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Couplings and Clutches

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on Helicopter Gears



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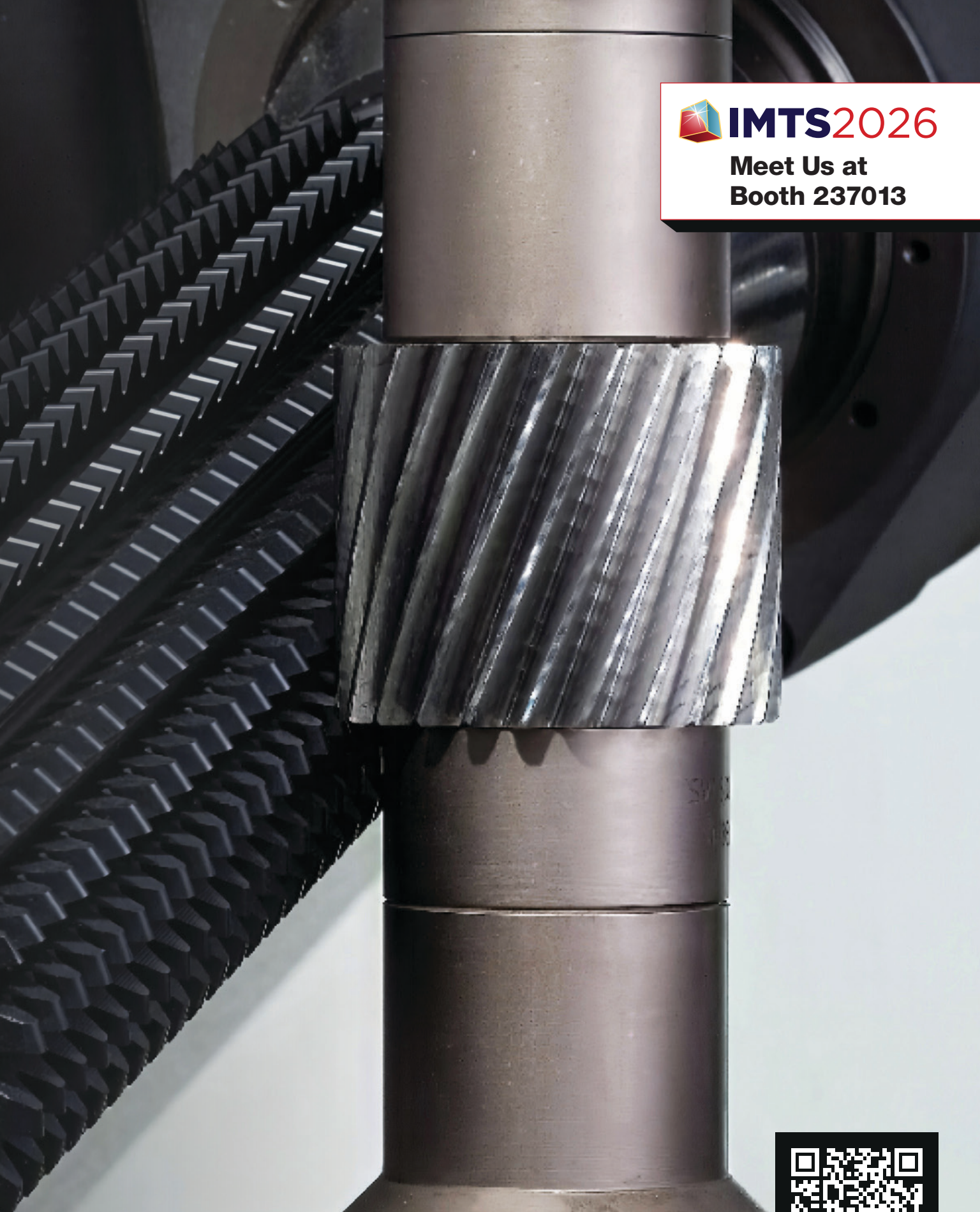
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- Master Gears, Ring and Plug Gauges
- Advanced Coatings Available





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GEAR CUTTING SOLUTIONS



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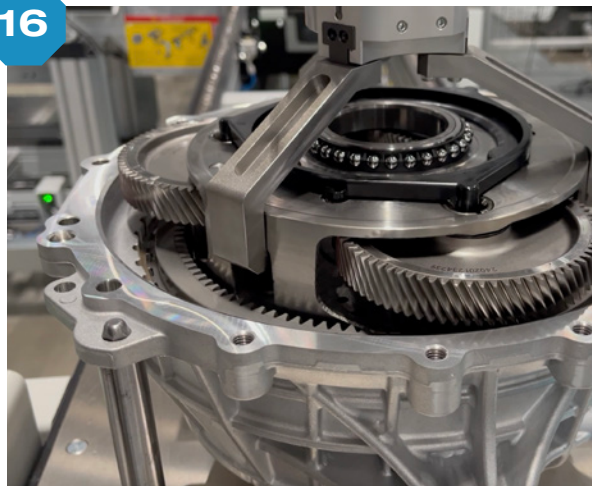
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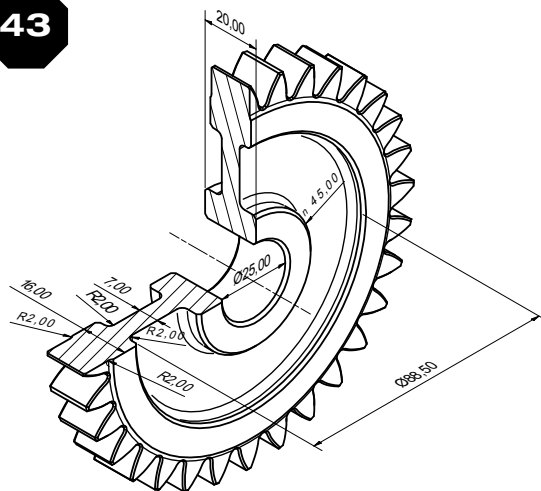
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GT VIDEOS

Mazak Redefines Labor Shortages with Automation Solutions

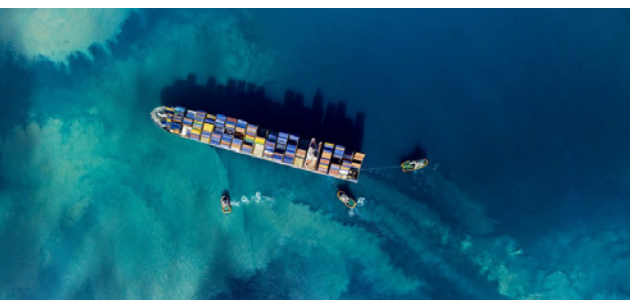
From adding automation functions to fully automating the whole production line, Mazak can suggest the best solution to solve your labor shortages with technology tailored to each customer's production needs.

[geartechnology.com/
videos/mazak-redefines-
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automation-solutions](http://geartechnology.com/videos/mazak-redefines-labor-shortages-with-automation-solutions)



GT REVOLUTIONS

Regal Rexnord Looks at Advantages of Hybrid and Electrification Technologies in Marine Propulsion

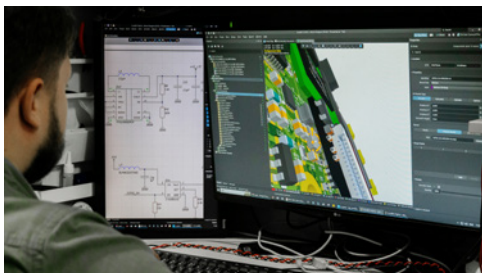


Few sectors are under as much pressure to clean up as shipping. The IMO's emissions targets—a 40 percent reduction in carbon intensity by 2030 and net zero by 2050—are shaping the choices owners and operators face on every new build and every major refit.

geartechnology.com/regal-rexnord-marine-electrified1

AS SEEN IN PTE

Data-Driven Production



Across sectors, the same operational truth is becoming harder to ignore: downtime has a direct impact on revenue. It ripples into supply chains, disrupts mission readiness, compromises service levels and, in some environments, creates genuine safety risk.

powertransmission.com/data-driven-prediction

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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.

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On the Road

“There was nowhere to go but everywhere, so just keep on rolling under the stars.”—Jack Kerouac, *On the Road*

Aaron Fagan, Senior Editor

As I write this, I am surrounded by boxes, about to head out across the country with my wife Camilla and our two dogs Zeus and Bob Fosse. Packing a home for a move like this turns out to be a fair way to think about an industry deciding what to carry forward, especially as a lot of companies are having discussions about what to pack, old and new alike, and display at IMTS this September in Chicago.

By the time this issue reaches the printer, we will be somewhere on the interstate between Tyler, TX, and our new apartment in Lancaster, PA—more than a thousand miles of it, with everything we own rolling along behind us. A move turns out to be an inventory exercise. We pick up every object in our lives and ask the same question: Does this come with us, or has it served its purpose? It is not a bad way to take stock—of a house, or of an industry: which tools genuinely move us forward, which we are keeping out of habit, and which we can finally set down.

The pages that follow are full of that sorting—automation reaching shops that could never before justify it, robots learning to handle parts that will not hold still, and design choices made long before the first chip is cut. Our decisions either smooth the road ahead or leave us stranded at the machine. We can plan a route, but the road always has the

final say—the closed lane, the storm over the mountains, the detour that turns out to be the scenic way. The map is not the road, and the design is not the part. What looks clean on the screen still has to be cut, measured, and made to work in steel.

A cross-country drive means living between worlds for a while—much like the before and after of a big show like IMTS, where the frontiers of technology open to something new. So it is with an industry that has spent a century turning raw energy into controlled, useful movement—and is now learning to hand some of that control over to machines that can sense and adapt on their own.

You do not make a trip like this alone. The industry's version is the harder, more important kind of company—the people entering the trades, the ones training them, the standards bodies arguing over the rules of the road so the rest of us can travel it safely. At IMTS, our industry will once again gather in one place to compare notes on the road so far. Consider this issue something to read before you go—a map spread across the hood, tracing where we have been and where we are going. And keep on rolling under the stars.





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Helios Gear Products

DEBUTS NEOPS 100 COMBINATION POWER SKIVING AND HOBBING MACHINE



Helios Gear Products will exhibit the NEOPS 100 CNC combination power skiving and hobbing machine at IMTS Booth #236906. Built to meet the production demands of the robotics industry, the machine is also suited to a broad range of internal and external gear work.

The NEOPS 100 runs power skiving and gear hobbing on a single platform with optimal automation. Manufacturers can switch between operations without a second machine or additional floor space. The machine was developed for the robotics industry, where internal gear tolerances are tight, and production volumes are high, and it also handles external spur and helical gears in both modes.

It is available for shops that want skiving capability for fine-pitch parts in a horizontal configuration.

“For a lot of shops, power skiving has simply been too expensive and risky to get into. The NEOPS 100 brings the entry point down without cutting corners on what the machine can do. It was designed for robotics production, which sets a high bar, and the combination design means shops don’t have to buy two machines to stay flexible,” said Adam Gimpert, president of Helios Gear Products.

Power skiving is a high-speed cutting process well-suited to internal or external gears and high-volume runs where shaping or hobbing is slower or geometrically limited. The NEOPS 100 was designed for operations producing fine-pitch gears, shafts, and other involute

components at scale, primarily for robotics and automation applications. The machine is the third in Helios’s CNC power skiving lineup, alongside the NEOPS 200 and NEOPS 400, and all three are backed by Helios’s applications engineering and service team in South Elgin, IL, and Pershore, England.

heliosgearproducts.com

L.S. Starrett

OFFERS FULL RANGE OF METROLOGY AND GAGING SOLUTIONS



The L.S. Starrett Co. will be demonstrating the latest in quality control inspection technology during IMTS 2026 at Booth #134244 located in the Quality Assurance Sector, East Building. Starrett will be debuting a lineup of new solutions including its HDV 250 digital comparator system, new electronic height gages, a new thread gaging line, and a new digital readout series for advanced gaging applications. Starrett will also feature its full line of precision solutions from vision metrology systems and measuring tools to granite surface plate, laser, force measurement, and custom gaging. Some show highlights:

The Starrett HDV 250 Digital Comparator provides increased surface illumination and enhanced measurement capability via a high-resolution digital monitor, enabling better images via state-of-the-art comparator technology in a compact, shop floor friendly design. Features of the HDV 250 include integrated LED ring light-based surface illumination for enhanced contrast and edge definition, a high-resolution digital video camera, micron-level accuracy and full digital documentation ability for SPC.

Starrett will also showcase its new HG Series Electronic Height Gages and new iterations of its 3700 series electronic height gages. The HG series is designed for intuitive and ergonomic operation, reliable measurement accuracy and increased productivity. A large touchscreen interface with clear icons and simple menu options is easy to learn and use and speeds up inspection.

Starrett will also highlight the new 770 Electronic Internal Micrometer series and 781 Accubore Electronic Pistol Grip Series product line expansion, providing advanced, easy to use gaging for fast accurate thread measurement, offering an ergonomic and highly repeatable non-destructive way to measure thread pitch diameters. The new series provides instant measurement feedback and actual size readings that eliminate multiple trial cuts of threads. Interchangeable gage heads are furnished for measuring different thread and bore sizes, further enhancing inspection time savings.

Rounding out the wide array of precision solutions to be featured in the Starrett booth will be a Starrett Tru-Stone granite metrology base, the innovative No. W4900 Wireless Digital Indicators, micrometers, calipers, bore gages, a Starrett Bytewise Profile360 Blue Laser Measurement System, and custom gage examples of Starrett Special Gaging capabilities.

Attendees are invited to bring their gaging and metrology challenges to the booth where Starrett engineers can provide demonstrations, technical support, or guidance on pursuing customized solutions when conventional products will not suffice.

starrett.com

Norton | Saint-Gobain Abrasives

SHOWCASES ADVANCED GRINDING SOLUTIONS AND ABRASIVE TECHNOLOGIES

Saint-Gobain Abrasives will showcase a broad range of advanced abrasive

grinding technologies and high-performance solutions for gear grinding and other applications at IMTS 2026, Booth #237042 located in the Abrasive Machining/Sawing/Finishing Sector, North Building.



Among the technologies highlighted at the show will be Norton gear grinding wheels featuring advanced VS3PN bond technology engineered to deliver exceptional profile retention, burn-free grinding and improved part quality in demanding gear manufacturing applications. Designed for today's high-efficiency gear grinding environments, the wheels provide superior form holding and consistent performance in worm, profile and bevel gear grinding operations where tight tolerances and productivity are critical.

Norton will also feature Paradigm Diamond Wheels for aerospace grinding applications. Designed specifically for grinding difficult-to-machine aerospace materials, the wheels combine advanced abrasive grain technology with a highly engineered bond system to deliver improved material removal rates, longer wheel life and excellent part quality. The technology is ideal for turbine blades, aerospace engine components and other hard-to-grind materials commonly used throughout the aerospace industry.

Also being highlighted at IMTS are Norton Paradigm Plus Diamond Wheels for round tool grinding. Featuring premium grain technology combined with a brittle metal bond system, Paradigm Plus wheels provide high grinding efficiency, reduced grinding forces and significantly improved wheel life for carbide round tool manufacturing applications. The wheels are designed to help manufacturers achieve

higher material removal rates and greater process consistency while maintaining precise tool geometries and surface finishes.

For high-performance external and internal grinding applications, Norton Vitron7 vitrified cBN grinding wheels will also be showcased. Featuring a high-precision vitrified bond system, Vitron7 wheels deliver exceptional wheel life, thermal stability and consistent grinding performance in demanding automotive, bearing and precision

grinding operations. The technology is particularly well-suited for applications involving camshafts, crankshafts and other hardened steel components requiring high levels of dimensional accuracy and productivity.

In addition, Norton Quantum Prime grinding wheels will be featured at the show. Utilizing proprietary nanocrystalline ceramic grain technology, Quantum Prime wheels offer exceptional grinding efficiency, improved part quality and significantly longer wheel

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life compared with traditional ceramic abrasives. Designed for a broad range of grinding applications, the wheels help manufacturers increase productivity while reducing overall grinding costs across a variety of industries and operations.

“Norton continues to focus on delivering innovative abrasive technologies that help manufacturers improve productivity, consistency and process efficiency,” said Ryan Johnson, director of technical business development. “IMTS provides an ideal opportunity

to demonstrate how our latest grinding solutions can help customers address the increasing demands of today’s advanced manufacturing applications.”

In addition to its show presence, Norton will be making a presentation at the IMTS Conference Sessions on “Grinding Automation: Turning Complexity into Competitive Advantage.” The presentation by Andrew Biro, APS manager, and Nathan Jackson, APS application engineer, Norton | Saint-Gobain Abrasives,

will be on Monday, September 14th at 3:15 p.m.–4:10 p.m. in Room W192-B, West Hall at McCormick Place.

nortonabrasives.com

Liebherr

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Liebherr will offer a variety of machining capabilities at IMTS 2026 including the LGP 2000 profile grinding machine, the PHS 3000 Allround pallet handling system, and advancements in waviness analysis that enables precise evaluation of noise generation in gearboxes.

Requirements for the finishing of large, hardened gears vary depending on the application. In wind power, the focus is on high volumes and cost efficiency, for example when producing planetary gears. In turbine gear units, marine drives and high-end industrial gear units with small batch sizes, process reliability is critical—the goal is a good part right from the first workpiece. Job shops require a high level of flexibility: a wide variety of components, internal and external gears, and complex geometries all need to be machined economically on a single system.

The LGP 2000 profile grinding machine is designed to meet these requirements. Like the other machines in the platform for workpieces up to two meters in diameter, it is based on a thermosymmetrical, optimally

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temperature-controlled bed and features a hydrostatically supported table with a wear-free direct drive. A stroke of up to two meters allows long shafts with multiple gears to be machined. Components up to 800 mm in diameter can be loaded automatically via a ringloader; additional automation solutions can be integrated depending on the component and application.

The high-performance PGH 450 FX grinding head allows a targeted combination of two grinding discs with different specifications in the dual-spindle configuration—from roughing and finishing through to fine grinding and polishing. This reduces machining times, increases process stability and lowers the risk of grinding burn. The result is excellent surface quality and high productivity, reducing cycle times by up to 35 percent.

The single-spindle configuration is particularly suitable for frequently changing components. An optional high-speed spindle is available for collision-critical parts, allowing the use of smaller grinding discs, including CBN discs where required. Internal gears can also be machined using optional internal grinding arms for the PGH 450 FX grinding head. Both options can be retrofitted if needed. Additionally, a swiveling probe enables in-machine gear inspection. The LHGearTec control system supports simple and reliable operation with its intuitive interface.

The PHS 3000 Allround automatically supplies machine tools with machine pallets. A flexible combination of standardized modules enables the user to uniquely configure their systems and allow for machine tools, setup stations, pallet storage and further modules to be added for expansion and scalability in all directions. In the new weight class, large and heavy parts weighing up to three tons of transport load can be automated—for example, valves for pipelines, axle components for heavy commercial vehicles or structural parts for the aerospace industry. For the PHS 3000 Allround, a particularly robust telescoping stroke was developed. This also retains the special advantage of frontal access; the operator is able to access the machine at all times through a door between the PHS and the machine. This ensures minimal downtime and

high productivity, since the system continues to run when decoupling individual machines for manual activities or maintenance work. The shelf magazine on the PHS 3000 Allround also offers pallet storage for up to three levels.

The demands placed on gear metrology are steadily increasing. In e-Mobility in particular, identifying and preventing unwanted gearbox noise is critical. Alongside highly accurate measurements, advanced analysis options are becoming ever more important. A key

aspect of this development is the identification of waviness components in gear measurement curves. In addition to single-flank analysis, evaluation as a closed curve across the entire gear circumference is also possible. This can be based either on full-gear measurements or on what are known as 4+X measurements, which deliver comparable results with significantly less effort using as few as six to eight measured teeth.

Using nonlinear optimization, the system calculates the frequencies



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and—where a topography measurement is available—the helix angles of the waviness components. These parameters are crucial for assessing potential sources of noise excitation in the gearbox. Tooth modifications such as crowning and relief can be selectively included or excluded. Stop by Booth #237044 in the North Building to see these and other machining technologies.

liebherr.com

Nidec Machine Tool America

EXHIBITS GEAR
MANUFACTURING
AND INSPECTION
TECHNOLOGIES AT IMTS
2026

Nidec Machine Tool America will exhibit gear manufacturing and inspection technologies at IMTS 2026. Located in the

North Building, Level 3, Booth #237054, the company will feature the newly released RoboCam inspection solution, the ZFA260 gear grinder, and the MSS300 Super Skiving machine.



RoboCam is a robotic camera solution for hob wear evaluation. By leveraging artificial intelligence, the system gives manufacturers an automated approach to assessing hob condition, helping reduce guesswork as well as time spent on evaluation.

Addressing the rising demand for high-volume automotive and robotic components, the ZFA260 gear grinder will be featured as a centerpiece of the exhibit. Designed for high-speed, high-precision machining, the ZFA260 accommodates gears with external diameters up to 260 mm. Its twin-table structure and high-speed rotary performance contribute to reduced non-machining time. The machine also incorporates simultaneous double-tooth flank bias adjustment to help suppress tooth-flank distortion.

Also featured at the booth will be the MSS300 Super Skiving machine for internal and external gear cutting. The MSS300 features a symmetrical structure designed for thermal and mechanical stability. Massive guideways on the three linear axes ensure optimal rigidity, while a twin-ball-screw drive on the z-axis provides stable power and control. Nidec's patented Super Skiving tools reduce chip loading, enabling high-efficiency machining with fewer passes. A center-trough base structure removes chips directly from beneath the cutting point to help suppress thermal deformation.

The machine accommodates workpieces with diameters up to 300 mm, a maximum gear width of 100 mm and a maximum spindle speed of 5,000 rpm. It is designed for manufacturers seeking to improve productivity in gear cutting

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while maintaining stable machining conditions and extending cutter life.

Beyond the equipment featured at IMTS, Nidec Machine Tool America offers a broader portfolio of Advanced Manufacturing Technologies, including LAMDA laser powder directed energy deposition systems, ABLASER laser micromachining systems, and Bond Meister room-temperature wafer bonding machines. These technologies serve specialized manufacturing requirements in large-scale 3D metal printing, precision laser processing, and semiconductor production.

Based in Wixom, MI, Nidec Machine Tool America provides in-house sales, service and parts support throughout North America. IMTS attendees are invited to visit Booth #237054 to discuss gear production, tooling, inspection and advanced manufacturing requirements with the company's team.

nidec-machinetoolamerica.com

United Machining Solutions

MAKES NORTH AMERICAN TRADE SHOW DEBUT

United Machining Solutions will showcase 17 CNC machines featuring the latest innovations from Mägerle, Blohm, Studer, Walter, Agie Charmilles, Charmilles, Mikron Mill and STEP TEC, as well as several new and noteworthy automation accompaniments, including the new Automated Tool Production cell from Walter, the WorkPartner 1 cell from system 3r, and the versaLoad cell from United Grinding North America at Booth #236802.

To kick off the show, IMTS press and visitors are invited to a special show at the United Machining Solutions booth on Monday, September 14 at 10:15 a.m. CDT. United Grinding (North America headquarters in Miamisburg, OH) and United Machining (North America headquarters in Lincolnshire, IL). Each division will showcase machines with a proven track record of increasing customer accuracy, productivity and revenue.

Mägerle, Blohm, Studer, and Walter will all have their latest grinding innovations and in some cases—inventions—on display. Studer, inventors of the first CNC cylindrical grinding machine in 1976, will debut the S23 universal cylindrical grinding machine for the first time at IMTS as well as the S131r, S41 and S33. Walter, inventors of the first CNC tool grinder in 1977, will showcase the new Helitronic Vision Laser and the Automated Tool Production (ATP) automation cell, as

well as the Helicheck Nano, Helitronic Micro, and the Power Diamond 400. And Blohm and Magerle will show the MC5 and the MFP 30, respectively. “We are extremely excited to show the manufacturing world our latest machines and software that will help our customers solve their greatest challenges,” said Markus Stolmar, president and CEO of United Grinding North America.

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AICA and Schaeffler demonstrate
the role Physical AI can play in the
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Matthew Jaster, Director, Editorial Content

The software was developed and adapted to work within Schaeffler's specific gearbox assembly process. (All images: AICA)

Conversations on the role Physical AI will play on shop floors across manufacturing took place at every stop I made during the Automate Show in Chicago. Robots—in addition to literally doing the heavy lifting—are now being asked to independently learn from experiences and discover solutions without the assistance of human programmers. At the Universal Robots (Teradyne Robotics) booth, I was treated to some amazing force sensing applications that led to a discussion on a recent gearbox assembly use case between AICA (a partner of UR) and Schaeffler that tapped robots to assemble gearboxes.

Schaeffler faced a variety of unique challenges in design and lifecycle for EVs at a time when the skilled labor force was shrinking. These challenges came to a head during the assembly of planetary gearboxes for an automotive axle. This assembly process exposed the limits of legacy automation: meshing toothed components that rotate independently and vary in tolerance. Conventional programming proved too rigid to adapt, driving up engineering costs and creating production bottlenecks.

The end game was to improve the efficiency and accuracy of their gearbox assembly process. This proved tricky because the parts—like planetary gears—moved freely and unpredictably. This made it hard to program the robots to work effectively. To make things even more complicated, the weight, size, and shape of the parts changed, which slowed everything down. Schaeffler also wanted to be able to switch between different robot brands without a lot of hassle.

Schaeffler sought a solution that could eliminate the dependency on manual labor, handle complex insertion trajectories without rigid, expensive coding, adapt quickly to batch and design changes and scale globally across different robot brands and regions.

These needs led to a partnership with AICA, a Swiss robotics software company specializing in AI-driven automation.

AICA's Smart Assembly module allowed Schaeffler's robots to adapt their movements between different batches in just one hour. The Smart Assembly application was developed with simplicity in mind allowing users to program both collaborative and industrial robots in three easy steps.

International Rollout

The International Federation of Robotics (IFR) reported that as part of the development cooperation between Schaeffler and AICA, AICA tailored its state-of-the-art robot software to Schaeffler's specific requirements and use cases. Smart Assembly used real-time adaption, force feedback and autonomous learning capabilities (reinforcement learning) to optimize the assembly process. As a result, the robot independently and autonomously trained the optimum assembly parameters based on previously defined framework conditions and success criteria.

As part of Schaeffler's industrialization efforts to transfer the AI-empowered automation solution from AICA into series production, a use case in the field of e-Mobility in Greater China was identified.

This use case focused on the automation of a helical planetary gearbox assembly, which is used as a subsystem in an e-axle drive system for electric vehicles. The challenge in the assembly process was due, in part, to the helical gearing of the three planets and the ring gear in the housing as well as the independently rotating planets (before assembly), which consequently have different initial positions themselves and in relation to each other.

Sensor-Driven Robotics

Founded in 2019 in Lausanne, Switzerland, AICA emerged from the Learning Algorithms and Systems Laboratory (LASA) at EPFL. Today, the company is based at the Unlimitrust Campus by SICPA, continuing to build on robotics research and innovation. Essentially, the goal is to transform the way industrial robots are programmed and deployed. The AICA System combines advanced AI algorithms with real-time, sensor-driven, adaptive robot control, simplifying the integration and programming of robotic systems. By streamlining these processes, they make industrial automation faster, more flexible, and significantly more affordable. This focus on flexibility and adaptability addresses many of the challenges manufacturers face today and unlocks the potential of intelligent automation.

The AICA System empowers users to develop advanced robot applications using AICA's extensive component library and customize them with AICA's Software Development Kit (SDK). Once ready, developers can deploy applications seamlessly into production or purchase a pre-built solution with a one-time deployment key.

Automate Examples

At Automate 2026, the Universal Robots (Teradyne Robotics) booth featured a UR7e robot executing learned trajectories from human demonstrations that are both adaptive and force-sensing. The robot picked up a metal part and buffed it against a polishing wheel.

Christopher Savoia, global head of UR+ Ecosystem, took me on a tour of the booth to explore the evolution of Physical AI across several robotic applications.

Both the e-Series and UR series robots, for example, have a built-in end of arm force torque sensor that can be leveraged for force sensitive control. In UR terminology, this feature is called force mode and can be used to perform motions along a desired direction or path while being force compliant in certain axes or directions.

According to Enrico Eberhard, CTO and co-founder of AICA, the hardware provided by AICA provides special tools and functionalities unique to UR robots including advancements to force sensing technology. The true power of this advancing technology comes from the versatility it offers to manufacturers. AICA has provided additional case studies in areas like screwdriving, polishing and assembling from prototyping to production across several industries.

Reinforcement Learning

On the industrial side, reinforcement learning has shown its strength in complex, high-precision tasks like this gearbox assembly example. AICA took a deeper look at these technologies in a blog posted earlier this year called "Deep Reinforcement Learning: A New Frontier for Robotic Arms," where they hinted at the shift taking place when robots are allowed to learn from experience and can discover solutions that human engineers might not think to program at all.

"Deep reinforcement learning is famously data-hungry, often requiring millions of trial-and-error interactions to learn a task. Running that many trials on a physical robot isn't practical, it would take weeks, wear down hardware, and burn through resources. That's why most training happens in simulation, where data is cheap, fast, and safe to collect.

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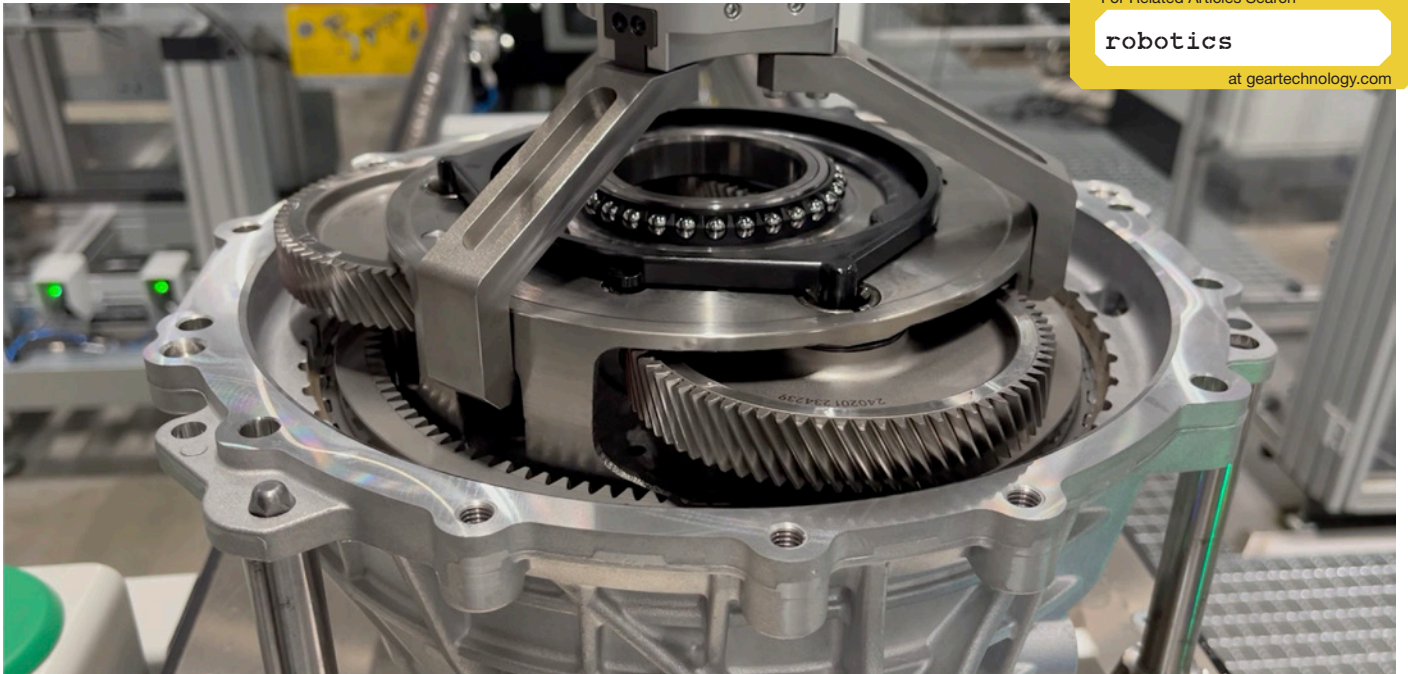
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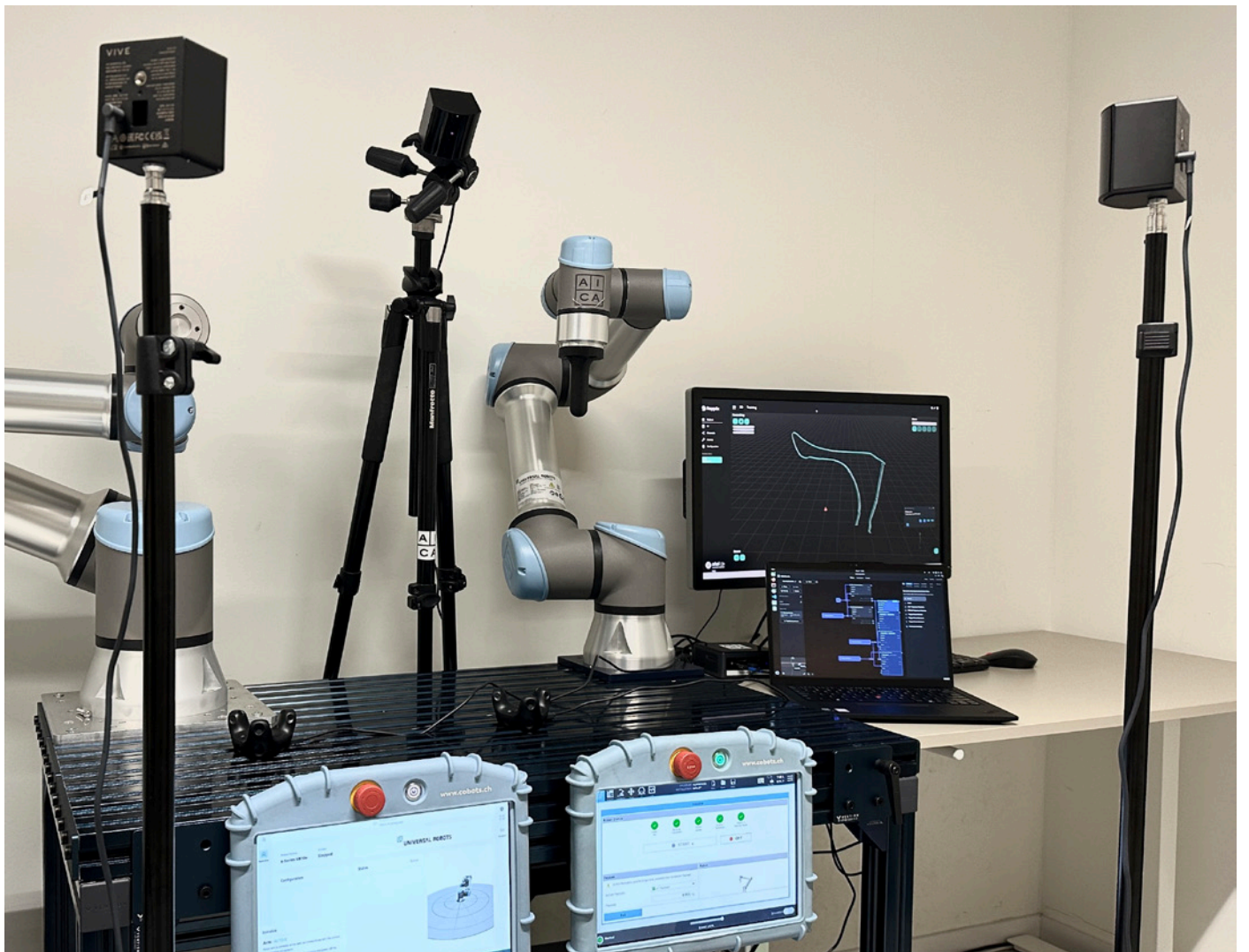
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AICA's Smart Assembly software reduced the required time to parameterize a new batch from days to just one hour.



AICA and Replixx (a hosting replication software) create AI content tools to automate manufacturing workflows and provide technical support.

Of course, simulations are never perfect. Even small mismatches between simulated and real-world physics, like slight changes in friction or lighting, can cause learned behaviors to fail once deployed. This sim-to-real gap remains a major hurdle in robotics. To close it, engineers enhance simulator realism by tuning physics parameters and use techniques like domain randomization and actuator dynamics modelling to train policies that can handle real-world unpredictability. Even when a policy works, understanding how it works can be tricky.”

The blog went on to examine how neural network controllers may be effective, but they often lack transparency.

“It’s difficult to know why a robot made a particular decision or how to adjust its behavior. As a result, many companies take a conservative approach: once a deep reinforcement learning policy is trained, they ‘lock it down’ and ship it as a fixed black box. It works, but you can’t inspect or modify it, much like proprietary software. This limits flexibility. Developers can’t easily adapt or build on top of it, and making small changes can require retraining from scratch. Yet this is a smaller issue when working with compact, well-trained policies designed for highly specific tasks, where the model’s scope is narrow and its behavior easier to characterize.”

Deep reinforcement learning isn’t a silver bullet, according to the AICA blog, but with the right tools and approach, it’s transforming robotics. Tasks that once seemed impossible to automate are now within reach.

Industrialization & Series Production

The Schaeffler gearbox assembly project is one example. After a successful proof of concept and multi-month endurance testing, the gearbox assembly solution was officially deployed in Schaeffler’s Greater China production facilities. This included the development and adaptation of the AI-driven Smart Assembly software directly into Schaeffler’s processes. It also included a cross-regional technology rollout and validation and long-term monitoring to track system performance.

By the numbers, Schaeffler achieved a 98 percent success rate with 75 percent less downtime and a 40 percent mark-down on expenses. This combination of adaptive learning, real-time control and modular software increased efficiency while reducing cost, complexity and risk.

In the past, a robot could only handle tasks that engineers anticipated ahead of time. Today, complex and unstructured tasks cannot be captured through instruction or prevention, it’s now the job of robots—supported by advanced software architecture—to figure out production steps in real-time. Physical AI is allowing robots, drones and autonomous vehicles to look at complex challenges and figure out solutions without assistance from their human counterparts. We’re entering a whole new level of autonomy with success stories like this.

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METAL's Manufacturing Workforce Network

**A DoW-funded partnership
brings online courses and
hands-on bootcamps to
Purdue's foundry lab, training
that feeds gear production**

Jennifer Jensen, Associate Editor

A participant pours molten metal during a METAL bootcamp, gaining hands-on foundry experience alongside instructors. (All images: Rosie Marketing)

Many students and job seekers are unfamiliar with the advanced technologies and career opportunities available in metal casting and forging. But thanks to the Metallurgical Engineering Trades Apprenticeship and Learning (METAL) program, led by the IACMI-The Composites Institute, that is changing. METAL is partnering with universities to showcase the rewarding careers these industries offer. Together, these institutions are hoping to revitalize American manufacturing by delivering responsive, scalable, and sustainable workforce development programs.

"We are helping the workforce be more skilled and talented in the right areas," said Mike Kubacki, program manager at IACMI.

One of METAL's newest partnerships is with Purdue University, where engineering programs will expand industry-driven training opportunities for current and prospective metalworking and manufacturing professionals. Funded by the Department of War's Industrial Base Analysis and Sustainment Program, the initiative focuses on casting, forging and plate rolling.

"Casting and forging is another industry that's really suffering and needs some help in the workforce development world," said Kubacki.

Purdue's School of Materials Engineering within the College of Engineering (<https://polytechnic.purdue.edu/academic-areas/soet>) within the Polytechnic Institute will implement METAL's curriculum in its program, beginning with a combination of online training and immersive in-person bootcamps held at a manufacturing lab equipped for metal melting, heat treatment and machining capabilities. The training is free to participants.

"It's being a long-standing partner in other areas, and it's a big win overall," Kubacki said. "They have such great facilities and really engaged professors in this, mission-minded like we are, so I think this is going to yield great results."

The METAL program will leverage Purdue's integrated Smart Foundry, embedding Industry 4.0 capabilities such as digital twins, advanced sensing, data analytics, robotics and AI directly into the foundry environment. This positions Purdue as a living laboratory where metal casting expertise and next-generation digital manufacturing technologies come together to advance productivity, sustainability and workforce readiness.

The online curriculum introduces participants to topics including heat treatment, sand casting, forging

and tensile strength, which Kubacki described as level one, basic curriculum. "You can take the online curriculum, learn broadly, not too deep, into every little topic," he said.

The coursework is designed for both newcomers and experienced workers looking to better understand other parts of the manufacturing process. "If you're in gear manufacturing and you are a CNC machinist, it might be helpful just to take the online curriculum and go learn a little bit about casting and forging, to understand the process before the one you're doing," he said. "That can be beneficial."

An entry-level operator just coming in off the ground floor could use the online class for onboarding and then go to boot camp to get a base knowledge and train them further. While the online course isn't a prerequisite to taking the boot camp, Kubacki said it is recommended to make the lesson a bit easier and move faster.

The boot camps allow participants to experience manufacturing firsthand by pouring their own metal and producing cast parts. "They can make a mug out of lost foam casting, which is related to engine blocks that are often made from lost foam casting," Kubacki

said. Participants also create sand molds, pack sand, and explore newer manufacturing technologies such as 3D-printed sand molds.

Purdue's facilities also expose participants to more specialized manufacturing equipment, including a Bridgman furnace used to produce jet engine turbine blades through investment casting. The university is also utilizing its smart foundry, and they're creating a boot camp around that to get students to connect to Industry 4.0. "We're looking at what data is being collected in a foundry," he said. "How can you analyze that data? How can you better fit your company up for success in the long term?"

Purdue's program is one version of a curriculum shared across METAL's university partners. Each university adapts the curriculum to its own facilities and areas of expertise while following the same core model. Whether students attend Purdue, Penn State, or Ohio State, Kubacki said they will receive a comparable training experience centered on six core activities, with each campus adding specialized experiences based on its strengths. "Our role really is focused on network workforce development for the manufacturing processes," he said. "And that makes gear production possible. Gear manufacturing does depend on advanced materials, forming,

machining, heat treatment, inspections, and most of all, skilled people."

Purdue's addition to the METAL network strengthens a growing national network of METAL hubs, including the University of Alabama at Birmingham, The Ohio State University, Pennsylvania State University, the University of Tennessee, Knoxville, Tennessee Tech, Michigan Technological University, California State Polytechnic University, Pomona and NC State. As demand for training grows, METAL hopes to expand its boot camp model across the country. "We want to be able to have the boot camps hosted everywhere," he said.

While Purdue focuses on training students and workers, METAL is also expanding industry engagement and recruitment efforts nationwide. IACMI continues to work with industry partners to participate in boot camps and potentially use those events as a recruitment tool. IACMI has a metal advisory network within the industry that provides support and feedback on curriculum, among other things.

The organization has also started using virtual reality (VR) to introduce students to manufacturing careers. Through VR headsets, participants can tour industrial facilities and gain a better understanding of modern manufacturing environments.

METAL will showcase that technology at the International Manufacturing Technology Show (IMTS) in Chicago this September. "One of those films is from McInnes Rolled Rings in Erie, Pennsylvania," Kubacki said. "They make rolled rings. That's a foundation for a lot of gears and bearing applications. Students can take a tour and understand what it would look like to be working in that factory."

This initiative is one of several new outreach efforts aimed at increasing awareness of careers in metal manufacturing. Beyond its partnership with Purdue, METAL is working with the Foundry Educational Foundation to introduce its curriculum in about 100 high schools. Students can participate in a two-week course that includes hands-on sandcasting activities designed to introduce manufacturing concepts at an early age. The program focuses on regions with strong manufacturing industries, including Pennsylvania, Ohio, Wisconsin, Michigan and Indiana.

With a shortage of workers within many industries, METAL, along with its other partners, is trying to get creative in recruitment. "We have K through 12 goals that we're trying to hit," he said. "We want to build that pipeline." They reach big audiences through STEAM events or a tradeshow, like IMTS. They also host smaller workshops where they bring the students to them to get more in-depth in key areas.

Those outreach efforts come as manufacturers across the country continue to face a shortage of skilled workers. "Our goal is to help the industry in the next six to 12 months," he said. "We're trying to get people trained, trying to get them just to understand that the industry needs help, and you can have a great, rewarding career."

metalforamerica.org



A heat-treated steel bar comes out of the furnace during a METAL bootcamp session—one of the core topics covered in both the online curriculum and hands-on training.

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From Design to Manufacturing

Once the design of a new gear set is complete, all requirements for strength, service life, efficiency, and noise appear to have been met. At this point, the design engineers' job is done—but is it really?

Stefan Beermann, Managing Director, KISSsoft AG

Manufacturing follows the design stage. Many design engineers assume that this step requires little attention. However, this can lead to problems, additional costs, or delays later. Figure 1 shows an example of a typical two-stage EV drive. The idler shaft has two gears, and the original idea was to manufacture it as a single piece. However, the pinion of the second stage is very close to the gear of the first stage. Hobbing teeth on the pinion in this position is not possible. Power skiving may also be unsuitable because optimal process parameters might not be achievable. One possible solution is to mount the gear after the pre-finishing step. Because of precision and noise requirements, the finishing step should be performed with the gear mounted. The same challenge arises for applying honing processes, as there is very little space available.

Even this simple design poses challenges for manufacturing and process engineers. This highlights the importance of considering manufacturing early in the design stage. It is not necessary to define every detail at this stage, but sufficient consideration should be given to avoid common manufacturing pitfalls.

KISSsoft is a comprehensive gearbox design software from Gleason Corporation. Since version 2025, an increasing number of features have been added to address typical manufacturing questions. The following sections highlight some of them. The first feature addresses the interference problem when cutting teeth. The hobbing process can now be modeled directly in the cylindrical gear calculation, with the option to define an

interfering feature on either side of the gear.

The built-in fine-sizing function of the hobbing process module systematically varies the outer diameter, the number of threads, and the number of gashes. It checks compliance with gear quality requirements, including the generation of flats and feed marks, as well as interference conditions. It then estimates the cutting time and usable tooth length. Figure 2 shows the resulting solutions, identified by their index in the results table, plotted as cutting time versus outer diameter, with the number of threads indicated by color.

For a given number of threads, increasing the outer diameter results in a higher number of gashes, allowing a larger axial feed rate. On the other hand, a larger diameter combined with a fixed cutting speed results in a lower rotational speed of the tool and the gear. A larger diameter also increases the approach distance. As a result, there is an optimal diameter that achieves the shortest cutting time.

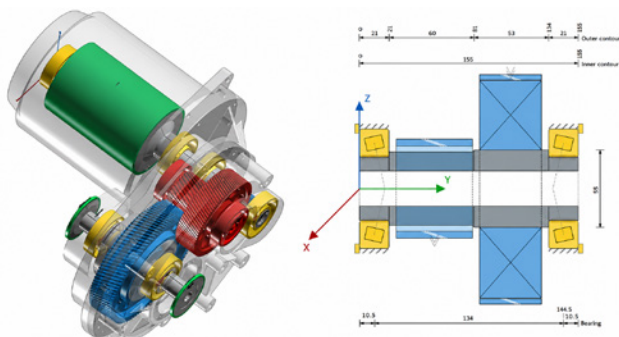


Figure 1—Example of an intermediate shaft. (All images: KISSsoft)

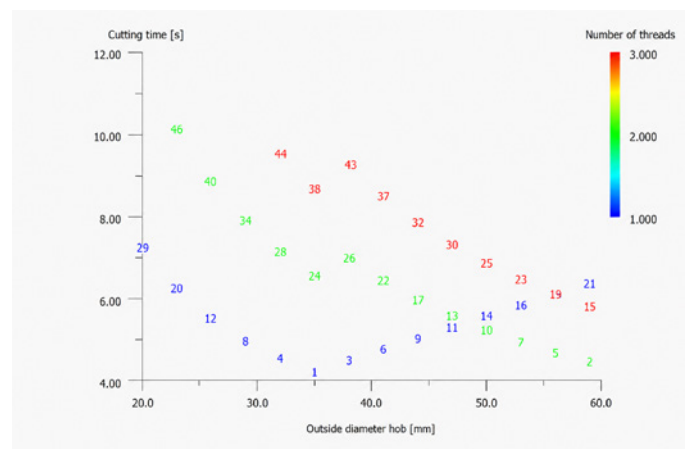
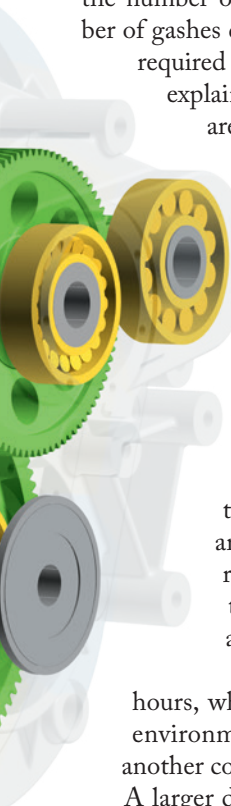


Figure 2—Cutting time versus hob outer diameter, for one-, two- and three-threaded hobs.



More threads typically require a larger diameter because the number of cutting edges per gear tooth equals the number of gashes divided by the number of threads. To achieve the required quality, more gashes are therefore necessary. This explains why the solutions with two and three threads are shifted to the right. They show the same trend: increasing axial feed and decreasing cutting time as the outer diameter of the tool increases. However, because of the defined interference conditions, the maximum possible tool diameter is reached before the optimal cutting time is achieved. In this case, a single-thread hob results in the shortest cutting time.

To illustrate the general trend more clearly, Figure 3 shows the fine-sizing results for the same case, but without any interfering features. Optimal hobs with two and three threads are also feasible and appear among the possible results. In this case, they would slightly reduce the cutting time, with an estimated reduction of about 10 percent.

Cutting time can be converted into machine hours, which directly affects costs in a mass-production environment. In addition, the cost of the tool itself is another component of the overall production cost.

A larger diameter allows a greater number of gashes and/or a longer usable tooth length (UTL) on the hob. More gashes reduce wear and enable more parts to be cut before the hob requires resharpenering. A longer UTL allows more resharpenering cycles before the hob reaches the end of its service life, thereby increasing the tool's total service life. On the other hand, the initial price of a hob also depends on its size. If a linear relationship with the number of gashes is assumed, because grinding a hob with more teeth requires additional processing, the cost increases linearly. If a constant

weight-based price is assumed, the increase is proportional to the square of the diameter, provided the hob length remains constant. Therefore, the hob price can be expected to increase somewhere between linearly and quadratically with its diameter.

Table 1 compares two hobs. The diameter of the second hob is 50 percent larger than that of the first. For the first hob, a tool price of 1,000 is assumed, while the second hob is assumed to cost 1,875, the mean value between 150 percent and 225 percent. For resharpenering, costs of 50 for stripping, 150 for sharpening, and 100 for recoating are assumed. Under these assumptions, the resulting cost per part is 0.048 for the first hob and 0.035 for the second. In this case, over the entire service life of the tool, the larger and significantly more expensive hob is the more economical solution. Of course, the result depends strongly on the specific circumstances, particularly the tool and resharpenering costs, and other cases may lead to different outcomes.

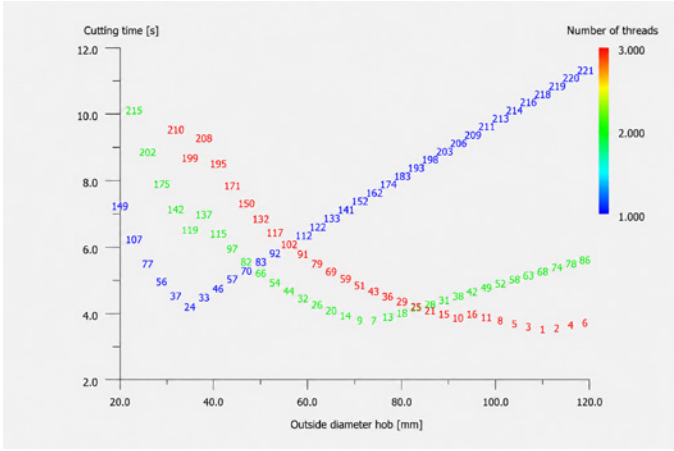


Figure 3—Cutting time versus hob outer diameter, for one-, two- and three-threaded hobs, for very large outer diameters.

Hob	#1	#2
Outer diameter (mm)	27	41
Number of gashes	8	12
Tool costs	1000.00	1875.00
Stripping costs	50.00	50.00
Sharpening costs	150.00	150.00
Coating costs	100.00	100.00
Total conditioning costs	6600.00	6900.00
Usable teeth	245	365
Tool life per tooth (m)	4.800	4.800
Cutting length per part (m)	0.170	0.170
Parts per conditioning	6917	10305
Number of conditionings	22	23
Parts per tool	159091	247320
Tool cost per part	0.048	0.035

Table 1—Cost calculation for two hobs of different sizes.

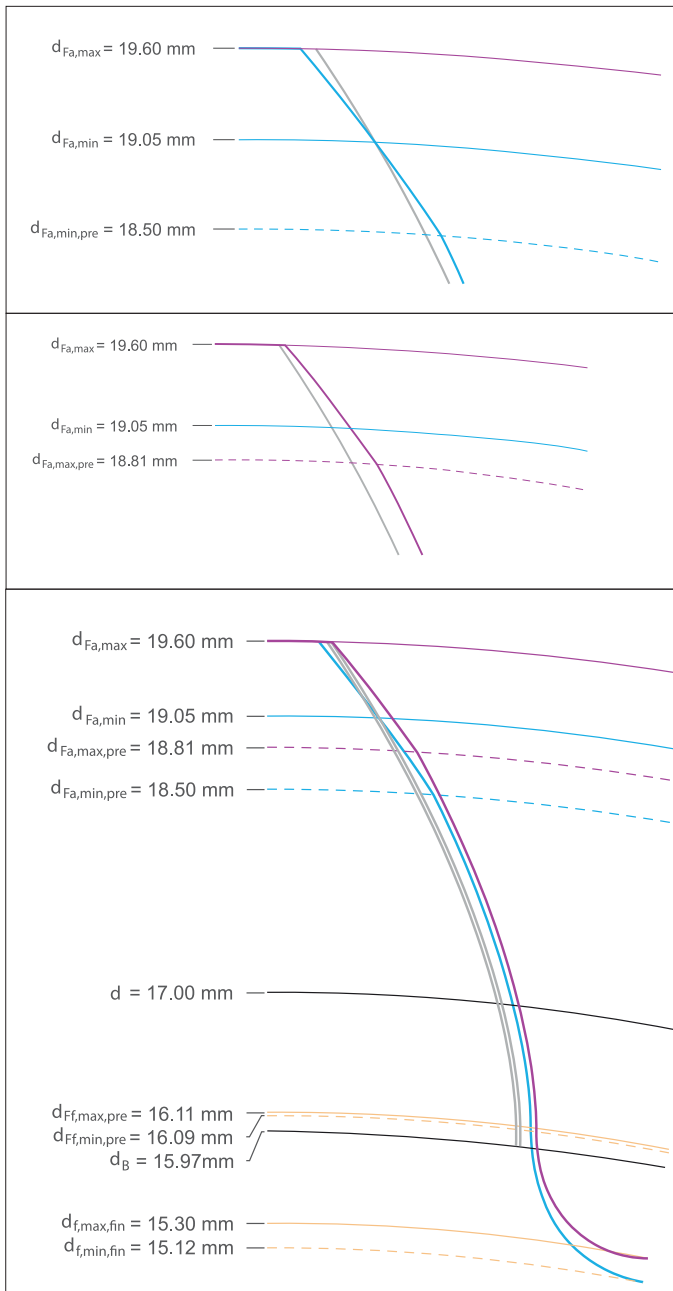


Figure 4—Rollout graphic for the whole profile (bottom), the tip area in minimal stock tip condition (top), and the tip area in maximum stock condition (middle).

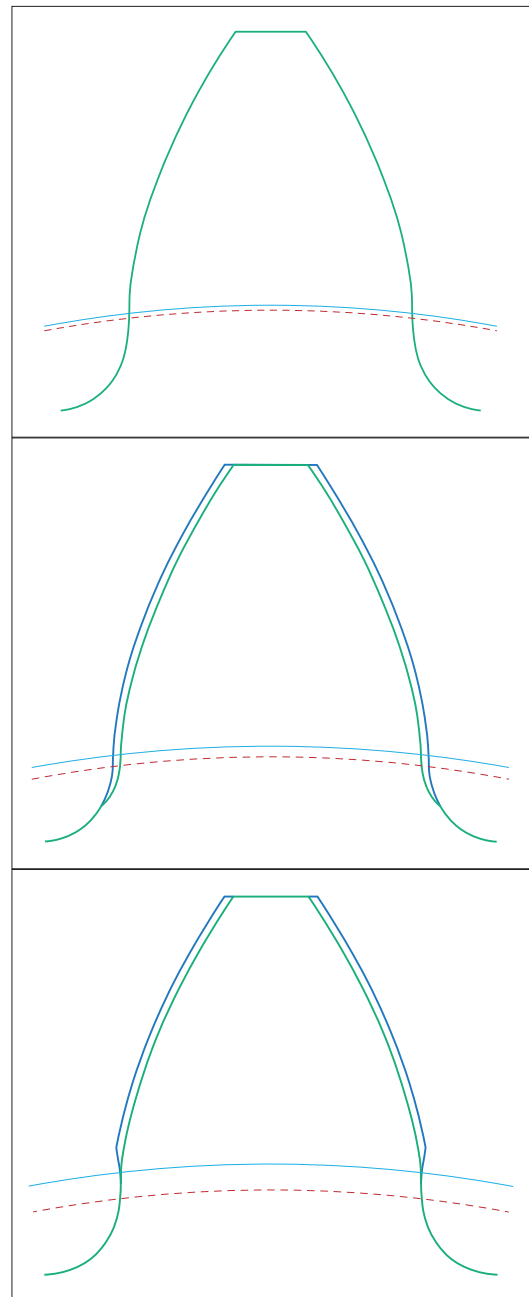


Figure 5—Three different situations that define the root form diameter: Single manufacturing step (top), pre-finishing and grinding (middle), pre-finishing with protuberance tool and grinding (bottom).

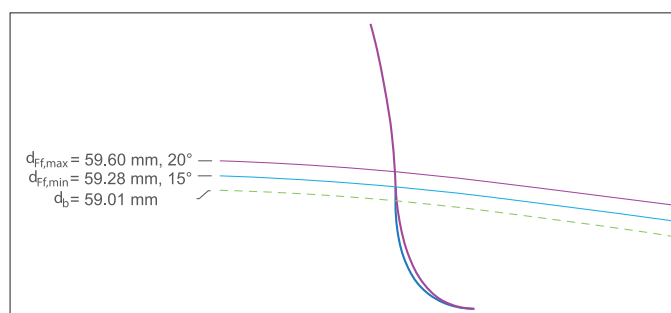


Figure 6—Effect of the short-lead tool on the root area.

Once the feasibility of the hobbing process has been confirmed, it is typically followed by grinding or another hard finishing process. Therefore, some stock is left during pre-finishing. This stock is often defined using typical values derived from experience. To go beyond experience alone, software can be used to investigate the resulting final tooth form in greater detail.

The rollout graphics in KISSsoft show the pre-finished tooth form for three material conditions: minimum, maximum, and a user-defined condition, which is typically between the other two, such as the mean value. This feature makes it possible to evaluate how stock and pre-finishing tolerances influence the finished tooth form, particularly the tip and root form diameters.

Figure 4 shows an example of such a rollout graphic with the maximum and minimum material conditions. To make the details easier to see, the upper-left section shows only the tip area for the minimum material condition, while the upper-right section shows the same area for the maximum material condition. Two profiles from the pre-finishing step are shown: the maximum-condition profile is pink, and the minimum-condition profile is light blue, with the defined stock tolerance between them. The two gray profiles on the left are involutes corresponding to the grinding step, and the finished tooth-thickness tolerance determines the distance between them.

This example shows a gear with a tip chamfer generated during pre-finishing with a semi-topping tool. The finishing step removes part of the chamfer. The point at which the chamfer begins on the profile defines the tip form diameter.

The tip form diameter decreases as less material is removed during finishing. Accordingly, the minimum-stock condition determines the minimum tip form diameter, shown in the figure as the light-blue solid circle. The dashed circle indicates the start of the chamfer on the pre-finished tooth form and is included for reference.

The maximum stock condition, which corresponds to the greatest amount of material removed during finishing, results in the largest tip form diameter. In this case, the entire chamfer is removed, so the tip form diameter coincides with the gear's tip diameter. Assessing these extremes is critical because variations in the tip form diameter can affect tooth contact, load distribution, and overall gear performance.

The permissible limits for the tip form diameter depend on the specific application. A smaller diameter may reduce the transverse contact ratio. However, if too much material is removed, as in this case, the chamfer may be eliminated. Ultimately, the designer must define the appropriate range of values.

Moving from the tip to the root, the next parameter to check is the root form diameter. The primary concern is to ensure that the root form diameter, true involute form (TIF), is smaller than the start of the active profile (SAP). If this condition is not met, contact with the mating gear is likely to occur in the non-involute root area.

The root form diameter can be generated in three different ways, shown from left to right in Figure 5. The left subfigure shows a tooth generated in a single step without pre-finishing. As the root is generated, the tip of the tool creates the trochoid in the gear's root area. The point at which the involute and the trochoid intersect defines the root form diameter.

The middle subfigure illustrates a process consisting of a pre-finishing hobbing step followed by a grinding step. The grinding disk or worm removes material along the flank down to the root, to a specified diameter determined by the grinding depth. At this point, the generated involute ends, thereby defining the root form diameter. Below this point, a grinding notch is created. Its rounding radius may be significantly smaller than that of the root area itself. This can reduce the tooth's bending strength because of additional stress concentration and the removal of the highly compressive residual stresses created during heat treatment. To avoid the grinding notch, an artificial undercut can be added. This is produced with a protuberance tool that has a section at the tip with a smaller profile angle. The resulting shape is shown in the right subfigure. The blue tooth profile represents the pre-finishing step with the undercut. The grinding step then removes most of the undercut, and the rounded tip of the grinding disk finishes outside the gear material, while still within the undercut area.

If the SAP is smaller than the root form diameter, a short-lead tool may provide a solution. A short-lead tool has a smaller profile angle than the nominal pressure angle of the gear. To generate the same involute while preserving the base circle, the tool module must be adapted so that the tool's base pitch matches that of the gear. This adjustment results in a different lead, which is why such tools are called short-lead tools. Figure 6 compares the root produced with a 20-degree tool and a 15-degree tool. The red tooth form and pink root-form circle are produced with the 20-degree tool, while the blue tooth form and blue circle correspond to the 15-degree tool. The root of the blue tooth has a significantly smaller rounding radius. This provides more space for the involute to extend closer to the base circle, shown as the green dashed circle, before transitioning into the trochoid. As a result, the blue root-form circle of the 15-degree tool lies below the pink root-form circle of the 20-degree tool. Because the short-lead tool has a smaller rounding radius, the root strength is lower with the 15-degree tool than with the 20-degree tool. This can be compensated for by increasing the hob tip radius, which is feasible due to the smaller profile angle. However, a larger tip radius also increases the root form diameter, so an appropriate compromise must be found.

In summary, rollout graphics are a powerful and precise tool for quickly evaluating the generating process while taking the relevant tolerances into account. They allow designers and manufacturing engineers to visualize the interactions among pre-finishing geometry, stock, and finishing operations, making it easier to evaluate critical parameters such as tip and root form diameters. This type of analysis is normally performed by cutting tool manufacturers, but it can now be integrated directly into the design process. As a result, potential manufacturing issues can be identified and addressed early in the design stage, reducing the risk of costly design iterations during prototyping or production.

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Automation for Every Shop Size

A new CNC-based application puts cost-effective robot part handling and articulation directly on the machine tool's control screen, eliminating the need for a separate robot pendant

John Meyer, Marketing Communications Manager, Siemens Industry, Inc.



Through a technology partnership that breaks new ground in the machine tool industry, Siemens presents an automation solution for the busy, multitasking, small to mid-sized machine shop, as it combines a digital twin of the software and programming of its popular Sinumerik 828 CNC, working in tandem with a Kuka robot, to simplify the operation and programming in part handling for the machine tool operator. Bringing the concept to life during a recent tradeshow, Kuka Robotics Corporation demonstrated the same control and its robot working in tandem with a Syil vertical milling machine. The machine featured the Syil R1 machine-tending automation package, developed with one of Kuka's system partners, Waybo, which seamlessly integrates the pick-and-place, part articulation, and communications with the CNC onboard, all at a very attractive price point.

The goal of the program, according to Frans Buikema, chief marketing officer at Syil, is to offer the small and mid-sized shops an entry point into automation without major capital investment. Likewise, as Ron Bergamin, key technology manager for machine tool automation at Kuka, adds, the ROI can be very short, as this automation advancement allows the addition of a lights-out second or third shift at job shops of almost any size. Automation is the key,

and this cooperative engineering venture has opened a new chapter for small to mid-sized machine shops.

Simplifying Robotics Through the CNC

A bit of history. Only a decade ago, integrating a robot with a machine tool required a separate learning curve for the shop, as robotics required specialized programming and teach-in communications, a separate pendant for operation, and other challenges that often required outside consultants to implement. For small and mid-sized machine shops, this barrier, combined with the cost involved, has resulted in today's market conditions, where fewer than a quarter of smaller job shops in America utilize automation, especially robotics, in their workdays.

History has advanced. As Tiansu Jing, product manager, Sinumerik CNC systems, explains, "The benefits of this development for the busy job shop are many. Setup, programming, operator interface and diagnostics are all improved with the Sinumerik *RunMyRobot/Handling* application, as it easily incorporates the Kuka robot with the Syil machine tool." The teach-in functions are implemented through the Sinumerik Operate HMI system on the control, while the proprietary Sinumerik *RunMyRobot/Handling* capability of

the CNC seamlessly integrates with the Kuka robot control. Jing further noted that, since there is no need to learn robotic programming, start-up time is reduced and the robot's separate control pendant is eliminated, simplifying the operator's task. The Sinumerik control's HMI is used to operate both the machine tool and the robot tender, with all commands and operating conditions displayed on a single screen. He also added that the greatest value for the busy job shop comprised the system's ability to integrate robots on all its machines, while economizing the learning curve for all the operators. This entire cooperative venture between Siemens, Kuka and Syil made this advancement possible, Jing noted.

From Complexity to Clarity

The Sinumerik 828D CNC utilized in this application is designed for the job shop market's use of turning centers, milling machines and vertical machining centers (VMCs), but it also offers machine builders and end users the flexibility to enhance the productivity of those machines with this new robotic automation, integrated directly into the control. As Jing points out, "The 828 is scaled to the functionality of the standard machines sold to the smaller job shops.

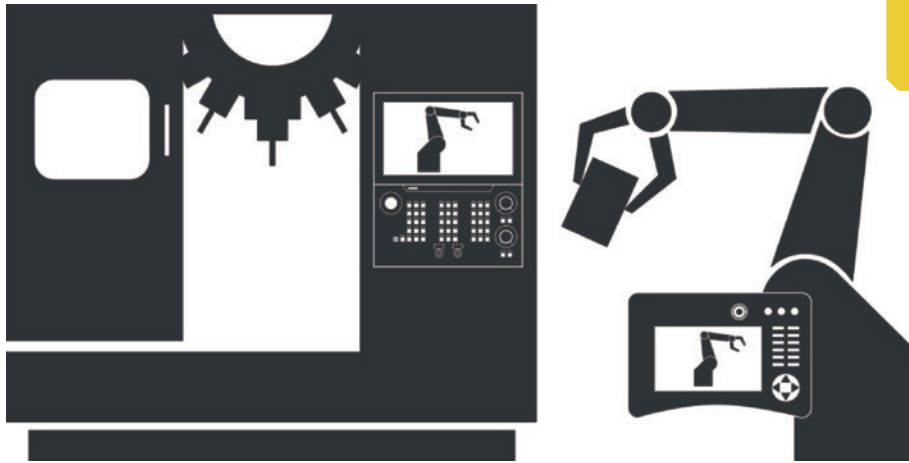


Figure 2—Robot and part programs reside in the CNC; Sinumerik RunMyRobot/Handling gives direct access to programming, manual travel, teach-in, and diagnostics through the Operate interface.



Figure 3—The SYIL R1 automation package includes a standard pneumatic clamping force block and an optional dual gripper, used when the finished part is a different shape from the blank.

With *RunMyRobot/Handling* included, programmers can use the same G-code for the robot and the machine tool.”

Designed for the Job Shop Including Affordable Lights-Out Manufacturing

As Ron Bergamin of Kuka notes, “Machine builders can now offer robotics from Kuka *mxAutomation*, a universal PLCopen-certified interface. It allows the user to program and operate all important robot functions directly in a busy shop’s familiar control environment.”

Jing further adds that the *RunMyRobot/Handling* application allows the machine builder to offer robotics as another option, at a far more affordable price than in the past, as all the engineering effort has been substantially reduced. With the connection of Ethernet and safety cables to the robot, the Syil customer finds it’s much easier to connect the robot. Bergamin adds that the robot can be up and running in a day, in most cases. “With the addition of a lights-out second or third shift at the shop, the spindles keep turning, and the shop makes more money. Plus, the ROI is very fast with this setup.”

Jing concludes, “The machine builder can easily add their own robot-specific screens to display the robot tasks and improve the usability. This solves long-time challenges for both the machine builder and end-user alike. Machine tool builders like Syil can now offer robotic packages to their customers with less price pain and more advantages in the shop.”

Philip Peloso, business development manager for machine tool automation at Kuka, expands, “We saw a resident robotic talent gap as well as price resistance in the smaller machine shop sector and decided we needed to pursue a solution. We turned to our official system partner, Waybo, presenting them with the facts. This solution would be an entry-level venture, addressing 75 percent of the job shops who currently have no robotic automation on their floors. We sought to present them an easy-to-use, robust system that allowed quick change-over for the busy shop doing multiple jobs or families of parts during the day.”

As Kuka has a long-time relationship with Siemens, their combined support

in the field would bring a further benefit to the solution. Once developed, this new system was presented to Syil, who adopted it as their Syil R1 solution for the job shop market. Peloso cites the key value proposition. “All meaningful controls and diagnostics were to be displayed on the CNC, thereby reducing or eliminating all the previous roadblocks for the shop personnel.” All the motion control of the grippers, pick-and-place functionality, and communications with the CNC on workholding are seamlessly transmitted from an application layer on the Kuka robot, so all commands are configured and programmed to take instructions directly from the CNC.

Ron Bergamin further notes, “Working with Waybo, we developed the automation around the robot. A new interface layer, run through our standard *mxAutomation* software, allowed the robot control from the Siemens CNC, so a single pendant is all that’s required to run the Syil machine tool and the robot package. All diagnostics are under the hood,” Bergamin muses.

A New Benchmark for Machine Tool Builders

On the tactical business level, Siemens had been providing CNC technology to Syil globally and brought the concept of robotic integration to Kuka, who worked closely with their partner Waybo to design and implement the package that became Syil R1 automation.

Frans Buikema of Syil details this development from the machine builder perspective.

“We’ve long had automation in our company’s vision and road map for the future. As we focus on the small and mid-sized machine shop world, we constantly encounter the lack of skilled labor, the price resistance, and the shortage of robotic knowledge in this sector of the machine tool market.”

Wesley Wang, managing director for Syil in North America, adds, “We have recently partnered with Titans of CNC to market our machines here and we feature the Sinumerik 828D CNC on most of our equipment, as it offers great motion control, monitoring and communications capability, plus the onboard

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Figure 4—The Siemens RunMyRobot software is now incorporated into the CNC on the machine tool, so all actions can be programmed and executed without the need for a second controller and separate robot language.

capacity to engage machine tending robotics, which opens the 24/7 running option to our customers in ways they have not imagined in the past.

Real Results on the Shop Floor

Buikema cites some hard numbers. “We believe we can tell our customers that automation is accessible today in new and exciting ways. It is decidedly not too complicated nor is it a major capital investment. For a \$60,000 package, they can be looking at a payback period of a year or less.” Wang adds, “It’s all about knowing your options today and how different they are from the not-too-distant past in the machine tool world.”

Expanding the Vision

Syil currently designs and builds CNC milling machines, CNC turning centers, and CNC Swiss-type lathes. According to Buikema, “This development with Siemens and Kuka represents our own entry into robotics, and we plan to expand the use of such packages onto all our machine offerings very soon.” He calls the implementation of the Sinumerik 828D CNC with *RunMyRobot/Handling* “... a real game changer, because it enables us to start creating more automation packages and make them accessible to our audience, the small to mid-sized machine shops.” The Syil R1 automation package utilizes the same technology integration shown by Siemens and Kuka during recent tradeshow in the industry.

Commenting on the relationship between Syil and Siemens, Buikema

observes, “It grew from supplier to strategic partner very quickly. The engineering support at Siemens collaborates with our own machine tool engineers at Syil on virtually all new machine developments at our company. This enables us to expand our machine range much faster and better than we could do on our own. That’s true synergy.”

Of equal importance, Buikema cites the support his company gets from Siemens in the North American market. “The help they provide to our dealers in Canada, the United States and Mexico is invaluable. It allows our dealers not only the ability to sell a higher level of machine and automation, but also the software support to fulfill the needs of all our end-users.”

The Syil R1 machine tending system, incorporating the Kuka robotic technology, is currently offered as a standard package by the machine builder, for parts up to 3 kg (6.61 lbs.), a payload of 6.7 kg (14.77 lbs.), and a reach of 901 mm (35.47 in). It offers an IP65/67 rating for harsh operating environments. It facilitates the loading and unloading of metal parts from the cutting zone and workholding devices being utilized, plus it is quick to install and easy to operate from the Sinumerik 828D control. The R1 system from SYIL removes the manual and repetitive tasks for a CNC machine operator by automating the load/unload process. It is an ideal solution for high-mix, low-volume tasks and can be fully integrated with parts conveying systems, bins and pallets. The R1 system is offered with a standard

workholding package, featuring pneumatic clamping force block design, as well as a dual gripper option when the finished part has a differing final shape from the blank.

In addition, the Syil R1 system features an “everything on one screen” format, integrating the robot’s programming and operation in the Sinumerik 828D control, using NC G-code and robot teach-in function for programming. This makes it very easy for machine tool operators to learn and use. All the robot diagnostic data is shown on the same HMI as the machine, allowing the entire automation cell to be monitored without the need for a second pendant.

According to Buikema, the Syil R1 automation package can be installed and fully operational in less than one day. The system is expandable with custom solutions and various pallet drawers provided.

The Future of Shop Floor Automation

Increasingly more job shops and machine operators are seeing that automation is an important asset when striving to achieve consistent workpiece quality and more flexibility on the shopfloor. Digitalization facilitates the higher level of automation needed and the networking of the components involved. With this new development, Siemens is offering a cost-effective solution that incorporates the Kuka robot functionality with a line of affordable machine tools, in this case, the Syil brand of machining centers and lathes for small to medium job shops.

From the Kuka perspective, Bergamin comments, “Kuka offers machine tool builders and end-users alike the ability to incorporate advanced robotics into their equipment and onto their shopfloors, to optimize productivity and reduce operator workload. Our partnership with Siemens has resulted in the synergy that brought this development to life.”

It substantially expands the ability of the small and mid-sized shops to utilize robotics in their work environment.”

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Emerging Technology Comes to the FTM

Mary Ellen Doran, Vice President, MPMA Emerging Technology



Jacques Lemire presents on behalf of the MPMA Robotics Committee at CCAT. (Image: MPMA)

Something new is happening at the 2026 Fall Technical Meeting, and it's been years in the making. This October in Rosemont, IL, the FTM introduces a second track of presentation-only sessions on emerging technologies, innovative solutions, and real-world applications. For those of us working inside the MPMA Emerging Technology committees, this feels like a natural arrival.

The committees have always been more than discussion groups. They're a pipeline: topics get introduced, experts get connected, relationships take shape, and over time those conversations feed into broader MPMA programming. Track 2 at FTM is the most visible expression of that pipeline yet.

So much of what's on this year's FTM agenda traces back to committee work. Justin Michaud, the first chair of the 3D Printing Committee nine years ago, helped lay the groundwork for conversations that now include using direct energy deposition to repair gear teeth. Etaxtar came before the committee a couple of years ago; we visited their booth on our 2024 RAPID tour; now they're on the new FTM track. REWITEC introduced their lubricant technology through the committees and can now reach a broader MPMA audience. The Electric Vehicle Technology Committee has been exploring PEEK gears for high-power transmission and is glad to see the topic get its own session. Liebherr brought their skiving technology to an emerging technology webinar earlier this year and returns with another talk at FTM. Tom Hart of Seco gave an emerging technology webinar in 2024.

Our work on outside events has strengthened these ties further. In 2025, CCAT, the Connecticut Center for Advanced Technology, hosted the Joint Technology Summit, bringing together technology committee members from NTMA, AMT, and MPMA. CCAT has excellent research underway, and I'm glad to fold their work more directly into MPMA's programming. Thomas Christiansen invited MPMA to a heat treat event at WPI just months ago; his FTM presentation is another example of what these relationships generate. That kind of traction only comes from sustained committee engagement over time.

MPMA currently runs five active Emerging Technology committees, each tied to a sector reshaping the gear and bearing industry. 3D Printing watches for the point where additive manufacturing moves from prototype to production. Electric Vehicle Technology follows standards development, critical materials, and the shifting EV and hybrid markets. Robotics is digging into supply chain pressure and gearbox innovation as automation demand grows. AI and IIoT keep an eye on cybersecurity, the CMMC framework, and where artificial intelligence is landing on the shop floor. And new this year, Air Mobility and eVTOL is examining the driveline technologies behind next-generation aircraft, and where gear and bearing manufacturers fit in.

Each committee meets regularly and hosts webinars. That steady work is what eventually surfaces at events like FTM. If you want to see where an industry is headed before it arrives, the committee room is the place to be.

That work shows up most visibly this October. The 2026 Fall Technical Meeting runs October 5–7 at the Hilton Rosemont near Chicago O'Hare, co-hosted this year with the Society of Tribologists and Lubrication Engineers (STLE). Track 2 opens Monday afternoon with a full session curated by STLE, building on their Emerging Issues and Trends in Tribology & Lubrication Engineering report. Tuesday covers AI and additive technologies, plus efficiency and lubrication. Wednesday continues with application, wear and failure, and manufacturing, materials, and heat treatment. Early bird registration ends August 14.

I hope to see you there. And if you haven't yet connected with one of the five Emerging Technology committees, there's never been a better moment. The conversations happening in those rooms keep shaping what the industry learns next.

To register for the FTM, visit motionpower.org. To get involved with any MPMA Emerging Technology Committee, contact Mary Ellen Doran, VP of Emerging Technology, at doran@motionpower.org.

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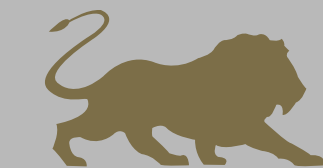
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ISO vs. MPMA Standard: Questions to Ask Before Adoption

Phillip Olson, Director, Technical Services

A common question that MPMA's technical committees face is whether to adopt an ISO standard or to maintain a separate American National Standard (ANS) on the same subject. The answer is rarely straightforward—it depends on the specifics of each case. Some questions to ask include:

Was the U.S. active in the ISO standard's development?

If MPMA experts have been actively participating in the ISO working group and have influenced the document, the result is likely to reflect U.S. practice well. If the U.S. had little involvement, or strongly disagreed with positions taken during development, the standard may have gone in directions that don't serve U.S. industry.

Have the standards converged over successive revisions?

Much of that depends on the standard's origins. ISO standards rarely start as a blank page—they generally begin from a draft national standard. If an MPMA standard served as the starting point for the ISO work, the differences between the two documents tend to be minor. If another country's standard was the starting point, the resulting ISO document may include assumptions, terminology, or technical approaches that fit that country's industry better than ours.

Will adopting the ISO standard improve trade and market access? When an MPMA standard and an ISO standard cover the same subject but differ in technical requirements, a U.S. company selling internationally may face duplicate design reviews, separate test programs, and parallel documentation—costs that foreign competitors who only deal with one standard do not bear. Adopting the ISO standard as the ANS eliminates that disadvantage and puts U.S. manufacturers on equal footing in global markets.

Is the ISO standard stable, or is it under active revision?

Adopting a standard that is about to be significantly revised could mean the committee inherits an outdated document shortly after adoption, triggering immediate follow-on work. If the ISO standard is currently under revision, it may be worth waiting for the new edition before making a decision.

What is the cost to members of switching? If U.S. industry has been using the MPMA standard for many years, products, contracts, regulation, codes, and quality systems may reference it. Adopting the ISO standard could require members to update internal documentation, re-qualify products, or renegotiate contracts—a real cost that should be weighed against the benefits of adoption.

Is the ISO standard widely used? If the ISO standard has become the document that U.S. and global industry relies on



in practice, maintaining a parallel American standard is difficult to justify. Developing and maintaining a standard requires sustained volunteer effort from technical experts who have many other demands on their time. Where global experts have already produced a high-quality ISO standard that industry has embraced, directing MPMA's volunteer resources toward a duplicative effort is hard to defend. Conversely, if U.S. industry is not using the ISO standard or is largely unfamiliar with it, the original American standard is clearly meeting the need and is worth maintaining.

Does adoption serve the members of the association?

Adopting the ISO standard makes the international text directly available to U.S. users through familiar channels, with the context and support of the MPMA community. If members would benefit from that access and alignment, adoption serves them well.

Reaching a Decision

After weighing these considerations, a decision is made to provide U.S. industry with the most useful, credible, and technically sound document possible—whether that means embracing the international consensus or preserving the distinctly American one.



Couplings and Clutches

Dr. Hermann J. Stadtfeld

The following chapter is from Gear Technology Solutions (The Gleason Works, 2025) by Dr. Hermann J. Stadtfeld. This is the fourth of four excerpts provided to Gear Technology readers to preview the book's insights into bevel gear theory, design, and manufacturing.

The Function of Couplings

Couplings are designed for a variety of duties. Hardy disks, for example, are compliant elements which connect a transmission output in a vehicle with the propeller shaft. Compliance is required to accommodate the misalignments the propeller shaft encounters when the vehicle is loaded with passengers, or if the vehicle drives on uneven pavement.

Bellows couplings are designed to transmit precise rotation between two slightly misaligned shafts. Those couplings are used to couple an encoder to an electric motor, for example. However, all couplings are, by definition, elements that do not allow any relative motion in their rotational direction. Couplings are not designed for frequent opening and closing. The two coupling halves are screwed or bolted together with the shafts they connect, and they are screwed or bolted together with each other. The coupling will stay in the connected position unless a repair or disassembly requires separating the two units that are connected by the coupling.

A good example is the Cyclocut coupling (Ref. 6), which is mostly used to connect drive shafts to the wheel hub unit. Although the drive shaft has, for example, a constant velocity joint (CV-Joint) to allow for the vertical movements of a vehicle, the CV-joint itself has one half of the coupling integrated. The wheel hub unit has the opposite coupling member integrated at the end facing the drive shaft. The coupling is the means to transmit high torque from the drive shaft to the wheel. Thus, the two coupling halves act as one solid unit after assembly. Any movement or compliance between the two coupling halves could have fatal consequences for vehicle safety.

Clutches, on the other hand, are designed for frequent connecting and disconnecting. Clutches might even accommodate some misalignment in special cases. Clutches are not bolted rigidly together like couplings.

In both cases, couplings and clutches do not perform a meshing action between their two members. In the case of couplings, this would physically not be possible because they are bolted together. In the case of clutches, the misalignment leads to unwanted friction and heating up of the

units. The reason is that the tooth geometry of couplings and clutches does not have involute flank surfaces and is therefore not designed to perform any meshing action. Meshing would not even be possible, because both coupling and clutch members are facing each other without any possibility of a defined relative motion between them.

An optical example is given with the coupling in Figure 1. The two halves are fitted together in their operating position. There is no possibility of relative motion or a tooth rolling action, as the photo clearly shows.

Hirth Couplings

Hirth couplings were invented by Carl Albert Hirth in 1928 (Ref. 1). Their traditional application is in turbomachines, similar to Curvic couplings. However, most Hirth couplings are not ground, which only qualifies them for moderate speeds. There are some characteristic design elements of Hirth couplings, which are listed below:

- High pressure angle, commonly 30 degrees, is used
- Included pressure angle is called β (= 60 degrees)



Figure 1—Hirth coupling members, engaged.

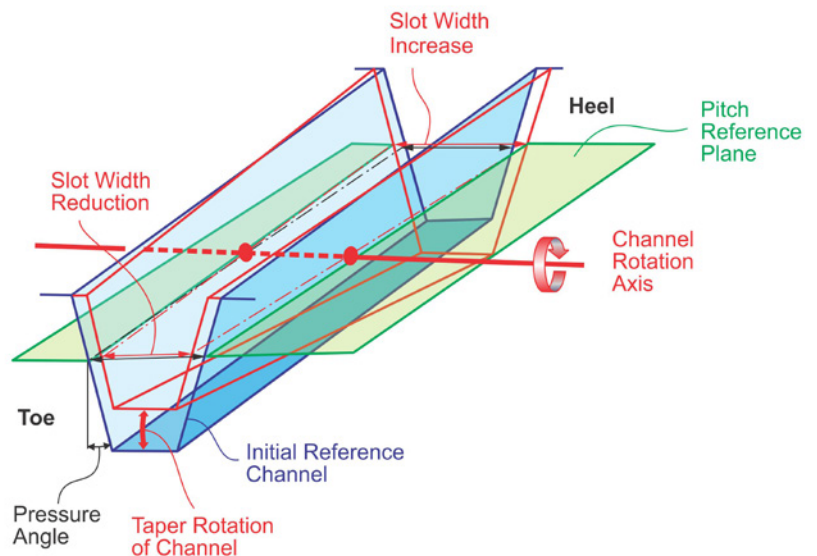


Figure 2—Cutting channel rotation to achieve a Duplex Taper.

- Fully rounded root fillet from toe to heel
- Duplex taper is used in order to achieve parallel root width
- Dedendum angle is called α
- Addendum angle is called α'
- Both members are the same
- Both members have the same strength
- Self-centering via opposite teeth and slots

The design of a duplex taper is shown in Figure 2. The initial reference channel is defined at the center of the face width, with a parallel root width. Then it is rotated about the channel rotation axis until a slot width reduction at the toe and a slot width increase at the heel (measured in the pitch reference plane) is achieved. The slot width changes results in a slot width tapering along the face width, which is proportional to the circumference of the radius at the respective face width position (Ref. 2).

The duplex taper makes it possible to machine the Hirth coupling slots, each in a single stroke with a disk milling cutter with cutting edge angles matching the pressure angle of the teeth. The root is fully rounded with a constant radius between toe and heel.

Topland chamfers cannot be produced with a special Flankrem design on the blades of the milling cutter because of the tapered depth slots. If top-land chamfering is required, then it has to be performed in a secondary operation.

In Figure 3, there is a principal graphic of a Hirth coupling with the basic design parameters shown. The name Hirth only stands for the coupling design; there is no dedicated manufacturing process.

Coniflex Couplings

A new software for the design and summary calculations of Coniflex couplings has been developed recently. This new software is implemented under the name Coniflex Clutches in the *GEMS* bevel gear design software.

Coniflex couplings are similar to Hirth couplings. The Coniflex design parameters can be used to duplicate the typical Hirth designs. However, even when duplication of a given Hirth design is required, a remaining difference is the curved root line of Coniflex, versus the straight root line of Hirth couplings. A

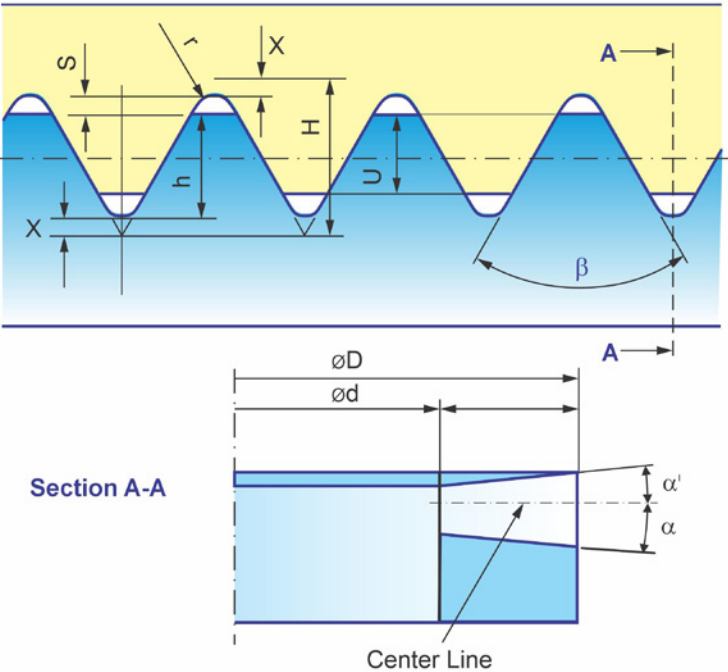


Figure 3—Basic design parameters of Hirth coupling.

Legend to Figure 3:

r	Root fillet radius	β	Included pressure angle
s	Root clearance	D	Outer diameter
H	Theoretical tooth depth	d	Inner diameter
h	Actual whole depth of teeth	l	Face width
U	Profile contact area	α	Dedendum angle
x	Access depth of pointed rack (2·x)	α'	Addendum angle



Figure 4—Typical Coniflex coupling parts.



Figure 5—Coniflex coupling for rotor connection.

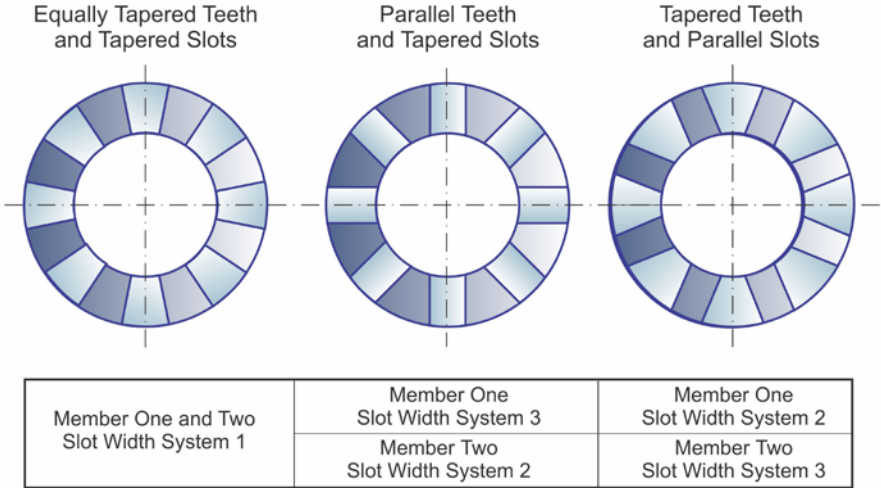


Figure 6—Three slot width systems of Coniflex couplings.

large cutter radius can reduce the curved root line, especially because the face width of most coupling teeth is very small, compared to bevel gears. In the case of duplicating the design parameters of a Hirth coupling, the Coniflex Clutch software can be forced, via input parameters, to match the duplex taper of a given Hirth design. In this case, the root width will also be parallel between toe and heel, which achieves the same Hirth fillet radius for a fully rounded root. The result is very fast cutting of high-quality Hirth couplings. A further advantage of the Coniflex Clutch process is the fact that grinding after heat treatment is possible.

The Formate cutting process of both members makes the Coniflex Clutch a special case of Coniflex straight bevel gears. Figure 4 shows a typical Coniflex coupling set. Unlike Hirth couplings, the root width is tapered, proportionally to the diameter change from the outside to the inside. The slot depth taper is a standard taper, which means that in addition to the slot width, the slot depth also changes proportionally with the diameter, from the heel to the toe.

The Coniflex Clutch input screen in *GEMS* gives the possibility to enter a desired root angle, to duplicate, for example, the Hirth duplex taper. The input also covers a depth factor, which can be used to match the depth of a Hirth coupling. In connection with the Hirth coupling pressure angle and the fully rounded root, a perfect duplication of the Hirth geometry is possible.

Often, Coniflex couplings are used as an alternative to Curvic couplings. Figure 5 is a photo of a Coniflex coupling member which has the typical appearance of a Curvic coupling. The Coniflex coupling is in some cases the preferred solution, especially when only cutting (no grinding) is required and when the cutting should be done on a Phoenix machine with cutters that are 9 in. or smaller in diameter. Topland chamfers like those on the part in Figure 5 are possible with the Coniflex Clutch process with blades which include Flankrem; however, the tooth depth needs to be uniform (not tapered).

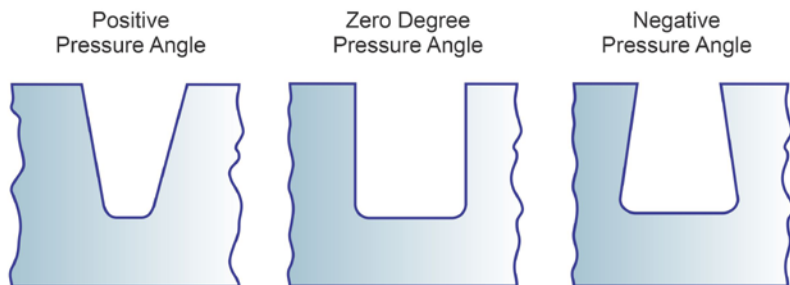


Figure 7—Three slot width systems of Coniflex couplings.

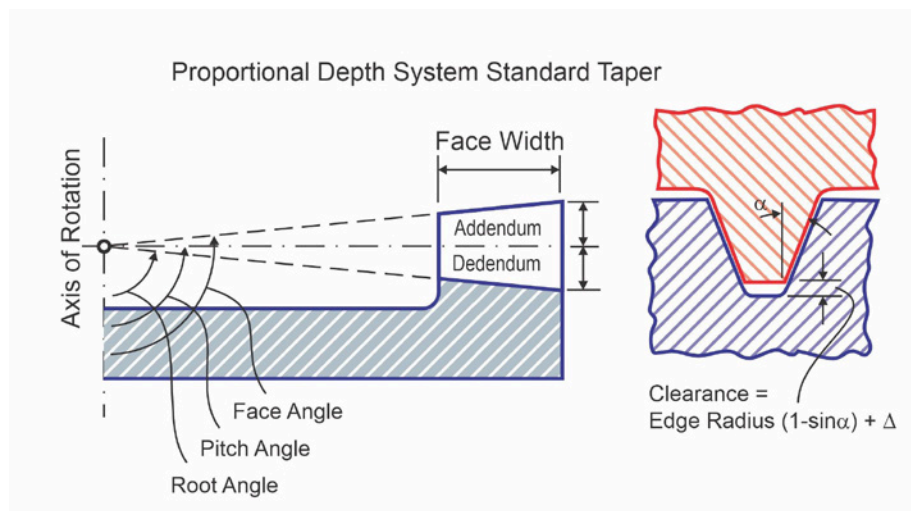


Figure 8—Standard taper.

Three Slot Width Systems

In the Coniflex Clutch *GEMS* program, the choice is between three different slot width systems given. These systems are shown in Figure 6. Equally tapered teeth and slots are the most common system (left in Figure 6). System 2 has parallel slots and tapered teeth as shown in the center of Figure 6. The coupling member with slot width system 2 has to be paired with a member that consists of slot width system 3. Slot width system 3, as shown to the right in Figure 6, has tapered slots and parallel teeth and fits in a member having slot width system 2. Some industries require, for some reasons, designs where one member has parallel slots, and the second member has tapered slots. One frequently mentioned reason for this design is the improved self-centering, which, however, has not been scientifically proven and is solely based on practical experience.

Free Choice of Pressure Angles

A significant advantage of Coniflex is the possibility to manufacture on standard Phoenix machines not only couplings with positive pressure angle (Figure 7, left side), but also to choose zero degree or negative pressure angles as shown in Figure 7, center and at the right side.

Due to the peripheral Coniflex Plus cutters, any customary pressure angle can be realized with the same cutter and even with the same cutting blade geometry. There is no negative machine root angle required, as in many cases of Curvic couplings with negative pressure angles. The radial tilt required for Curvic couplings with negative pressure angles requires negative machine root angles, which are limited on standard bevel-gear machines.

Free Choice of Slot Depth Taper

Due to the independent cutting of flank one and flank two in the typical Coniflex lower and upper cutting cycle, it is possible to control the slot depth taper independently from the slot width taper.

Coniflex Clutch designs use, as default, a standard taper. Standard taper means that the extension of the face line, the extension of the pitch line, and the extension of the root line all meet and intersect with the axis of rotation.

This principle is shown in Figure 8. A standard taper delivers the strongest coupling regarding root bending stress of the coupling teeth. Slot width and tooth thickness are equally spaced, which means that both members have equally strong teeth.

Parallel depth couplings are often chosen as fixed couplings where the members are permanently bolted together. The graphic shown in Figure 9 has a pressure angle of zero degrees and is assembled without top-root clearance and without any backlash as a transitional fit.

Figure 10 shows a Coniflex coupling with a duplex taper. The graphic represents the case where the Coniflex coupling duplicates precisely the geometry of a Hirth coupling. The root width is parallel, and the root fillet is rounded with a uniform radius along the face width.

Flank Surfaces and Tooth Contact Analysis

Flank surface generation and tooth contact analysis are standard features in the GEMS software system for Coniflex couplings. In Figure 11, a tooth contact analysis with Ease-Off and contact pattern is shown. The Ease-Offs have a length crowning of 20 microns and no profile crowning. Length crowning is realized as in regular Coniflex with a cutter dish angle. Because the Coniflex Clutch machining is a non-generated process, profile crowning cannot be generated kinematically as it is done in regular Coniflex. The only possibility to generate profile crowning is the application of curved blades.

Cutting, Grinding and Closed Loop

As mentioned above, both members for Coniflex couplings are cut or ground in a non-generating process. Only plunging is possible to form the flank surfaces. The lower flanks are plunged first, as shown in Figure 12. After all lower flanks (flanks 2) are cut, the cutter changes from the lower to the upper position, where it plunge cuts all flanks 1.

If the slot bottom is wide, like in cases of zero degree and negative pressure angle, the fin removal function can be applied to have the blades sweep in

the root width direction and clean out remaining fins or ridges. It is possible to save time for fin removal by using an increased blade point width. This has the advantage that the chip load during the plunge is not applied to a small cutting blade tip but to a wider and flat top cutting edge. Cutting with wide tips can result in a step or a fin. If sufficient top-root clearance is given, then an elegant

solution is to create a gable bottom by using blades with a positive top slope angle, which is a standard in Curvic couplings (Ref. 3).

Coniflex couplings can be ground after heat treatment. Dressing of grinding wheel profiles is not possible for Coniflex gears and couplings because of the slim profile and the fact that dressing axially to the profile would change

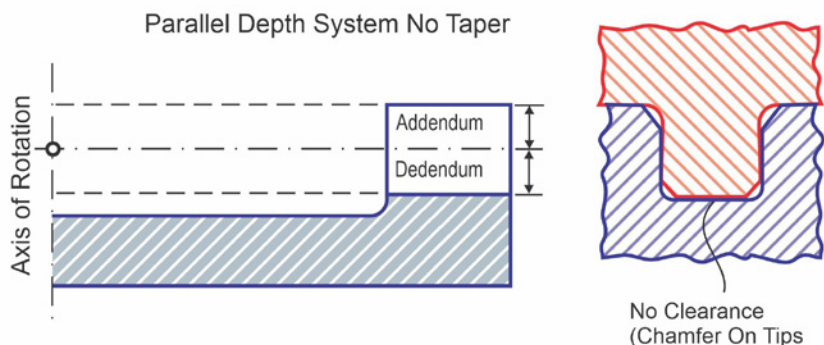


Figure 9—Parallel depth, no slot depth taper.

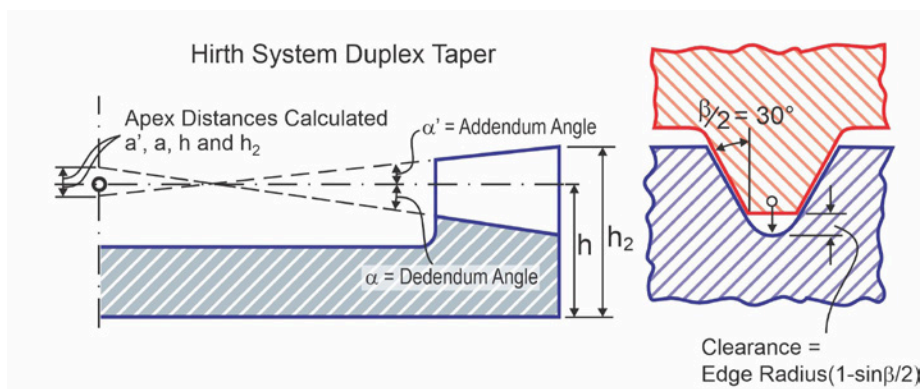


Figure 10—Duplex taper with parallel root.

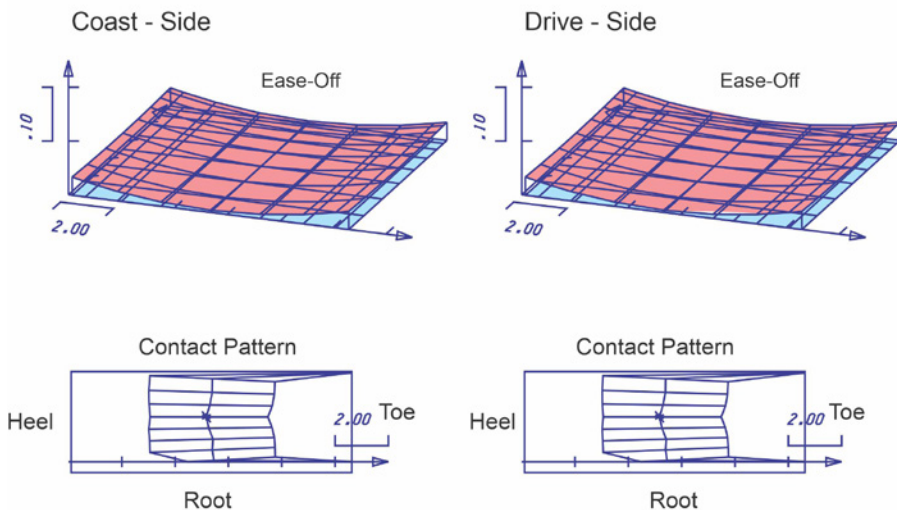


Figure 11—Tooth contact analysis.

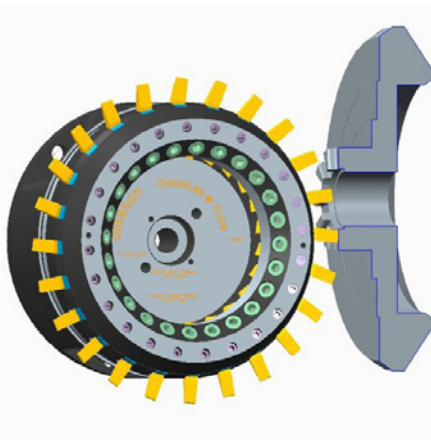


Figure 12—Cutting of a Coniflex coupling—CAD model.

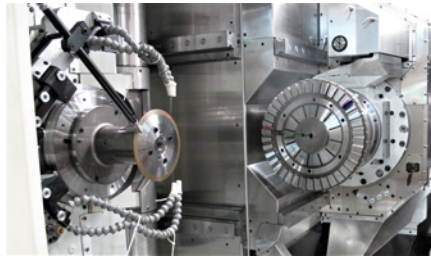


Figure 13—Grinding of a Coniflex coupling with a CBN-grinding wheel.

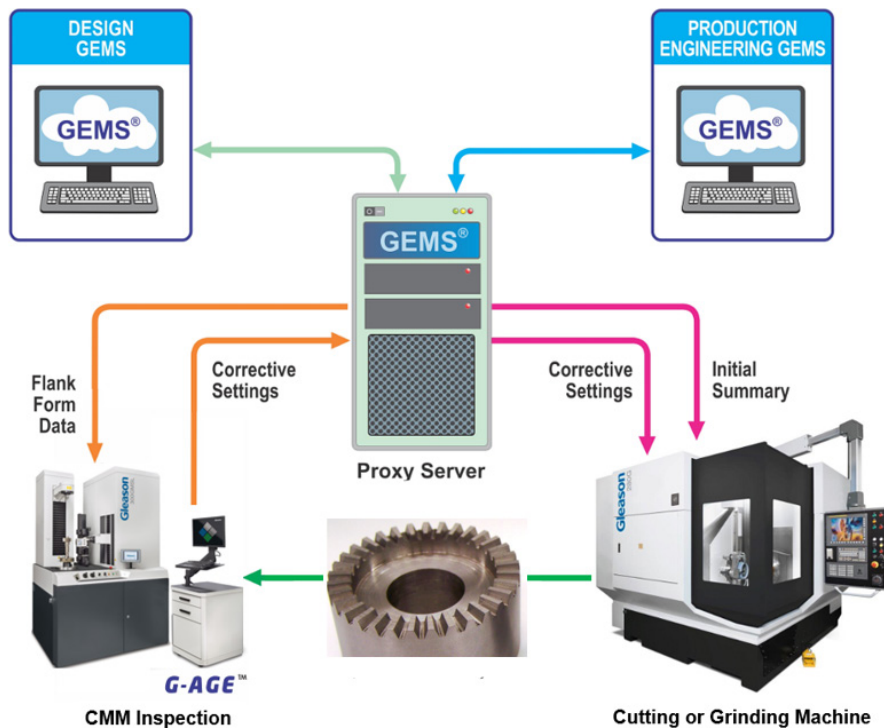


Figure 14—Closed-loop manufacturing for Coniflex couplings.



Figure 15—Jet engines of airplanes use Curvic couplings to stack rotors.

the grinding wheel diameter, which in turn would change the root geometry from part to part. The solution for Coniflex grinding was the use of permanently coated and non-dressable CBN grinding wheels.

The process in Figure 13 is not a standard Coniflex coupling grinding process. Based on the large part and the large face width, the Uniflex process was applied (Ref. 4). In Uniflex, the grinding wheel moves along the face width and produces a straight root line, independent of the grinding wheel diameter.

Like in regular Coniflex straight bevel gear calculations, GEMS produces a download file with flank form coordinates, normal vectors, and correction matrices for coordinate measurements with G-AGE correction output. Together with a company network, a fully automated closed-loop manufacturing can be set up.

Curvic Couplings

Curvic couplings are the gold standard for precision face couplings and clutches. The rotor wheels in jet engines and power plant turbines are all exclusively stacked together with Curvic couplings. Figure 15 shows a twin-engine airplane, where each engine uses 25 fixed Curvic couplings to connect their high-speed compressor and expansion rotors.

The main characteristic of Curvic couplings is the shape of the teeth. One member has barrel-shaped teeth while the other member has hourglass-shaped teeth. With this geometry, every single tooth, when engaged in a slot of the opposite member, contributes to self-centering between the two members. Other couplings like Coniflex or Hirth require two opposite teeth and slots to achieve a centering of a shaft in the face width direction.

A graphic of the orientation between the grinding wheel and Curvic coupling members is shown in Figure 16. In this graphic, the outside of the grinding wheel profile forms two concave flanks of the member with hourglass-shaped teeth (left). In one revolution, all teeth are finish ground. The opposite member is ground with the inside profile of a different grinding wheel and forms two convex flanks simultaneously, which results in hourglass-shaped teeth (right

graphic in Figure 16). The wheel point diameter between the left and right graphics is adjusted such that either a full-face width contact or a located contact pattern is achieved. Profile crowning is also possible by dressing a curved grinding wheel profile.

It becomes clear that a single tooth and slot centering force requires a high accuracy of the tooth surfaces. In many steam turbines, more than 50 rotors are bolted together to one unit. The radial centering must provide low radial runout, but also the axial runout has to be in the fractional micron range in order to minimize the unbalancing of a long rotor unit. There is software available which uses spacing measurement results from coordinate measuring machines to calculate an optimal timing between two rotors. If all rotors are assembled with their optimal Curvic coupling timing, then the overall runout and unbalance of a long rotor unit can be minimized to sustain the highest rotational speeds.

Figure 17 shows the nomenclature of Curvic coupling tooth profiles. The tooth depth of all Curvic couplings is uniform between toe and heel. The face width should be 12.5 percent or more of the outside diameter. The three types of Curvic couplings are explained in the next section.

Curvic couplings do not have a fully rounded root as the Hirth coupling. The stub tooth proportions of Curvics still allow sufficient fillet radii and a large area with a gable bottom (Ref. 2).

Flank Surfaces and Tooth Contact Analysis

Curvic coupling design and optimization is integrated into the GEMS software system. Just recently, the software for flank surface generation was developed and added to the Curvic module in GEMS. After the design calculation, a thorough checking of the tooth contact area and even the topline chamfer or topline rounding is possible with the TCA module. The TCA module also calculates effective backlash and root clearance. Figure 18 shows the Ease-Offs of both tooth flanks of a fixed Curvic coupling with 30 degrees topline chamfers with a chamfer depth of 0.3 mm. The Ease-Offs are based on cou-

pling member 2 (gear). The center portion in the Ease-Offs is flat, without any crowning. On top of the Ease-Offs, the reliefs created by the topline chamfers of member two are visible. At the bottom of the Ease-Offs, the reliefs from the member one topline chamfers can be observed.

The contact patterns in Figure 18 show a full flank surface contact, which is on top and root only limited by the topline chamfers. Coordinate measurements with nominal flank coordinates and normal vectors are possible with the flank form generating module in GEMS, which generates CMM

download files and also has corrective information for G-AGE corrections.

Fixed Curvic Couplings

They are precision face splines with a mostly 30-degree pressure angle, no backlash, and a very small root clearance. Root fillets are ground with a gable bottom to avoid ridges or steps. The members of a fixed Curvic coupling are bolted together to connect two or more rotating units, such as impellers of a turbine, for example, and form one operating unit. Fixed Curvic couplings are self-centering and must be manufactured by grinding with high accuracy, such as AGMA 13 (Ref. 2).

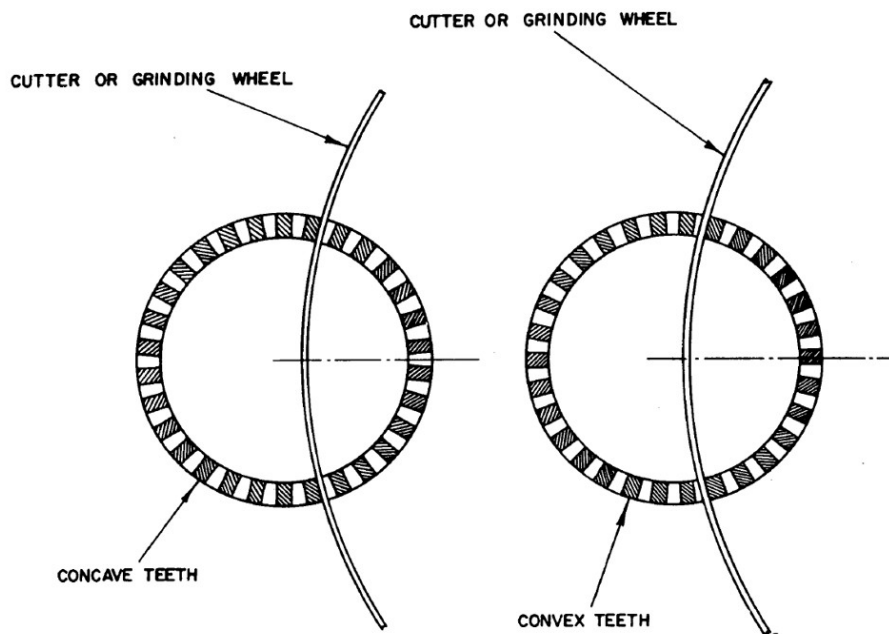


Figure 16—Grinding of two convex flanks simultaneously.

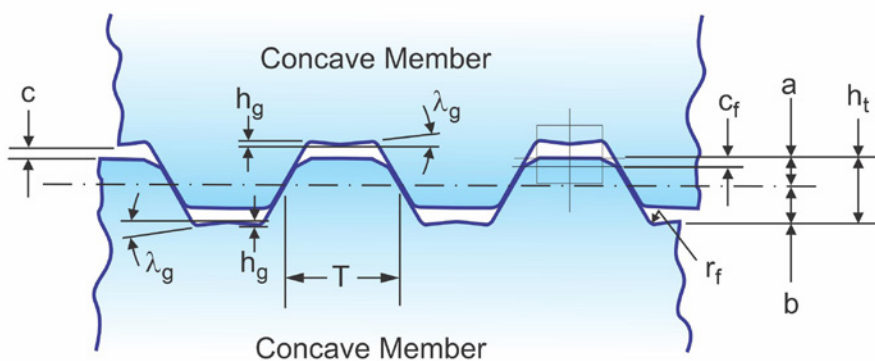


Figure 17—Nomenclature of Curvic coupling profile.

Legend to Figure 17:

c Clearance
 h_g Gable height
 λ_g Gable angle
 c_f Chamfer width

r_f Fillet radius
 a Addendum
 b Dedendum
 h_t whole depth

Semi-Universal Curvic Couplings

Semi-universal Curvic couplings are commonly designed with a zero-degree pressure angle and with backlash. The coupling between the two members is rather loose and includes axial play to permit up to 2 degrees of shaft misalignment. The profile on the teeth of one member is curved to keep localized contact and provide a nearly uniform motion between the two coupled shafts (Ref. 2).

Releasing Curvic Couplings (Clutches)

Releasing couplings or clutches have a helical surface to maintain proper tooth contact during engagement and disengagement of the clutch. For smaller-size clutches, this is often approximated with a special localized contact bearing. The two members of overload clutches are held in the engaged position by spring load. The spring load and the pressure angle are used to control the point of disengagement. Pressure angles of releasing clutches and overload clutches are mostly between zero and 10 degrees. Also, shift clutches are considered releasing clutches. To achieve smooth shifting and engagement, the toplands have a slope angle in the circumferential direction and are chamfered (Ref. 2).

Manufacturing of Curvic Couplings

Often the outer diameter of the rotor hub is large, for example 1,500 mm, where the Curvic coupling, which is an integral part of the rotor hub, only has a diameter of 750 mm. It requires special grinding machines, which can accommodate these large outer diameters and which can perform a roughing and finish grinding cycle. The most common Curvic coupling grinders are the Gleason No. 887 (and 887 CNC) and the Gleason No. 888 (and 888 CNC). The Curvic coupling grinders use a reverse pulse cycle for roughing, where the grinding wheel moves forward a certain pulse stroke and immediately withdraws the grinding wheel about 50 percent of the forward stroke amount. Roughing the slots stops 0.254 mm from full depth. In the finishing cycle, a different grinding wheel specification, with a finer grit and a forward pulse, is used. The wheel pulses forward and sparks out before pulsing again forward. After four to five forward pulses, a slot is finished. No. 887 and 888 grinders have a grinding wheel spindle quill that makes fast pulsing possible, avoiding moving the substantial mass of the sliding base for each pulse. Dedicated Curvic coupling grinders have a machine root angle adjustment of ± 90 degrees. This freedom allows for easy loading and unloading of large rotors

with a crane and also makes it possible to grind negative pressure angles.

For smaller Curvic parts, standard Phoenix cutting and grinding machines can also be used. Instead of reverse pulsing, Phoenix grinders use forward pulsing in combination with a Waguri eccentric spindle motion (Ref. 5). Grinding parts with negative pressure angles is limited with Phoenix grinders due to the limitation of negative machine root angles at -6 degrees.

Summary

Three of the most well-known face couplings have been discussed in this chapter. Gleason has only two established manufacturing processes for the manufacture of Hirth couplings, Coniflex couplings, and Curvic couplings.

Hirth couplings are designed for maximal strength with a fully rounded root, a pressure angle of 30 degrees, and a duplex taper. There is no special Hirth cutting or grinding process, which suggests that the Coniflex Clutch process is best suited regarding manufacturing speed, accuracy, surface finish, and closed-loop manufacturing possibility of Hirth couplings.

The advantage of the Coniflex coupling manufacturing method over older methods and machining center solutions is the fact that a large-size disk-shaped cutter can finish one flank in a single plunge, without the requirement of any stroke motion along the face width. This makes the Coniflex process very fast despite the single-flank cutting in a lower and upper cutting cycle. The advantage of the single-side cutting is the "unlimited" freedoms for pressure angle and tooth depth taper, for example to duplicate Hirth couplings with a fully rounded root fillet, with the same radius along the entire face width.

Curvic couplings are cut or ground with large cutter or grinding wheel diameters up to 20 in. The fixed Curvic coupling is used as a precise and stiff connection between turbine rotors. The compressor and expansion rotors in nearly every jet engine are connected with fixed Curvic couplings. Also, nearly all rotors in power plant steam turbines are bolted together with fixed Curvic couplings. There is no alternative solution to connect the high-speed

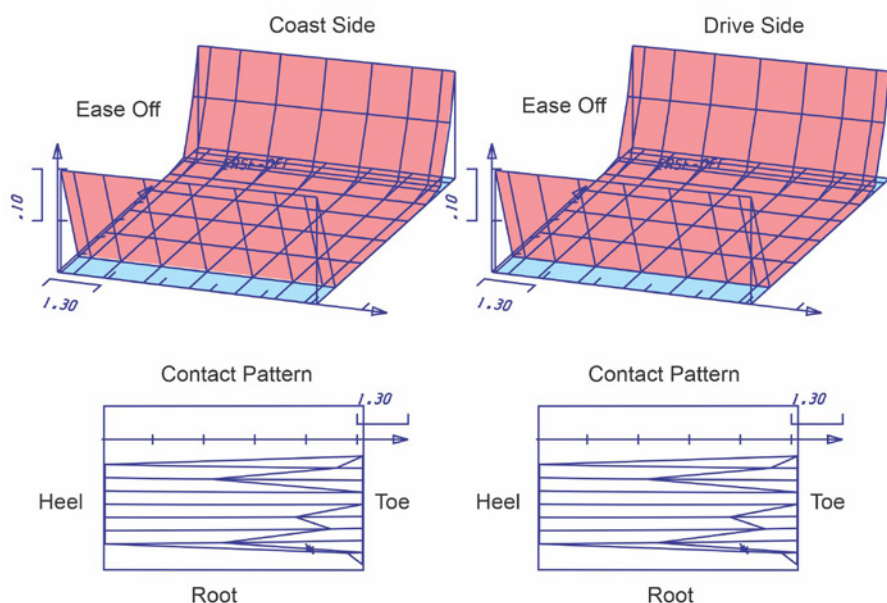


Figure 18—Curvic contact analysis.

rotors of gas, water, and steam turbines. The Curvic coupling cutting and grinding finishes two flanks in two different quadrants (see Figure 16) simultaneously. This arrangement only allows a cutter tilt around the vertical axis in Figure 16. Consequently, only limited corrections via machine settings are possible. Pressure angle changes can be accomplished by changing the pressure angles of the tool. Spiral angle changes are possible with a horizontal repositioning of the tool in connection with a change of the point diameter of the tool. Spiral angle cross changes can be accomplished by small amounts of

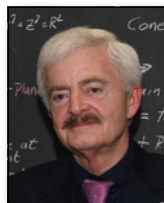
vertical machine settings (which is generally zero). Semi-universal Curvic couplings have localized contact and backlash. They allow, with good lubrication, up to 2 degrees of shaft misalignment, without significant influence on the smoothness of transmission. Overload-releasing Curvic clutches have a positive pressure angle of up to 10 degrees and are held engaged by spring load. Curvic shift clutches have mostly negative pressure angles and backlash. Their flank forms are helical, and their top lands have a slope angle in the circumferential direction to enhance engagement with low jerking.



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Gear Technology Solutions continues and completes his 2019 work, *Practical Gear Engineering*. Recently awarded a patent for MicroForm, the innovation marks his 70th patented invention.

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Twenty Years of Pulsator Tests on Helicopter Gears

Luca Bonaiti, Carlo Gorla, Ugo Mariani, Rosanna Molinaro, Sara Rustici, Sergio Sartori

In the design of aerospace transmission systems, particularly those used in rotorcraft, fatigue life prediction plays a pivotal role in ensuring both performance and reliability. Due to the very high values of the torque and power densities of the main gearboxes (MGB) of modern helicopters and to the catastrophic consequences of their failure, a precise and reliable approach to the design and rating of gears is fundamental. In general, the tooth root bending fatigue failure is not the most limiting failure mode for an MGB, but it is the most critical, due to the consequent immediate interruption of the transmitted power.

For this reason, Leonardo Helicopters started a systematic campaign of testing 20 years ago, aimed at characterizing the tooth root bending properties of the gears applied in MGBs. More in detail, the purpose of the program was to investigate the performance of the applicable design solutions and parameters, in terms of materials, cleanliness, manufacturing processes, heat treatments, finishing and superfinishing approaches, and shot peening. The purpose was not limited to determining validated data in terms of fatigue limits. A precise understanding of the morphology of the S-N (Wöhler) curve is critical, as helicopter gear components are typically designed to operate within the very high cycle fatigue regime, and at the same time, they must also be capable of withstanding occasional short-duration overloads, arising from transient operating conditions. Enhanced characterization of the S-N curve facilitates more refined and efficient gear design, minimizing unnecessary conservatism while maintaining adequate safety margins and structural integrity under complex loading spectra (Refs. 1, 2).

A first technical paper, with the results for some families of case-hardening steels, was presented at the 2008 AGMA FTM (Refs. 3, 4). Since then, many other materials and influencing parameters have been investigated; some results have been presented at gear conferences (Ref. 5) or in journals (e.g., Ref. 6), and some of them are still unveiled. In any case, a comprehensive summary of the results and a systematic comparison and analysis of the influence parameters have never been published.

For this reason, after 20 years of testing, the time is mature to propose such a comprehensive synthesis, and the authors believe that the AGMA FTM is the most suitable place to present it, not only for its scientific relevance, but also for its focus on the practical application of the knowledge.

Pulsator Test as a Means to Estimate the Root Strength

When investigating the strength of gears, experience suggests that it is not sufficient to conduct tests on standard specimens, like those for rotating bending or axial tests, for instance. To appropriately consider all the characteristics related to the gears manufacturing process, including those coming from the cutting and finishing processes, like roughness and residual stresses, and from the heat treatment, which is dependent on the specific geometry, the most suitable option is to test gear specimens. In this way, the process to transfer the strength data obtained from the tests to the real design application is more straightforward and does not require additional assumptions, besides those already necessary to consider several factors. At most, the information provided by tests on standard samples is useful in preliminary pre-screening because they can provide data in a short time, but they are not suitable for a detailed and reliable assessment.

Gears are susceptible to a variety of failure mechanisms, the prevalence of which is influenced not only by material properties but also by numerous factors related to the specific design and operational conditions (e.g., Ref. 7). Certain damage modes—such as scuffing and contact fatigue—can only be effectively investigated under conditions that replicate gear meshing. For these mechanisms, dedicated testing methodologies and specimen geometries have been developed over time to ensure that the experimental setup selectively targets the intended failure mode while minimizing interference from others. Even if the tooth root fatigue fracture failure mode shows some difference depending on whether meshing is or is not reproduced, experience demonstrates that tests in which selected tooth flanks are loaded by means of a universal testing machine with appropriately designed anvils provide a reliable and effective means of evaluating the bending fatigue strengths.

The simplification of loading conditions in this type of test offers several advantages over conventional meshing tests. Firstly, these tests are carried out on universal testing machines and not on a dedicated gear test rig, thereby streamlining test setup and management. This configuration allows greater freedom in the specimen geometry, enabling the testing of a wide range of spur gear sizes, geometries, and profiles, with only minor practical limitations for very small modules. By isolating and testing individual teeth instead of the whole gear, multiple samples can be obtained from a single gear specimen,

significantly reducing testing costs. Furthermore, unlike running gears (RG) tests, which require a loaded tooth contact analysis (LTCA) method to exactly estimate the force cycle acting on a single tooth, followed by a stress analysis calculation method to determine the corresponding root stress cycle, pulsator tests necessitate only the latter. The force acting on the specimen is known a priori: indeed, the applied load is directly imposed (and measured) by the machine itself, eliminating the need for force estimation.

Nevertheless, pulsator tests, which do not involve meshing, lead to different results due to differences in statistics and in the fatigue damage mechanism: in particular, higher strength values are obtained if compared to those obtained through RG (Refs. 8, 9, 10, 11). The fatigue limit of pulsator tests can be 20 percent higher than in the RG case (e.g., Ref. 12). During the years, calculation methods, like the one developed in the German gear scientific community (i.e., Ref. 13), have been elaborated, and they allow a validated transfer of pulsator test data into strength values that can be used in the actual design phase.

Specimen Definition

The definition of the gear specimen geometry includes both the selection of the number of teeth and the design of the tooth geometry and profile. This has been done considering two main constraints. Firstly, the selection of a hobbing tool that already exists. Secondly, the possibility of performing tests at loads compatible with the testing machine, whose maximum load is 60 kN.

Moreover, although the test results should be independent of the geometry used, it has been considered that the calculation methods, however sophisticated they may be, introduce

approximations in the calculation of the tooth root stress starting from the applied force. A first approximation regards the effect of the load application point on the state of stress of the tooth root, which is not subjected to a pure bending phenomenon but also compression and shear components. Therefore, an additional geometric requirement is that the position at which the pulsator applies the load corresponds to the highest point of single tooth contact when the toothed sample meshes with itself in its nominal condition.

An additional design choice is about the selection of the number of teeth that are located between the test punches, which corresponds to the number of teeth covered by the Wildhaber (or span) measurement (Ref. 14). To avoid testing teeth adjacent to those previously loaded, whose roots may have experienced prior stress cycles, albeit minor, the authors opted to exclude such teeth from subsequent tests. Consequently, the span measurement was selected to include an odd number of teeth, maximizing the number of usable specimen's extractable from a single gear.

All the above requirements lead to the definition of the spur gear geometries reported in Table 1. The gears have 32 teeth, and the number of teeth considered for the span measurements was set to 5. As a result, each gear specimen allows for the extraction of eight testable pairs of teeth.

The adopted gear specimens completely follow the production cycle of Leonardo. Hence, all gears present ground flanks. The difference between the two geometries is related to the possibility of having or not having a ground tooth root, depending on the different manufacturing processes. That is, the "Fillet Unground" geometry has a tooth root whose actual profile is produced during the tooth generation process, while the "Fillet Ground" root is manufactured using form grinding.

		Fillet Ground	Fillet Unground
Number of Teeth	[-]	32	32
Normal Module	[mm]	3.76	3.71
Normal Pressure Angle	[°]	22.00	20.00
Base Diameter	[mm]	111.55	111.55
Effective Face Width	[mm]	15.00	15.00
Tip Diameter	[mm]	130.00	130.00
Root Diameter	[mm]	111.33	111.33
Add. Modification Factor (x)	[-]	0.13	0.37
Tool Dedendum Coefficient	[-]	1.16	1.15
Tool Addendum Coefficient	[-]	1.33	1.36
Root fillet radius (full fillet)	[mm]	1.67	-
TIF diameter	[mm]	113.96	-
Top land	[mm]	1.71	1.71

Table 1—Spur gear geometries.

Furthermore, the adopted geometry incorporates features representative of practical applications, as shown in Figure 1. For instance, a thin rim—characteristic of lightweight gear designs—was included with proportions consistent with typical helicopter industrial practice. Another example is lateral fillets, which reduce stress at the base of the tooth.

Starting from the gear geometry, the relationship between the applied load and the corresponding tooth root stress can be assessed by means of both FEM analysis and the application of AGMA and ISO standard rating formulae, as summarized in Table 2.

Test Method

There are two main types of pulsator testing (e.g., Refs. 15, 16, 17). In the first, called symmetric, the gear blank is not supported during the test execution and is loaded isostatically by the anvils, which, thanks to the Wildhaber measurement principle (Ref. 14), load two teeth at the same diameter, thus testing a pair of teeth at a time. Since the gear is not constrained by anything other than the anvils, once the test is completed (i.e., when the tooth fails), it can be immediately removed by an extraction device. For this reason, this approach, which is more common in Europe, can also be applied to mechanical resonance pulsators. In the second, corresponding to the SAE J1619 (Ref. 18) (firstly proposed by Buenneke et al., Ref. 15) called asymmetric, the gear blank is supported by a pin and only one tooth is actually tested: due to the presence of a supporting pin, the procedure is not compatible with a mechanical resonance pulsator because the gear cannot be immediately removed at the end of the test.

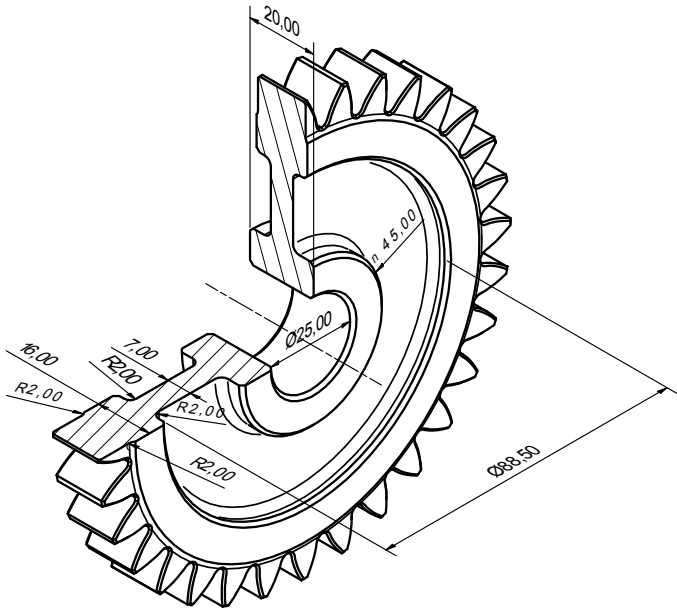


Figure 1—Isometric section of the specimen with some dimensions highlighted.

Grinding process	F [kN]	σ_{F0} – AGMA [MPa]	σ_F – ISO [MPa]	σ_I [MPa] - FEM
Fillet Unground	10	382.2	513.4	421.9
Fillet Ground		361.6	474.3	417.6

Table 2—Force-stress relationship.

The latter layout corresponds literally to the definition of single tooth bending fatigue (STBF). This test configuration, which is typically applied with hydraulic machines or with machines that can be immediately stopped at failure, is more frequently applied in the United States and United Kingdom.

The tests performed within the framework of the present experimental program have been carried out with the symmetric configuration on a mechanical resonance pulsator, except for some tests that have been performed with a different layout and fixture, with a hydraulic machine, suitable for the application of load spectra to assess the robustness of the approach under variable load conditions.

For each family of gears considered, two types of tests are performed to investigate the strength of the tooth root. One is the actual fatigue test, in which a pulsating load is applied at a fixed position of the tooth flank until the failure of the specimen. The fatigue tests discussed here have been performed on a 60 kN Schenck mechanical resonance pulsator at a load frequency of about 35 Hz.

The latter is a static test on a hydraulic machine, performed to evaluate the ultimate strength of the teeth. Even if the static properties of the materials are already part of Leonardo’s expertise, and the quality control of production processes guarantees the fulfillment of the relevant requirements (i.e., all incoming raw materials are tested), for the sake of completeness, static tests are also performed on the gear specimens (and not on classical uniaxial specimens) to be consistent with the fatigue tests. In this way, a more complete and coherent characterization of the root strength is provided.

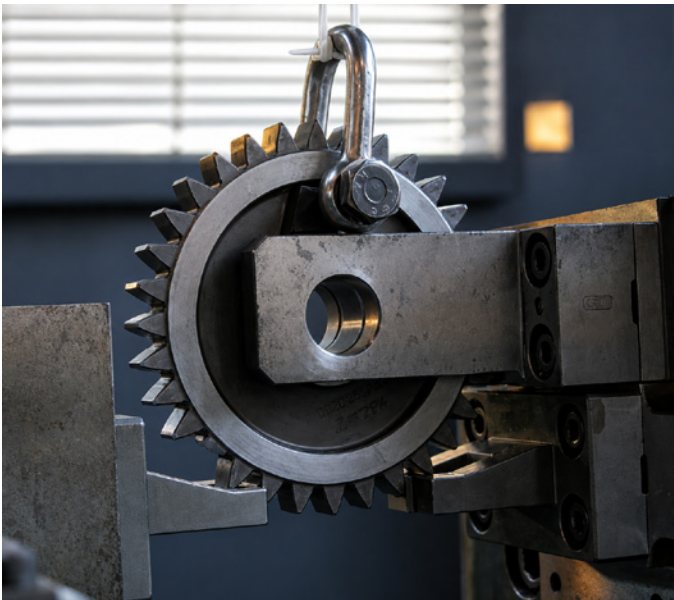


Figure 2—Pulsator test arrangement.

A typical test campaign involves the execution of about 35 pulsator tests, with points distributed along the entire Wöhler curve. The run-out level was set at 10 million cycles. Conversely, for the root ultimate load, 2/3 tests are carried out for each family. Figure 2 shows the fatigue test, while Figure 3 shows an example of the results obtained from the static tests.

Pulsator tests are completed with various related activities. The first, carried out at the beginning of each test batch, involves the use of a strain-gauged gear to verify the alignment of the machine, checking that the machine provides a well-distributed state of stress along the root width. The information provided by this gear, shown in Figure 4, has also been used to verify the validity of the developed FEM models (e.g., Refs. 3, 6). Other related activities are aimed at evaluating the material from a more metallurgical point of view, such as SEM analysis

of fracture surfaces to investigate the origin of the fracture (e.g., Figure 5), and microhardness profile analysis (e.g., Figure 6).

Data Evaluation Procedure

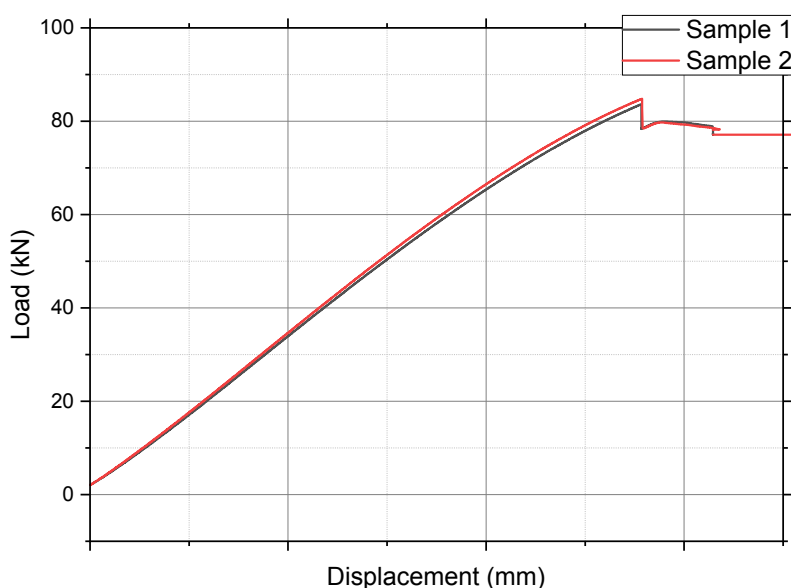
The aim of each experimental campaign is the definition of a continuous function that characterizes the complete S-N curve, ensuring a seamless representation across all fatigue life regions. According to the design procedure adopted by Leonardo, a continuous curve defined according to the following analytical equation has been used:

$$\frac{S}{S_L} = 1 + A(N + C)^B \quad (1)$$

where S is the stress, N the number of cycles, S_L the fatigue limit, and H, A, B and C are constant.



(a) Static test arrangement



(b) Static test outcome

Figure 3—Static test phase.

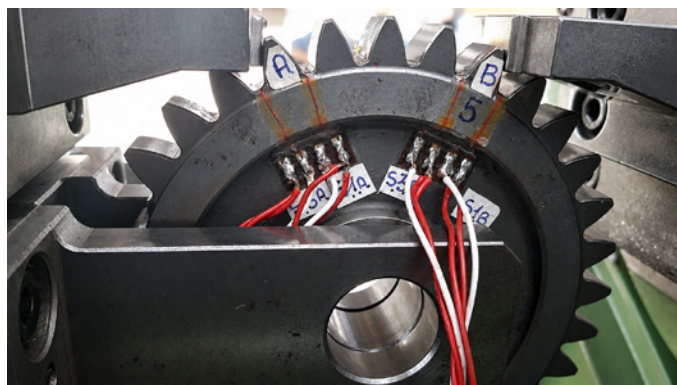


Figure 4—Strain-gauged gear for alignment verification.

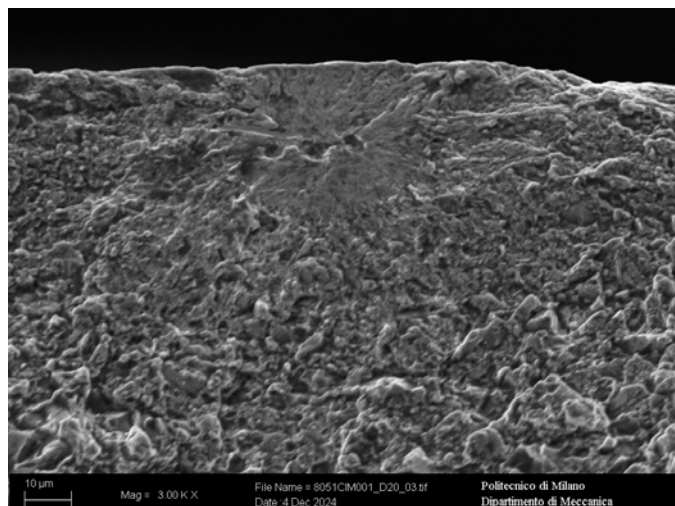


Figure 5—Example of SEM analysis of a broken tooth. Here, the failure was caused by a subsurface defect.

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Depending on the constants introduced, different trends can be obtained. In the first phase, several shapes have been considered based on previous experiences of Leonardo to understand which were more suitable to fit the experimental test data on gears. Eventually, one of those, named GEAR05, has been selected. The selection of the most suitable curve has been done based on the minimum value of the coefficient of variation (CV), i.e., the ratio between standard deviation and mean, of the fatigue limit predicted by each of them. One more shape curve, named GEAR06, has been defined during the present research program, with the scope of enabling the fitting capability in the region of fatigue strength, and of obtaining CV values lower than those of the already available curves.

Therefore, the constants of the GEAR06 curve have been determined by means of a minimization procedure of the CV, for each of the families considered in the research program. In this context, CV is also used to evaluate the robustness of the single tested family.

In the definition of the GEAR06 curve, the ultimate strength of the tooth is also considered. In this way, a strong

correlation between the fitted curve and the experimental data in the low-cycle fatigue regime is provided. In any case, this does not mean that the curve is meant to be applied in the low-cycle fatigue region, where a strain-based approach should be used instead of the stress-based one, which is limited to the high-cycle fatigue region.

This paper is not focused on discussing the differences among the different shapes of the S-N curve, and for this reason, the results of the single families of materials are presented in terms of the GEAR06 curve only. Nevertheless, a summary in terms of the GEAR05 is also included.

The parameters are estimated by means of a minimization procedure in which, for mathematical reasons, tests that did not end with a failure (i.e., the runouts) are considered as failures. At the earliest stages of this long-term research project, some very-high-cycle (i.e., $\geq 10^8$) pulsator tests have been conducted to verify that the proposed curve properly represents the root lifetime at a very high number of cycles; that is, to verify the presence of the horizontal asymptote represented by the fatigue limit. Figure 7 shows an example of the estimated curve together with the experimental points.

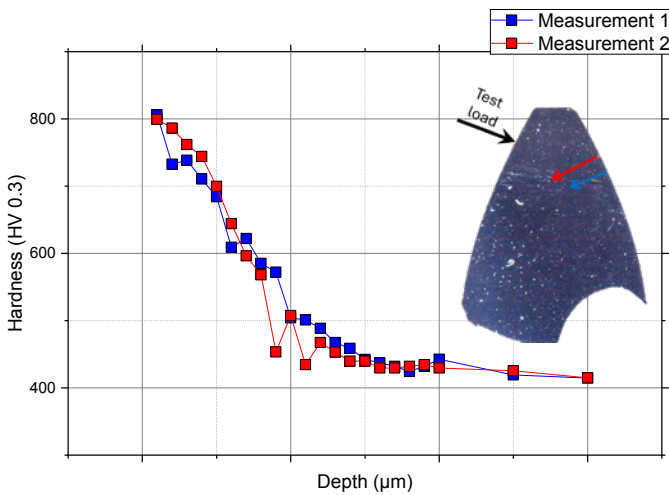


Figure 6—Example of a hardness profile as a function of depth.

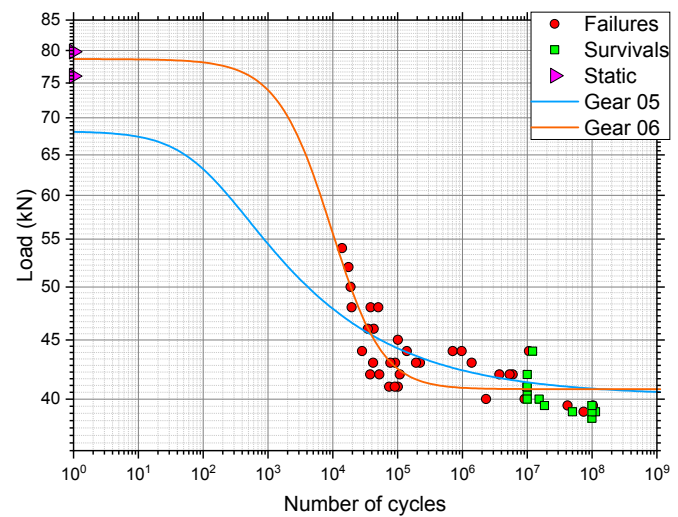


Figure 7—Example of estimated curves.

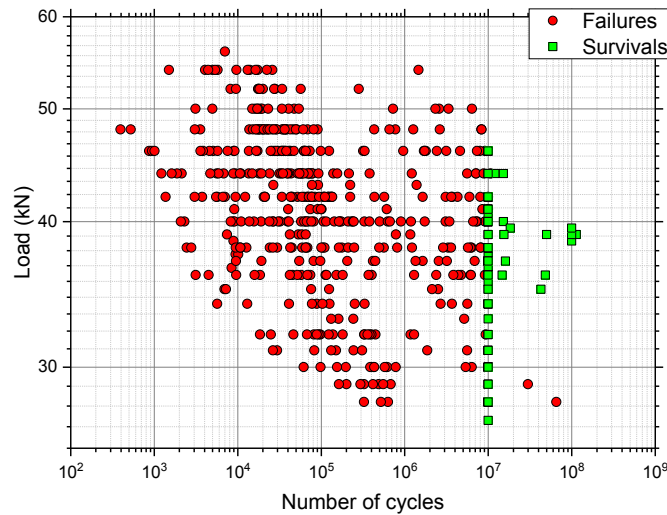


Figure 8—Fatigue data overview.

Base material	Shot peening	Tooth root condition	Family name	S_L kN	CV %	No. tested specimen
9310 VIM-VAR	No	Ground	9310 VIM-VAR	35.781	12.4	16
	1st variant	Ground	9310 VIM-VAR – SP1	40.807	4.4	39
	2nd variant	Ground	9310 VIM-VAR – SP2	39.629	6.8	29
	3rd variant	Ground	9310 VIM-VAR – SP3	39.644	3.1	32
	1st variant	Ground+Isotropic superfinishing NO REACH compliant	9310 VIM-VAR – SP+ISF	44.006	8.06	36
	1st variant	Ground+Isotropic superfinishing REACH compliant				
	Ultrasonic SP	Ground	9310 VIM-VAR – USP	36.558	17.7	32
	1st variant	UnGround	9310 VIM-VAR – SP+UG	36.140	4.3	20
9310 VAR	Yes	Ground	9310 VAR	37.464	3.4	22
VASCOJET	Yes	Ground	VASCOJET	27.400	13.7	32
X-53 VIM VAR	Yes	Ground	X-53 VIM-VAR	41.590	5.5	29

Table 3—Main families of tested case-hardened gears.

Base material	Shot peening	Tooth root condition	Family name	S_L kN	CV %	No. tested specimen
32CDV13	No	36-40 HRC	32CDV13 – 01	38.485	3.08	24
	No	40-44 HRC	32CDV13 – 02	36.492	3.79	34
	No	36-40 HRC	32CDV13 – 03	41.613	12.4	32
	Yes	40-44 HRC	32CDV13 – SP	37.882	10.3	28
Nitalloy N	No	40-44 HRC	Nitalloy N	30.918	4.40	34
	Yes	38-42 HRC	Nitalloy N – SP	38.593	8.65	25

Table 4—Main families of tested nitrided gears.

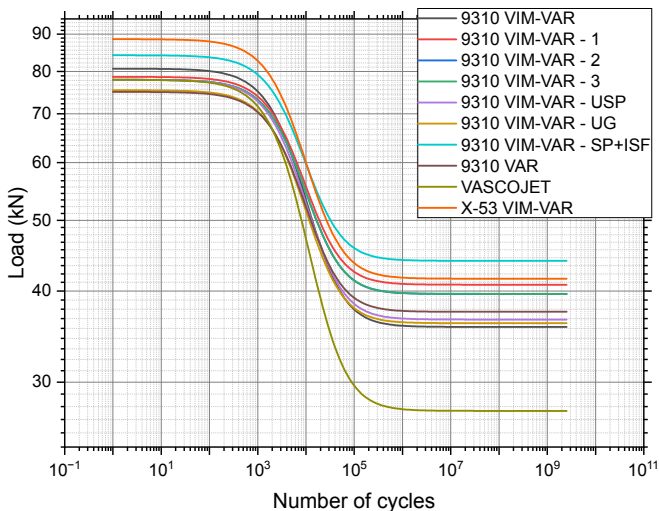


Figure 9—Curves of the tested case-hardened gears.

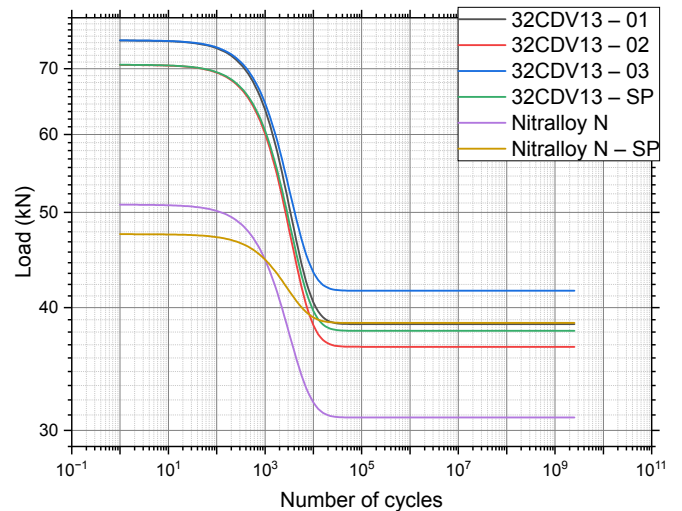


Figure 10—Curves of the tested nitrided gears.

Base material	Heat treatment	S_L kN	CV %	No. tested specimen
AERMET100 (AMS6532)	Hard. and double draw	32.237	7.89	25
CRES, PH13-8MO (AMS5629)	Prec. hard. H1000	29.596	6.13	29
CRES, 15-5PH (AMS5659)	Prec. hard. H1025	29.880	6.24	25
STL-ALY 4340 (AMS6415)	Hard. and draw (Ftu 1099/1246)	28.789	3.24	25

Table 5—Other families.

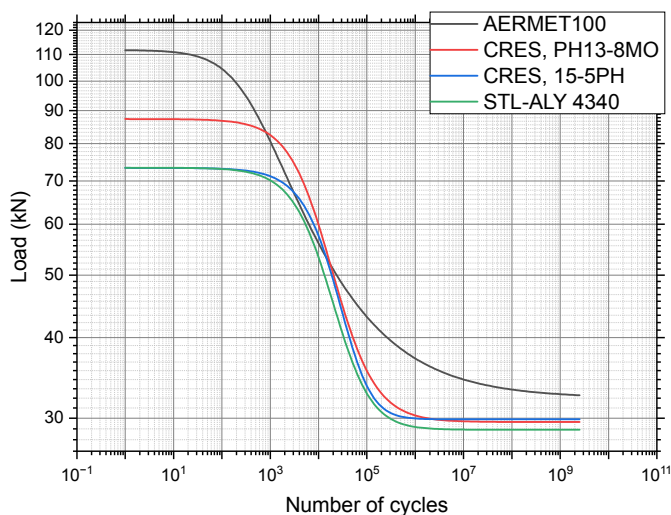


Figure 11—Curves of the tested “other” materials.

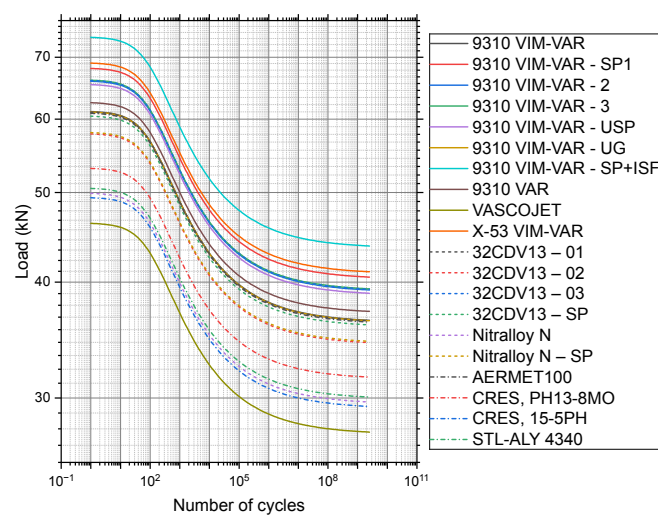


Figure 12—All curves, estimated according to the GEAR05 curve shape.

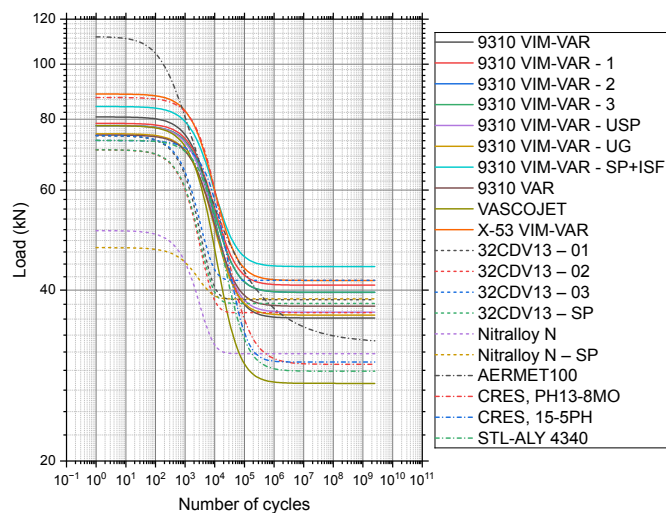


Figure 13—All curves, estimated according to the GEAR06 curve shape.

Tests Results

More than 650 fatigue tests have been performed in these 20 years, for a total number of cycles of 3.13 billion load cycles, which corresponds to a machine time of almost 3 years. Figure 8 reports all those data points. Among the tested families, the application of isotropic superfinishing to the root with two different processes (i.e., REACH-compliant and non-REACH-compliant) to gears in AISI 9310—shot peened—did not result in curves that are statistically different. Therefore, both families have been merged into a unique one (i.e., 9310 VIM-VAR – SP+ISF)

Table 3, Table 4, and Table 5 summarize the main tested families, while Figure 9, Figure 10, and Figure 11 report the corresponding GEAR06 curves. Instead, Figure 12 and Figure 13 provide a comprehensive summary of all the tested specimens. All curves (and data) reported here are average ones (i.e., 50 percent probability of failure).

Considering the gear material presented here, for case-hardened gears, X-53 VIM-VAR presents higher strength values than 9310 VIM VAR. However, at this moment, the application of Isotropic Superfinishing to shot peened 9310 VIM VAR (i.e., 9310 VIM-VAR – SP+ISF) provides the highest fatigue limit. In any case, tests on the isotropically finished version of X-53 VIM-VAR are currently ongoing. Focusing on nitride gears, 32CDV13 can be considered the most suitable one. Other materials presented here exhibit lower performance and are used for noncritical parts and accessories.

The tooth root grinding is beneficial to the load capacity of the tooth root. This not only reduces the nominal stress at the tooth root (see Table 2) but also improves the surface conditions of the same. In fact, comparing the allowable stress limit for “9310 VIM-VAR – UG” and “9310 VIM-VAR – 1,” higher values are shown by the case with ground root.

Shot peening can significantly improve the root strength, inducing beneficial compressive residual stresses in the surface layer. This surface treatment mitigates the initiation and propagation of fatigue cracks, particularly under high-cycle loading conditions, thereby extending the service life and reliability of critical transmission components. In particular, for nitrided gear teeth, the possibility of increasing the fatigue limit through shot peening has been shown.

The strength values reported here are significantly higher than the values typically proposed by the standards, which are, fittingly, conservative. Such high strength values are achieved thanks to the selection of materials with very high cleanliness. Indeed, the higher the cleanliness, the higher the fatigue strength, as can be seen by comparing the cases of “9310 VAR” and “9310 VIM-VAR.”

It is important to note that the curves presented herein correspond to experimental data obtained from pulsator testing. These results reflect raw test outputs and are not directly applicable to design calculations. Before use in the design process, the data must be appropriately elaborated. A recommended method for such data processing is described in Refs. 13 and 19.

Conclusions

The extensive test campaign presented herein, encompassing the principal design alternatives currently in use, has resulted in the development of a comprehensive material database that serves as a foundational element for a robust and efficient design methodology. This dataset also enables refined fatigue damage assessments based on the complete operational flight spectrum.

The test procedure developed through this research initiative has been institutionalized as the standard protocol within Leonardo Helicopters for the systematic evaluation, benchmarking, and qualification of novel materials, advanced manufacturing processes, and innovative structural designs for gear components. This methodology now serves as a foundational element in Leonardo’s material and process validation framework, ensuring consistency, reliability, and compliance with aerospace performance and safety requirements.

The availability of a comprehensive database of Wöhler curves for materials employed in helicopter applications—capturing both the fatigue limit and the low-cycle fatigue behavior—enables a more accurate and reliable design process. Such a resource allows engineers to better predict component life and optimize structural integrity from the earliest stages of design. Although regulatory standards mandate full-scale testing, these tests not only confirm the results derived from the initial material testing campaign that generated the database but also provide essential data for calculating cumulative damage in accordance with the operational flight spectrum.

In compliance with current regulatory requirements (CS 29.571, Ref. 20), full-scale fatigue testing of complete helicopter gearboxes is performed to gear safe life substantiation. These tests are conducted under conditions that reflect the expected in-service power levels for each gear, incorporating a safety factor of 1.4 for a single test (or derived for multiple tests) to account for material and manufacturing variability.

The Safe Life evaluation is conducted through cumulative damage analysis in accordance with Miner’s Rule, utilizing the Wöhler curves positioned in accordance with the full-scale test outcomes in conjunction with the detailed flight load history.

Acknowledgement

The completion of this work, the result of over two decades of dedication, would not have been possible without the invaluable contributions of numerous individuals. We are grateful to all the people who contributed to the experiment with their ideas and work. We extend our deepest gratitude to students, researchers, professors, engineers, and the professionals from the Transmission, Fatigue, and Technological Laboratory Departments at Leonardo Helicopters. We thank them all. In particular, we would like to acknowledge Piermaria Davoli, Giuseppe Gasparini, Edoardo Conrado, Mauro Filippini. Special thanks go to the late Francesco Rosa, to whom this work is dedicated.





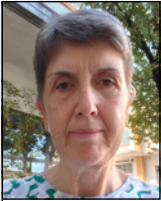
Luca Bonaiti is an assistant professor (RTDA) at Politecnico di Milano, Italy. His research involves the design, analysis, and experimental testing of gearboxes, covering fatigue strength and NVH characterization. His primary field is endurance testing and failure analysis of gears, with particular focus on tooth root fatigue fracture phenomena.



Carlo Gorla is associate professor of machine design at Politecnico di Milano, lecturing in mechanical engineering and PhD coursework on helicopter transmission design. His research focuses on power transmissions, gears, fatigue, efficiency, and structural analysis. He is technical director of Organi di Trasmissione and an AGMA academic member.



Ugo Mariani earned his degree in aeronautical engineering from Politecnico di Milano and joined Agusta (now Leonardo) in 1988. As head of the Fatigue Department for more than 20 years, he advanced helicopter fatigue methodology from safe life to flaw tolerance and fracture mechanics. He retired from Leonardo in 2025.



Rosanna Molinaro studied aeronautical engineering at Politecnico di Torino, Italy. Since 1997, she has worked as a fatigue specialist in the Helicopters Division of Leonardo, Italy, where her work supports the structural integrity and fatigue substantiation of helicopter components.



Sara Rustici received her degree in aerospace engineering from the University of Pisa, specializing in structures, materials, and fatigue. Since 2011, she has worked in Leonardo's Helicopters Division, serving as fatigue chief project engineer. Her recent focus is unmanned helicopter technologies alongside her role as Compliance Verification Engineer for fatigue.



Sergio Sartori is head of Analysis & Innovation in the Transmission System department at Leonardo Helicopters. With more than two decades of aerospace experience, he has managed structural and gear analysis teams and integrated research projects focused on technology and innovation. He is vice president of Innovation & Technology at FEDERTEC.

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Gleason Corporation

APPOINTS BIJAL THAKKAR
PRESIDENT AND CHIEF
OPERATING OFFICER

Gleason Corporation has appointed Bijal Thakkar as president and chief operating officer, effective July 6, 2026.



Bijal Thakkar

With Bijal Thakkar's appointment, Gleason reinforces its commitment to long-term growth while remaining focused on delivering innovative solutions that help customers succeed in an increasingly dynamic global marketplace.

John J. Perrotti, Gleason chairman and chief executive officer, stated, "Bijal brings deep experience, strong energy, and a proven track record of leadership working for different multi-national manufacturing companies. I am confident she will play an important role in advancing Gleason's global leadership in gear technology and other key markets."

Bijal commented, "I am honored to assume the role of president and COO of Gleason Corporation. Gleason has a remarkable legacy of technological leadership and customer focus. I look forward to working with our talented employees around the world to build on that success, deliver value for our customers and advance our strategic objectives."

Bijal Thakkar has more than 20 years of experience in senior strategic and business development positions across a broad range of manufacturing organizations. Most recently, she served as vice president and general manager of a major division at TE Connectivity. Earlier in her career, she held roles at Trane Technologies, Johnson Controls, Siemens, and General Electric.

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Rapid Gear

CELEBRATES 50 YEARS OF
CUSTOM GEAR
MANUFACTURING



Rapid Gear, based in Kitchener, Ontario, marked its 50th anniversary with a company picnic attended by employees and Kitchener Mayor Berry Vrbancovic. Founded in 1976, the company has grown from a small shared facility to more than 40,000 square feet of manufacturing space, producing custom gearing, gearboxes, and power transmission components for customers across North America and internationally. Rapid Gear is now a second-generation, female-led business and credits its participation in the Canadian Tooling & Machining Association's (CTMA) Career-Ready program as a factor in developing manufacturing talent.

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Solar Atmospheres

WELCOMES NEW
METALLURGICAL/R&D
ENGINEER AND QUALITY
MANAGER

Solar Atmospheres announced the addition of Ava Conolly to its Research & Development team as a metallurgical/R&D engineer.

She recently earned her bachelor of science degree in chemical engineering from Lehigh University, with a concentration in materials science and metallurgy. Her academic background and passion for metallurgical engineering make her a valuable addition to Solar's technical team.

"We are excited to welcome Ava to Solar Atmospheres," said Jamie Jones. "Her knowledge, enthusiasm and fresh

perspective will strengthen our R&D capabilities as we continue to develop innovative thermal processing solutions for our customers."



Ava Conolly

In her new role, she will support research and development initiatives, process optimization, and metallurgical analysis, helping advance Solar Atmospheres' commitment to technical excellence and continuous innovation.

Solar Atmospheres also appointed Karla Clement as the company's new quality manager. She brings a wealth of experience and expertise to this crucial role. Her extensive background in quality management aligns perfectly with Solar Atmospheres' commitment to excellence and customer satisfaction.



Karla Clement

"We are thrilled to welcome Karla to the Solar Atmospheres team," said Derek Dennis, president. "Her dedication to quality and proven track record will be invaluable as we continue to uphold our high standards."

She will be instrumental in overseeing our quality management systems and ensuring compliance with industry standards. We are very excited to have her on board and look forward to her contributions.

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SEPTEMBER 14–19
IMTS 2026


The largest manufacturing technology trade show in the Western Hemisphere (Chicago) and among the largest in the world, IMTS attracts nearly 90,000–130,000 attendees from over 112 countries. Pavilions include Gear Generation, Additive Manufacturing, Machine Components, Metal Cutting & Machining Centers, Tooling & Workholding Systems, Controls & CAD-CAM and Quality Assurance. From quality and inspection to process optimization, downtime reduction, cybersecurity, ergonomics, safety, and demand forecasting, the Industrial AI Arena showcases breakthrough tools, prototypes, and platforms—real solutions that redefine what's possible on the manufacturing floor.

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SEPTEMBER 22–23
RPM Symposium 2026


The RPM (Reliability Process & Maintenance) Symposium (Kalamazoo, MI) is a conference event where end users can network and learn about industrial facilities, reliability, maintenance best practices, electric motor driven powertrains, and IIoT. Topics include pumps, gearboxes, vibration analysis, drives, bearings, motors, couplings, condition monitoring, controls, automation and more. A keynote presentation will examine monitoring, maintenance and repairs. Additional sessions will focus on VFDs, managing critical equipment, AI, gearbox validation and pump failure.

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SEPTEMBER 21–24
TPS (Turbomachinery & Pump Symposia) 2026


TPS (Houston) is a vital industry event, offering a forum for the exchange of ideas between rotating equipment engineers and technicians worldwide. Now surpassing 54 years, TPS is known for its impact on turbomachinery, pump, oil & gas, petrochemical, power, aerospace, chemical and water industries through two pathways: an exhibition and a technical program. The TPS technical program is hand-selected by advisory committees made up of key industry players and led by highly respected practitioners and leaders in their fields. Topics cover maintenance, reliability, troubleshooting, instruction on emerging designs, technology, and best practices that include case studies with real-world relevance on problems solved and lessons learned.

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OCTOBER 12–14
Furnaces North America (FNA) 2026


FNA (Indianapolis) is produced by the Metal Treating Institute (MTI) with media partner Heat Treat Today. The heat treat-only trade show and technical conference includes the latest products and technologies on industrial furnaces and ovens, atmosphere generation and control, quenching systems and quenchants, induction heating equipment, vacuum furnaces and pumps, heat treat software and controls and more. One of the biggest features of FNA is the quality of the technical sessions. Experts from all over the world share their knowledge on the latest trends and technologies in equipment, processes, and materials.

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The Art of the Repurposed Past

Matthew Jaster, Director, Editorial Content

Bruce Rosenbaum, reimagineer and owner of ModVic, LLC, said the air at Snow Farm, the New England Craft Program located in Williamsburg, MA, is usually filled with the scent of sawdust or the glow of a kiln. but recently, it hummed with a different kind of energy—mechanical, historical and re-imaginative. Under Rosenbaum's guidance, a group of 10 skilled artists and makers showed that when it comes to art, they certainly know how to 'shuttle' in a new era of creativity.

Rosenbaum said steampunk is more than just gears and goggles; it is a philosophy of "creative reimagining." Rosenbaum brought his signature blend of history and whimsy to the hills of Western Massachusetts for the Steampunkinetics workshop. The centerpiece of this year's workshop was the textile loom flying shuttle. Once a hardworking component of the textile industry, these wooden and metal artifacts served as the "spine" for the students' sculptures.

"The assignment was to turn the flying shuttle into some type of Steampunk vehicle," Rosenbaum explained. "So, for example someone sculpted a Steampunk-type car, a boat, a rocket, an airplane, and in some cases, they would be multi use, for example a vehicle that could fly and then dive underwater."

There must always be a good story behind Steampunk art. By centering the projects on a uniform historical object, the workshop challenged crafters to see the infinite possibilities within a single form.

"The assortment of found objects that Bruce brought with him helped everyone create an imaginative project that they can be very proud of," said Alex M., a 2026 student of the workshop. "He and his assistant Joe Sommers were able to assist those students whose experience with tools was a new challenge. This was my third time at Snow Farm and it was my most memorable."

The workshop format involved two full days plus additional evening work sessions, creating an intense, hands-on learning environment. The participants all created amazing projects, with some finishing early and working on additional designs.

"Snow Farm is an ideal setting with quality tools, lots of support and extended work hours that really fostered creativity *and* productivity," Rosenbaum said. "Many of the artists already had tool experience and I was so impressed with the level of everyone's work."

Participants spent their days at Snow Farm diving deep into the mechanics of assembly. Under Rosenbaum's mentorship, the process went beyond simple drilling and bolting. Makers learned to:

- **Curate with Intent:** Selecting repurposed antiques that complemented the aesthetic of the flying shuttle.
- **Problem-Solve Mechanically:** Integrating movement and balance into their sculptures.



Students participating in the Steampunkinetics course were tasked with creating steampunk vehicles from textile loom flying shuttles. (All Images: Modvic)

- **Balance Form and Function:** Ensuring that the Steampunk elements felt integrated and authentic rather than merely decorative.

Bruce's assistant, Sommers, a retired engineering professor, provided valuable technical support. The atmosphere in the studio was one of intense collaboration.

Snow Farm provided the perfect backdrop for what Rosenbaum called, "this mechanical metamorphosis." The organization has long been a sanctuary for those who work with their hands and the Steampunkinetics workshop is a perfect example of this. Snow Farm's mission is to provide a specialized environment where artists can push the boundaries of their medium.

"These sculptures stand as a testament to the power of the maker movement," Rosenbaum added. "They remind us that history isn't something to be tucked away in a museum—it is a raw material, waiting for a creative spark to set it back in motion."

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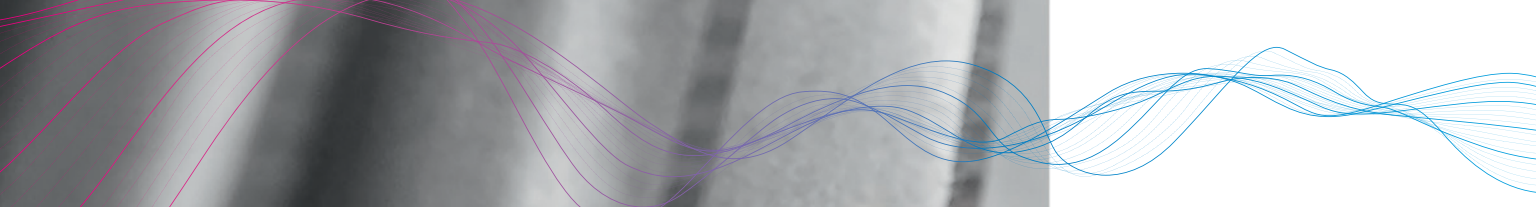
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