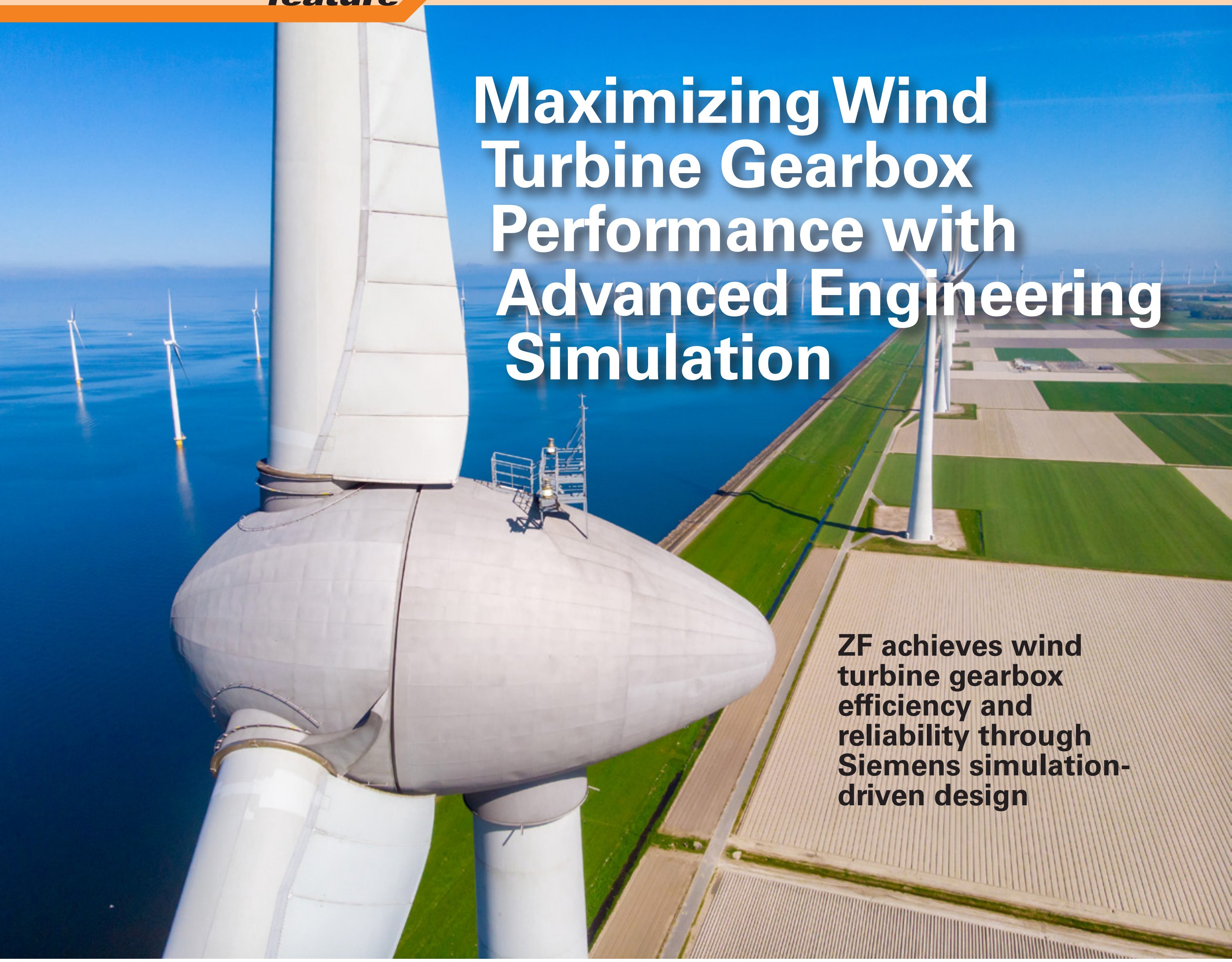
Solar Atmospheres of California (SCA) successfully installed a brand new 14-ft. long car bottom Air Furnace with a total load capacity of up to 30,000 lbs. The furnace was surveyed in accordance with AMS2750 and is uniform within ±10°F (Class 2). The furnace has a working zone that is 60-in. square by 168-in. long and handles a workload up to 30,000 pounds. With a maximum operating temperature of 1450°F, this furnace accommodates not only the tempering of large tool steel components but also age hardening of 15-5 PH, 17-4 PH, 13-8PH and nickel-based alloys, and the annealing of Titanium Forgings.

Solar is typically known around the world as a "vacuum only" heat treater. However, there is a great need for heat treating non finished parts and materials in accordance with the same specifications (AMS, MIL, Boeing and Airbus) within different atmospheres where surface oxidation is permissible. This new 14-ft. Air Furnace allows the "raw material customer" an option, while being more price competitive than with a vacuum environment. This new investment will only complement the vast array of vacuum furnaces that Solar operates every day.

Derek Dennis, president of Solar Atmospheres of California states, "Solar Atmospheres of California is excited to be adding this new furnace and the added capability/capacity. SCA's customers have requested this additional capability and it's our responsibility to meet their needs in supporting the valuable partnerships that we share."

solaratm.com

Maximizing Wind Turbine Gearbox Performance with Advanced Engineering Simulation



ZF achieves wind turbine gearbox efficiency and reliability through Siemens simulation-driven design

Siemens **Simcenter** *solutions can replace tedious and time-consuming calculation with system-level simulation in wind applications.*

Wind power has emerged as one of the most important sources of renewable energy in recent years. The global wind power capacity was estimated to be 837 gigawatts in 2021 (*statistica.com*). In the United States alone, wind is the largest source of renewable electricity, providing 10.2 percent of the country's electricity and still growing (*cleanpower.org*). However, to ensure maximum power generation, the efficiency and reliability of the wind turbine are critical.

Wind turbines are complex machines with several core components, such as blades, towers, gearboxes, and direct drive motors. The gearbox is responsible for converting the low rotational speed of the blades to the high-speed rotation required to generate electricity. Due to complex dynamic loads, the high-speed rotation in wind turbines can generate a large amount of heat in the bearings and gear mesh contacts. This heat can impact gearbox performance and durability, making it crucial for engineers to introduce simulation-driven design to identify potential issues and develop effective cooling strategies.

Balance heat generation with cooling and lubrication networks

ZF Wind Power has implemented Siemens *Simcenter Flomaster* software, a system-level thermo-fluid simulation tool, to streamline their engineering design processes and improve the productivity of their teams.

A business unit of ZF Friedrichshafen, ZF Wind Power is a leader in designing, manufacturing, supplying, and servicing wind turbine gearboxes.

Prior to implementing the *Simcenter* software, ZF Wind Power relied on Excel spreadsheets to calculate the appropriate flow rates and pressures of the gearbox flow paths. According to Jo Loenders, product management engineer, ZF Wind Power, this was "a very complex and time-consuming process, as the distribution systems for the lubrication can involve hundreds or even thousands of small components that result in pressure losses."

Simcenter Flomaster allows engineers to quickly validate the models since each component comes with validation data and results. "With the ability to determine flow rates and pressures anywhere in the model, the verification of the system against

Simcenter Flomaster ***software offers a system-level thermo-fluid simulation tool. The software offers built-in empirical data, a large library of components and sample systems to boost engineering efficiency.***

test data from flow measuring devices under realistic circumstances is easy," said Loenders.

In addition, the software includes built-in empirical data, a comprehensive library of components, and sample systems to enhance engineering efficiency. According to Loenders, "the use of *Simcenter Flomaster* allows a significant streamlining of the development process. From the very beginning, creating the fluid model is easy and intuitive."

Using strategic testing and simulation to reduce gearbox weight

As wind turbines increase in size and power output, the gearboxes required to handle the increased torque and rotational speed also increase in size and weight, posing significant transportation and installation challenges. Gearbox manufacturers can optimize the design process to reduce weight by introducing advanced engineering simulation and test methods early in the design phase. This allows engineers to evaluate the gearbox's performance and reliability under real-world operating conditions and identify any potential issues or areas for improvement before the product is released to the market.

Moventas, a leader in wind turbine gearboxes, has successfully used Siemens *Simcenter Testlab* software and *Simcenter* SCADAS hardware for high-speed data acquisition, testing, and design troubleshooting.

The company aimed to engineer a lightweight gearbox that minimized vibrations and develop components for higher input torque while reducing size, weight, and cost.

According to Jari Toikkanen, head of research and development, manager of conceptual design and analysis, Moventas, "by implementing a strict, step-by-step simulation and testing measurement procedure, we offer our customers an extremely reliable design process as well as gearboxes with superb product properties delivered within a very competitive time-to-market timeframe."

In addition, given the new regulations in the wind energy industry, smaller and more compact gearbox designs have made torsional dynamics a key consideration. Turbine manufacturers must gain a thorough understanding of the gearbox's behavior and internal dynamics under different operating conditions. "You need to know exactly how it behaves," Toikkanen explains. "This is a key aspect of a reliable machine. The wind turbine driveline consists of many components. It is known that the dynamics factors inside the turbine components can differ even 15 percent from simplified rotor loads." The key is to use simulation software to understand these loads, and then confirm the results with a robust testing procedure which involves validating specific torsional dynamics and structural deflections.

Over the past decade, Moventas has honed its design process to perfection, resulting in 10 tons of weight reduction in its gearbox design.

Wind gearboxes are a critical part of the turbine as they translate relatively slow-moving rotation from the large blades to a much higher rotational speed needed for the onboard electrical generator.

A holistic approach to design

Wind turbine manufacturing is a complex process that requires precise engineering and manufacturing techniques. Because of the intricate dynamic loads, the turbine components can occasionally malfunction, leading to high lifecycle costs.

In addition, the energy industry is grappling with multiple challenges, including market volatility, supply chain issues, increased regulations, and geopolitical tensions. To keep pace with the changing industry landscape, siloed approaches to managing projects are no longer sufficient. What's needed is a holistic approach to integrate all processes within a comprehensive digital platform to tackle the increased complexity of gearbox design.

By integrating advanced engineering simulation into their design phase earlier, engineering teams can gain better understanding of the intricate physics involved in gearboxes and identify potential issues early on, reducing costly iterations while accelerating application development. In addition, once inefficient processes are identified, they can be improved to reduce the environmental impact of the manufacturing process. Thanks to the digital twin, the entire process chain can be digitalized, allowing companies to drive faster time-to-market at a lower cost.

The *Simcenter* portfolio is a crucial component within *Siemens Xcelerator*, a comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software. The *Xcelerator* portfolio of solutions is designed to help businesses create and leverage a comprehensive digital twin that provides organizations with new insights, opportunities, and levels of automation to drive innovation.

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Simcenter Flomaster also helps reduce the design time required to size distribution lines to achieve the required flow rates. In wind turbine gearboxes there is always more than one flow path that requires fluid flow.

Take Control of Quenching

Press quenching technology for more hardening consistency, improved operator efficiency, and faster throughput of a wide range of gears and other close-tolerance cylindrical components

Ian Schickling, Bevel Workholding Lead Engineer, Gleason Workholding Products

Press quenching is a tried-and-true process for the controlled hardening of flat, circular close tolerance parts. The process ensures good dimensional control and uniform hardening, thus allowing for seamless processing post heat treatment. The most common method of quenching used in the quench presses built by Gleason and others utilizes the circulation of temperature-controlled oil through a defined path and at a specified rate of flow around the part being quenched, to rapidly cool the part. During this process, die quench tooling is used to hold the component with precisely controlled force. Today, however, with demand growing fast for improved quality and faster, more efficient throughput for parts of these types and sizes, a better press quenching solution is required, which is what led to Gleason's new 685Q.

Smarter, Faster, More Efficient

The 685Q offers increased productivity. With its Siemens Programmable Logic Controller, the 685Q significantly reduces setup and part changeover time. Automated setup ensures repeatability of all setup functions, including expander, inner/outer ring pressures, quench oil flow rates, cycle times, and pulsing.

Additionally, the machine has been designed from the ground up to deliver excellent part quality with minimum distortion and positive control of material hardness and uniformity.

Gain New Business with Expanding Press Quench Possibilities

Since Gleason started building quench presses in the 1930s, over 7,000 specialized sets of die-quench tooling have been designed for nearly every conceivable press quench application. This helps open a world of application possibilities for the 685Q. Customers include those with a part that must be hardened and controlled in a press quenching situation or those who are having distortion problems caused by free quenching. A wide variety of part geometries can be quenched on the 685Q, not just those related to the gear processing industry. Gleason provides the right type of precision manufactured equipment to ensure proper oil flow and the application of forces to control roundness, taper, and flatness during the cooling process based on the customer part geometry, datum structure, and timed relationships within the part itself. Companies

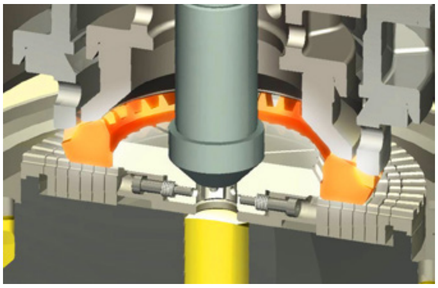
At a Glance

- Fast initial quench to control the cooling rate for proper material transformation; slow intermediate quench to minimize distortion.
- Precise pulsing action alternately applies and releases pressure to the die assemblies, thus minimizing forces that can distort the workpiece.
- Flow rates, pressures, and pulsing options to meet a wide range of application requirements.
- The machine houses the universal lower die with dish and cone capability.
- Available with front, side, and locking side-mount pendant configurations.
- Designed for improved serviceability with better access to the quench oil strainer, transducers, gauges, and valves.
- Improved pressure control filtration.
- Improved oil flow monitoring and internal oil return path.
- Speed control valve settings are selectable through the HMI.
- Improved guarding design.

Robot with appropriate end-of-arm tooling loads the red-hot part onto the expanding die quench tooling on the quenching table.

that do just heat treating can also benefit from Gleason's ability to design and manufacture die quench tools, thus helping them gain new business.

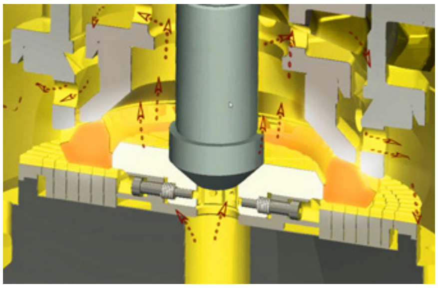
The pictures show an example of a standard automotive/truck ring gear being quenched in the 685Q machine. This type of design lends itself to the use of an expanding bushing for the centering of the part bore while two pressure rings make contact on the face of the gear during the oil quench process. Larger parts that have external teeth will have contracting bushing equipment to make contact with the outside diameter of the customer part. Customer parts with taller bores may have stacked expanding bushings to make contact along the whole bore, whereas smaller diameter bores will have a plug design that must be pressed out of the customer part post-quench.



Hot ring gear placed into expanding die with two pressure rings.

Automate, for Quicker and Safe Quenching

The 685Q is available with automation to speed part load/unload, whether operating as a stand-alone or for integration into a complete system or the customer's existing production processes. A variety of automation solutions are available, in conjunction with Gleason Automation Solutions (GAS). GAS's team works closely with the machine and workholding design teams to ensure that proper loading clearances and required features are factored into a total solution. Typical loader systems offer the loading of cold parts from the inbound rack storage, placement on the hearth, pickup of heated parts, movement to the quenching machine, and returning the quenched parts to outbound storage. Due to the nature of the quenching process and the need to transition a red-hot customer part to the die quench tooling already on the machine, appropriate measures are taken to ensure that the arm of the robot and any other ancillary equipment are protected from the heat of the part during the loading process. Note that all GAS loader systems include a vision system, which compares the actual part location to a known location. This information is communicated to the robot, which then can precisely pick up the part even if the part is out of its ideal position.



Quenched ring gear showing oil flow during the quench cycle.

Gleason Automations Systems provides protective guarding around the loading area to provide a safe work environment.

The 685Q is a significant advance over earlier generations of press quenching machines. It offers the long-sought versatility that users increasingly need to meet a wide range of production quenching applications, coupled with consistently high quality, improved operator efficiency, and reduced cost.

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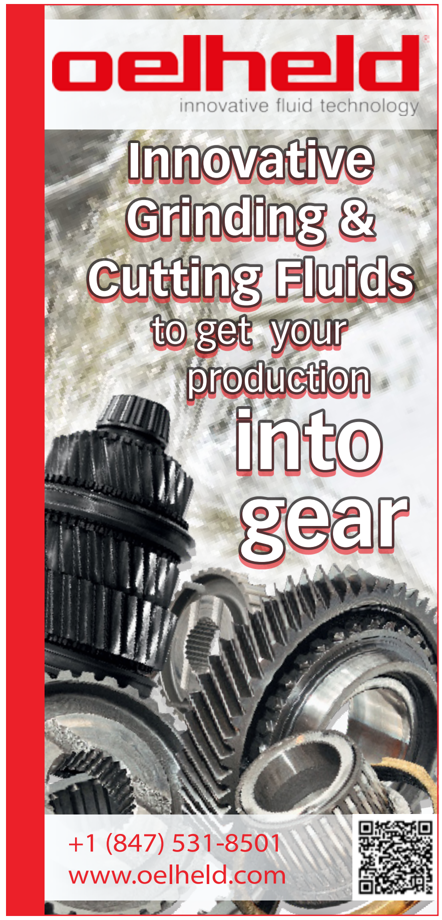
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Fail Better

Phillip Olson, Director, AGMA Technical Services

> "Ever tried. Ever failed. No matter. Try Again. Fail again. Fail better."
> —Samuel Beckett

This month's issue of *Gear Technology* covers a subject engineers love to learn about from others but hate to learn about through firsthand experience: gear failure. In a broad sense, all engineering is concerned with failure. Eventually, all parts fail, so engineers need to determine the limits of their design and ensure that it will meet the requirements of the particular application. How do they do this? One option is trial and error; despite being expensive and slow, it is a good way to test things that have never been done before. Another option is studying academic papers and textbooks, which is good for building your base knowledge. But in my opinion, designing to industry standards, and learning directly from experts that have already seen what can go wrong, is the best way for engineers to avoid unexpected failures.

Standards are based on proven and verified practices and capture years of industry knowledge in two ways. First, the authors of the standards bring all their knowledge of what works—and just as important, what doesn't work—to the table. And second, because the first AGMA standards were published over 100 years ago, countless gears have been designed using these standards—and revisions to the standards have been made where necessary—so the engineer can have confidence that these established practices work.

Broadly speaking, all AGMA standards and information sheets are concerned with gear failure, but in the narrow sense, AGMA has two gear failure-specific definition documents that need to be mentioned. Every gear engineer should be familiar with ANSI/AGMA 1010-F14, *Appearance of Gear Teeth—Terminology of Wear and Failure*. This standard identifies and describes common gear failures and offers recommendations to avoid the failure modes. The current, 6th edition was published in 2014 with 89 detailed color figures showing gear failures over 81 pages. This is quite the leap from the first edition, titled AGMA 110.01, published in 1943 with 20 black and white pictures within 10 pages. AGMA's other failure nomenclature document is AGMA 944-A19, *Mechanisms of Powder Metal, PM, Gear Failures*. It is written similarly to ANSI/AGMA 1010-F14 but covers powder metal gear-specific failures over 30 pages and includes 11 detailed color figures. AGMA's goal for the next revision of ANSI/AGMA 1010 is to incorporate powder metal gear failures and expand the standard to include plastic gear failures—definitions never published by AGMA before.

On the ISO side, ISO 10825-1:2022 and ISO/TR 10825-2:2022 are very similar to ANSI/AGMA 1010-F14. This is due to AGMA being a member of the ISO working group that published both documents and due to AGMA offering ANSI/AGMA 1010-F14 to the working group as the starting point. A main difference with the ISO version is that the subject has been split into two documents, with ISO 10825-1 covering definitions of gear failures and ISO/TR 10825-2 covering recommendations to avoid the failures.

I should also mention AGMA's top-notch gear education program, where you can learn directly from experts in the industry. Similar to standards, one could argue that most education courses are concerned with failure. But specifically, the gear failure topic is front and center in two of AGMA's most popular courses: Gear Failure Analysis, and Gearbox CSI.

In the Gear Failure Analysis course, students not only see slides of failed gears but can also hold and examine over 130 specimens with the same failure modes covered in the seminar. Approximately half of the course time consists of groups of students identifying failure modes on failed gears and working on a case study.

In the Gearbox CSI course, students define and explain the nature of many gear and bearing failures, and they also discuss and describe various actual failure scenarios. In addition, a detailed primer on bearing technology prefaces the failure scenario discussions. Students gain a better understanding of various types of gears and bearings, learn about the limitation and capabilities of rolling element bearings and the gears that they support, and grasp an understanding of how to properly apply the best gear–bearing combination to any gearbox, from simple to complex.

In conclusion, I encourage you to take advantage of the information out there, to learn from others, and to "fail better" which means avoiding repeating the mistakes of the past and then making and sharing the new ones that are an inseparable part of pioneering progress.

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Conjugate Gears

Robert Errichello and Dr. Hermann Stadtfeld

Glossary

Base pitch—The pitch that is measured on the base circle. In the basic rack similar sides of the teeth consist of a series of equally spaced parallel lines, and the base pitch is the perpendicular distance between the lines.

Basic rack—The rack or segment of a gear wheel with an infinite radius belonging to a system of gearing in which the tooth forms are conjugate. Its pitch line is straight.

Bevel gear—A gear for connecting shafts whose axes intersect, and whose pitch surfaces are cones. The apexes of the cones coincide at the intersection of the axes of the shafts, and their surfaces touch along a line lying in the plane containing the axes.

Common connecting line—A straight line connecting the axes of bevel, hypoid, and worm gears and passing through the pitch point of conjugate gears.

Common line of centers—A straight line joining the axes of a spur, helical, and crossed-axis helical gears, which is perpendicular to both axes, and is the shortest distance between the axes.

Common normal—A straight line passing through a point of contact in a direction perpendicular to the tangent plane between the surfaces.

Common tangent plane—The plane passing through a point of contact on two curved surfaces and is tangent to both surfaces.

Conjugate action—The property of conjugate gears that produces a constant angular velocity ratio during meshing.

Conjugate—Gear tooth profiles that produce a constant angular velocity ratio during meshing.

Contact line—The effective line or curve of contact between mating gear teeth without rotation of the gears. Spur gears have contact lines that are parallel to the gear axis. Helical gears have straight contact lines that are inclined to the gear axis. Straight bevel and skew bevel gears have straight contact lines that consist of a cone element. Zerol, spiral bevel, hypoid, and worm gears have curved contact lines.

Contact plane—See surface of action.

Contact point—The point at which meshing gear teeth touch each other.

Crossed-axis helical gear—Gears that connect shafts that are inclined to one another, but whose axes do not intersect. They are distinguished from hypoid gears in that their pitch surfaces are cylinders.

Crossing points—The ends of a common connecting line that joins the axes of a pair of gears.

Generatrix—A point, curve, or surface that, when moved along a given path, generates a new shape.

Helical gear—A gear that has teeth in the form of a helix or screw. Helical gears connect parallel shafts.

Helicoid—The tooth surface of screws, worms, and helical gears.

Hypoid gear—A gear similar to a bevel gear, but one that operates on offset axes.

Involute helicoid—A surface that is geometrically the same as the tooth surface of a helical gear. Its generatrix is tangent to a base cylinder that is concentric to the gear axis. Its tooth profile is an involute curve in the plane of rotation and an axvolute in the axial plane.

Line of action—A straight line, normal to both mating tooth profiles at the point of contact that passes through the pitch point.

Line of centers—See Common Line of Centers.

Normal base pitch—The base pitch in the normal plane. It is the perpendicular distance between the parallel planes forming the sides of adjacent involute gear teeth of the basic rack. To be conjugate, any two gears must have the same normal base pitch.

Path of contact—The locus of all points of contact between meshing gear tooth profiles.

Pitch—The spacing between a point on one tooth and the corresponding point on an adjacent tooth.

Pitch circle—A theoretical circle, concentric with the gear axis, having a diameter equal to the pitch cylinder.

Pitch cone—The pitch surface of a bevel gear.

Pitch cylinder—The pitch surface of a spur, helical, or crossed-axis helical gear.

Pitch element—The line of tangency between two contacting pitch surfaces. It is the instantaneous axis of rotation. See common connecting line.

Pitch line—A line tangent to the pitch circle at the pitch point. It is the line in the basic rack that rolls with the gear pitch circle without slipping.

Pitch plane—The imaginary surface in a rack or generating crown gear that rolls without slipping with a pitch cylinder or pitch cone of a mating gear. It is tangent to the pitch surfaces and contains the pitch element.

Pitch point—A fixed point in the common connecting line at which the pitch surfaces touch each other. In a hypoid gear, this is only meaningful at the mean point.

Pitch surface—For parallel-axis spur and helical gears, and intersected-axis bevel gears, the imaginary planes, cylinders, or cones that roll together without slipping.

Pressure angle—The angle between the line of action and the pitch line. It is so named because it indicates the direction of the pressure or force between meshing teeth.

Profile shift—The amount that the pitch line of the basic rack cutter is shifted away from the gear reference circle.

Reference circle (or cylinder)—The pitch circle or cylinder of engagement with the basic rack.

Screw helicoid—A surface generated by a straight-line generatrix that intersects the axis of the helicoid. It is the form of a common screw thread. Also known as an Archimedean screw.

Shaft angle—The angle between the axes of two non-parallel gear shafts.

Spur gear—A gear having a cylindrical pitch surface and teeth that are parallel to its axis.

Surface of action—The imaginary surface composed of all positions of the lines of contact. For parallel-axis spur and helical gears, and intersected-axis bevel gears, the surface of action is a plane surface that is tangent to either the base cylinders or the base cones. Crossed-axis helical gears have point contact and a line of action. Worm gears and hypoid gears have a warped surface of action.

Tangent plane—The plane tangent to the tooth surfaces at a point or line of contact.

Transmission error—The deviation of the position of a driven gear, for a given angular position of a driving gear, from the position that the driven gear would occupy if the gears were conjugate.

Worm—A gear in the form of a screw thread, having one or more starts.

Worm wheel—A special gear for engaging with a worm.

Introduction

The conjugacy of meshing gears is one of the most important attributes of gears because it ensures a constant velocity ratio that gives smooth, uniform transmission of motion and torque. Some of the world's greatest gear theoreticians like Earle Buckingham (Ref. 1), Wells Coleman (Ref. 2), and John Colbourne (Ref. 3) laid the foundation for understanding conjugacy. Their teachings and interpretations of the law of gearing have been used by generations of gear engineers to design and manufacture gear transmissions for almost everything that is mechanically actuated. The law of conjugate gear-tooth action according to Earle Buckingham (Ref. 1) is:

"To transmit uniform rotary motion from one shaft to another by means of gear teeth, the normals to the profiles of these teeth at all points of contact must pass through a fixed point in the common center line of the two shafts."

In this paper, the authors use graphics and written explanations to present the requirements for conjugacy for the following involute-based gear types: spur, helical, crossed-axis helical, worm, bevel, and hypoid. Here the authors generalize the law of gearing such that it applies to all forms of conjugate gears:

Conjugate gears transmit uniform rotary motion from one shaft to another by means of gear teeth. The common normal to the profiles of these teeth, at all points of contact, must pass through a fixed point P in the common connecting line that intersects the two shaft axes and is normal to the pitch element.

During the past 50 years, sophisticated computer software for the design of gears has been developed. However, today, some gear engineers might take the results of these software systems for granted without recognizing the details upon which conjugacy in some cases depends.

With a knowledge of the requirements for conjugacy, the gear engineer can choose the right type of gear for a particular application, for example, spur versus helical, crossed-axis helical versus worm, and worm versus high-ratio hypoid gears.

However, if the gears are conjugate only under ideal operating conditions, they are not likely to remain conjugate when they are subjected to actual operating conditions of load, speed, temperature, and manufactured accuracy. Therefore, it is necessary to modify the microgeometry of gear teeth by adding ease-off, which includes a slope, crown, and end-relief to compensate for distortion of the teeth due to the actual operating conditions. Fortunately, for the gear engineer, there is modern computer software that features 3D graphics that allows the optimization of the ease-off to avoid geometric stress concentration due to edge contact and to obtain minimum Hertzian stress and optimum contact patterns.

Spur Gears

Figure 1 shows a pair of spur gears contacting at the pitch point P at the intersection of the line of centers and the line of action. The red vector is normal to the common tangent line to the contacting tooth profiles. It represents the transmitted force in the zone of single-pair contact. The pitch point P is the only point along the line of action where there is pure rolling contact. At other points of contact, there is a combination of rolling and sliding.

The line of centers is the common connecting line between the two axes of the mating gears, which is the shortest distance between the axes.

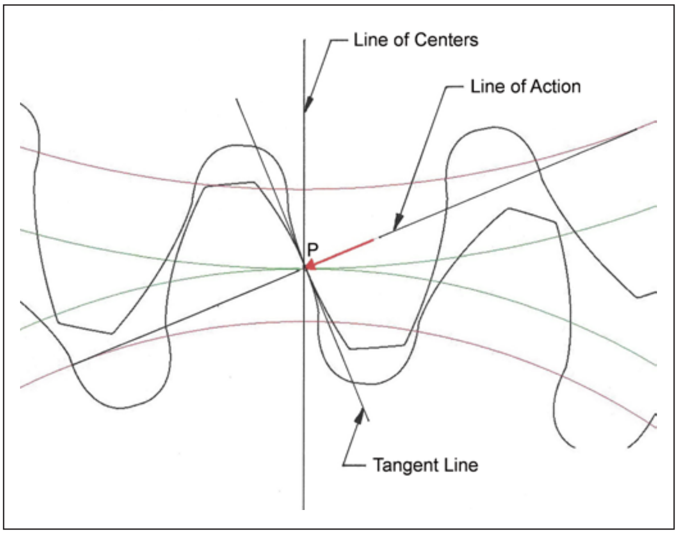


Figure 1—Contact at pitch point P in the transverse plane (Ref. 4).

Figure 2 shows a pair of spur gears contacting at two points in the double-pair zone along the line of action. The red vectors that are normal to the common tangent planes to both contacting tooth profiles represent the transmitted forces in the zone of double-pair contact. With conjugate spur gears these vectors along the common normal at both contact points pass through the pitch point P. The two contact points along the line of action also have tractional forces in the tangent planes due to sliding. The tractional forces are in opposite directions on either side of the line of centers.

If the pitch point remains fixed on the line of centers (the connecting line between the two axes) the velocity ratio (gear ratio) remains constant, and conjugate action is achieved.

In the axial plane, the pitch point P is an axis parallel to the gear axes and is termed the pitch element. The pitch element is the line of tangency between the two pitch cylinders and is the instantaneous axis of relative rotation of the mating gears.

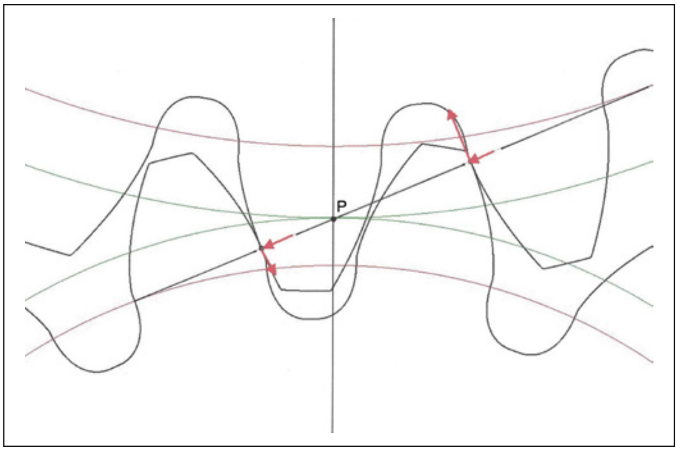


Figure 2—Contact at two points in the double-pair zone in the transverse plane (Ref. 4).

Helical Gears

Figure 3 shows helical gear velocities in the tangent plane. The tangent plane is perpendicular to the contact plane or surface of action. The tangent plane contains the contact line and is perpendicular to the common normal of the contacting teeth. The contact line is located at the intersection of the tangent plane and the contact plane. The red line labeled zo is a general coordinate in the normal plane that locates the contact point Q from pitch point P on the pitch element.

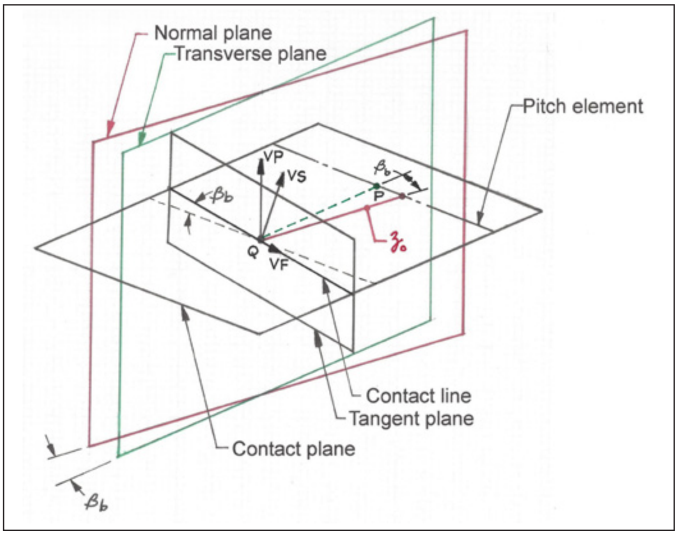


Figure 3—Helical gear velocities in the tangent plane (Ref. 4).

Figure 4 shows contact point Q at a distance z_o from pitch point P on the pitch element in the normal plane. Distance z_o is a general coordinate, that locates point Q in the normal plane (z_o is positive to the left of P and negative to the right of P). Figure 4 shows the contact point Q at the tip of the pinion tooth where the sliding velocities are often maximum.

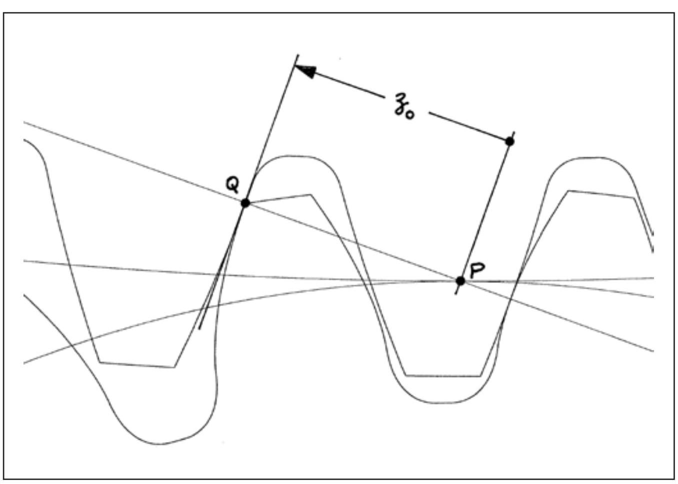


Figure 4—Contact point Q at distance zo from pitch point P in the normal plane (Ref. 3).

Figure 5 shows helical gear sliding velocities VP, VF, and VS at point Q in the tangent plane. It is well known that helical gears have no sliding in the axial direction. However, there is sliding along the contact line in the tangent plane represented by velocity VF.

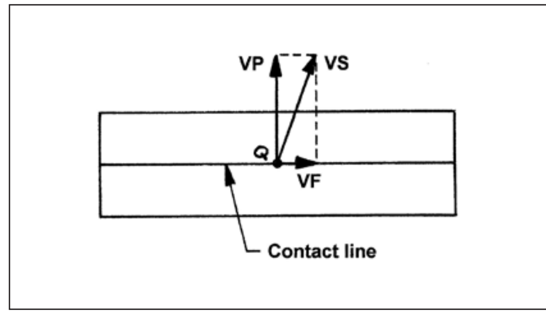


Figure 5—Helical gear velocities VP, VF, and VS at point Q in the tangent plane (Ref. 4).

Table 1 shows sliding velocities calculated with the Mathcad program given in GEARTECH Report (Ref. 4). The equations are from Wells Coleman (Ref. 2). The example is for module 10 helical gears operating at 10,000 rpm and 131 m/s pitch line velocity.

Table 1—Sliding velocities per Refs. 2,4

β (deg)	VF (m/s)	VP (m/s)	VS (m/s)
0	0.000	31.140	31.140
10	1.862	30.882	30.938
15	2.800	30.551	30.679
20	3.743	30.071	30.303
30	5.647	28.599	29.151
45	8.471	24.767	26.176

Figure 6 shows how the sliding velocities VF, VP, and VS vary with helix angle. Note that the calculations were performed for point Q at the pinion tooth tip, which is often the point of maximum sliding velocities. However, depending on the pinion profile shift, the point of maximum sliding velocity might be at the other end of the path of contact.

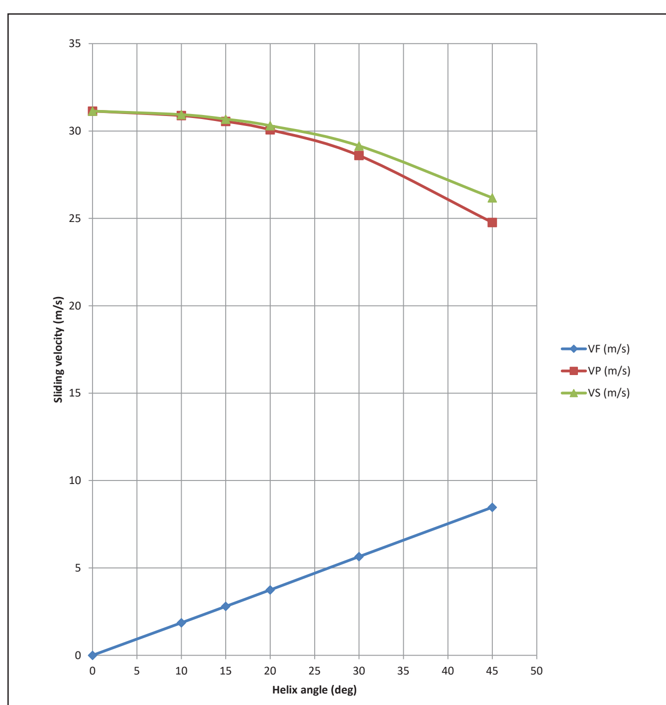


Figure 6—Sliding velocities per reference (Refs. 2,4).

Comparison of Helical Gears and Spur Gears

Helical gearing is essential when tooth-to-tooth transmission smoothness (low transmission error) is required. The smooth running characteristic of helical gears is achieved because all phases of tooth meshing occur simultaneously provided that the face width is large enough to give an axial contact ratio (overlap ratio) greater than unity. In contrast, spur gears have alternating single-pair and double-pair tooth contact that results in much higher transmission error. Furthermore, the resulting stiffness variation causes a nonlinear dynamic response, which increases the risk of resonant vibration that results in much higher dynamic tooth loads. Consequently, audible noise and vibration levels are much higher with spur gears than with helical gears.

Helical gears are capable of very high speeds with pitch line velocity approaching 200 m/s. However, such high speed requires very sophisticated design practice, which includes analyses of temperature rise due to sliding in gears and bearings, windage between gear teeth and the gearbox internal environment, and shearing of lubricant films in gears and bearings. Furthermore, as gear teeth mesh at high speed the air/oil mist in the space between teeth must be expelled by meshing teeth. Helical gears pump the air/oil mist in the axial direction much more efficiently than spur gears. This is the primary reason that spur gears have much lower speed limits than helical gears. On the other hand, the axial pumping velocity of helical gears with low helix angles can be very high (reaching Mach 3), which causes thermal bulging of the gear teeth. Therefore, helical gears with pitch line velocity greater than 100 m/s usually require curvilinear helix modification to compensate for thermal bulging.

Crossed-Axis Helical Gears (Colbourne)

The following analysis is based on Chapter 15, pages 414–429 of Colbourne (Ref. 3).

Requirements for Conjugacy

To be conjugate, the normal base pitches of each crossed-axis helical gear must be the same. This is the only requirement that must be met for conjugacy.

$$p_{nb1} = p_{nb2}$$

Center Distance

The center distance is the line joining the axes, which is perpendicular to both axes and is the shortest distance between the axes. See Figure 7. The center distance is the line C between the points on the axes C_{o1} and C_{o2}. If an imaginary rack is inserted between the teeth of both gears, it touches the pitch cylinders of the gears in two parallel pitch planes. Crossed-axis helical gears are generally designed so that the values of C and Σ are either equal or approximately equal, to the reference (standard) center distance C_s and reference (standard) shaft angle Σ_s.

$$C_s = R_{s1} + R_{s2}$$
$$\Sigma_s = \psi_{s1} + \psi_{s2}$$

For the particular case where the center distance equals C_s, the shaft angle must equal Σ_s to maintain conjugacy.

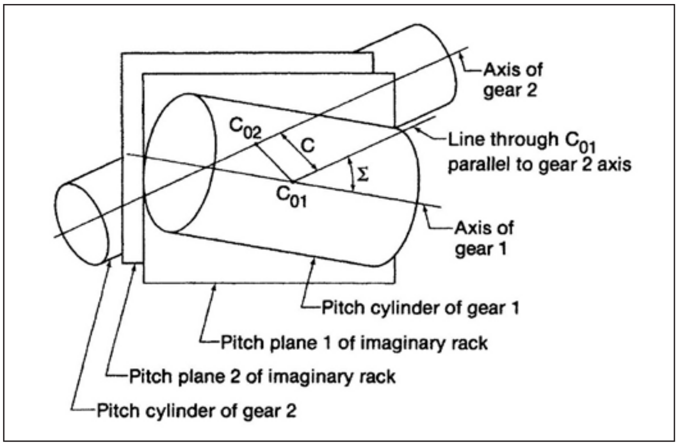


Figure 7—Pitch cylinders in a crossed-helical gear pair (Ref. 3).

Shaft Angle

Figure 8 is a view in the direction of the line of centers. The shaft angle equals the sum of the two working helix angles.

$$\Sigma = \psi_{p1} + \psi_{p2}$$

Because crossed-axis helical gears have point contact, they are not sensitive to shaft angle, and they remain conjugate even with small errors in Σ.

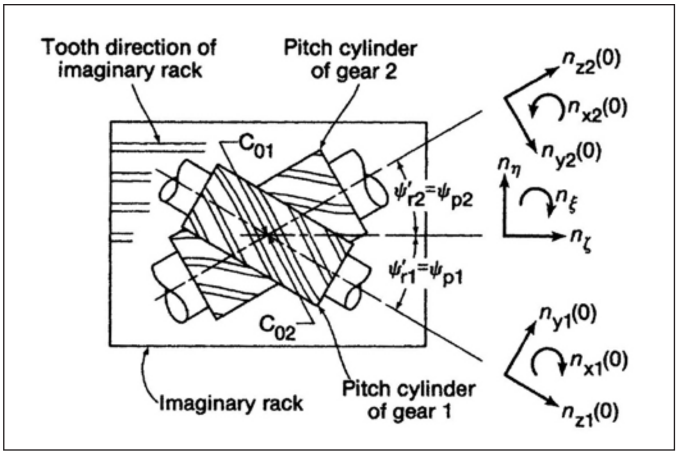


Figure 8—Directions of the unit vectors (Ref. 3).

Pitch Planes

The two pitch cylinders and the imaginary rack pitch planes are shown again in Figure 9, but viewed this time in the negative $\boldsymbol{n}_\eta$ direction, which is perpendicular to the teeth of the imaginary rack.

The center distance is not necessarily equal to the sum of the pitch cylinder radii. Figure 9 shows an example where the pitch planes of the imaginary racks are separated by the distance ΔC_p.

$$\Delta C_p = C - R_{p1} - R_{p2}$$

There is no relation between the pitch cylinders and the center distance C, Therefore, the pitch cylinders do not touch, and there is no point of pure rolling.

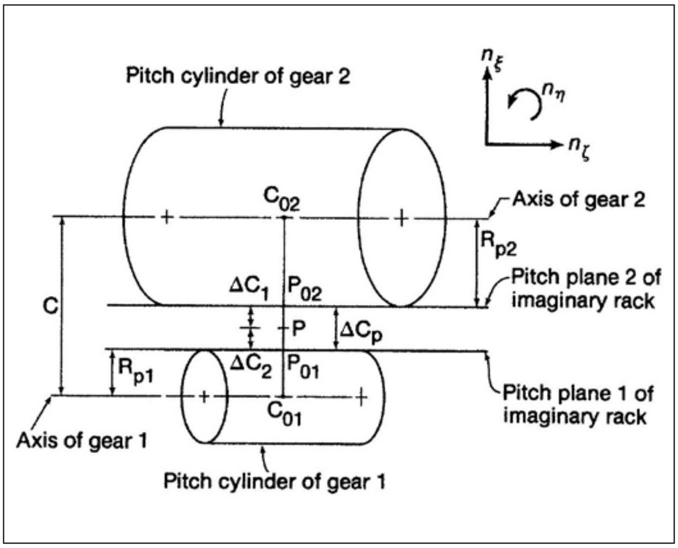


Figure 9—Pitch cylinders perpendicular to teeth of the imaginary rack (Ref. 3).

Pitch Points

Figure 10 shows that the path of contact is a straight line that coincides with the line of action, exactly as it does in the case of a spur gear pair. The path of contact is inclined at the working normal pressure angle to the pitch planes of the imaginary racks and intersects the points P_1 and P_2 on the pitch planes.

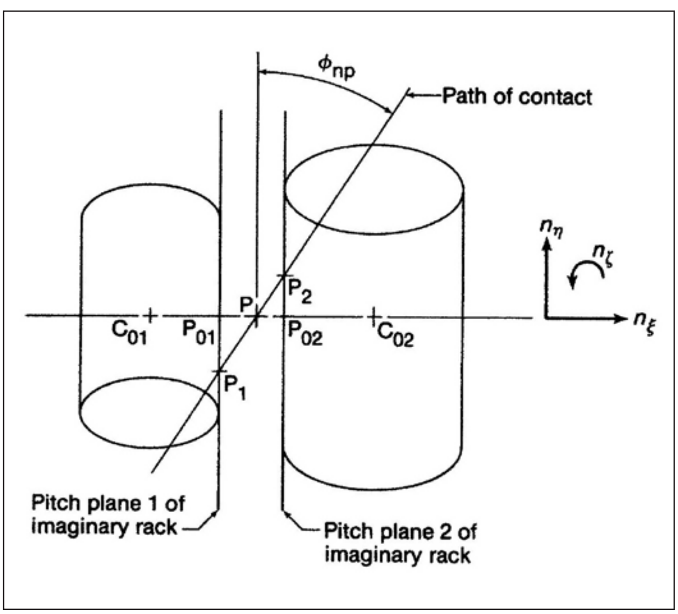


Figure 10—Pitch cylinders viewed along the teeth of the imaginary rack (Ref. 3).

Analogy to a Spur Gear

When the pinion is viewed in the axial direction, as shown in Figure 11, the path of contact appears exactly the same as the path of contact in a spur gear pair. The straight line containing the path of contact extends from a typical contact point A_1, passes through the pitch point P_1, and touches the base cylinder at point E_1.

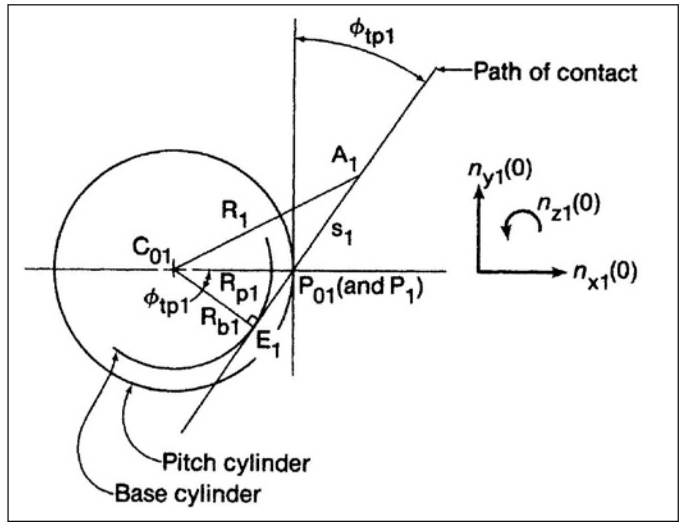


Figure 11—Pitch cylinder of gear 1 viewed along the gear axis (Ref. 3).

Crossed-Axis helical gears (ISO 21771-1:2022)

Figure 12 is based on Figure 32 of ISO 21771-1:2022 (Ref. 5). ISO nomenclature is somewhat different from the nomenclature of this paper. Therefore, certain terms are defined here:

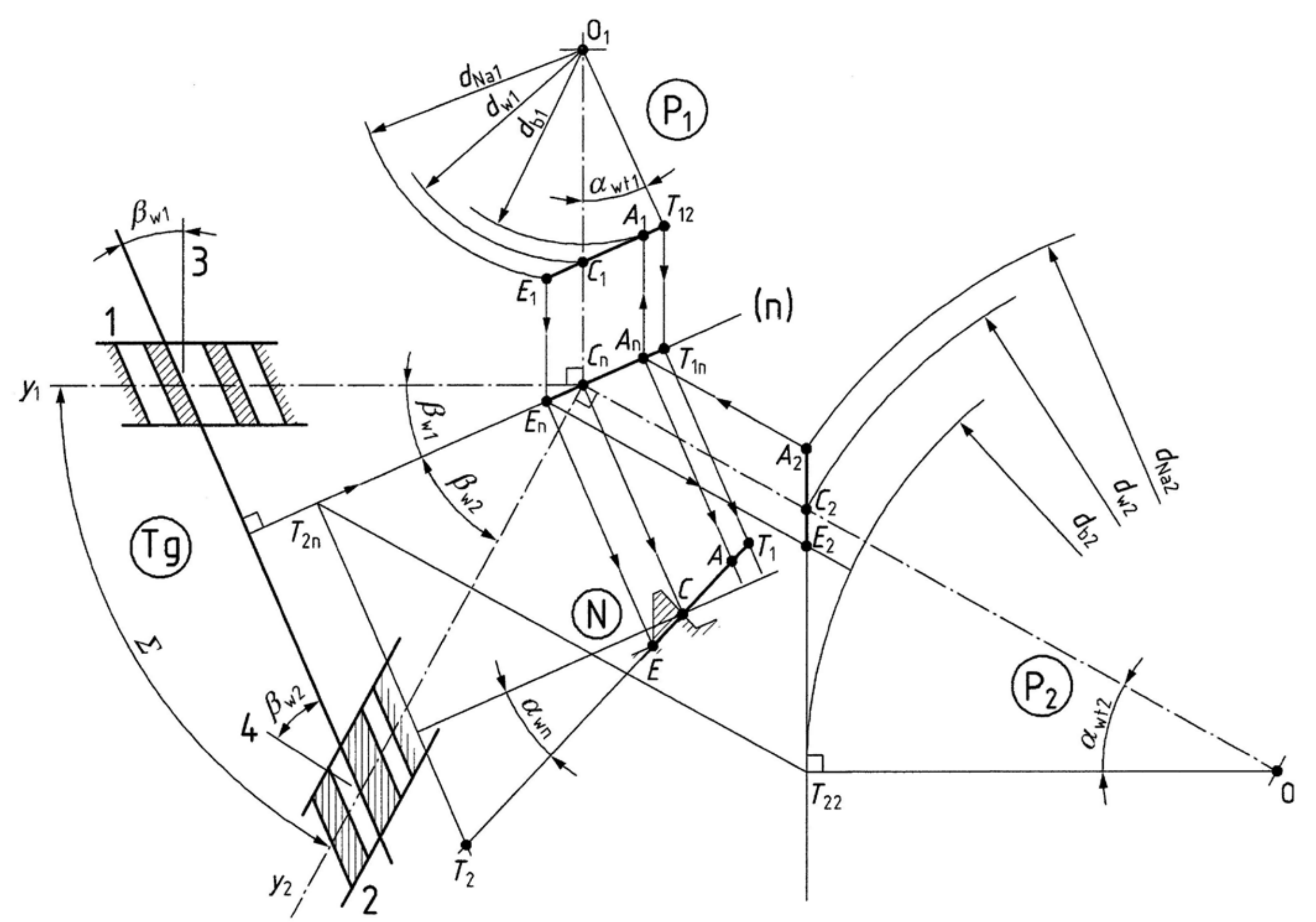
C = P Pitch point in the normal plane
C_1 = Pinion pitch point in the transverse plane
C_2 = Gear pitch point in the transverse plane
C_n = Pitch point in the tangent plane
Line $T_1 - T_2$ = Line of action that passes through the pitch point C = P in the normal plane

Comparison of Helical Gears and Crossed-Axis Helical Gears

Parallel-axis helical gears have contact lines similar to that of parallel cylinders, which take place along straight line generatrices, similar to spur gears, but the lines of contact slope instead of remaining parallel to the axis of the gear. Crossed-axis helical gears have contact lines similar to two cylinders whose axes are not parallel. With axes crossed at 90 degrees, and under near zero load, point contact occurs. At less than a 90-degree shaft angle, and at working load, the contact spreads to an elliptical contact area. Hertzian stress in crossed-axis helical gears with point contact is very much higher than that of parallel-axis helical gears with line contact.

Point contact occurs in crossed-axis helical gears because the straight generatrix of each involute helicoid are tilted relative to each other and cross at a single contact point. With a rotation of the gears, the contact point travels in a straight path of contact in the normal working plane as shown by the line between points A and E in Figure 12.

A high sliding velocity, equal to the vector difference of the two pitch line velocities, is present at all phases of tooth engagement of crossed-axis helical gears. A third vector normal to the other two adds a component of sliding velocity similar to that which occurs in parallel-axis helical gears. This third vector has zero magnitude when contact is at the pitch point and is a maximum when contact is at its furthest point from the pitch point.



Key:

***1** Intermeshing rack of helical pinion* — ***2** Intermeshing rack of helical gear wheel*

***3** Parallel to axis of rotation of the pinion* — ***4** Parallel to axis of rotation of the gear wheel*

***Tg** Tangent plane to working pitch cylinders* — ***Y_1,Y_2** Mid planes of working racks crossing at Cn*

***P_1** Transverse plane of the pinion* — ***P_2** Transverse plane of the gear*

***N** Working normal plane and true length of line of action*

***(n)** Trace of normal plane in Tg*

Subscripts:

***1** for pinion* — ***2** for gear wheel*

***n** projected on the trace of the working normal plane*

Figure 12—Meshing conditions in transverse planes and working normal plane (Ref. 5).

Because of point contact, crossed-axis helical gears are insensitive to changes in center distance, changes in shaft angle, or changes in the axial position, and they remain conjugate even with reasonably small mounting errors. Furthermore, crossed-axis helical gears are among the easiest to manufacture, which makes them among the least expensive gears. Despite all these advantages, the gear designer must consider that the load capacity of crossed-axis helical gears is severely limited because of the point contact.

Worm Gears

The following three paragraphs are from Buckingham (Ref. 1):

- "The conjugate gear-tooth action between a worm and a worm gear is the same whether the worm is revolved to screw the thread along its axis or whether the worm is moved axially without revolving."
- "The basic-rack form of the worm gear is the form of that section of the worm thread which actually engages with the worm-gear teeth. This form changes across the face of the worm gear. When these forms are established for any given planes of rotation of the worm gear, conjugate gear tooth forms and trochoidal fillets of the worm gear are determined for these planes of rotation in exactly the same manner as for spur gears."
- "The essential requirement is that the thread form of the worm and that of the hob or other tool used to generate the worm gear be as nearly identical as possible."

Buckingham's statements mean that the conjugacy requirements of worm gearsets are the same as that of a spur gear meshing with its basic rack.

Buckingham (Ref. 6) gives the calculation procedure for contact analysis of worm gear drives in Chapter 11, on pages 240–255. The procedure is as follows:

- The profile of the intersection of the worm thread on planes parallel to the worm axis forms the basic rack profile in the axial plane of the worm.

- Using tangents to the basic rack profiles, coordinates of the path of contact are calculated for each basic rack profile.
- The rack profiles and their paths of contact are then plotted from the calculated data. Where a path of contact intersects its rack profile, it defines one point of contact between the worm and its mating worm gear.
- Several points of contact thus determined are projected into the plan view of the worm to their respective traces of intersecting plane and are then connected with a smooth curve. This curve is the projection of the actual contact line on the plan view of the worm.
- These same points of contact on the rack profiles are also transferred or projected into the end view of the worm to their respective sections. These points, when connected by a smooth curve, give the projection of the actual contact line on the end view of the worm.

The following three figures give the results of an example from Buckingham's contact analysis of a screw helicoid worm drive (Ref. 6).

Figure 13 shows the end view of a screw helicoid worm. Five axial planes A, B, C, D, and E were selected for the analysis. Distance R_1 locates the height of the pitch plane of the worm above its axis. Angles ε_E and ε_A are generatrix rotation angles.

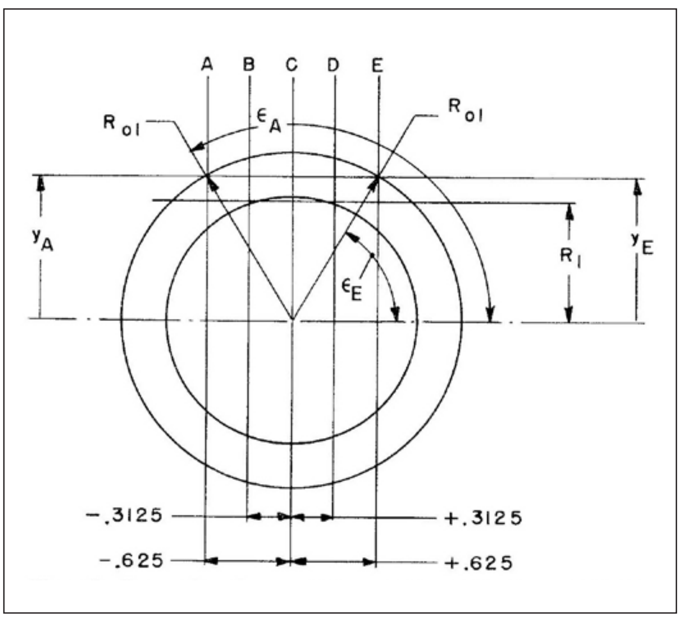


Figure 13—Axial planes, pitch plane, and generatrix rotation angle (Ref. 6).

Figure 14 shows the paths of contact for the axial planes A, C, and E. The rack profile for section C is the generatrix of the helicoid. The intersection between rack profile C and the worm axis is shown after the worm has moved along the worm axis at a distance equal to one-quarter of the lead because it has revolved 90 degrees or one-quarter of the full circle. The intersection of path C with rack profile C locates a contact point between the worm and worm gear. Sections A and E are at the side edges of the worm gear. For section A, the path of contact is outside the rack profile and therefore the contact point is nonexistent. For section E, the contact point is below the pitch plane and beyond the outside radius of the worm gear. Therefore, the contact point is non-existent.

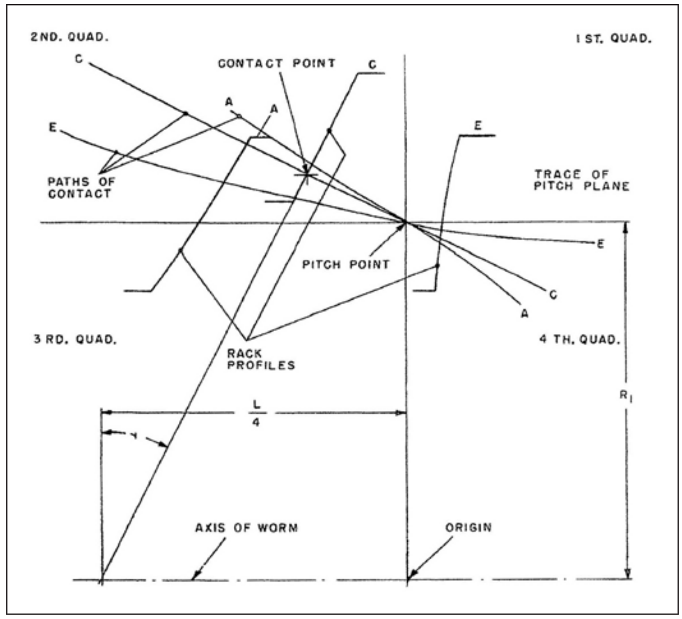


Figure 14—Paths of contact for sections A, C, and E (Ref. 6).

The lower right side of Figure 15 shows a repeat of the Figure 14 paths of contact, but it adds the rack profiles and paths of contact for sections B and D. The outside radius of the worm gear R_2, which is also the gear pitch radius, is also shown.

The upper area of Figure 15 shows a plan view and projected field of contact on the worm. The space between the lines marked "root" and "crest" represents the flank of the worm thread on which contact will exist. Contact lines marked 1 and 2 exist on adjacent teeth.

The lower left side of Figure 15 shows the end view of the worm with the projected points from the paths of contact plotted to show the contact lines 1 and 2 on the flanks of adjacent worm teeth.

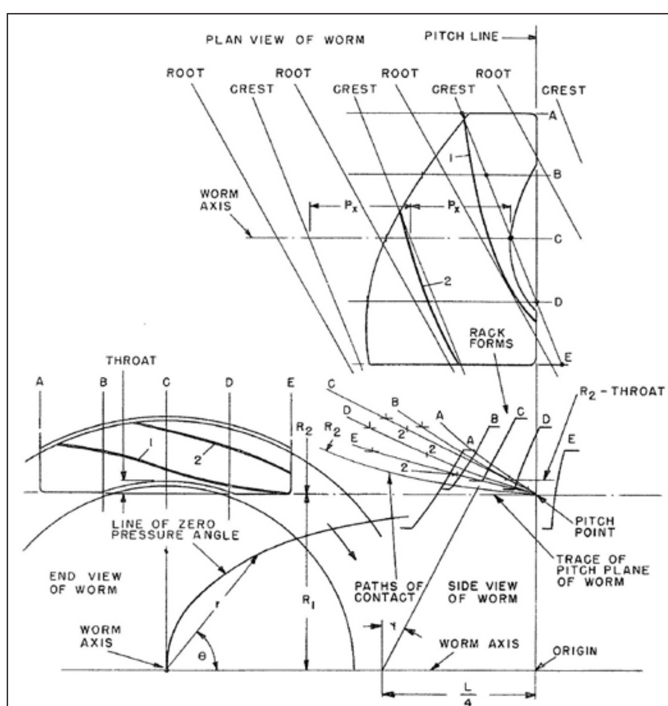


Figure 15—Paths of contact, the field of contact, and contact lines (Ref. 6).

Comparison of Crossed-Axis Helical Gears and Worm Gears

Crossed-axis helical gears are sometimes confused with worm gears. This is probably because a standard single-start worm can mesh properly with either a standard spur gear or a standard helical gear. When the worm thread is an involute helicoid and the gear is a helical gear, the gear pair is an example of crossed-axis helical gears. There will be true conjugate action, but there will be point contact and low load capacity.

The most common worm gear drive consists of a cylindrical worm (not necessarily with an involute helicoid thread) and an enveloping worm wheel. This is called a single-enveloping worm drive. As discussed in the worm gear section, this combination has line contact in place of the point contact that exists in crossed-axis helical gears. Consequently, a worm drive with a cylindrical worm and an enveloping worm wheel has a much higher load capacity than a crossed-axis helical gear drive. However, many of the advantages of crossed-axis gears such as insensitivity to mounting errors are lost with a worm gear drive.

A double-enveloping worm drive consists of an "hourglass" worm and a throated worm wheel. As the name double-enveloping implies, the worm and the wheel "wrap around" each other. A double-enveloping worm drive has line contact with more teeth in contact and higher load capacity than a single-enveloping worm drive. However, the axial alignment of the worm and wheel in a double-enveloping worm drive is more critical. Furthermore, manufacturing costs are higher than a single-enveloping worm drive.

Bevel Gears (Ref. 7)

Figure 16 shows the conical pitch surfaces of a bevel gearset. Bevel gears have pitch cones that contact along the pitch element. The pitch apexes coincide at the intersection of the axes of the shafts. The pitch point P is on the connecting line normal to the pitch element and intersects the shaft axes at crossing points $n_{o1} - n_{o2}$.

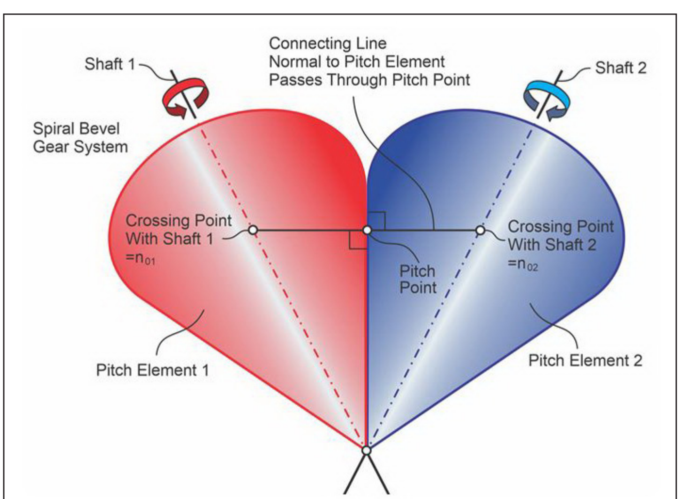


Figure 16—Bevel shaft axes connecting line, pitch point P, and pitch surfaces (Ref. 7).

Figure 17 shows that the base surfaces of bevel gears are cones whose cone apexes coincide at the intersection of the axes of the shafts. In analogy to cylindrical gears, the line of action is straight and is tangent to the two base circles at a respective location along the width of the cones. If the line of action is shifted along the width of the base cones, the plurality of the lines of action forms the surface of action, which is a plane. This occurs because of the equal and proportional change of the respective base circles while the line of action is shifted. When viewed in the direction of the pitch element, the plane of action appears as a line, like that shown in the two right-side graphics in Figure 17.

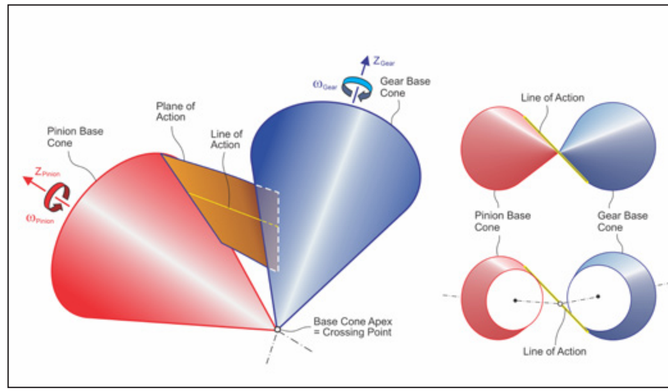


Figure 17—Bevel base cones, the plane of action, and line of action (Ref. 7).

Comparison of Straight Bevel Gears and Spiral Bevel Gears

This comparison is very analogous to the comparison between spur gears and helical gears. The spiral angle results in a face contact ratio larger than zero. The modified contact ratio considers both the transverse contact ratio and the face contact ratio. Typical modified contact ratios of spiral bevel gears are between 2.0 and 2.5. Straight bevel gears cannot achieve modified contact ratios greater than 1.5 because the face contact ratio is always zero. Therefore, spiral bevel gears have a smoother and quieter operation than straight bevel gears.

Straight bevel gears have the significant advantage of the largest possible root thickness for a given module. In the case of bevel gears that are heat treated after cutting but not hard finished, the root bending strength of a spiral bevel gearset would be rather low. The tooth indexing errors resulting from heat treatment distortions reduce the real contact ratio in the operation, so the benefit from the spiral angle diminishes, but the disadvantage from the smaller tooth root thickness remains. This leads manufacturers that do not apply hard finishing to their bevel gears to prefer straight bevel gears.

Straight bevel gears are also preferred in cases when the bearing forces must be low. Many aircraft gear manufacturers apply ground straight bevel gears for the actuation of wing flaps and other components, but they prefer ground spiral bevel gears for power transmission such as the main rotor drives in helicopters.

Hypoid Gears (Ref. 7)

Conjugacy between a hypoid pinion and a hypoid gear is established when the hyperbolic pitch surfaces are designed as explained in Figure 18. The screw axis is the axis of a cylinder, on whose surface the pitch generator line "g" is found as the plurality of points where the shaft connecting line $n_{op} - n_{og}$ passes through the cylinder and is normal to the cylinder. When line "g" is rotated around the pinion axis Z_a, it generates the pinion pitch surface. When rotated around the gear axis Z_b, it generates the gear pitch surface. After one or both pitch surfaces are found, the shaft connecting line $n_{op} - n_{og}$ is added. It describes the location of the pitch point "P" where the connecting line passes through the two contacting pitch surfaces.

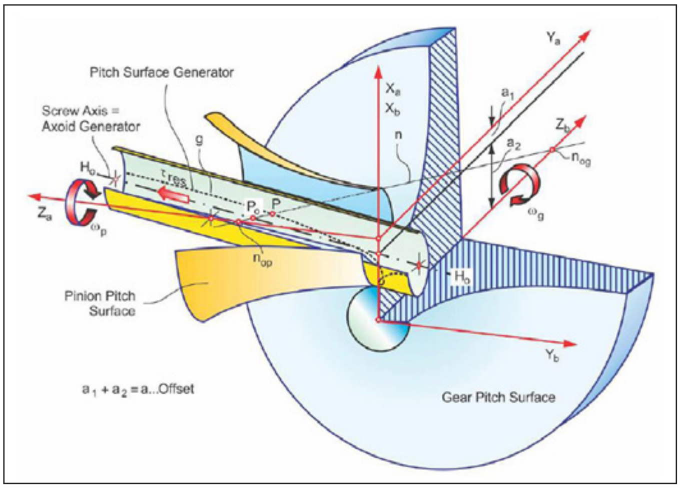


Figure 18—Hypoid shaft connecting line, pitch point P, and pitch surfaces (Ref. 7).

Figure 19 shows the hypoid gear base surface and the surface of action. The surface of action connects the base surface of the pinion and the gear and contacts both base surfaces tangentially. Because the base surfaces are also hyperboloids, the surface of action is not a plane, but a warped surface.

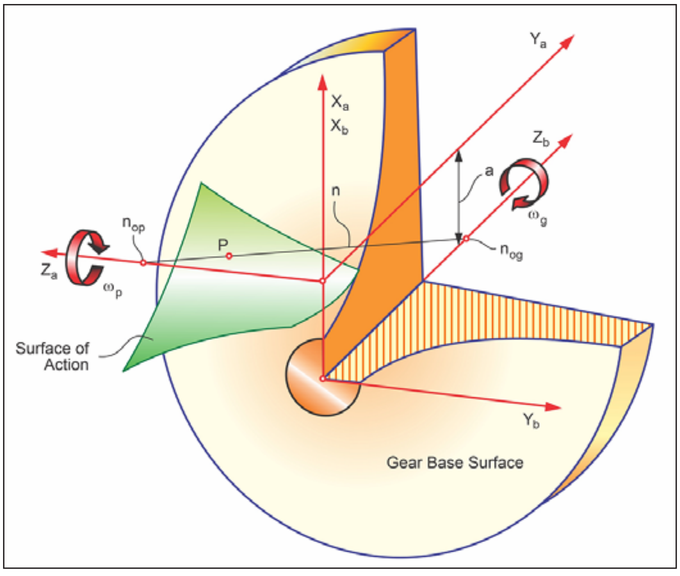


Figure 19—Hypoid gear pitch surface and surface of action (Ref. 7).

Comparison of Bevel Gears and Hypoid Gears

The original intention of the development of hypoid gears by Ernest Wildhaber was to provide the additional design freedom of a pinion shaft offset in bevel gearing. This freedom allowed the automotive manufacturer in the 1920s to lower the bodies of their vehicles by up to two inches. The lower center of gravity of these vehicles provided more safety and better handling in the early vehicles. Still, today, rear-wheel and all-wheel drive vehicles use hypoid gears for this reason.

The hypoid offset increases the pinion spiral angle, which leads to a pinion diameter increase of up to twice the diameter of a spiral bevel pinion. The size increase strengthens the hypoid pinion, which for spiral bevel gears is the weaker of the two members. In addition to the sliding velocities in the profile direction, hypoid gears have a screw motion between pinion and gear, which creates sliding velocities in the face-width direction. These lengthwise sliding motions can be two to three times in magnitude compared to the profile sliding. The lengthwise sliding provides several advantages. The elasto-hydrodynamic lubrication film is not compromised at the pitch line, where spiral bevel gears exhibit pure rolling and no sliding. The lengthwise sliding also provides a dampening effect, which in combination with the larger pinion spiral angle makes hypoid gearsets operate quieter.

The disadvantage of lengthwise sliding is that it limits the pitch line velocity of hypoids. While spiral bevel gears are used in aircraft applications well above 120 m/s pitch line velocity, hypoid gears, depending on the hypoid offset, are limited to about 60 m/s. A further disadvantage for hypoid gears is that the lengthwise sliding creates the risk of rippling, ridging, or scuffing failure modes. This is the reason that hypoid rear axle drives require lubricants with antiscuff additives.

The manufacturing process of spiral bevel and hypoid gears is identical. The same machines and cutting tools are used for both bevel gear types. In cases where the hard finishing process is lapping, hypoid gears have an advantage. The additional lengthwise sliding of hypoid gears provides a more effective and uniform material removal during lapping. Spiral bevel gears show no material removal by lapping along the pitch line, but lapping grit is often pressed into the surface at the pitch line and remains there, which can cause surface damage such as pitting in a medium to high load operation.

Significance of Conjugacy and Conclusions

Conjugacy is a good basis for gear design, but conjugate gears are not practical for typical gear applications where operational loads, speeds, temperatures, and manufacturing deviations cause displacements of the gear teeth that disrupt conjugate action. The displacements include:

- Elastic deflections of the pinion and gear teeth, shafts, bearings, housings, and foundations due to applied loads.
- Centrifugal distortion of pinion and gear teeth and gear bodies due to high speeds.
- Thermal expansion and distortions caused by power losses due to sliding in gears and bearings, windage between gear teeth and the gearbox internal environment, and shearing of lubricant films in gears and bearings.
- Rigid body displacements of the pinion and gear teeth, shafts, bearings, housings, and foundations due to manufacturing deviations and assembly clearances.

Consequently, modern gear teeth are designed to compensate for all the above displacements that disrupt conjugate action by modifying the profile and helix of gear teeth to have a combination of slope, crown, and end relief such that the gears are as conjugate as possible under the actual operating conditions.

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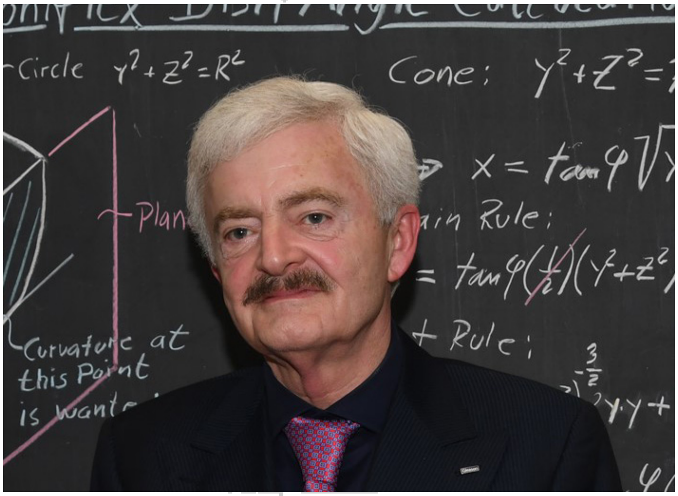


Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in bevel gear technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems and gear manufacturing methods, as well as cutting tools and gear manufacturing machines. Under his leadership the world of bevel gear cutting has converted to environmentally friendly, dry machining of gears with significantly increased power density due to nonlinear machine motions and new processes. Those developments also lower noise emission level and reduce energy consumption. For 35 years, Dr. Stadtfeld has had a remarkable career within the field of bevel gear technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. He held a professor position at the Rochester Institute of Technology in Rochester, New York. From 1992 to 1994. In 2000, as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards—one for his high-speed dry-cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year." Between 2015–2016 CNN featured him as "Tech Hero" on a website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency. Stadtfeld continues, along with his senior management position at Gleason Corporation, to mentor and advise graduate level Gleason employees, and he supervises Gleason-sponsored Master Thesis programs as professor of the Technical University of Ilmenau—thus helping to shape and ensure the future of gear technology.

Closed Loop for Gears: Some Case Studies

Massimiliano Turci and Vincenzo Solimine

Introduction

The closed-loop concept has become widespread in recent years, especially in relation to the Industry 4.0 concept (Ref. 1). The term "closed loop" will be used herein to refer to the pairing of specifications and checking (Figure 1) which all ISO standards, starting with ISO 1 (Ref. 2), the "mother" of all standards, use in relation to GPS (Geometrical Product Specifications) (Ref. 3).

The process of design of gears involves several steps, such as study of the market's requirements, general sizing using formulas, and numerical checking and optimization (Ref. 4), but it must end with the production of a drawing providing clear and unquestionable instructions for the manufacturer of the item. These are what are known as specifications.

On the other hand, manufacturing of gears also involves several steps (forging, cutting, heat treatment, finishing), but must end with checking that the product complies with requirements. That is called verification.

If specification is a two-dimensional design with 2D CAD dimensions, tables, and symbols, verification is a report with figures and tables generated by CMM or GMM, or compiled by an operator with the aid of hard-gauging.

The closed loop requires both specifications and verification to be complete, with no incomplete parts.

For example, the drawing of a gear listing only the number of teeth, module (without specifying whether normal or transversal), and helix angle cannot be defined as proper specification, and neither can a drawing whose table lists span measurements and measurements between rollers that do not correspond.

Likewise, the delivery of a batch of gears without a quality control report cannot be classed as a verification.

The closed-loop concept for design, manufacturing, measurement and testing of three types of gears with modified microgeometry for improved loaded tooth contact will be presented from several case studies to improve the documentation and performance of bevel, cylindrical, and worm gears.

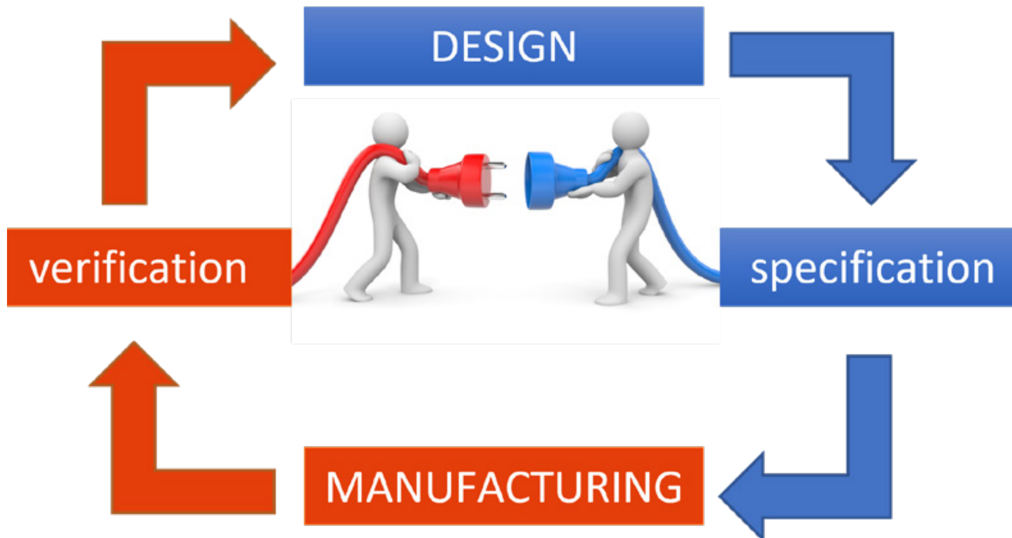


Figure 1—Closed loop.

Bevel Gears

Traditionally speaking, the closed loop for gear use were designed for bevel gears. The traditional cutting processes used for bevel gears, known as face-milling or face-hobbing, intrinsically involve adjustment of cutting and machine parameters, which is itself a closed loop. Modern cutting simulation techniques prior to checking the contact pattern on tester (Figure 2) have made production times quicker, but the concept has remained more or less unchanged, as described by Refs. 5 and 6.

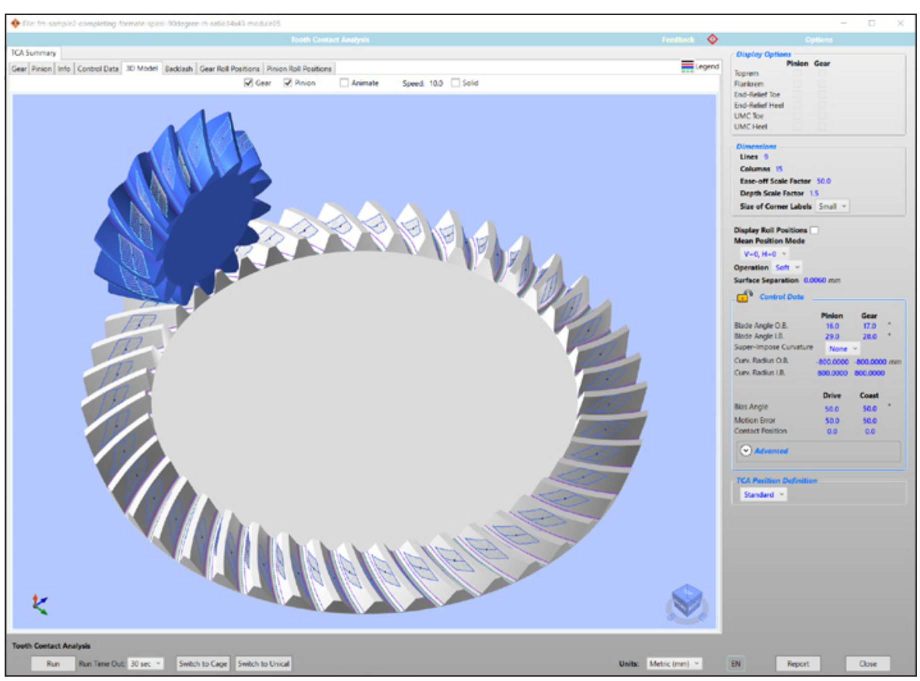


Figure 2—Simulation of the contact pattern (Ref. 7).

However, not all bevel gear designers have dedicated machine tool software.

In this case, they follow in the footsteps of Socrates: they know that they know nothing (Ref. 8). They can limit themselves, in the first instance, to only establishing the module and number of teeth, as well as the pressure angle (often 20 degrees or 22.5 degrees), the spiral angle (almost always 35 degrees), and face width (approximately one-third of the outer cone distance) values. It is almost embarrassing to think that the tooth thickness and tooth root radius, which are considered so carefully for cylindrical gear wheels and so important when calculating the bending strength, are ignored when designing bevel gears. Even if standards to calculate strength for both cylindrical (ISO 6336 and AGMA 2001) and bevel gears (ISO 10300 and AGMA 2003) require the values of both tooth thickness and tooth root radius or provide formulas to calculate them (AGMA 929), designer of bevel gears are not always able to fix these values in the drawings.

Most of the time, bevel gear designers that do not have dedicated machine tool software try to guess what the face angle of blank and the root angles will be, as well as tooth thickness, possibly wishing for a full radius for the tooth root. At the present time, the freely accessible bibliographical source offering the most realistic definition of the final geometry of spiral face milling is Ref. 9.

	A	B	C
Mean circular thickness pinion [mm]	7.85	7.60	7.01
Mean circular thickness gear [mm]	3.10	3.40	3.98
Whole depth	8.09	8.40	8.09
Edge radius used in strength—pinion [inch]	0.015	0.020	0.040
Edge radius used in strength—gear [inch]	0.060	0.035	0.045
Cutter radius [inch]	3.000	3.750	3.000
Geometry factor—Strength—J pinion	0.2878	0.2831	0.2769
Geometry factor—Strength—J gear	0.2909	0.2861	0.3440
Strength factor Q—pinion	10.889	11.071	11.318
Strength factor Q—gear	2.74577	2.79255	2.32188

Table 1—Three different cases of Duplex Helical Spiral Bevel with the same number of teeth (13–51), module (4.126), facewidth (30 mm), and pressure angle (22.5 degrees).

In some cases, the drawing comprises two stages and keeps track of the effect of the closed loop as shown in Figure 3. The top half shows the geometry defined by the designer, while the bottom half shows the actual geometry, taken from the dimension sheet generated by the workshop.

In other cases, the same drawing of the bevel gear pair with only basic data is sent to many suppliers. Each of them cuts according to different parameters (Table 1). The same spiral gear pair is manufacturing with different geometries and so with different strength. In this case, the technical department cannot send a realistic calculation report to customers or to certification bodies.

This primitive closed loop for bevel gears, which limits itself to intervening in the design process prior to part manufacture, in other words to intervening exclusively in the definition of specifications, could terminate with the microgeometry grid obtained by GMM being transferred to the design software.

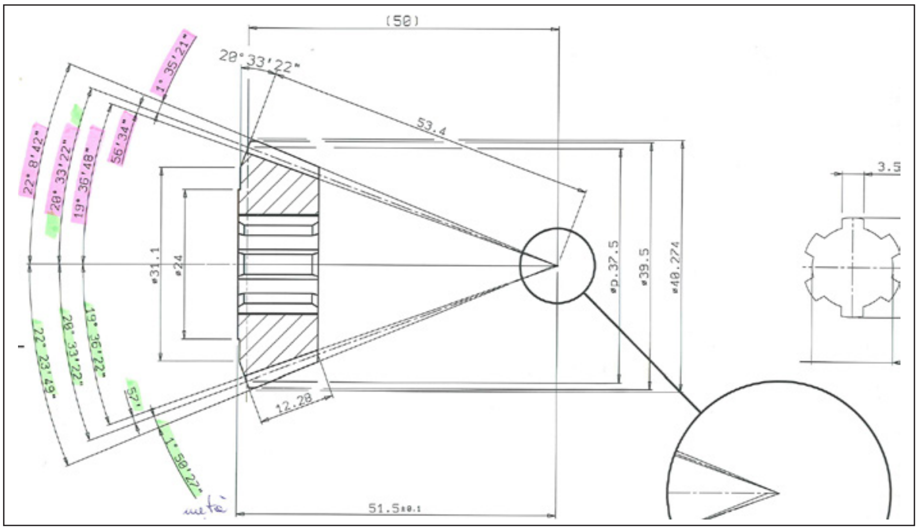


Figure 3—Drawing of a bevel gear: on the top side, there is the initial dimensioning (all apexes are in the same point). On the bottom, there are dimensions from the workshop.

Cylindrical Gears

Three different case histories can be found below in relation to cylindrical gears.

Manufacturing Twist

The first case history concerns an automotive transmission. A check was requested of the contact pattern under load of spiral gears. Given the main geometry of the two gears and deflection calculated by a multibody simulation software, analysis of contact under load with various types of microgeometry was requested:

- microgeometry defined in the drawings which included both profile and flank line crowning (Figure 4);
- microgeometry estimated by design and analysis software, which adds an unwanted yet inevitable twist due to the manufacturing process, when not compensated (Ref. 10);
- microgeometry estimated by grinding machine software applying a partial compensation method (Figure 5);
- microgeometry measured by GMM (Figure 6).

The last two were fairly similar as regards the twist, but the latter clearly is more "contaminated." In both cases, the grids could be accessed in an importable file format from the design and analysis software (Ref. 11).

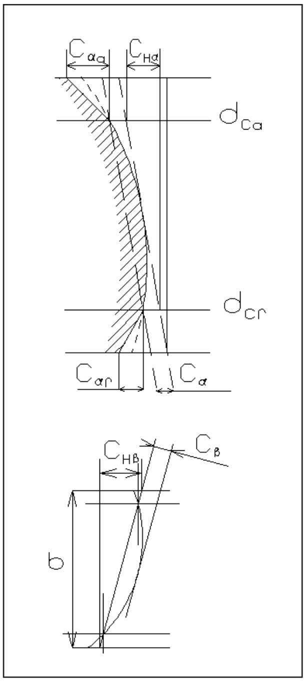


Figure 4—Profile and lead diagram not to scale, used to define micro-geometry in drawings.

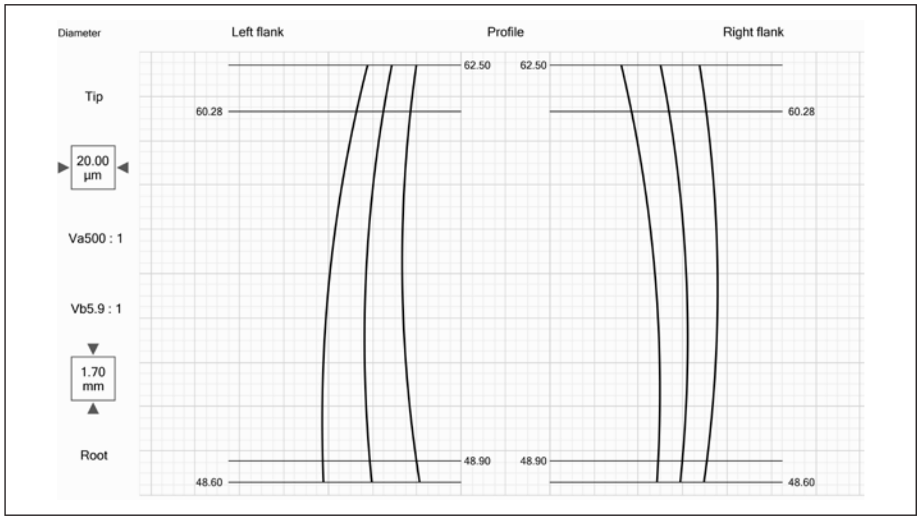


Figure 5—Profile and lead diagram, estimated by grinding control (values on axes are intentionally blank or without references).

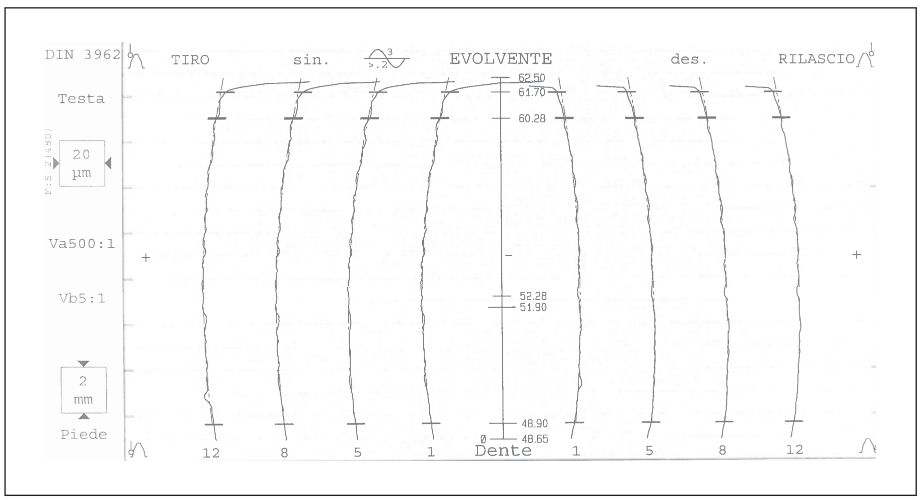


Figure 6—Profile and lead diagram, measured by GMM (values on axes are intentionally blank or without references).

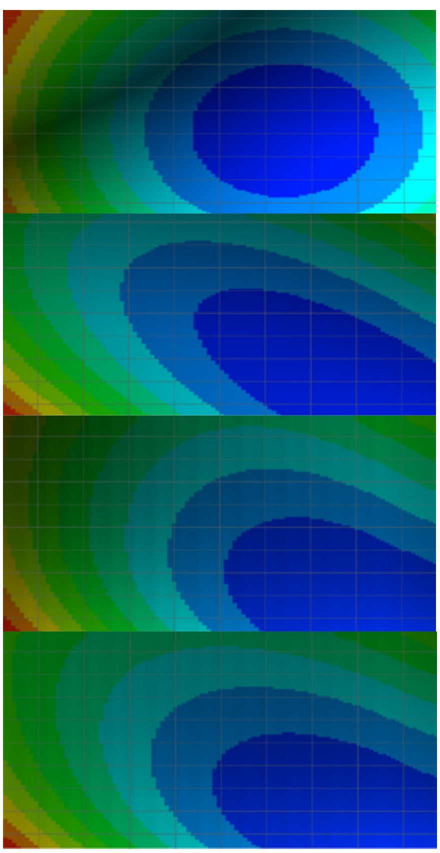


Figure 7—Some topography of the microgeometry. From top to bottom: defined in the drawing, estimated without compensation, estimated with compensation, measured (values on axes are intentionally blank or without references).

In this case, not only does the closed loop consist in being able to perform a LTCA on the measured microgeometry, but also in being able to design while taking into account the unwanted, yet clearly present, manufacturing twist.

K-chart

The second case history springs from the need to have a flexible tool to design and alter the K-profile with freedom of representation of the tolerance range. The designer needed to be able to check whether differences measured that exceeded the required tolerance were still acceptable. In this case, the technical office draws up an exemption and the design with the new tolerance area of the K-profile. These are the steps of this closed loop:

- design of cylindrical gears;
- drawings of gear, complete with K-profile with tolerance established in accordance with company specifications;
- manufacture and measurement of workpiece;
- in the event of a piece whose measurements exceed set limits, LTCA with new tolerance range;
- in the event of acceptance of results, drawing up of exemption and update of drawing with new K profile.

The tool shown in Figure 8 is an *Excel* worksheet, which reads formulation of the macro- and microgeometry from *KISSsoft* through COM interface and generates the DXF file of the K-profile for 2D drawings.

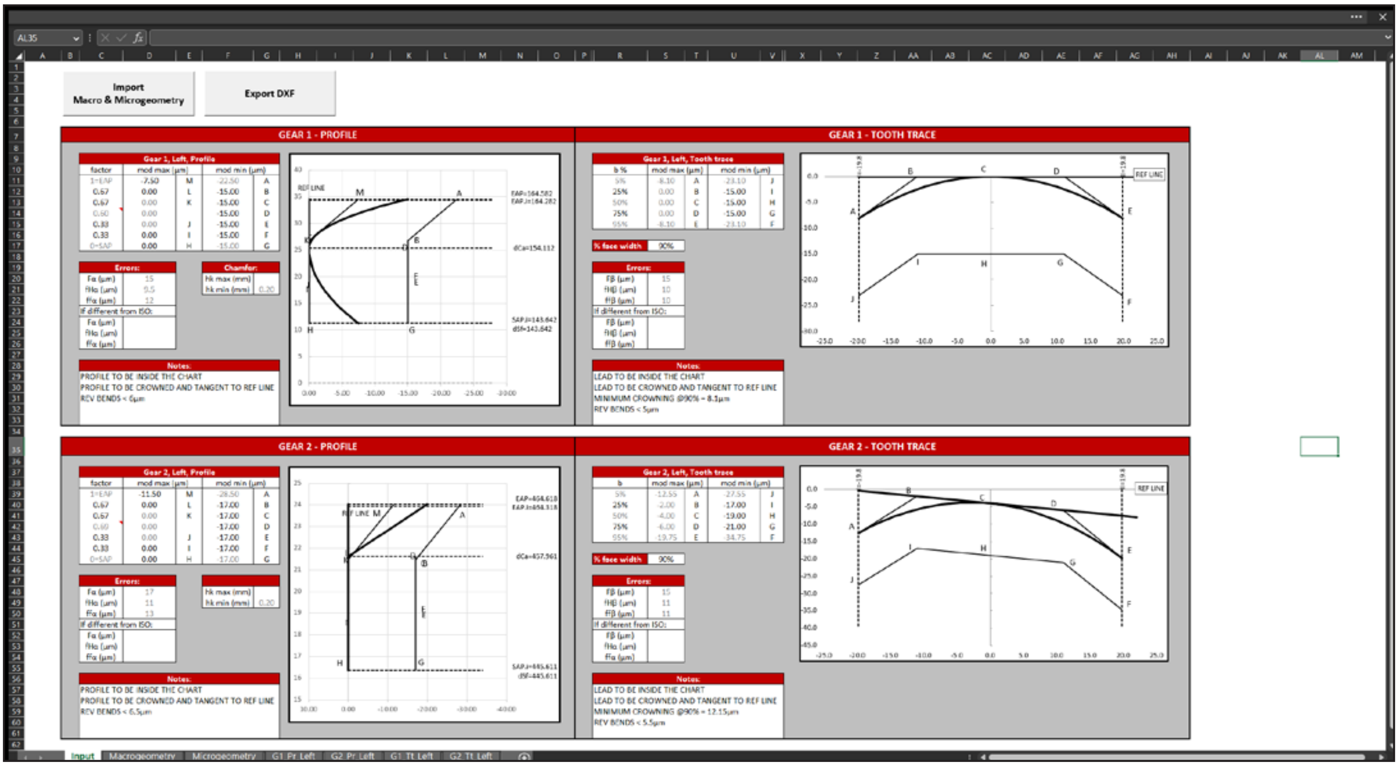
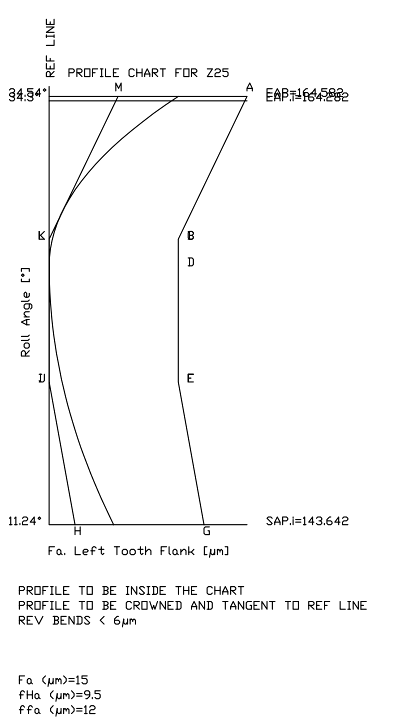


Figure 8—Excel tool to define K-chart tolerances.



	PROFILE CHART			
	Fa[µm]	xi [°]	Ly[mm]	d[mm]
A	-23	34.54	42.48	164.58
B	-15	26.77	32.93	155.58
C	-15	26.77	32.93	155.58
D	-15	25.33	31.15	154.11
E	-15	19.01	23.38	148.51
F	-15	19.01	23.38	148.51
G	-18	11.24	13.83	143.64
H	-3	11.24	13.83	143.64
I	0	19.01	23.38	148.51
J	0	19.01	23.38	148.51
K	0	26.77	32.93	155.58
L	0	26.77	32.93	155.58
M	-8	34.54	42.48	164.58

Figure 9—K-chart DXF file generated by the tool of the previous figure.

Waviness

The third case history concerns the need to limit the profile waviness (reverse bending), which some companies are showing on their drawings (Ref. 12).

A possible definition of waviness could be the distance between two peaks on involute profile measured in perpendicular direction with to the involute profile. Waviness w is measured only among peaks that are spaced at least 20 percent of the length of path of contact ($Lw > 0.2\ g_\alpha$). The maximum acceptable waviness could be defined by a fraction of the profile error (profile form deviation) $f_{f\alpha}$. However, no tolerance value has been yet standardized for these values (Ref. 13).

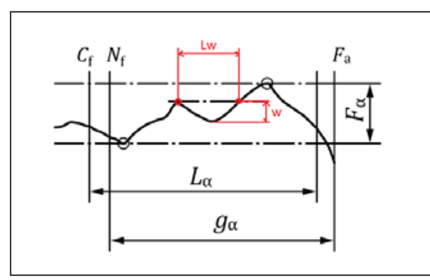


Figure 10—Waviness.

In this case, the closed loop consists of assessing the effect of the measured waviness on the transmission error.

The measured profile is then exported from GMM and imported into the design and analysis software (Figure 11). Waviness effects have been quantified with a loaded contact analysis (Figure 12). This type of analysis can be performed considering a single tooth or every tooth of the gear, using a fast GMM (Ref. 14), and a TCA software can manage different microgeometry for each tooth (Ref. 11).

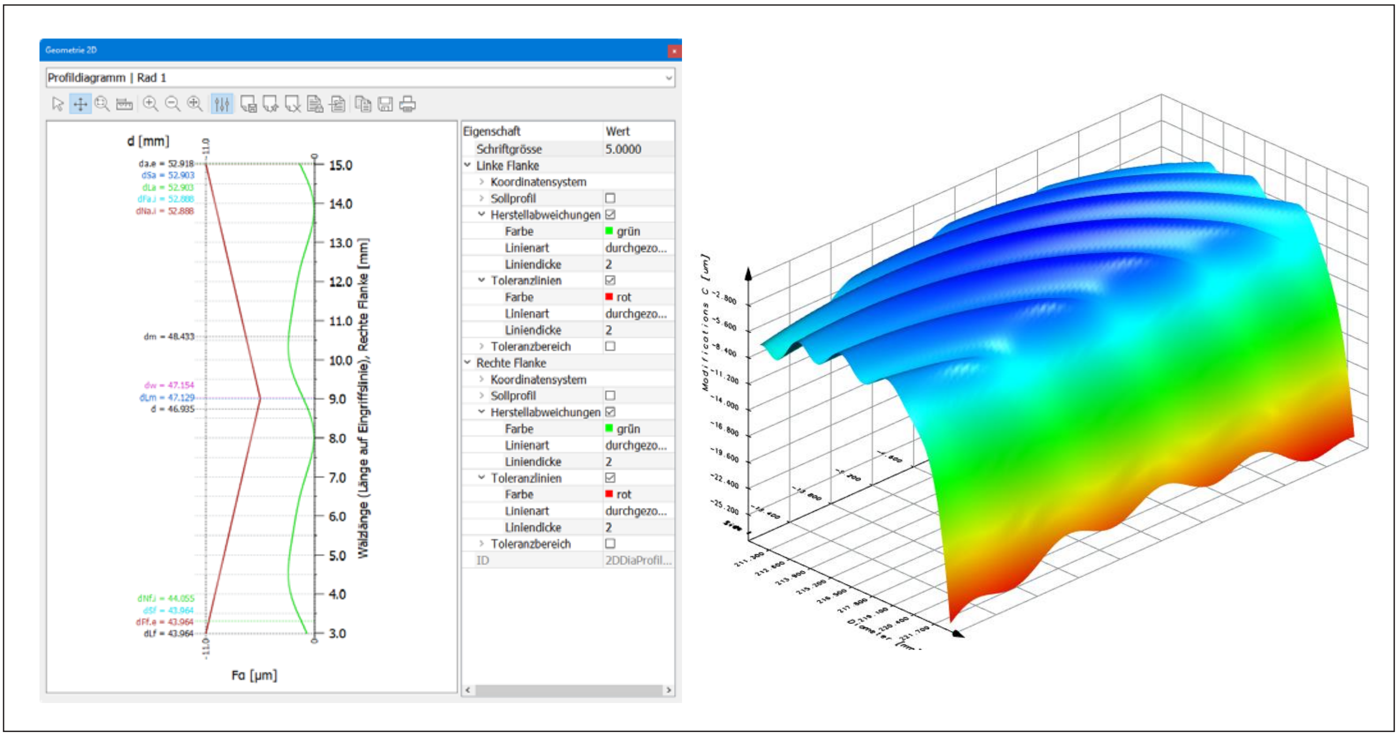


Figure 11—Measured profile with waviness imported into KISSsoft *(Ref. 11).*

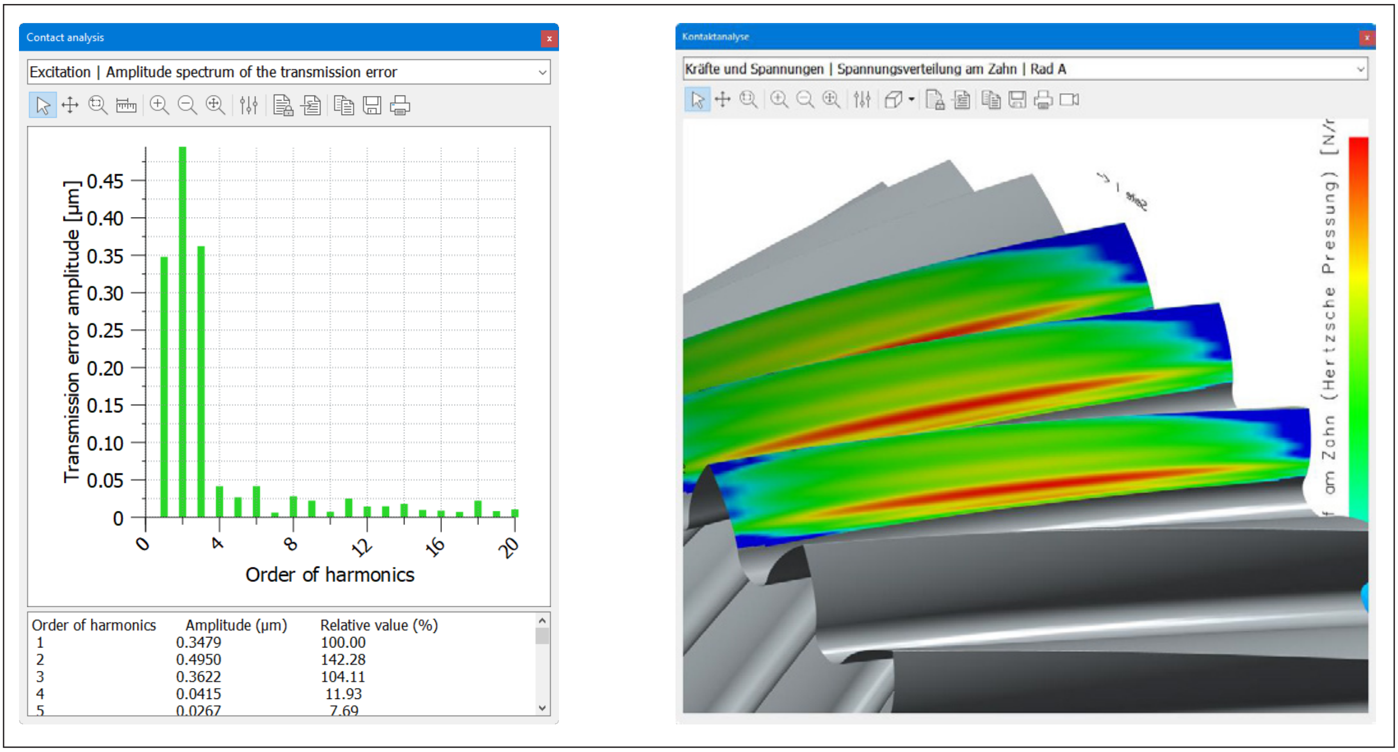
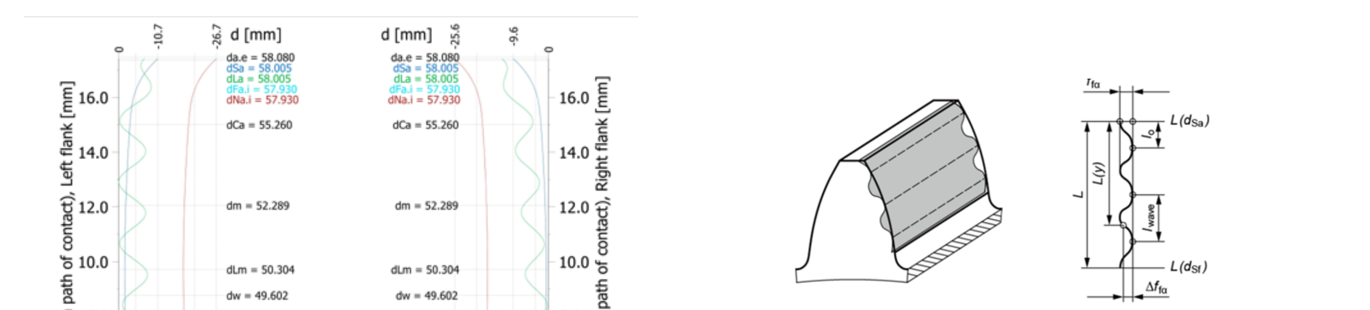


Figure 12—Results of the LTCA, considering the measured profile with waviness (Ref. 11).



d_{Sa}	profile form deviation, start, at tip	d_{Sf}	profile form deviation, end, at root
L	roll length	l_0	phase shift
l_{wave}	wave length	$f_{f\alpha}$	profile form deviation, value

	Value	Factor 1	Factor 2
Inputs	$f_{f\alpha}$	l_{wave}/m_n	l_0/m_n
Conditions	> 0	> 0	-
Equation	$\Delta f_{f\alpha} = \frac{f_{f\alpha}}{2} \cdot \left[1 - \sin\left(90^\circ + 360^\circ \cdot \left(\frac{L(y)}{Factor\ 1 \cdot m_n} - \frac{Factor\ 2}{Factor\ 1}\right)\right)\right]$		

Figure 13—$f_{f\alpha}$ modification to simulate waviness in the design process (Ref. 11).

However, before getting the measured profile form GMM, a first attempt to consider waviness during the design process could be made by adding the modification of profile form $f_{f\alpha}$ with analytic formulation (Figure 13).

Worm Wheels

The design (specification) for worm gearboxes often lacks specific information regarding crowning, hence regarding the contact pattern under load.

Suggestions concerning what the contact pattern should be like can be found in Ref. 15, as shown in Figure 14.

Generally speaking, crowning is obtained by oversizing the hobbing tool with regard to the worm dimensions (Refs. 16, 17) and by tilting it in relation to the worm's axis, at a clearly increased center distance.

Unlike cylindrical gears, whose microgeometrical adjustments are usually obtained during grinding, with specifically dressable tools, worm wheels, in bronze or cast iron, are finished by the hobbing. So the cutter's resharpening and changing the tool diameter also changes the contact pattern in the worm wheel.

These conditions must be complied with in order for meshing requisites to be met (Ref. 18).

$$d'_{m0} \cdot \sin\gamma'_0 = d_{m0} \cdot \sin\gamma_{m1} \quad (1)$$

$$\eta = \gamma'_0 - \gamma_{m1} \quad (2)$$

$$\tan\gamma''_0 = \frac{d'_{m0}}{d''_{m0}} \cdot \tan\gamma'_0 \quad (3)$$

where

d_{m1} is the worm reference diameter

γ_{m1} is the reference lead angle of worm

d'_{m0} is the oversized hobber reference diameter

γ'_0 is the oversized hobber reference lead angle

d''_{m0} is the hobber reference diameter after resharpening

γ''_0 is the hobber reference lead angle after resharpening

η is the backing angle of the hobber

Some companies have recently adopted the closed loop for worm screw crowns by following the steps listed below:

- design of the worm gearbox (worm and worm wheel) providing for an oversize of the crown cutter (Figure 15);
- numerical and graphical check of contact pattern (Figure 16);
- generation of "hobber tip diameter | backing angle of the hobber | cutting center distance" table, taking into account that the hobber tip diameter decreases when resharpened (Table 2);
- exporting of grid for GMM without taking into account cutter oversize (digital master) (Figure 17);
- cutting as per listed parameters;
- measurement on GMM and comparison with digital master (Figure 18).

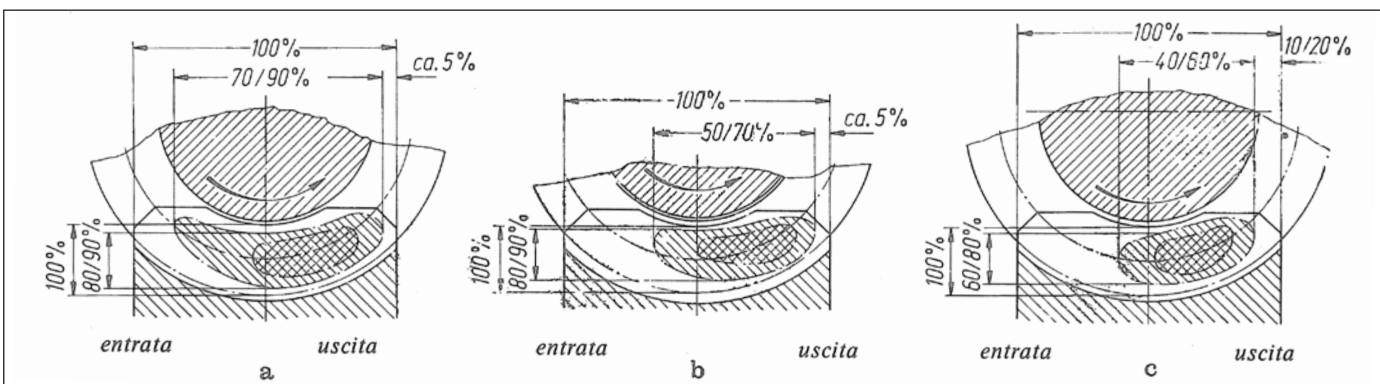


Figure 14—Proposal for the contact pattern in worm gearboxes (Ref. 15).

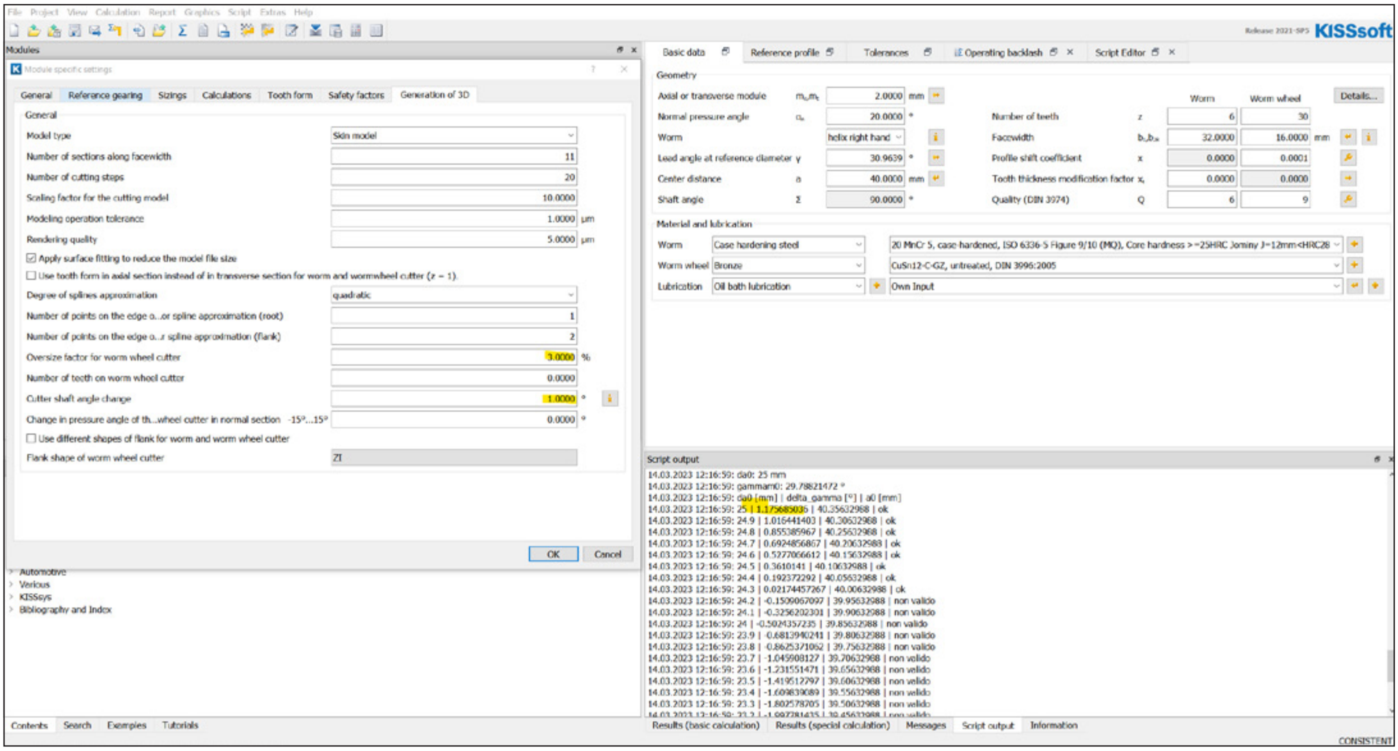


Figure 15—Design of the system worm and worm wheel with oversized hobber (Ref. 11).

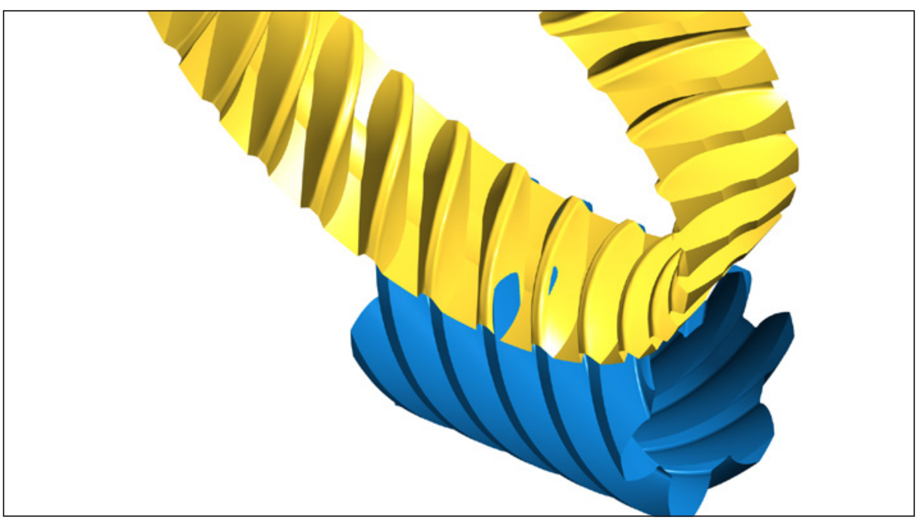


Figure 16—Check of the contact pattern on the design software (Ref. 11).

d_{a0} [mm]	η [°]	a [mm]	usability
24.887	0.996396079	40.30	✓
24.787	0.835111711	40.25	✓
24.687	0.671978307	40.20	✓
24.587	0.506961855	40.15	✓
24.487	0.340027451	40.10	✓
24.387	0.171139267	40.05	✓
24.287	0.000260518	40.00	✓
24.187	-0.172646576	39.95	χ

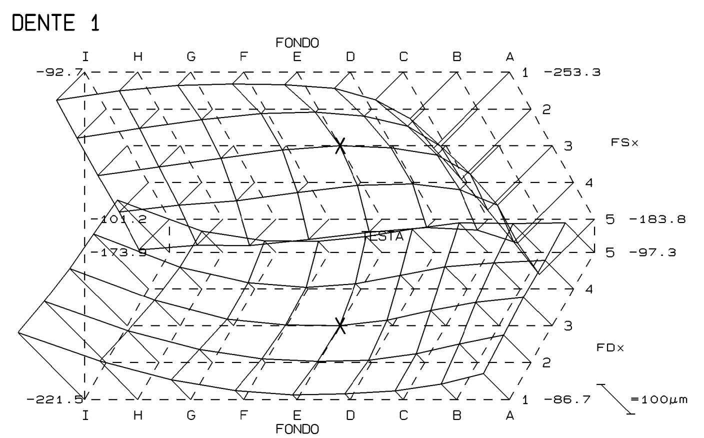
Table 2—Backing angle of the hobber and manufacturing center distance vs. resharpened hobber tip diameter.

RECHTE FLANKE RAD
DATUM / ZEIT : 11.01.2022 / 11:54

IN SPALTE 5 / ZEILE 3 : ZAHNDICKENWINKEL = 0.119521 rad

J	I	XP	YP	ZP	XN	YN	ZN
1	1	-4.8699	-45.9436	-8.9981	-.8625	-.0671	.5014
1	2	-4.7820	-46.7550	-8.9981	-.8520	-.1153	.5105
1	3	-4.6463	-47.5668	-8.9981	-.8407	-.1648	.5157
1	4	-4.4665	-48.3772	-8.9981	-.8293	-.2071	.5189
1	5	-4.2429	-49.1910	-8.9981	-.8176	-.2429	.5219
2	1	-3.6710	-44.8900	-6.7486	-.8775	-.0654	.4750
2	2	-3.5530	-45.9931	-6.7486	-.8597	-.1182	.4969
2	3	-3.3669	-47.0950	-6.7486	-.8430	-.1715	.5096
2	4	-3.1057	-48.1983	-6.7486	-.8263	-.2253	.5160
2	5	-2.7704	-49.2985	-6.7486	-.8101	-.2721	.5192
3	1	-2.5962	-44.2012	-4.4991	-.8946	-.1266	.4284
3	2	-2.3974	-45.4065	-4.4991	-.8717	-.1647	.4614
3	3	-2.1437	-46.6103	-4.4991	-.8501	-.2011	.4865
3	4	-1.8276	-47.8081	-4.4991	-.8292	-.2435	.5029
3	5	-1.4350	-49.0099	-4.4991	-.8080	-.2909	.5122
4	1	-1.6439	-43.8121	-2.2495	-.9018	-.1931	.3863
4	2	-1.3700	-44.9346	-2.2495	-.8783	-.2313	.4183
4	3	-1.0504	-46.0619	-2.2495	-.8549	-.2583	.4497
4	4	-0.6948	-47.1785	-2.2495	-.8334	-.2807	.4759
4	5	-0.2979	-48.2897	-2.2495	-.8128	-.3070	.4949
5	1	-0.7733	-43.6874	0.0000	-.8978	-.2878	.3330
5	2	-0.4134	-44.7845	0.0000	-.8777	-.3132	.3624
5	3	0.0000	-45.8799	0.0000	-.8544	-.3394	.3933
5	4	0.4501	-46.9695	0.0000	-.8317	-.3564	.4256
5	5	0.9284	-48.0469	0.0000	-.8090	-.3716	.4553
6	1	0.0538	-43.8436	2.2495	-.8849	-.3771	.2730
6	2	0.5224	-44.9530	2.2495	-.8657	-.3939	.3087
6	3	1.0551	-46.0604	2.2495	-.8394	-.4245	.3391
6	4	1.6332	-47.1539	2.2495	-.8130	-.4476	.3722
6	5	2.2470	-48.2373	2.2495	-.7885	-.4581	.4102
7	1	0.8750	-44.2686	4.4991	-.8787	-.4232	.2207
7	2	1.4947	-45.4482	4.4991	-.8464	-.4770	.2366
7	3	2.1863	-46.6071	4.4991	-.8167	-.5139	.2621
7	4	2.9439	-47.7552	4.4991	-.7874	-.5430	.2916
7	5	3.7553	-48.8872	4.4991	-.7589	-.5632	.3268
8	1	1.7469	-45.0071	6.7486	-.8630	-.4810	.1543
8	2	2.4083	-46.0653	6.7486	-.8213	-.5499	.1513
8	3	3.1398	-47.1065	6.7486	-.7934	-.5852	.1670
8	4	3.9328	-48.1327	6.7486	-.7645	-.6176	.1844
8	5	4.7844	-49.1436	6.7486	-.7358	-.6451	.2057
9	1	2.7470	-46.1188	8.9981	-.8273	-.5540	.0926
9	2	3.3081	-46.8823	8.9981	-.7887	-.6086	.0854
9	3	3.9020	-47.6297	8.9981	-.7690	-.6317	.0970
9	4	4.5342	-48.3724	8.9981	-.7459	-.6574	.1062
9	5	5.2007	-49.1034	8.9981	-.7227	-.6812	.1161

Figure 17—Grid exported by the design software.



Tpz:22.1 C Ta:23.3 C T: (#10.1) 1 mm

Grandezza caratteristica	teorica	reale	scost.	tol.inf.	tol.sup.	unità
Somma degli assoluti		3966.1				µm
Corda sez. front.	5.481	5.488	0.007			mm
(E3; R=45.880; Z=0.000)						mm
Dist. di montaggio	0.0000	0.0000	0.0000			mm

FONDO (FSx)

	I	H	G	F	E	D	C	B	A
1	-92.7	-62.5	-43.9	-39.1	-42.6	-54.0	-92.1	-153.9	-253.3
2	-96.4	-64.4	-35.3	-14.8	-10.8	-23.6	-57.1	-123.1	-233.1
3	-98.0	-70.5	-41.4	-13.7	0.0	-6.3	-30.4	-94.9	-214.2
4	-97.7	-75.6	-60.9	-33.6	-10.8	-4.5	-23.7	-75.1	-197.6
5	-101.2	-85.0	-87.3	-67.6	-42.6	-28.3	-36.7	-79.3	-183.8

FSx

TESTA

FDx

	I	H	G	F	E	D	C	B	A
5	-173.9	-69.9	-37.3	-35.7	-51.6	-76.7	-97.3	-95.0	-97.3
4	-182.7	-72.6	-21.1	-6.0	-17.9	-46.2	-74.3	-87.2	-95.1
3	-191.0	-84.6	-21.2	-2.6	0.0	-18.6	-50.8	-76.9	-95.1
2	-204.6	-105.3	-42.8	-11.6	-2.7	-7.9	-28.7	-61.8	-90.9
1	-221.5	-126.8	-65.2	-30.2	-15.2	-18.2	-28.3	-50.6	-86.7

FONDO (FDx)

Unità: [µm]

Figure 18—GMM measurement (A) and report (B).

The first result to check in the GMM report is the tooth thickness (chordal in transverse section): this is what makes it possible to keep a check on gearing backlash. Single-flank gear inspection was performed prior to adopting this procedure.

Figure 18B shows crowning until the tool reaches the end of its life. Crowning disappears at the precise moment when the tool takes on the worm's dimensions.

The operator has the same software in the workshop as used during design and can generate the grid (digital master) that takes into account the actual dimensions of the cutter that cut the wheel it is measuring. In this case, the drawing will not show crowning, but only any errors.

Conclusions

The goal of this paper was to help the reader improve the documentation and performance of bevel, cylindrical and worm gears. The closed loop is an improvement in the manufacturing process of gears, which connects design and production in a two-way manner. A necessary condition for its adoption is an awareness that specification and verification must also be connected. You cannot request what you cannot measure. The measurement process must be defined in a clear, unambiguous way, just as the measurements to be taken already are.

Acknowledgments

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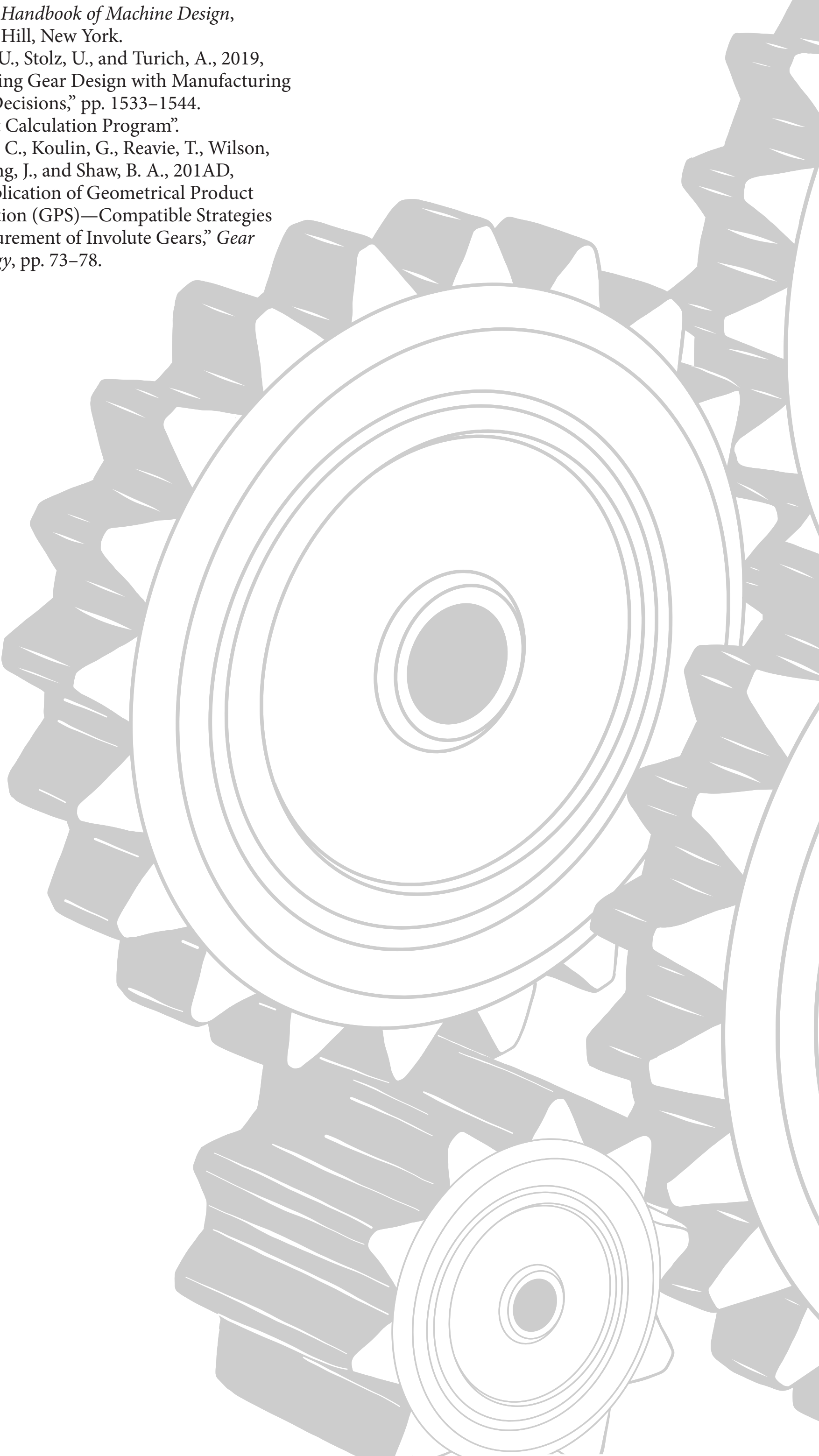

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Max Turci is a consultant in gears and cam mechanisms design. He received his master's degree in mechanical engineering at University of Bologna in 1996. He began as a CAD manager and he developed *X-Camme*, a software for the design of cam mechanisms. In 2004, he started working on gears as an application engineer for KISSsoft: now he is the team leader of the Italian technical staff of KISSsoft. His professional experience is primarily in the development of computational models for industrial gearboxes and vehicle transmissions. He is a member of the AGMA worm gear committee and some ISO WG for gears. As a mechanical engineer, he is an expert witness for the civil court.

Vincenzo Solimine is a mechanical engineer, with in-depth knowledge of *KISSsoft* and *KISSsys*, who consults and trains on transmission systems and gears. He received a master's degree in mechanical engineering (2006) from the University of Napoli Federico II where he also completed a postgraduate master's program in automotive engineering (2007). For over a decade, he served as a virtual validation engineer for Dana Graziano where he was involved in a wide variety of activities related to modeling, verification, and sizing of different types of transmission systems optimizing for both durability and NVH performance, which he continues to do in his capacity as a trainer and consultant.

Klingelnberg

NOW A MEMBER OF INNOVATION HUB, BERGISCHES RHEINLAND

Machine manufacturer Klingelnberg now ranks among the new members of Innovation Hub, Bergisches Rheinland. The company signed its membership contract on February 17, 2023, at the headquarters of Innovation Hub, Bergisches Rheinland in Gummersbach, Germany. Innovation Hub Bergisches Rheinland (InnoHub for short) is the central hub for small and medium-sized business networks in the regions; for scientific institutions focusing on research and teaching; for interest groups in the districts of Oberberg, Rhein-Berg and Rhein-Sieg; and for local politics. By partnering with regional businesses and organizations, InnoHub aims to strengthen their competitive edge and innovative capacity.

"We are delighted to enter into this future partnership with InnoHub," says Dr. Christof Gorgels, vice president, technology and innovation of the Klingelnberg Group. "By learning together and exchanging ideas with other companies in our region, we are further strengthening our strong position in the market."

Christoph Küster, CFO of the Klingelnberg Group, is also pleased: "We are certain that by working together, we will gain valuable insight and will be able to generate innovative ideas for our business and production processes."

klingelnberg.com

Forest City Gear

PROMOTES ZAC DENNY TO SETUP TECHNICIAN

Forest City Gear is proud to announce the promotion of Zac Denny to setup technician. In this role, he will oversee setup and operation of the MZ130 and Koepfer 153 machines.

Denny began his career with Forest City Gear in January 2022. Previously he was a floating operator in the hobbing department, running machines and maintaining the quality of parts that were under his care.

"Zac is learning very quickly what it takes to produce high quality parts here at FCG," said Kent Blatchford, hobbing supervisor. "As he continues to learn there will only be room for growth in knowledge and ability to produce these higher quality parts. The ability to understand the production of high-quality gears will continue throughout his career, as this is such a fine field of expertise. I have the utmost confidence that with continued training he will be a valued asset to the FCG team."

forestcitygear.com

Lockheed Martin

ENTERS LONG-TERM AGREEMENT WITH RONSON GEARS

Lockheed Martin Space has entered into its first-ever international long-term agreement with Melbourne-based manufacturer Ronson Gears under its Global Supply Chain (GSC) Program agreement with the Commonwealth of Australia. This long-term agreement will supply multiple gear and gear sets across various space programs to enhance lead times while decreasing administrative burdens.

The a showcases Lockheed Martin's dedication to growing partnership alliances in Australia. Lockheed Martin is dedicated to building an Australian supply chain, with procurement executives from our Space Business Area having undertaken five visits to Australia since 2018 to assess and qualify world-class Australian capability.

Ronson Gears was awarded its first GSC Program contract by Lockheed Martin in 2019, becoming the first-ever Australian company to supply gear components that will be carried into space. Since then, Ronson Gears has secured a total of fourteen GSC export contracts with Lockheed Martin to supply a range of precision gear components and assemblies for both military and commercial satellite platforms. More opportunities are on the horizon for Ronson Gears as they continue to deliver exceptional quality and performance.

Lockheed Martin Australia's Chief Executive, Warren McDonald, congratulated Ronson Gears on securing the international long-term agreement.

"Ronson Gears is an example of the outstanding Australian Industrial Capability available to our nation and the global space industry," he said.

"It has been a privilege to support the development and transformation of this business, and we look forward to partnering with them well into the future."

Lockheed Martin Australia's Head of Industrial Development, Christopher Hess, said he was delighted to be continuing to work with Ronson Gears under the GSC Program.

"The global strategic environment is constantly evolving, and Lockheed Martin Space is committed to working with industry to deliver a world-leading space capability," he said.

"Since commencing our partnership in 2019, Ronson Gears has demonstrated its commitment to investing in the people, technology and capabilities required to compete internationally."

Gavin New, Ronson Gears' managing director, is also a graduate of Lockheed Martin's Program Management Institute held at the Ccorporate Hehadquarters in Bethesda, Maryland. This training is designed for only a selected number of external candidates each year that have a direct export opportunity link to Lockheed Martin's Global Supply Chain.

"Lockheed Martin Space brings an unparalleled legacy in military and commercial satellite programs," said New.

"Ronson Gears is grateful for the support Lockheed Martin has shown our business to date and the trust they have shown in offering this long-term agreement.

"Through our work under the GSC program, we have been provided access to global networks and the ability to contribute to space programs that will shape international defense capabilities.

"This would not have been possible without the opportunities Lockheed Martin has provided and, with this Agreement in place, we are excited about the opportunities that are to come."

ronsongears.com.au

Croix Gear & Machining

ANNOUNCES NEW PRESIDENT

Croix Gear & Machining, recognized as a leader in the custom manufacturing of loose gears, announced the hiring of Michael J. Lindsay as president. Lindsay will assume responsibility for all manufacturing and business operations. Lindsay brings a proven track record for continual improvement in supply chain, scheduling, production, and quality to Croix Gear.

Ruthie Johnston will continue her role as CEO/owner with a focus on developing deeper relationships with customers, spending more time in the marketplace, and leading the strategic growth of the organization. Lindsay will report directly to Johnston as they work together to continue the process of engineering an exceptional customer experience.

"We are excited about the positive impact these changes will have for our customers and employees," stated Johnston. "As we continue our growth by providing customers with precision gears and a precision experience, Michael's proficiency in building high-performing teams will be a tremendous asset."

croixgear.com

Saacke

ANNOUNCES NEW MANAGING DIRECTOR TEAM

Saacke Precision Tools and Grinding Machines, a family business started in 1892, has announced a Georg Saacke as president to lead a new management team: Ilona Schrade, CFO; Arno Fabry, CTO machine department; Thomas Roscher, CTO tool department. For more than 125 years, Saacke has manufactured precision tools and tool-grinding machines and continues to create products that combine the latest technologies and decades of experience.

saacke-usa.com

Southern Gear

ADDS CAPACITY FOR LARGE RING GEARS

Southern Gear has added two Hwacheon VT-1150+ Vertical Turning Centers to its gear production operations, both capable of high-speed, complete machining of ring gears and other cylindrical parts with diameters of 1,320 mm and lengths up to 950 mm.

The machines, with powerful 55 kW spindles, rapid 24 m/min. axis travel and a 24-tool turret for "turnmill" machining, enable Southern Gear to perform multiple turning, milling and other operations in single setup, thus greatly reducing the cycle times required to completely machine a typical ring gear.

Additionally, the VT-1150+ provides an extremely stable heavy duty cutting platform, with a highly rigid box-way feed structure, air-floating system, and unique, one-piece machine bed—all designed to deliver reliable, high precision with minimal thermal displacement.

"These new Vertical Turning Centers meet the dual challenge of delivering larger parts faster with the highest quality," explains Southern Gear President Karen Malin. "They're a great fit for our fast-growing aerospace and defense business where larger gears of this type are today in very high demand."

The addition of the Hwacheon VTC's is part of a multimillion-dollar, company-wide investment in new technologies, methodologies and processes that, over the last several years, has, according to Malin, added much needed capacity to Southern Gear's vertically-integrated shop floor.

southerngear.com

Sandvik Coromant

EMBRACES EQUITY FOR WOMEN IN STEM

This year's International Women's Day (March 8) followed the theme of "embracing equity"—focusing on giving fair opportunities for everyone to succeed. As a business invested in its people, Sandvik Coromant highlights the experience of its president, Helen Blomqvist.

One of IWD's key missions is to forge inclusive work cultures where women's careers thrive and their achievements are celebrated. This year, the campaign centers around equity and how providing equal opportunities is no longer enough. So how do we achieve equity?

At Sandvik Coromant, the number of females in functional management roles currently sits at 43 percent. This is above the estimated industry average, which is considered to be 38 percent, according to the Chartered Management Institute (CMI). However, if we're to look across the manufacturing industry, it's clear there's still a lot to be done to truly achieve equity. A recent report by the Manufacturing Institute found that females make up just 29 percent of the manufacturing workforce.

Staggeringly, it also finds that 63 percent of women struggling to get into the field face challenges due to the sector's lack of flexibility, and almost half are deterred due to childcare issues, compared to just 8 percent of males.

It seems, therefore, that females wanting to succeed in the manufacturing industry still face challenges that rarely affect their male counterparts. If the industry is to truly reach equity, it must be aware of the unconscious bias certain groups face and find ways of managing that bias. But first, businesses must realize that hiring diversely does not just help fulfil a quota. In fact, it can bring real, measured business benefits.

Time to act

According to a Wall Street Journal report examining diversity and inclusion among S&P 500 companies, "diverse and inclusive cultures are providing companies with a competitive edge over their peers." What's more, a pre-pandemic McKinsey report, Delivering Through Diversity, showed companies in the top quartile of their rankings for successful gender diversity on their executive teams were 21 percent more likely to have above-average profitability. For ethnic and cultural diversity, that figure was 33 percent.

Despite efforts to increase diversity, many businesses still aren't doing enough. In January 2023, Gartner published a survey detailing the top five challenges facing diversity, equity and inclusion (DEI) leaders. The survey found that over half of DEI leaders fail to take responsibility for driving diverse outcomes, while a third feel they don't have the power to make real change.

It's clear that businesses have to take strides to truly reap the benefits of diverse teams. One way of inspiring a more balanced working environment is to promote the voices of those already in the industry, such as Blomqvist.

Meet the president

After starting as a research engineer at Sandvik Coromant 20 years ago, it's safe to say Blomqvist has risen through the ranks successfully after becoming the company's president in 2020. Many experiences have shaped Helen's experience as an engineer—and everything she's achieved has been a learning opportunity. "I like to see feedback as a gift, rather than a criticism. I never stop learning, and everyone at Sandvik Coromant can teach me something," she explained.

"To provide fair and equal opportunities for all members of the organization, it's important we're continuously learning how we can do better. At Sandvik Coromant, we have a regular feedback system where employees can anonymously voice how they're feeling in their role. From our most recent survey, we've found that 82 percent of respondents feel they can be themselves at work, while 83 percent say they feel proud to work at Sandvik Coromant. Those are good figures, but there's always room to do better."

A believer that a learning culture feeds curiosity and sparks innovation, Helen feels it is important to provide the opportunity to develop one's skills and nurture personal development. "A big part of delivering equity is providing opportunity for development and making sure everyone feels confident, successful and happy at work," she adds.

"There was an initiative at Google called 20 percent time, which I've always admired. The scheme meant that, for a portion of a worker's week, they could dedicate their time to exploratory work, focusing on creativity and learning that was outside of their normal responsibilities. It's where Google Mail was born, among many other landmark creations.

"While I don't invest quite so much time into other activities, I try to lead by example and dedicate 90 minutes of my time each week to my own learning. Whether it's attending a training session or speaking to one of our product experts, there's always something new for me to learn. Of course, fostering this learning culture isn't the only way to achieve equity in a workplace—and actions will always speak louder than words. However, being able to create that space for development, at a rate that's flexible to each individual and that plays to their own strengths, plays a huge role in creating a more diverse workforce."

The facts speak for themselves—industry must do more to encourage women to enter the manufacturing field. Celebrations such as IWD play a key part in showcasing the options available for women, who must not be held back by stereotypes. But, perhaps more importantly, sharing the stories of women in the industry who have overcome hurdles and developed true industry innovations is key to forming the next generation of manufacturing heroes.

sandvik.coromant.com

May 2–4—AGMA Gear Manufacturing and Inspection

While function and rating are important factors in a successful gear design, to be truly optimal and successful, the gear designer must also design the gears to be manufactured and inspected. In this course (Cincinnati, Ohio), therefore, AGMA will address key factors in a wide variety of manufacturing and inspection processes to enable the gear designer to better design optimal gears considering both rating and the necessary manufacturing and inspection processes to produce the gears as designed.

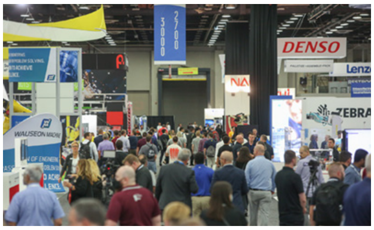
geartechnology.com/events/5057-agma-gear-manufacturing-and-inspection

May 22–25—Cleanpower 2023

Cleanpower 2023 (New Orleans) unites the most knowledgeable minds in clean energy to chart the future of this powerful industry and discuss the opportunities ahead. As previous attendees attest, the conference grows clean energy businesses by gathering key decision makers and stakeholders across the wind, solar, storage, hydrogen, and transmission industries for discussion, deal making, networking and fun. The trade show not only brings together the different technologies that make up the renewables mix; onshore wind, offshore wind, solar, storage, and transmission but also the different segments within the industries; manufacturers, construction firms, owner operators, utilities, financial firms, corporate buyers and more. Cleanpower will feature the latest products, services and technologies coming to the renewable energy industry.

geartechnology.com/events/5066-cleanpower-2023

May 22–25—Automate 2023



Between intimate workshops, news making keynotes, networking events, innovation competitions and live demonstrations, Automate (Detroit) offers comprehensive automation education and cutting edge robotics, vision, AI, motion control and other technologies. Automate delivers the latest innovations in manufacturing automation technology from more than 600 leading exhibitors. Each day also offers inspirational keynote sessions and theater presentations to help attendees find the best solutions for their unique business needs. In addition to seeing demos of the latest automation solutions, Automate show attendees can watch keynote sessions highlighting how these technologies solve real-world challenges or participate in small group discussions in the theater sessions covering important topics.

geartechnology.com/events/5065-automate-2023

May 24–25—CTI Symposium USA 2023

The CTI Symposium USA (Novi, Mich.) will update attendees on the latest technical developments and applications on automotive transmissions for conventional and alternative drives. Exchange experiences, discuss technologies and strategies with automotive experts from the United States, Asia and Europe. The conference and exhibition provide expert-led plenary and technology sessions as well as expert discussions and product showcases representing the full range from complete drivetrain systems to components and engineering services. CTI drives progress in passenger cars and commercial automotive transportation. Manufacturers and suppliers are actively demonstrating how to keep pace and staying ahead of customer needs, environmental, institutional and economic demands.

geartechnology.com/events/5064-cti-symposium-usa-2023

June 5–8—Gear Dynamics & Gear Noise Short Course

The purpose of this unique short course (Ohio State University) is to provide a better understanding of the mechanisms of gear noise generation, methods by which gear noise is measured and predicted, and techniques employed in gear noise and vibration reduction. Over the past 40+ years about 2,500 engineers and technicians from more than 385 companies have attended the Gear Noise Short Course.

geartechnology.com/events/5049-gear-dynamics-short-course

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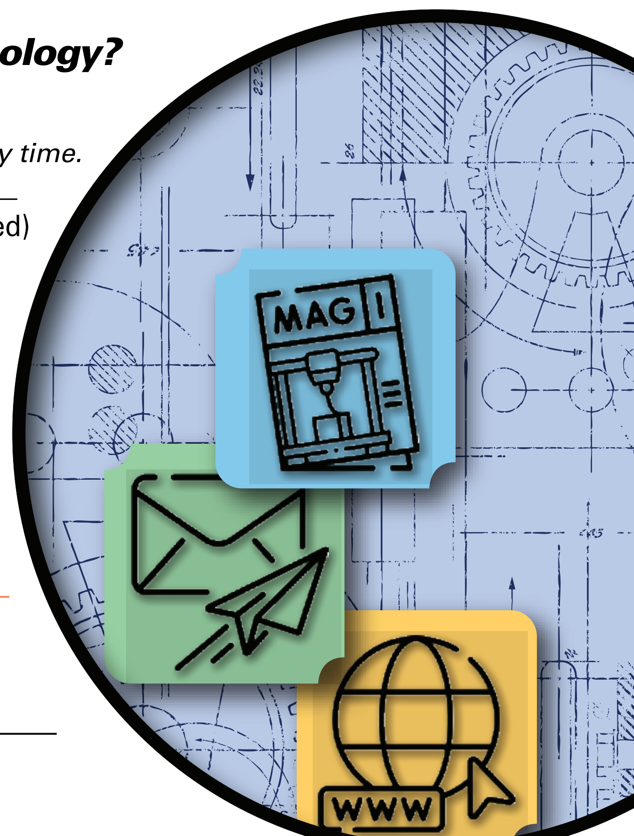

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Hazardous Occupation

Combat engineers have stood at the forefront of military campaigns throughout history.

Matthew Jaster, Senior Editor

Where there's war, there's a combat engineer (sapper) waiting in the wings to construct fortifications, build strategic roads or blow up enemy fortresses. For as long as humanity has been fighting, engineers have risked their own lives carrying out vital tasks on the battlefield.

War (From Ancient Egypt to Iraq) is a coffee table book examining major military campaigns from 3000 BCE to 2009. The reference book is 500+ pages of in-depth military history with sidebars on everything from swords and helmets to mercenaries and for our benefit—engineers in combat situations.

As far back as 701 BCE, Assyrian engineers were mining walls and building ramps during the Siege of Lachish in Palestine. Roman engineers—possibly the first to be directly employed in the army—built a mountainside siege ramp to assault the fortress of Masada. Roman engineers crafted ballistas (catapults) to fire bolts and stones at enemy troops up to 450 meters away. They tunneled under walls so they would partially collapse and open breaches for an assault.

The key permanent works of engineers throughout history, however, dealt with fortification, including the Great Wall of China, Hadrian's Wall and the countless military castles and strongholds built throughout Europe.

Vauban, considered by some to be the greatest engineer of his time (1633–1707), created French military fortifications that were widely used globally for nearly 100 years. He founded the Corps royal des ingénieurs whose curriculum was based on Vauban's publications on engineering design, strategy, and training.

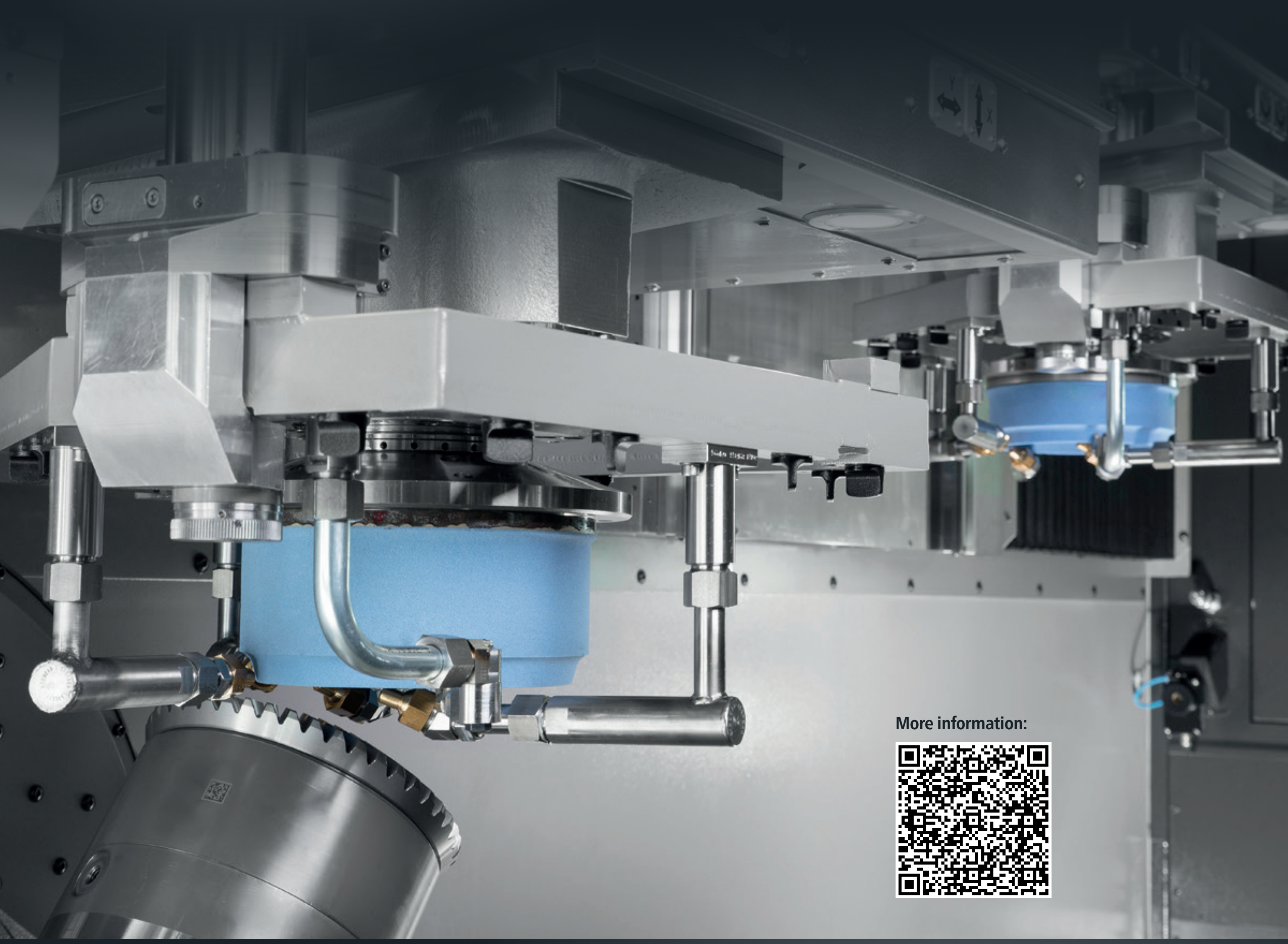
Fast forward to the early 1900s and combat engineers were tasked with clearing obstacles, building roads and bridges, creating temporary bases, and carrying out small-unit raids to lay explosive charges against enemy targets. Mine clearing became one of the most dangerous occupations for combat engineers during World War II.

Not to take away anything from the infantry, but imagine being tasked with highly dangerous engineering duties while operating in exposed positions in advance or to the rear of the main army unit.

Combat engineers were asked to blow up key fortifications on the Normandy beaches during D-Day or carve out makeshift helicopter landings in Vietnam. More recently, they built pipelines from Kuwait into Iraq to protect NATO troops and set up outposts in the mountainous terrain in Afghanistan.

The military has been working hard to modernize today's combat engineers. Modernization starts by connecting future concepts to engineering priorities like floating bridges that assemble themselves or drones, robots and AGVs that can be deployed versus sending out soldiers to the frontlines to support military operations.

The evolution of the combat engineer is set to change drastically as we embrace the age of robotics, automation, and data-driven manufacturing. How these soldiers will "Build for Your Navy" during the Information Age remains to be seen.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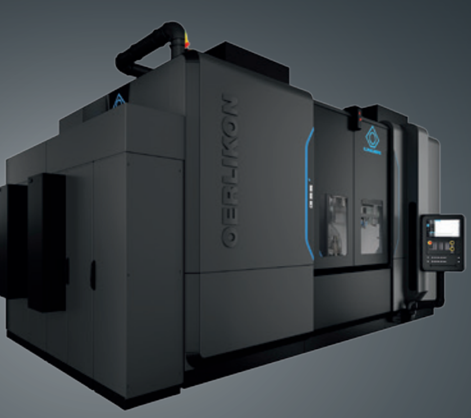
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