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Hard Skiving of an Internal DIN5480 Spline—A Process Analysis

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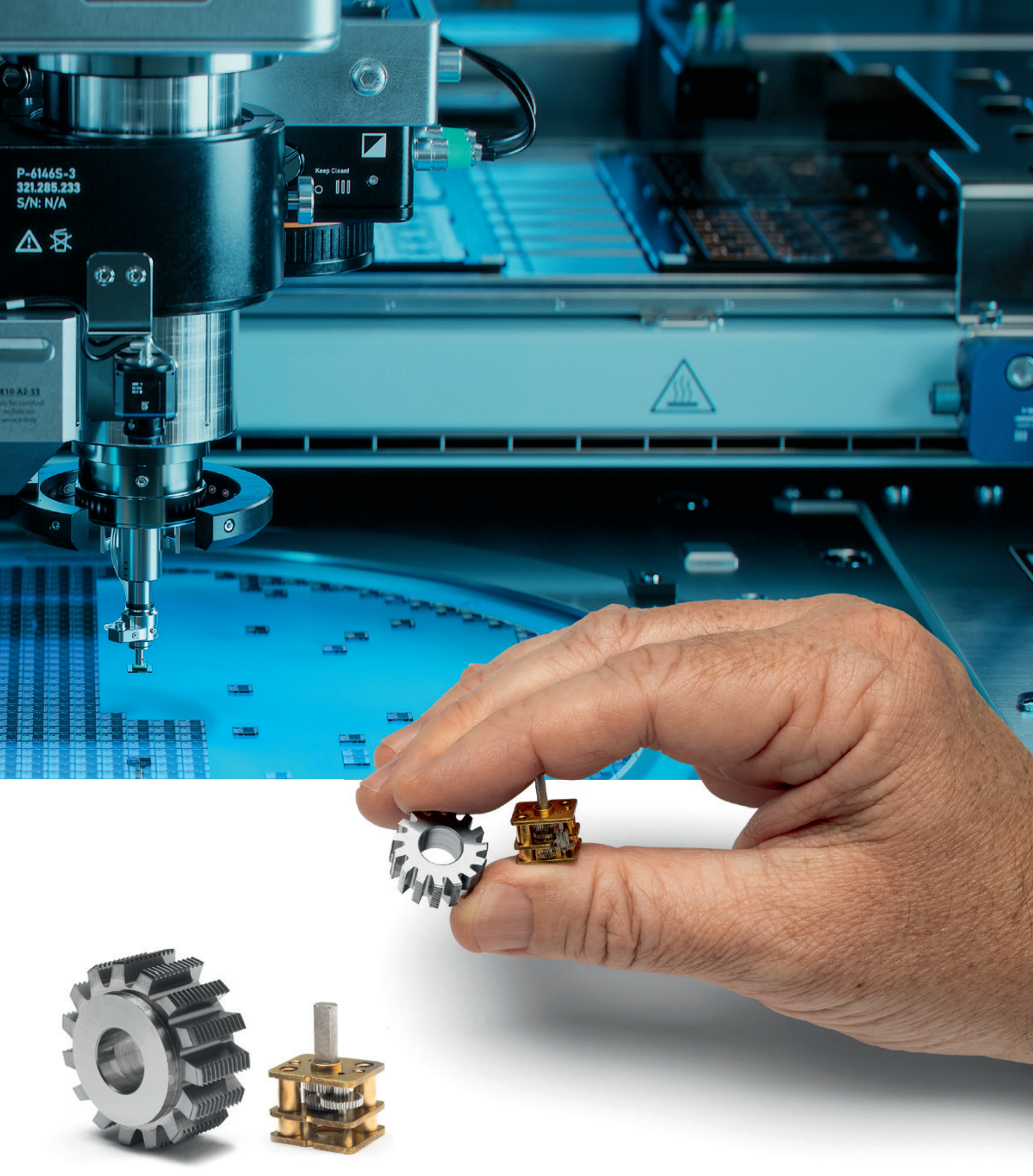
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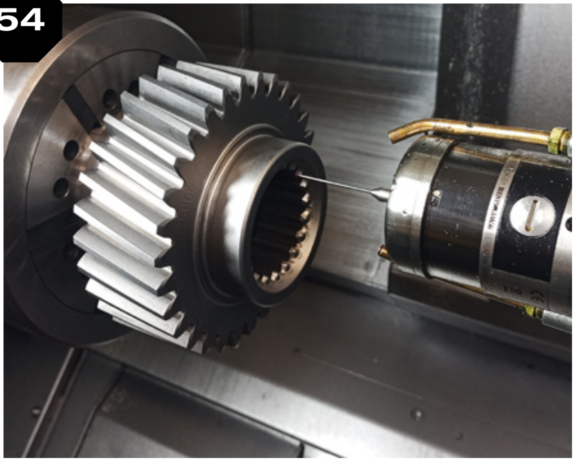

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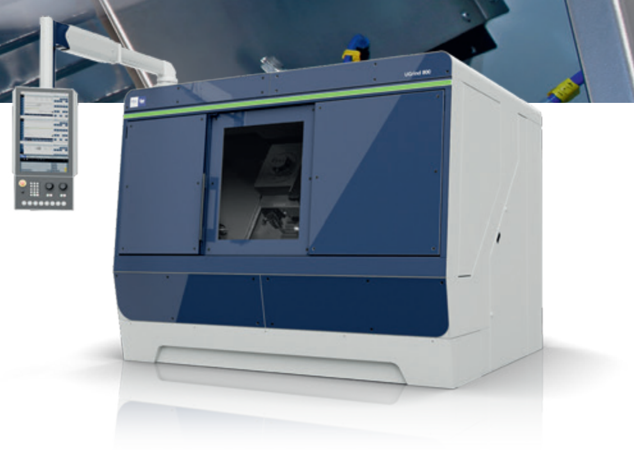

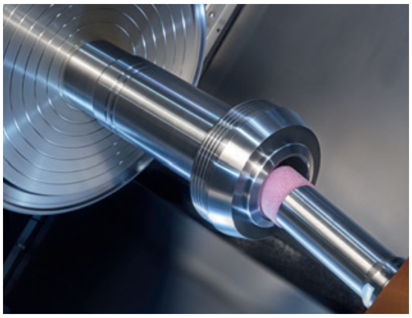

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Vol. 41. No. 5

Photo courtesy of Gleason

gear TECHNOLOGY

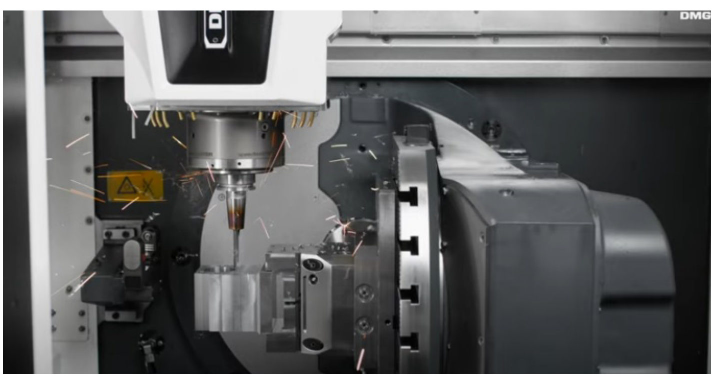
GT VIDEOS

Aerospace Grinding Summit Recap

United Grinding recaps a successful Aerospace Summit 2024 where the industry showcased the latest aerospace technologies and innovations. Demos included grinding of nonferrous advanced aerospace material with dressable super abrasives on the Mägerle MFP 30, improving grinding performance through optimized dressing techniques, single-step finishing of multifeature and mixed-material shaft components containing hard coatings on the Studer S41 and much more!

geartechnology.com/media/videos/play/279

DMG Mori: 3-Axis vs. 5-Axis Machining



DMG Mori highlights the advantages of 5-axis in order to increase efficiency and precision. This includes avoiding chip nests, reducing clamping positions as well as throughput times by changing from 3-axis to 5-axis machining.

geartechnology.com/media/videos/play/278

AS SEEN IN *PTE*

Automation Nation

Almost 43,000 registrants came together in Chicago to seek out the latest and greatest automation and robotic technologies during Automate 2024 in May. As always, A3 did not disappoint with a comprehensive conference paired with new automation technologies on the exhibition floor.

powertransmission.com/blogs/1-revolutions/post/9841-automation-nation

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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 40 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 *mwg42@hotmail.com.*

THE GEAR INDUSTRY'S INFORMATION SOURCE

No Secret Handshake Required

Most things grow thin when you spread them, like butter on toast or the money in your wallet. We've all felt overwhelmed by our schedules and commitments to the point that our very lives feel like they're spread too thin.

But there's one thing that gains strength and power the more it's spread, and that's knowledge.

Take this issue of *Gear Technology*, for example. It's full of really great knowledge, including information about the latest technology for manufacturing; important gear-related events that have taken place or are about to; technical knowledge based on R&D, academic research and product development; and much more.

In your hands, this issue has a lot of power. It can give you ideas about ways to help your company improve operations, become more profitable or make better gears. Maybe this knowledge could help you become better at your job.

But just think what would happen if you shared this knowledge with that new colleague in your department, the new kid they just hired, your customer who's struggling to understand what you do, your boss (who's also struggling to understand what you do—just kidding, bosses are great), or anyone else you know who's connected to the world of gear manufacturing.

When you share it, knowledge doesn't get spread thin. It multiplies.

Gear Technology was built on the foundation of sharing knowledge, but we need your help to get it into the hands of the people who need it most. Ours is not a secret club where you have to know the password or secret handshake to get in. Knowledge is for everybody.

I guarantee that you know at least one person who *should* be a *Gear Technology* reader but isn't. I challenge you to come up with a short list of associates who could benefit from this information.

Then, please, invite them in to become a part of our little club. Because the readers of *Gear Technology* are the movers and shakers, the doers and innovators of the gear industry. And we need more people like us.

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Siemens Digital Software

AUTOMATICALLY IDENTIFIES VULNERABLE PRODUCTION ASSETS

Production facilities are increasingly the targets of cyberattacks. Industrial companies are therefore required to identify and close potential vulnerabilities in their systems. To address the need to identify cybersecurity vulnerabilities on the shop floor as quickly as possible, Siemens has launched a new cybersecurity software-as-a-service (SaaS).

The cloud based *SINEC Security Guard* offers automated vulnerability mapping and security management optimized for industrial operators in OT environments. The software can automatically assign known cybersecurity vulnerabilities to the production assets of industrial companies. This allows industrial operators and automation experts who don't have dedicated cybersecurity expertise to identify cybersecurity risks among their OT assets on the shop floor and receive a risk- based threat analysis. The software then recommends and prioritizes mitigation measures. Defined mitigation measures can also be planned and tracked by the tool's integrated task management. *SINEC Security Guard* is offered as cybersecurity SaaS, is hosted by Siemens and will be available for purchase in July 2024 on the Siemens Xcelerator Marketplace and on the Siemens Digital Exchange.

Increasing protection by reducing manual effort

"With *SINEC Security Guard*, customers can focus their resources on the most urgent and relevant vulnerabilities, while having full risk transparency in their factory. It is unique because it takes the specific situation of the customer's operational environment into consideration while providing a single pane of glass for security- relevant information in the OT area," says Dirk Didascalou, CTO of Siemens Digital Industries. "When developing the *SINEC Security Guard*, we drew on our extensive experience with cybersecurity in our own factories."

Today, industrial operators are tasked with continuously safeguarding their production assets on the shop floor. They need to analyze vendor security advisories, manually match them to the asset inventory of their factory and prioritize mitigation measures. Because this process is time-consuming and error-prone using the existing tools, factories are running the risk of missing critical vulnerabilities in their assets or producing false-positives. This can lead to incorrectly configured plant components and inadequately allocated resources. With the software, industrial operators can tackle these challenges without needing in-depth cybersecurity knowledge.

Attack detection at scale with Microsoft Sentinel

For a comprehensive view of IT and OT cybersecurity, *SINEC Security Guard* will also offer a connection to Microsoft Sentinel, Microsoft's Security Information and Event Management (SIEM) solution for proactive threat detection, investigation and response. Once connected, it can send alerts for security events including attacks to Sentinel, enabling a security analyst to incorporate *SINEC Security Guard* insights and conclusions in investigations and responses with Microsoft Sentinel powered Security Operations Centers.

"As information technology and operational technology systems continue to converge, a holistic cybersecurity architecture is key to protecting IT and OT capabilities alike. By combining our domain knowledge, Siemens and Microsoft make it easier for industrial operators to efficiently detect and address cybersecurity threats at scale," says Ulrich Homann, corporate vice president, Cloud + AI at Microsoft.

The software also supports the manual upload of existing asset information for asset inventory. Siemens recommends, however, that industrial operators use the Industrial Asset Hub, the Siemens cloud-based Asset Management solution, to enable continuous automated asset inventory management.

Functionalities also include signature-based network intrusion and attack detection via the *SINEC Security Guard Sensor*, an Industrial Edge app, which gives users live information about their industrial network. The *SINEC Security Guard Sensor App* is available at the Siemens Industrial Edge Marketplace.

The initial release of *SINEC Security Guard* only supports Siemens OT assets but third-party device support is planned in the future. *SINEC Security Guard* will expand the existing Siemens software portfolio for OT network security consisting of *SINEC Security Inspector* and *SINEC Security Monitor*.

usa.siemens.com/sinec-security-guard

Emuge–Franken USA

OFFERS COMPLETE GEAR SKIVING TOOL SOLUTIONS

Emuge–Franken USA offers gear manufacturers a single source for a full range of Skiving Tool Solutions including wheels for internal and external gears as bell-type or shank tool variants in the module sizes m 0.4 to m 5, as well as tool and workpiece clamping solutions. Emuge–Franken produces high-precision skiving tools on state-of-the-art tool grinding machines with appropriate grinding software. A measurement report and corresponding technology data are supplied with every delivery of skiving tools. Application specialists are available to assist with the initial use of the tools, and tool repair is also offered.

Skiving tools can be used in a variety of gear applications including the production of ring gears, shafts with internal and external splines and splined shaft profiles. Emuge–Franken Skiving Tools have no restrictions regarding the material to be machined and are highly suitable for the soft machining of internal and external gears, as well as hard machining. The skiving tools can be used on turning/ milling centers with b or a axes (swivel axes).

The Emuge–Franken clamping division specializes in providing highly accurate, almost maintenance-free customized solutions for applications ranging from low volume job shops to high volume automotive production environments. Emuge–Franken designs and develops optimal, often complex clamping solutions by working closely with its customers to learn about the unique application challenges and production environments.

emuge-corp.com

Adelbert Haas

OFFERS SINGLE MACHINING OPERATION FOR AVIATION COMPONENTS

The Curvic coupling from the aviation sector is a critical component used in helicopters. Previously, the external helical gearing was manufactured on one machine and the Curvic coupling gearing on a second machine. The external and internal cylindrical grinding was then carried out on a third machine in two consecutive process steps.

On the high-precision Multigrind CA high-tech grinding machine, the complete workpiece can be machined in a single clamping operation. This grinding strategy is unique, and the process design is innovative. The Multigrind CA produces maximum precision and enormous time savings with minimum space requirements. The process guarantees repeatable results in series production and is also ideal for prototyping and one-off production.

From precision tools and turbine blades to gearbox shafts and knee implants: You can grind just about anything on the Multigrind CA. The center features the Adelbert Haas Multicube design with a cubic mineral composite base and symmetric arrangement. There are no mechanical surpluses and no projections. Tool changers and automation make your grinding projects cost-effective and reliable.

The Multicube is made from a thermally stable mineral composite with cast-in x- and y-axes and a central grinding unit. There are no surpluses, little thermal expansion and vibration dampening for maximum stability. Thanks to its kinetic arrangement, the grinding wheel lies in the machining center of the z-axis. Located at the top, the z-axis ensures significantly reduced paths and faster machiningin an impressive working range of 630 mm (x-axis), 345 mm (y-axis) and 430 mm (vertical z-axis).

multigrind.com

Jenoptik

OFFERS VARIETY OF NEW MEASUREMENT TECHNOLOGIES

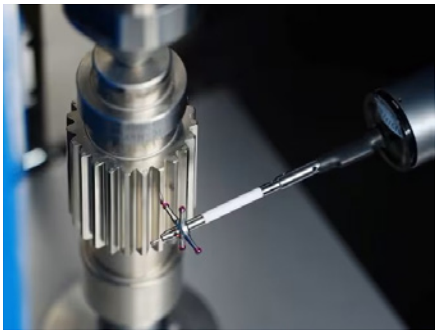
At the Control trade fair for quality assurance, Jenoptik offered a variety of automated measuring and inspection stations as well as new sensors and functions of the proven measurement technology for the target groups of automotive manufacturers and suppliers. Here are some highlights:

The Jenoptik Opticline C series is being expanded to include measuring systems for larger and heavier workpieces, a wide range of automation solutions and additional multi-sensor applications.

The addition of the C923 and C1223 variants means that the proven technology platform of the Opticline C series can now also be used for large and heavy workpieces. This means that customers from market segments such as e-mobility, energy generation, commercial vehicles and aerospace can now also benefit from the highest accuracy and widest range of functionality in optical shaft measurement technology.

With integrated machine monitoring and compensation algorithms for temperatures and ambient conditions, solutions for fully automatic workpiece loading and independent calibration sequences, automation solutions can be individually scaled and long-term stable process reliability can be guaranteed even in harsh environmental conditions.

With the optional T3D tactile sensor, the Opticline systems can be expanded into a complete multi-sensor shaft measuring device. This means that all tactile and optical features can be recorded with high precision within a single measuring sequence in just seconds, and cycle times are significantly reduced. With the integrated option for gear measurement, typical gear features for spur and helical gears can now also be measured, which further increases the flexibility of the Opticline measuring system and enables fast process-oriented quality statements. Established functions such as automatic probe arm changes and system checks also increase efficiency directly in the production process.



The advanced *Tolaris Optic 6* measurement and evaluation software provides support for programming all the extensive new functions. The highlight of the new software version is a clearer user interface with improved functions, which makes programming and operator self-monitoring even easier and faster in just a few minutes.

In the field of roughness and contour measurement technology, the new W40 hand-held measuring device will complement the Waveline product family. It offers a handy feed unit that can be used for all common roughness measurement tasks. The W40 device can optionally be used as a compact measuring station and can be used both in the measuring room and on the shop floor. The motorized zero-point search for automatic positioning of the probe, the variable measuring speed, measurements in all positions and orientations—even overhead—are some of the advantages of the new product.

Above all, the product impresses with its PC-based evaluation option with the Evovis Mobile software. This covers all current standards, including the new DIN EN ISO 21920 series of standards. As it clearly displays the results of various standards, the software offers a considerable advantage and thus meets the future challenges in roughness measurement technology.

The new Gageline complements the Hommel Etamic pneumatic tester product family. Pneumatic testers are known for their excellent repeatability and high accuracy—especially in production environments. However, until now these devices have not offered any flexibility regarding multiple measurement requirements.

With the new Gageline, precisely this flexibility has been created, making it a promising solution for many areas of application. For example, it can measure shaft parts such as pins or cones with diameters from 10 to 130 mm. The same base can also be configured for testing other workpieces, such as rings from 20 to 150 mm in diameter. In addition, the Gageline can be combined with a collaborative robot to provide a complete, flexible, and automated solution.

jenoptik.us

Schunk

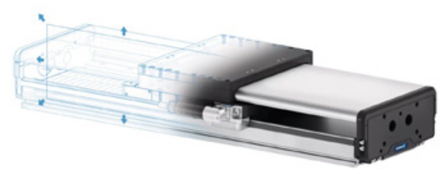
ENHANCES AUTOMATION DESIGN WITH DIGITAL LINEAR MODULES

Schunk expands digital planning options for automated solutions with two new tools for designing and configuring linear modules. This easy access to expert knowledge is a further step towards offering customers an uncomplicated and secure way to customize design and to quickly integrate it into the system planning.

The valid design and construction of high-tech components for automation technology is one of Schunk's core competencies. The higher the information content at the customer inquiry state, the faster and more targeted the perfect component can be found for the respective customized application. With two new professional digital services, a sizing assistant and configuration tool for linear modules, customers can now also select these components themselves conveniently, easily, and reliably. This allows them to expand their own expertise and find the optimal solution more quickly.

The Schunk portfolio offers over 500 variants of linear modules. To find the right one, the automation expert provides its customers with a user-friendly sizing assistant based on years of experience and proven design logic. It can be used to record all relevant performance parameters for an individual component in a simple and standardized manner. Furthermore, visual support enhances security. Based on this information, the program creates a technically valid recommendation of suitable Schunk linear modules. In addition, the sizing assistant provides important information such as the application-specific service life of the respective component and its degree of utilization. When selecting a linear module, users can see whether the component is suitable for a specific application on a one-to-one basis or whether there is scope to extend applications.

Once the right linear module in the correct technical design has been found, it can be further specified using the Schunk configurator. All non-design-relevant add-on parts are available to the user in a wide range of variants and options. Configurations can be easily cached, forwarded, and edited again and again. Parallel to the configuration process, the program generates a 3D CAD model of the linear module. This visual inspection always provides the user with an overview of the configuration. In addition, the model can be downloaded in over 60 formats, and can therefore be integrated directly into further system planning during the design process.

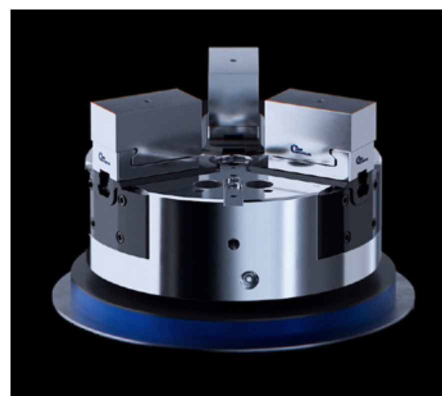


In the final step, the user can call up the complete data sheet for their individual linear module and request the product. However, they also have the option of taking advantage of personal advice from Schunk's sales and automation experts. In this case the data sheet serves as a perfect basis for discussion. The practical assistants are available worldwide and in 13 languages.

schunk.com

SMW Autoblok

RELEASE KIT-RR CHUCK SYSTEM



The KIT-RR Chuck System from SMW Autoblok is comprised of the RR Adapter and the RR soft top jaws, which can be easily locked and unlocked with the push of a pin. The RR System is designed to provide the highest levels of quality, precision, and safety, while eliminating the need for screws and complicated change operations. Developed by the company's expert R&D team, the KIT-RR is ideal for both manual and robotic usage and can be adapted to meet a wide range of manufacturing requirements. In addition, KIT-RR can be mounted on all power chucks on the market for quick and easy integration with your current machinery.

smwautoblok.com

Investing in Industry 4.0 for the Gear Manufacturer/Job Shop (Part 1)

The benefits of lean manufacturing cannot be gained by just using tools primarily suited for an assembly factory

Shahrukh Irani

This article requires that the reader be familiar with Job Shop Lean, an approach to adapt the principles of lean manufacturing for a job shop, regardless of its size or industry sector. The following articles will give the interested reader a sufficient background on the many differences between Job Shop Lean and Lean:

1. Adapting Lean for High-Mix Low-Volume Manufacturing Facilities (*Gear Technology*, August 2012)
2. A Quick-Start Approach for Implementing Lean in Job Shops (*Gear Technology,* October 2012)
3. Remaster the Five Principles of Lean Manufacturing (*The Fabricator,* August 2018)

Preparing for Adoption of Industry 4.0 by *Any* Job Shop

The Toyota Production System was designed for assembly plants that produce hundreds of thousands of automobiles. Figure 1 compares a job shop and an assembly plant using two key characteristics of any production system—production quantity and product mix. Clearly, an assembly plant focuses on low-mix, high-volume (LMHV) production, whereas a job shop focuses on high-mix, low-volume (HMLV) production. Lean manufacturing is based completely on the Toyota Production System. So, a job shop cannot expect to realize the complete benefits of lean by using just tools that are primarily suited for an assembly factory.

Today, nearly every job shop has benefitted from implementing one or more of the lean tools listed in the left-hand column of Table 1. In contrast, the lean tools in the right-hand column of Table 1 are ineffective or inapplicable in any job shop. They cannot handle the complexity of a make-to-order high-mix, low-volume gear manufacturer, especially if it is a job shop.

Unfortunately, Industry 4.0 lacks the capability to help design a production system that suits their HMLV shop floor. There is a very good chance any software or technology the shop invests in will never help them to achieve the performance goals they wish to achieve!

Strategies to Lay the Foundations for Industry 4.0

This article discusses several viable Job Shop Lean strategies that are guaranteed to help any gear manufacturer/job shop lay the foundations for adoption of Industry 4.0. These strategies can be implemented using the Job Shop Lean tools listed in the left-hand column of Table 1.

Segment the product mix: Most job shops choose to make a diverse range of products that differ in their annual production volume, demand pattern and profit margin. Based on these three business attributes, they should segment their product mix into two segments: 1)Runners + Repeaters, and 2) Strangers. For parts in the Runners + Repeaters segment, batch sizes will tend to be medium or large with many parts having LTA (long term agreements). In contrast, for parts in the Strangers segment, batch sizes will tend to be small because orders for these parts tend to be hot/rush, one-offs, repair, prototype, start-of-lifecycle or end-of-lifecycle. For each of these two segments, the order fulfillment strategies, rules for CRM (customer relationship management), business practices, etc. that need to be used are different. This practice of a shop-within-a-shop is on display at every hospital, which is essentially a health care job shop where an emergency department operates like a standalone hospital. Due to this, an ER can achieve the short lead times that are essential to give rapid customized care to many patients who do not need to be admitted to the main (and much larger) hospital.

Split the shop into two shops: In Shop #1, produce orders for parts/products that are in the Runners + Repeaters segment of the product mix. In Shop #2, produce orders for parts/products that are in the Strangers segment of the product mix. Set up Shop #2 to operate as a QTS (quick turnaround shop) with AM (additive manufacturing) machines, flexible automation, multitasking machines, machining centers with pallet-changers, etc. that can produce any part in any quantity in a single setup. In fact, even the skill levels of the employees in the two shops ought to be different. The employees in Shop #1 will be those who prefer production runs of mature parts; whereas the employees in Shop #2 will be those who prefer the challenges of one-off manufacture of complex parts and have an intrinsic desire to master new technology.

Rationalize the product mix at the end of every year: At the end of each year, eliminate those products that are losing money. As the GM of a fabrication job shop quipped to me years ago, "We are happy to send our difficult parts, and sometimes our difficult customers, too, to our competitors. It does not hurt our business if the production efficiencies and profit margins of our competitors get damaged because they hire the customers we fire!"

If the shop currently has a process layout, change it immediately! In a process layout, similar/identical machines are colocated in functional departments (manual lathes, CNC lathes, manual mills, CNC mills, etc.). Any job shop that has a process layout will always operate in a batch-and-queue production mode. Figure 2 shows the production flow for a sample of 150+ different machined components produced in a CNC machining job shop that has a process layout. I would hesitate to recommend to any gear manufacturer/job shop to invest in Industry 4.0 if they persist with the worst type of factory layout for HMLV manufacturing.

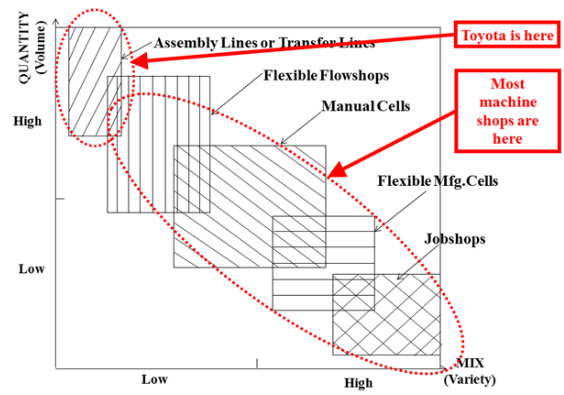


Figure 1—Comparison of a gear job shop and an assembly plant.

Tools to Use	Tools to Avoid
Strategic Planning	Pencil-and-Paper Problem Solving
Top-Down Leadership	Value Stream Mapping
Gemba Walks by Managers	Assembly Line Balancing
Employee Engagement	One-Piece Flow Cells
Workplace Design with 6S	Product-specific Kanbans
TPM (Total Productive Maintenance)	FIFO Sequencing of Orders
Setup Reduction (SMED)	Pacemaker Scheduling
Error-Proofing (Poka-Yoke)	Inventory Supermarkets
Quality At Source	Work Order Release based on Pitch
Visual Workplace	Production based on Level Loading
Product and Process Standardization	Mixed Model Production with Takt Time
Multitasking (= Flexible) Machines	Right-sized (= Inflexible) Machines
Standard Work	Pull-based Production Scheduling
Continuous Problem-Solving	Manual Scheduling with Whiteboards

Table 1—Lean tools that a gear job shop should use or avoid.

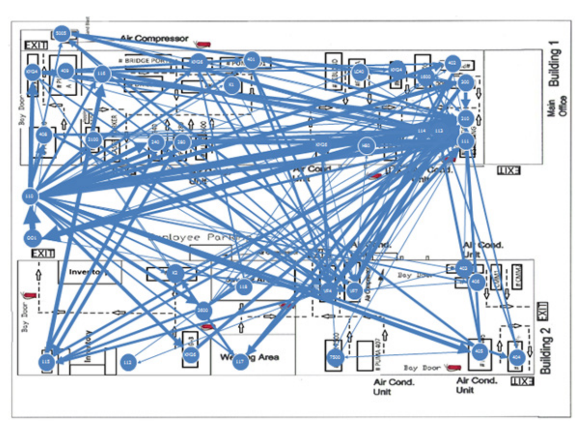


Figure 2—Production flow in a CNC machine shop with a functional layout.

Before Grouping

Pump Machining Production Flow Analysis		Broach	HMC	Lathe-Chuck	Hob	Lathe-Manual	Hob	Lathe-Bar	Lathe-Vert
61354	Cover Bearing			X					
70852	Gear Driven 8P,56T, RH	X		X	X		X		
52594	Spacer,cplg Shaft							X	
81357-T	Impellor	X		X					
50547-D	Gland, MU, 6"					X			
70935	Gear,Driven,8P,26T,LH	X		X	X		X		
51171	Retainer Bushing							X	
81176	Body Volute		X						X
72298	Elbow, Relief Valve		X						
50763	Spacer, Bearing							X	
71972-8	Adapter, Intake, 8"		X			X			X
62575	Shaft Shift							X	
63160	Seat, Spring							X	
62966	Generator, Tach Pulse			X	X				
71928	Head, Pump					X			X

Figure 3a—Initial product–process matrix before grouping to identify part families. (Source: **https://strategosinc.com/RESOURCES/06-Cellular_Manufacturing/gt-production_flow_analysis.htm***)*

Pump Machining Production Flow Analysis		Lathe-Manu	Lathe-Vert	HMC	Lathe-Chuck	Broach	Hob	Lathe-Bar
50547-D	Gland, MU, 6"	X						
71928	Head, Pump	X	X					
71972-8	Adapter, Intake, 8"	X	X	X				
81176	Body Volute		X	X				
72298	Elbow, Relief Valve			X				
81357-T	Impellor				X	X		
62966	Generator, Tach Pulse				X		X	
70852	Gear Driven 8P,56T, RH				X	X	X	
70935	Gear,Driven,8P,26T,LH				X	X	X	
61354	Cover Bearing				X			
52594	Sp[acer,cplg Shaft							X
62575	Shaft Shift							X
63160	Seat, Spring							X
51171	Retainer Bushing							X
50763	Spacer, Bearing							X

Turn-Mill Cell

Chucking Lathe Cell

Barfeed Lathe Cell

Figure 3b—Final product–process matrix after grouping to identify part families. (Source: **https://strategosinc.com/RESOURCES/06-Cellular_Manufacturing/gt-production_flow_analysis.htm***)*

Implement a Cellular Layout in Shop #1: First identify the product families in the Runners + Repeaters segment of the shop's product mix. From the ERP system extract the routings of all the parts/products to create the initial product-process matrix. An example of an initial product-process matrix is shown in Figure 3a. Next, use any commercially available data analysis package like *Minitab*, *SPSS* or *JMP* to manipulate this matrix to get the final product-process matrix shown in Figure 3b. In Figure 3b, each family of parts has routings that contain the same (or similar) machines. Each part/product family suggests the group of machines that must be colocated in a manufacturing cell to produce those parts.

Exploit the cellular layout of the shop floor to foster a culture of teamwork: The key to successful implementation of a cell is to colocate all its machines, personnel and support services in one area. Figure 4a and Figure 4b display the material flows for the part family that was being produced in a machining cell before and after re-layout, respectively. If a cell is implemented with management's support, it will 1) have manufacturing focus, 2) retain operational flexibility bounded by the parametric limits of a part family, 3) foster a culture of continuous improvement within a group of employees that accepts performance metrics that do not promote selfish, individualistic and elitist behavior, 4) promote a sense of ownership in every member of the cell's team and 5) encourage management to give some level of self-governance and autonomy to the cell's team so they can complete and ship products to their customers. But, from a management perspective, if they wish to discuss performance or delivery issues involving a certain part family, they will need to take much shorter walks by visiting that one cell which is producing those parts.

Right-size nonmachining processes to absorb them into the cells: In general, like all other job shops, gear manufacturing job shops tend to focus on improving delivery performance and profitability by acquiring multimillion dollar metal-cutting machines. Most often, it is the manual machining processes, such as saws and drills, the inspection department and non-machining processes, such as heat treatment, electroplating, coating, washing/cleaning, etc. that are often the root cause for their long delivery times.

Right-sizing a process that is currently external to a cell, such as washing, painting, deburring, inspection, etc. would allow it to be brought into the cell. This will have a significant impact on quality, delivery time and work-in-process. Also, it would improve the morale and job satisfaction of the cell personnel. Now, their team's performance will not be affected by the workmanship and schedule priorities of those who work in other cells and/or external departments whose services are shared by all the cells.

Unfortunately, there are limitations with right-sizing the equipment used in any machine shop. Processes like heat treatment, electroplating or welding don't lend themselves to being colocated with CNC machines in a cell. Maybe deburring could be in a corner of the cell if it was contained within a sound-proofed chamber having a dust collection system. Even the affordability of the smaller equipment could be a constraint since a single monument would be replaced by multiple workstations (or machines) given to all the cells whose parts use that process.

Will the day come when the inspection department in a gear job shop can be right-sized and that department is eliminated altogether? The inspection department, which has zero visual connectivity with the rest of the shop due to its location in a corner of the typical job shop, is often the real bottleneck in the shop. Can a CMM and other inspection devices be put on a mobile truck that travels around the shop? If that were possible, then inspectors would receive electronic requests from machinists and go to their cells to perform FAI (first article inspection). Also, while there is an abundance of

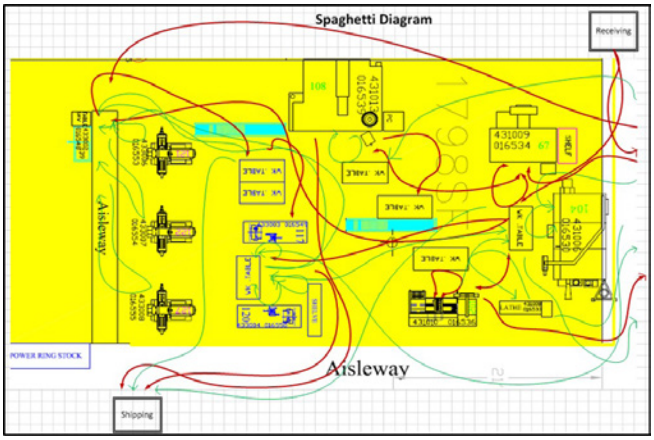


Figure 4a—Material flows for a part family prior to implementation of its machining cell.

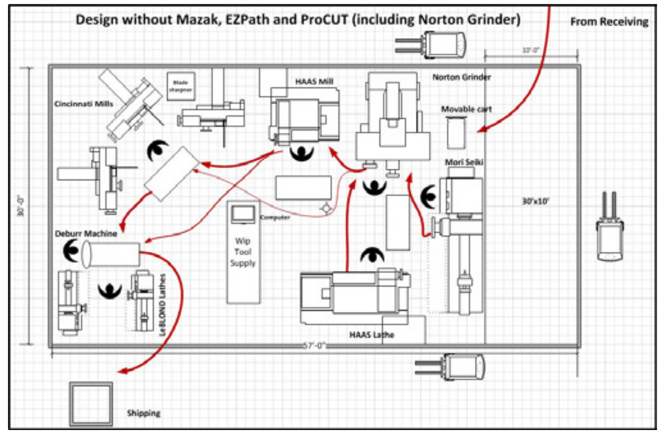


Figure 4b—Material flows for a part family after implementation of its machining cell.

machine monitoring systems on the market (*FactoryWiz.com*, *MemexOEE.com*, *FORCAM.com*, *MachineMetrics.com*) that are compatible with all CNC machines, it is unclear if these systems can monitor the "slow poke" CMMs that reside in any inspection department.

"Raze" and standardize the routings of all the parts within a part family: Every effort should be made to critique and re-engineer the routings of all the parts that have been grouped into a part family based on their similar (or identical) routings. First, the routings should be standardized by eliminating the differences in the machines used and the sequences in which the machines are used. Next, the routings should be standardized by eliminating the differences in the fixtures, tools, gauges, etc. used. Although my research is ongoing, I have reason to believe that the functional layout of any job shop could be replaced by a Hybrid Flexible Flow Shop. What will that do to simplify the chaotic material flows that are typical in any job shop? Say you were to go and stand on the roof of the job shop and look down at the material flows on their shop floor. Instead of the Spaghetti Diagram seen in Figure 2, the material flow of each job, regardless of the sequence of machines in its routing, will follow a linear path from one end of the shop to the other as is always the case on an assembly line.

Purchase a multifunction machine tool (or a flexible machining system) that combines two or more machines (or replaces an entire multimachine cell): It appears that metal removal rates remain the chief driver of a gear job shop's capital investment choices. Unfortunately, this mindset of "keep making chips" results in the purchase of expensive new machines that 1) do not alleviate the shop's capacity constraints, 2) do not increase throughput at their bottlenecks, 3) waste payroll dollars to keep employees busy producing WIP and 4) do not reduce the total distance that the typical order must travel all over the shop. Let us take the case of this family-owned machine shop in Houston that serves several customers in the oil and gas industry. The routing for the most complex component they make for a down-hole drilling tool assembly is Saw→Hole Drilling and Boring (Vendor Op)→Manual Lathe→CNC Lathe→CNC Mill→Shaper→Inspect→Ship. But they make other components that may have a routing like Saw→Manual Lathe→CNC Lathe→Inspect→Ship or a routing like Saw→CNC Lathe→CNC Mill→Inspect→Ship.

Should this job shop buy a new CNC lathe with higher metal removal rates so the manual lathes department can be eliminated? Or should it buy a CNC turning center that combines the operations done on the CNC lathe and CNC mill? Or should it explore how to eliminate the shapers by using their CNC mills to cut the internal splines on some of their parts? Having observed the WIP in the three buildings that comprise this machine shop, the CNC lathes department is not the shop's bottleneck. Plus, they have a classic process layout. So, the purchase of a high-priced CNC lathe with a faster metal removal rate and in-cut spindle time would not reduce their WIP nor help them to quote shorter lead times. Guess what their management team eventually did to drastically reduce delivery times? They 1) eliminated the manual turning department by moving their work to the larger CNC lathes and 2) re-organized the shop into three cells as follows: Cell #1, CNC Turning; Cell #2, CNC Turning→CNC Milling; Cell #3, CNC Turning→CNC Milling→Spline Cutting.

Instead of their prevailing fixation with metal removal rates and machine utilization, gear job shops should buy multifunction machines and systems that combine consecutive operations currently being done on different machines—especially if those machines are currently located in separate departments, such as CNC lathes and CNC mills. By combining machines, the significant delays due to 1) material handling between several machines, 2) waiting for material handlers to pick up and move a batch of parts from one machine to another, 3) batch-and-queue production flow, 4) setup and gauging at every machine, 5) waiting in queue at machines that are shared by multiple part families, etc. are reduced.

For example, in the case of the family-owned machine shop discussed earlier, given the many pallets loaded with turned parts machined by their CNC lathes, I tried to impress upon their GM to limit new orders released to that department every day. This is what I told the GM of that shop, "Are you in the business of keeping your lathe operators busy making

Editor's Note:

In the second part of this feature article (August issue of *Gear Technology*), several more strategies will be suggested that could guide any gear manufacturer/job shop to re-think their product mix, shop floor layout, current manufacturing technology investments, management policies, outsourcing decisions, employee training and development, etc. prior to investing in IoT software and/or technology.

The author encourages gear manufacturers to post any lean questions they may have for a future article in *Gear Technology*. Submit your questions to *shahrukhirani1023@yahoo.com* or *jaster@agma.org*.

parts? Or should you focus on completing and shipping as many parts as you can every day?"

So how could a job shop make a major investment to upgrade equipment on their shop floor by buying a new machine or system that reduces material flow? By *first* selecting a cell that currently produces a family of parts a*nd later* reducing the number of separate machines in it. If you are a gear job shop, have you done a product-process matrix analysis of your product mix to find any part families that could each be produced in a standalone cell (shop-within-a-shop)? In fact, go to the floor and ask a couple of your shop supervisors to scope out a potential family of gears (for example, splined shafts). Next, draw a material flow map and compute workloads on the different machines for the machines that would be put in their cell. Now, identify a set of two or three machines that perform consecutive operations that appear in the routings of that family of gears. For all those operations that would have to be done on a single machine, prepare the list of specifications (work envelope, axes of freedom, number of tools, in-process gauging, etc.). Finally, present that list of specifications to the different machine tool vendors, such as Mazak, Okuma or Mori Seiki, who could build the multifunction machine (or system). Do they come back to you with any multitaskers that they could build for you?

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IMTS 2024 Will Be Here Before We Know It

A preliminary look at the Gear Generation sector

Aaron Fagan, Senior Editor

The International Manufacturing Technology Show (IMTS) September 9–14 at Chicago's McCormick Place is fast approaching and, for newcomers and veterans alike, it is always worthwhile to plan as much as possible in advance to make the most of it. For *Gear Technology* readers looking for gear manufacturing equipment such as gear cutting, forming, and finishing, as well as broaching, shaping, and slotting machines, you must first visit the Gear Generation sector in the North Building, Level 3. In addition to traditional applications such as auto, construction, medical, mining, and shipbuilding, gears are finding even greater importance in the emerging robotics, alternative energy, and wind power sectors. Software solutions integrating AI technology are playing a bigger role than ever from design to production. You will find everything from advancements in abrasive machining to improve dressable tooling applications to increased multifunctional, automated solutions to minimize workpiece movements to improve overall production time.

IMTS is where the creators, builders, sellers, and drivers of manufacturing technology come to connect and be inspired. Attendees discover advanced manufacturing solutions that include innovations in CNC machining, automation, robotics, additive, software, inspection, and transformative digital technologies that drive our future forward. Powered by AMT—The Association for Manufacturing Technology, IMTS is the largest manufacturing technology show and marketplace in the Western Hemisphere. With more than 1.2 million square feet of exhibit space, the show attracts visitors from more than 110 countries. IMTS 2022 had 86,307 registrants, featured 1,816 exhibiting companies, saw over 7,600 people attend educational events, and included a Student Summit that introduced the next generation to manufacturing. *Gear Technology* looks forward to seeing you at IMTS 2024, September 9–14, 2024.

What follows is the current list of registered exhibitors in the Gear Generation sector and others offering solutions in automation, broaching, cutting, grinding, hobbing, shavers, shapers, skiving, software, metrology, workholding, and more.

A view of the Gear Generation Sector at IMTS 2022.

Basaran Grinder Corporation

BOOTH #236817

American-based and family-owned manufacturer of high-precision CNC internal radius grinders, external cylindrical grinders, creepfeed grinders, and vertical radial grinders for aerospace, automotive, and job shops.

basarangrinder.com

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BOOTH #237275

Broach Masters and Universal Gear are a complete source for all your tooling and production needs. We will supply you with the highest quality products and services that you and your customers expect.

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acmemfg.com

Adelbert Haas LLC

BOOTH #237505

Haas grinding centers can be found in state-of-the-art manufacturing facilities worldwide. Industries include medical engineering, precision tool manufacturing, gear manufacturing, the aerospace industry, the energy industry, and more.

multigrind.com

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centerless.com

Achieving Digitalization through Data Diversity

Scott Lowen, Software Product Manager at Zeiss Industrial Quality Solutions

In modern manufacturing, digitalization is key to overcoming many challenges and achieving continuous process improvement. Implementing a successful digitalization strategy involves using the right metrology technology to accurately digitize, analyze, and connect parts as they move across the product lifecycle. With different stages of the product lifecycle requiring different metrology solutions, understanding the specific advantages of each technology for specific applications helps to understand which to use to achieve digitalization efficiently and sustainably. This session will focus on helping the IMTS audience understand how to achieve digitalization for continuous process improvement across the product lifecycle by applying a connected and efficient approach to data acquisition and analysis. IMTS audience members will also understand how to strategically select the optimal metrology technology to collect accurate data to feed into digital twin and digital transformation initiatives efficiently. IMTS audience members will benefit from learning how to tap advantages driven by digital twin methodology. For example, they will learn to reduce costs and save time with digital assembly analysis powered by accurate 3D measurement data.

Thursday, September 12; 3:15 PM–4:10 PM
LOCATION: W193-A

Cincinnati Gearing Systems

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cincinnatigearingsystems.com

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BOOTH #237218

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Dontyne Gears provides gear design and analysis services with prototyping and testing options.

dontynegears.com

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DTR is a global gear-cutting tool brand. As a total solution company, as well as manufacturing and sales of gear-cutting tools, DTR supplies production facilities, tool management services, coating services, and environmentally friendly machining technologies.

dtrtool.com

DVS Technology Group

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The DVS Technology Group brings together some of the most experienced and innovative mechanical engineering companies in Germany for high-precision gearing and ultra-fine surface machining, focusing on turning, grinding, skiving, gear cutting, and gear honing technologies. As a unit, DVS is a leading system provider in the global marketplace.

dvs-technology.com

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BOOTH #237047

If your company machines metal components, manufactures gears, and uses laser welding or electro-chemical machining, EMAG can provide automated machinery, from standalone pick-up turning machines to complete machining lines capable of manufacturing entire workpiece families.

emag.com

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Custom gear cutting tools, broaches (round, helical, flat), hobs, skives, milling cutters, spline gages (functional and variable—ISO 17025 certified), industrial machining tools, annular cutters, drilling and milling tools, CNC broach sharpening and repair.

est-us.com

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BOOTH #236060

Excellence Gear Company provides high-precision spiral bevel gears to a wide range of industries.

exce-gear.com.tw

Gear Technology (AGMA Media)

BOOTH #237314

Gear Technology, published by the American Gear Manufacturers Association, is the journal of record for the gear industry and includes technical articles and in-depth features about trends and technologies in gear design, manufacturing, inspection, heat treating, and much more. *Power Transmission Engineering*, the magazine of mechanical components, provides the latest product and technology news about gears, bearings, motors, and gear drives.

agma.org
geartechnology.com
powertransmission.com

General Broach Company

BOOTH #237229

Over 80 years in business as a designer and manufacturer of linear broaching tools, machines, and turnkey applications for the gear, turbine, hand tool, off-road, and firearm industries.

generalbroach.com

German Machine Tools of America

BOOTH #237126

Sales and service organization and distributor for various German machine tool companies. Specialized in turnkey solutions and over 25 years in business supplying the automotive industry with sales and service locations in the USA and Mexico.

gmtamerica.com

Gleason Corporation

BOOTH #236909

Gleason is a global leader in gear technology ranging from gear and transmission design software to the development and production of gear manufacturing machines and related accessories, gear metrology equipment, and automation systems. Gleason products are used by customers in the automotive, commercial vehicle, aerospace, agricultural, mining, energy, construction, power tool, marine, and many other industrial equipment markets. Gleason has manufacturing facilities in the U.S., Brazil, Germany, Switzerland, India, China, and Japan, and operates sales and service offices in North and South America, Europe, and Asia Pacific.

gleason.com

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United Grinding North America, Inc., a subsidiary of the United Grinding Group, represents a union of leading companies in grinding and ultra-precise finishing solutions for the manufacturing industry. Through its surface and profile grinding, cylindrical grinding, and tool grinding technology groups, the company sells and supports precision machines for grinding, eroding, laser ablation, combination machining, and measuring under the Mägerle, Blohm, Jung, Studer, Schaudt, Mikrosa, Walter, and Ewag brands. Headquartered in Miamisburg, Ohio, United Grinding North America is ISO 9001 certified to ensure quality in product development, production, shipping, and support operations.

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Understanding Bevel Gear Grinding

Key techniques for optimal surface finish and gear quality

Spencer Artz, Corporate Application Engineer and Josh Fairley, Product Engineer at Norton | Saint-Gobain Abrasives

The world of bevel gear grinding is a complex topic. How do you determine which grinding and dressing parameters to select for a desired surface finish? What type of grinding wheel should be used? What type of dresser should be used? How do all these factors affect the gear noise and quality levels? These are some questions that will be addressed in this article.

It's important that manufacturing engineers and machine operators fully understand the inputs and outputs of bevel gear grinding and the variables that affect the process. Proper selection of tooling and process parameters is key to achieving consistent gear quality and extending the life of the grinding wheel and dresser.

Part 1: Grinding Parameter Selection

There are two main methods of bevel gear grinding—"plunge grinding" and "generating grinding."

Plunge grinding uses a grinding wheel with the same curvature as the gear tooth and plunges the form into the gear. This method uses what is called a "Waguri" spindle to reduce contact length between the grinding wheel and gear flanks and keep grinding temperatures low.

Generating grinding is more complex than plunge grinding and uses coordinated machine motions to "roll" the grinding wheel across the gear tooth.

The main parameters to control both grinding processes, along with some recommended settings for each, are explained as follows:

Plunge Grinding Parameters

Grinding Wheel Surface Speed

The peripheral speed of the grinding wheel is programmed using the mean wheel diameter, which is calculated using the center of the profile. Lower grinding wheel speeds will make the wheel act softer and reduce grinding temperatures, but often at the expense of wheel wear and surface finish. Higher grinding

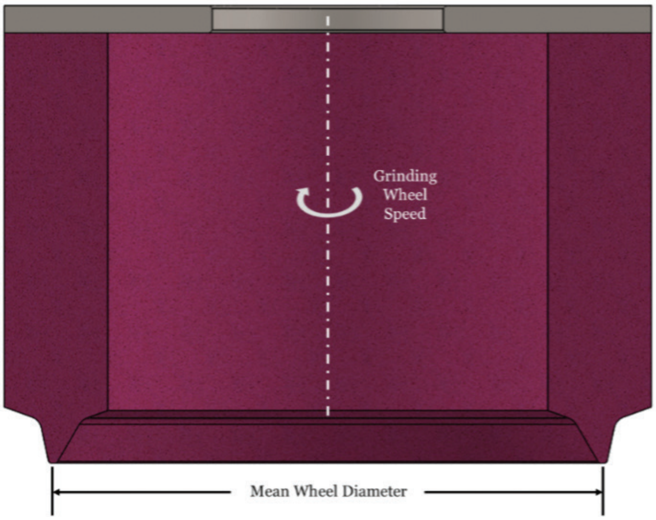

Figure 1—Grinding wheel speed/mean diameter.

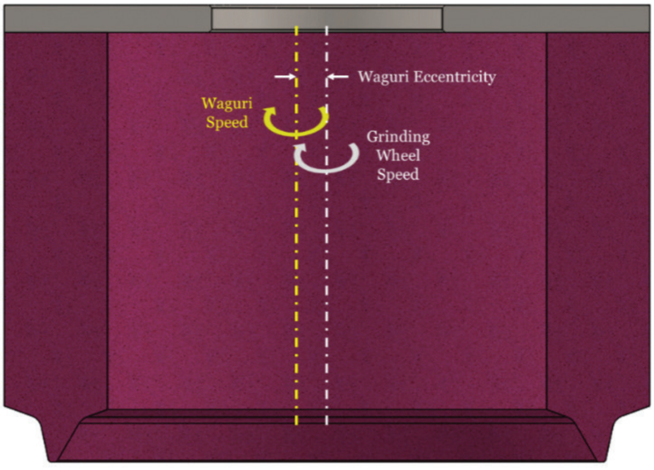

Figure 2—Waguri spindle rotation.

wheel speeds will make the wheel act harder and reduce surface finish, but at the risk of increased grinding temperatures. The recommended range for grinding wheel speeds with plunge grinding is 23–25 m/s.

Waguri Spindle Speed

For plunge grinding operations, an eccentric spindle called a Waguri spindle is used. The Waguri spindle rotates the entire grinding wheel spindle by a small eccentric amount, typically 0.05–0.2 mm to create space for coolant to enter the grinding zone. The Waguri speed is typically around 2,000 rpm which is 200–500 rpm less than the grinding wheel speed. The grinding wheel spindle and Waguri spindle always spin in the same direction as one another.

Plunge Feed Rates

Plunge feed rates are programmed in mm/min and use two to three feed rates per grinding cycle. The first feed rate is used for fast positioning, and this value is usually set by the machine manufacturer to minimize cycle time. The second feed rate is for rough grinding, and this value is set based on what is called the *specific material removal rate* or Q', which is explained in more detail in Figure 3 and Equation 1. The final feed rate is set based on the required surface finish and gear quality level -- feed rates for this step are typically in the range of 10–40 mm/min.

Equation 1 calculates Q' for plunge grinding. For most plunge grinding applications, the maximum recommended Q' is 20 mm^2/s.

$$Q'_{Plunge}\left(\frac{mm^2}{s}\right) = \frac{v_t \sin(\varphi_s)\, b}{60 \cos \beta_m} \tag{1}$$

v_t= plunge feedrate (mm/min)
φ_s=grinding wheel profile angle (deg)
b=gear face width (mm)
β_m=gear mean spiral angle (deg)

Number of Rotations

For higher precision gears, or gears with a large amount of grinding stock, multiple grinding passes around the gear may be necessary to meet the required quality. However, for most applications, one rotation of the gear is sufficient with plunge grinding.

Plunge Grinding Positions

Plunge grinding positions will depend on the amount of incoming stock and heat treat distortion of the gear. To avoid excessive grinding wheel wear, the grinding wheel should not contact the gear during the first position.

Dwell Time

The dwell takes place at the end of each plunging cycle and allows the entire grinding system to return to its normal state. The workpiece and grinding machine will deflect during the grinding cycle, like a spring being compressed, and the dwell time allows that spring to return to its normal state. It also has the added benefit of reducing the surface finish. Dwell time typically ranges from 0.1 to 0.4 seconds, or at least 6 to 8 revolutions of the Waguri spindle.

Generating Grinding Parameters

Grinding Wheel Speed

Grinding wheel speed with generating grinding cycles, as with plunge grinding cycles, is typically in the range of 23-25 m/s. Similar to plunge grinding, there is a careful balance between wheel wear, surface finish, and grinding temperatures that must be considered when selecting a grinding wheel speed.

Grinding Passes

Like plunge grinding, one grinding pass ("single roll") is sufficient for generating grinding, however, there are some circumstances where two passes ("double roll") are necessary. Double roll grinding consists of splitting the grinding stock into two parts and performing a grinding pass in one direction along the tooth, then reversing the grinding direction to grind the remaining stock.

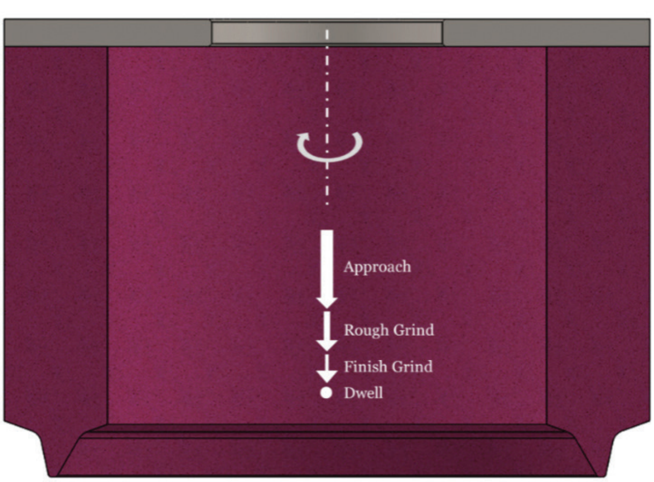

Figure 3—Example grinding plunge cycle.

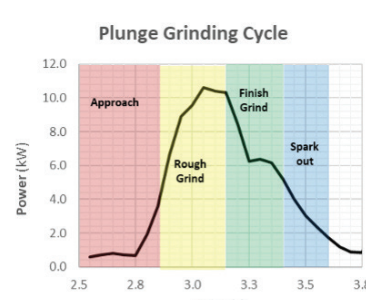

Figure 4—Example grinding cycle spindle power.

Generating Feed Rate

The feed rate for generating grinding is programmed in degrees of roll per second. This feed rate is selected based on the calculated specific material removal rate, for which 4.0mm^2/s is a conservative starting point. The calculation for generating grinding Q' is shown in Equation 2:

$$Q'_{Generating}\left(\frac{mm^2}{s}\right) = \frac{v_w\, b\, \Delta_2}{\Delta_\alpha \cos\beta_m} \tag{2}$$

v_w= *generating feedrate (deg/s)*
b=*gear face width (mm)*
Δ_s=*stock amount normal to flank (mm)*
$\Delta\alpha$=*generating interval—can assume 30° (deg)*
β_m=*gear mean spiral angle (deg)*

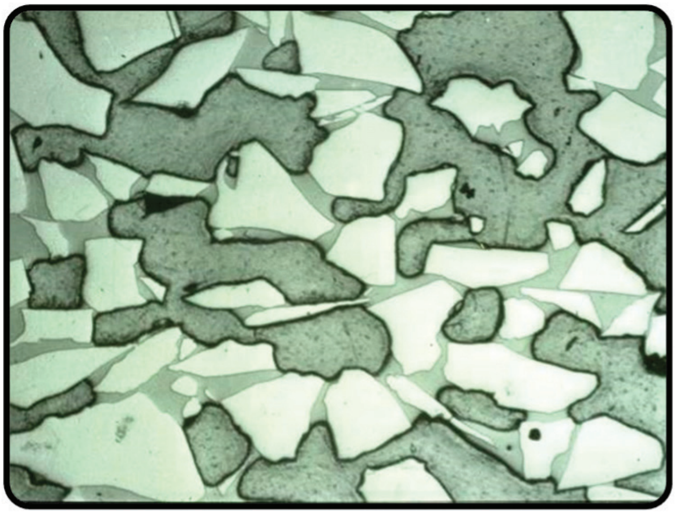

Figure 5—Grinding wheel cross-section.

Figure 6—Norton angular and extruded ceramic grains.

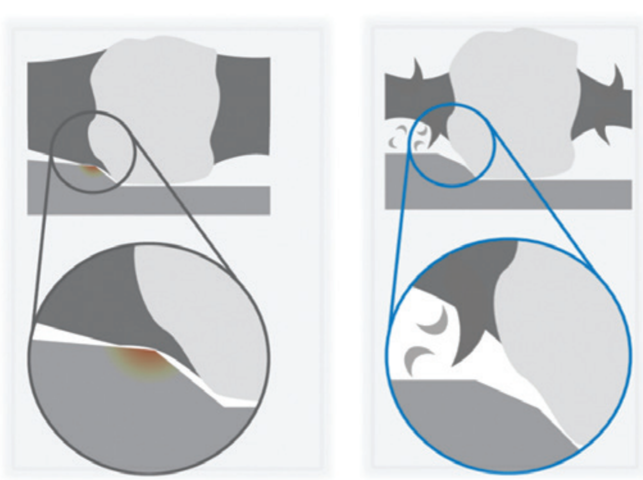

Figure 7—Standard bond (left) vs. Next Generation VS3PN Norton Bond (right).

Part 2: Grinding Wheel Selection

The selection of the grinding wheel will depend on the module of the gear to the ground, the material and hardness of the gear, and the desired surface finish. A vitrified grinding wheel consists of three main parts: abrasive, bond, and air (porosity). A careful balance is needed between these three variables, and that is controlled by the wheel specification which should be carefully matched to application requirements.

Abrasive Types

The main types of abrasive used in bevel gear grinding are conventional aluminum oxides, and sintered aluminum oxides, also known as ceramics. Modern bevel gear grinding wheels are all either a blend of ceramic and conventional aluminum oxide, or 100 percent ceramic. Ceramic abrasive is expensive to manufacture, so 100 percent ceramic wheels are less common and typically limited to high material removal rate applications such as when grinding from solid.

Norton | Saint-Goban Abrasives offers several types of ceramic abrasives for bevel gear grinding including Quantum Prime which is a sharp, angular ceramic grain, and TQ which is a shaped extruded ceramic grain. Images of both grain types are shown in Figure 6.

Grit Size

Grit size is the size of the abrasive in the grinding wheel, represented as a mesh size. The higher the grit mesh size, the smaller the abrasive. For most automotive or industrial bevel gear applications, an 80-grit size is adequate to achieve the required surface finish and tip geometry. For finer-pitched gears, a finer mesh size (100, 120, or 150) would be used to improve tip form holding. For grinding gears from solid, a coarser mesh size may be used, likely 60 grit.

Wheel Grade

The grade, or hardness of the grinding wheel represents the amount of bond that is present in the grinding wheel. The ideal amount of bond retains a sharp grit as long as possible and releases it when the grit becomes dull. The addition of more bond in a grinding wheel can increase its strength and reduce wheel wear but can also cause higher grinding temperatures due to friction interaction between the bond and workpiece, as well as from holding on to dull grits for too long. Similarly, not enough bond in the wheel can result in the bond releasing sharp grits too early, resulting in high wheel wear.

Structure

The structure represents the amount of abrasive in the grinding wheel. This directly impacts the spacing between the abrasive grains, which—when too close together—can cause workpiece chips to get stuck in the grinding wheel. If there is not enough abrasive in the wheel, this can also increase wheel wear. Lower structure numbers mean there are more abrasives closely spaced together, whereas higher structure numbers mean there are fewer abrasives spaced further apart.

Bond Type

Vitrified grinding wheel bonds are primarily glass, but different characteristics of the bond can be modified to provide better retention of the abrasive grain with a smaller amount of bond. Still, even with a very strong bond and a low bond amount, some interaction between the grinding wheel bond and workpiece results in rubbing and heat. This heat both increases grinding temperatures and weakens the bond itself. After all, the glass will soften as it heats, which can reduce its ability to retain abrasive.

The newest Norton bond system for gear grinding, VS3PN, provides a solution to this problem by giving the bond itself the ability to remove material from the workpiece. This reduces heat generation from bond rubbing, which not only reduces grinding temperatures but also strengthens the bond.

Recommended Specification for Small to Medium Bevel Gears (Module < 7.5)

For small to medium-sized bevel gears, we recommend using the Norton WGNC grinding wheel specification. This specification uses the Norton VS3PN bond system paired with a blend of ceramic grain and premium aluminum oxide grain. The bond and structure have been optimized specifically for bevel gear grinding to provide an excellent balance of low grinding temperatures and long grinding wheel life. For example, see Figure 9 for the good quality results that can be achieved when using this grinding wheel.

Recommended Specification for Large Bevel Gears (Module > 7.5)

For larger bevel gears, we recommend using the Norton WGRC grinding wheel specification. Like the WGNC specification, WGRC uses the VS3PN bond system paired with a blend of shaped extruded ceramic grain and premium aluminum oxide grain. See Figure 11 for examples of the surface finish that can be achieved.

Recommended Specification for Grinding from Solid

Grinding bevel gears from solid is becoming more popular, especially for prototyping or for low volume product runs. When grinding bevel gears from the solid, manufacturers can avoid the additional expense of purchasing complex cutting

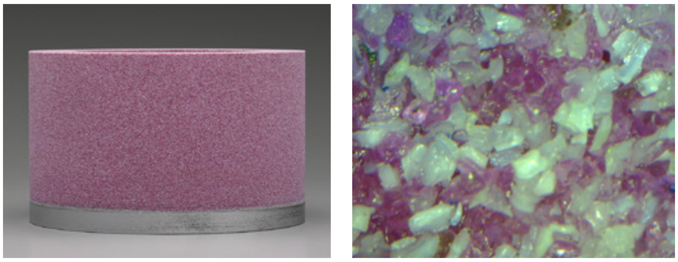

Figure 8—Norton WGNC grinding wheel (left) and grain micro view (right).

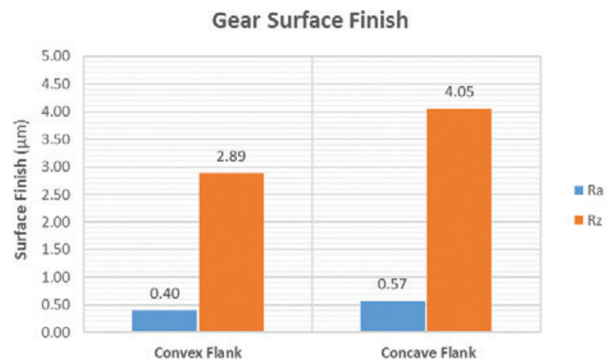

Figure 9—WGNC surface finish.

Figure 10—Norton WGRC grinding wheel (left) and grain micro view (right).

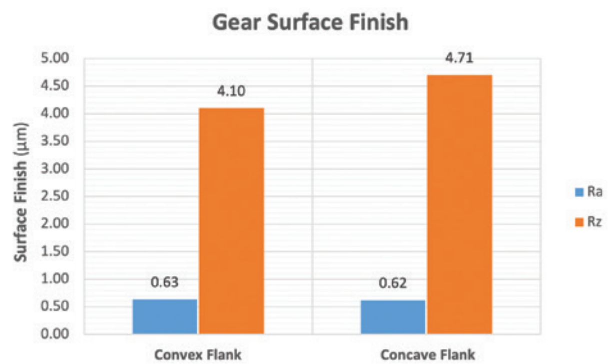

Figure 11—WGRC surface finish.

tools which may have a long delivery time, and sometimes even avoid purchasing an additional machine.

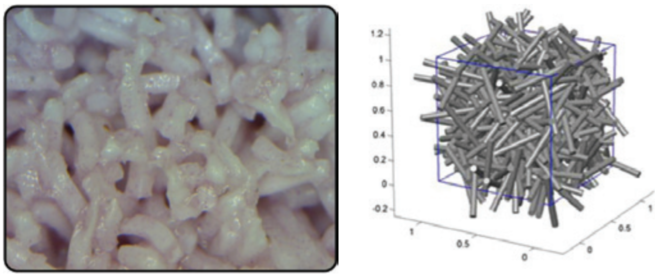

Figure 12—TG2/TQX grain image and packing density (Ref. 1).

New advancements

Extruded ceramic grains, TG2 and TQX, excel at grinding from solid. Running a 100 percent TG2 or TQX grinding wheel will offer the highest performance, while blended ceramic grinding wheels provide a more economical option. Grinding wheels comprised of 100 percent TG2 and TQX have the added benefit of a higher natural porosity that occurs from packing the grains together with a longer aspect ratio as shown in Figure 12.

Part 3: Dressing Parameter Selection

Equally as important as grinding parameters are the dressing parameters of the grinding wheel. This has a direct impact on the resulting surface finish of the grinding wheel and the waviness of the flanks. Here are the main parameters to consider regarding the dressing cycle:

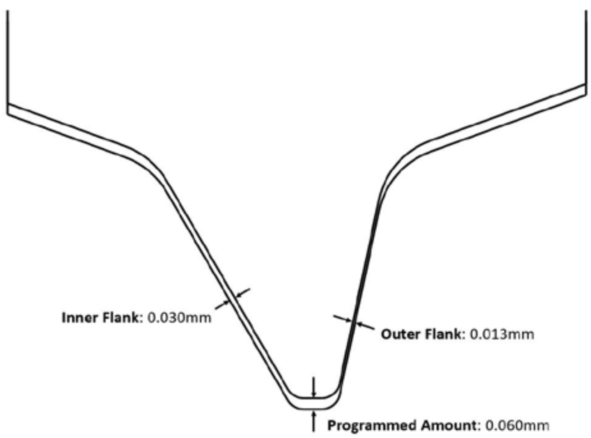

Figure 13—Dressing depth vs. profile angle.

Dressing Depth

Dressing depth is the amount of material removed from the grinding wheel during the dressing cycle. Higher dressing depths will result in higher surface finish and higher dresser wear. It's very important to take the flank angles of the grinding wheel into account, as the dressing amount will vary widely from the root and inner flank to the outer flank.

Equation 3 is for equivalent dressing depth:

$$a_{ed} = a_d \, x \sin(\emptyset_s) \tag{3}$$

a_{ed}=equivalent dressing depth (mm)
a_d=dressing depth (mm)
$\emptyset_s$=grinding wheel profile angle (deg)

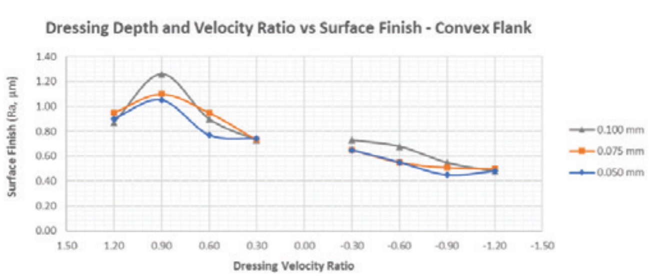

Figure 14—Dressing depth and velocity ratio vs. surface finish—convex flank (Ref. 2).

Dressing Velocity Ratio

The dressing velocity ratio (see Equation 4) is the ratio of the dresser surface velocity versus the grinding wheel velocity. Lower velocity ratios will result in lower surface finish and higher grinding forces/temperature, while higher velocity ratios will give higher surface finish and lower grinding forces/temperature. The charts shown below are from an excellent thesis by Nicole Weßels at RWTH Aachen University in 2009, showing the relationship between dressing parameters on surface finish and grinding spindle load.

$$q_d = \frac{v_s}{v_d} \tag{4}$$

q_d=dressing velocity ratio
v_s=grinding wheel velocity (m/s)
v_d=dresser velocity (m/s)

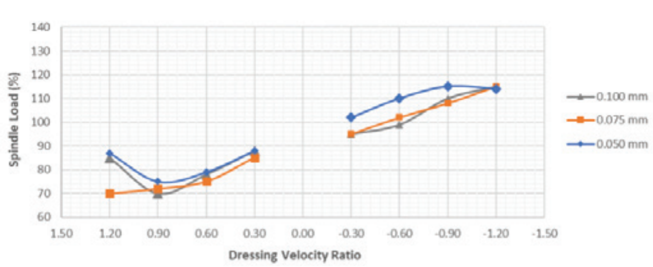

Figure 15—Dressing depth and velocity ratio vs. grinding spindle load (Ref. 2).

Dressing Overlap

The dressing overlap (see Equation 5) represents the number of times the dresser contacts a single point on the grinding wheel.

For example, an overlap ratio of 2 means the dresser contacts the grinding wheel at one point exactly twice. Lower overlap values result in lower surface finish and lower waviness, while higher overlap values give higher surface finish and higher waviness.

Dressing lead is one of the variables used to calculate dressing overlap. Think of it as programming a feed rate on a lathe, in millimeters of feed per revolution, except in the case of dressing lead the measurement is millimeters of feed per revolution of the grinding wheel rather than per revolution of the workpiece. As the dresser is fed across the grinding wheel, a "thread" pattern is created, and both the feed rate and dressing depth affect the resulting surface finish.

$$u_d = \frac{a_{pd}}{s_d} \tag{5}$$

$$a_{pd} = \frac{b_d + s_d}{2}$$

$$b_d = 2\sqrt{p_r^2 - (p_r - a_d x \sin Ø_s)^2}$$

$$s_d = \frac{v_{fd}}{n_s}$$

u_d=dressing overlap ratio
a_{pd}=effective dresser contact width (mm)
s_d=dressing lead (mm/rev)
b_d=dresser contact width (mm)
p_r=dresser tip radius (mm)
a_d=dressing depth (mm)
$Ø_s$=grinding wheel profile angle (deg)

v_{fd}=dressing feedrate (mm/min)
n_s=grinding wheel speed (rpm)

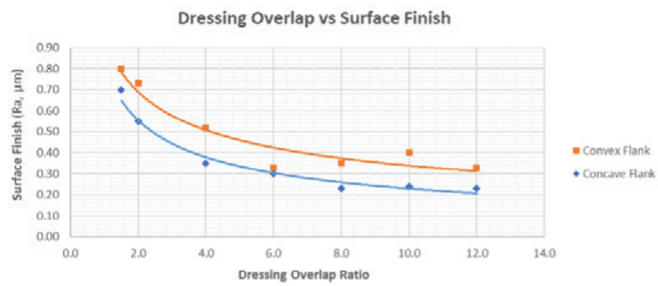

Figure 16—Dressing overlap vs. surface finish (Ref. 2).

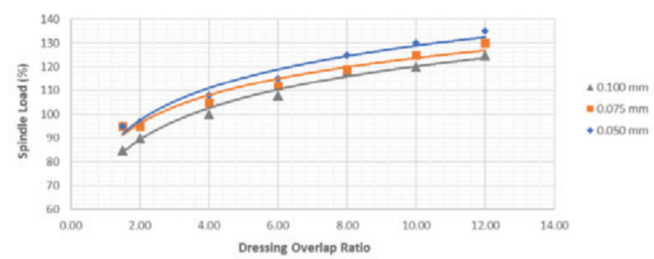

Figure 17—Dressing depth and overlap ratio vs. grinding spindle load (Ref. 2).

Dressing Interval

The dressing interval is the number of parts that can be ground before dressing the grinding wheel. The setting will depend largely on the aggressiveness of the grinding parameters, and the volume of material that will need to be removed. Typically, larger module gears will require a lower (more frequent) dressing interval than smaller module gears, but this is not always the case. The dressing interval can vary widely, anywhere in the range of 1 – 20 parts per dress!

Part 4: Dresser Selection

The dresser geometry, diamond type, and bond type must be considered carefully for each application. The resulting geometry and surface condition of the grinding wheel are influenced by several different factors that are listed as follows, the first being the diamond type.

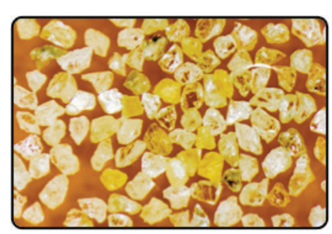

Figure 18—Natural diamonds.

Natural Diamond

Natural diamonds are typically very hard, but since they are formed in nature, they can have flaws which if large enough, can impact the resulting wheel surface. Natural diamonds are not as tough as synthetic diamonds, so they are susceptible to fracturing under abusive dressing conditions.

CVD

CVD is a type of synthetic diamond created by a chemical vapor deposition process. CVD is tougher than natural diamonds and is the better option for dressing grinding wheels with ceramic abrasives, as they are more resilient to impact and have fewer flaws than natural diamonds.

Dresser Tip Radius

Just like in turning operations on a lathe, the tip radius of the diamond directly impacts how quickly you can feed across the surface of the grinding wheel. In general, a larger dresser tip radius can feed faster across the grinding wheel and have a slower wear rate, but sometimes a larger dresser radius is not feasible due to the dressed profile geometry of the grinding wheel.

Figure 19—CVD diamond segments.

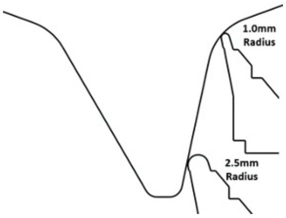

Figure 20—Dresser tip radius comparison.

Figure 21—Electroplated dresser.

Figure 22—Infiltrated CVD dresser.

CVD Segment Size

CVD segments come in many different sizes. The surface area of the CVD segment that is in contact with the dresser bond directly impacts the "gripping" strength that the bond has on the CVD segment. If the surface area of the CVD segment is too small, the segment can potentially pop out of the bond, causing surface finish, or NVH issues on the gear. Norton recommends using a large CVD segment to allow for a strong bond.

CVD Segment Pitch

The spacing between the CVD segments, or pitch, can also affect the resulting finish and waviness of the gear flank. Like a milling cutter, CVD segments that are spaced closer together (higher number of cutting edges) will give a smoother finish, and potentially a longer dresser life. While such results are usually desirable, a fine CVD segment pitch can sometimes have a negative impact on the sharpness of the grinding wheel. When selecting a CVD segment pitch, you must always consider the careful balance between wheel sharpness, dresser wear, and gear surface finish.

There are different types of bonding systems available for bevel gear dressers including the most common examples listed here:

Electroplated Bond

An electroplated bond is a layer of nickel that is deposited onto the dresser while the diamonds are tacked to the dresser steel core, creating a mechanical bond. Electroplated dressers typically use smaller mesh natural diamonds as compared to infiltrated bond dressers. The smaller diamond sizes allow for an accurate profile and low surface finish but also tend to wear quickly. The nickel bond facilitates exposure of the diamond, but it is not as strong as other bond types and is more susceptible to damage than an infiltrated dresser.

Infiltrated Bond

Infiltrated dressers use a very tough tungsten/bronze matrix to retain the diamond. Infiltrated dressers can use natural diamond or CVD and can typically handle abuse much better than electroplated dressers. When using grinding wheels with ceramic abrasive, an infiltrated dresser bond is recommended.

Summary

If you would like a prebuilt *Excel* spreadsheet to calculate bevel gear grinding and dressing parameters, reach out to Spencer Artz at *Spencer.L.Artz@Saint-Gobain.com* for more information.

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Spencer Artz is a Norton | Saint-Gobain Abrasives grinding application engineer with ten years of experience in high-precision automotive grinding applications including camshaft, crankshaft, continuous variable transmission, and gear grinding.

Josh Fairley is a Norton | Saint-Gobain Abrasives Product Manager with 11 years of experience in the manufacture, design, and application of bonded vitrified precision grinding wheels in major industries such as automotive, aerospace, and agriculture.

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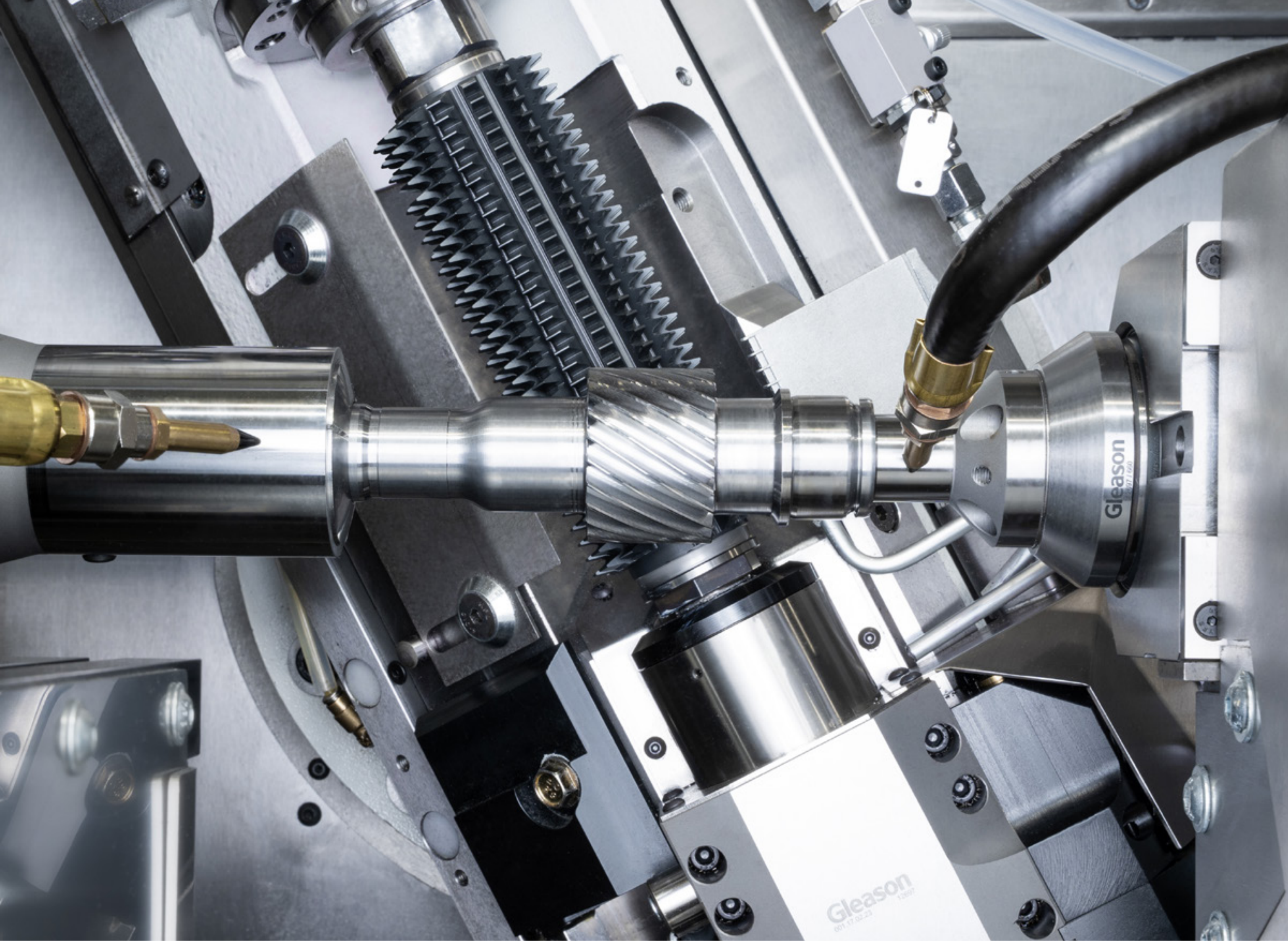
Radial Chamfering Arrives for E-Drive Gears

Horizontal hobbing makes an ideal solution for geared shafts with interfering contours, including EV transmission shafts

Gottfried Klein, Director of Product Management, Soft Machining Solutions, Gleason Corporation



The 100HCD is designed for a wealth of geared profiles up to a workpiece diameter of 120 mm, module 4, and a shaft length of 450 mm.

Manufacturers of EV drive systems are leaving no stone unturned in their quest for quiet-running, dependable transmission gears and shafts. Where once chamfering and deburring operations were almost an afterthought, they're now considered a primary soft machining process, with widespread recognition that anything less than a flawless tooth flank can result in premature transmission failure, less-than-optimal efficiency, and unacceptable noise.

Gleason has been comprehensive in its pursuit of new chamfering technologies that can be more easily, and economically, integrated into the gear manufacturing processes, whether to produce smaller automotive gears, pinions, and shafts, or larger gears for trucks and tractors. In every instance, these new technologies have been combined with proven horizontal or vertical hobbing machines so that the chamfering operation can be performed with minimal impact on cycle times and tool cost per piece. One such example was the recent introduction of the vertical Genesis 280HCD gear hobbing machine, which combines two chamfering processes: chamfer hobbing, ideal for high volume automotive and light truck applications, including final drive ring gears and shafts; and fly cutter chamfering, delivering exceptional flexibility for lower volume, small lot jobber applications. Both are performed in parallel to the hobbing operation.

Introducing the New 100HCD

Now, Gleason has a solution for smaller e-drive transmission gears, pinions, and shafts that require both production in high volumes, and the cutting of precise, repeatable chamfers. With the introduction of the 100HCD horizontal hobbing machine allowing radial chamfering in parallel with hobbing, the platform is ideally suited to meet the challenges posed by today's very high precision, ultra-quiet e-drive transmission gears and shafts.

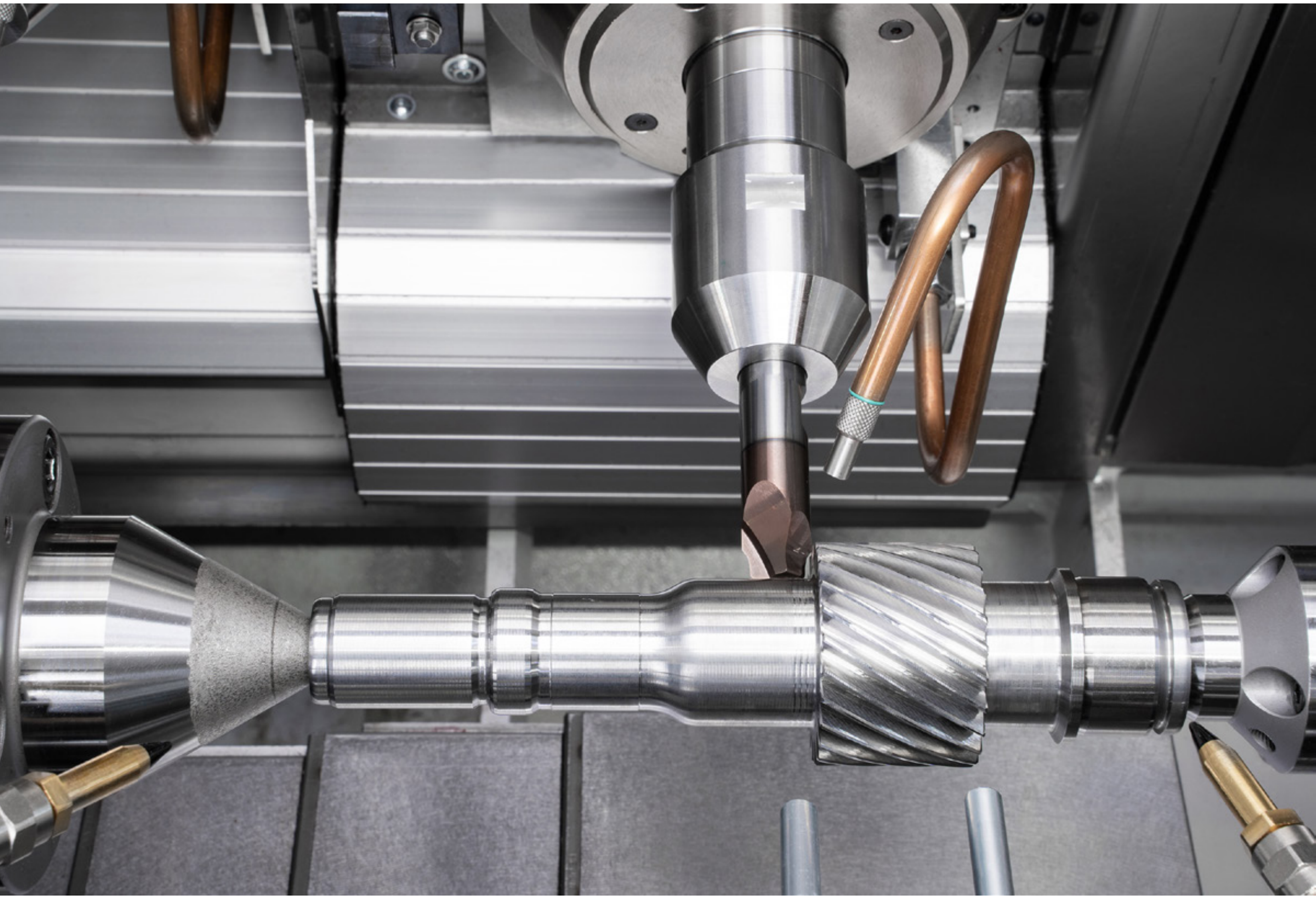
Background

The 100HCD is a variation on Gleason's recently developed 100H horizontal hobbing machine—the next generation of the well-known P90 Series, with improvements in design, functionality, and operator interface. This new series, including variants such as the 100HCD, is designed to handle a wealth of geared profiles up to a workpiece diameter of 120 mm, module 4, and a shaft length of 450 mm. With design improvements to the hobhead and workspindle and the use of the Gleason GEMS human-machine interface (HMI), the 100 series delivers extremely fast cutting and processing times, making it a good match for the large batch production of gears and pinions. And like the P90 series, which integrated chamfering/deburring along with horizontal hobbing, the 100HCD also combines this new and improved hobbing platform with an integrated chamfering/deburring station.

Reinventing Radial Chamfering

Most importantly, with the 100HCD, a significant improvement has been made as compared to the P90, with the replacement of the traditional chamfer rolling process with radial chamfering. How are they different? Chamfer rolling, also known as rotary deburring, is a fast, versatile forming process that creates chamfers along the tooth edges using gear-shaped tools that mesh with the workpiece. Excess material flows mainly to the face side of the gear, where it's then cut away by single blades, deburring discs, or file discs, depending on gear shape and/or machine configuration. However, small amounts of material can also flow into the gear tooth flank itself, thus forming a secondary burr, necessitating that this secondary burr be removed by either edge zone burnishing or a two-cut-hobbing process before the subsequent hard finishing operations downstream.

With radial chamfering however, applied in parallel with hobbing by the 100HCD, the chamfer is produced with a cutting process using one or two single-point cutting tools, rather than rolling, thus eliminating a subsequent operation needed to remove excess material in the form of the secondary burr that can result from chamfer rolling. With cycle times and tool cost per piece of paramount importance, the replacement of chamfer rolling with radial chamfering makes perfect sense. And while Gleason's chamfer hobbing process—first introduced with the 160HCD and the 280HCD—is ideal for disc-type parts, radial chamfering is better suited for shafts typically produced on a horizontal hobbing machine of this type. These shafts, often with the root diameter of the chamfered gear and the shaft diameter in very close proximity, are inherently more difficult to chamfer and deburr due to the clearance requirement. The hob-type cutting tool used in the chamfer hobbing



With radial chamfering, available now in parallel with hobbing on the 100HCD, the chamfer is produced with a cutting process using one or two single-point cutting tools. This eliminates subsequent operations needed to remove the secondary burr that often resulted from the chamfer rolling process used in the past.

process, while ideal for disc-type parts, makes it challenging to chamfer shafts with interferences typical of those found in today's most common e-drive transmissions.

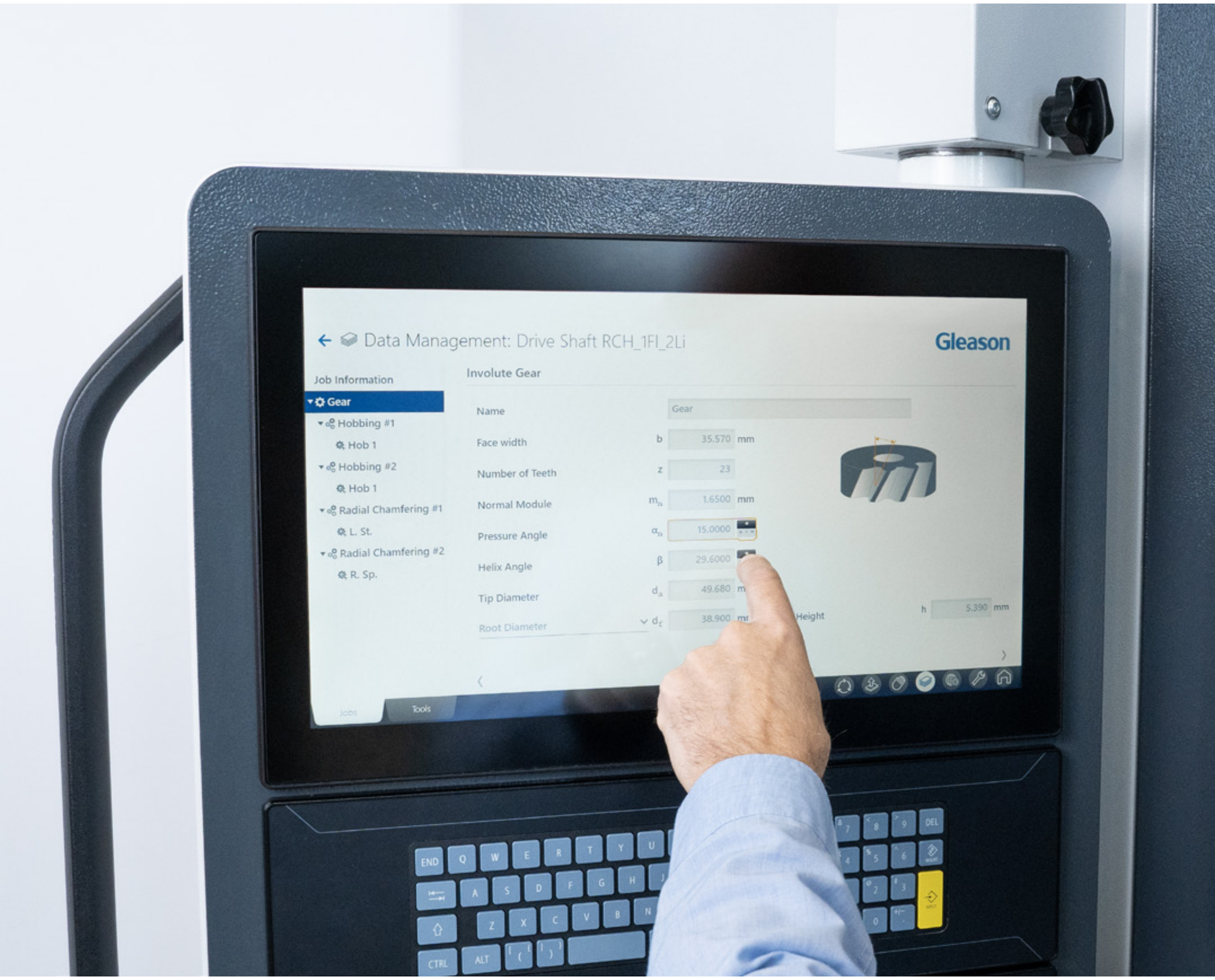
Parallel Performance

Gleason's radial chamfering process uses economical, highly productive resharpenable carbide cutting tools, with from one to three cutting edges.

The 100HCD operates similarly to its P90CD predecessor. By performing chamfering/deburring in parallel with hobbing, it delivers a remarkable cycle time, with the assistance of highspeed gantry load/unload automation and Gleason workholding with a very fast clamp/ unclamp capability. The gear is first hobbed and the rough burr that results from hobbing is removed in a single setup at the hobbing station. The gear then is unloaded by the gantry and loaded into the chamfering/deburring station, where radial chamfering is performed simultaneously while another gear is hobbed. Depending on the application requirements, the chamfering station can be equipped with a single-tool spindle or an optional two-tool spindle for single or two-tool radial chamfering. Economical, highly productive resharpenable carbide cutting tools, with from one to three cutting edges, and sourced through Gleason are used in both cases. A single tool can be designed for chamfering the gear flanks, with or without root chamfering. The two-tool option adds more flexibility to influence the chamfer angle with tools specifically designed for the obtuse and acute edges (particularly advantageous in the case of gears with high helix angles where obtuse and acute angles can be quite different) to meet a customer's specific design requirements in advance of the subsequent hard finishing operations. In both cases, radial chamfering is fast and efficient, with no impact whatsoever on chip-to-chip times since the operation is performed in parallel to the hobbing of more workpieces.

The Complete Package

The 100HCD has a redesigned direct-drive hob head, delivering speeds up to 12,000 rpm, and with three different power options, combined with several hob clamping alternatives, ensures every application can benefit from the best possible cutting tool solutions, now and in the future. For dry cutting, for example, the latest G60, G90, or carbide hob cutter material is ideal. Several chip evacuation options ensure dry, hot chips



Coupled with the latest Siemens Sinumerik One control, Gleason's GEMS HMI hobbing software guides the operator intuitively through the workflows of the machine, both hobbing and radial chamfering.

won't interfere with the highly productive cutting process. The CNC tailstock will support clamping disc- and shaft-type parts as long as 450 mm, using the fast, adaptable Quik-Flex horizontal workholding system for hobbing, which cuts workholding changeover in both the hobbing and chamfering stations to under a minute each.

Shorter cycle times and more efficient, error-free operation also result from Gleason's GEMS HMI hobbing software, which makes setup and changeover more intuitive and simpler to both learn and operate. This HMI, coupled with the latest Siemens Sinumerik One control, provides several new process options and guides the operator intuitively through the workflows of the machine, both hobbing and radial chamfering.

Like all the latest generation of Gleason machines, the 100HCD is supported by Gleason's complete manufacturing system, including hobs, radial chamfering tools, modular workholding, and smart grippers, as well as process engineering and ongoing training to help ensure the system is operating at peak efficiencies and producing the optimum in quality.

Summary

Manufacturers now have a variety of integrated and fully automated chamfer/deburr options available, whether for gears or shafts, of the type in high demand for the latest e-drive transmissions and larger vehicles. These latest Gleason solutions are available today to apply the right chamfer process for applications as widely disparate as automotive-type gears and shafts, truck-size gears, or job shop applications.

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AGMA Live Events Advance Understanding of Emerging Technologies

Mary Ellen Doran, AGMA Director, Emerging Technology

I just returned from two information-packed days in Detroit, running the 2024 AGMA Emerging Technology Forum and the AGMA Technical Committee meeting on standards development for electric vehicle technology. AGMA provided attendees with high-level presentations on materials, advanced IIoT experiences, interactive sessions on the future of robots, and initial standards work for EV technology.

Let me start with the backdrop for our events, LIFT—the National Advanced Materials Manufacturing Innovation Institute. It is one of the 17 U.S. Manufacturing Institutes and one of nine institutes created by the U.S. Department of Defense. LIFT bridges the gap in manufacturing innovation at the crosspoint of research and commercialization, specifically in the materials space. We learned from Noel Mack, CTO at LIFT, that LIFT is out front on projects spanning from developing advanced materials for extreme environments, like hypersonic speeds pushing Mach 30; to gaining a better understanding of the chemistries and microstructures of multi-material additive manufacturing prints.

The LIFT High Bay space looks very different from what I saw just six months ago when I visited. LIFT will continue to iterate as it brings new partners into its ecosystem and expands. I learned that LIFT is actively creating a middle ground for material creation. Currently, manufacturers can get small amounts of additive metal powder from academic researchers, or large amounts from material makers. LIFT is working to fill the space in the middle and provide small development-scale batches of materials that manufacturers can use for prototyping and testing. This accessibility will naturally move projects forward faster.

This thread—the pace of technological growth—pulled through every presentation and discussion of the two days. Thanks to the increased capacity of AI and IIoT solutions, we can analyze much larger data sets in a much smaller amount of time to get to not only the solutions that work but also to gain insights into why some solutions will not work. Tom Hoffman, Business Manager for Siemens Digital Experience Center at LIFT, discussed how we have moved way past IIoT solutions simply collecting data to installations that allow for immediate feedback and correction for quick, better outcomes. He discussed process simulation utilizing various digital threads with a heavy emphasis on digital twin technology. The Siemens Experience has a hands-on example of a manufacturing line utilizing robots and AI-driven vision technology. The staff works with manufacturing partners to test scenarios and continue to optimize automation technologies.

We went from looking at industrial and collaborative robots for manufacturing spaces to discussing the future of robots. Participants Kel Guerin, Co-Founder and CIO at Ready Robotics, and Robert Kufner, President & CEO at SDP/SI, and Chair of the AGMA Robotics Committee led attendees through an interactive dialog of what types of changes may need to come as the world introduces robot technology into service sectors and homes. Through his early work on space robots, Kel has a good understanding of gearboxes and provided his insights on how he thinks they will need to change for these new applications. Products need to be functional, affordable, safe, and quiet. He predicts that we will see the first humanoid robots in service in the next 5 to 10 years, but there is a longer trajectory to get to the point where robots behave more like humans. Robert produces many parts for the robot industry and emphasizes encouraging robot start-ups to work with manufacturers early to best scale up their new products. Both men say there is a lot of opportunity for gear manufacturing in the future of the robot industry.

AGMA will continue to provide opportunities for members to learn and explore emerging technologies. I encourage you to join us at our future events, attend our free webinars in person or on demand, and stay current on these technologies that will impact our collective futures.

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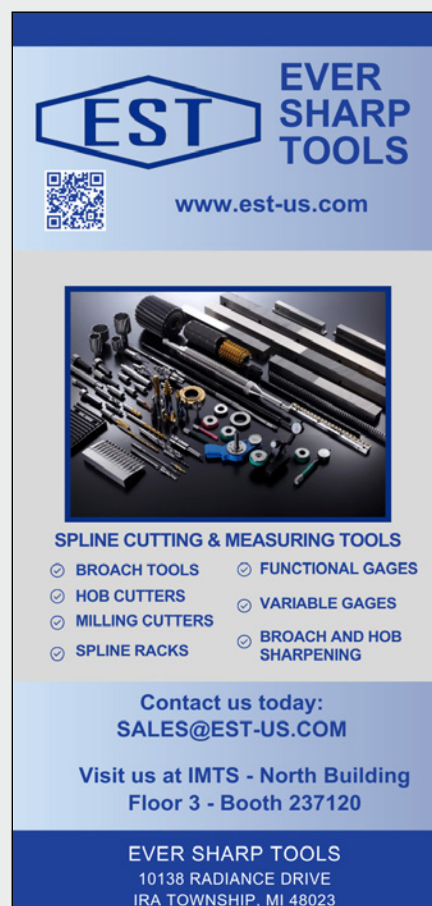

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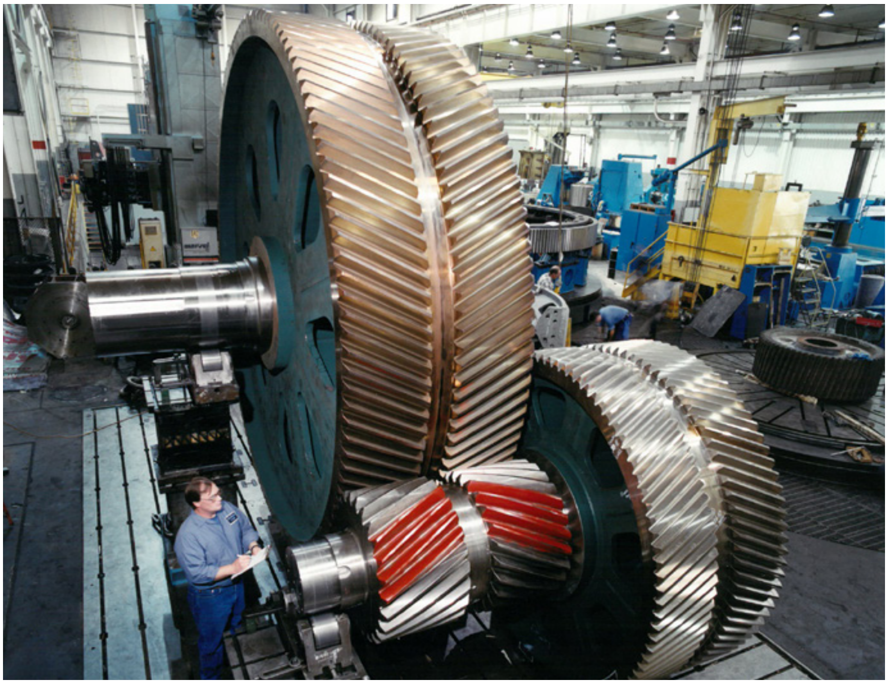
AGMA wants you to be involved in gear standards development. Committee meetings are a great place to network and collaborate with experts in the field, broaden your knowledge, capture technical expertise in writing, refine the standards you use, and see how your influence helps shape best practices throughout America and around the world. We are especially looking for experts to join four new standardization projects.



General example of a gear train being mesh checked with dye. (Photo courtesy of Horsburgh & Scott.)

From the AGMA Accuracy and Nomenclature Committee, a new project has been proposed to update a standard every gear engineer should be familiar with, ANSI/AGMA 1010-F14, *Appearance of Gear Teeth—Terminology of Wear and Failure*. This nomenclature standard identifies and describes the classes of common gear failures and illustrates degrees of deterioration. The current, sixth edition was published in 2014 with 89 detailed color figures showing gear failures over 81 pages. Proposed updates for the next edition include aligning nomenclature with ISO 10825 and ISO 15243, reorganizing clause numbers, and adding additional failure modes, including plastic and powder metal gear failure modes.

From the AGMA Metallurgy and Materials Committee an update to AGMA 930-A05, *Calculated Bending Load Capacity of Powder Metallurgy External Spur Gears* has been proposed. This information sheet has 78 pages and describes a procedure for calculating the load capacity of a pair of powder metallurgy external spur gears based on tooth bending strength. Two types of loading are considered, repeated loading over many cycles; and occasional peak loading. Proposed updates for the next edition include aligning rating methods with the soon-to-be-published new edition of AGMA 2101 and MPIF 35, adding helical gear rating, adding pitting resistance rating, adding internal gear rating, and updating dynamic factors.

A brand-new project to create an information sheet on gearbox repair recommendations is also seeking experts. The proposed subjects for the document to cover are best practice steps to take during repair, quality levels for customers to compare different repair and rebuild companies, common terms, recommended testing, and separate sections for components such as gears, seals, and bearings.

Last, AGMA has formed a new working group to discuss standardization for gears used in electric vehicles. The scope of vehicles runs the gamut from automotive to agricultural to mining and more. The working group will likely propose writing an information sheet of recommended design practices, but currently, members are gathering information on subjects that need special consideration when designing EV gears.

For over 100 years, AGMA has been the facilitator for the development of American gear standards. For AGMA to make gear standards the best they can be, everyone in the industry needs to be involved. When AGMA standards-writing technical committees have open projects, they meet approximately six times per year for two-hour virtual meetings, and approximately once per year for a two-day in-person meeting. If you are interested in working on any open AGMA project, please contact us at *tech@agma.org*.

Bevel Gear Speed Increasers

Question:

Subscriber Binish Kunnathully asks, "While considering bevel gears as a speed increaser, what is the influence of the following in the design?

- ***a) Profile shift.***
- ***b) Spiral angle and Helix directions***
- ***c) Gear Modifications***
- ***d) Gear Ratio***
- ***e) Specific Sliding***
- ***f) Lubrication***
- ***g) Special applications like Test Bench—in bidirectional gear units"***

Expert response provided by Dr. Hermann J. Stadtfeld.

For cylindrical gears, speed-increasing transmission stages are well known, and regarding profile shift, preferred pressure angles, and helix angles a set of rules applies, which is not much different from the rules for speed reducers (Ref. 1). It is important to acknowledge that basically a speed increaser has to be designed just like a speed reducer, but then the gear with the lower number of teeth is the output. Of course, the torque and the speed of the gear with the lower number of teeth (output) and the gear with the higher number of teeth (input) must be the same as if this transmission was used as a speed reducer.

In the case of straight bevel gears, spiral bevel gears, and hypoid gears the same rules apply with some additions. Spiral bevel gears have many applications as speed increasers. One example is the helicopter main rotor drive in Figure 1. The ring gear is driven by two pinions, that are connected to a first-stage reduction which is actuated by two jet engines. The additional pinions have a power take-off function and operate the tail rotor, oil pumps, an air compressor, and an electrical generator. These power take-off pinions have ratios of 4 to 6 with the central ring gear which makes them speed increasers (Refs. 2, 3).

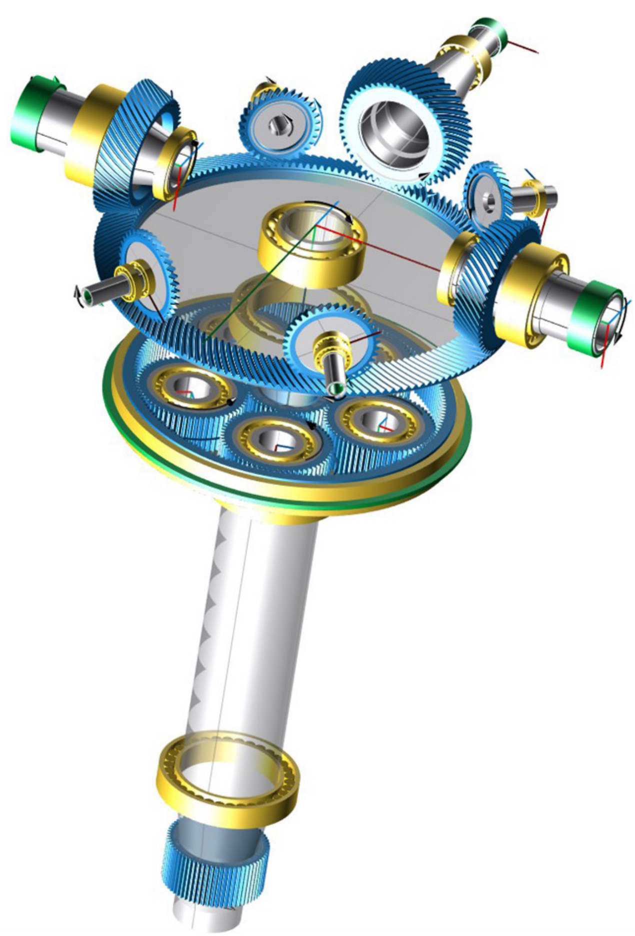


Figure 1—Helicopter main rotor drive.

Another prominent example of a speed increaser is the power take-off transfer case of an SUV, shown in Figure 2 (Ref. 4). The specific SUV has an east-west engine orientation and requires a 90-degree speed-increasing transmission to actuate the propellor shaft to the rear axle. At the rear axle, there is a second hypoid gearset required to drive the rear wheels, but this rear hypoid gearset is a speed reducer.

The examples in Figures 1 & 2 show that it is common to use bevel and hypoid gear speed increasers. The following sections will explain the differences between speed-increasing and speed-reducing bevel gear transmissions.

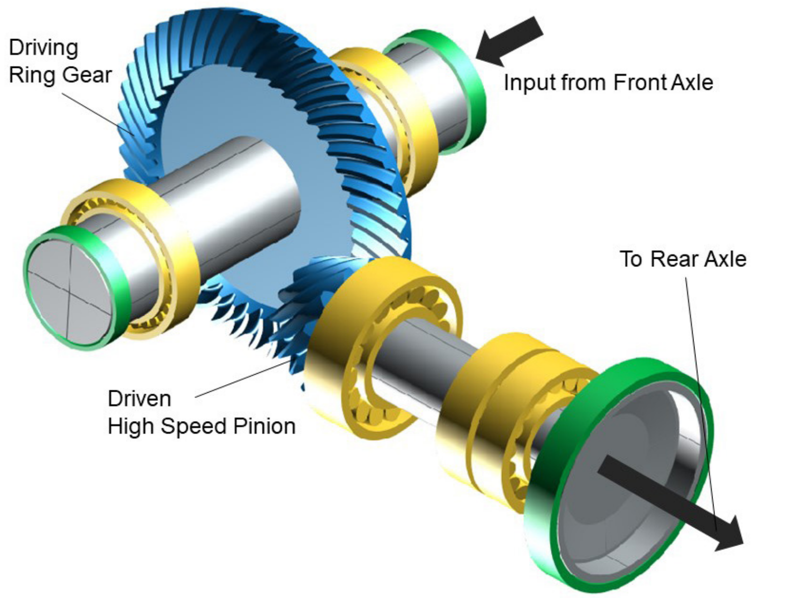


Figure 2—Power take-off transmission of an all-wheel drive SUV.

Design Parameters—Spiral Angle, Profile Shift

A typical spiral bevel gearset with a ratio of 13:45 and a right-hand gear meshing with a left-hand pinion is shown in Figure 3. In case of a speed increaser, the gear rotates in a counter-clockwise direction, such that it drives the pinion on the drive side. The drive side is defined as the convex gear flank, meshing with the concave pinion flank. The contact force is shown in Figure 6 related to the gear member. The force F_z presses the gear in an axial direction away from the pinion and the force F_y presses the gear away from the pinion in the lateral direction. This is the preferred condition that allows the lubrication oil to enter the contacting zone and separate the two "contacting" flank surfaces. In the case of the opposite gear driving direction (clockwise), the contact of the pinion and gear flank is on the coast side which creates the opposite force directions and attracts the gear towards the pinion. This will reduce or eliminate the backlash which leads to an interruption of the lubrication film, followed by scuffing on the flank surfaces in the area of high sliding velocities. These are the areas with the largest distance to the pitch line (Ref. 5).

If the main driving direction is a clockwise gear rotation (relative to Figure 3), then the hand of the spiral has to be changed to a left-hand gear and a right-hand pinion. In the case of a bidirectional speed increaser,

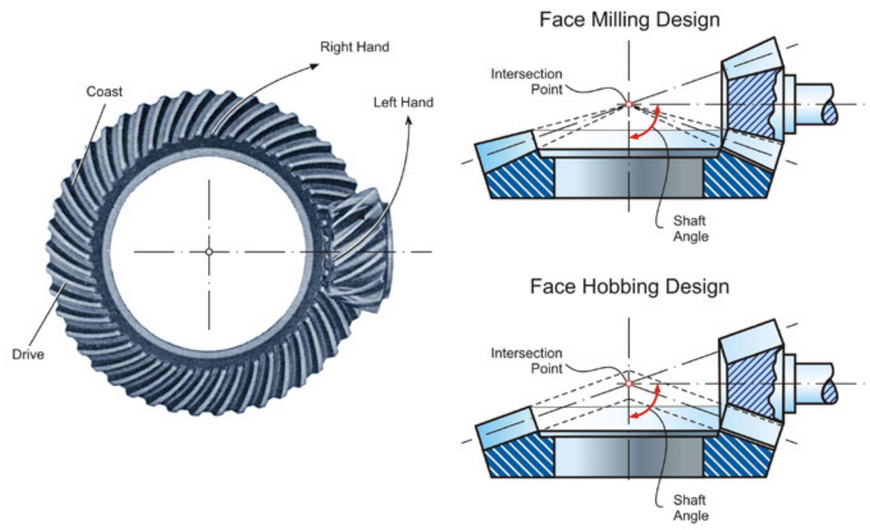


Figure 3—Spiral bevel gearset definitions.

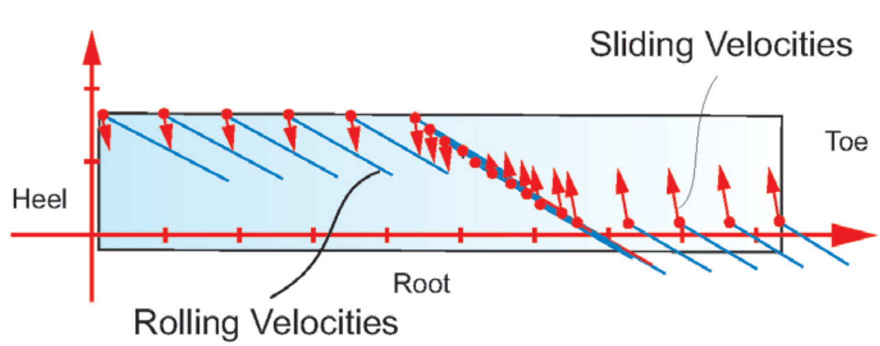


Figure 4—Sliding and rolling velocities along the path of contact of a spiral bevel gear.

Figure 5—Scuffing in the root area of a hypoid pinion without profile shift.

the effects of the coast side have to be reduced. This can be accomplished by reducing the spiral angle and by increasing the cutter diameter. Against the standard recommendation of a 35-degree spiral angle, a 20-degree spiral angle should be used for bidirectional operation in a speed-increaser. The involute outer cone ratio, shown in the dimension sheet of every spiral bevel gearset, should not be used as a guide for selecting the optimal cutter diameter for bidirectional speed-increasers. The cutter diameter should be selected close to the mean ring gear diameter.

Also, for unidirectional speed increasers, the spiral angle should not exceed 27 degrees to keep the additional contact and bearing forces low and to guarantee good hydrodynamic lubrication. The circumferential speed of 60 m/sec is possible if the gears are ground and if good lubrication is provided.

Profile shift might be necessary for the ratio shown in Figure 3 to avoid undercut and achieve a large active working profile. For speed increasers with a ratio greater than 3, the root transition of both the driving gear and the driven pinion are prone to scuffing. To keep the sliding velocities low, close to the transition to the root area, the profile shift of pinion and gear should be zero or very low. This translates to an addendum modification factor which results in a pinion and gear dedendum (listed in the dimension sheet) which is about 50 percent of the working depth.

Specific Sliding and Lubrication

Figure 4 shows the sliding and rolling velocities of a spiral bevel gear. The velocity directions are based on the sliding and rolling of the gear flank versus the pinion flank. While the rolling velocities have only moderate changing magnitudes in the entire flank area, the sliding velocities reduce their magnitude from the root line to the pitch line and become zero at the pitch line. At the pitch line, the sliding velocities change their direction and increase in magnitude as they get closer to the tip.

If driving on the drive side as explained in Figure 3 is realized, the sliding and rolling velocities are still of the same magnitude but in the opposite direction as it would be in the case of a speed reducer. Positive pinion profile shift or addendum modification will increase the diameter of the pinion root and face, and therefore position the pitch line (which cannot be moved) close to the flank transition to the root fillet. This will cause the lowest sliding velocities at the pinion root transition. However, in turn, the largest sliding velocities are now at the pinion tip and the gear root. Because speed increasers are prone to scuffing at the pinion and gear root, it is recommended to avoid profile shift to achieve balanced conditions between both meshing members.

To further reduce the risk of scuffing and the risk of lubrication deficiencies, the applied lubrication concept is most important. The optimal orientation of a speed-increasing gearbox is such that the gear has a horizontal axis and is about 50 percent below the oil level, while the pinion just dips below the oil level. This orientation will keep oil churning at the lowest possible level and forced lubrication is not required. The basic rule is to keep the low-speed member about 50 percent below the oil and ensure that the high-speed member just contacts the oil, such that after long periods of not operating the gearbox, the pinion is not dried off on all of its teeth.

Recommended oil types are high-pressure fully synthetic oil, as used in hypoid axles of premium class vehicles (for example Castrol SAF-XO). These synthetic oils have low viscosity and provide high pressure and scuffing-prevention properties which are beneficial for speed-increasing transmissions.

Figure 5 shows a severe case of scuffing in the high sliding area (dedendum) of a hypoid gear. The gear in Figure 5 was mating with a pinion which had a too large profile shift, which made the gear dedendum large. The large distance from the pitch line caused high sliding velocities along the flank-root transition which initiated the scuffing. As mentioned in the last section, a zero profile shift in the driven pinion is advisable. The risk of scoring of hypoid gears is always larger than in the case of spiral bevel gears, which comes from the additional sliding in the face width direction, in a magnitude that is nearly proportional to the hypoid offset and larger than the profile sliding.

Starting with Full Output Load

The forces on the contacting flank surfaces are identical between speed increasers and speed reducers. Figure 6 shows the simplified representation of the flank and bearing forces. In both operating directions (speed reduction or speed increase) the force diagram in Figure 6 applies equally. During the startup of a transmission, it is important to consider if the load is applied with a smooth ramp-up or if the transmission has to work against full load from the start. Speed increasers may work in a steady-state operation, however, during the startup, the acceleration of the output gear, turning faster than the input gear, increases the torque versus the steady-state torque. This effect is no issue in a speed-reducing transmission, but it requires designing the gearset for a higher output torque in the case of speed increasers. The load exaltation factors (L_{EF}) in Table 1 are proposed to account for the additional inertia torque during the acceleration from zero to nominal RPM. The factor L_{EF} has to be multiplied by the overload factor found in AGMA 2101 or the application factor found in ISO 6336 or DIN 3990 (Ref. 6).

Depending on a smooth load increase proportional to the RPM ramp-up, or an instant full load condition with an abrupt input speed increase, two categories are listed in Table 1. The table also differentiates between ratios of one to four. In case of ratios higher than four, the values in Table 1 for the ratio 4:1 can be used. Most real applications have a startup characteristic between proportional and full-load startup. It is up to the gear engineer to estimate the L_{EF} that applies to the input/output conditions of a particular gearbox.

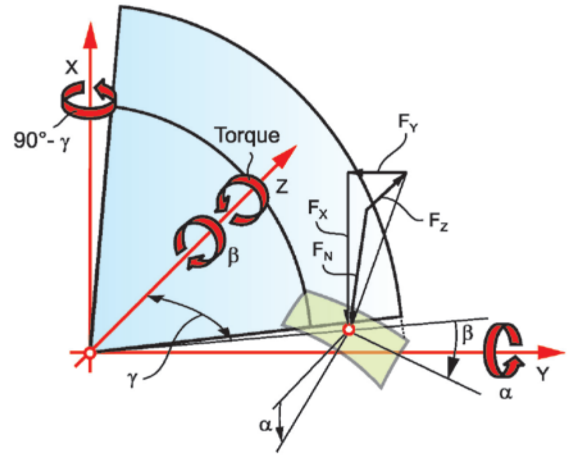


Figure 6—Flank contact forces and bearing forces.

Ratio	Proportional and Smooth Load Increase	Full Load and Instant Input Speed Increase
	Load Exaltation Factor L_{EF}	Load Exaltation Factor L_{EF}
1x1	1.00	1.00
2x1	1.03 – 1.05	1.10 – 1.15
3x1	1.05 – 1.08	1.15 – 1.20
4x1	1.08 – 1.15	1.20 – 1.30

Table 1—Load exaltation factor.

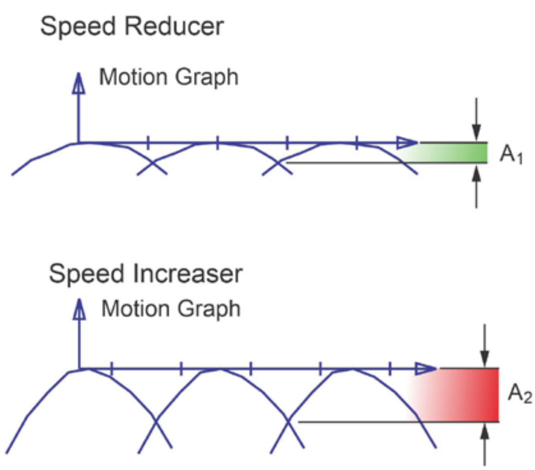


Figure 7—Motion error increase due to speed-increasing arrangement.

Dynamic Effects

One dominant effect of a bevel gear speed increaser is the increase of the motion error amplitude of the output gear. This is caused by the flank surface crowning, which is significantly larger in bevel gears compared to cylindrical gears. The same gear set was first applied as a speed reducer with the pinion driving the gear. It shows a motion error amplitude of A_1 of the output gear in Figure 7 (top graphic). Then, the gearset was used as a speed increaser with the gear driving the pinion, which resulted in a motion error amplitude of A_2 of the output pinion, shown in the bottom graphic of Figure 7. Caution has to be applied during the design because this effect is not seen in a common TCA which bases all results on the ring gear. The ratio of the gearset in Figure 7 was 17:45 (R = 2.64). Reversing the driving direction increased the motion error by the exact factor of 2.64 of the ratio.

The output pinion in a speed increaser has a motion error amplitude that is larger by the factor of the ratio compared to a speed reducer. This presents in many cases a severe problem in the performance of the transmission. The first derivative of the motion error $\Delta\varphi$ in Figure 8 is the angular velocity $\Delta\omega$. The graphic shows that, against the common opinion, the gearset slows down along the entire motion error graph. Only at the transfer point between the actual pair of teeth to the following pair does the angular velocity (RPM) increase to the level at the starting point very instantly. This abrupt speed increase is called the meshing impact. To

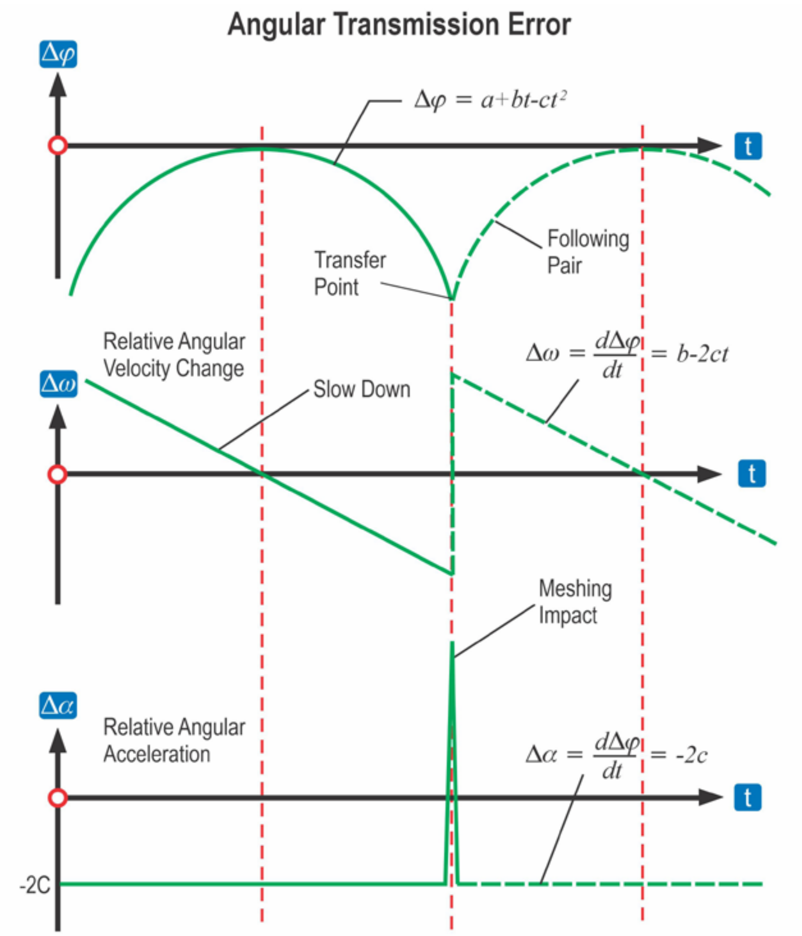


Figure 8—Impulse caused by motion error (angular transmission variation).

Ratio	Low Output Inertia	High Output Inertia
	Dynamic Load Factor D_{LF}	Dynamic Load Factor D_{LF}
1x1	1.00	1.00
2x1	1.03 – 1.05	1.20 – 1.25
3x1	1.05 – 1.08	More conjugate Ease-Off required
4x1	1.08 – 1.15	More conjugate Ease-Off required

Table 2—Dynamic load factor accounts for motion error elevation.

quantify the impact, the second derivative of the motion graph is made which results in the angular acceleration $\Delta\alpha$. The amplitude of the peak in the acceleration graph will be 2.64 times higher in the case of a speed increaser, versus a speed reducer. In the case of large inertia on the output side of the speed increaser, the higher acceleration peak will be smoothed out and less disturbing. However, the exaggerated impulse will increase the load that the teeth of both members (pinion and gear) are experiencing.

In the case of a low inertia on the output side of the gearset, vibrations with the tooth mesh frequency will be experienced. These vibrations can result in flank separation during the slow down period (along the drop of the $\Delta\omega$ velocity graph) because the deceleration $\Delta\alpha$ of the speed increaser is elevated by the factor of the ratio $\Delta\alpha = R \cdot (-2C)$. Flank separation will not only cause a hammering sound but will also result in a lubrication film interruption at the transfer point when the impulse occurs. Reducing the motion error in the design calculation will reduce the flank separation effect and applying the dynamic load factor D_{LF} will account for the higher average contact forces.

A lubrication film interruption cannot be compensated in the design calculation of the gearset in the case of a higher output inertia. Because the flank separation is more likely with ratios greater than 2, it is required to design the Ease-Off of a gear set with a ratio larger than 2 nearly conjugate and account for the prevention of edge contact in case of deflections and component tolerances, by applying blended Toprem and kinematic heel relief.

Recommended dynamic load factors D_{LF} are listed in Table 2. For low output inertia, the factors in the left column are a guide for the design of a gearset. The D_{LF} factors have to be multiplied with the nominal load of the particular application (in addition to the dynamic factors from the standards or the literature [Ref. 7]) when strength calculations are performed. For high output inertia and ratios above 2, an increase in the strength of the speed increaser will not help to account for the separation, the flank hammering, and the interruption of the oil film. A good guide is to reduce the motion error by the factor of the ratio. Ideal in this case are motion errors in below 15 microradians. Low motion errors require nearly conjugate flank surfaces with very low Ease-Off magnitudes. Because the Ease-Off accounts for deflections, heat-affected deformations, and manufacturing tolerances, a conjugate Ease-Off will result in edge contact in the operation of the gearset. To re-establish the required insensitivity of the gearset and prevent edge contact, the conjugate design requires blended Toprem in the pinion and gear member as well as a kinematic heel relief. Because speed increasers for power transmissions should be ground, Toprem and end relief are easy to realize and are standard features of bevel gear grinding machines.

Maximal Ratios and Self Locking

High-reduction hypoids, such as HRH and SRH have a tapered worm as a pinion (Figure 9). The common ratios of these transmissions are between 7 and 50, however, larger ratios are possible. The lowest number of pinion teeth is one, which will result in a very low pinion lead angle.

Gleason developed the calculation of a backdriving coefficient ($C_{BD} = T_{br}/T_{dr}$), especially for SRH gearsets. This calculation is based on a friction factor of $\mu = 0.08$ and computes the torque that tries to backdrive the pinion versus the breaking torque. If $CBD > 1$, then backdriving is not possible. The backdriving ability of SRH gearsets is important for all applications that require smooth coasting if the driving torque from the prime mover is reduced or turned off.

The lead angle of a 5-tooth and a 2-tooth pinion are compared in Figure 10. A worm with a lead angle of less than 10 degrees is considered self-locking (Ref. 8). Self-locking means the gear cannot drive the pinion. This is a general statement and must be verified, considering the type of lubrication, the lead curvature of the gear teeth, and if the backdriving occurs on the drive side (if the gear in Figure 9 rotates counterclockwise) or if the backdriving occurs on the coast side.

It is advisable not to use high-reduction bevel worm gear drives as speed increasers. The efficiency of such a transmission when used as a speed increaser is considerably lower than in the case when it is used as a speed reducer.

Bidirectional Operation

If a speed increaser is used bidirectionally, then it has to transmit the same torque on the drive side and the coast side. The effect of coast-side driving like the aforementioned reduction of backlash down to zero has to be reduced (Figure 6 with reversed force directions). One solution is the use of straight bevel gears. Straight bevel gears can be designed and manufactured today with low motion error and acceptable contact ratio. Also grinding of modern Coniflex Pro straight bevel gears is applied today for many industrial applications. If spiral bevel gears are used as bidirectional speed increasers, then a reduced spiral angle and a large cutter diameter should be used. The recommendations for speed reducers in textbooks and design manuals call for a 35° spiral angle and a cutter diameter which puts the involute point at the outer diameter. This is called the ratio of involute to outer cone. In the case of a bidirectional speed-increaser, the spiral angle should not exceed 20 degrees and the cutter diameter should be chosen close to the gear mean diameter. This means, if the mean gear diameter is 190 mm, then the cutter diameter should be 7.5 in. The involute to outer cone rule was established to achieve a favorable contact movement under load-affected deflections on the drive side. In case of a low spiral angle of 20 degrees, and driving on both the drive and coast side, the rules of the involute to outer cone would result in a very small cutter diameter, which is not recommended for speed-increasing transmissions.

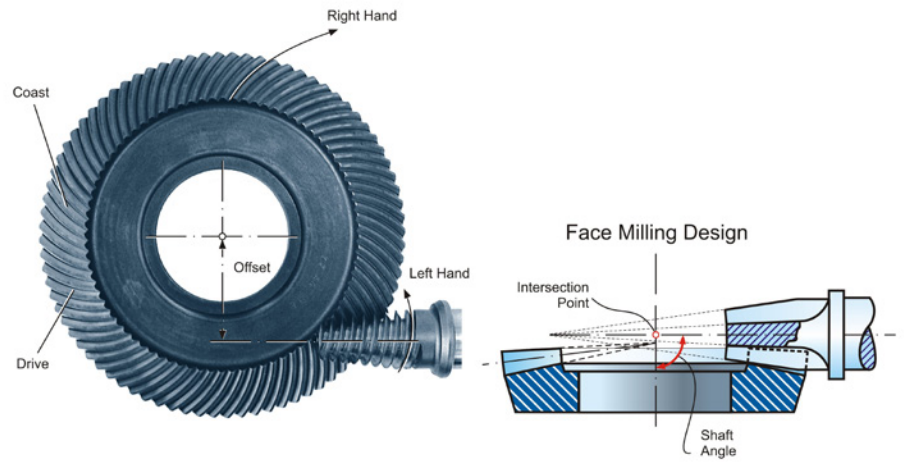


Figure 9—Super reduction hypoid (SRH) used as a speed increaser.

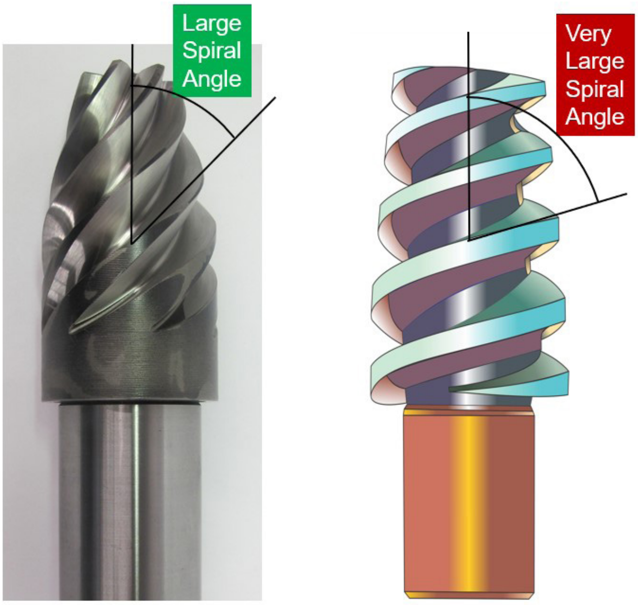


Figure 10—Bevel worm pinion with large lead angle (left) and low lead angle (right).

Manufacturing and Operation

Either straight bevel gears or spiral bevel gears are recommended as speed increasers. For straight bevel gears, the *Coniflex Pro* design software and the Coniflex cutting process provide the optimal geometry and optimization features, like conjugate flanks with kinematic tip relief. For spiral bevel gears, the Gleason face milling completing design offers kinematic flank optimizations (UMC) for conjugate profiles and end relief.

It is recommended to case carburize pinion and gear and heat and quench the pinions to a surface hardness of 62 HRC and the gears to 59 HRC. The difference in surface hardness reduces the metallurgic affinity of the contacting surfaces and therefore reduces the risk of scuffing.

After heat treatment, the speed increaser gears should be ground with a low surface roughness, preferably below

0.5 μm Ra. If a controlled break-in with moderate loads and speeds that increase from low to high is not possible, then a superfinishing or phosphate coating of the flank surfaces is recommended.

Hypoid gears which are used as speed increasers should receive a small root relief of 10 to 15 microns in the grinding process. This will prevent load concentration peaks, leading to scoring. After heat treatment, a phosphate coating of the flank surfaces will reduce or prevent flank surface damage.

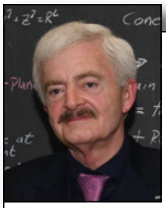
All speed increasers should be lubricated with fully synthetic high-pressure oil, for example, Castrol SAF-XO. A speed-increasing bevel gear transmission should be filled with 40 to 50 percent of its inside volume with oil. The fast-running pinion has to be placed above the oil level, or just slightly dipping into the oil. If the gearbox is used unidirectional, then an orientation like in Figure 3, with a counterclockwise rotating gear will transport the oil from the sump directly to the pinion teeth. The described arrangement will reduce oil churning. Excessive oil churning reduces the cooling effect the oil should provide, and it reduces the ability for a hydrodynamic oil film between the meshing flanks because the churned oil foam delivers mostly air between the meshing flank surfaces.

If the described ideal condition for an oil sump is not given for a certain design, then a piping system for forced lubrication which pumps low quantities of oil into the meshing zone must be considered. The oil must be supplied before the mesh which means, referring to Figure 3 (gear rotates counterclockwise), the oil supply comes from below. In the case of a bidirectional speed increaser, the oil supply must come from both directions into the meshing zone (above and below in Figure 3).

Summary

Speed-increasing bevel bear transmissions are used in many applications successfully. To create a new speed increaser, the following guidelines and rules of thumb should be considered:

- Meshing on the drive side is important.
- Spiral angle not larger than 27 degrees (single directional on drive side).
- Spiral angle not larger than 20 degrees (bidirectional).
- Avoid profile shift as it improves the sliding condition on one member and worsens the sliding condition on the second member.
- Torque increase during start-up (acceleration because output is faster than input) can be considered with L_{EF} factor in Table 2.
- Motion error increase by speed-increasing arrangement is not seen in TCA and leads to flank separation in the case of high output inertia.
- Low output inertia and ratios below 1:3, reduce profile crowning and apply factor D_{LF}.
- High output inertia and ratios above 1:3 require nearly conjugate Ease-Off and apply blended Toprem and heel relief.
- Avoid worm-shaped pinions with less than 5 teeth.
- If high-reduction gearsets with worm-shaped pinions are used, apply the recommendations mentioned with hypoids and use the largest number of pinion teeth possible in the respective design.
- Ground bevel gears should be used as speed increasers.
- Surface hardness of pinion 62 HRC and Gear 59 HRC (or similar).
- Superfinished flank surfaces are mostly an advantage.
- Phosphate-coated surfaces are always an advantage, especially for hypoids.
- Use oil filling or forced lubrication as recommended above.
- Fully synthetic high-pressure oil reduced the risk of scuffing.



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. Of his numerous accolades, the most recent is the Ernst-Blickle Award 2023 presented by SEW Eurodrive Foundation in recognition of his outstanding achievements relating to research into bevel gear technologies, the application of these technologies, and the design of drive systems.

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Hard Skiving of an Internal DIN5480 Spline—A Process Analysis

Dr.-Ing. Thomas Glaser and Jochen Sapparth

Nomenclature

Formula symbol	Unit	Description
α	[°]	Pressure angle
α_{kin}	[°]	Kinematic clearance angle
β_0	[°]	Helix angle tool
β_2	[°]	Helix angle gear wheel
κ	[°]	Position angle
Σ	[°]	Cross-axis angle
φ	[°]	Pendulum angle
ae	[mm]	Engagement width
ap	[mm]	Engagement infeed tool
b	[mm]	Tooth width
fz	[mm/rev]	Tooth feed
fa	[mm/rev]	Axial feed
$hi\ max$	[mm]	Maximum local chip thickness
mn	[mm]	Normal module
n_0	[1/min]	Tool speed
n_2	[1/min]	Rotational speed of work wheel
v_0	[m/min]	Tool peripheral speed
v_2	[m/min]	Peripheral speed of work wheel
v_c	[m/min]	Cutting speed
x	[-]	Profile shift factor
z	[-]	Number of teeth

Introduction

Nowadays, gear skiving is widely used in industry for the production of tooth profiles. It is a highly productive continuous cutting process with a geometrically defined cutting edge for rotationally symmetrical periodic profiles, which is mainly used in the manufacture of toothed components (Refs. 1, 2, 3, 4, 12). Due to developments in the field of cutting materials, machine technology, and process understanding, the process can now also be applied and used on universal machining centers (Refs. 1, 12). In addition, new cutting materials and tool designs enable the machining of soft and hard components, which means that this technology offers great potential for optimization. Due to the complex engagement conditions and the interaction of these with the process parameters and process control, a good understanding of the process is the basis for a stable machining process and high-quality parts during gear skiving (Refs. 1, 3, 12, 15).

This report uses an application case to demonstrate the optimization potential of gear skiving in the production of internal splines on a universal machining center. The process established in the example is then analyzed using the software tool *OpenSkiving* developed by the *wbk Institute of Production Science* of the *Karlsruhe Institute of Technology (KIT)* (Ref. 13) and the results are discussed. Finally, the most important findings are summarized.

Gear Skiving

During gear skiving, the tool and workpiece are engaged and rotate continuously and synchronously in the same way as crossed helical gears (Ref. 1). The tool axis is inclined relative to the workpiece axis by the axis cross angle ∑, which is calculated by the helix angle of the tool and workpiece (Refs. 1, 2, 3). The profile to be produced on the workpiece is created by the rolling process in combination with the tool shape and the relative movement of the tool and workpiece. The cutting speed component v_c is created by the relative movement and the axis position, the feed movement f_a takes place along the axis of rotation of the workpiece, Figure 1 (Refs. 1, 2, 3).

The radial infeed usually takes place in several cuts, which can be adapted to the respective machining case using different infeed strategies. It is often useful to differentiate between roughing, semifinishing, and finishing cuts and to vary the process parameters accordingly.

Different processes and tool types are used in gear skiving. A distinction is made between centric processes with conical tools and eccentric processes with cylindrical tools (Refs. 1,3,4). With conical tools, the clearance angle is designed into the tool. Machining takes place in the center, Figure 2. The regrinding of conical tools is only possible in a small profile accurate area due to the constructive clearance angle. Cylindrical tools are designed without a constructive clearance angle, which means that these tools can be reground profile accurate more often. Due to the lack of a constructive clearance angle, a kinematic clearance angle is generated via an eccentric tool position, Figure 3 (Refs. 1, 4). The different process and tool shapes are shown in Figures 2 and 3. Tools are generally designed as indexable inserts, solid carbide, or HSS tools. The tool selection must be matched to the corresponding machining case.

Compared to conventional methods for machining internal gears, gear skiving offers economic optimization potential. Compared to gear shaping, shorter machining times and lower tool costs compared to gear broaching can be realized (Ref. 3).

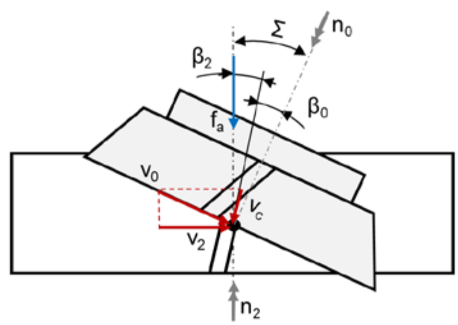


Figure 1—Process kinematics for gear skiving (Ref. 14).

Use Case

New technologies such as skiving offer enormous potential for optimization. To exploit this potential, it is necessary to analyze existing process chains and identify possible starting points. The application case described here involves the production of an internal DIN 5480 spline with small to medium batch sizes of 10–40 parts, the gearing data is summarized in Table 1 (Refs. 8, 9).

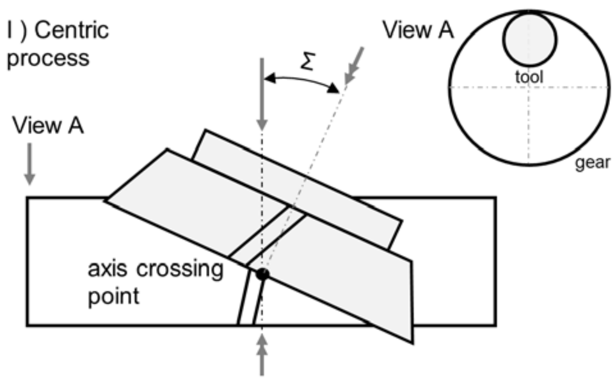


Figure 2—Conical tool (Ref. 14)

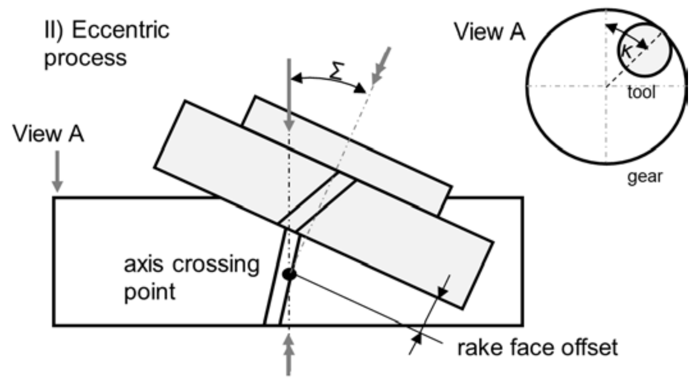


Figure 3—Cylindrical tool (Ref. 14).

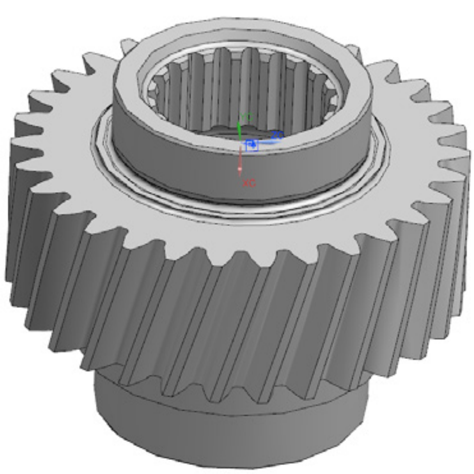
Internal Spline Data	Parameter	Description	
	DIN 5480	NI 62 x 3 x 30 x 19 H6 H8	
	Normal module [mm]	mn	3
	Number of teeth	z	-19
	Profilshift factor	x	-0.283
	Pressure angle [°]	alpha	30
	Helix angle [°]	beta	0
	Face width [mm]	b	29
	Material	CrNi-based case-hardening steel	
	Hardness [HV]		740 +/- 40
	Target pre machining quality	Qpre DIN 5480	10
	Target finish machining quality	Qfin DIN 5480	8

Table 1—Gear data.

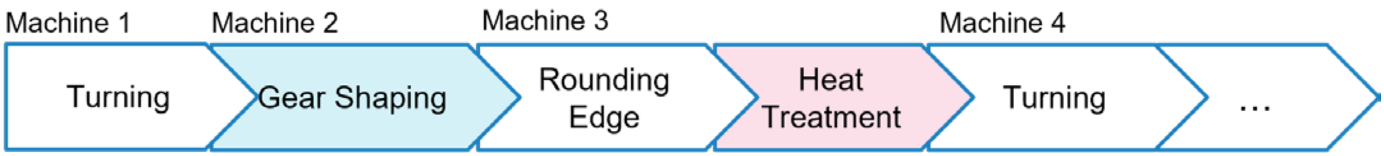


Figure 4—Sequential process chain on single-purpose machines.

The sequential process chain established before optimization is shown in Figure 4.

Sequential machining on single-purpose machines has so far led to a long process chain with a long throughput time. The manufacturing processes commonly used to date for internal gears, such as gear shaping or gear broaching, offer only limited possibilities for economically viable hard-finishing processes, which is why the gearing was previously finished before heat treatment. Due to the lack of a hard finishing process, there was no possibility of compensating for the changes in volume, shape, and position of the gearing induced by the heat treatment. In addition, these geometry changes are very difficult or even impossible to predict due to the large number of influencing factors, making stable prediction extremely difficult. Due to the lack of a hard finishing process, the process chain described was quality-critical and the manufacturing process was not stable.

Due to today's customer and market requirements, continuous process improvements in terms of costs, throughput time, and quality are essential. In the example considered here, the implementation of gear skiving and the associated process integration on a universal machining center made it possible to significantly reduce the process chain and throughput time. By adapting the process characteristics, e.g., to small chip thicknesses and the use of high-performance cutting materials and coatings, it is also possible to carry out hard finishing after heat treatment using gear skiving (Ref. 3). This can sustainably improve component quality. The optimized combined integrative process chain on universal machining centers is shown as an example in Figure 5.

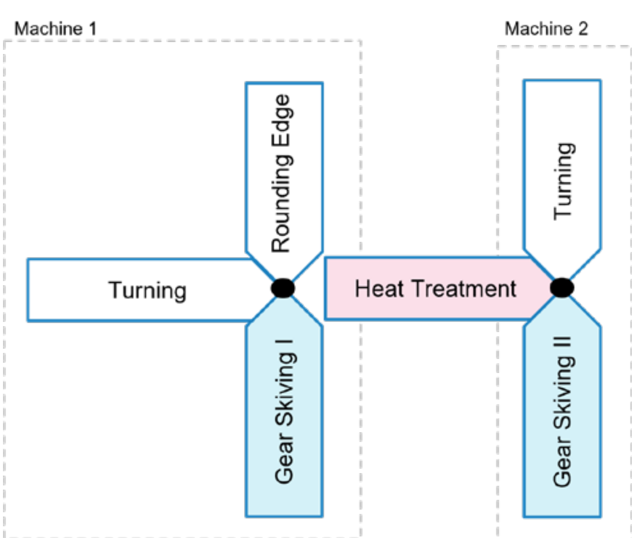


Figure 5—Combined integrated process chain on a universal processing machine.

The tool and process design is crucial for a stable gear skiving process. Due to the complex engagement conditions during gear skiving, which change throughout the process, a deep understanding of the process and high-quality calculation and simulation tools are the basis for a stable process, good component quality, and low tool wear (Refs. 1, 2, 3, 13, 15). In the application considered here, a gear skiving tool was designed for premachining in the soft state and for hard fine machining in the hard state (Ref. 16).

A centric process with a conical tool as shown in Figure 2 is used. The tool data is summarized in Table 2.

Tool Data	
Outer diameter [mm]	46.08
Teeth number [-]	13
Helix angle [°]	17°
Helix direction	RH
Shank diameter [mm]	25
Facewidth of Tool [mm]	11.1
Substrate	solid carbide H10F
Coating	PVD AlCrN
Edge rounding [µm]	6-10
Front rake angle [°]	10°
Clearance angle (TIP)	8°
Clearance angle (Flank)	ca. 3.95°

Table 2—Tool data.

Setup

The components are manufactured on a DMG CTX beta 1250 TC universal machining center with main and counter spindles. The GearSkiving 2.0 gear skiving cycle from DMG is used for process control (Refs. 10, 11). The workpiece is clamped in a collet for gear skiving on the main spindle on the bearing seat previously machined on the counter spindle. Figure 6 shows the tool and the workpiece in the processing machine.

Premachining

During premachining, the root circle is finished with the narrow tool in the direction of the upper root circle dimension without protuberance. The allowance provided in the tool is approx. 0.1 mm/flank. The cutting values summarized in Table 3 are used.

Figure 6—Skiving tool in use.

Cut		vc [m/min]	fz [mm/rev]	ap [mm]
1-5	roughing	100	0.11	0.7 – 0.5
6	semifinish	110	0.08	0.2
7	finish	130	0.04	0.095

Table 3—Cutting data, semifinishing.

Machining is performed with a degressive infeed strategy in seven cuts, whereby the cutting values for semifinishing and finishing are adjusted in the last two cuts. The following figure shows the infeed strategy for semifinishing, Figure 7.

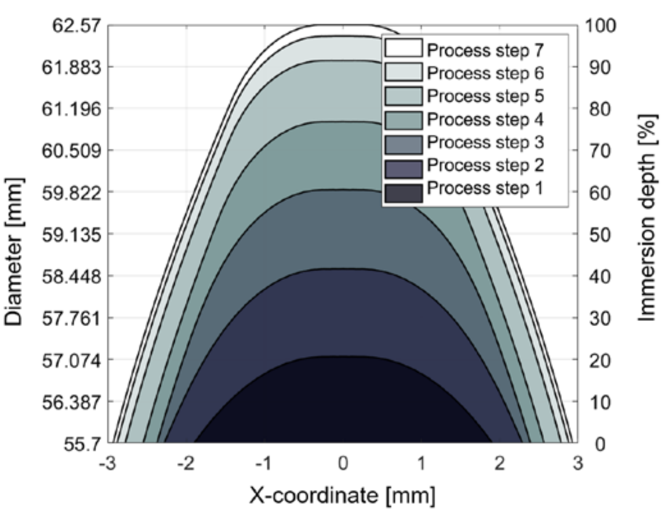


Figure 7—Premachining infeed strategy, OpenSkiving result graphic (Ref. 13).

Finishing After Heat Treatment

After heat treatment, machining takes place in the same setup as during premachining. Due to the existing tooth gaps in the workpiece, determining the tooth gap position is crucial for machining after heat treatment. For this purpose, a macro was implemented on the universal processing machine which determines the angular position of the tooth gap using a measuring probe. Figure 8 shows the determination of the tooth gap position on the processing machine and the tool cutting edge centered in the tooth gap.

In addition to the angular position of the tooth space on the workpiece, the exact angular position of the cutting edge must also be determined. Deviations in the angular positions of the tool and workpiece lead to incorrect effective positions in the process, resulting in deviations in the tooth profile and changing the meshing conditions.

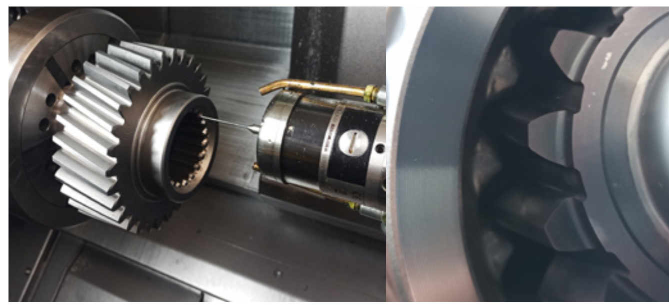


Figure 8—Indexing on the processing machine and tool in the engaged position.

Hard machining is carried out in a single flank cut in the application to reduce the tool load. The infeed is performed rotationally via the pendulum angle φ separately for the right and left tooth flank. This reduces the tool load and both tooth flanks can be corrected and modified independently. Machining is carried out with the theoretical machining parameters summarized in Table 4. Due to the changes in shape, position, and volume induced by the heat treatment and inaccuracies in determining the angular position, the actual infeed in the process can vary in the first cut.

Cut		vc [m/min]	fz [mm/rev]	φ [°]	ae [mm]
1		60	0.08	0	0
2, 3	semifinish	60	0.04	+/- 0.151	0.065
4, 5	finish	60	0.04	+/- 0.302	0.065

Table 4—Cutting data, hard-fine-machining.

The used processing principle is outlined in Figure 9.

In hard fine machining, it is advisable to design the process parameters in such a way that the resulting chip thickness is low to reduce the load on the tool's cutting edge. The process considered here was simulated with *OpenSkiving* (Ref. 13) to evaluate the chip thickness, clearance, and rake angle as well as cutting arc length, etc. arising in the process. Figure 10 shows the calculated values of the maximum local chip thickness over the unwound tool cutting edge.

The analysis shows that the process according to Table 4 produces very low local chip thicknesses along the tool cutting edges. These small chip thicknesses lead to a low tool load,

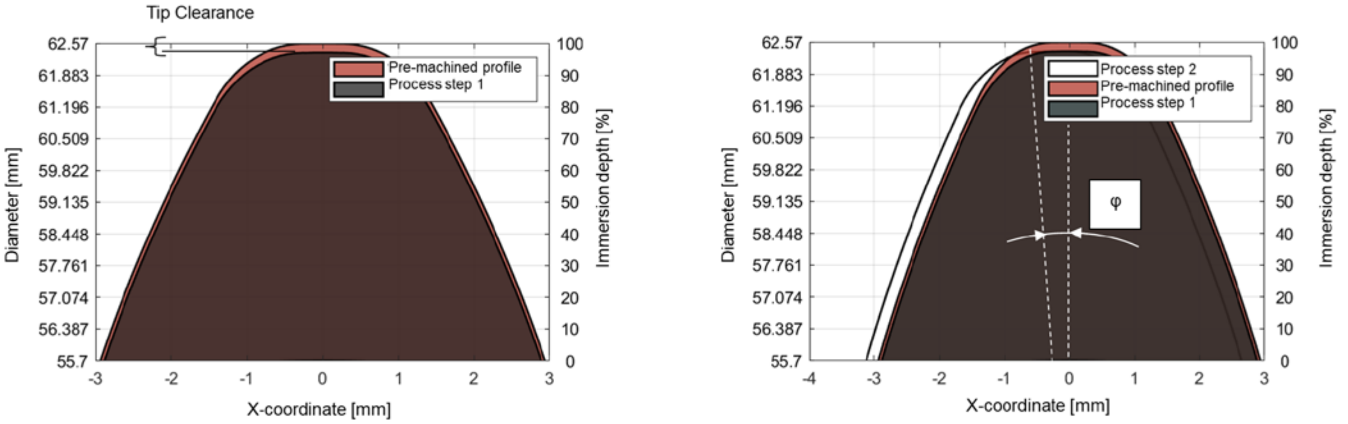


Figure 9—Processing principle hard skiving, OpenSkiving result graphic (Ref. 13).

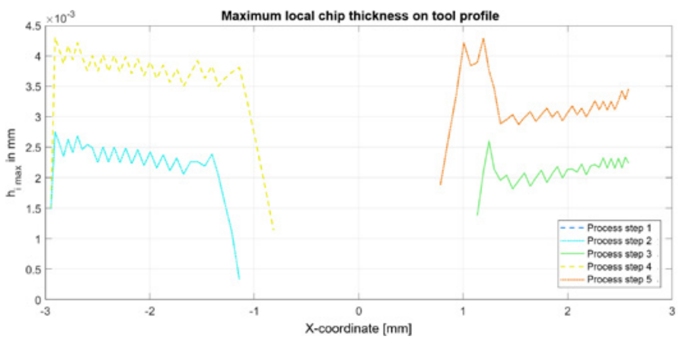


Figure 10—Maximum local chip thickness on the unwound tool profile, OpenSkiving result graphic (Ref. 13).

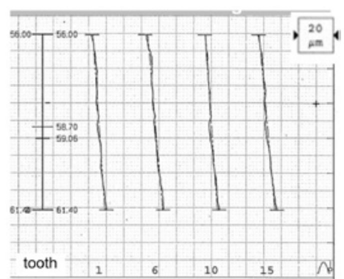


Figure 11—Profile angle error before correction.

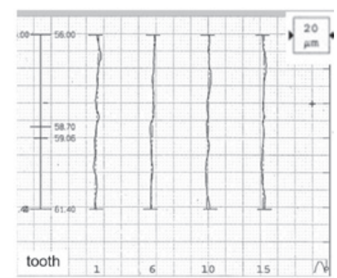


Figure 12—Corrected profile.

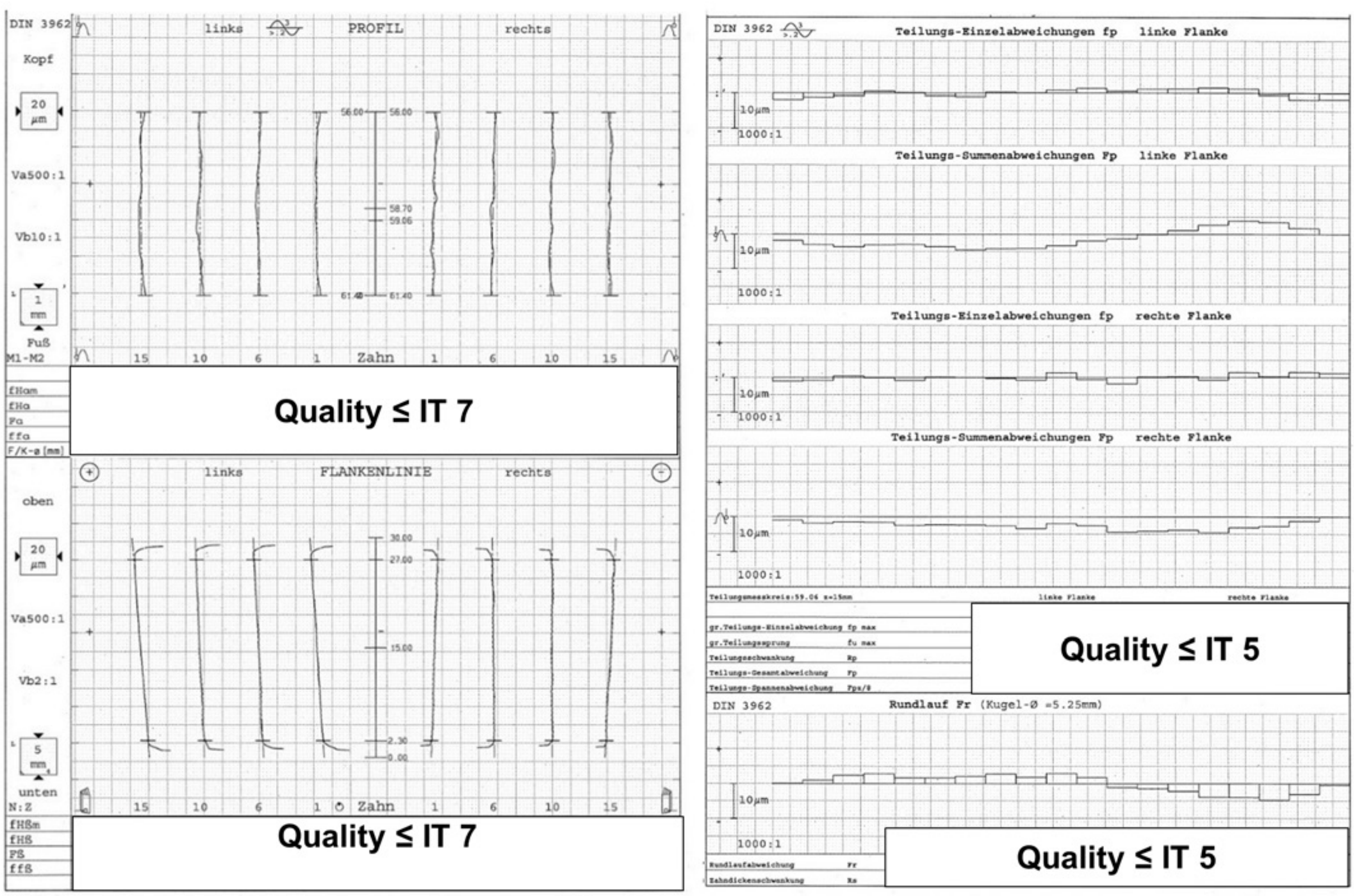


Figure 13—Final result hard hard-skived internal spline.

which is beneficial for hard machining. Single flank machining reduces the contact length of the tool's cutting edges. It is also seen, that the tool tip area with the theoretically expected maximum chip thickness is left out (Refs. 1, 2). This has a positive effect on tool wear and machining quality.

The chip thickness is influenced by the axial feed, among other things. When adjusting the axial feed, a compromise must be found between tool load, envelope cut deviation in the flank direction, and machining time to meet the requirements for hard machining.

During the implementation of the hard skiving process, profile angle deviations were observed on the right tooth profile, the outgoing flank, Figure 11. These profile angle deviations are partly due to the different meshing conditions on the incoming and outgoing flanks. The profile angle deviation can be corrected by correcting the relative position of the tool to the workpiece. Here, the position and axis cross angles are the control variables. In the application considered here, the profile angle error $f_{H\alpha}$ on the right tooth flank could be corrected by adjusting the axis cross angle Σ. For the correction of such deviations, a deeper understanding of the process and the support of calculation models for process simulation is necessary (Refs. 13, 15). Figure12 shows the corrected result after adjusting the process control.

Figure 13 summarizes the final results after process optimization. In addition to the evaluation according to DIN 5480 (Refs. 8, 9), the gearing was also evaluated according to DIN 3962-1 to DIN 3962-3 (Refs. 5, 6, 7) in order to be able to evaluate the quality achieved in relation to this standard. The gearing qualities reliably achieved in the hard skiving application are summarized in Figure 13.

Result and Summary

By changing the process from sequential processing on single-purpose machines to combined processing on universal processing machines, the process chain and therefore the throughput time could be reduced by three weeks. The use of new cutting materials and technologies has also drastically reduced the machining costs of internal spline by 30–50 percent. Furthermore, the newly introduced hard-finishing process increases component quality and significantly reduces quality costs. In the example presented here, process integration, process analysis, and optimization made it possible to introduce process-reliable hard fine machining with skiving up to a quality of IT 7.

The right process design is always a balancing act between cost-effectiveness, quality, and process stability. Here, gear skiving offers a wide range of control variables that must be coordinated on a case-by-case basis.

Practical implementation in production shows that a cross-functional understanding of the process by all parties involved in the process is essential for the successful implementation of gear skiving technology (Ref. 15).

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Dr.-Ing. Thomas Glaser has worked for J.M. Voith SE & Co. KG | Group Division Turbo since 2018 as an operating engineer with a focus on gear technology. In addition, he is a leading member of the CoC Gear Production of Voith Turbo.

Jochen Sapparth has accumulated 37 years of experience as a mechanical engineer within the Sandvik Group, specializing in cutting tools across various sectors. Over the past 13 years, he has served as a project engineer concentrated on Sandvik Coromant gear-cutting tools and strategies with a primary focus on power skiving.

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Ernst-Blickle Award 2023

PRESENTED TO PROF. DR. HERMANN J. STADTFELD

Prof. Dr. Hermann J. Stadtfeld, vice president of the Gleason Corporation in Rochester, New York, has been presented with the Ernst-Blickle Award 2023 in recognition of his outstanding achievements relating to research into bevel gear technologies, the application of these technologies, and the design of drive systems. Presented every two years, this award comes with prize money of 100,000 euros, making it one of the biggest and most prestigious awards worldwide. At the joint award ceremony, 17 carefully selected university graduates from Germany, Austria, and Switzerland also received Graduate Awards in recognition of their excellent bachelor's and master's theses. Graduate Awards are presented each year by the SEW Eurodrive Foundation and are each worth 2,500 euros.

In presenting the Ernst-Blickle Award to Prof. Stadtfeld, the SEW Eurodrive Foundation of SEW Eurodrive – the global market leader in drive and automation technology headquartered in Bruchsal–is honoring a man who has not only been responsible for pioneering developments in drive technology but whose work also benefits society. Prof. Stadtfeld was born in 1951 in Manderscheid, a small town in the southern Eifel mountains in the Rhineland-Palatinate region of Germany. He also grew up there, starting off his school years in the town's elementary school. He began his career with a toolmaker's apprenticeship at Zahnradfabrik Friedrichshafen (ZF) in Schwäbisch Gmünd. He also continued working toward his high school graduation certificate at night school. He then went on to study mechanical engineering, first in Dortmund and later at RWTH Aachen University.

In his award speech, Prof. Fritz Klocke, deputy chairman of the SEW Eurodrive Foundation board, spoke about this award winner's remarkable career, the key milestones in his research activity, and his services to society. As Prof. Klocke pointed out, it is no easy task to summarize Prof. Stadtfeld's achievements, which include more than 60 inventions that have been registered for patents.

Prof. Stadtfeld's fundamental inventions and research results have revolutionized the manufacture of bevel and helical gear units and are still used in the industry on a daily basis – including in the cutting-edge production workshops at SEW Eurodrive. "Thanks to Prof. Stadtfeld, today's bevel gears deliver 5 to 10 percent better efficiency and a power density that is around 30 percent higher compared to 20 years ago," pointed out Prof. Klocke in his award speech. He paid tribute not only to the inventions themselves but also to how Prof. Stadtfeld enables both the world of drive technology and society to benefit from his work. Thanks to his many publications, both the specialist sector and industrial companies all over the world can reap the rewards of his work. He successfully achieves the difficult task of sharing complex specialist knowledge in a clear, easy-to-understand way. "As a passionate university lecturer, he has passed on his enthusiasm for mechanical engineering to many young people, and has helped and supported them in their education," said Prof. Klocke. Here, he particularly addressed his remarks to the young people from Germany, Austria, and Switzerland, who were also being presented with awards at the ceremony. In total, 17 university graduates received Graduate Awards from the SEW Eurodrive Foundation in recognition of their outstanding academic performance and degree theses. Each award comes with prize money of 2,500 euros.

The guests at the award ceremony learned more about Prof. Stadtfeld from Prof. Klocke's speech–for example, the fact that his love of technology started in his very early childhood and that he delighted his classmates with his experiments from a very young age. The audience also heard how, in his limited and precious free time, Prof. Stadtfeld turns his technical aptitude and skills to re-storing

vintage cars and pursuing creative woodworking projects.

"I've always wanted to know exactly how something works and all the details of how things are interlinked. I kept on working at it, learning and studying, until I had solved the problem and had a crystal-clear understanding of how everything is interlinked." This is apparently how Prof. Stadtfeld himself described his love of both pure research and applied science. He certainly does not believe in working in isolation, as another of his many quotes makes abundantly clear: "People who work alone get backed up; people who collaborate multiply themselves!"

After being presented with the prize by Jürgen Blickle, chairman of the SEW Eurodrive Foundation and managing partner of SEW-Eurodrive, Prof. Stadtfeld made it very clear in his speech of thanks that he was highly honored to have received the award. Given the previous winners of this award from the SEW Eurodrive Foundation, who include what he described as the "crème de la crème of gearing technology experts in the Western world", he said that, as the 21st winner of the Ernst-Blickle Award , he felt as though he had been admitted to the "hall of fame". The 1997 award winner, Prof. Manfred Weck, who passed away in 2023, had a huge influence on him as his PhD supervisor. He also has a personal connection with the 2006 award winner, Prof. Bernd-Robert Höhn, whose father was a primary school teacher in Manderscheid, the town where Prof. Stadtfeld grew up.

sew-eurodrive-stiftung.de/en/

JULY 16–18

WZL Gear Conference USA

The 10th WZL Gear Conference – USA is being hosted by Gleason Corporation in Rochester NY and will provide the opportunity for North American companies to connect with WZL and learn about current research activities. For more than 50 years the annual WZL Gear Conference in Aachen, Germany, has been fostering technical collaboration and communication among the members of the WZL Gear Research Circle. The two-day conference is devoted exclusively to the presentation of the latest research in gear design, manufacturing, and testing. Additionally, the software resources of the WZL Gear Research Circle are available for examination, including solutions for ger design and manufacturing process development. Participants of the conference are encouraged to tour the WZL laboratory with its shop floor and test rigs. Within this environment associations are formed and the exchange of knowledge among the members of the technical community is promoted. With up to 300 participants from Europe and overseas, the WZL Gear Conference is one of the largest annual events dedicated to gear technology in Europe.

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IMTS 2024

The International Manufacturing Technology Show (IMTS) is the largest manufacturing technology show in the Western Hemisphere. The IMTS conference brings the industry together to discuss new opportunities and network with the manufacturing community. Highlights in Chicago include the Smartforce Student Summit, Exhibitor Workshops, the Emerging Technology Center and more. Pavilions include additive, gear generation, machining, tooling, quality, automation, software, and more. Explore even more exhibits at the Automation Sector featuring advanced motion systems, vision and imaging, data analytics, systems integration, artificial intelligence, and cloud and edge computing.

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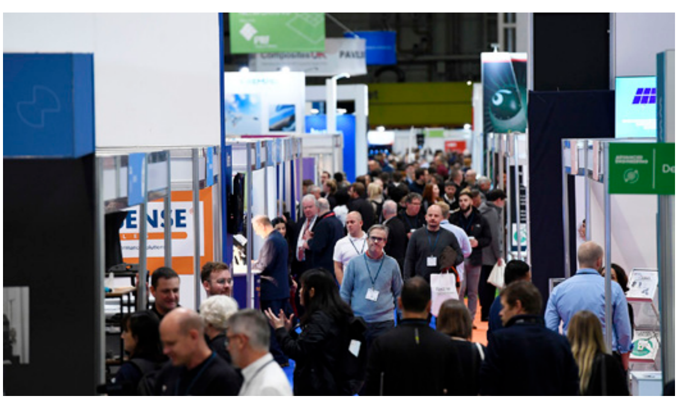

Advanced Engineering (Birmingham) has rebranded to celebrate the evolution and new developments in industrial manufacturing. Sectors include aerospace, automotive, defense, composites, marine, rail, energy, medical and more. To ensure that visitors and exhibitors can still easily find relevant contacts, Advanced Engineering exhibitors will now be categorized by the services, products and solutions offered. They will have the opportunity to highlight all of the sectors they work in, removing any limitations created by the specific show zones. Advanced Engineering will welcome back a full speaker program with representatives from some of the leading companies in UK manufacturing including GE, Shell, ZF, Bosch, Siemens, 3M, IBM, Airbus and more.

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NOVEMBER 6–7

Aachen Conference on Gear Production 2024

Although gears have been indispensable components in various areas such as mechanical engineering, the automotive industry and industrial gear production for many decades, increasing requirements and current market developments are constantly presenting the drive technology sectors with new challenges. The aim of the Aachen Conference on Gear Production is an exchange of knowledge and experience between engineers who work in or are responsible for the design, development, production, assembly and application of gears.

geartechnology.com/events/5101-aachen-conference-on-gear-production

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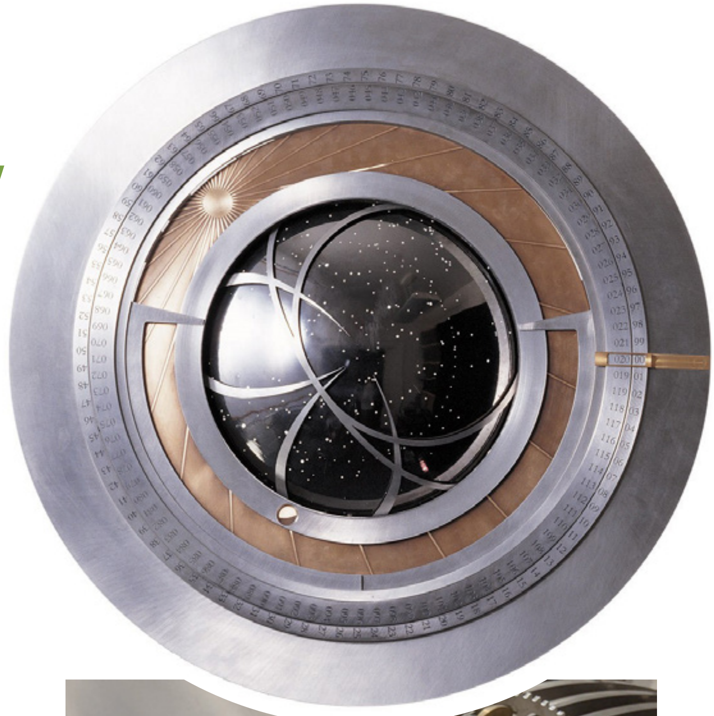
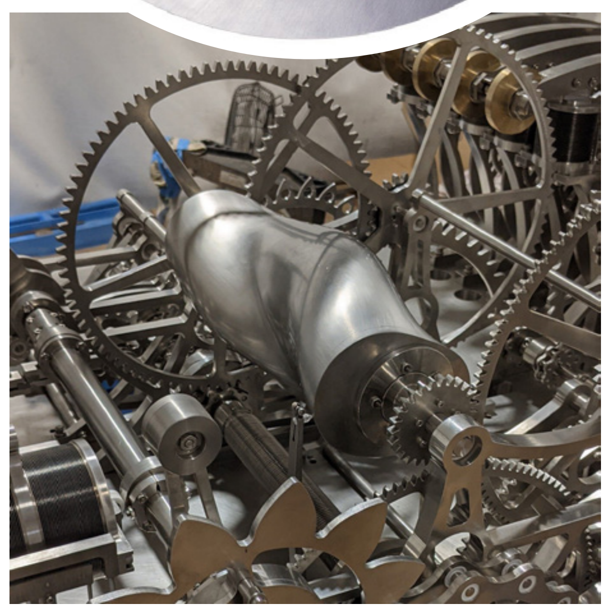
The Long Now

Aaron Fagan, Senior Editor

"The Long Now is the recognition that the precise moment you're in grows out of the past and is a seed for the future."

—Brian Eno (founding board member of The Long Now Foundation)





The 10,000-Year Clock, also known as the Clock of the Long Now, is a visionary project aimed at fostering long-term thinking and responsibility. Located inside a mountain in West Texas on land owned by Jeff Bezos, this clock is designed to keep accurate time for 10,000 years, serving as a powerful symbol of longevity and sustainability.

The clock is a creation of the Long Now Foundation, a non-profit organization founded in 1996 by a group including Danny Hillis, Stewart Brand, and Brian Eno. Danny Hillis, the lead designer, envisioned a timepiece that could endure millennia, challenging humanity to think beyond our lifetimes and consider the long-term impact of our actions. The clock is powered by thermal cycles—the difference in temperature from night to day—and mechanical winders, ensuring minimal human intervention.

At the heart of this ambitious project are its gears, designed and crafted with exceptional precision and durability. The gears were manufactured by Machinists Inc., a Seattle-based company renowned for producing high-quality, complex parts for industries like aerospace, medical, and energy. Their involvement underscores the high level of expertise and craftsmanship required to create components that can endure for ten millennia.

The gears are made from stainless steel and titanium, materials chosen for their strength, corrosion resistance, and long-term durability. These properties are essential for the clock to withstand the environmental conditions inside the mountain over thousands of years. The largest gears, with diameters measuring several feet, reflect the monumental scale of the clock and the robust nature of its mechanisms.

The production of these gears involves advanced machining techniques, including computer numerical control (CNC) milling and turning. These methods allow for the precise shaping and cutting necessary to meet the exact specifications of the clock. The precision of the gears ensures the smooth operation of the clock's intricate mechanical system, which is crucial for maintaining accurate timekeeping over such an extended period.

The gears are installed deep within the mountain that was chosen for its geological stability and isolation. This controlled environment helps protect the clock from external influences and potential damage. Designed to require minimal maintenance, the clock's choice of materials and the precision of its gears ensure it can run with minimal human intervention. This aspect is critical to the clock's longevity and reliability.

Beyond their functional role, the gears carry significant symbolic meaning. They represent human ingenuity and the potential for creating lasting legacies. The intricate design and durable construction of the gears serve as a metaphor for the careful consideration and effort needed to address long-term challenges. They remind us of the importance of thinking beyond immediate concerns and focusing on the future of our planet and society.

The 10,000-Year Clock is a fascinating blend of art, engineering, and philosophy. Its gears, crafted with unparalleled precision and durability, are central to the project's success. As a monument to long-term thinking and sustainability, the clock inspires us to consider the enduring impact of our actions and to become stewards of the future. By encouraging a broader perspective, the 10,000-Year Clock aims to foster a greater sense of responsibility and stewardship for generations to come.

longnow.org