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MARCH/APRIL 2026

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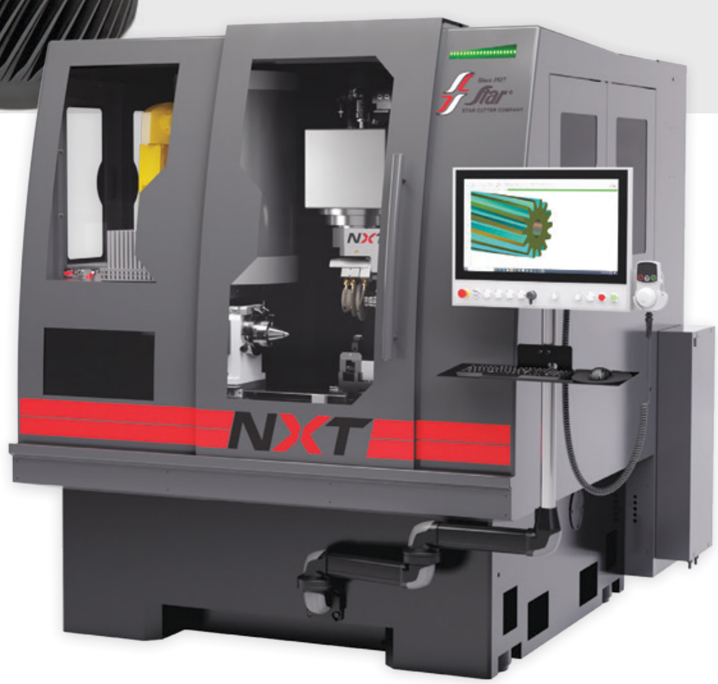

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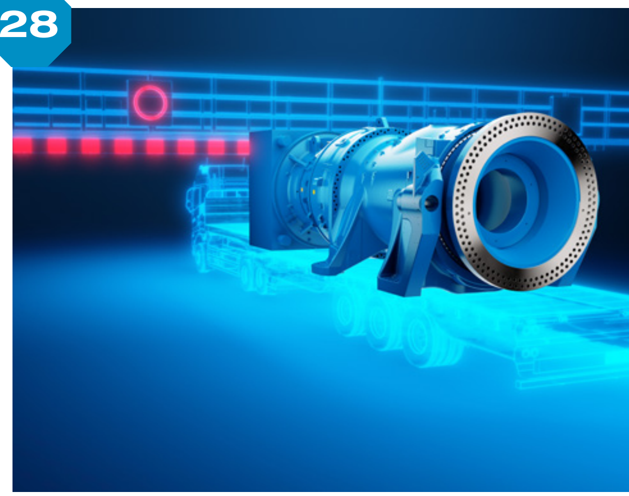

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From smarter alloys to water-spray quenching, this issue explores the latest advances in gear heat treatment and manufacturing.

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GT REVOLUTIONS

After the Ruling

In March, when we published "Farewell to an Idea," the gear industry was bracing for the full weight of Section 232 tariffs—25 percent on steel and aluminum, no more exclusion process, no more relief valves. The Supreme Court case challenging the president's broader IEEPA tariffs was still months from oral argument. The question then was how to survive. The question now is different.

geartechnology.com/after-the-ruling

Broaching Fundamentals

In a single stroke, a broach can transform a pilot hole into a finished involute spline or a precision keyway to tight tolerances. That combination of speed and accuracy is why broaching remains one of the most enduring metal-cutting processes in gear manufacturing.

geartechnology.com/broaching-fundamentals

AS SEEN IN *PTE*

Input Shaft Tradeoff Options for Single Speed Gear Reducers

As expected, EV demand has waned following some deregulation and tax credits being dropped as of September 2025. For us industry folks, this is simply reality catching up with the narrative. On the plus side, 2025 was a very good year for global vehicle sales—the best since 2019. A good economy can forgive many blunders. As gearbox designers, our work continues as our EV offerings are likely a permanent part of our product lineup, even if at a reduced volume.

powertransmission.com/input-shaft-tradeoff-options-for-single-speed-gear-reducers

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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

The Fact and Fiction of Man vs. Machine

Aaron Fagan, Senior Editor

Around the corner from my home in Tyler, TX, the Liberty Theater is screening *Metropolis*. Fritz Lang set his dystopian epic in the year 2026, and now that the calendar has caught up, the film is making the rounds again. Nearly a century ago, Lang imagined this year as an industrial future defined by towering skylines, vast machinery, rigid class division, and workers reduced to components in a system too large to comprehend.

The imagery is unforgettable: bodies moving in rhythm with pistons, humans absorbed into gear trains, the machine elevated above the person. The metaphor works because it assumes interchangeability. All the things of this world are eminently replaceable, anonymous, and identical.

But anyone who has spent time in gear manufacturing knows this is not how the world actually works. On a drawing, a gear appears exact. The involute is mathematically defined. The pressure angle is specified. In the abstract, geometry behaves. In steel, reality asserts itself. Every gear carries the imprint of its making. Tool wear leaves its signature on the flank. Heat treatment introduces distortion that must be anticipated and corrected. Even in highly automated environments, variation is merely managed, never erased.

Our industry functions not because parts are identical, but because variation is understood, measured, and controlled. Tolerances are not admissions of failure; they are acknowledgments of physical truth. Statistical process control exists because steel does not read blueprints. The machinist, the quality engineer, and the process technician remain essential not because automation is inadequate, but because the physical world resists reduction.

The articles in this issue illustrate this principle in action. When Gleason (p. 16) developed its A(X) infeed strategy for profile grinding, the solution was not to force the grinding wheel into an ideal path, but to adapt the swivel angle stroke by stroke to match the actual tooth-gap geometry as material is progressively removed. The result: 21 percent cycle time reduction by responding intelligently to variation rather than ignoring it.

Similarly, when Ovako (p. 35) engineers confronted intergranular oxidation in conventional carburizing steels, they did not attempt to perfect the atmospheric carburizing environment. Instead, they redesigned the alloy itself—20NiMo9-7—to respond differently to the same physical conditions, achieving fatigue performance that eliminates compensatory post-treatment.

***The Liberty Theater marquee in Tyler, TX, announces a revival screening of* Metropolis*, which was set in 2026 and debuted in the United States on March 13, 1927.* (Image: Aaron Fagan)**

The pattern repeats throughout this issue. PairGears (p. 24) presents a heat treatment selection framework built not on ideal material behavior, but on matching duty requirements to actual process windows and proof tests. Dr. Heuer's technical article (p. 40) on water spray quenching offers adjustable intensity precisely because one quench profile cannot suit all geometries and hardenabilities. Flender's (p. 28) achievement of 300 Nm/kg torque density in wind gearboxes represents design evolution within real constraints—transportation limits, tower loading, material availability, acoustic requirements. Sandvik's (p. 21) focus on exchangeable-tip drills for high-volume holemaking acknowledges that in production environments, tools wear and geometry varies; consistency comes through quick, reliable adaptation.

In the real year of 2026, we find ourselves not in Lang's imagined dystopia where machinery overpowers humanity, but in a manufacturing world where advanced automation, digital twins, and AI-assisted monitoring work alongside human expertise. The irreducibility of physical variation has made human judgment and process knowledge more essential, not less. Machines extend capability, but they do not eliminate judgment.

The popular imagination still uses gears as symbols of sameness and submission to a system. Those of us who work with them understand something different. A gear is not a faceless cog. It is a precisely engineered component whose reliability depends on disciplined attention to variation. It performs not because the world is perfectly reducible, but because skilled people refuse to ignore the parts that are not.

As we publish this March/April issue, it is worth remembering that precision is not the denial of reality; it is the art of working within it.

KR

TITAN ULTRA PROVIDES SECURE PERFORMANCE FOR HEAVY-DUTY APPLICATIONS

Kuka Robotics announced a new addition to its product portfolio with the KR Titan ultra robot. Designed for load-intensive automation applications, the robot combines extensive reach with precise dynamics ideal manufacturers the automotive, battery/electromobility, and large part handling, as well as heavy logistics sectors.

The KR Titan ultra's mechanical design supports stable motion during high-payload operation. The robot's kinematics and structural rigidity are optimized to support accurate path control across a wide range of projects.

The KR Titan ultra weighs 4.6 tons and carries a payload of up to 1,500 kg and a reach of up to 4,200 mm, depending on the specific application. This allows the robot to withstand lifting various difficult-to-lift parts, including battery packs, car chassis, engine blocks and other large components.

The KR Titan ultra's versatile geometry allows for the efficient use of available floor space, supporting deployment in new installations and retrofit scenarios. It's also compatible with Kuka's controller technology for easy integration into automated production environments that require connectivity with modern safety systems and digital manufacturing workflows.

The mechanical components of the robot are designed for continuous industrial operation, with a focus on maintaining uptime and reducing maintenance demands over the lifecycle of the robot.

kuka.com

Hainbuch

EXPANDS MAXXOS FAMILY OF MANDRELS WITH T-212

Hainbuch has expanded its Maxxos family of mandrels with the Maxxos T-212, a next-generation ID clamping solution engineered around a powerful idea: geometry creates rigidity.

At the center of the Maxxos design is a hexagonal pyramid clamping interface that replaces the traditional round mandrel connection between the mandrel body and the segmented clamping bushing. Instead of relying on friction alone, the hexagonal geometry creates a positive mechanical fit that dramatically increases torque transmission and resistance to vibration.

The result is a mandrel that holds parts with exceptional stability, even during aggressive machining operations.

Compared to conventional round mandrels, the Maxxos system delivers greater transmissible torque and higher rigidity. This added stability allows shops to increase feed rates, take heavier cuts, and maintain consistent part quality while extending tool life.

The hexagonal pyramid design distributes forces across six contact surfaces rather than relying on a single round interface. This creates a highly rigid connection between the clamping bushing and the mandrel body, reducing micro-movement and improving damping during machining.

In practical terms, the Maxxos T-212 behaves less like a traditional mandrel and more like a structural extension of the spindle, giving manufacturers the confidence to push machining parameters further while maintaining process reliability.

The Maxxos T-212 also features a draw-bolt-free design, making it ideal for components with blind bores or minimal clamping lengths. Because no draw bolt extends into the workpiece, the full clamping length of the mandrel can be utilized, providing greater flexibility for challenging part geometries.

An integrated pull-back effect ensures the workpiece is securely positioned against the end stop, improving axial stability and supporting repeatable precision during complex machining operations.

The mandrel offers runout accuracy of ≤0.01 mm as standard, with ultra-precision options available down to ≤0.002 mm.

Combined with Hainbuch's segmented clamping bushings, the Maxxos T-212 delivers a combination of precision, rigidity, and vibration damping, enabling manufacturers to achieve both high performance and consistent part quality.

The Maxxos T-212 is designed for shops that need more than traditional ID clamping can provide. By combining the structural strength of hexagonal geometry with Hainbuch's advanced clamping technology, the system delivers the stability required for modern high-performance machining.

hainbuchamerica.com

Weiler Abrasives

INTRODUCES TIGER 3D MAX CERAMIC FLAP DISCS AND BLENDING DISCS

Weiler Abrasives announced the new Tiger 3D MAX Ceramic flap discs and blending discs, which are products built for maximum material removal, durability and consistency. This expansion of the 3D MAX lineup brings advanced precision-shaped grain technology to a wider range of grinding applications.

"Our 3D MAX technology is built to let the grain do the work," says Michael Zulauf, product manager, Weiler Abrasives. "By maximizing the cut rate and reducing the effort required by the operator, we are helping our customers improve efficiency and consistency and reduce fatigue, all while cutting down on costly disc changeovers."

The Tiger 3D MAX products feature 3D precision-shaped grain to help operators remove more material in less time. The grain stands upright and micro-fractures to stay sharp. The design also optimizes grain retention, which extends product life.

Tiger 3D MAX Ceramic flap discs are designed for maximum metal removal while maintaining control across a wide range of grinding and finishing applications. Flap discs are available in 4.5- and 7-in. sizes, with 7/8 open arbor and 5/8-11 hub options.

Blending discs are available in both Type S and Type R style connections to allow for quick mounting and disc changes.

The Tiger 3D MAX portfolio also includes resin fiber discs.

3D precision-shaped grain maximizes cut rates, enabling up to 30 percent faster material removal than standard ceramic grain. Optimized grain retention extends product life and reduces changeovers. A specialized top coat reduces heat buildup and glazing, protecting high-value parts from discoloration and damage. Micro-fracturing grain technology lets the grains do the work, reducing the required operator pressure and making tough grinding jobs easier. Both disc types are contaminant-free, making them safe for use on stainless steel and aluminum.

weilerabrasives.com

MFI

WILL DEBUT INDUSTRY'S SMALLEST FINISHING MACHINE AT RAPID + TCT 2026

Mass Finishing Inc. (MFI) will unveil its new HZ-6 compact, centrifugal barrel-tumbler finishing machine at the RAPID + TCT 2026 event April 14–16 at the Thomas M. Menino Convention and Exhibition Center in Boston. At Booth #2033, visitors will learn how this new system reduces labor costs, decreases production times and frees up valuable floorspace. The compact finishing machine removes both surface roughness and scale simultaneously to consistently generate mirror-like finishes on 3D printed metal parts.

MFI described the HZ-6 as the smallest industrial high-energy finishing machine on the market. A footprint of only 3-ft. x 2-ft. allows the machine to fit into most operations without sacrificing finishing speed or quality. An optional stand with large caster wheels is available and multiple available barrel styles give the machine flexibility to work in most industries.

For the simultaneous finishing of multiple parts, the machine uses the pressure and friction created through centrifugal force to remove excess material and burrs, polish part surfaces and create a uniform finish. MFI said the system is quieter than vibratory tumblers and achieves finishes that are isotropic, meaning parts are polished uniformly and evenly in all directions.

The machine's barrel tumbler features two cradle positions, a standard full-size latched-end barrel (8.375 in.), and two half-size latched-end barrels (3.625 in.). When using the full-size barrel, the HZ-6 accommodates parts up to 8-in. long and 4.5-in. o.d., while the half-size barrels are suited for processing small, micro-precision parts. The barrels require a small amount of media, which makes for easy iterative testing with different material types and processing diameters.

Centrifugal barrel finishing, also known as centrifugal barrel tumbling, operates on the "Ferris Wheel" principle with a one-to-one ratio of barrel rotation to turret rotation. The process involves loading one or all four chambers with a mixture of parts, water, compound and media, which are filled to 50–80 percent capacity. As the machine rotates, the barrels spin around the turret in a planetary motion, creating a highly effective sliding force inside the barrel.

The machine is suited for common part materials such as titanium, aluminum, Inconel, nitinol, printable plastics, carbon steel, gold and silver. For the best finishing results, it uses ceramic, plastic and porcelain media in a variety of 3D shapes and size variations.

massfin.com

Tungaloy

RESPONDS TO RISING CARBIDE COSTS WITH LONG-TERM SOLUTIONS

As cost pressure increases, manufacturers are being challenged not only to manage higher prices but also to rethink how cutting tools are designed, used and replaced. Tungaloy is addressing this challenge through tool architecture. The company emphasized using exchangeable-head solid carbide systems that reduce material consumption and environmental impact while achieving high machining performance.

Conventional solid carbide tools require full replacement once worn. With exchangeable-head systems, only the worn cutting head is replaced, reducing carbide usage, limiting waste, and lowering exposure to raw-material price volatility.

Tungaloy's DrillMeister drilling system and TungMeister milling system are designed around this principle. Beyond material efficiency, the modular design provides a high degree of versatility. TungMeister offers a wide range of milling heads for applications such as high-feed, face, shoulder, slotting and chamfering operations, while DrillMeister provides various drilling heads optimized for different drilling requirements. This flexibility allows manufacturers to adapt to changing production needs while reducing tooling inventory.

When material costs continue to rise, the industry must look beyond short-term reactions. Smarter, long-term solutions are needed, including solutions built into the architecture of the tool itself. By reducing material waste and improving versatility, manufacturers can maintain productivity and stability even under changing conditions.

tungaloy.com

Vomat

SUPPORTS GRINDER OF THE YEAR COMPETITION FOR YOUNG TALENT

Modern precision tools are created through the perfect interaction of the entire grinding process chain—from the machine, software, grinding wheel and clamping technology to the cooling lubricant. Clean, temperature-stable cooling lubricant microfiltration forms the basis for consistent quality, efficient processes, and sustainable manufacturing. As a supporter of the Grinder of the Year (GOTY) competition for young talent at GrindingHub 2026 in Stuttgart, filter specialist Vomat from Treuen is investing in the future of grinding technology together with other renowned technology providers and positioning itself against the shortage of skilled workers.

"As co-sponsor of GOTY 2026, Vomat is contributing its expertise at precisely this interface. The competition shows that top quality in tool grinding is always the result of a perfectly coordinated overall system. For us, this commitment is a logical consequence of our own self-image: promoting enthusiasm for technology, process knowledge, and quality thinking at an early stage," said Steffen Strobel, technical sales manager at Vomat.

The GOTY competition for young talent has been held since GrindingHub 2024. Organized by the PR and advertising agency KSKcomm, the challenge offers young grinding talents a platform to demonstrate their technical skills, their understanding of processes, and their confident use of modern grinding technology. Grinding is carried out on the Helitronic Mini Plus from Walter, which provides participants with state-of-the-art machine technology as the competition machine.

The GOTY is therefore aimed specifically at young professionals and trainees in the DACH region. The aim is to make the multifaceted job profile of grinding specialists in metalworking more visible, attractive, and technologically tangible, thereby helping to counteract the shortage of young talent and skilled workers. Through the interaction of machines, peripherals, and process partners, the competition demonstrates in a practical way how crucial the smooth interaction of all components is for reproducible grinding results. It brings young grinding talents together with leading technology partners in the industry and highlights how closely interlinked the individual process steps are in practice.

Modern precision tools are created through the perfect interaction of the entire grinding process chain. The key to this is an optimally coordinated overall system that makes quality, cost-effectiveness, and sustainability possible in the first place. The cooling lubricant and its purity play an often underestimated but central role in this.

"In tool grinding, the condition of the cooling lubricant has a decisive influence on surface quality, dimensional accuracy, service life, and process stability. Fine particles from grinding abrasion, binder residues, or carbide dust act like grinding paste in the process: they deteriorate surfaces, increase tool wear, destabilize the process, and drive-up costs. High-performance fine filtration of cooling lubricants should not be a secondary process. It is a fundamental factor in productivity and quality in tool grinding," adds Strobel.

Vomat filters clean at full flow and separate dirty and clean oil 100 percent. This means that the user always grinds with pure cooling lubricant. To keep the filters clean, Vomat technology flushes them back as needed. To do this, the degree of contamination of each individual filter element is determined. Once a certain value is reached, the control system automatically initiates the backflushing process. Meanwhile, the other filter elements continue to ensure a continuous and complete supply of clean oil with a purity level of 3–5 μm. This fully automatic control and regulation of the filter capacity keeps energy and operating costs low. In addition, Vomat technology controls the temperature of the cooling lubricant medium within a range of ±0.2 K during the grinding process. With special concepts for recycling and reprocessing, the recyclable material can be collected directly in the recycling company's collection container and then disposed of and reprocessed in a cost-optimized manner.

"With intelligent, energy-efficient microfilter systems, Vomat pursues a holistic approach to cooling lubricant management. The systems are modular in design, can be integrated close to the process, and are designed to keep the cooling lubricant in optimal condition at all times—regardless of the material, grinding strategy, or batch size. They thus make a decisive contribution to stable processes, lower operating costs, and reproducible tool quality. As co-sponsor of the GOTY 2026 competition for young talent, we emphasize the importance of a clean, stable, and intelligently managed cooling lubricant system for excellent grinding results, while at the same time sending a clear signal for the promotion of young talent and process thinking," said Strobel.

Vomat will be exhibiting at Grindinghub in Hall 7, Booth #D80, where it will be showcasing high-performance solutions for fine filtration of cooling lubricants. At the GOTY competition booth (Hall 9, Booth #D45), the focus will be on the entire tool manufacturing process chain. Grindinghub takes place May 5–8.

vomat.de

Siemens

DELIVERS VERIFIED AI-DRIVEN CYBERSECURITY SOLUTION FOR INDUSTRIAL 5G WITH PALO ALTO

At Mobile World Congress 2026, Siemens announced a cybersecurity solution for industrial private 5G Networks in collaboration with Palo Alto Networks. The solution combines Siemens' Private 5G infrastructure with Palo Alto

Networks' Next-Generation Firewall (NGFW), specifically optimized for AI.

"A pharmaceutical plant has different security requirements than an automotive assembly line," says Michael Metzler, vice president of horizontal management cybersecurity for digital industries at Siemens. "Siemens' verified solution with Palo Alto Networks addresses these industry-specific needs through purpose-built architecture. Manufacturers get secure 5G connectivity tailored to their operations without performance trade-offs."

"Palo Alto Networks and Siemens are not just connecting the factory floor, we are building the central nervous system for the future of industry—a future that is intelligent, autonomous and secure by design," says Dharminder Debisarun, smart industries cybersecurity executive at Palo Alto Networks.

Palo Alto Networks has specifically optimized its Next Generation Firewalls technology for Siemens' Private 5G infrastructure through Siemens' extensive testing across multiple deployment scenarios.

Siemens has specifically tested and verified the solution for industrial environments in its Digital Connectivity Lab in Erlangen (Germany).

Siemens' private 5G Infrastructure provides on-premises, deterministic wireless connectivity for mobile and moving assets with built-in security features protecting the core network infrastructure.

SINEC Security Monitor, which is Siemens' software for passive, non-intrusive, continuous on-premises security monitoring during production, identifies communication anomalies, unauthorized devices, or potential threats without impacting production operations.

Palo Alto Networks Firewall delivers Layer 7 security and OT protocol analysis specifically optimized for industrial environments. It provides deep packet inspection for OT protocols while maintaining the low latency required for real-time control applications—now also in wireless communications via private 5G networks. This includes protection against malware, intrusion attempts, and data exfiltration without the performance degradation typical of off-the-shelf security tools.

This verified architecture meets IEC 62443 requirements for industrial automation and control systems security. The solution is now available as part of the Siemens *Xcelerator* portfolio, an open digital business platform where companies of any size can find, try, and buy the technologies they need. It brings together solutions from Siemens and certified partners in one marketplace to help solve industrial challenges from production planning to supply chain and customer management.

siemens.com

Profile Grinding of Large Gears

Increasing material removal efficiency through advanced infeed strategies

Dr. Antoine Türich, Director Product Management Hard Finishing Solutions, Gleason Corporation

(All images: Gleason Corporation)

Profile grinding is the hard-finishing process of choice for large gears with demanding requirements regarding load transmission, running smoothness, and complex tooth modifications. No other hard-finishing process offers a comparable level of flexibility across such a wide range of applications. Profile grinding can be applied to very small as well as very large gears, to external and internal gearing, to involute and non-involute tooth forms, to components with and without interfering contours, and to both simple and highly complex tooth modifications. Furthermore, profile grinding allows the achievement of excellent quality levels that cannot be attained by any other hard-finishing process over this broad application range.

Traditionally, the only disadvantage attributed to profile grinding has been its productivity. As a single-tooth-gap process, it is associated with higher nonproductive idle times compared with continuously generating processes. Through consistent further development of both process technology and machine design, however, this perceived disadvantage has been largely eliminated. This article presents examples illustrating how material removal efficiency during profile grinding can be significantly increased by optimizing the infeed strategy.

Conventional Infeed Strategy

When non-grinding time is discussed, attention is often limited to unproductive machine and workpiece movements between individual tooth gaps. However, the machining of

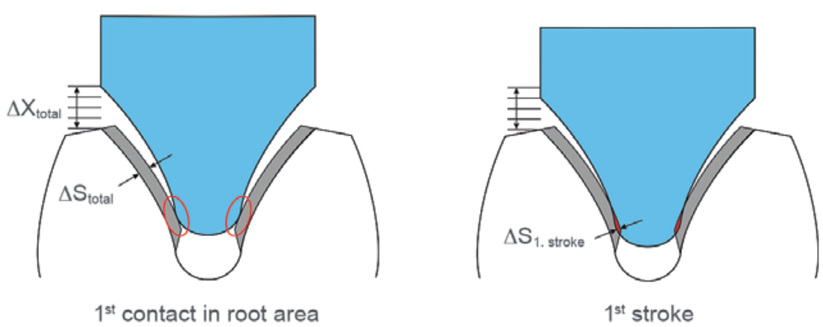


Figure 1—Contact conditions using a conventional infeed strategy.

each tooth gap itself already offers considerable optimization potential. To identify this potential, it is necessary to first understand the traditional infeed strategy that is still commonly applied in profile grinding.

In conventional profile grinding, the total stock to be removed—including heat treatment distortion—is typically removed successively in multiple grinding strokes or passes. The grinding wheel is dressed to the final tooth gap geometry, including any specified profile modifications. Due to the remaining stock, however, the grinding wheel does not initially fit into the tooth gap. As illustrated in Figure 1 (left side), contact occurs only in the lower profile region near the tooth root.

If the same radial infeed is applied in each grinding stroke, material removal during the first strokes is very limited and concentrated primarily in the lower portion of the tooth profile toward the root. Full contact along the entire tooth profile is achieved only in later strokes (in the example shown, starting with the third of four strokes). Consequently, the full material removal potential of the process is not utilized from the beginning but only during subsequent strokes. The initial strokes are therefore highly inefficient, even though the same infeed values and feed rates are applied as in all other strokes. This inefficiency can be clearly observed by analyzing the spindle power used during grinding (Figure 2, left side).

In the example shown, the first two of four grinding strokes require only very low spindle power, reflecting the extremely low material removal rate in these strokes. Only during the third and fourth strokes does spindle power reach the level corresponding to the defined process parameters. A noteworthy detail is that the highest spindle power of 15.8 kW occurs in the final stroke. In addition, this infeed strategy results in uneven loading of the grinding wheel along the tooth profile, which can lead to premature and unevenly distributed wheel wear.

The described effect of inefficient and uneven material removal occurs on all machines using a conventional infeed strategy, which is still common practice in many applications. For gears with low tooth numbers, the curvature of the involute profile is more pronounced, further intensifying this effect.

Degressive Infeed Strategies as Starting Point for Optimization

Uneven material removal associated with the conventional infeed strategy can be partially compensated for by using a degressive infeed strategy. In this case, larger radial infeed is applied in the initial strokes, followed by smaller infeed in the later strokes. The effect of this strategy can again be clearly seen by evaluating spindle power demand (Figure 2, right side).

Although full contact along the entire tooth profile is still not achieved in the first stroke, the subsequent strokes show significantly higher and more evenly distributed spindle power levels. In addition, the maximum spindle power required (12.6 kW) is approximately 3 kW lower than with the conventional strategy, even though the same gear geometry is ground. This reduction in maximum spindle power corresponds either to a lower risk of grinding burn or to additional potential for increasing feed rates and thus productivity.

While the degressive infeed strategy reduces inefficiencies within the grinding cycle, it still does not provide full utilization of the material removal potential in the early strokes.

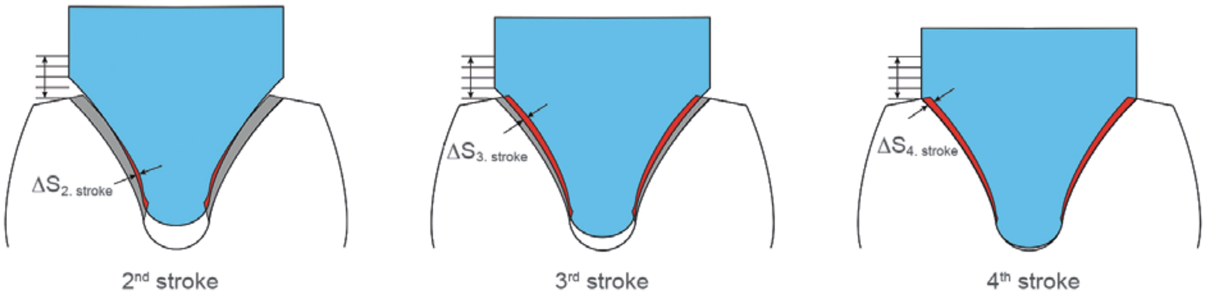
A(X) Technology: Ensuring Optimal Contact Conditions

To achieve maximum material-removal efficiency in nearly all grinding strokes, a further infeed strategy, referred to as A(X), was developed by Gleason. This patented technology uses an additional adjustable parameter critical to profile grinding: the swivel angle of the grinding wheel relative to the gear. This angle does not necessarily have to correspond to the helix angle (β) of the workpiece.

Different swivel angle settings are commonly used in practice, depending on the intended objective. While the contact line between the grinding wheel and a tooth gap of a spur gear ($\beta = 0$) lies in a single plane—the axial plane—this contact line is spatially distributed along the tooth flank in helical gears ($\beta \neq 0$) (Figure 3).

The contact line, therefore, extends axially along the tooth gap on both the left and right flanks. The start position, end position, and axial length of the contact lines on the two flanks can be strongly influenced by the selected swivel angle. Each swivel angle variant requires an individually calculated and dressed grinding wheel profile.

In conventional double-flank profile grinding, the swivel angle is often selected such that the contact lines on the left and right flanks are located at the same axial position. This ensures that the grinding wheel engages and disengages both flanks simultaneously during a grinding stroke, preventing



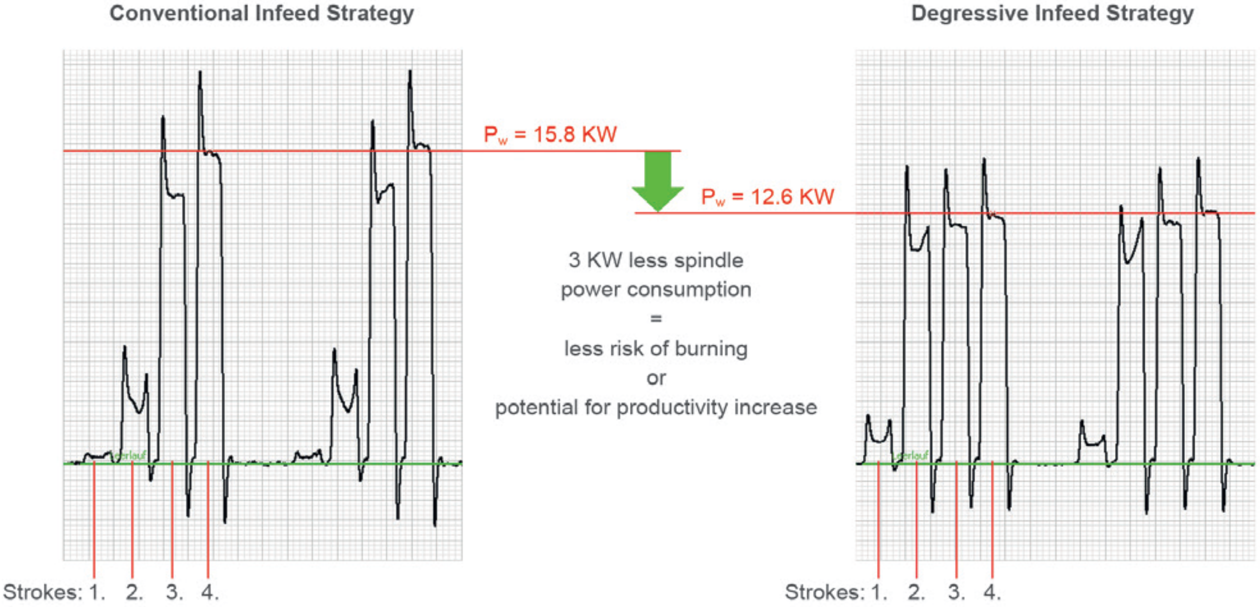


Figure 2—Spindle power consumption conventional infeed strategy versus degressive infeed strategy.

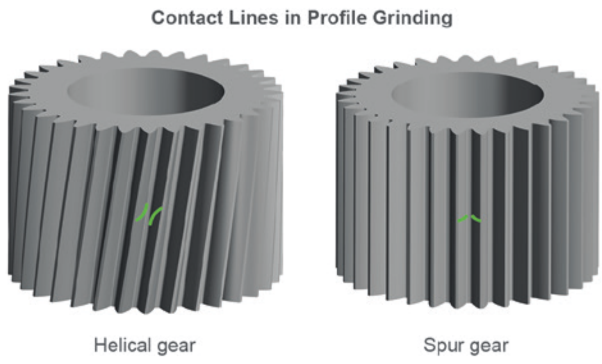


Figure 3—Contact lines in profile grinding.

undesired entry and exit effects caused by grinding-force-induced flank deflection. Such effects often appear in measurement as unwanted flank-line deviations at the beginning and end of the contact zone.

Other swivel-angle variants are used, for example, to minimize the axial extension of the contact line, thereby largely avoiding bias/twist effects during single-flank grinding. Additional swivel angle settings can be applied to achieve balanced peak positions of flank line crowning (c_β) on the left and right flanks.

With the A(X) infeed strategy, the swivel angle of the grinding wheel varies from stroke to stroke without changing the grinding wheel profile. The grinding wheel is dressed for the swivel angle effective in the final stroke and remains unchanged throughout the entire grinding process. By adjusting the swivel angle for each grinding stroke, the contact line between the grinding wheel and the tooth-gap geometry in that stroke conforms optimally to the profile.

As a result, near-full contact along the entire tooth profile is achieved in almost every stroke, with the contact line running nearly equidistant to the tooth profile. Material removal per stroke is therefore uniform along the profile and consistent across all strokes. In contrast to conventional and degressive strategies, the grinding wheel is no longer subjected to localized loading but is instead loaded evenly over the entire profile. This uniform and highly effective material removal allows the total stock to be removed in fewer grinding strokes, resulting in a significant reduction in cycle time with reduced process risk, such as thermal damage, so-called grinding burn. The designation A(X) reflects the underlying mathematical relationship, in which the swivel angle (A-axis) is adjusted as a function of the radial infeed (X-axis).

Application Example: Planetary Gear for Wind Turbine Gearboxes

The effectiveness of the degressive infeed strategy and A(X) infeed strategy is demonstrated using a practical application example of a planetary gear typical for modern wind turbine gearboxes. The gear parameters were as follows: number of teeth (z) = 33, module (m) = 24 mm, helix angle (β) = 8.1 degrees, pressure angle (α) = 20 degrees, tip diameter (da) = 894 mm, and face width (b) = 600 mm. The assumed tooth flank stock, including heat-treatment distortion, was 0.7 mm.

Using the conventional infeed strategy as a reference, the stock was removed using 17 roughing strokes and two finishing strokes, resulting in a total cycle time of 82 minutes. With the degressive infeed strategy, two roughing strokes could be eliminated, reducing cycle time to 78 minutes (–5 percent). By applying the A(X) infeed strategy, the number of roughing strokes was reduced to 11, resulting in a total cycle time of 65 minutes and a cycle time reduction of 21 percent.

	conventional	degressive	A(X)
Roughing strokes	17	15	11
Finishing strokes	2	2	2
Total strokes	**19**	**17**	**13**
Total cycle time [min]	**82**	**78**	**65**
Cycle time improvement		-5%	-21%

Table 1—Comparison of different infeed strategies.

Figures 4 to 6 show the actual material removal per stroke for the different variants, with the tooth flank allowance in µm plotted on the vertical axis and the tooth profile plotted as roll length on the horizontal axis from the root (Lf) (left) to the tooth tip (La) (right). Analysis of the material removal per stroke shows

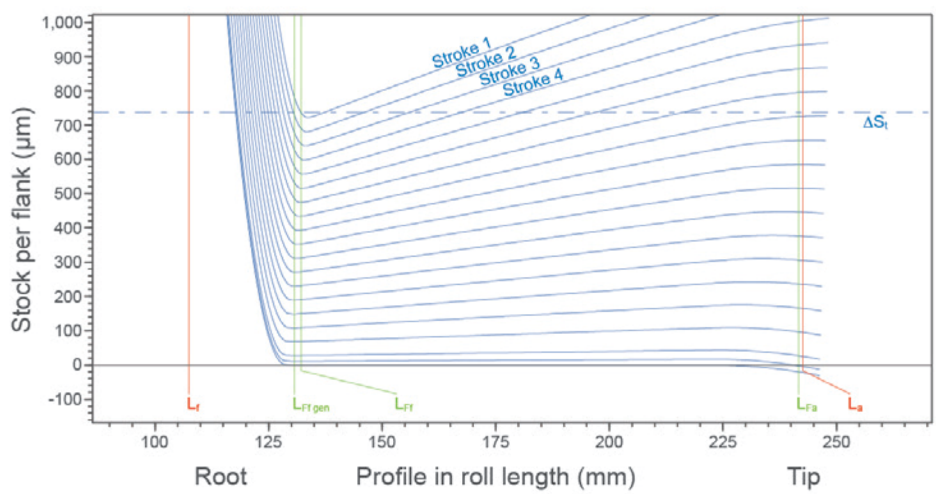


Figure 4—Material removal for all passes with a conventional infeed strategy.

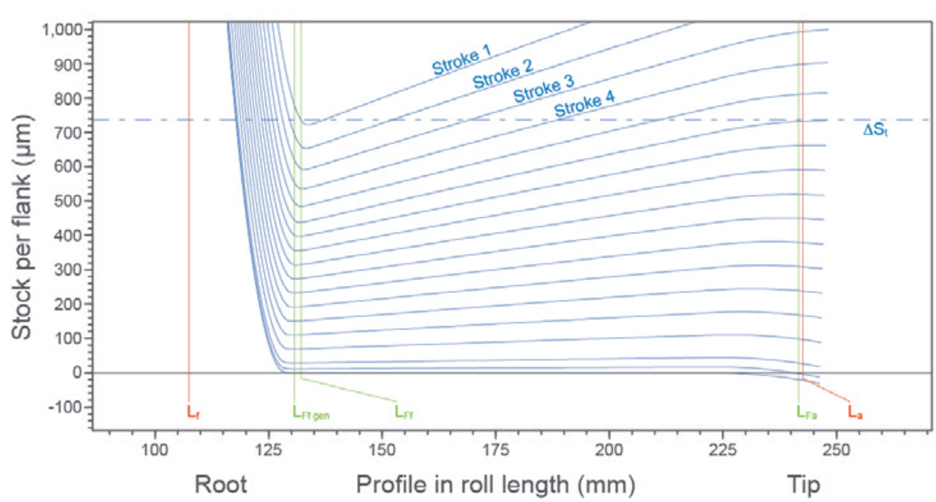


Figure 5—Material removal for all passes with a degressive infeed strategy.

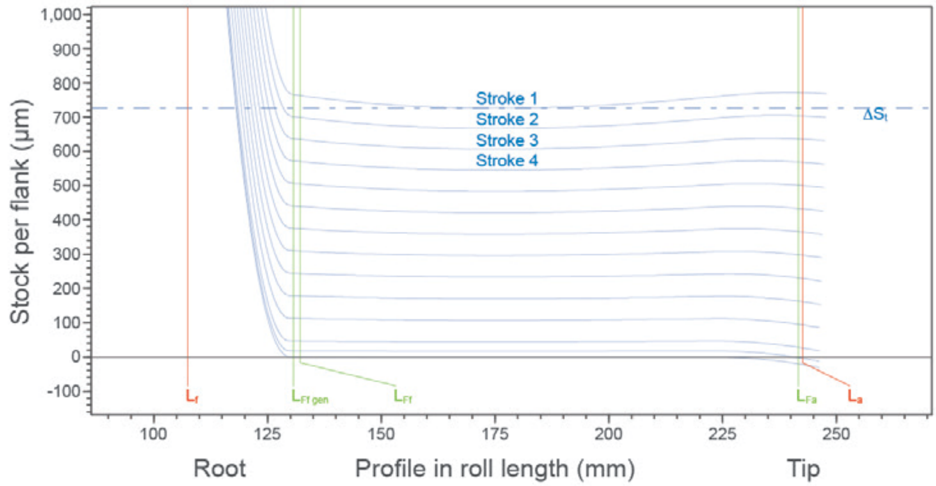


Figure 6—Material removal for all passes with the A(X) infeed strategy.

Figure 7—All Gleason profile grinding machines up to 6,000 mm in workpiece diameter feature the A(X) infeed-strategy software.

that the conventional strategy requires seven strokes before full contact along the entire tooth profile is achieved. With the degressive strategy (Figure 5), full contact occurs after five strokes, while with the A(X) infeed strategy (Figure 6), full contact is achieved starting with the second stroke. The diagrams further illustrate how closely the grinding wheel profile conforms to the tooth gap geometry when using the A(X) infeed strategy, as indicated by nearly parallel material removal curves across successive strokes.

In all three strategies, the maximum material removal measured perpendicular to the tooth flank is identical. This indicates that the significantly shorter cycle time achieved with the A(X) infeed strategy does not increase the risk of grinding burn.

The A(X) infeed strategy is available with many other technological functions, such as smart dressing, wobble and eccentricity compensation, and twist-controlled double-flank grinding to maximize efficiency, productivity, and gear quality. These functions are implemented on all high-precision Gleason profile grinding machines, covering gear sizes up to 6,000 mm in workpiece diameter.

Conclusion

By combining advanced infeed strategies with modern machine technology, the traditional productivity limitations of profile grinding can be largely overcome. While degressive infeed strategies already reduce inefficiencies, the A(X) infeed strategy enables near-constant contact conditions and uniform material removal throughout the grinding cycle. This results in substantial cycle time reductions without compromising quality or process stability, making profile grinding a highly competitive hard-finishing process for large, high-performance gears.

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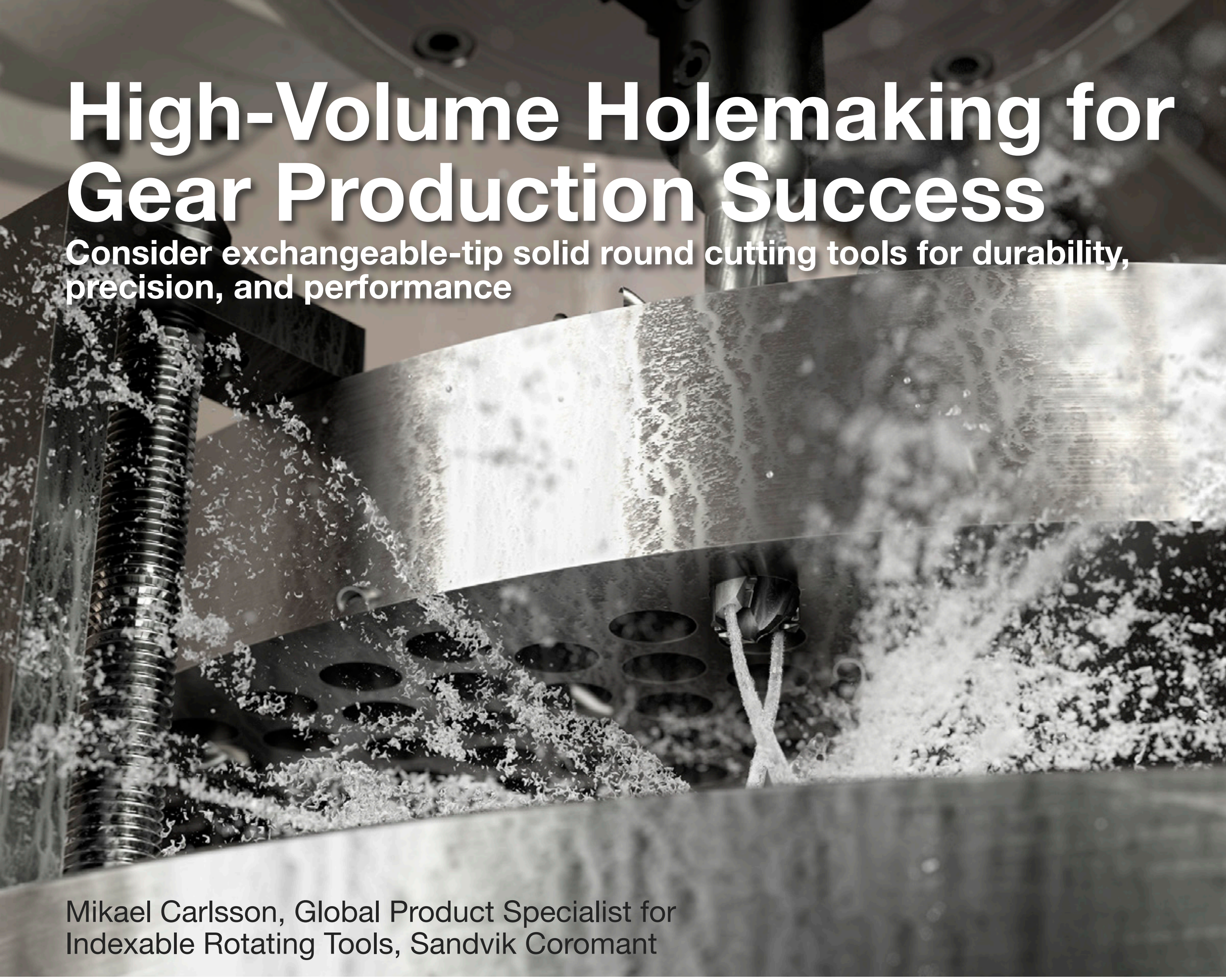
High-Volume Holemaking for Gear Production Success

Consider exchangeable-tip solid round cutting tools for durability, precision, and performance

Mikael Carlsson, Global Product Specialist for Indexable Rotating Tools, Sandvik Coromant



When drilling in high volumes, exchangeable-tip drills can offer a highly efficient solution. **(All images: Sandvik Coromant)**

High-volume holemaking in gear production demands not only speed and efficiency but also precision and reliability, particularly when working with critical components such as gearbox housings and gear blanks. These parts often require tightly toleranced holes that must be perfectly aligned to ensure proper assembly, load transfer, and long-term durability. For manufacturers, achieving these standards while maintaining cost-effectiveness is an ongoing challenge.

Gearbox housings are complex, high-precision components that typically require multiple critical holes, all of which must meet tight tolerances to ensure proper alignment, sealing, and load distribution.

Drilling operations may be complicated by the materials involved, such as hardened or alloyed steels, and by the geometric demands of the parts themselves, which can introduce access limitations or require long-reach tools. Maintaining consistent hole quality across high production volumes—all while managing heat buildup, chip evacuation, and tool stability—makes gearbox drilling a particularly demanding area of metal cutting.

Common Gearbox Challenges

So, what must manufacturers consider when drilling holes for gearboxes? Challenges for this application go beyond basic holemaking, and accuracy is everything.

Gearbox housings, for instance, typically involve several types of precisely located holes, including bolt-circle patterns for cover and case fastening, dowel-pin bores for alignment, and through-holes for mounting the housing to the vehicle chassis or transmission subassemblies. These holes often vary in diameter and depth but share a common requirement: strict positional tolerances and consistent surface finish to ensure proper mating with gears, bearings, and shafts.

Because housings are usually forged from materials such as cast iron and then semi-finished to tight specifications, the drilling process must contend with scale, hard inclusions, and interrupted surfaces—all of which can increase tool wear and risk of vibration or deflection. Additionally, holes are often located near thin sections, where stability can be compromised, and chip evacuation becomes difficult.

Even though these hole depths are typically short or moderate, it's essential to ensure the drilling occurs without excess vibration or misalignment so the gearbox can function as intended. In high-volume production, these challenges are further amplified by the need for long tool life, minimal setup time, and consistent hole quality across a large run of parts. Addressing them requires a drill that combines strong centering capability, predictable wear behavior, and robust design.

Gear Blank Challenges

It's also important to consider components that will interact with these housings, such as gear blanks. As the pre-machined forms that will eventually become finished gears, these components must align seamlessly with bearings, shafts, and the gearbox housing itself. Gear blanks are often made from hardened or alloyed steels, which require precise machining tolerances. Ensuring that gearbox housing holes are produced to exact measurements will help maintain the overall dimensional stack-up that's required for these hard components to fit and function properly.

Since gear blanks are subject to extremely high forces during machining, especially during tooth cutting, any flaws in alignment can be magnified downstream in the drivetrain. Precision in holemaking is therefore not only critical for assembly, but also for ensuring the long-term performance of the gearbox.

Machining Tips

The overall machining setup plays a critical role in ensuring process stability, tool life, and part quality in gearbox and blank machining and directly impacts the overall machining result. For short- to medium-depth drilling, especially in alloyed or cast materials common to gearbox housings, moderate to high feed rates and cutting speeds are typically used to maintain productivity. However, stability and chip evacuation must be carefully balanced.

Excessive speed can lead to heat buildup and premature tool wear, while an insufficient amount of speed can result in poor chip formation, something that can lead to serious consequences such as increased tool wear, poor hole quality, and possible chip jamming. Coolant plays an integral role in alleviating issues with chip jamming, and an optimized chip flute geometry with twisted coolant holes encourages good chip evacuation.

Using internal coolant supply at pressures between 145–436 psi (10–30 bar) is generally recommended, particularly in blind or interrupted holes, to promote reliable chip evacuation and minimize heat transfer to the workpiece. Emulsion-based coolants are most common for steel and cast iron, though some shops may use straight oils for improved surface finish in critical sealing surfaces or alignment bores.

Consider Exchangeable-Tip Drilling Tools

Selecting the right drilling tool is pivotal to overcoming the challenges of high-volume holemaking in gear production and to achieving consistent, high-quality results. The ideal drill must balance

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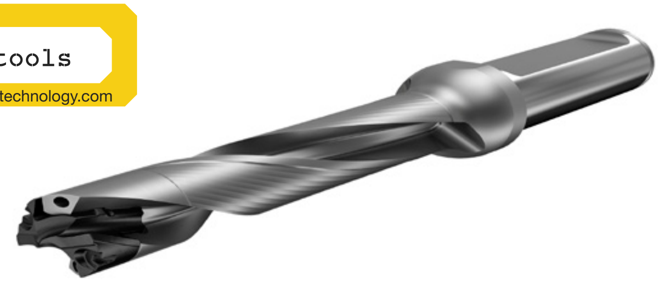
Featuring a replaceable carbide tip, tool changes can take place faster without needing to remove the drill body from the holder.



When drilling components such as gear housings and gear blanks requiring tight positional tolerances, exchangeable drill tips can give manufacturers better process stability while lowering overall tooling costs.

Some exchangeable-tip drills, like Sandvik Coromant's CoroDrill DE10, are designed to eliminate the need for a pilot hole, thereby drastically reducing cycle times.

accuracy, durability, and productivity, especially in high-output environments where even small improvements can yield significant cost and time savings.

When drilling in high volumes, exchangeable-tip drills can offer a highly efficient solution. Featuring a replaceable carbide tip, tool changes can take place faster without needing to remove the drill body from the holder. In addition, some exchangeable-tip drills are designed to alleviate the need for pilot holes or presetting equipment, thereby drastically reducing cycle times and minimizing the reliance on operator intervention.

An exchangeable-tip drilling strategy can reduce downtime, simplify inventory in busy machine shops and ensure more consistent hole quality. When drilling components such as gear housings and gear blanks that demand tight positional tolerances, using exchangeable drill tips gives manufacturers better process stability while lowering overall tooling costs.

When considering exchangeable-tip drills, it's important to evaluate the clamping interface. Choose one that enables fast and easy tip changes without spare parts, ensures reliable drilling at high feeds and speeds, and delivers superior clamping strength. This will help you achieve straighter holes with tighter tolerances. It also extends drill body life for a more robust exchangeable-tip drill.

Improving Productivity in Gearbox Drilling

Recently, an automotive manufacturer faced issues with high cutting forces deforming its drill bodies, specifically while machining gearbox housing components from 47CrMo4 alloyed steel. This issue led to tool failures and increased costs.

Switching to Sandvik Coromant's CoroDrill DE10 resolved these challenges. DE10 is an advanced exchangeable-tip drill that's engineered specifically for high-volume holemaking and is shown to boost productivity while streamlining operations, thanks to its advanced M5 tip geometry. This innovative design achieves an ideal balance between high feed rates and precise penetration, enabling the tool to deliver exceptional performance across diverse materials from steel alloys to stainless. And, as a plug-and-play solution, CoroDrill DE10 integrates easily into existing setups, making it a practical upgrade for manufacturers without having to overhaul their systems.

Using a feed rate of 0.0138 in./rev (0.35 mm/rev) at a depth of cut of 2.5 times the drill diameter, the tool delivered a 17 percent productivity boost. CoroDrill DE10's robust design and patented pre-tension clamping interface ensured exceptional accuracy, extended tool life, and minimized downtime.

As gearbox designs grow more complex and production volumes continue to rise, manufacturers face mounting pressure to improve accuracy, consistency, and cost-efficiency in holemaking. Success in this area depends not only on smart machining strategies and optimal cutting parameters but also—and perhaps most critically—on selecting the right tool for the job.

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Gear Heat Treatment Selection with a Duty Test Matrix

A practical framework for matching requirements to process routes and proof tests

Feng Liu, CEO of PairGears

Heat treatment decisions for gears are often reduced to a surface hardness number. That shortcut can work for mild duty, but it frequently breaks down when contact fatigue, scuffing risk, shock events, distortion limits, or finishing constraints become dominant. Many late-stage issues trace back to the same pattern: the duty case is incompletely defined, the process window is underestimated, or verification confirms "a number" without proving the full property profile.

This article offers two practical tools for cross-functional reviews and early process alignment. Table 1 links common duty drivers to a shortlist of heat treatment routes, helping teams narrow options quickly and consistently. Table 2 maps each route to a minimum proof-test plan—case/layer depth, hardness gradients, microstructure confirmation, geometry stability checks, and surface integrity checks when hard finishing is involved. Used together, these matrices connect design intent to measurable evidence and inspection gates, reducing rework and late-stage surprises.

Figure 1—Heat treatment builds durable gear surfaces. **(All images: PairGears)**

Define the Duty Case First

You do not need a perfect model to make a better selection. You need a shared duty description that captures the dominant drivers.

Duty Inputs Checklist:

- Torque level: average and peak
- Shock severity: none / occasional / frequent (include reversals)
- Speed regime: low-speed high-torque vs high-speed sensitivity to small deviations
- Operating temperature: typical and peak
- Lubrication regime: full-film vs mixed/boundary; supply method
- Cleanliness risk: filtration level and ingression risk
- Life target: hours/cycles/warranty profile
- Distortion tolerance: runout/tooth deviation/fit-critical dimensions
- Finishing plan: grinding/honing/superfinishing available? stock allowance?

A practical method is to label each as Low/Medium/High, then pick the top two or three "non-negotiable" drivers. Those drivers determine the route shortlist.

Heat Treatment Routes: Strengths and Limitations

This section summarizes common routes used in gear manufacturing. The focus is not on marketing claims, but on what each route tends to deliver and what must be proven.

Induction (Surface) Hardening

Best at: Localized hard surface with a tougher core; efficient flow for many parts; can support distortion control when implemented well.

Where it fits: Moderate to high duty parts where selective hardening is practical and cycle time matters.

Limitations: Pattern coverage and uniformity; tooth-to-tooth variation; setup drift (coil path, scan strategy, quench stability).

Verification emphasis: Hardness mapping and depth checks at the highest-stress regions; distortion checks before/after finishing.

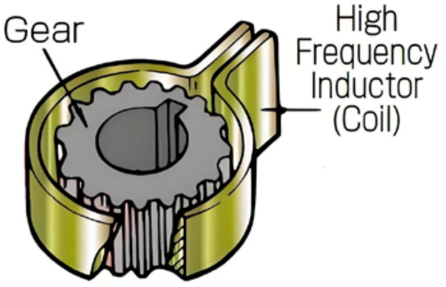

Figure 2—Induction hardens teeth fast with a coil.

Carburizing + Quench + Temper (Case Hardening)

Best at: Strong contact fatigue resistance with a tough core when case depth and gradient match the stress field.
Where it fits: High load, long life, and demanding durability requirements.
Limitations: Distortion scatter; coordination with finishing (stock, correction capacity, and surface integrity risk).
Verification emphasis: Effective case depth and hardness traverse, microstructure confirmation, core hardness, distortion statistics across loads; surface integrity checks after hard finishing when risk is elevated.

Nitriding

Best at: Hard surface with minimal distortion due to lower temperature; attractive for distortion-sensitive components.
Where it fits: Precision gears or parts where dimensional stability is the dominant constraint; wear/scuffing risk control in certain duty profiles.
Limitations: Typically thinner hardened layer; layer and compound-zone control; core must already be sufficiently strong.
Verification emphasis: Layer depth, near-surface hardness (often HV-based), microstructure/layer characterization, geometry checks pre/post.

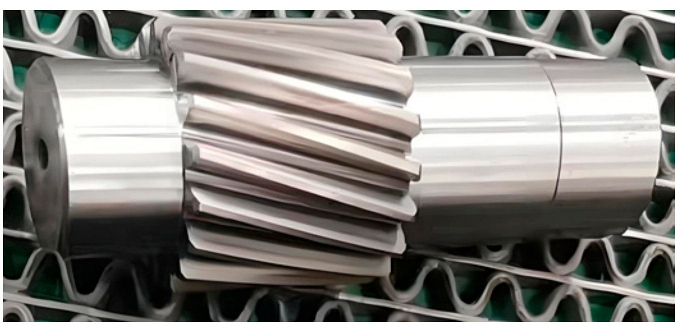

Figure 3—Nitriding gives the shaft a hard, stable layer.

Through-Hardening (Quench & Temper, Q&T)

Best at: Economical route for bulk strength; robust process flow for modest-duty gears.
Where it fits: Lower contact stress designs, auxiliary gears, and applications where a deep hardened case is not required.
Limitations: Limited surface contact fatigue and wear resistance versus case-hardening routes; higher sensitivity to lubrication regime.
Verification emphasis: Bulk hardness and microstructure, geometry stability, surface finish compliance.

Normalizing (Primarily a Pretreatment)

Best at: Stress relief and microstructure refinement to support machinability and consistent downstream response.
Where it fits: Pretreatment to stabilize machining and reduce variability prior to hardening processes.
Limitations: Normalized properties alone rarely meet higher-duty requirements unless followed by hardening.
Verification emphasis: Hardness range, microstructure consistency, dimensional stability before next steps.

Route Selection Matrix (Duty Drivers → Route Choice)

The fastest way to shortlist routes is to identify the dominant duty drivers. Use Table 1 to narrow options, then confirm geometry/process compatibility and build the proof-test plan.

Dominant Driver / Constraint	Induction	Carburize + Quench	Nitriding	Q&T	Normalizing
High contact stress, long life (pitting resistance)	C	R	C	A	A
High shock / bending-root robustness	C	R	C	C	A
High-speed sensitivity to small deviations	C	C→R (with finishing)	R	C	A
High scuffing risk (boundary lubrication events)	C	C	R	A	A
Distortion-sensitive geometry / tight fit	R	C	R	R	C
Limited post-heat-treat finishing margin	C	A→C	R	R	C
Selective hardening needed (local zones)	R	A	C	A	A
Short lead-time / flexible routing	R	C	C	R	C

Table 1—Simplified route selection matrix. Legend: R = Recommended; C = Conditional; and A = Generally Avoid.

Verification Matrix (Route → Proof Tests)

Route selection should come with a verification plan that proves the assumptions the design relies on—especially for case-based routes.

Route	Key Assumption to Prove	Typical Evidence Set (select per risk)
Induction	Hardened pattern covers critical zones; uniformity is stable	hardness map; depth checks at critical sections; microstructure sampling; distortion/runout checks
Carburize + Quench	Case depth/gradient matches stress field; tough core; stable metallurgy	effective case depth; microhardness traverse; microstructure confirmation; core hardness; distortion scatter across furnace loads; post-finish surface integrity checks when needed
Nitriding	Layer is consistent; minimal distortion; core strength adequate	layer depth; near-surface hardness (HV); layer/microstructure characterization; geometry checks pre/post
Q&T	Bulk properties meet duty; contact stress is modest enough	bulk hardness; microstructure; geometry stability; surface finish verification
Normalizing	Stable microstructure and response downstream	hardness range; microstructure; dimensional stability before subsequent hardening

Table 2—Verification Plan Matrix (Typical Minimum Evidence).

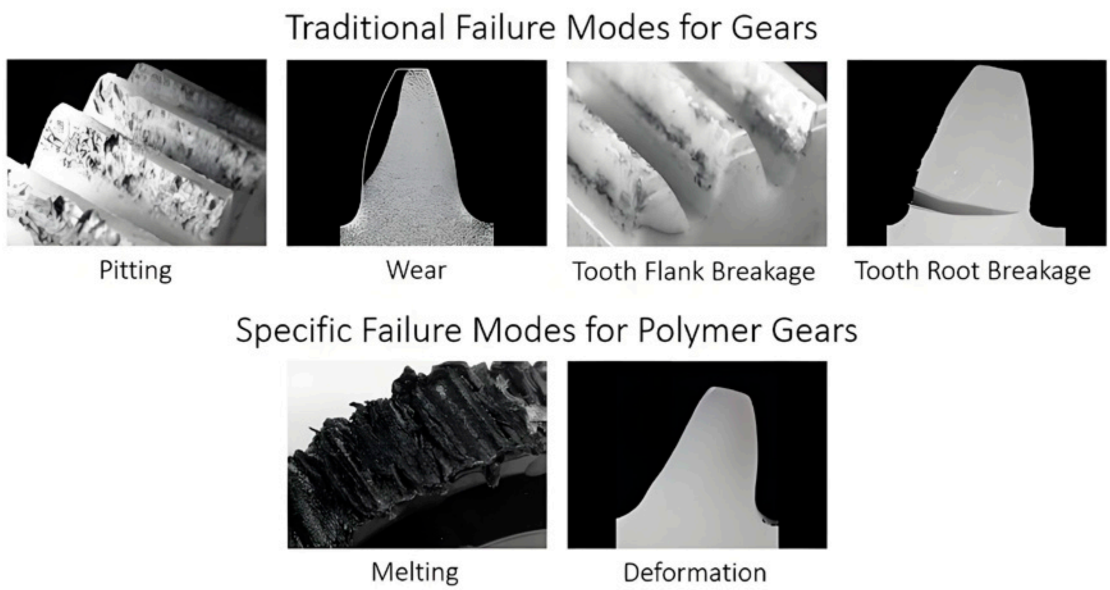

Figure 4—Typical gear damage patterns and failure appearances at a glance.

Representative Duty Profiles

The same route can succeed or fail depending on which constraints dominate. The examples below illustrate how the matrix approach works.

Agricultural Machinery Drives

Typical traits: long service hours, contamination exposure, seasonal shock events, durability-first.
Route tendencies: carburizing for primary torque paths; induction for selective needs and robust cores where appropriate.
Proof-test focus: case-depth strategy or pattern coverage; distortion control plan; cleanliness and lubrication assumptions documented.

Heavy Truck Power Transmission

Typical traits: high torque, long mileage, repeated duty cycles, strict repeatability requirements.
Route tendencies: carburizing for high-load gearsets with hard finishing; nitriding for distortion-sensitive precision parts where the layer matches the duty case.
Proof-test focus: hardness traverse and depth evidence; distortion statistics; post-finish surface integrity risk control when grinding is aggressive.

Construction Equipment Reducers and Drives

Typical traits: transient peaks, shock loading, bidirectional events, rugged reliability.
Route tendencies: carburizing for heavily loaded stages; induction for large components and selective hardening cases; Q&T for modest-duty gears with appropriate design margins.
Proof-test focus: core robustness indicators, distortion gates, and documented acceptance criteria.

High-Speed Electric Drivetrains

Typical traits: high rpm and continuous duty where small geometry variation becomes more noticeable; stable finishing and distortion control are often decisive.
Route tendencies: carburizing paired with controlled finishing; nitriding where dimensional stability dominates and the layer fits the duty assumptions.
Proof-test focus: geometry stability pre/post, consistent finishing output, and verification that the achieved layer/case matches the design model.

Failure Modes and Evidence Chains (Fast Troubleshooting)

When a program experiences early failures or fit problems, the fastest path is symptom → evidence → correction.

Pitting / Spalling

- Symptom: pits growing into spalls on active flanks.
- Evidence: duty severity review; case depth/gradient vs stress region; surface condition and cleanliness.
- Corrections: revise duty assumptions; adjust case strategy or route; improve finishing/lubrication/cleanliness controls.

Scuffing (Adhesive Wear)

- Symptom: smeared or torn surfaces, rapid damage progression under boundary lubrication.
- Evidence: duty temperature and lubrication regime; surface condition; contact pattern and alignment checks.
- Corrections: raise scuffing margin via lubrication/cleanliness/finish strategy; reconsider route if scuffing is dominant.

Tooth Fracture

- Symptom: fracture often originating at root under shock.
- Evidence: shock classification; core microstructure/hardness; stress raisers and origin analysis.
- Corrections: ensure core robustness matches duty; stabilize process; adjust design margins or route as needed.

Fit or Assembly Problems After Heat Treat

- Symptom: parts do not assemble or require excessive correction.
- Evidence: geometry measurements pre/post; distortion scatter across loads; stock allowance vs correction capability.
- Corrections: distortion control plan, fixturing/quench strategy, gating inspections, and finishing alignment.

Distortion and Finishing: The Hidden Coupling

Even an appropriate route can fail without an aligned distortion and finishing plan.

Practical Actions

- Identify distortion-sensitive features early (runout, fit bores, tooth deviations).
- Define measurement gates: pre-HT baseline → post-HT → post-finish.
- Align stock allowance with realistic correction capability.
- Where hard grinding is used, include surface integrity risk controls appropriate to the process window.

Program Checklist

1. Capture duty drivers (shock, temperature, lubrication, cleanliness, life).
2. Select 2–3 non-negotiable drivers.
3. Shortlist routes using Table 1; eliminate A for non-negotiables.
4. Confirm geometry/process compatibility and finishing capacity.
5. Build proof tests using Table 2; prove case/layer assumptions.
6. Add distortion gates and acceptance limits.
7. If hard finishing is used, plan surface integrity risk controls.
8. Link failure modes to evidence chains before production ramp.
9. Lock process settings and traceability to reduce scatter.
10. Update matrices as capability data accumulates.

Conclusion

A robust gear heat treatment decision is not a single process choice. It is a matched set of duty assumptions, route capability, finishing constraints, and proof tests. The duty-to-route matrix helps shortlist workable options early, but the decision only becomes reliable when the verification plan proves the key assumptions with measurable evidence—such as case/layer depth, hardness gradients, microstructure confirmation, and post-heat-treat geometry stability.

Most late-stage surprises—premature surface distress, tooth fracture under shock, or fit and assembly issues—can be traced to an incomplete duty description, an underestimated distortion/finishing window, or verification that checks "a number" without confirming the full property profile.

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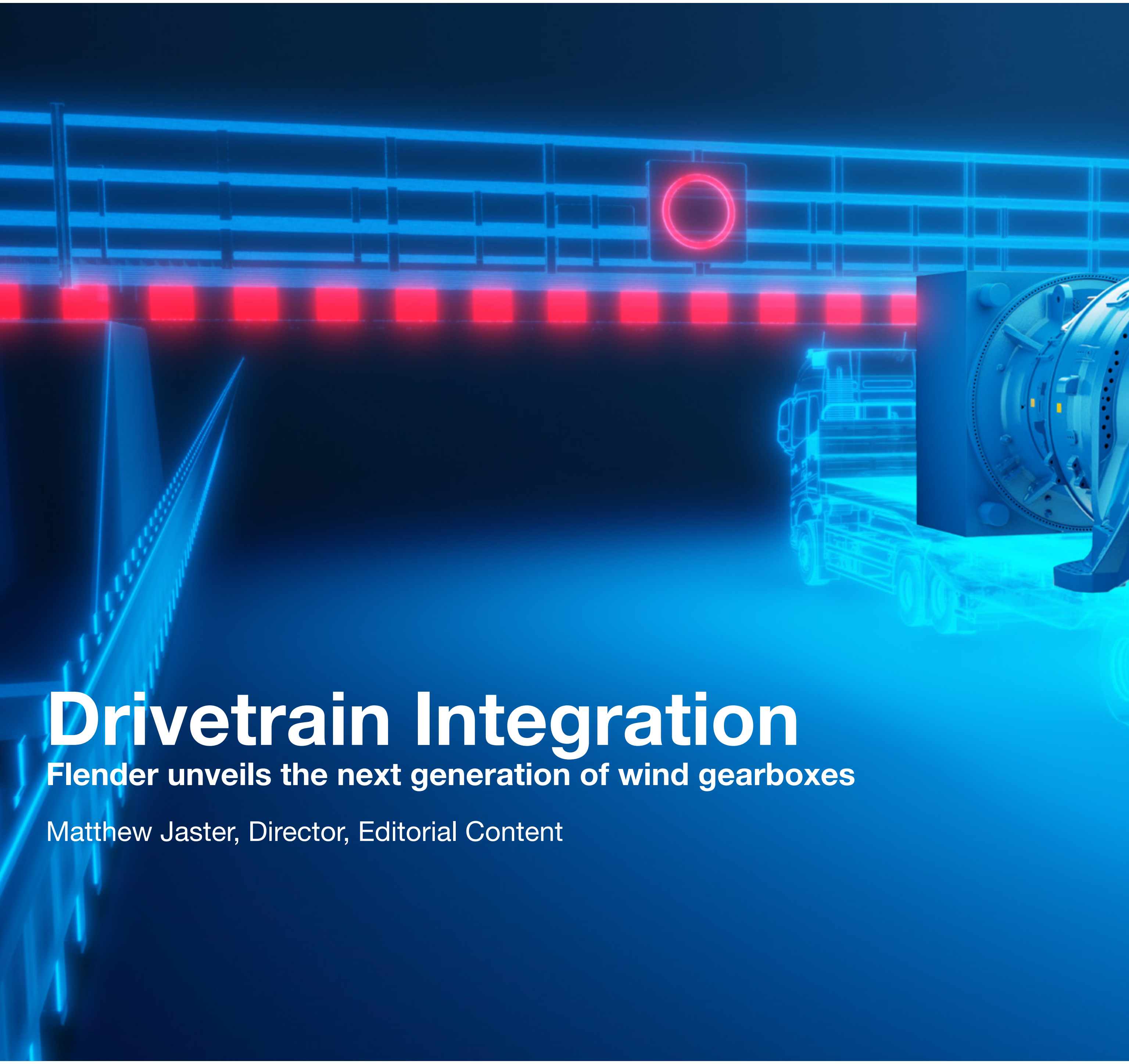


Drivetrain Integration

Flender unveils the next generation of wind gearboxes

Matthew Jaster, Director, Editorial Content

The reduction of transportation costs using smaller components can accelerate wind energy development. **(All images: Flender)**

Logistics, transportation and maintenance have always been critical challenges in wind turbines. There's truth to the notion that large components can cause bigger headaches on their massive size and scope alone. A smaller, compact drive solution can help eliminate today's renewable energy challenges while reducing costs.

Flender, under its wind energy brand, Winergy, for example, realizes wind turbines need higher power ratings without growing larger. Wind turbine components must be accessible and able to be shipped to installation areas quickly and efficiently. The nacelle's weight needs to be low to avoid massive foundations.

A milestone in this effort is the introduction of REVO, a new drive concept that has achieved the coveted threshold of 300 Newton meters per kilogram (Nm/kg) in torque density. REVO is a design concept offering 300 Nm/kg for new turbine developments. The result is a significantly more compact drive system. For the same power output, the required outer diameter can be reduced by up to 25 percent.

"Torque density—sometimes also named power density—refers to how much torque a drive can transmit per

kilogram of material. It's a key metric for the overall CAPEX (capital expenditure) of a wind farm," said Andreas Klein, vice president of drive systems and gear engineering at Flender's wind segment.

The compact gearbox design addresses several critical challenges in developing next-generation turbines. Transportation costs are reduced and drive systems remain road-transportable—even for current and future turbine classes exceeding eight megawatts. REVO's compactness opens previously inaccessible installation sites, accelerating wind energy deployment. Reduced material usage also enables smaller, lighter nacelles and lowers the mass at the top of the tower.

This, in turn, allows for cost savings in tower and foundation construction. Compared to gearboxes of the same power class in 2010, REVO enables a 70 percent reduction in CO_2 emissions thanks to its efficient use of materials. Additionally, the use of low noise journal bearings ensures compliance with European noise emission regulations and increases reliability.

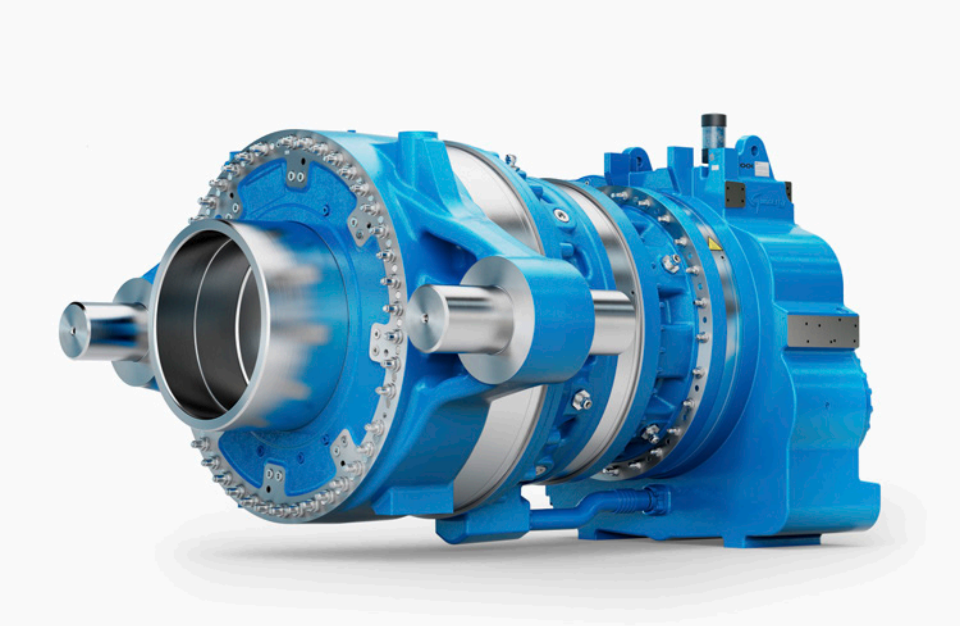
One key design element is the unique combination of new technologies resulting in better torque density. These include an optimized combination of planetary stages and gears per stage, as well as space-saving, noise-reducing second generation journal bearings. Enhanced gear materials and induction hardening further improve drive reliability.

The goal is to achieve higher power classes within the same design space. To this end, Winergy optimizes all gearbox components and uses new technologies to achieve a space-optimized design. Today, a design space that could accommodate a 4.5 MW power class in 2017 can already handle twice as much in 2024: a 9 MW gearbox in the same size. Gearboxes with the same power class today are significantly smaller than previous models.

The Development Process

For R&D efforts, Winergy has spent a great deal of time identifying future bottlenecks in wind applications. By optimizing the planetary stage layout, enhancing bearings and gears, and utilizing advanced materials with induction hardening all these technologies have been integrated into a single prototype to demonstrate system functionality and reliability. REVO can be integrated into a customer's individual drivetrain and tailored to meet their specific needs.

This development began by adding a third planetary stage to the process. By adding a third planetary stage, a significantly higher overall gear ratio can be achieved. In addition, the number of planets per stage is higher: In the first planetary stage, Winergy increases the number of gears from the original four to eight or nine. In a multi-stage planetary gearbox, the load to be transmitted is thus distributed over several gears and stages, reducing the load on individual components. Smaller gear



Wind turbines can be built today more compactly and efficiently to deliver greater output without increasing size. This significantly lowers energy production costs.

sizes can now be used, which enables a higher power class without increasing the design space.

The forces are distributed more effectively through several stages, reducing the load on the bearings and housings. This allows the design to be further optimized. With three stages, planetary gearboxes can often be better modularized and adapted to various design requirements, which optimizes the use of space and thus increases torque density.

Another key aspect of the design process was the introduction of journal bearing technology for the gearboxes. Bearings have a crucial impact on the reliability of the entire gearbox and its operating costs: With the right installation, journal bearings are more reliable and cause less downtime compared to planet roller bearings. Journal bearings enable increased torque density, which leads to more power in the same design space. Compared to planet roller bearings, journal bearings are significantly cheaper—and shorter lead times are possible.

The first ideas for the use of journal bearings came up back in 2009 and the first prototype was tested in the field four years later. Today, Winergy has a track record of more than 50,000 journal bearings in serial gearboxes worldwide since the first small series production in 2017. This is around 23 GW of installed base with lower failure rates compared to planet roller bearings. For perspective, this amount of energy could power around eight million electric vehicles for a year.

The conversion of speed and torque takes place in the geared components. In the further development of these components, Winergy has continuously improved materials, processes, and methods in recent years.

One example is the introduction of inductively hardened internal gears representing an optimal solution in terms of cost and power density. In line with the V-model, Winergy, together with its development partners, has examined this process at the metallurgical level. Furthermore, the gearings were validated on component test benches, and subsequently, the components were thoroughly tested in extensive gearbox tests. Field experience from several small series confirmed the robustness of the gears.

Winergy found a way to design gears more compactly while maintaining the same robustness against tooth root breakage. This was made possible by combining modern simulation methods with customized manufacturing tools. This step was validated by intensive gear testing and by analyzing field data from more than 400 GW of installed wind gearbox capacity. Understanding the natural variation in material quality and the loads was a key factor in achieving higher power densities. Here, Winergy developed the latest methods along the entire value chain to offer an optimal product in terms of reliability and cost.

A Shifting Global Outlook

A joint report between the World Meteorological Organization (WMO) and the International Renewable Energy Agency (IRENA) concluded that 2024 was the warmest year on record, with global temperatures reaching around 1.55°C above pre-industrial levels. This brought pronounced regional shifts in solar, wind and hydropower potential, alongside a four percent increase in climate-driven global energy demand compared with the 1991–2020 average. These climate-driven changes are occurring as global renewable energy capacity surpassed 4,400 GW, amplifying the interaction between climate conditions and energy systems at an unprecedented scale.

Closer to home, America's demand for electricity continues to grow, according to *cleanpower.org*. Clean energy projects in rural areas represent a unique opportunity to meet our power needs while delivering tangible local benefits. Offshore wind power offers a vital solution for the U.S. electric grid by delivering clean, reliable energy to densely populated coastal regions, while also bolstering the economy and protecting our air and water from harmful pollution and emissions.

With nearly 80 percent of Americans living within 200 miles of the coast, offshore wind is uniquely positioned to meet the rising demand for electricity in these high-consumption areas. The consistent winds offshore ensure a stable and sustainable power source, making it America's next great energy opportunity. Both onshore and offshore wind production will benefit greatly from enhancements to the drivetrains powering these systems.

"In recent years, we've already managed to double the torque density of our drives," said Tommy Rahbek Nielsen, president of Winergy. "With REVO and the achievement of the 300 Nm/kg mark, we're unlocking even more possibilities for our customers—greater output in the same footprint, or more compact components without sacrificing performance and reliability. Together, we select the optimal technology package for each project."

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Additive Manufacturing at Scale

Mary Ellen Doran, VP, Emerging Technology, MPMA

In February, I had the privilege of being invited to speak on a panel at the Additive Manufacturing Strategies (AMS) conference in New York City. AMS is a three-day, in-person event that brings together leaders from across the additive manufacturing space, including investors, OEMs, researchers, and end-users. I was honored to represent MPMA and the motion and power transmission community in a room full of people who live and breathe this technology every day.

From left, Filippos Voulpiotis, managing director of 3Dnatives, moderates panelists Mary Ellen Doran, vice president, MPMA Emerging Technology; Kevin Kassekert, CEO of VulcanForms; and Phil DeSimone, CEO of Carbon. **(Image: Additive Manufacturing Research)**

My panel, "High Volume Industrial Part Production," was moderated by Filippos Voulpiotis, Managing Director of 3Dnatives. Joining me were Kevin Kassekert, CEO of VulcanForms, and Phil DeSimone, CEO of Carbon. One representative from metal and one from polymer additive manufacturing. These are not small names. VulcanForms, based in Massachusetts, operates purpose-built digital factories that combine laser powder bed fusion, precision machining, and AI-driven software into a single end-to-end production platform, serving aerospace, defense, medical, and transportation sectors. Caron's subscription-based platform is built around their proprietary Digital Light Synthesis process, paired with advanced photopolymer resins and software that allows brands to design, develop, and manufacture high-performance parts at scale—from NFL helmet liners to dental devices to industrial components.

The central question driving our discussion was deceptively simple: What does it take to produce industrial parts at high volume using additive manufacturing? The honest answer is that we are still working it out and that tension between the promise of AM and the realities of scaling it was a thread woven through the entire conference.

From my vantage point, the most valuable part of being in that room was the intelligence I could bring back to MPMA's 3D Printing Committee as we continue to educate the gear and bearing industry on additive manufacturing. Our members need to understand where the industry stands today. They don't need the headlines but the ground-level reality of what is production-ready, what is still maturing, and where the honest barriers remain.

The components our members make—precision gears, actuators, and drive systems—are exactly the kinds of parts where additive manufacturing either opens new doors or hits a wall. Tolerances matter. Material properties matter. Cost per part at scale matters enormously. But most importantly, engineers need to think about all the tools available to solve problems.

What I heard from the other panelists reinforced something MPMA has been watching closely: the gap between prototype capability and production readiness remains real, but it is narrowing. Companies like VulcanForms are building purpose-built production infrastructure, not adapting R&D machines. Carbon's platform has already demonstrated what repeatable, certified production can look like across multiple industries. These are not pilot programs, but rather early signals of what a scaled additive supply chain can look like.

I'm also seeing more companies convert stored spare parts to print-on-demand. At the conference, a representative from Deutsche Bahn noted that roughly 10 percent of their parts have been converted into on-demand printing, saving thousands of dollars on storage costs alone. There was also significant discussion around the ramp-up of additive for defense manufacturing, a topic we'll be exploring further at the committee level.

At the same time, the conference did not shy away from hard realities. There were candid discussions about consolidation in the industry, pressure on AM hardware companies to show a path to profitability, and the challenge of convincing procurement teams to qualify a printed part when they have decades of experience specifying traditionally manufactured ones.

For our members, that is precisely where the opportunity lies. Motion and power transmission manufacturers who understand precision, who operate under tight tolerance regimes, and who have experience with demanding customer qualification processes are well-positioned to engage with additive manufacturing, not to replace what they do, but to expand what is possible.

Stay tuned for upcoming committee discussion, and if you are curious about where additive fits in your roadmap, join the committee or contact me: *doran@motionpower.org*.


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State of the Union

Todd Praneis, Vice President, MPMA Technical Division

At the last Technical Division Executive Committee (TDEC) meeting, beyond reviewing all the excellent Fall Technical Meeting track 1 abstracts, the committee was busy approving three new projects:

- A limited scope revision to ANSI/ABMA 10A *Metal Balls for Unground Bearings and Other Uses* to make some corrections found during a recent reaffirmation ballot.
- A major revision to AGMA 913 *Method for Specifying the Geometry of Spur and Helical Gears*. This revision will not only revise the title to Basic Rack and Profile Shift for Cylindrical Gearing (temporary title) but will also gather similar topics from several other documents that discuss a basic rack and profile into a single document.
- A brand-new document, ABMA 602, will focus on bearing testing and is aimed at bearing users to be able to understand what to do to compare a manufacturer or supplier to a baseline. The document will cover the primary fatigue characteristics and will also include mention of other types of testing, such as lubrication, noise, temperature, geometry, and material.

But that is not all! Our technical volunteers have been diligently working on many other projects.

Accuracy and Nomenclature:

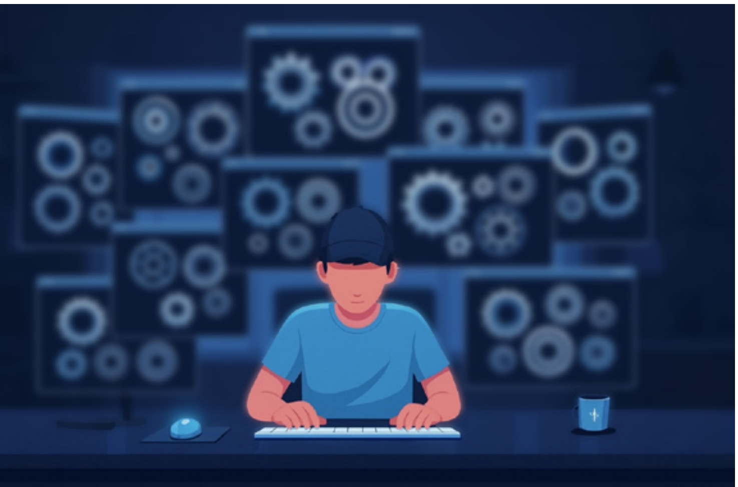
- AGMA 951-Axx, *Gear Surface Texture Measurement*
- AGMA 1010-Gxx, *Appearance of Gear Teeth—Terminology of Wear and Failure*

Aerospace Gearing:

- AGMA 926-Dxx, *Recommended Practice for Carburized Aerospace Gearing*

Bearings:

- ABMA B3.1, *Rolling Element Bearings—Aircraft Engine, Engine Gearbox, and Accessory Applications—Eddy Current Inspection*
- ABMA B3.2, *Rolling Element Bearings—Aircraft Engine, Engine Gearbox, and Accessory Applications—Surface Visual Inspection*
- ABMA 601-Axx *Atlas of Roller Bearing Failures in Wind Turbines*



Cutting Tools:

- AGMA 1104-Bxx, *Tolerance Specification for Shaper Cutters*

Cylindrical Gear Rating:

- AGMA 908-Cxx, *Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth.*
- AGMA 936-Axx, *Calculated Bending Load Capacity and Pitting Resistance of Powder Metallurgy, PM, External Spur and Helical Gears*

Flexible couplings:

- AGMA 9002-Dxx/9102-Dxx, *Bores and Keyways for Flexible Couplings*
- AGMA 9013-Exx/9113-Exx, *Flexible Couplings—Potential Unbalance and Mass Elastic Properties*

Gear Applications:

- AGMA 948-Axx, *Electrified Vehicle Drivetrains*
- AGMA 949-Axx, *Guidelines for Repair of Industrial Gearboxes*

Metallurgy and Materials:

- AGMA 2104-Dxx 924-Axx, *Gear Materials, Heat Treatment and Processing Manual*

Sound and Vibration:

- AGMA 919-2-Axx, *Condition Monitoring and Diagnostics of Gear Units and Open Gears: Part II—Applications and Advanced Analyses*

Wind Turbines:

- AGMA 950-Axx, *Wind Turbine Main Gearbox Condition Assessment based on Visual Inspection*

Wormgearing:

- AGMA 6122-Exx, *Standard for Design Manual for Cylindrical Wormgearing*

If you're counting, that's twenty open projects! I think we have some tired volunteers! Speaking of that, if you or someone in your organization is interested in learning about any one of these topics, there are only two requirements for being on a technical committee or working group:

1. Be a member of MPMA.
2. Have an interest in the subject and commitment to participate.

There are many benefits to being involved in a standardization project, both for the participant and MPMA. There's not a training opportunity that is much better, and the networking connections are invaluable. MPMA and the entire US bearing and gear industries benefit from having the latest and greatest technology represented in our documents.

So, that's the basics of what is going on in the MPMA Technical Division. Sorry, got to go. So many things to do!

Smart Alloying Eliminates Manufacturing Steps in Automotive Gears

Elias Löthman

The shift toward electrification, combined with the demand for greater energy efficiency, means that the automotive industry is undergoing a period of profound transformation. In particular, the increasing uptake of electric drivetrains calls for gears to meet increasing requirements for torque capacity, durability, and NVH (noise, vibration, and harshness), while also supporting more sustainable and cost-effective manufacturing.

Historically, conventional carburizing steels like 20MnCr5 have proved successful in gear applications. However, they usually require post-treatment processes, including shot peening to achieve the required fatigue performance, and tooth root grinding for a further boost. These additional steps add complexity and cost.

Against this background, Ovako has investigated the application of innovative alloying design to minimize intergranular oxidation and eliminate the need for post-treatment. The result of this program is 20NiMo9-7 (Ovako 158Q) that offers a potential pathway to more efficient, reliable, and sustainable gear manufacturing.

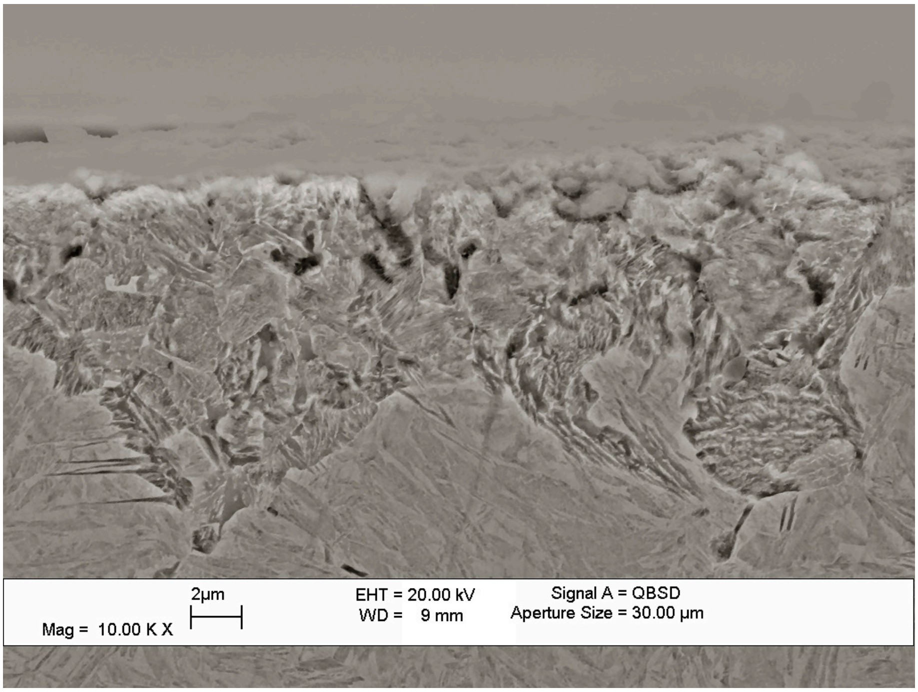


Figure 1—Surface oxidation of 20MnCr5 after case carburizing. **(All images: Ovako)**

Why Gas Carburizing Is an Issue

During gas carburizing of steel, there is a low partial pressure of oxygen. Under these conditions, alloying elements with a strong thermodynamic affinity for oxygen, such as silicon, chromium, and manganese, tend to undergo selective oxidation that propagates along grain boundaries. This results in the inward growth of oxide phases from the surface into the steel substrate, often referred to as intergranular oxidation (IGO) (Ref. 1).

This leads to localized depletion of alloying elements in the vicinity of the oxides formed, with a resultant reduction in the hardenability in these regions. When the steel is quenched, this reduction in hardenability increases the likelihood of forming non-martensitic microstructures in the affected areas, see Figure 1.

Furthermore, the reduced hardenability near the surface means that the transformation of the surface layer occurs earlier than in the underlying case during quenching. As the deeper regions of the case subsequently transform martensitically, accompanied by volumetric expansion, tensile residual stresses are introduced at the surface.

The net effect of the oxide and the low-strength surface structure, in combination with tensile residual stresses, is to adversely affect fatigue performance and increase susceptibility to crack initiation.

Overcoming the Limitations of Conventional Carburizing Steels

The development program was driven by the need to overcome the limitations of conventional carburizing steels like 20MnCr5, particularly their susceptibility to IGO and reliance on post-treatment processes such as grinding and shot peening to achieve their required mechanical properties.

The result is 20NiMo9-7 (158Q), alloyed with nickel (Ni) and molybdenum (Mo), elements with low oxygen affinity and strong hardenability contributions, while minimizing the presence of silicon (Si), manganese (Mn), and chromium (Cr)—see Table 1. This composition suppresses IGO and enables the formation of a fully martensitic surface layer with high compressive residual stresses, even under standard atmospheric carburizing conditions, see Figure 2. Additionally, this steel is produced via a premium production process (IQ-Steel), which ensures low levels of detrimental non-metallic inclusions. This ensures that steel cleanness is not the limiting factor for the fatigue properties.

The result is a steel that delivers high fatigue strength directly after carburizing, reducing or eliminating the need for post-processing. This makes 158Q particularly suitable for complex or small gear geometries where grinding or shot peening are impractical, offering a streamlined, cost-effective, and sustainable manufacturing route.

Fatigue Performance of 158Q

The fatigue performance of 158Q has been evaluated in several studies using different test setups and reference materials. The alloy has consistent high bending fatigue strength, particularly in the as-carburized condition, without the need for post-treatment processes.

Variant		C%	Si%	Mn%	P%	S%	Cr%	Ni%	Mo%	V%
158Q/20NiMo9-7*	Min	0.18	-	0.22	-	-	0.35	2.25	0.67	-
	Max	0.21	0.10	0.30	0.025	0.002	0.40	2.35	0.70	0.100

Table 1—Chemical composition of 158Q.

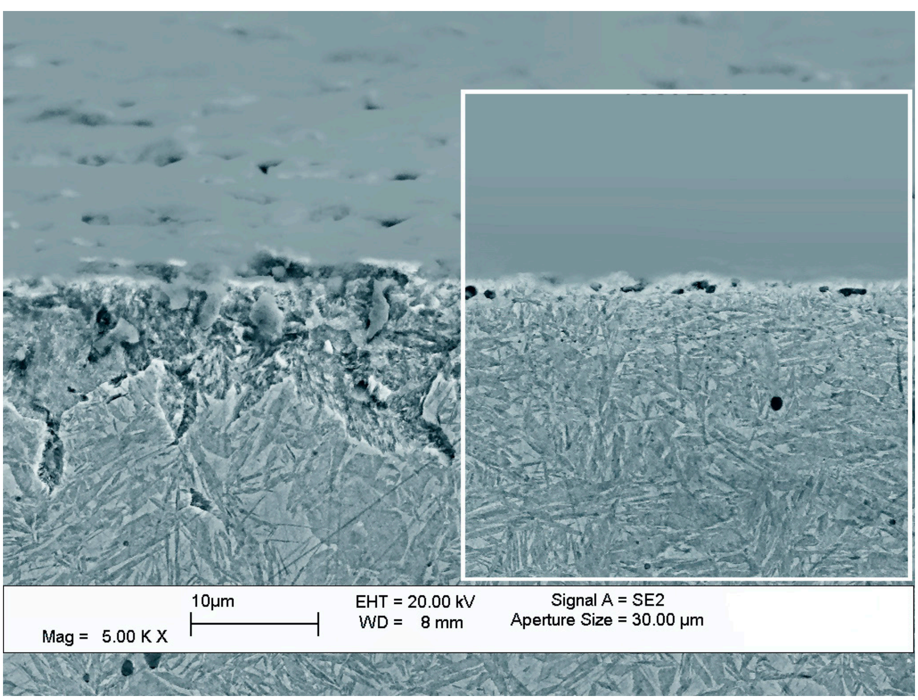


Figure 2—Surface appearance in 16MnCr5 and 158Q subjected to the same gas carburizing process.

Steel grade	Fatigue strength, mas. Load [kN]	Standard deviation [kN]	Approximate stress conversion [MPa]	Increased fatigue strength compared to 16MnCr5 [%]
16MnCr5	55.5	2.1	888–927 (±35)	0
157Q	60.6	2.6	969–1,011 (±43)	9
158Q	82.0	1.2	1,312–1,369 (±20)	48

Table 2—Fatigue strength test results based on staircase fatigue testing (Ref. 2).

In the VBC report (Åslund et al., 2010), gear tooth bending fatigue tests were conducted on158Q, 157Q, and 16MnCr5 using pulsator test rigs (Ref. 2). The results showed that 158Q achieved a fatigue strength approximately 48 percent higher than 16MnCr5, see Table 2. This was attributed to its fully martensitic surface, minimal intergranular oxidation (<2 µm), and absence of non-martensitic transformation products. In contrast, 16MnCr5 exhibited deeper oxidation (10–15 µm) and a soft surface layer. The study also noted that 158Q developed high compressive residual stresses and low retained austenite, both favorable for fatigue resistance.

The report further emphasized that 158Q achieved this performance using standard atmospheric gas carburizing, without requiring low-pressure carburizing (LPC) or additional surface treatments. This demonstrated the alloy's ability to deliver LPC-like surface quality using conventional equipment. The comparison with 157Q, which also underwent the IQ process but retained higher levels of Mn, Cr, and Si, highlighted the importance of alloy composition in suppressing oxidation. While 157Q showed some improvement over 16MnCr5, it did not match the performance of 158Q, reinforcing the role of oxidation resistance in fatigue behavior (Ref. 2).

Temmel et al. (2009, 2011) examined 158Q in comparison to 20MnCrS5, including the effects of single and double shot peening (Refs. 3, 4). In the unpeened condition, 158Q showed a 23 percent improvement in fatigue strength, see Table 3. Single peening provided a modest additional increase, while double peening did not yield further benefits and, in some cases, even reduced performance, likely due to exceeding baseline performance and its limited sensitivity to surface enhancement treatments.

The 2011 study also explored the residual stress profiles introduced by peening and found that double peening reduced surface compressive stress, likely due to stress relaxation or surface damage. This suggested that 158Q's surface condition after carburizing did not exhibit any significant grain boundary oxidation or non-martensitic structure.

Therefore, additional treatments need to be carefully tuned to avoid deteriorating the properties. These findings supported the idea that 158Q could be manufactured without additional post-processing (Ref. 4).

Borg (2008) evaluated the fatigue performance of 158Q and 16MnCr5 using rotating bending tests on notched specimens, both in the as-carburized and shot-peened conditions (Ref. 5). 158Q showed the highest fatigue limit in the as-carburized state, reaching 985 MPa, compared to 811 MPa for 16MnCr5, see Table 4. The tests were designed to simulate gear root conditions.

The test results demonstrated that 158Q could achieve high fatigue resistance without the need for surface treatments. 16MnCr5 showed deeper internal oxidation and the presence of non-martensitic transformation products near the surface, which negatively affected their fatigue strength.

Residual stress measurements showed compressive stresses at the surface for 158Q, while 16MnCr5 exhibited tensile stresses. Fractographic analysis revealed that cracks in 158Q initiated at the surface due to surface roughness, while in 16MnCr5, cracks were often associated with inclusions and surface degradation. The study highlighted the importance of surface condition and residual stress state in fatigue performance, particularly in geometries where post-processing is limited or impractical (Ref. 5).

In the AGMA technical paper (Aylott et al., 2024), 158Q was tested under various surface conditions, carburized, shot peened, ground, and in different combinations of them (Ref. 6). It consistently outperformed 20MnCr5, even when the latter was subjected to duplex shot peening or grinding, see Table 5. While post-treatments further improved performance, the gains were relatively small, indicating that the as-carburized properties were already reaching a level normally expected after shot peening, see Figure 3.

The study also noted that the standard deviation in fatigue strength increased for the 158Q variant when additional treatments were applied, suggesting that these processes introduced variability that was not present in the as-carburized condition. This consistency in performance is particularly valuable in production environments where process stability is critical. The AGMA paper provides a comprehensive comparison across multiple surface conditions, reinforcing the robustness of 158Q and its suitability for applications where post-treatment is impractical or undesirable (Ref. 6).

Series	Mean value [kN]	Standard deviation [kN]	Improvement [%]
20MnCrS5	38.1	1.9	0
158Q	46.9	6.6	+23.1
158Q shot peened	52	2.2	+36.5
158Q double peened	50.8	1	+33

Table 3—Fatigue test results on 20MnCrS5 and 158Q (Ref. 3).

Series	Fatigue limit [MPa]	Standard deviation [MPa]	Improvement [%]
16MnCr5	811	12.2	0
158Q	985	8.5	+21
16MnCr5 shot peened	964	16.8	+18
158Q shot peened	941	27.4	+16

Table 4—Fatigue test results for notched specimens, 16MnCr5 and 158Q (Ref. 5).

Root surface condition		Standard deviation	Bending fatigue strength		Improvement 1%
			50% probability	1% probability	
		MPa	MPa	MPa	
20MnCr5	Carburized	79.4	1,077	771	0%
	Carburized + duplex shot peened	90.4	1,360	1,012	31%
	Carburized + ground	56.3	1,274	1,063	38%
	Carburized, ground + duplex shot peened	60.5	1,491	1,264	64%
15BQ	Carburized	67.4	1,394	1,142	48%
	Carburized + duplex shot peened	98.5	1,629	1,250	62%
	Carburized + ground	102.7	1,633	1,224	59%
	Carburized, ground + duplex shot peened	73.7	1,560	1,277	66%

Table 5—Summary of bending fatigue test results (Ref. 6).

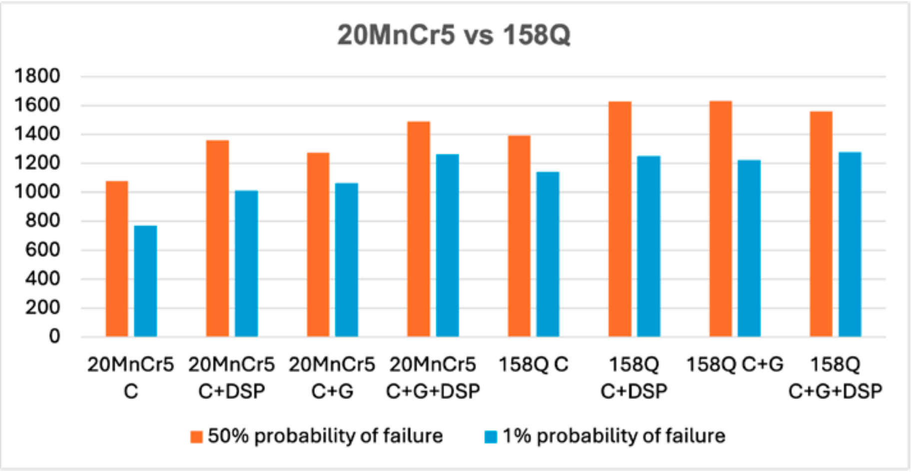


Figure 3—Bending fatigue strength comparison (C = carburized, DSP = duplex shot peened, G = ground) (Ref. 6).

The Key Benefits and Possible Applications of 158Q

Post-Treatment Response

Experimental results have consistently shown that 158Q exhibits high fatigue strength in the as-carburized condition, reducing the need for post-treatment processes such as shot peening or grinding. While shot peening can provide modest improvements, the gains are often limited and, in some cases, performance is reduced, particularly with double shot peening. This might be due to over-peening effects, stress relaxation, or induced surface damages.

The alloy's high surface hardness and clean martensitic structure limit the effectiveness of plastic deformation-based treatments. Additionally, increased surface roughness or variability introduced by post-processing can offset the potential benefits. Data from AGMA testing (Ref. 5) also indicate that post-treated samples showed higher scatter in fatigue strength, suggesting reduced process consistency. These findings underline that the surface condition of 158Q is already near optimal and that post-treatment should be carefully evaluated or potentially eliminated.

Addressing the Challenges of Hard-to-Grind and Small Gears

Grinding is often the desired finishing process for gears that require dimensional accuracy, surface quality, and correct gear tooth geometry. However, it becomes particularly challenging when dealing with complex shapes and tight tolerances. Influencing factors such as limited tool access, risk of thermal damage, and the need for specialized machinery often complicate the process. Hypoid gears, internal gears, and small-module gears often present limited tool access, making full-profile grinding either extremely challenging or entirely unfeasible.

Full profile grinding is often used when there is a need to further enhance the gear performance. This is challenging on the gears mentioned above. And in such cases, the materials must deliver the final surface integrity directly after heat treatment. This makes 158Q particularly well-suited for gear types where traditional finishing methods are not viable.

Shot peening is a widely used surface treatment to enhance fatigue strength by introducing compressive residual stresses. However, its effectiveness diminishes significantly when applied to small gears with narrow tooth roots and complex geometries. These features are difficult to access with conventional peening equipment, making it challenging to achieve uniform coverage in critical stress regions. To avoid damaging delicate surfaces, smaller shot particles must be used, but they carry less kinetic energy and may not impart sufficient compressive stress unless applied at higher velocities, introducing further complexity and variability in the process.

This limitation is particularly relevant in modern automotive and electrified drivetrain systems, where compact, high-precision gears are common. For such applications, materials like 158Q, which deliver high fatigue performance without relying on post-treatment, offer a more robust and cost-effective solution.

Bridging the Gap Between Carburizing and LPC

Low-pressure carburizing is widely recognized for its ability to produce clean, uniform case-hardened surfaces with minimal oxidation. Operating in a vacuum-controlled environment, LPC eliminates the intergranular oxidation typically associated with traditional gas carburizing, resulting in superior surface quality and fatigue performance. However, the adoption of LPC is often limited by high capital investment, specialized equipment requirements, and the need for advanced process control expertise.

For many companies, especially those with established gas carburizing infrastructure, the transition to LPC can be expensive and operationally disruptive. In this context, 158Q offers a compelling alternative as it achieves a clean, oxidation-resistant surface even under standard atmospheric carburizing conditions, without the need to overhaul existing heat treatment lines.

Therefore,158Q provides a practical, lower-cost pathway to enhanced gear performance and sustainability for companies seeking to bridge the gap between conventional carburizing and LPC.

Sustainability Through Process Optimization

Post-treatment steps such as shot peening and root grinding consume energy, generate waste, and increase the carbon footprint of gear production. In contrast, 158Q achieves high fatigue strength in the as-carburized condition, eliminating the need for these energy-intensive treatments

Beyond reducing processing steps, 158Q enables more compact and material-efficient component designs. Its ability to withstand higher loads allows for smaller designs, reducing the overall steel consumption for each component. In high-volume applications, even modest size reductions can lead to significant cumulative savings in raw material, energy, and emissions. These benefits align with broader sustainability goals and support more environmentally responsible manufacturing across the product lifecycle.

Cost Efficiency and Manufacturing Simplification

The ability of 158Q to achieve high fatigue strength in the as-carburized condition enables significant cost savings and production efficiency. By eliminating post-treatment steps, manufacturers can reduce labor, equipment use, and maintenance demands. This streamlining shortens production cycles, lowers overheads, and increases throughput.

Avoiding abrasive processes also reduces tooling wear and consumable costs, while minimizing process bottlenecks, particularly in high-volume environments where operations like root grinding can be time-consuming. The simplified workflow improves scheduling flexibility and reduces work-in-progress inventory, allowing manufacturers to meet performance targets at lower cost and with fewer processing steps.

Conclusion

A new alloy 20NiMo9-7* (Ovako 158Q) is a carburizing steel designed to minimize intergranular oxidation and eliminate the need for post-treatment processes such as shot peening and grinding. Through a review of multiple experimental studies, 158Q has consistently demonstrated superior fatigue performance compared to conventional steels like 20MnCr5 and 16MnCr5, even in the as-carburized condition. Key findings include:

- Up to 48 percent higher fatigue strength than 16MnCr5 in the as-carburized condition
- Comparable or superior performance to shot-peened or ground 20MnCr5 without these additional steps

158Q offers significant potential to streamline gear manufacturing by reducing complexity, cost, and environmental impact. Its isotropic properties and high surface integrity make it particularly suitable for complex or small gear geometries where traditional finishing methods are impractical. Ultimately, 158Q offers a compelling path towards more efficient, reliable, and sustainable gear production in the automotive industry and beyond.

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Water Spray Quenching—A New Intensive Quenching Process for Case Hardening of Gears

Dr.-Ing. Volker Heuer, Christof Ziegler, Dr.-Ing. Klaus Löser

Motivation

Water-spray quenching (WSpQ) has been established in industry for many years, e.g., in steel production for the quenching of strips or for semi-finished products. When applying WSpQ, water mist is formed in nozzles and accelerated with high velocities towards the components to be quenched. WSpQ provides very high cooling rates that are much higher than quenching in a liquid medium (e.g., with oil or with polymers). Additionally, by varying airflow and water flow, the quench intensity can be varied in a wide range (Refs. 1, 2).

However, for the heat treatment of complex-shaped, industrially manufactured serial components, such as gearwheels or gear-shafts, this process has not yet been successfully implemented. So far, this was not possible, since the water spray could not reach into the center of the heat treat loads consisting of multiple layers, where the outer parts of the load shield the inner parts from the effect of the water spray.

The objective was to develop a quenching process for the heat treatment of complex-shaped parts that provides exceptionally high cooling rates, offering the following benefits:

- Potential material substitution: to enable the use of less alloyed steel grades, leading to cost reduction.
- Improved quality after quenching: by enhancing the mechanical properties of the treated parts, including:
  - increased strength,
  - higher Martensite content,
  - increased compressive stresses on the surface of the treated components.

Additionally, the new process should provide the options for:

- Tailored quench intensity: adjustable cooling rates to tailor the quench intensity for each specific part-geometry and for each specific hardenability of the steel-grade.
- Dynamic quenching capability: the ability to vary quench intensity throughout the process, such as maintaining a specific temperature level during the quenching-process.

Test Rig

A test rig for WSpQ was designed and built. It can be found in Figure 1. The treated components are first austenitized in a vacuum furnace (SyncroTherm). This furnace can be used for neutral hardening (Ref. 3) as well as for low-pressure carburizing (Ref. 4) of single trays of parts (Ref. 5). This is referred to as single-layer vacuum heat treatment. However, for the development of the WSpQ-process, the parts are not quenched in the vacuum furnace, but the hot parts are manually transferred to the WSpQ-test rig.

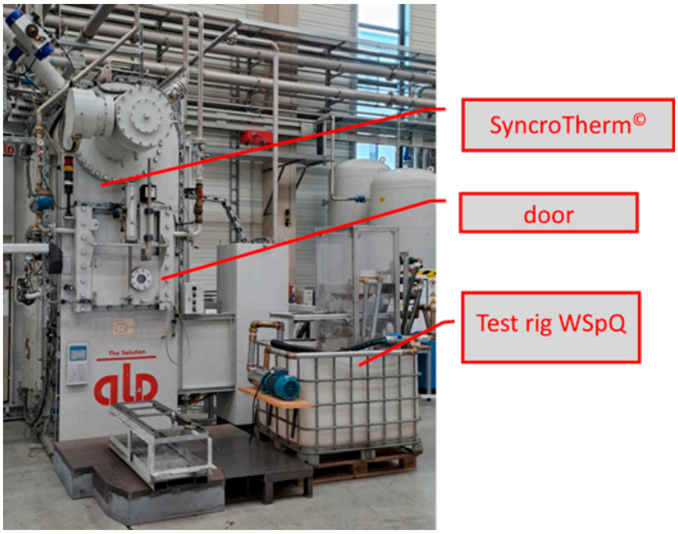


Figure 1—Vacuum furnace (SyncroTherm) and test rig for WSpQ.

The test rig for WSpQ consists of two nozzle fields, which are positioned above and below the parts to be quenched, see Figure 2. The nozzle fields—consisting of nine nozzles each—can be independently adjusted in terms of:

- distance between nozzles and parts to be quenched,
- flow rate of water,
- flow rate of compressed air.

In the test rig, water is circulated in a closed loop. No losses due to steam formation or similar effects were observed.

The tray size of this test rig is one-quarter that of the SyncroTherm furnace. The decision was made not to construct the test rig at full scale to reduce the initial financial investment for the development works.

Figure 2—Test rig for WSpQ, providing a nozzle system positioned above and below the parts to be quenched.

Results

A series of tests was performed on several specimen and gear components made from various steel grades.

Hardness

Figure 3 shows the hardness uniformity of a bolt made of 18CrNiMo7-6 (d = 50 mm, l = 100 mm, m = 1.5 kg) after WSpQ, measured across its cross-section along two measurement lines positioned at a 90-degree angle to each other.

The WSpQ-process provided a complete through-hardening of the bolt.

Three different gear-components were quenched using WSpQ. A small gear made of 20MnCr5, a final drive ring gear made of 20MnCr5 and an internal ring gear made of 18CrNiMo7-6 were treated.

Figure 4 shows the achieved core hardness values, demonstrating the very high quench intensity of the process.

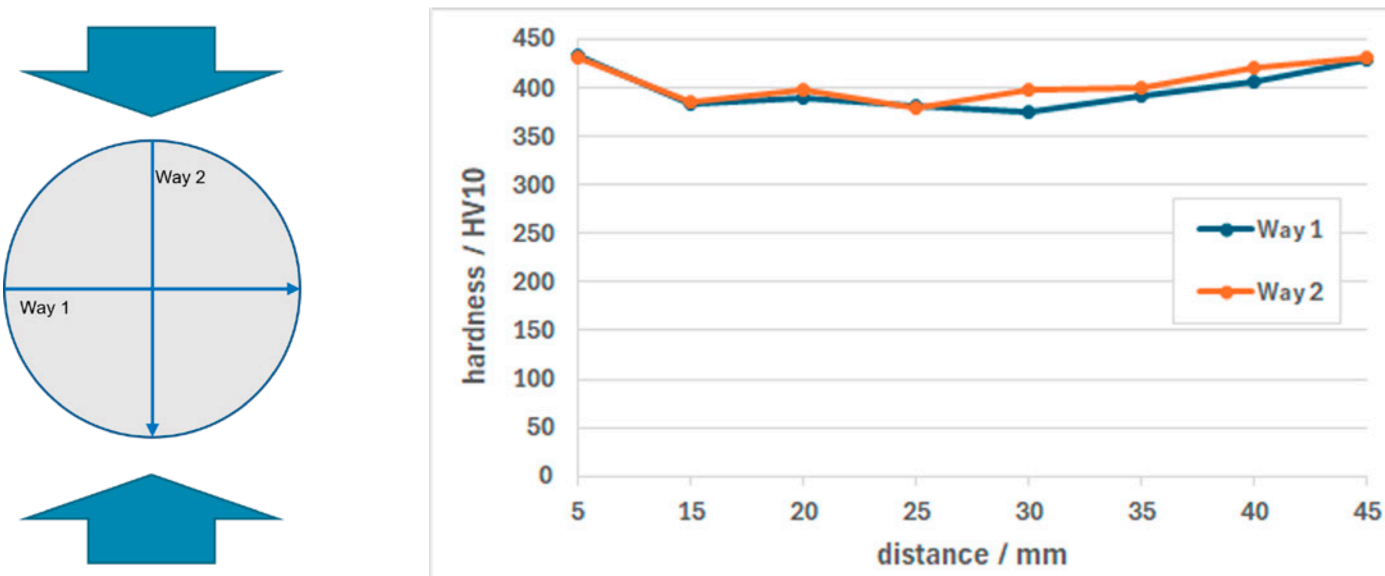
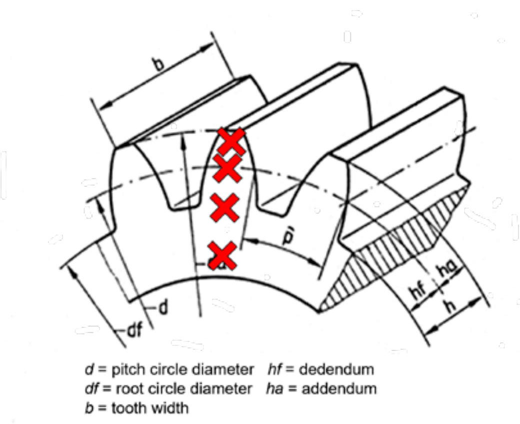


Figure 3—Hardness uniformity through a bolt made of 18CrNiMo7-6 (d = 50 mm, l = 100 mm, m = 1.5 kg) after WSpQ.



Position	Small gear (20MnCr5) OD = 34 mm width = 42 mm	FDR (20MnCr5) OD = 210 mm width = 38 mm	Internal ring gear (18CrNiMo76) OD = 230 mm width = 35 mm
¼	510	454	445
½	497	456	440
Tooth root	521	461	441
core	521	423	442

hardness-values in HV

Figure 4—Core hardness values (HV) of three different types of gears after quenching with WSpQ.

Cooling Speed

Two bolts with diameters of 25 mm and 40 mm were equipped with thermocouples positioned at depths of 3 mm, 7 mm, and 12 mm to measure cooling curves during the quenching process.

A portable data logging system was used to measure the cooling curves. The bolts were quenched from 930°C, applying WSpQ.

Within just 28 seconds, the bolt with $d = 25$ mm is fully cooled down to below 100°C, which demonstrates again the very high quenching intensity of the process.

Furthermore, a numerical model was used to calculate the heat transfer coefficient (HTC) based on the measured cooling curves. For this purpose, the cooling behavior was analyzed in the temperature range between 900°C and 150°C. HTC values of up to 4,000 W/(m^{2}K) were determined for the WSpQ-process, significantly exceeding those of oil quenching (1,500–2,500 W/(m^{2}K)) and helium-gas quenching (1,000–1,500 W/(m^{2}K)).

Surface Appearance and Microstructure

After treatment with WSpQ, the components exhibited a smooth but slightly grey surface appearance. No intergranular oxidation (IGO) was detected. Furthermore, no scaling, decarburization, or other surface defects could be found. The case hardening depth (CHD) turned out as expected. Figure 6 shows the microstructure of a bolt ($D = 25$ mm, $L = 100$ mm) made of 20NiCrMo2 after WSpQ. The surface exhibits a fully martensitic structure (100 percent martensite), while the core microstructure consists of a mixture of ferrite, pearlite, bainite, and martensite.

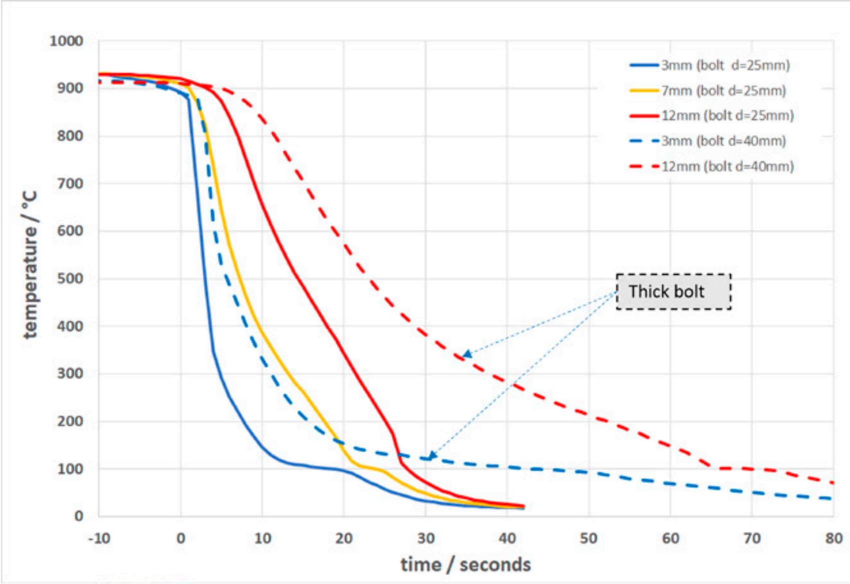


Figure 5—Cooling curves of bolts with d= 25 mm and d=40 mm measured at depths of 3 mm and 12 mm from the surface during quenching with WSpQ.

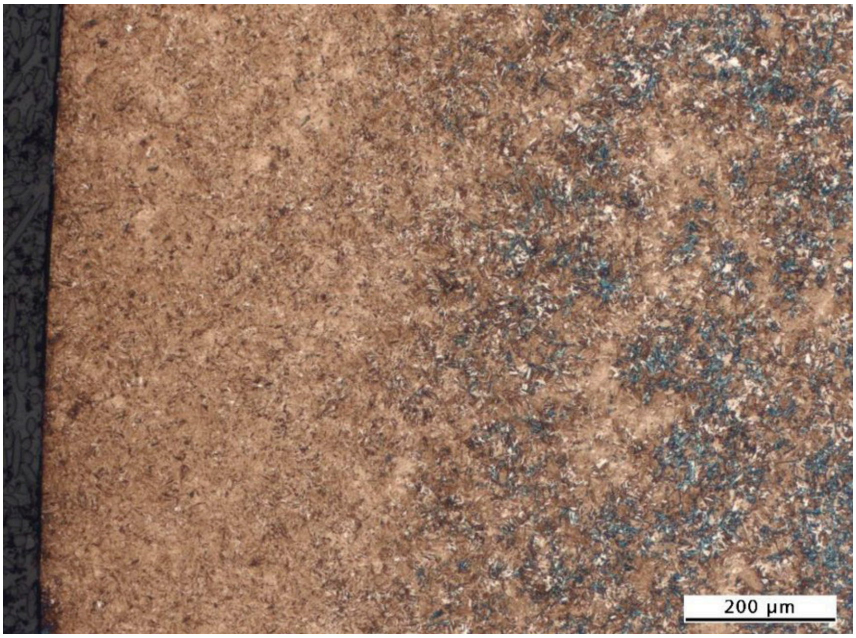


Figure 6—Surface microstructure after quenching with WSpQ (bolt with D = 25 mm and L = 100 mm made of 20NiCrMo2-material, etching with 3 percent Nittal-solution).

Conclusion and Future Work

WSpQ has proven to be an effective method for intensive quenching. This process offers heat transfer coefficients (HTC) of up to 4,000 W/(m^2K), which is significantly higher than those attained with conventional oil quenching methods (1,500–2,500 W/(m^2K)).

Furthermore, compared to oil quenching, WSpQ eliminates the Leidenfrost effect, ensuring that the high HTC remains constant throughout the complete quenching process.

The combination of WSpQ with single-layer heat treatment enables, for the first time, the successful application of WSpQ to the treatment of complex-shaped components. This approach offers several advantages:

- Potential material substitution: to enable the use of less alloyed steel grades, leading to cost reduction.
- Improved quality after quenching: by enhancing the mechanical properties of the treated parts, including:
  - increased strength,
  - higher Martensite content,
  - increased residual compressive stresses on the surface of the treated components.

Additionally, the process provides the options for:

- Tailored quench intensity: adjustable cooling rates to tailor the quench intensity for each specific part-geometry and for each specific hardenability of the steel grade.
- Dynamic quenching capability: the ability to vary quench intensity throughout the process, such as maintaining a specific temperature level during the quenching-process.

WSpQ is primarily suitable for single-layer (or at most double-layer) treatments, as well as for the treatment of large individual components. Bulk load treatment is possible when arranged in a single-layer configuration.

In future investigations, the distortion of components after WSpQ will be examined, along with their fatigue resistance and residual compressive stresses after heat treatment.

The next stages of development will focus on developing and designing a WSpQ chamber compatible with the SyncroTherm furnace, featuring full batch capacity and an automated transfer from the furnace to the quenching unit.

Further testing will be conducted on the following:

- bulk loads,
- individual large components,
- additional materials, including low-alloy steels, free-cutting steels, and potentially titanium.

Dr.-Ing. Volker Heuer studied metallurgy and material science at RWTH Aachen University in Germany. Starting in 1999, he worked as a research engineer at ALD-Vacuum Technologies; from 2007 to 2020, he was the Director of R&D; since 2020, he has been the CTO of the Heat Treat Service Division.

Christof Ziegler finished university in 1999 with a degree in process engineering. He worked for eight years at bifa GmbH in Augsburg and joined ALD Vacuum Technologies in 2007, where he worked in heat treatment for research and development, process optimization, and the worldwide commissioning of ALD heat treatment plants.

Dr.-Ing. Klaus Löser studied Mechanical Engineering at TU Darmstadt, Germany. Then, a scientist in materials technology at TU Darmstadt with a focus on high-temperature materials. Since 1991, he has been with ALD Vacuum Technologies GmbH in Hanau, responsible for the heat treatment department. From 2021 until 2025, he was SVP R&D Heat Treatment and Metallurgy in ALD.

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Remembering Robert Errichello

Robert Errichello with his dog, Corny

The gear industry has lost one of its most respected figures. Robert Errichello, founder of GEARTECH and a leading authority on gear design, failure analysis, and tribology, has passed away. He was 84. With a career spanning nearly 60 years, Bob made contributions to gear engineering and standards development that will endure for generations.

Bob published more than 80 articles on the design, analysis, and application of gears, authored three widely used computer programs for gear design and analysis, and consulted for more than 50 wind turbine manufacturers, purchasers, operators, and researchers. He taught courses in material science, fracture mechanics, vibration, and machine design at San Francisco State University and UC Berkeley, and presented numerous seminars to the gear, bearing, and lubrication industries. He served as technical editor for both *Gear Technology* and STLE's *Tribology Transactions*. A graduate of UC Berkeley, he held BS and MS degrees in mechanical engineering and a Master of Engineering in structural dynamics. His contributions were recognized with the AGMA TDEC Award, the AGMA E.P. Connell Award, the AGMA Lifetime Achievement Award, the STLE Wilbur Deutch Memorial Award, the STLE Edmond E. Bisson Award, and the AWEA Technical Achievement Award.

But the vitae only hints at what made Bob exceptional. He was one of the people doing the foundational technical work that informed AGMA standards—producing dozens of original reports on gear rating, metallurgy, tribology, and nomenclature. These were not summaries or opinion pieces, but original derivations and analyses that directly supported the standards development process. His work on AGMA 925 alone comprised 23 reports over seven years, methodically addressing gear tribology from elastohydrodynamic lubrication theory to scuffing prediction.

"Bob Errichello was a powerhouse within the gearing technical community for 50+ years," noted Jason Daubert, MPMA's Technical Division Executive Committee Chair and Chief Engineer at Fuller. "In 2025 alone, he participated in 54 technical committee calls across 14 committees and working groups, providing complex data and sage engineering guidance across a wide range of topics. His mind was truly amazing, and AGMA standards strongly benefited from his support."

For 27 years, Bob and Jane Muller taught the AGMA Gear Failure Analysis seminar, which became AGMA's most popular course. In 2016, he separately gave his Gear Failure Analysis course to MPMA, where it has also become their most popular offering. "His legacy will live on through Gear Failure Analysis—one Bob gave to MPMA in 2016, and that has since benefited thousands of engineers," said Sara Zimmerman, MPMA Chair and Vice President CX and Product at Sumitomo. "On behalf of the Board of Directors, our sincerest condolences to Jane and the Errichello family."

"Bob was great to work with," noted Todd Praneis, Vice President of Technical Services at MPMA. "His passion was contagious and he was a fierce advocate for the science of our craft, requiring everyone to be on their A-game when forming standards. We will miss him terribly."

Frank C. Uherek, Principal Engineer at Regal Rexnord, pointed to several defining technical contributions. Among them was Bob's development of a calculation method for the geometry factor used in bending-strength power capacity, which eliminated the labor-intensive practice of hand-drawing large-scale tooth-root fillets and made it possible to compute the factor accurately by computer. Bob also played a major role in creating the first AGMA information sheet for wind-energy gearboxes—work that ultimately led to an AGMA rating standard and became a major source of technical content for a joint ISO/IEC wind-turbine standard. "Bob was unwavering in his belief that gear rating practices must be grounded in sound science," Uherek noted. His insistence that every technical term carry a single authoritative definition shaped both AGMA 1012, Gear Nomenclature, and AGMA 1010. "Thanks to his efforts, gear engineers can communicate with clarity and precision—speaking the same technical language across the industry."

Fellow *Gear Technology* technical editor Chuck Schultz first met Bob at an AGMA committee meeting in 1979. "He was a leader in modernizing the gear rating method, taking it away from pages of charts and into formulas that could be written into computer programs," Schultz recalled. "He and Jane were instrumental in AGMA being world leaders in wind turbine gear design standards. Bob, in my mind, was the best of the best in the gear engineering trade. There will never be another like him."

The thousands of engineers who learned failure analysis through his courses, the standards that bear his contributions, and the pages of this magazine that carry his name—these are what Bob leaves behind. On behalf of the entire staff of *Gear Technology* and *Power Transmission Engineering*, we extend our deepest condolences to Jane and the Errichello family. Rest in peace, Bob.

MAY 19–20

CTI Symposium USA 2026

CTI Symposium USA (Novi, MI) examines the challenges in automotive powertrain development from passenger cars to heavy-duty vehicles. The program offers the latest solutions in the fields of electric drives, power electronics, battery systems, e-machines, components and the supply chain. Market and consumer research results as well as infrastructure related topics supplement the exchange of expertise. Speakers from Stellantis, Toyota, BorgWarner, General Motors, Ford, ZF and more will be on hand to discuss trends in individual and commercial automotive transportation.

geartechnology.com/events/cti-symposium-2026-02-04

MAY 20–21

Control–Expert Days 2026

Control has always been the international benchmark for quality management. Control-Expert Days 2026 turns this claim into a focused format that addresses the key questions facing the industry: What does modern quality management need to become faster, more resilient, and more sustainable? Stuttgart provides the ideal place for this event. As an industrial hotspot, the region brings together companies, decision-makers, and industry professionals who are responsible for daily audit processes. The two-day setting creates a space where solutions are not only presented, but also critically discussed from all perspectives. The mix of "old and new faces" on site makes the format particularly valuable: practical knowledge, new requirements, and technological possibilities come together.

geartechnology.com/events/control-expert-days-2026

JUNE 1–4

Cleanpower 2026

Cleanpower 2026 (Houston) grows businesses by gathering key decision makers and stakeholders across the wind, solar, storage, hydrogen, and transmission industries for discussion, deal making, networking and a whole lot of fun. The trade show not only brings together the different technologies that make up the renewables mix; onshore wind, offshore wind, solar, storage, and transmission but also the different segments within the industries; manufacturers, construction firms, owner operators, utilities, financial firms, corporate buyers and more. Cleanpower will feature the latest products, services and technologies coming to the renewable energy industry.

geartechnology.com/events/cleanpower-2026

JUNE 15–18

Reliable Plant 2026

This event (Reno, NV) offers attendees learning sessions and case studies on the latest industrial lubrication and oil analysis technologies. The comprehensive conference schedule covers every facet of the machinery lubrication industry and includes workshops on topics such as employee performance, lubrication fundamentals, condition-based maintenance and planning. Reliable Plant attendees come to the conference to connect with suppliers and service providers who can help them achieve bottom-line results in maintenance, reliability, and operations. From technicians and planners to management and leadership, you will be able to meet and influence entire buying teams at Reliable Plant.

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ADDENDUM

Generational Heat Treatment

Matthew Jaster, Director, Editorial Content

If you're a parent with kids at home you've likely suffered through a 20-minute conversation of unusual phrases and offbeat acronyms that sound like an alien dialect. If you have three or more kids talking in the back seat of your car you may wonder—as I often do—can I hire a translator or AI Assistant to figure out exactly what these weirdos are talking about?

Of course, these kids talk and text so fast because they've all grown up with everything they need in front of their curious faces. They live and breathe information. They Tik. They Tok. They shorten every word in the English dictionary.

We're knee deep in the Electronic Age where complex digital systems, microprocessors and artificial intelligence have replaced the gears, slide rules and printing presses of the Mechanical Age. Kids are building their own language to accommodate these wholesale changes.

Objectively, the shop floor might sound very different in 15 years. Will the future robotic workforce understand what their human counterparts are saying? Strictly for research purposes, we fed some common heat-treating facts (our issue focus) into an unofficial Gen-Z/Gen Alpha translator. I must admit the results were extremely fascinating:

"I have no idea what he said ... but he's so darned cute."

Our custom heat-treating services include stress-relieving, induction hardening, through-hardening and a complete metallurgy laboratory for your heat treatment needs.

"We do, like, custom heat treating for real. Got stress? We'll relieve it. Need induction or through hardening, we can do this. Plus, a whole lab for, like, metal stuff. Need all that heat treatment? Say less."

The gears underwent quenching to enhance their hardness and durability, ensuring they could withstand heavy operating loads.

"We quenched those gears to make 'em extra tough and durable, so they can handle, like, a TON of stress. No more stress. Finished."

Vacuum carburizing offers many advantages in comparison with traditional atmosphere carburizing.

"VC? Yeah, we can VC. Period. It's way better than that old-school atmosphere carburizing. Our VC is valid. Bet."

Can you recommend a heat treat process for a gear that spends its whole life oscillating back and forth and causing a large amount of shock?

"What's the best heat treat for a gear that's, like, constantly vibing back and forth and taking major L's from all the shock?

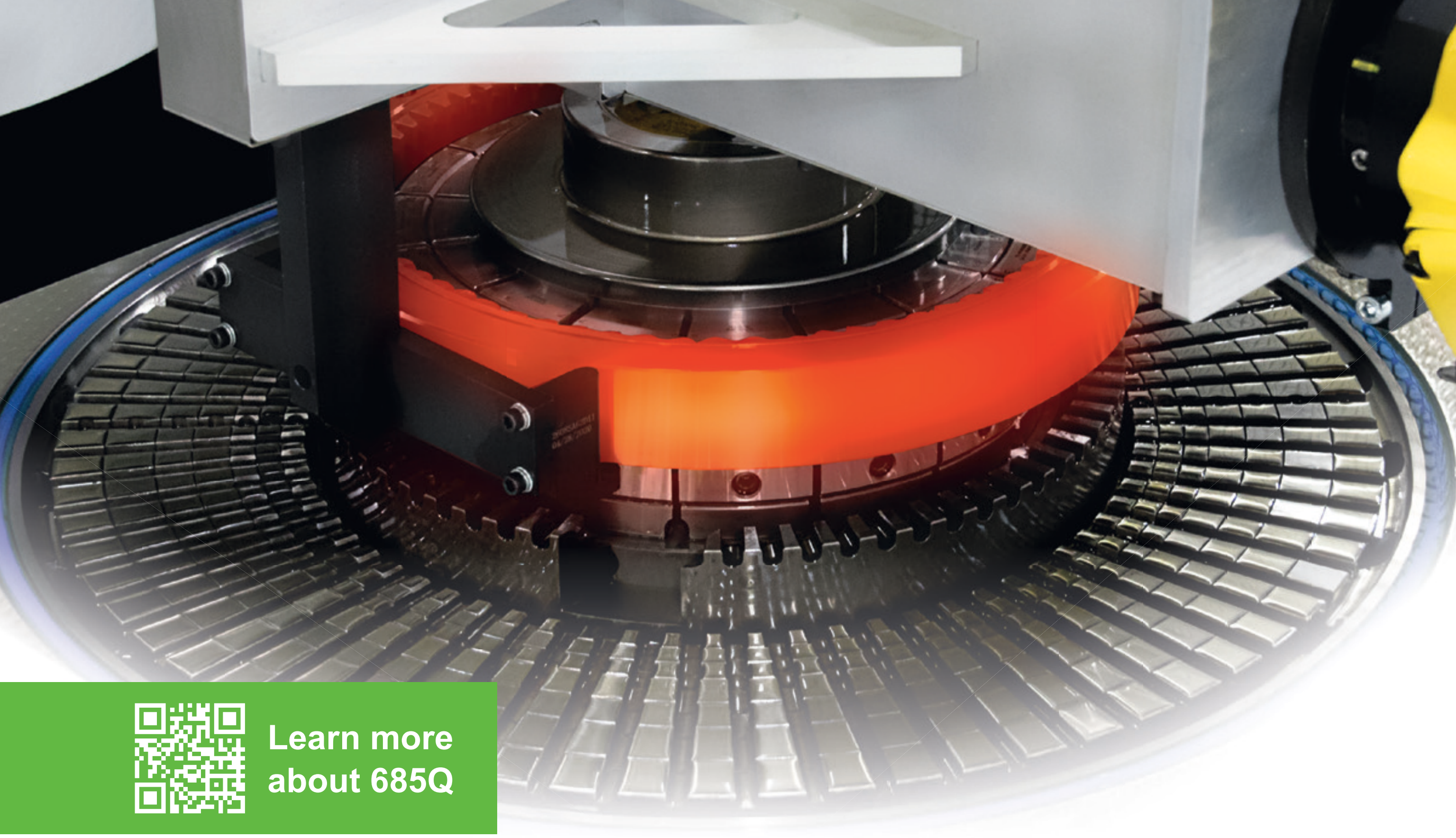
Is it better to find a reliable heat treat partner at a trade show or by going online and conducting major research?

"Should I find a solid heat treat wizard at a trade show or by deep diving online? Like, is it giving trade show or is it giving Google?"

I am extremely worried about the state of manufacturing and engineering conversations based on what I'm hearing from children today. Is there any hope for humanity?

"I'm low-key stressing about the manufacturing and engineering convos I'm hearing from kids. Big yikes. Is there even hope for us? OMG, I'm crashing out about the future of making stuff. We're doomed. Major anxiety. Future bleak. I'm shook. NGL. Need snacks."

While the translator is just poking fun at our current text-heavy universe, truth is, the Baby Boomers, Gen-Xers and Millennials had their own equally ridiculous words and phrases growing up. The real enemy was always the parents, unable to stay in the conversation and not cool enough to hang longer than six, seven minutes, tops.



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