

# gear

## TECHNOLOGY®

SEPTEMBER/OCTOBER 2026



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Automation**

**Strain Wave Gear  
Production for  
Humanoids**

**Sustainable  
Rotor Shafts**

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Machine Learning  
Optimization of Gear  
Microgeometry

**Deburring  
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# Better Gear Cutting Results Start with the Right Partner

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- Skiving Cutters
- Shaving Cutters
- Rack and Saw Cutters
- Master Gears, Ring and Plug Gauges
- Advanced Coatings Available





GEAR CUTTING SOLUTIONS



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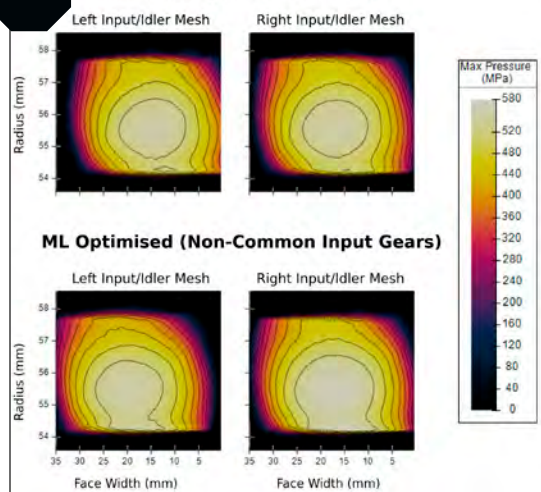
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If We Ain't Got It, It's Gonna Be Hard to Find!



This issue features Gleason Corp.'s solutions for manufacturing humanoid robots and more.



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## GT REVOLUTIONS

## IMTS 2026 Accelerates Technology Adoption, Shapes Next Chapter of Manufacturing



The 2026 edition of IMTS—The International Manufacturing Technology Show, which ran Sept. 14–19, reflected dynamic changes in manufacturing investment and how people view the industry, as well as an expanding ecosystem of technologies emphasizing AI and automation. IMTS 2026 attracted 91,295 registrants, including 14,447 students and representatives from all 50 states, Washington, D.C.,

Puerto Rico, and 123 countries. The show featured 1,788 exhibiting companies and 1.17 million square feet of exhibit space.

[geartechnology.com/imts-2026-accelerates-technology-adoption-shapes-next-chapter-of-manufacturing](https://geartechnology.com/imts-2026-accelerates-technology-adoption-shapes-next-chapter-of-manufacturing)

## TPS Highlights Latest Rotating Equipment Technology

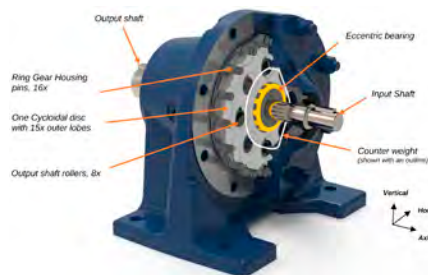
The 55<sup>th</sup> Turbomachinery & 42<sup>nd</sup> Pump Symposia (TPS) concluded in Houston recently. Its wide reach and exceptional program further solidified TPS as a premier event in the rotating equipment industry, fostering meaningful exchanges among professionals and businesses alike in industries such as turbomachinery, pumps, oil & gas, petrochemical, power, aerospace, chemical and water/wastewater.



[geartechnology.com/tps-highlights-latest-rotating-equipment-technology](https://geartechnology.com/tps-highlights-latest-rotating-equipment-technology)

## AS SEEN IN PTE

## Vibration Analysis for Fault Diagnosis of Cycloidal Gearbox Using Wavelet Transform



For years, the cycloidal reducer has proven its performance in a variety of applications, from robotics to wastewater treatment. Along with involute gearing, the cycloidal mechanism has its place in the mechanical power transmission world. It is well known for its high torque density, high integer ratio per stage, and shock load handling capabilities. Its poke-yoke assembly refrains from introducing any

errors during assembly and allows the unit to operate with low maintenance.

[powertransmission.com/vibration-analysis-for-fault-diagnosis-of-cycloidal-gearbox-using-wavelet-transform](https://powertransmission.com/vibration-analysis-for-fault-diagnosis-of-cycloidal-gearbox-using-wavelet-transform)

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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](https://geartechnology.com). Michael continues working with the magazine in a consulting role and can be reached via e-mail at [mwg42@hotmail.com](mailto:mwg42@hotmail.com).

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# We'll See

Aaron Fagan, Senior Editor

Between this year's IMTS and the MPMA's Fall Technical Meeting (FTM), I heard a lot of confidence about where manufacturing is headed, and the most sensible response to much of it is still "we'll see." Plenty of what was on display at IMTS works, but what hasn't been shown yet is how well it holds up over years of service.

At IMTS 2024, the conversation was mostly about uncertainty: the election, interest rates, tariffs and whether EV adoption would keep its pace. This year it was about AI and robotics. A large share of the exhibit floor showed automated machine tending, robot integration and software that generates CAM code. Tariffs haven't settled, but some gear manufacturers have stopped waiting for them to. I heard about several large orders for gear-cutting machines that had been on hold, and at least part of that demand appears to come from robot gear production.

The two big stories of the last few years ask different things of gears. An EV drivetrain uses fewer gears than a conventional transmission, but those gears turn at motor speeds with no engine noise to mask them, so they have to be made to something close to aerospace quality at automotive volumes. A humanoid robot needs many more gears to the same exacting standard. Schaeffler puts the count at 25 to 30 actuators for the major joints alone. Once you add dexterous hands, many with their own miniature gear-boxes, a single machine can carry well over a hundred gears: strain wave, planetary, worm and spur, most of them small and all expected to hold position without backlash for years. EV makers have already shown they can build at volume. For humanoids, that is still the open question.

This issue of *Gear Technology* carries both stories. Felss describes axial cold forming of helical gears directly on EV rotor shafts, displacing material instead of cutting it away, which saves energy and preserves the fiber flow that fatigue strength depends on. Gleason and KISSsoft walk through

the design, power skiving and sub-micron inspection of strain wave gears, a part that is simple to sketch but hard to make in the thousands. And Jacques Lemire's update of the MPMA Emerging Technology Robotics Committee white paper

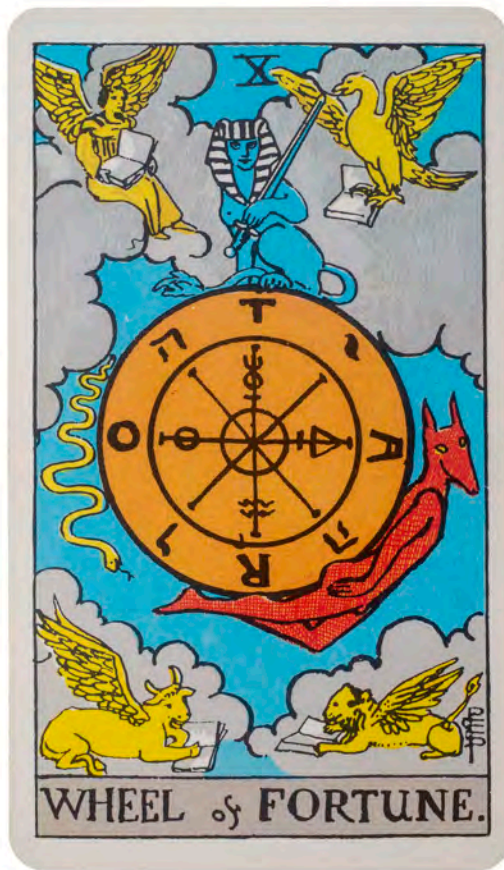
is a useful corrective to the investor headlines. AI has given the humanoid a far better brain, but safety at speed, reliability and cost in the actuator drivetrain still stand between the demo and the customer.

On the AI side, Paul Langlois and his co-authors show a machine-learning optimizer arriving at gear microgeometry comparable to what an experienced engineer produced by hand, in about 30 minutes, then going further to find a microgeometry that holds up across a range of torques. The engineer is still the one deciding what a good result looks like. The software gives back the hours that used to go into hunting for it.

FTM had plenty of the same. In the emerging technology session, Frank Kressel of Reishauer made the case for tying machine, process and inspection data into a single picture of a grinding operation, and Arian Sardari of RWTH Aachen presented a framework pairing physics-informed neural networks with causal models to find the root of an NVH problem instead of cataloging its symptoms. Faisal Ahmed Youssef of MOPCO put large language model (LLM) output up against expert-approved vibration diagnoses, an important

test these tools need. Meanwhile, FZG was still pulsator testing coarse-grained case-hardened teeth, and Timken was still refining bearing life predictions, because none of the new work stands up without the foundational work underneath it.

That is what keeps "we'll see" from turning cynical. Robots and algorithms are real, and some of them will matter a great deal to this industry, but whether they matter on the timeline the keynotes promise depends on gears that are designed, made, measured and tested by people who have been doing it for a long time. We'll see. I expect much of the answer will show up in future pages of this magazine.



**Caption:** *The Wheel of Fortune, from the 1909 Rider-Waite tarot deck. In a reading, it means change is coming, and the only thing to do is wait and see which way the wheel turns.*



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37 pages covering force-controlled, precision deburring with an OB7 cobot, from no-code simplicity of use, to calculating ROI.

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# Verisurf Software

POWERS NEW RENISHAW PH20 PLUS



Verisurf Software demonstrated Renishaw's new PH20 Plus 5-axis touch-trigger probe head at IMTS 2026 in Chicago, running it with Verisurf's CAD-based inspection software. The PH20 Plus has a maximum working length of 300 mm from the center of the A-axis. That is more than 50 percent more reach than the current PH20.

The new head keeps the speed of the original PH20 and adds a redesigned A-axis and kinematic mount. These accept a wider range of probe module extensions, including longer and heavier probe configurations. The redesign adds 107 mm of reach, and the head takes stylus lengths up to 50 mm. The added reach gives better access to deep, recessed and otherwise hard-to-reach features.

The PH20 Plus is backward compatible and is designed as a direct replacement for the PH20. It works with the existing range of TP20 probe modules except the extended force module. The powered PCR20 rack holds multiple probe modules and accessories and exchanges them automatically during measurement routines.

"With PH20 Plus, we've focused on extending capability, which we think will appeal to both existing PH20 customers and those with measurement requirements that could previously not be met by the existing head," said Nathan Fielder, product manager at

Renishaw. "Existing PH20 users will be able to adopt the new head and reuse existing programs and measurement strategies, while benefiting from increased reach and greater flexibility."

Verisurf's software uses model-based definition (MBD) to plan measurements directly from the CAD model, and it provides device controls and repeatable inspection routines for CMM operation. "Extended value comes from combining advanced sensor capability with software that makes that capability practical and repeatable on the shop floor," said Nick Merrell, executive vice president at Verisurf.

Verisurf software works with major CAD systems and measurement devices, including CMMs, portable arms, laser trackers, scanners and machine tool probing systems.

[verisurf.com](http://verisurf.com)

## Universal Robots

UNVEILS GEN 7 FOR INDUSTRIAL AUTOMATION AND PHYSICAL AI



Universal Robots (UR), a Teradyne Robotics company, introduced Gen 7, its seventh-generation collaborative robot platform, at IMTS 2026 in Chicago. Gen 7 has a redesigned control box, teach pendant and tool flange and runs on the company's PolyScope X operating system. It is designed to support AI-based applications such as vision guidance and force-sensitive assembly on the production floor.

"Built on what we have learned from over 20 years of cobot innovation and more than 100,000 industrial

deployments worldwide, Gen 7 is an end-to-end redesign of our platform that reduces integration friction and dramatically expands application capabilities," said Jean-Pierre Hathout, president of the Teradyne Robotics Group.

The platform adds three g-Series robot arms: the UR10g-1750, UR17g-1300 and UR18g-950. Each model name gives the arm's payload in kilograms and its reach in millimeters. The arms join UR's e-Series and UR Series lines. The g-Series tool flange carries data, power and safety signals, so cameras and high-bandwidth sensors connect without extra cabling. Built-in force-torque sensing, impedance control and Real-Time Data Exchange (RTDE) support tasks such as dexterous manipulation and force-sensitive assembly.

UR said the CB7 Core controller has 40 percent more computing power and a 30 percent smaller footprint than previous generations. It communicates across multiple networks, connecting to PLCs, HMIs, MES platforms, industrial PCs and vision systems, which reduces the need for external switches. It comes as a standalone control box or as a compact unit for mounting in an automation cabinet. CB7 also works with e-Series and UR Series arms.

PolyScope X provides the programming tools, ISO 10218-1 safety functions and cybersecurity compliance for Gen 7. Its open APIs and ROS 2 communication let programmers build edge-AI applications that use industrial PCs and external AI processing. Optional software packages add PROFI-safe, OPC UA and logic programming, along with third-party applications such as Rocketfarm Pally and Inbolt 3D Vision Guidance.

The TP7 Core teach pendant is more than 20 percent lighter than earlier pendants. It has multiple grip positions, configurable smart buttons, a full HD display and a virtual joystick. The new SP7 Smart Panel mounts at the tool flange so operators can teach and program at the point of the task. It provides safety-compliant freedrive, LED indicators and three configurable input buttons that can run PolyScope X Smart Skills. UR is aiming the panel at high-mix, low-volume production, where operators frequently teach the robot by hand.

Gen 7's safety functions use a PLd, Category 3 architecture certified to ISO 13849-1. All g-Series robots are TÜV certified to ISO 10218-1 and UL 1740. For cybersecurity, Teradyne Robotics is certified to IEC 62443-4-1 ML3, which covers secure software development practices.

At IMTS, more than 20 partners showed products with Gen 7, including Cognex, Schunk, Magswitch, Smooth Robotics, Psyonix, Robotiq and Inbolt. "With Gen 7 and PolyScope X, Inbolt's vision now runs natively on the UR controller itself, available directly through UR. No external vision PC, no extra cabling," said Rudy Cohen, CEO of Inbolt. Partner products sold through UR's UR+ program are tested and validated by both the partner and UR.

[universal-robots.com](http://universal-robots.com)

## Emuge-Franken USA

OFFERS J-THREAD TAPS, THREAD MILLS AND GAGES



Emuge-Franken USA has released a brochure on its line of UNJC, UNJF and MJ taps, thread mills and gages for J-thread applications in aerospace, defense and transportation. J-threads are used in high-stress, safety-critical joints. The taps and thread mills cut internal threads to a 3B or 4H fit and meet SAE AS8879 and ASME B1.15.

The J-thread taps have geometry and coatings matched to specific materials. AL-GLT-104-coated HSSE taps are for through and bottoming holes in aluminum. TI-TiCN-coated HSSE taps are for through and blind holes in titanium alloys. NI-TiCN-coated powder-metal HSSE taps are for through and blind holes in nickel alloys. Z-series UNJC and UNJF taps, uncoated or with GLT-1 coating, are for blind holes in a range of materials. Inch taps cover

UNJC sizes #4-40 to 3/8-16 and UNJF sizes #4-48 to 3/8-24, 98 SKUs in all. Metric MJ taps range from MJ3 × 0.5 to MJ10 × 1.5, in 40 SKUs.

Thriller/Aero drill/thread mills drill the core hole and mill the internal thread in a single operation. During interpolation, the tool's milling face can also chamfer the thread entry, so no separate drill or deburring tool is needed. The tools are left-hand rotating and are designed for stainless steel, titanium and nickel alloys such as Inconel. Their ALCR-89 coating reduces friction and wear. Inch versions come in 2xD and 2.5xD lengths, covering UNJC #6-32 to 3/4-10 and UNJF #6-40 to 3/4-16, 76 SKUs in all. Metric MJ versions range from MJ3 × 0.5 to MJ24 × 3, in 72 SKUs.

For inspection, Emuge offers UNJC, UNJF and MJ plug and ring gages. The plug gages are made of aged gage steel for dimensional stability and meet NIST certification standards. The GO/NO-GO ring gages are made of hardened tool steel, have knurled outer surfaces and meet ANSI/ASME B1.2.

[emuge.com](http://emuge.com)

## Siemens

LAUNCHES MEET AT THE MACHINE INITIATIVE



At IMTS 2026 in Chicago, Siemens introduced Meet at the Machine, an initiative in which Siemens and machine tool builders jointly develop machining solutions. Each solution combines Siemens engineering software and automation hardware with the builder's machine. TRAK Machine Tools is the first partner.

The first phase focuses on the time between buying a new machine and cutting production parts on it. Programming, validation and training

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usually begin only after a machine is installed. Under the initiative, manufacturers can program, simulate and validate production jobs while their machine is still being built, so they can start preparing for production before the machine is delivered.

“By bringing together engineering software, automation hardware and machine expertise, we enable our customers and users to be productive faster, accelerate return on investment and

reduce ramp-up time by up to 50 percent,” said Mark Hindsbo, head of operations software at Siemens.

“When our customers invest in a new machine, their goal is to achieve productivity and business results as quickly as possible,” said Steve Pinto, president of TRAK Machine Tools.

Siemens plans to add machine builders to the initiative and develop solutions for other manufacturing challenges.

*siemens.com*

## Sandvik Coromant

**ADDS DEEP-HOLE DRILLS TO CORODRILL DURA 462 LINE**



Sandvik Coromant has added deep-hole solid carbide drills, from 12xD to 30xD, to its CoroDrill Dura 462 family. With this range, the family now covers micro, short-hole and deep-hole drilling across a range of materials. The drills are aimed at general engineering, automotive, aerospace, oil, gas, pump and valve work.

The new drills use grade X2BM, which has a micrograin carbide substrate and Zertivo 2.0 PVD coating. Deep-hole drilling makes positional accuracy, thrust force and chip evacuation harder to control. To address this, the geometry has a revised flute design, offset double margins, double gashes, blended root radii and a 135-degree point angle. The company says these features improve stability, reduce cutting forces, and improve hole quality and tool life.

Sandvik Coromant reports that in customer field trials against competitor drills, the deep-hole drill averaged 45 percent longer tool life and 25 percent higher productivity.

For holes deeper than 15xD, Sandvik Coromant recommends drilling the pilot hole with a 3xD or 5xD CoroDrill Dura 462 short-hole drill of matching diameter, instead of using a dedicated pilot drill. The drills can also be reconditioned several times without losing their original cutting diameter.



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“What we hear clearly from customers is that process security remains one of their top priorities,” said James Thorpe, global product manager at Sandvik Coromant. “At the same time, many manufacturers aren’t looking for an optimized tool for a single application. They want one solution that delivers reliable results across a wide range of materials and conditions.”

[sandvik.coromant.com](http://sandvik.coromant.com)

## James Engineering

INTRODUCES PNEUMATIC  
P-CENTER FOR PRECISION  
WORKHOLDING



James Engineering has introduced the P-Center, a pneumatic workholding system designed to provide accurate and repeatable between-center positioning for CNC machining, gear manufacturing, grinding, finishing, inspection and automated production applications. The system uses a stationary center and a moving live center to locate a workpiece before pneumatic clamping force is applied.

The P-Center provides positioning accuracy of 0.001 in. TIR or better over an 18-in. long workpiece. The system can accommodate parts weighing up to 150 pounds and provides up to 251 pounds of gripping force. Pneumatic actuation allows the system to be integrated into automated production equipment and CNC machine environments.

The system is designed to be machine-ready for integration into CNC equipment and other automated systems. Integrated rotary table options are

available for applications requiring part rotation during machining, inspection, grinding, finishing or other operations.

For loading and unloading, the P-Center incorporates a ballasting system that allows the upper live center to be lifted from the workpiece with one hand. The system is designed so that clamping does not occur until the machine doors are closed, helping prevent operator contact with the clamping mechanism during loading and unloading.

The P-Center was originally developed by James Engineering for use with its own automated finishing equipment and is now available as a standalone workholding system. The between-center design can be used for applications including CNC machining, gear processing, robotic handling, welding, inspection, grinding and finishing where repeatable workpiece positioning is required.

[james-engineering.com](http://james-engineering.com)



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# Productive Robotics

## OFFERS 7-AXIS COBOT WITH PHYSICAL AI

Cobots are moving from execution-based programming to adaptive partners with the integration of AI and the growing use of no-code interfaces. For more than a decade, Productive Robotics has dominated the market with its 7-axis

OB7 collaborative robots engineered with the company's zero-programming, teach-by-touch technology. At IMTS 2026, Productive Robotics set a new technical benchmark with the introduction of OB7-AI. The new addition gives job shops and contract manufacturers the capability to shave additional time from their CNC machine tending tasks.

"Our collaborative robots and robotic welding systems operate in nearly every industry including small to mid-sized enterprises that run high-mix,

low-volume parts," says Zac Bogart, president of Productive Robotics. "Teaching OB7 is exceptionally simple and only has to be performed once per job, but it's a task that takes time. Now operators can recoup that time because OB7-AI scans and finds its own way around a shop's machine. And there are no AI training cycles required for new parts or tasks."

OB7-AI automatically scans a machine's work area to learn where everything is located. Operators don't have to precisely place blanks on the work table for the cobot. As long as there is "finger room" between each blank, OB7-AI's gripper can easily reach the parts. Once the cobot finds a blank, it opens the door, loads the part in the vise, closes the door and pushes the start button. To determine when a cycle is finished, OB7-AI reads the CNC screen, then opens the door, unloads the finished parts and repeats the process until the job is complete.

"The automotive and CNC machining industries are the key markets for cobots with physical AI," says Bogart. "The difference is that our OB7-AI is designed to work on a production floor now without training. The added capability also opens the door to non-factory sectors such as laboratory research and healthcare."

Productive Robotics LLC designs, manufactures and services its collaborative robots, robotic MIG, and laser welding systems and accessories in the United States. Unlike conventional cobots, which rely on 6 axes, Productive Robotics' OB7, OB7 Stretch model, MAX 8, Max 12 and MAX 16 along with its Blaze and Blaze MAX series feature a 7-axis robotic arm that provides human-like dexterity to maneuver around obstacles without the need to redesign workspaces. A proprietary, "no programming" user interface allows operators with no engineering or robotics experience to grab and move the 7-axis arm to teach it a task. OB7 and Blaze record the steps and are ready to perform in minutes. The plug-and-play machines are engineered to integrate with new or legacy equipment to boost production, handle repetitive, dangerous tasks or high-precision work in a wide range of applications. A secure

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## Solar Atmospheres

### EXPANDS TITANIUM PROCESSING CAPABILITIES WITH NEW WATER QUENCH FURNACE

Solar Atmospheres of Western PA has expanded its heat treatment capabilities with the delivery of a new water quench furnace specifically designed to process large titanium components. The company is currently commissioning the new system at its Hermitage, PA, facility and is expected to be placed into production November 2026.

Manufactured by Heat Treat Equipment Inc. of Canton, MI, the new furnace significantly expands Solar Atmospheres of Western PA's ability to provide controlled heat treatment for large titanium components weighing up to 7,500 pounds. The system is designed to maintain temperature uniformity within  $\pm 5^{\circ}\text{F}$  and achieve rapid water quenching within seven seconds.

Titanium alloys are widely used in aerospace, defense, medical and other critical applications where high strength-to-weight ratios and reliable performance in demanding environments are essential. The new furnace provides Solar Atmospheres of Western PA with the capability to process larger titanium components while thermocoupling the actual workload, providing precise monitoring and control throughout the heat treatment process. An in-process camera will also be installed to monitor the workload while being heated above the critical beta transus temperatures.

"This new furnace is an important investment in our continued commitment to serving our customers," said Bob Hill, president of Solar Atmospheres of Western PA. "This equipment finally gives us the opportunity to solution anneal critical titanium

alloys that our titanium customers have continuously asked for over the years."

The 14-foot-long by 54-inch-wide by 48-inch-high furnace is positioned directly above an 11,000-gallon, multidirectional, highly agitated water quench tank. This configuration is designed to minimize transfer time between the furnace and quench tank, enabling extremely rapid quenching of titanium components that is required by stringent aerospace specifications. Additionally, a closed-loop cooling

system provides a water quenchant temperature never to exceed 100°F.

Once fully operational, the new system will further expand Solar Atmospheres of Western PA's comprehensive range of vacuum and air heat treatment services. The investment reinforces the company's commitment to maintaining state-of-the-art equipment and delivering advanced heat treatment solutions for customers across demanding industries.

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# Sustainable Rotor Shaft Manufacturing

## Reducing CO<sub>2</sub> footprint with cold forming innovations

Dr.-Ing. Nadezda Missal, Maximilian Ludwig and Stefanie Schwertel; Felss Systems GmbH, Königsbach-Stein

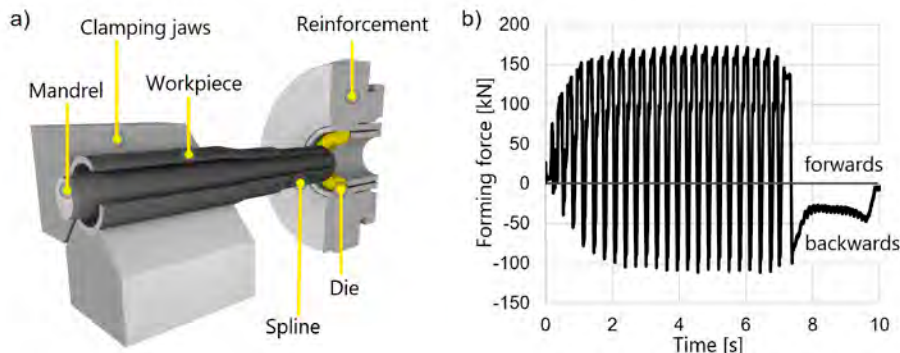


Figure 1—Axial forming process, including a) the process setup and b) the specific force curve.

The automotive industry and its suppliers are undergoing profound structural change. Electrification, volatile markets and geopolitical instability, along with increasingly intense global competition, are creating high costs and innovation pressures across the entire value chain. These developments not only affect the general drivetrain components but also rotor shafts for electric motors, which combine high functional density with demanding manufacturing and quality requirements. Recent restructuring efforts, plant closures and bankruptcies have highlighted the need to critically reassess existing manufacturing concepts, especially for components such as rotor shafts with integrated functional elements. For automotive suppliers, technological capability and cost efficiency are no longer the only priorities; process robustness and investment security are increasingly moving into focus. New manufacturing solutions must not only be technically convincing, but also enable a substantial reduction in manufacturing costs, energy consumption, the associated CO<sub>2</sub> emissions and process complexity (Refs. 1,2).

At the same time, the requirements for drivetrain components are undergoing fundamental change. Electrified drives operate at high rotational speeds in compact designs and set higher standards for noise performance, efficiency and power density. Helical gears play a key role in meeting these demands, as they enable improved operating characteristics and more uniform load distribution. However, their industrial production has so far been carried out primarily through machining processes, which involve material removal, multistage process chains and correspondingly high energy consumption.

Based on rising energy prices and regulatory requirements to reduce CO<sub>2</sub> emissions, the focus is increasing on how to make

the production of highly loaded gear geometries such as those used on rotor shafts more cost-effective and resource-efficient.

Axial forming is an incremental cold forming process first patented by the Felss Group in 1997 and enables the precise production of rotationally symmetric components with integrated functional geometries. While the process is already established for spline connections, transferring axial forming to the helical gear profiles frequently used on rotor shafts introduces additional technological and mechanical challenges. Through targeted process development, supported by structural and forming simulations of the machine behavior and tool loading, a new machine generation has been developed. This machine generation provides the required kinematic capabilities and structural rigidity to form helical gears directly on rotor shafts in a dimensionally accurate and reproducible manner and, at the same time, offers a more energy-efficient and CO<sub>2</sub>-friendly alternative to conventional machining.

### Preliminary Work on the Axial Forming of Helical Gears

Axial forming is a cold forming process in which a tube or bar is reduced in cross section or formed into a specific profile. Most applications involve the production of internal and external splines. To produce external splines, the forming tool, a die with the exact negative contour of the desired gear, is guided axially over the workpiece, thereby precisely reproducing the tool contour (Figure 1a). A major advantage of this process is the simultaneous forming of all teeth using a single-piece tool, which results in excellent total pitch deviation accuracy of the produced gear.

A key feature of axial forming is modulation, where the specific force profile is shown in Figure 1b. In this approach, the forming process does not occur in a single forward stroke across the entire forming zone, but rather through a series of small, incremental forward and backward strokes. The highly loaded forming zone is exposed by short backward strokes performed between the forward strokes, allowing for relubrication. The continuous renewal of the lubricant film ensures optimal friction conditions, resulting in a significant reduction in forming forces. This is particularly beneficial for spline forming on thin-walled components without bulging or buckling, while also increasing tool life and enabling the use of simple lubricating oils. Compared to conventional extrusion processes, incremental axial forming is especially suitable for producing functional elements such as splines. Due to the locally confined forming zone and reduced process forces, components can be formed without negatively affecting adjacent areas of the component. In this process, the material is not removed but is targeted for displacement, which largely preserves the material's fiber orientation and redirects it along the profile contour. Combined with a more uniform stress distribution within the component, this leads to improved mechanical properties, particularly with regard to fatigue strength and load-bearing capacity. At the same time, the lower forming forces enable more precise compensation of elastic deformations, resulting in high dimensional and profile accuracy.

While axial forming, with its process-specific advantages for producing splines, is already well established both technologically and industrially, the manufacture of axially formed helical gears presents entirely new challenges in terms of process kinematics, machine design, drive control and tool design. The results of numerical and experimental investigations, including a new generation of machines equipped with an additional electric rotary drive for the axial forming of helical gears, are outlined below.

## Requirements for Helical Gearing on the Machine and Tool

The production of splines and helical gears using axial forming requires forming presses that meet the highest standards of precision and rigidity. Only in this way can dynamic loads be reliably absorbed and the required manufacturing accuracy of the gears be achieved with process stability. This applies in particular to the precise alignment of all components involved in the load path, especially tools, mandrels, clamping devices and workpieces, which must exhibit only minimal deviations in coaxiality relative to one another. To ensure that this accuracy is maintained across the entire gear length, the axis guides must provide excellent overall runout as well as high repeatability and positioning accuracy. This prevents geometric errors such as runout or wobble and protects the tools from unacceptable transverse loads caused by tilting or off-center loading.

These basic requirements apply equally to presses used for manufacturing helical gears. However, the additional rotational kinematics raise further technical requirements. Since helical gears are produced by the superposition of axial and rotational tool movements, which are provided by separate drives, highly

precise control of these movements is essential. The electric rotary axis and the hydraulic stroke axis must operate in precise synchronization both during stationary operation and during acceleration phases, as well as during the cyclic reversal of the modulation.

Furthermore, the rotational axis must be designed to be free of play and torsionally rigid so that the required pivoting angles can be achieved with high precision even under heavy loads. Only in this way can the helix angle and the resulting gear tolerances, such as total helix deviation, be maintained. Beyond the design of the drives and guides, the entire press frame must also provide the necessary rigidity to safely absorb the torques introduced by the rotary drive without significant elastic torsion or elongation. If these conditions are met, the workpiece itself becomes the most compliant element in the overall system consisting of the press frame, tools and clamping device. In conventional axial forming of splines, this compliance has only a minor effect, as the resulting component deviations occur primarily in the axial direction and can be directly compensated by tolerances or by a simple correction of the final position. In helical gear forming, however, the situation is significantly more complex, since elastic strain and torsion components do not remain constant throughout the process and can influence the helix angle. These factors must therefore be considered and compensated for already during the forming operation. As the tool moves toward the clamping device, the length of the component, over which the torque from the helical gear forming acts, decreases. Consequently, the effective angular error resulting from the torsional elasticity of the workpiece is reduced over the course of the process and must be accounted for in the machine control system.

In addition to the elastic effects, the risk of undesired plastic deformation of the workpiece must also be considered. While conventional axial forming transmits only compressive forces through the workpiece into the clamping device, the additional rotational movement in helical forming generates torsional stresses that must be safely absorbed and withstood by the component. As the outer diameter increases, the polar moment of inertia of the workpiece and thus its torsional stiffness also increases, thereby reducing the risk of unwanted stress-induced deformation.

The tools, as well as the tool assembly consisting of the die and the reinforcement, are subject to more stringent requirements necessary for the axial forming of helical gears. The reinforcement assembly performs several mechanically critical functions in this process. The preload generated in the die ensures that the high internal pressures occurring during the forming process are absorbed. At the same time, the radial stiffening of the system reduces elastic die deformation, thereby improving the dimensional accuracy of the resulting gear.

Beyond these functions, the press fit also serves to mechanically fix the die. Although the axial forming forces are transmitted through a positive fit, the die is retracted during the backward stroke and prevented from slipping or rotating during helical gear forming by the frictional fit in the reinforcement. This requires a specifically engineered press-fit design. The frictional stresses must be high enough to reliably

transmit the required torque, while the permissible radial press-fit limits must not be exceeded, as excessive reinforcement would lead to unacceptable stress conditions and material damage.

The helix angle in helical gears generates additional lateral loads on the tooth profile of the die. These loads are the primary cause of failure in the form of tooth breakage. The shear stress occurring in the tooth root must therefore remain within permissible limits. Likewise, inaccuracies in tool movement must be avoided, as even minor deviations lead to increased transverse and bending moments on the teeth and significantly exacerbate the stress situation.

Due to these constraints, the design of the gear profile requires careful selection of the manufacturing process. Each available manufacturing technology produces specific geometric characteristics, such as edge radii, surface roughness or manufacturing deviations, that directly influence tool loading and the achievable component quality. Experimental investigations and numerical forming simulations were used to determine the optimal combination of manufacturing process and tool loading.

## Influence of the Die Geometry

While the die contour for helical gears can be freely optimized in numerical simulations, many of these geometries cannot be manufactured in practice or only with considerable effort. For this reason, two practical and industry-established manufacturing routes, wire electrical discharge machining (EDM) and sinker EDM, were evaluated with respect to their geometric flexibility, cost efficiency, and their influence on the forming process.

Wire EDM represents the more economically attractive option. It offers short manufacturing times, high repeatability and low tool costs. Although the constraints imposed by the continuous wire path limit the achievable geometric freedom, particularly for helical contours or calibration sections, a wire-EDMed die can still be designed to serve as a robust and process-reliable tool for a wide range of gear geometries.

In comparison, sinker EDM provides significantly greater geometric flexibility. It enables the fabrication of spatially curved contours, defined calibration sections, and complex helical shapes, which in principle allows for a more accurate reproduction of the target gear geometry. This increased design freedom, however, is accompanied by higher manufacturing costs and a more demanding electrode production process, which can impose economic limitations, particularly in environments with high product variability or small batch sizes.

To assess the actual influence of both manufacturing approaches on the forming process, die variants produced by wire EDM and sinker EDM were analyzed using numerical forming simulations. The simulation results shown in Figure 2 illustrate the investigated gear with a pitch diameter of 55.3 mm, 26 teeth, a module of 1.8, and a helix angle of 22.5 degrees. By utilizing the cyclic symmetry capabilities of the *Simufact* software, a helical segment of 41.5 degrees, corresponding to three teeth, could be simulated, enabling a high spatial resolution of the material flow while significantly reducing computational effort.

The simulation results indicate that the sinker-EDMed die generates a highly uniform material flow due to its contour-conforming helical geometry. The frictional conditions on both tooth flanks remain nearly identical, which promotes a slightly more complete formation of the tooth tip and a more symmetrical shaping of the flanks. This behavior results primarily from the continuous geometric guidance provided by the true helix contour.

Due to geometric constraints imposed by the wire path, the wire-EDMed die exhibits a slight deviation from the ideal helical profile. This deviation must be compensated during the forming process through the material flow, which results in locally increased effective plastic strain. This effect is also reflected in the required torque, which is approximately 3.5 times higher than that of the sinker-EDMed variant. This does not constitute a fundamental disadvantage; rather, it indicates that the wire-EDMed die relies more

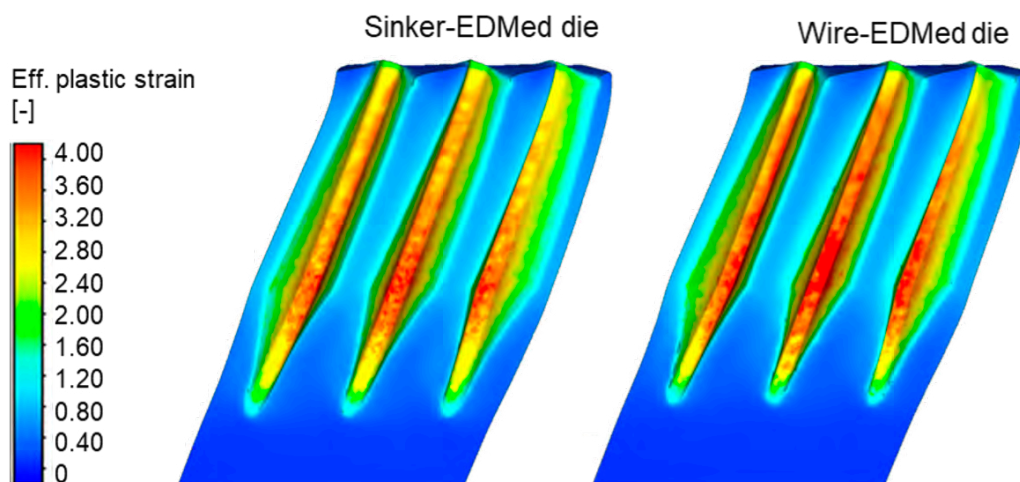
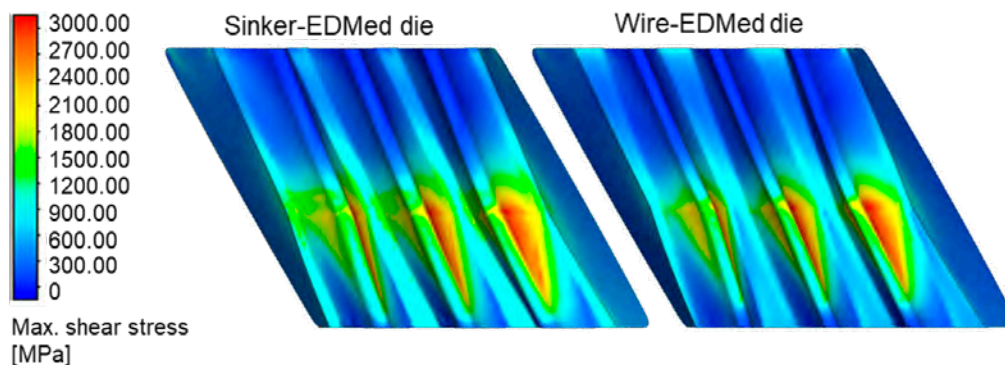


Figure 2—Comparison of the simulated effective plastic strain on the toothed component produced using a sinker-EDMed and a wire-EDMed die.



**Figure 3—Comparison of the simulated maximum shear stress in the sinker-EDMed and wire-EDMed dies during the forming process.**

strongly on process force regulation to reproducibly achieve the target gear geometry. Moreover, the minor differences in tooth tip filling can be fully compensated by adjusting the initial outside diameter of the preform, a parameter that is tailored for each gear anyway to account for material and batch-dependent deviations between simulation and actual forming behavior.

The approximately 20 percent higher axial force observed for the sinker-EDMed die is attributable to the enlarged contact area resulting from the more pronounced tooth geometry and the integrated calibration section. While this increased contact area has a beneficial effect on component quality by further reducing the total helix deviation, the longer calibration section requires a longer retraction stroke during modulation, which can accelerate tool wear. Conversely, if the retraction stroke is not adjusted to match the length of the calibration section, insufficient relubrication may occur, which can adversely affect the frictional conditions during the process.

The maximum shear stresses shown in Figure 3 reveal only minor differences between the two tooling concepts. This confirms that the wire-EDMed die exhibits a very favorable stress distribution despite its simplified contour and the higher torque required during forming. Its smaller effective contact area reduces the transverse loading on the teeth, making the tool less sensitive to minor positional deviations. In addition, the adapted entry and exit geometry provides design flexibility that enables targeted process adjustments, for instance, through modification of the helix angle. In contrast, the sinker-EDMed die, due to its closer approximation of the ideal target contour, exhibits a larger contact and effective area, which increases the transverse loading on the teeth, particularly when small deviations from the ideal helix angle occur.

Overall, the simulation study demonstrates that the wire-EDMed die is the preferred solution for many applications due to its lower force requirements, its higher robustness with respect to positional deviations, and its more cost-effective manufacturability. The sinker-EDMed version offers advantages primarily in cases where the highest demands on lead accuracy are required and where a potentially shorter tool life is acceptable in favor of maximum profile fidelity.

## From Prototype to a New Generation of Machines for Helical Gears

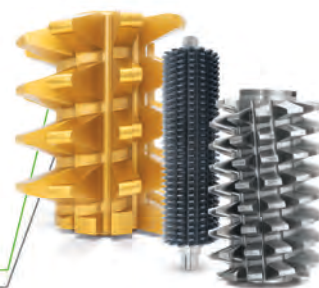
The prototype used for the evaluation was based on a conventional axial forming press equipped with a servo-electric rotary drive, providing the kinematic capability required for helical gear forming. The experimental trials showed that helical gears could indeed be produced, although the resulting component quality did not yet meet the required specifications. The observed profile slope deviation and total helix deviation led to the early conclusion that the torsional stiffness of the machine frame was insufficient to withstand the

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complex loading conditions of helical gear forming. This made a detailed structural analysis necessary to quantify the cause-and-effect relationships between machine stiffness and the resulting gear geometry.

Based on these findings, structural FEM simulations were conducted to systematically investigate the torsional behavior of the system. The simulated loads were intentionally increased conservatively compared to the actual process parameters in order to account for both safety margins and potential scaling possibilities. All FEM simulations were conducted using identical boundary conditions, including an applied torque of 9,000 Nm. The resulting torsion angle was evaluated at two critical positions: the forming axis and the clamping device. The

relative deformation between these points is crucial for process accuracy, as this is where the direct tool-workpiece interaction occurs. Even minor elastic torsional deflections can lead to measurable deviations in the resulting gear geometry.

The results of these analyses enabled a targeted evaluation of alternative guidance concepts. The original dual-arm configuration of the prototype shown in Figure 4a exhibited significant torsional deformation of the tool holder. The version with additional guide arms, shown in Figure 4b, was substantially stiffer. Simulation and experimental results both showed that it reduced the torsional deflection by about 41 percent. This was directly reflected in improved gear tolerances and confirmed the effectiveness of the modified guidance concept.

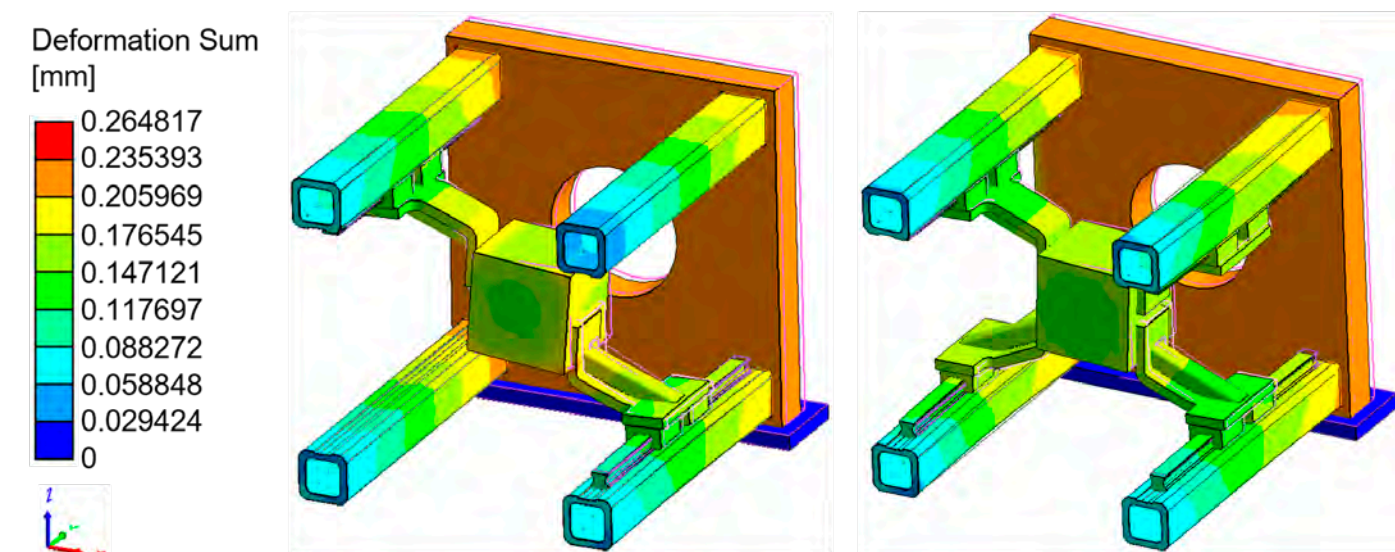


Figure 4—Comparison of the simulated deformation of the press frame under load using different guide systems (Ref. 3).

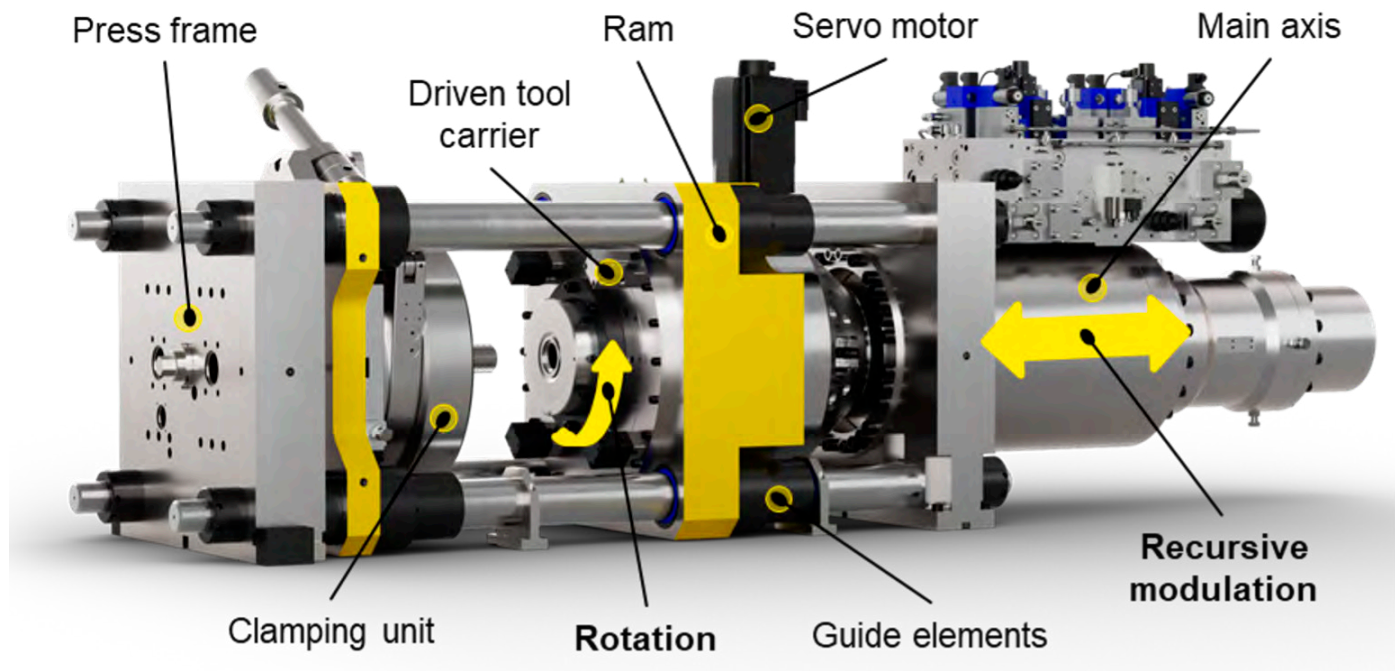


Figure 5—Newly developed generation of axial forming machines for the production of helical gears (Ref. 4).

For the development of a new generation of machines specifically designed for helical gears, the objective was to reduce torsional deflection by at least 50 percent compared to the first prototype system, in order to significantly expand the process limits. This target was not only achieved but clearly exceeded. The new concept incorporates four highly rigid guide columns with internal tie rods, enabling a nearly closed and flexurally rigid load path between the press plates. The comparison of torsional deformations for the evaluated guidance and machine concepts, as shown in Table 1, indicates that the new machine generation reduces torsional deflection by 78.6 percent compared to the prototype configuration, which corresponds to nearly five times the torsional stiffness. This improvement provides the necessary precision and process reliability for helical gear forming for the first time.

The helical gear machine (Figure 5) is designed to substantially expand the process window of the previous axial forming machine. Its press plates, tie rods and column guides form a highly rigid assembly that keeps tool movement virtually free of tilt, and a tandem cylinder, with its larger piston area, provides higher axial forces. The mandrel axis inside the tandem cylinder supports the inner diameter of tubular workpieces or parts with internal bores and keeps thin-walled components from buckling.

The central functional element of the new machine is the cylinder-driven ram, which is designed to withstand axial forces of up to 1,000 kN and incorporates a bearing system that ensures play-free rotation of the tool holder under load. Torque of up to 10 kNm is supplied by a play-free system consisting of a servo motor and gear assembly, enabling highly

| Evaluation of torsional stiffness at 9000 Nm |                                        |                      |
|----------------------------------------------|----------------------------------------|----------------------|
| Machine type                                 | Total torsion                          | Reduction in torsion |
| Aximus H02 dual guide                        | $9.753 \times 10^{-4}$ rad<br>0.0559°  | Reference            |
| Aximus H02 four guide                        | $5.785 \times 10^{-4}$ rad<br>0.0331°  | 40.7 %               |
| New machine generation round guide           | $2.0866 \times 10^{-4}$ rad<br>0.0120° | 78.6 %               |

Table 1—Comparison of simulated elastic torsional deformation angles of the guide systems under load.



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dynamic and precise rotational movement of the tool. A switchable clutch also allows the system to operate in a freely rotating mode, permitting the tool to be withdrawn from the interlocking mechanism with virtually no load once the forming process is complete. This protects both the tool and the component.

## Experimental Trials

The experimental validation of the new machine generation was carried out using a sequential testing strategy. First, all basic system functions were examined under no-load conditions to characterize the dynamic behavior of the axes and drive structures. This included modulation tests to adjust axis synchronism and evaluate the resulting positional and guiding accuracy, as well as metrological measurement of the reversal clearance in the rotary drive. In this way, it was verified that the design-specified minimum clearance is maintained and can be fully compensated by the control system.

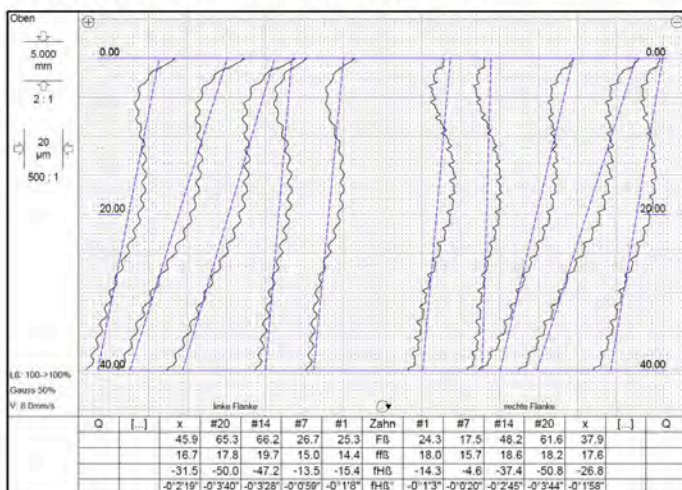
In the next step, a characteristic torque curve was determined for the rotary drive. This curve serves to prevent overload conditions and to enable precise process monitoring during the forming operation. The map was generated using a load cell positioned on a defined lever arm. By starting the system in a controlled way with limited force, the measured tangential force could be directly converted into an equivalent drive torque. In parallel, the elastic torsional deformations of the entire system at the respective load levels were

recorded so that they could be specifically compensated for during process control.

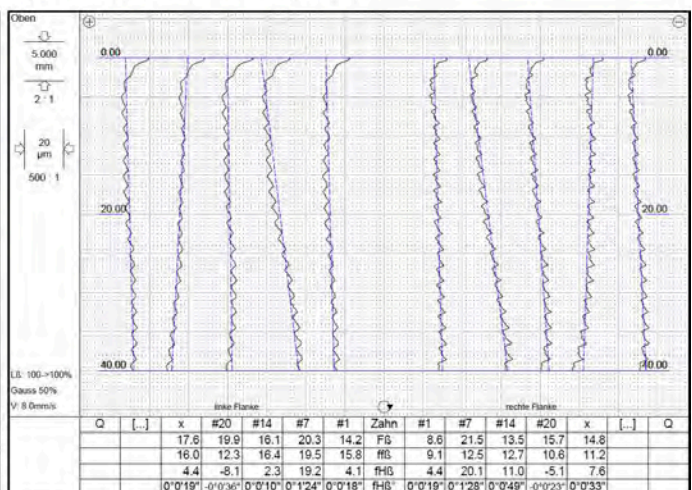
On this basis, the first helical gears with a helix angle of 16 degrees were manufactured. The results confirmed the high process capability of the new machine generation. The gear quality met the required tolerances with a substantial margin of safety. Furthermore, it was demonstrated that the total helix deviation caused by elastic effects can be fully compensated through targeted local modification of the helix angle to be formed. This adaptability also enables the deliberate creation of defined helix-angle modifications, for example, to compensate for anticipated distortion during heat treatment.

During an extended trial phase, a helix angle of 22.5 degrees was investigated. The results showed that the combination of a higher helix angle, a reduced clamping diameter, and the resulting smaller effective cross-sectional area leads to increased local stresses in the workpiece. Consequently, for certain blank geometries, plastic torsional deformations of the shaft occurred, causing the resulting helix angle on the component to deviate from the target value defined by the machine. Although this deformation was not detectable externally, it could be clearly identified via the resulting profile deviations (see Figure 6a). By selecting a blank with higher torsional stiffness, it was subsequently possible to produce gear teeth that fully meet the specifications of the technical drawing, thereby confirming the fundamental suitability of the process for larger helix angles (Figure 6b). The results thus

### a) Workpiece undergoing torsion



### b) Reinforced workpiece



**Figure 6—Comparison of tooth measurement reports for the formed gear teeth with a) lower torsional stiffness and b) higher torsional stiffness of the component.**

demonstrate that the reliable production of helical gears with high helix angles depends significantly on a suitable blank geometry, whose torsional stiffness sufficiently counteracts the resulting stresses and thereby ensures the complete reproduction of the helix angle specified for the forming process.

## Summary

The development of the new generation of machines demonstrates that the key challenges in the axial forming of helical gears have been successfully overcome. Thanks to the significantly increased torsional rigidity of the press frame, the precise synchronization of the axes, and the high-performance tool mounting, a process window has been established that enables the reproducible forming of helical gears. Investigations of the die contours demonstrate that both wire-EDM and sinker-EDM dies can be used reliably in the process, and each offers specific advantages. The wire-EDM design stands out for its cost-effectiveness and robustness against positional deviations, while the sinker-EDM contour demonstrates advantages where the highest requirements for total helix deviation accuracy apply. The experimental results also demonstrate the reliable production of helical gears across various helix angles. With suitable blank geometry and adapted process control, dimensionally accurate profiles can be produced and elasticity-related deviations reliably compensated for.

In summary, the axial forming process has been confirmed as a highly effective and industrially viable method for

manufacturing high-load helical gears not only for rotor shafts but also for many other components requiring integrated helical gearing. The achieved results present new possibilities for the cost-effective production of gears with high profile accuracy, reduced process costs and increased energy efficiency, thereby making an important contribution to future manufacturing technology in the automotive and powertrain sectors.

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## References

1. Raedt, HW.: Klimapfad Massivumformung – Wege zu CO2-freien Komponenten. ATZ – Automobiltechnische Zeitschrift 124 (2022) p. 26-31.
2. Wurm, T.; Busse, A.; Raedt, HW.: Initiative Massiver Leichtbau – Phase III: Werkstofflicher Leichtbau für Hybrid-Pkw und schweren Lkw. ATZ – Automobiltechnische Zeitschrift 121 (2019) p. 16-23.
3. Missal, N.: Umweltfreundliche Fertigung von Rotorwellen. Ein innovativer Weg zu Effizienz, Kostenreduktion und Verringerung des CO2-Fußabdruckes – 37. Jahrestreffen der Kaltmassivumformer 2024.
4. Missal, N.; Beihofer D.: Effizient. Intelligent. Nachhaltig. Die neue innovative Felss-Lösung für Rotorwellen – 39. Jahrestreffen der Kaltmassivumformer 2026.

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# The Near Future of Mechanical Drive for Humanoid Robots

AI has moved humanoid robots forward, but safety, reliability and cost in the actuator drivetrain still stand in the way of commercial deployment

Jacques Lemire, PDB Consulting

***Note:** Since this white paper on the near future of mechanical drive for humanoids was first published last year by the MPMA Emerging Technology Robotics Committee, we have seen progress toward lighter polymer gears and more adaptable robotic gearboxes. The recent improvements in AI have surpassed expectations by providing greater adaptive decision-making and control. However, there is still innovation required to improve the safety, reliability and cost-effectiveness of mechanical drives for humanoids. This shall remain a challenge and priority.*

With the development of AI and powerful computer algorithms, is the future of humanoid robotics now? The reality is that safety at speed, reliability and cost for electromechanical actuation still represent a significant challenge that limits the near-future commercial deployment of humanoids. In 1973, Ichiro Kato et al. at Waseda University developed WABOT-1. WABOT-1 could recognize and manipulate objects, speak and walk. In 1996, Honda developed the more advanced P2 Asimo humanoid robot. Honda's humanoid launched the development of the first harmonic drives to minimize backlash and turn small electric motors into high-torque actuators for a stable walking biped. Honda's robot had six-axis force/torque sensors and encoders that constitute today's humanoid hardware.

Humanoid robots have been around for decades, but few have moved beyond laboratory development and robotics conferences. The 2024 headlines from market reports suggest otherwise and have raised the interest of numerous investors and corporate boards of directors (see Figure 3). This surge in interest in robotics is driven by the convergence of advanced AI, machine

learning, computer vision and control algorithms that were not present in the Honda P2 Asimo humanoid. This has generated much enthusiasm and the promise that we are at the tipping point of a new technological era for humanoid robotics. Are we at the technological tipping point for humanoids, or are other developments still needed to meet the market forecasts?

The experts are not convinced. Rodney Brooks, professor of robotics (emeritus) at MIT, co-founder and chief technical officer of Robust.AI, is more cautious in predicting the future of humanoid robots, as he explained during the 2024 RoboBusiness Conference. Brooks highlighted that robots are subject to external forces in the real world and in their interactions with humans, who are very variable in their behavior. Demonstrating success in controlled settings, such as in laboratories, is very different from getting consistent results for the customer, where there is far more uncertainty.

This is where the real challenges arise in robotics. Dave Coleman, chief product officer at PickNik, which develops advanced robotics software applications, said in a similar assessment that the most common reason that robotics companies fail is that they underestimate the complexity of robotics (Ref. 4).

The MPMA Emerging Technology Robotics Committee reviewed these recent developments and the design and manufacturing impact on gears, drives and mechatronic actuation systems for humanoids. We looked at the contextual differences between humanoid and

industrial robotics, the physical (electromechanical) and semantic (software and AI) safety and reliability challenges, attributes to consider for rotary actuator mechanical drive actuation, and finally, what emerging technologies the industry should consider for future humanoid actuator solutions to support large-scale deployment of safe humanoids.

Discussion

Industrial and Humanoid Robots

Industrial robots are automated machines that perform repetitive and, oftentimes, dangerous tasks in factories and warehouses. These tasks may include welding, gluing, inspection, assembly, disassembly, packaging and labeling, palletizing, and material handling.

These industrial robots are large, heavy machines that are often placed in fixed and fenced positions within a plant and have a high degree of precision and endurance. Repetitive tasks and controlled environments allow for sensors to communicate data that helps reliably predict operational performance. Some top industrial robotic companies include ABB, Fanuc, Kuka, and Yaskawa. These companies' industrial robots can be found in thousands of facilities worldwide and together they command roughly 75 percent of the market for robotics. Fanuc Corp. develops health usage monitoring and predictive maintenance programs such as Fanuc's ZDT (zero downtime) and FIELD systems. These systems help

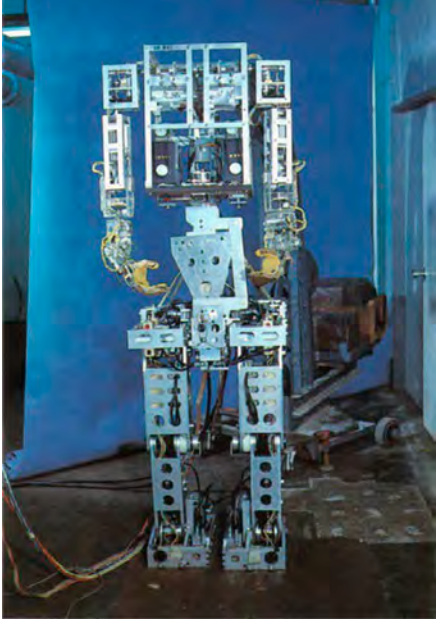


Figure 1—WABOT-1 (1973). (Image: Courtesy of Humanoid Robotics Institute, Wasada University)



Figure 2—Honda P2 (1996). (Image: Courtesy of Humanoid Robotics Institute, Wasada University)

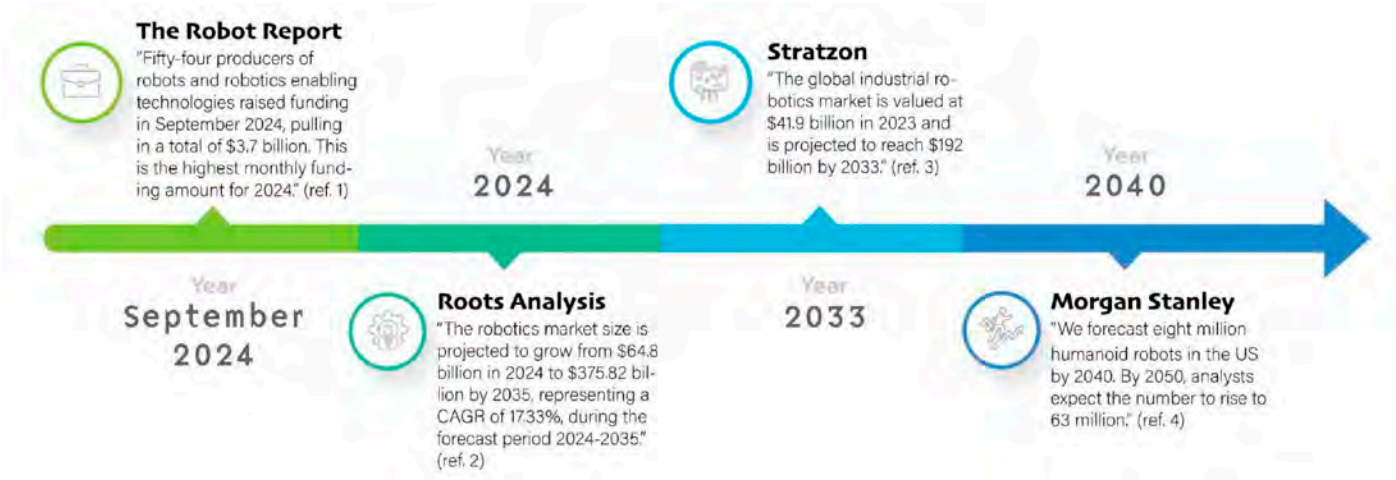


Figure 3—Financial headlines on humanoids.

improve robot performance and safety and eliminate downtime. ZDT connects robots to the Ethernet to create a centralized management system that can check the mechanical condition of robots and provide preventive maintenance diagnosis information.

It is common in industrial robotics to use harmonic drives, also known as a strain wave gear, that utilize an elliptically shaped component called a “wave generator” to deform a flexible spline, allowing for high torque transmission with minimal backlash and precise rotational movement. High gear ratios ranging from 100:1 to 300:1 minimize intrinsic gearbox backlash. The high-speed deterministic trajectory and position control, close to 0.02 mm at high velocity, do not require low mechanical impedance or backdrivability, as discussed in the MPMA Emerging Technology Committee white paper Robotics and Gear Backlash (Ref. 5), published in February 2024.

Humanoid robots are not as clearly defined. Traditionally, they have been defined as robots that have a human-like shape or, according to the Oxford Dictionary, as robots with a human appearance. Our research has demonstrated that a consensus is building to define humanoids more broadly, using the three categories of environment of operations, capabilities and user interface.

- Environments
  - Predetermined with no human interaction (examples: warehouse, deep-sea mining).
  - Hybrid with colocation and minimal interaction (manufacturing assembly line, farming field, package delivery).
  - Dynamic with complete human interaction (home, assisted living residence, school, hospital).
- Capabilities
  - Locomotion (wheeled, legged, tracked) on various terrains.
  - Manipulation with passive and active end-effectors.
  - Communication and interaction with humans through speech, gesture and facial expression.
  - Assisted or autonomous navigation mechanically guided, non-contact guidance, visual and GPS.
- Users

- Trained: engineers, experts, factory operators, healthcare staff.
- Untrained: children, pets, seniors.

Based on the above definitions, humanoids should not be restricted to human likeness or shape but much broader in scope. Because of the many variables that humanoids encounter, considerations for mechanical actuation design, construction, operation and maintenance of humanoids are tenfold greater than industrial robots.

### Mechanical Safety, Reliability and Cost

Humanoids experts assembled at the November 2024 IEEE-RAS International Conference on Humanoid Robots in Nancy, France, recognized that one of the most significant obstacles to full industrialization of humanoids is safety. Safety is crucial in humanoid robots because they are designed to interact closely with humans, meaning any malfunction or unexpected behavior could potentially lead to serious injury, making it essential to implement robust safety features to protect both the user and the surrounding environment when working with humanoids, including collision avoidance, force limitations and clear communication of robot actions to prevent accidents and build trust in human-robot interactions. As Aaron Prather (director, Robotics & Autonomous Systems Programs, ASTM) mentioned, “Considering that hundreds of operation and design standards and requirements already exist, from ANSI, UL, ASTM, IEEE, ISO, OSHA, and U.S. Consumer Product Safety, safety is not only design critical, but also hugely complex to manage.”

Safety considerations for humanoids should encompass not only functional safety (tip-over, breakage, electrocution, fire, hazardous and toxic materials,



Figure 4—Industrial robot.



Figure 5—Dynamic interaction.



Figure 6—Wheeled humanoid.

|                                                |                                    |                                                                        |
|------------------------------------------------|------------------------------------|------------------------------------------------------------------------|
|                                                |                                    |                                                                        |
| MOTION                                         | BEHAVIOR                           | MECHANICAL DESIGN                                                      |
| Predictive safe motion<br>Advanced computation | AI supervision and decision making | Low weight, low inertia, backdrivability, backlash errors, reliability |

Figure 7—Humanoid failure categories.

etc.), but also physical movements. As such, we could consider three categories of failure in humanoids: motion, behavior and mechanical design (see Figure 7). As motion and behavior fall primarily within the semantic safety domain, developments in artificial intelligence supervision, more advanced computational models, and predictive safe motion have provided significant improvement for these two categories. Mechanical design will be our primary focus.

The mechanical design category consists primarily of actuation, including motor, gearbox, reducer, coupling, brake, sensors, wires and connectors, and the following elements shall be optimized for safety:

- Weight reduction to minimize impact on falling, reduce energy requirements, reduce torque and force momentum, and reduce metallurgical component fatigue.
- Lower inertia allows for faster acceleration and deceleration, enabling quicker response times, improved agility, and more precise control. A robot with lower inertia can start, make emergency stops, and change direction more quickly due to its reduced resistance to changes in motion.
- Backdrivability for accurate position control ensures that the robot operates within its defined workspace and avoids collisions or accidents. As such, backdrivability (i.e., a low-impedance system) is essential for mechanical compliance to be driven from the load side, managing contact with humans and undefined objects (Figure 8, Refs. 5 & 6). The backdrivability is characterized by its mechanical impedance consisting of the gearbox inertia, stiffness, and losses due to backlash and friction.
- Backlash error refers to the gear clearance or play between the teeth of gears in a mechanical transmission system (see Figure 9). Excessive backlash can lead to inaccuracies in positioning and reduced repeatability. Backlash can contribute to oscillations and vibrations in the robotic system, especially when the robot changes direction or stops and starts suddenly. These vibrations can affect the overall stability of the system, create wear, and affect the reliability of the drive system. For humanoids, the close interaction between robots and humans requires low forces when there is a deviation from

the position trajectory. Therefore, they require low mechanical impedance, or backdrivability, and a low gear ratio for safety reasons. With a lower gear ratio, the backlash errors become more predominant. Even a small amount of play between gear teeth will result in a larger noticeable movement at the output due to the increased mechanical advantage provided by the low ratio, leading to decreased precision and safety issues.

The second element necessary for successful commercialization of humanoids

is reliability. Brandon DeHart (RoboHub manager and adjunct assistant professor, Faculty of Engineering, University of Waterloo) knows about humanoid reliability. The RoboHub hosts a fleet of more than 70 robots consisting of fixed-base, walking, rolling and flying robots, including a full-size humanoid. The RoboHub is a real-life setting for humanoids. DeHart commented that physical intelligence is one of the greatest challenges and limitations they see every day in their laboratory. Pins

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- ✓ Pitch characteristics
- ✓ Tooth thickness
- ✓ Gear diameters
- ✓ Radial runout
- ✓ Internal spline measurement



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get broken, and motors, bearings and gear trains fail regularly. Lubrication changes over time. The impact that robots encounter in everyday use is much higher than designers anticipated, particularly on hips, knees and elbows. Predicting failures such as tipping over or uncontrolled movement when humanoids interact with the public is also challenging. The unpredictable failure of hardware is a prime consideration for safety reasons, but operational profitability and return on investment must also be taken into consideration.

The third element for successful commercialization is one that is significant for investors and corporations, and that is the cost of humanoids. Robots vary significantly based on their design, materials, type of sensors/navigation system, processing power, and actuators, with prices for commercial robots ranging from \$10,000 to \$100,000, and advanced models for research exceeding \$200,000. Factory automation, where humanoids interact with industrial robots, will likely be the initial application of humanoids since they would be deployed in a pre-determined hybrid environment with trained users. For continuous operations in the current state of the industry, a business is likely to need up to 3:1 robot ratio for each application: one working, one charging, and one undergoing maintenance due to reliability. Adding support technicians, spare parts, maintenance crews, and networking IT systems, the return on investment will be difficult to justify unless the price is closer to the \$2,500–\$10,000 range.

Humanoid Actuator Mechanical Drives

Rotary joints are the most common type in humanoid robots, in ways that replicate the human motion of ankles, knees, hips, shoulders, elbows and wrists. We looked at five types of mechanical drives that have been used and conducted a multi-attribute value assessment. The evaluation below in Table 1 is not absolute and depends on the robot’s task and factors like operational environment, speed and load capacity, required accuracy, and cost target. These would determine the best mechanical drive choice. Further descriptions of each mechanical drive technology can be found in the

February 2024 AGMA Emerging Technology Committee white paper, Robotics and Gear Backlash (Ref. 6).

Emerging Technologies to Support Future Humanoid Actuation Systems

The following five technologies show promise for further development and their combination represents potential for the next generation of humanoid actuation gear technology.

Plastic Gears

Some of the most innovative gears today are machined from advanced engineering plastics. According to Eric Wiita at Victrex, some of the key benefits of plastic gears include reduced weight and lower inertia up to 70 percent, the ability to absorb shock and vibration due to the elasticity of the material, reduced noise, low coefficient of friction, and, in most cases, the ability to self-lubricate. Plastic gears also provide flexibility of design, with the injection molding process maximizing flexibility, enabling complex shapes, intricate geometries, and weight-reduction cavities.

However, as Borut Cerne (co-founder and CEO at RD Motion) highlighted in Material Communication Today (Ref. 9), to ensure the gearbox achieves its required lifespan, plastic gears must be meticulously designed, accounting for all potential failure modes under specified operating conditions.

Reliable gear design hinges on precise, gear-specific data about the material’s wear behavior (wear factors) and fatigue performance (S-N curves), enabling optimal material utilization while minimizing the risk of failure. However, the analytical

description of the thermomechanical behavior of thermoplastic gears while running is very problematic due to the transient nature of the process and the phenomenological behavior of thermoplastic materials. As has been shown in numerous works, these materials exhibit markedly time/rate-dependent, in many

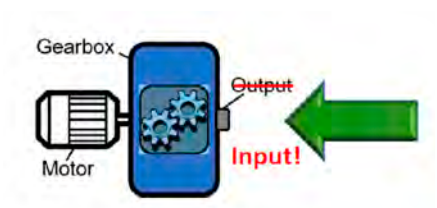


Figure 8—Backdrivability input side.

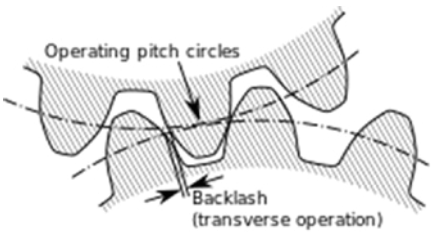


Figure 9—Gear backlash.



Figure 10—Plastic spur gear. (Image: Designatronics SDP/SI)

| Table 1 - Humanoids rotary actuator mechanical drive attributes |            |          |               |                           |         |
|-----------------------------------------------------------------|------------|----------|---------------|---------------------------|---------|
|                                                                 | Planetary  | Harmonic | Belt & pulley | Roller planetary traction | Cycloid |
| Ratio                                                           | Low - high | High     | Low           | Medium - high             | High    |
| Backlash                                                        | Some       | None     | Some          | None                      | Minimal |
| Backdrivability                                                 | Possible   | No       | Yes           | Possible                  | Minimal |
| Weight                                                          | Low-medium | Medium   | Low-medium    | Medium                    | High    |
| Torque density                                                  | Medium     | High     | Low           | Medium                    | High    |
| Reliability                                                     | High       | Medium   | Low           | High                      | High    |
| Efficiency                                                      | High       | Low      | Medium        | Medium                    | Low     |
| Cost                                                            | \$\$       | \$\$\$   | \$            | \$\$                      | \$\$\$  |

Table 1—Humanoid rotary actuator mechanical drive attributes.

cases nonlinear, mechanical behavior, which is also highly dependent on the material's temperature. These characteristics, along with geometric tolerance deviations that are detectable on the gears, can lead to substantial deviations from the expected theoretical gear meshing kinematics. These deviations can result in increased contact loads, in terms of leading to higher generated frictional heat and accelerated failure of these components. Considering many advantages of plastic gears for humanoid actuation systems, it remains of paramount importance to study in detail the nonlinear, temperature-dependent properties of the thermoplastics used for gear applications, as well as the effects that these properties have on the gear meshing process and resulting frictional heat.

### Nanocomposite Coating

Nanocomposite coating technology is a process that involves applying a thin layer of material to a surface to improve its properties or give it new functionality. The layer is typically 3 to 5 nanometers thick, about 30 times smaller than a human hair (see Figure 11). Nanocomposite coatings can be applied through Physical Vapor Deposition (PVD), Plasma Enhanced Chemical Vapor Deposition (PECVD), or hybrid form (PVD + PECVD). A scanning electron microscope (SEM) micrograph of nanocomposite coating layers is shown in Figure 12. Currently, nanocomposite coating can be used on engineered alloy gears such as alloy steel, stainless steel, aluminum, bronze, powdered metals and tungsten carbide ceramics. On metallic engineered alloy gears, Aaron Byrum of United Protective Technologies (UPT), mentioned that a nanocomposite coating, when applied to a gear made from traditional materials, can provide multiple improvements, like reduced friction, which leads to reduced heat generation, minimized wear, lower lubrication dependency, and increased efficiency of the power transmission system. Additionally, a nanocomposite coating may also increase allowable contact stress as presented by Peter Schmidt at the recent 2024 AGMA Fall Technical Meeting (Ref. 10). All these improved characteristics can result in a more reliable and predictable mechanical system.

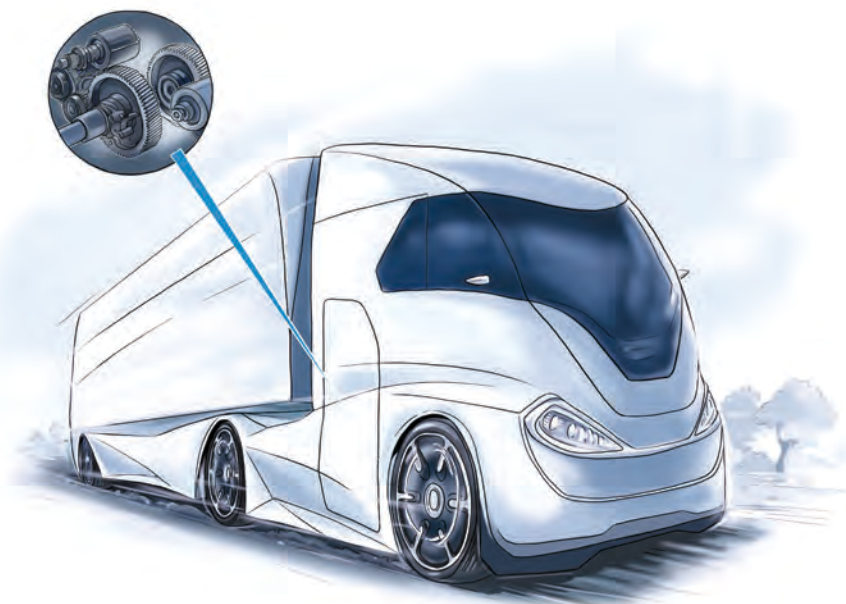
### Integrated Actuation System With Low Gear Ratio Planetary

Actuators for humanoids must integrate many elements as shown in Figure 13 below. With humanoid design focusing on very compact packaging and cost, traditional separate subsystem designs can be expensive and difficult to manage. Having integrated solutions allows maximum cost efficiency and compactness. The additional output encoder allows compensation for gear backlash that may result in a different load posi-

tion on the output side, causing delays and oscillations at the start or stop of the movement. New solutions are emerging from MyActuation (Figure 14) and Synapicon with integrated actuators that offer planetary gearmotors with high power/current density, compact form factor, integrated high-resolution encoders, integrated brake systems, highly optimized mechanics and thermals, and more. The integrated planetary gears allow for low gear ratio and focus on cost efficiency while still delivering necessary

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performance in this space. For humanoids, where there is a need to actuate multiple axes, integrated design of motor and reducer on one level with sensors and controllers offers the possibility for low weight, compact actuation with cost suitable for large-scale industrialization.

### Affordable Mechanical Joint

Mass market appeal demands functional yet affordable solutions for robotics. This involves prioritizing key functionalities over desirable attributes with respect to cost. The alternative to pursuing complex over-engineered outcomes is simple solutions that achieve functional requirements that are more likely to be compact and cost-effective.

Take, for example, a humanoid robot knee joint. The archetypal implementation would maximize torque with potentially large and heavy actuation. However, careful consideration of a passively inspired walking gait would identify that the shank, which can be lightweight, merely needs to swing at the knee. This prevents foot scuffing during walking. Shanks can support upper body mass if knee joints are lockable. Impetus for forward motion could be provided by powered ankles, or by dynamically moving the robot's center of gravity forward.

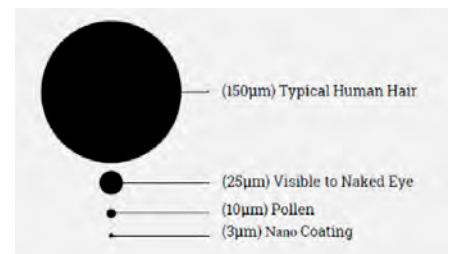
One solution proposed by Cheng-Yueh Liu et al. (Ref. 8) revolves around a compact planetary gearbox, which doubles as a clutch (Figure 15). A pair of small, low-power DC motors rotate a compound sun gear as part of a speed reduction transmission. The central sun gear is free to translate vertically by a lateral displacement marginally greater than the gear tooth depth. This facilitates compound sun gear decoupling from the output gear set. Such functionality is permitted by contra-rotating the two planet motors in opposite directions. Retaining the sun gear axle in the up or down position enables transmission disengagement or engagement, respectively. An independent solenoid can lock the knee joint when required. All necessary modes of operation for a basic knee joint are achieved by simplifying requirements to achieve balanced outcomes. Redefining research-oriented robotics with this mindset offers endless possibilities to realize commercially viable humanoids.

### Nanocomposite Coating and Plastic Gears

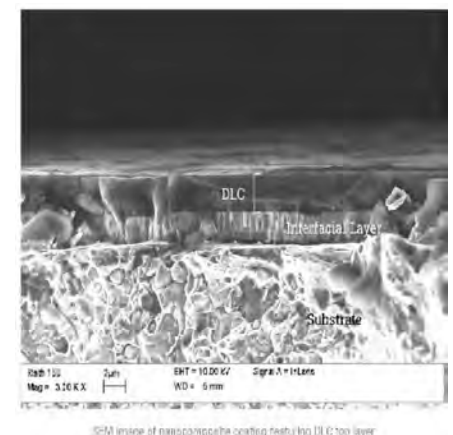
As we discussed above, the benefits of plastic gears are limited by the transient nature of the thermomechanical behavior and strength of polymers. Could plastic gears be nanocomposite-coated to create lightweight, complex, and thermally stable gears? If so, humanoids actuation systems, typically reserved for metal gears, could be designed with nanocomposite-coated plastic gears and provide the desired affordability, strength, reliability, and weight reduction.

We asked Mike Greenwald, vice president of engineering at UPT, if PEEK (polyetheretherketone) thermoplastic, which is often considered a suitable replacement for metal gears for its strength and high temperature capabilities, could benefit from a nanocomposite coating. Greenwald is cautiously optimistic about this prospect but warned the concept needs further investigation for the following reasons:

- Stress-strain compatibility of polymer and coating material under tensile and shear stresses.



**Figure 11—Relative size comparison of nanocoating.** (Image: United Protective Technologies)



**Figure 12—SEM micrograph of nanocomposite coating layers.** (Image: United Protective Technologies)

- **Deposition temperatures**—Nanocomposite coatings have been deposited at elevated temperatures for engineered alloys. Polymer gear coating deposition below the glass transition temperature would be required for polymers.
- **Surface-finish**—Due to the scale of nanocomposite coatings, these coatings are highly conformal to the texture of the substrate surface. Therefore, the surface finish of the polymer gear contact areas before coating should be in the range of 4–26 Ra  $\mu\text{m}$ , which would require hobbing, milling, shaping, broaching, skiving and grinding processes typically done with metallic gears.
- **Outgassing**—Because nanocomposite coatings are deposited under vacuum, outgassing from the polymer must be considered. Outgassing during deposition may adversely affect the adhesion of the coating and contaminate the vacuum chamber.

## Conclusion

We have seen that humanoids have been around for many years, but recent progress in control algorithms, sensing technologies and AI has created a lot of excitement for investment in the commercialization of humanoids. The reality is that safety, reliability, and cost for electromechanical actuation still represent a significant challenge that limits

the near-future commercial deployment of humanoids. When a humanoid robot stumbles, there are risks for humans, as these machines can be heavy. Furthermore, stumbles can damage the robot, leading to costly repairs, downtime, and even compromised functionality.

The MPMA Emerging Technology Robotics committee supports investment in emerging technologies and collaboration for the development of actuation systems that will reduce weight, gear drives with backdrivability and low backlash, integrated motor-controller-gear-sensors, and lower-cost solutions. Building trust in humanoid robots starts with addressing the concerns and issues outlined in this paper. By combining cutting-edge technological innovation with thoughtful safety and reliable design on actuation mechanical drives, we are not just improving gear performance; we are shaping the future of humanoids.

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## References

1. The Robot Report, WTHW Media LLC, November 1, 2024, Dan Kara.
2. Roots Analysis, Robotics Market Report, 2024.
3. Stratzon Global Robotics Report, December 2024.
4. Morgan Stanley, Technology That Could Define the Decade, November 13, 2024.
5. Top Reasons Robotic Companies Fail, Dave Coleman, RoboBusiness October 2024.
6. AGMA Emerging Technology Committees—Robotics and Gear Backlash, Jacques Lemire (February 2024).
7. High-ratio planetary gearboxes for the next robot generation AGMA-2022 Fall Technical Meeting (FTM) Dr. Ir. Pablo López García.
8. On the Development of a Multi-Modal, Selectively Lockable, Compact, Affordable Knee Joint Assembly for Bipedal Robots, Cheng-Yueh Liu et al. IEEE-RAS Humanoids November 2024.
9. Influence of temperature- and strain-rate-dependent viscoplastic properties of polyoxymethylene on the thermomechanical response of a steel polyoxymethylene spur gear pair, B. Černe et al., Faculty of Mechanical Engineering, University of Ljubljana, Slovenia, Materials Today Communications, May 2020.
10. Nanocomposite Coatings for Gears, AGMA Technical Paper 24FTM20, Peter L. Schmidt et al. United Protective Technologies.

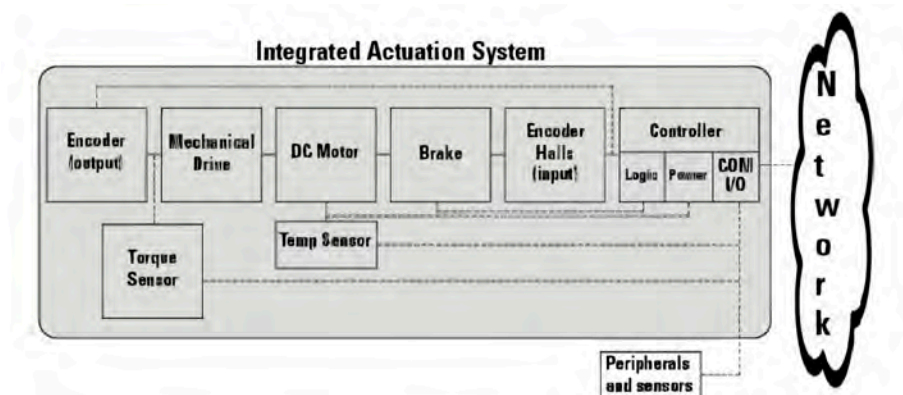


Figure 13—Schematic of integrated actuation system. (Image: Designatronics SDP/SI)



Figure 14—Dual encoder integrated planetary actuator. (Image: MyActuation Ding's Motion USA)

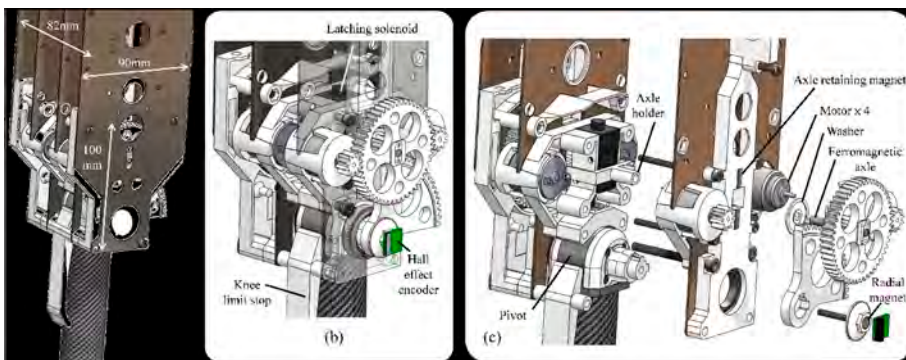
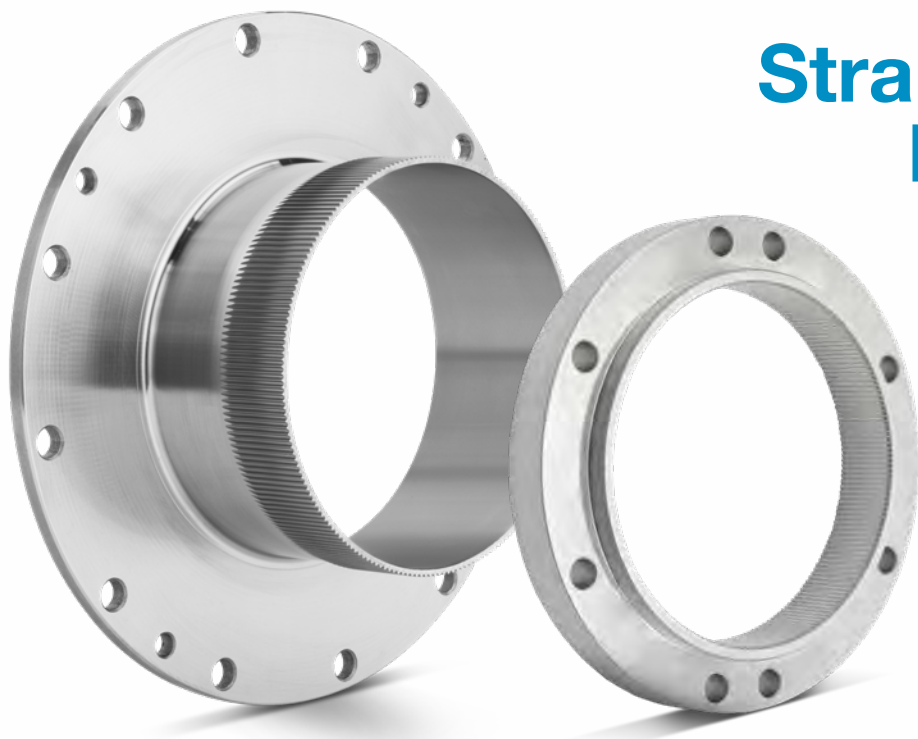


Figure 15—Mechanical knee actuator. (Image: University of Auckland)



*Strain wave gearbox with internal and external gears, both cut on 80PS.  
(All Images: Gleason Corp.)*

# Strain Wave Gear Production in the Age of Humanoid Robots

**Humanoid robots need precise strain wave gears in their joints, and building and inspecting those gears at scale will call for equally advanced production technology**

Dr. Stefan Beermann, Managing Director, KISSsoft AG; Gottfried Klein, Director of Product Management, Soft Machining Solutions, Gleason Corp.; Dr. Markus Kroemer, Director Technology and Software, Gleason Switzerland AG; Klaus Deininger, International Sales Manager, Gleason Metrology Systems

“The time has come for robots,” Nvidia CEO Jensen Huang proclaimed at his company’s annual GPU Technology Conference in March 2026. “Everyone, pay attention. This could very well be the largest industry of all.”

What was once considered pure science fiction is rapidly becoming reality: thousands, perhaps even millions, of humanoid robots could soon be working alongside—or in place of—their human counterparts. They are expected to play a role across a wide range of environments, from hotels and hospitals to factories and warehouses, as well as in homes, offices, and the defense industry.

Early “droids” were clumsy and relatively unintelligent, but they are evolving rapidly thanks to advances in artificial intelligence and engineering. These innovations are enabling robots to become increasingly capable, with more sophisticated functionality, greater dexterity, and an ever more human-like appearance.

While the humanoid “brain” has come a long way and gets much of the attention, it’s the “body” that most concerns the gear manufacturer—particularly the shoulder, arm, wrist, knee and ankle joints that must somehow replicate the amazing flexibility and dexterity of the human body. These joints must be small, efficient and lightweight—yet also able to bear the brunt of the repeated motion and impact that plays havoc with the human body—over time. Manufacturers have several different rotary and linear joint

actuation options to consider but, increasingly, strain wave gears like Harmonic gear drives have been found to outperform other solutions. Strain wave gear-based actuators offer very high reduction ratios that cannot be matched by traditional geared actuators in such a compact, lightweight package. Furthermore, the design offers the added benefits of zero backlash, high torque, accuracy and reliability. Ultimately, these characteristics deliver the stability required for robot joints performing complex, human-like movements.

The world’s leading robotics manufacturers have been quick to recognize the benefits of strain wave gears and are now gearing up to meet demand. Naturally, strain wave gears for these applications vary in size and complexity. In general, they consist of three main components: a wave generator that delivers shaft input by fitting into a flex spline; a flex spline with external gearing; and a circular spline with internal gearing that meshes with the flex spline. This may sound simple, but their unique operating characteristics, compact size, and the need for exceptional positional accuracy, repeatability and reliability over thousands of duty cycles are a production challenge not to be underestimated.



## Case in Point

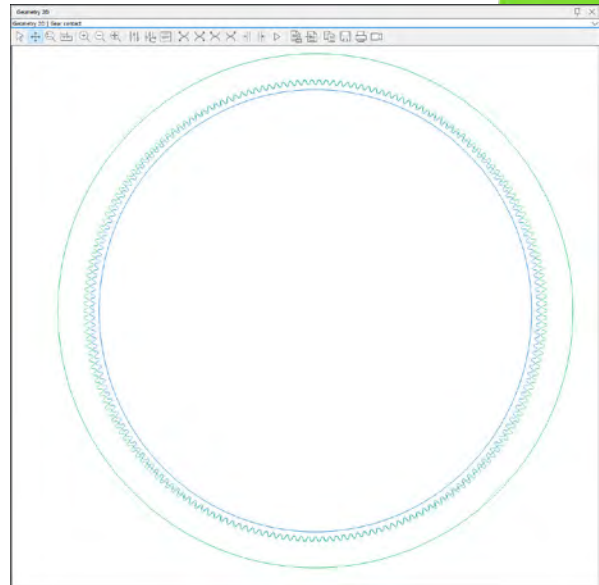
Production of a strain wave circular spline internal gear with 320 teeth. In the case of this small-module internal gear (about module 0.25 mm) with a high number of teeth, power skiving proves to be the perfect solution to achieve significant improvements in productivity and quality. For this application, Gleason provides a solid-carbide tool with AlCroNite Pro coating. The tool features standard quality, 163 teeth, designed for a 10-degree cross-axis angle. The power skiving application results in a total cycle time of just 0.7 min, performed in four cuts with automatic workpiece change. Gear quality is exceptional as well, achieving IT5 acc ISO 1328, with most criteria even better in the range of IT2.

The hobbing operation is required to produce the flex spline with external gear teeth. In this case, Gleason provides a carbide shaft-type hob in AAA quality with AlCroNite Pro coating to deliver high durability, toughness, and resistance to wear and tear. Both hobbing and power skiving allow flexible lead line modifications for optimized assembly and load bearing of the gear set, as well as the use of topping tools for excellent profiles.





*Many joints in humanoid robots (depending on the specific model) are powered by strain wave gears.*



**Example of a strain wave gear set in KISSsoft.**

## First, Start With the Design

Strain wave gears have some specific requirements that need to be considered during the design process. Compared with a conventional gear pair consisting of an internal ring gear and a pinion, a strain wave gear has a significantly higher number of teeth in contact. This is one of the major advantages of the concept: the load is distributed across many teeth, allowing smaller modules to be used.

However, this advantage comes at a price. The gear designer must pay particular attention to potential tooth interference outside the intended contact zone. In *KISSsoft*, Gleason's gear design software, a graphical representation of the gear set makes it easy to identify and evaluate potential interference during the design phase.

A second important consideration is the assessment of gear strength. Although the formulas specified in ISO 6336 can be applied, some adjustment of the input parameters is required. In particular,  $K_{Ha}$ , the factor, which accounts for the load distribution between the teeth, needs to be adapted appropriately.

Strain wave gears also operate with a very high sliding component in the tooth contact. This can best be accounted for by increasing the required contact safety factor.

## Manufacture: Single Platform, Multiple Processes

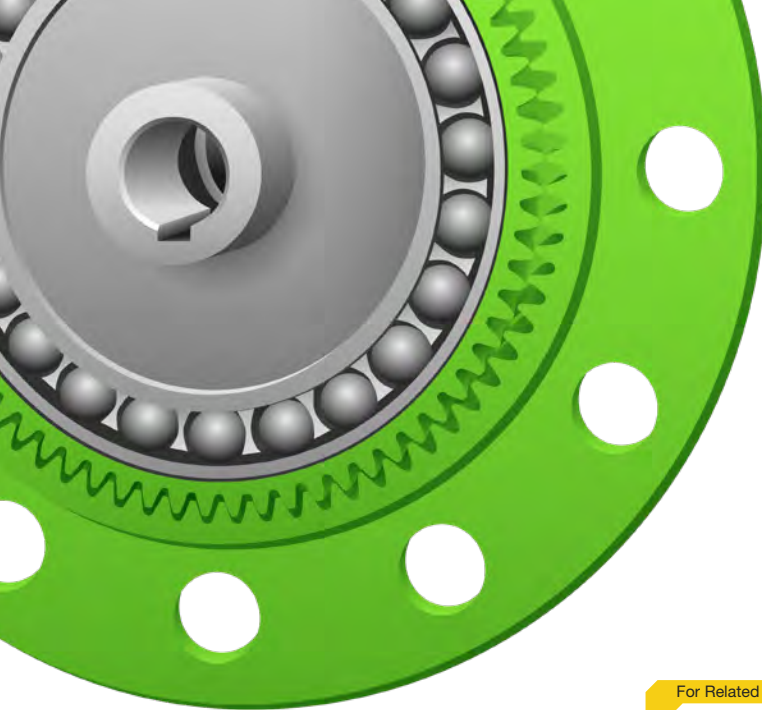
The Gleason 80PS power skiving machine is tailor-made for production requirements of both internal and external strain

wave gears. While many robotics manufacturers have already ordered the machine, many more are on the way. It's the closest thing yet to a universal gear production machine and it's not just for power skiving—the 80PS also serves as an excellent platform for hobbing, and in fact features technology used by Gleason on horizontal gear manufacturing machines in over 1,000 installations worldwide.

As a power skiving machine, the 80PS is ideal for the economical production of internal gears such as the circular spline of a strain wave gear, and gears with interfering contours that can't easily be hobbled, up to module 1.5 mm. The Gleason 80PS's horizontal axis and tailstock also make the machine highly suitable for shaft-type parts. And in the case of external gears with small overrun space, power skiving may even outperform hobbing, since hobs with very small diameters may not be applied efficiently.

In addition, Gleason offers comprehensive power skiving technology and simulation software that makes it easy to simulate the entire cutting process and determine the most effective process strategy. The software can analyze the influence of different cutting tool geometries and process parameters on chip formation, gear quality, collision situation, cycle time and tool cost. The design of power skiving tools is always based on simulation and technology requirements. Ultimately, it makes the implementation and application of power skiving as simple and familiar as other, simpler gear manufacturing processes.

For those external gears that allow for the higher productivity of hobbing, such as the flex spline referenced earlier, the 80PS can be quickly and easily changed over in just minutes from its power skiving configuration into a powerful hobbing machine: The power skiving cutter is replaced by a hob; for the added stiffness required when hobbing, counter bearings are manually installed; and workpiece clamping is changed depending on the application.



*Power skiving of robotic strain wave internal ring gears for robotic gearboxes with carbide cutter.*

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The use of the same Gleason GEMS HMI to operate both processes makes it fast and seamless for the operator to change over from one to the other. Ultimately, performing both processes on the same machine will, in almost every case, result in faster, more economical production and better control. Strain wave gears are typically not heat treated; therefore, the cutting process determines the final quality and the 80PS has proven to fulfill or overachieve those requirements. If deburring operations are necessary, the 80PS can fulfil this requirement as well. Deburring, turning and brushing can be integrated into the machine and eliminate further operations and additional clamping of these fragile parts.

For medium and high-volume production, several options for automating the machine are available. Internal loading takes place with a gantry, while conveyor or basketized systems can be used for parts storage before and after machining, thus elevating the machine to fully automated production cells.

## Closing the Loop on Quality

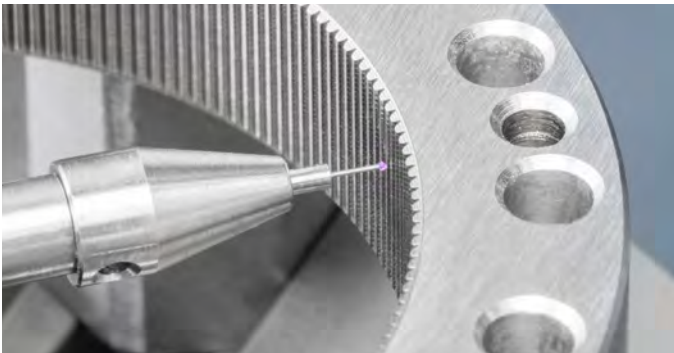
Strain wave gears place particularly demanding requirements on gear metrology. In addition to their small module design, which is essential to the functionality of the gearbox, they require the highest levels of measurement, quality and reliability. For small gears, Gleason offers the 175GMS nano metrology system, equipped with a probe head specifically suited to these demanding applications. Even seemingly minor factors, such as a different probe reset position after measurement, can make the measurement challenging. The probe may fail to find its way reliably into the tooth gap, potentially resulting in a cancelled measurement—or, more critically, unreliable measurement results.



*80PS is a power skiving and hobbing solution for robotic gears.*



*Hobbing of external strain wave gears in robotic gearboxes on 80PS with carbide hob.*



*Measurement of an internal strain wave ring gear on a humanoid robot.*



*Inspection of external strain wave gear on the 175GMS nano Gear Metrology System.*

To address these challenges, the *GAMA* software integrated into the 175GMS nano includes dedicated measurement cycles for small-module gears. For example, these cycles help prevent the probe from becoming caught on burrs at such small dimensions, which could otherwise result in damage to the probe tip. The flex spline workpiece itself also presents measurement challenges. Its thin walls can cause the workpiece to deform after unclamping once gear cutting has been completed. While this deformation is completely acceptable in the final application—indeed, deformation of the cup is fundamental to the functionality of a strain wave gear—it must be taken into account during measurement. To overcome this issue, Gleason provides special mandrels for securely clamping the workpiece during measurement. This compensates for the deformation that occurs after unclamping and enables a reliable measurement process for the qualitative classification of the gearing.

The tooth profile can present another challenge, particularly where high tip reliefs are required on flex spline gears. These profiles can be evaluated using a standard involute profile measurement cycle according to DIN, ISO, AGMA and other applicable standards. Alternatively, scanning measurements can be performed using theoretical profile data supplied in a data file and uploaded directly to the 175GMS nano control. A theoretical-versus-actual comparison can then be carried out easily. Maximum profile deviation points are automatically identified, and a tolerance field can be defined in both directions to highlight excessive or insufficient material. This provides the operator with a clear and intuitive assessment of the quality of the flex spline gearing.

Naturally, conventional measurements such as pitch and runout are also supported. In addition, noise analysis can be performed using Gleason's Advanced Waviness Analysis software. The 175GMS nano is supplied with a wide range of styli, including special small probe sphere diameters for small-module applications, as well as a proprietary probe calibration library. The system also provides 3D measurement and analysis capabilities that are typically associated with a CMM.

Finally, the complete measurement process can be integrated seamlessly into Gleason's Closed Loop concept to support optimization of the production process. By networking the 80PS directly with a Gleason 175GMS nano Gear Metrology System, sub-micron-level measurements and the resulting corrective actions can be performed quickly, accurately and automatically.

[gleason.com](http://gleason.com)  
[kissofft.com](http://kissofft.com)



*175GMS nano is ideally suited to meet the highest inspection and analysis requirements for small, fine-pitch gears.*



# The Robotics Committee Update

Mary Ellen Doran, VP, Emerging Technology

Last year, the MPMA Robotics Committee debuted “The Near Future of Mechanical Drive for Humanoid Robots,” a white paper that cut through the 2024 headlines to ask a narrower, harder question: even if the investment and AI breakthroughs are real, can the mechanical drive side of humanoids (the motors, gearboxes and actuators) actually get safe, reliable and cheap enough to support commercial deployment at scale? The paper’s answer was candidly cautious. It walked through five rotary drive technologies (planetary, harmonic, belt and pulley, roller planetary traction and cycloid) on a shared set of attributes and made the case that no single option wins across the board; the right choice depends on the application. It also named the three barriers that still stand between humanoids and the factory floor: mechanical safety, reliability and cost, with return on investment difficult to justify until unit prices fall well below where they were, and still sit today.

We have chosen to republish the paper in this issue (Page 24) because that framing hasn’t aged. If anything, the time since has sharpened it. Here’s

what the committee has heard, seen and debated since.

One of the more sobering conversations came from Ruben Scriven of Interact Analysis, who joined one of our webinars to temper some of the enthusiasm the white paper itself had to work around. Scriven pointed out that insurers remain reluctant to cover humanoid robots given the lack of technical standards and an immature regulatory environment, and that, at the time, only about 27 percent of manufacturing roles in the United States were even technically feasible candidates for humanoid replacement. His firm’s own forecast (tens of thousands of humanoid units sold per year by 2032, generating more than \$2 billion in revenue) is real, but it’s a multiyear curve, not an overnight one. That framing has stuck with the committee: the mechanical drive challenges laid out in the white paper aren’t urgent because humanoids are already here at scale. They’re urgent because the industry has a runway to get the engineering right before they are.

On the engineering side, there’s better news. The white paper closed by

flagging five emerging technologies worth watching, from plastic gears to nanocomposite coatings, as the pathway to lighter, cheaper, more reliable actuation. Since then, the committee has hosted four separate presentations on new gearbox innovations aimed at robotics, and two of those concepts have already moved into production, a sign that at least some of what the paper described as promising is now leaving the lab. We also held a joint session with the MPMA Electric Vehicle Committee to look at the Hoop Drive, a new gearing concept with implications well beyond either sector.

The committee’s momentum carries into this fall as we celebrate the addition of a second track in the MPMA Fall Technical Meeting. This track was specifically created to showcase emerging technologies, innovative solutions and real-world applications—several of which have been previously discussed in our emerging technology meetings. And we are already preparing for a strong 2027.

The webinar replay of “The Near Future of Mechanical Drive for Humanoid Robots” remains free on the MPMA website. A year on, the paper’s questions are sharper, not softer, and the committee would welcome your voice in answering them. Reach out any time, or better yet, join us for a meeting.

Send your thoughts to [doran@motion-power.org](mailto:doran@motion-power.org).

*Thanks again to Jacques Lemire, principal at PBD Consulting, who led the efforts in producing the white paper last year.*



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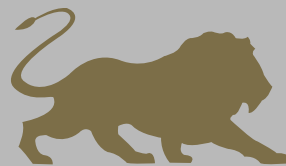
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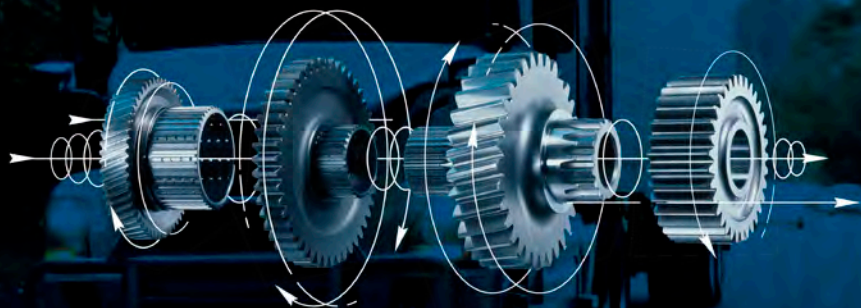
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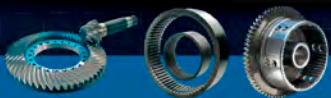
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# Crystal Ball

Todd Praneis, Vice President,  
MPMA Technical Division

As I write this, it is before the 2026 Fall Technical Meeting being held October 5–7, 2026, in Rosemont, IL. But as you read this, the event has already happened, so I must look deeply into my crystal ball to read the reflections and predict how great the event was. If I can see the images clearly, we all had a great time hearing from all of our presenters, relishing the many networking opportunities, figuring out “whodunnit” in our murder mystery dinner, and enjoying our new second track presentations. For now, I want to highlight a very important part of our program: the awards presentations.

The Motion + Power Manufacturers Alliance (MPMA) presented numerous awards during the 2026 Fall Technical Meeting (FTM). The event took place on the first day of the FTM, which was co-located with the Society of Tribologists and Lubrication Engineers (STLE). Awards were presented to MPMA technical committee members who have published a document within the last year, ISO delegates representing the United States on working groups, and a very special posthumous award.

The members of the AGMA 948 Working Group were awarded for publishing AGMA 948-A26, Electrified Vehicle Drivetrains. The following working group members were given awards:

- Anu Anisetti, Eaton Corporation
- Michael Tekletsion Berhan, Ford Motor Company
- Matthew Bollman, Charter Steel
- Jeffrey Daniels, Twin Disc, Incorporated
- Jacob Dickie, Ontario Drive & Gear
- Brett Dionne, RENK America
- Bill Hanks, Thyssenkrupp Polysius North America Inc.
- Vanyo Kirov, Caterpillar Inc
- Michael McKernin, McKernin Consulting
- Jitesh Modi, Schaeffler Group USA Inc.

- John O’Neil, Star Cutter Company
- Calogero Principato, KISSsoft AG
- Andy Raycraft, JTEKT North America
- Ernie Reiter, Web Gear Services Ltd.
- Brian Rhode, Afton Chemical Corporation
- Patrick Ridgley, The Boeing Company
- J. Kirk Storey, Alchemetric Engineering LLC
- David Talbot, Ohio State University, Department of Mechanical Engineering
- Antoine Tuerich, Gleason Pfauter Maschinenfabrik GmbH
- Dairene Uy, Shell Global Solutions (US) Inc.
- Walt Weber, Flender Corporation
- Allen Williston, A&J Engineering
- Carlos Wink, Eaton Mobility
- Hai Xu, General Motors Company
- Shuo Zhang, Allison Transmission

MPMA also recognized our new volunteer ISO delegates who represent the U.S. position on ISO standards development projects in both the bearing and gearing committees.

- Hani Almoghrabi, NORD Gear Corporation
- Chris Bartus, Dodge Industrial
- Nikhil Londhe, The Timken Company
- Doug Martin, SKF Americas and Pacific
- Keith Meyers, SKF Americas and Pacific
- James Voisine, RBC Bearings
- Scott Warren, The Timken Company

Our special award, the MPMA Hall of Fame, was given to the late Robert Errichello’s wife, Jane, in recognition of Bob’s many years of standards contributions, education, publications, and consulting in the bearing and gear industries. One of Bob’s last acts was to donate his entire library of books, research and documents to MPMA. Thanks to the MPMA Foundation and with Jane’s assistance, we are working on making that library available to our members. We even had a table at the FTM with some of Bob’s general engineering books available for free to help spread his work throughout the industry.

My crystal ball rarely gets it right. This time, I hope it did!



# Efficient Machine Learning Optimization of Gear Microgeometry and Comparison With Manually Designed Gears

Dr. Andrew Wild, Simon Terry, Dr. Paul Langlois, Jaekwon Lee, Shinya Sudo

The automotive industry is experiencing a paradigm shift in its move away from internal combustion engines (ICE) toward electric vehicles (EVs). The high speeds of electric motors, combined with a lack of ICE masking noise, demand that powertrains be optimized for noise, vibration and harshness (NVH) to prevent undesirable phenomena such as gear whine, a high-frequency tonal noise generated between two meshed gears. Alongside ever-increasing demands on vehicle performance and the need to minimize cost and development time, gear whine must be considered alongside a multitude of other factors, including gearbox performance, efficiency and durability.

Whilst there exists a variety of techniques an engineer could use to improve gear whine, one particularly effective method is to reduce the transmission error (TE) excitation, i.e., the variation in relative displacement between two meshed gears as they rotate. Optimizing an excitation source such as TE has the benefit of improving NVH over a range of operating conditions and can be quantified independently of the downstream dynamics of the system through a resource-efficient static loaded tooth contact analysis (LTCA). Often the most effective way to reduce TE is by varying the microgeometric relief applied to the loaded flanks of gear teeth (Ref. 1).

Optimizing gear microgeometry can provide an effective route to reduce TE whilst minimizing redesigning the wider gearbox; however, its optimization can be difficult to automate. The microgeometry of a gear tooth is a two-dimensional surface typically defined through a set of scalar parameters encoding a variety of linear and quadratic modifications along the lead and profile directions. The relationship between these microgeometry parameters and LTCA results, such as TE, is not necessarily convex, meaning that whilst gradient descent (Ref. 2) or derivative-free simplex methods such as Nelder-Mead (Ref. 3) are effective, they can get stuck in local optima. Another approach to select gear geometry uses search strategies such as Design of Experiments (Refs. 4–6); however, these methods become infeasible for high-dimensional optimization problems.

In the literature, gear microgeometry optimization is at times considered alongside gear macrogeometry optimization (specifying tooth numbers, helix angle, etc.) subject to other metrics such as gear ratios or durability considerations. The nonlinear and high-dimensional nature of gear optimization has led to the wide adoption of evolutionary and pattern-based algorithms for gear optimization. Evolutionary strategies such as the genetic algorithm (Refs. 7–16) or particle swarm

(Refs. 17–19) are underpinned by natural phenomena such as genetic mutations and swarm intelligence to identify a Pareto optimal set of solutions (often optimizing several metrics of gear NVH, durability and efficiency). For example, Bonori et al. (Ref. 8) varied tip and root relief of two meshed spur gears using a genetic algorithm, achieving up to an 85 percent reduction in peak-to-peak TE as calculated via a static nonlinear finite element method calculation. Alternatives to metaheuristic algorithms include the pattern-based Dividing Rectangles method, which was successfully employed by Artoni et al. in the optimization of face-hobbed hypoid (Ref. 20) and cylindrical (Ref. 21) gears to minimize TE subject to contact patch considerations.

Whilst metaheuristic and pattern-based algorithms offer a reliable tool for optimizing nonlinear functions with many local minima, the run time of these algorithms can be prohibitive. To ensure that these algorithms converge often requires more than 104 function evaluations, making them time-consuming for high-fidelity analyses with individual runtime on the order of seconds. Furthermore, microgeometry optimization can be considered as a suboptimization routine that falls within (or alongside) macrogeometry and wider gearbox optimization. This has inspired efforts to reduce the computational complexity of metaheuristics; e.g., Qiu et al. (Ref. 22) optimized the microgeometry of a herringbone gear to minimize TE, meshing impact excitation, and vibration acceleration using a more efficient fitness-predicted genetic algorithm. This algorithm limits computational complexity by only running analyses in previously unseen areas of the optimization space, which in this case resulted in a modest 67 percent reduction in runtime when compared to a standard genetic algorithm.

The need for increasingly efficient microgeometry selection has led to a recent trend in the gear optimization literature: the use of machine-learned models as computationally efficient surrogates or emulators for expensive finite element analyses, thus enabling otherwise costly optimization techniques. Some examples of surrogate models within gear optimization literature include polynomial functions (Refs. 23, 24), neural networks (Refs. 25, 26), Gaussian processes conditioned on past analysis results (Ref. 27), and many others (Refs. 28–30). For example, Korta & Mundo (Ref. 28) trained a variety of surrogate models to predict TE, contact stress, and bending safety factors for spur gears with varying tooth profile modifications using a dataset of 38 finite element analyses. These

computationally efficient surrogates were then used to identify optimal spur gear profile modifications using a genetic algorithm with up to 50,000 surrogate function evaluations. In another example, Tang et al. (Ref. 25) used 200 past analysis results to train a neural network that emulated NVH results and used it to optimize six gear parameters with a genetic algorithm. Lastly, Heafner et al. (Ref. 26) used a neural network to efficiently predict tooth root stress and thus the life of microgears; a typically lengthy analysis requiring finite element techniques to capture large deflection effects.

Whilst machine-learned surrogate models permit the use of otherwise costly search algorithms, ensuring model accuracy and selecting appropriate optimization techniques for gear microgeometry optimization requires both machine learning (ML) and engineering domain knowledge. For this reason, we explore the utility of optimization guided by ML surrogate models for microgeometry optimization. Directed by user-defined LTCA targets and constraints, the optimization technique uses surrogate models to efficiently explore the whole problem space, only performing analyses for microgeometries that are either likely to improve on previous results or explore a previously unseen region of the problem space. The optimization technique can be used to identify microgeometries for cylindrical gearsets with multiple meshes, including planetaries, conducting bespoke workflows minimizing a target function and any number of constraints spanning multiple operating conditions.

To demonstrate the ML microgeometry optimization technique, the authors recreate a past optimization study. The focus of this paper will be the optimization of a gear set in which an idler gear is driven by two input gears; the gear set will be optimized for NVH and durability across both meshes using Advanced-LTCA, a hybrid Hertzian and FE-based loaded tooth contact analysis (Ref. 31). In the section “Optimization of a Gear Set,” the ML optimization technique is used to validate and improve upon the manually optimized microgeometry, demonstrating that it is possible to identify similar optimized microgeometries to an engineer within a drastically reduced timeframe. Moving beyond the original optimization scope, in the section “Optimization with Common Input Gears,” we perform the same optimization whilst ensuring the same microgeometry is applied to the two input gears, revealing what performance can be achieved with reduced manufacturing costs. Lastly, in the section “Optimization for Torque Robustness,” we explore how we can optimize over different operating conditions to obtain a torque-robust microgeometry. It is emphasized that the variety of optimizations undertaken in this paper are made possible by the highly efficient nature of the microgeometry optimization technique. Whilst traditional optimization requires manual input from an engineer, the ML microgeometry optimization technique runs in approximately 30 minutes and frees up an engineer’s time, allowing them to focus on what performance metrics they want from a microgeometry rather than how to find it. The presented method is implemented in SMT’s *MASTA* software.

## Optimization of a Gear Set

To compare the ML microgeometry optimization technique to an engineer, we begin by recreating the optimization scope used within the original manual process. Each of the three gears (idler and the two input gears) can have distinct microgeometries with their own lead slope, lead crowning, profile slope, profile barreling and tip relief. The idler gear meshes with the two input gears labelled left (L) and right (R), with the optimization targeting improved NVH and durability across both meshes under 90 Nm of torque. The optimization of gear microgeometry at a single torque is chosen to match the scope and allow comparison with the original manual optimization; consideration of multiple operating conditions will be explored in later sections.

## Optimization Setup

One common task within microgeometry optimization is the mitigation of misalignment, in which imperfect shaft and gear alignment leads to uneven contact across the tooth’s face width (lead direction). Considering that the misalignment will be different across the two gear meshes, we choose to independently optimize the lead slope at each mesh, allowing the optimization technique to effectively reduce misalignment. The lead slope on a given mesh depends linearly on the lead slope of the two meshed gears; as the idler meshes with both input gears, its lead slope can be fixed without limiting the scope of the optimization technique. To independently reduce stress concentrations at the tips of all gears, tip relief is allowed to take different values on each gear. All remaining microgeometry parameters, e.g., lead crowning, profile slope and profile barreling, are only varied on the idler to reduce the dimensionality of the problem space (see Table 1).

In this initial optimization, we optimize the gear set for a single torque, targeting improved NVH whilst ensuring durability by retaining good stress distributions across the faces of the gear teeth. Whilst the primary goal of the optimization is the reduction of the first harmonic of TE at each mesh, it is important that the first harmonic not be optimized at the expense of higher harmonics. For this reason, the weighted harmonic sum of transmission error (WHSTE) will be minimized across both meshes:

$$\text{WHSTE}_m = \sum_{n=1}^{10} n \delta_m^{(n)}, \quad (1)$$

where  $\delta_m^{(n)}$  is the  $n^{\text{th}}$  TE harmonic for gear mesh  $m$  which can take one of two values, L or R. The optimization technique will minimise the root sum of squares of the WHSTE across both meshes:  $\text{Target} = \sqrt{\text{WHSTE}_L^2 + \text{WHSTE}_R^2}$ . To ensure that stress is well-distributed over each mesh, we use edge load factors:

$$\text{LF}_{m,e} = \frac{\max(\sigma_{m,e}) - \min(\sigma_{m,e})}{\max(\sigma_{m,e}) + \min(\sigma_{m,e})}, \quad (2)$$

where  $\sigma_{m,e}$  is the stress on mesh  $m$  along edge  $e$  (top, bottom, left, or right) and  $\sigma_{m,e}$  is the stress everywhere other than that edge. To ensure the optimization technique returns durable microgeometries, we constrain left and right edge load factors to be below 75 percent and top and bottom edge load factors to be under 50 percent.

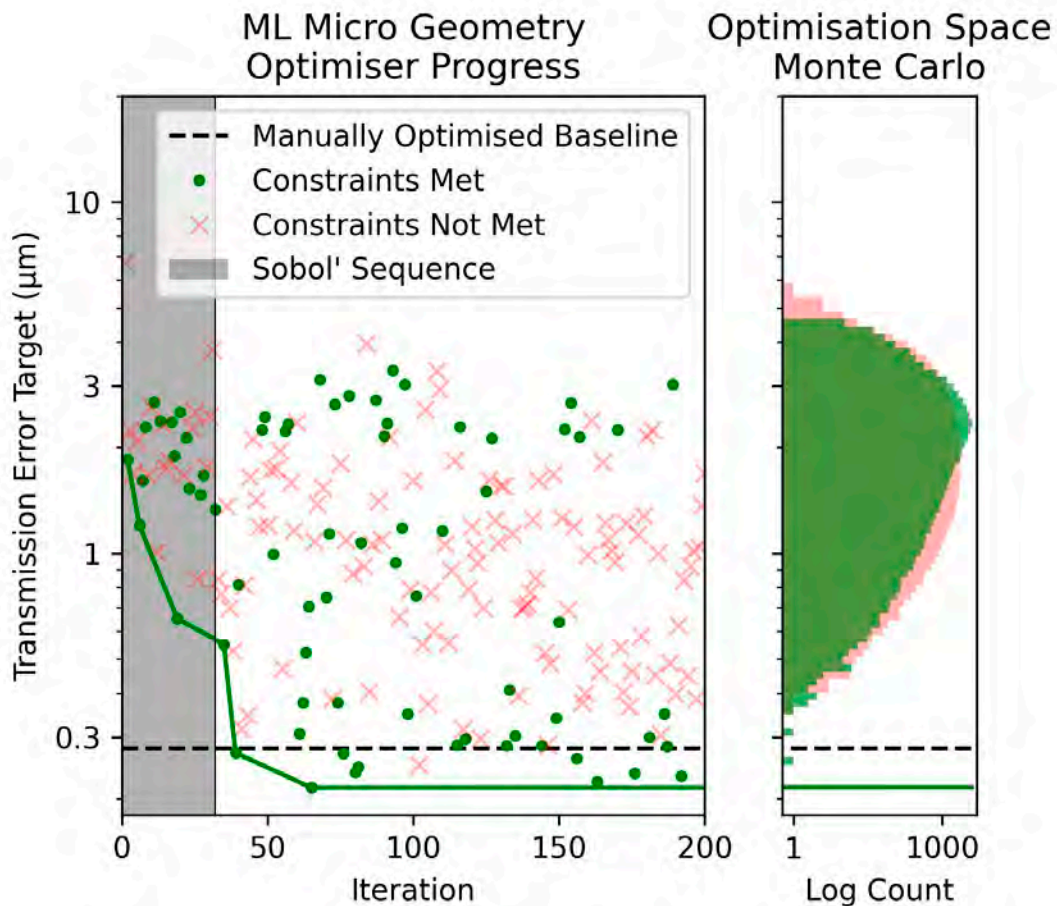


Figure 1—Machine learning microgeometry optimizer (left) compared with a 100,000-sample Monte Carlo experiment over the optimization space (right). In both plots, the main text defines the transmission error target as the root-mean-square of the weighted sum of TE across both gear meshes.

| Microgeometry Parameter | Gear  | Manually Optimized | Machine Learning Optimized (Scope)                      |
|-------------------------|-------|--------------------|---------------------------------------------------------|
| Lead Crowning           | Idler | 2 $\mu\text{m}$    | 2 $\mu\text{m}$ (2 $\mu\text{m}$ –20 $\mu\text{m}$ )    |
| Profile Slope           | Idler | 0 $\mu\text{m}$    | -1 $\mu\text{m}$ (-30 $\mu\text{m}$ –30 $\mu\text{m}$ ) |
| Profile Barreling       | Idler | 2 $\mu\text{m}$    | 2 $\mu\text{m}$ (2 $\mu\text{m}$ –20 $\mu\text{m}$ )    |
| Tip Relief              | Idler | 7 $\mu\text{m}$    | 10 $\mu\text{m}$ (0 $\mu\text{m}$ –10 $\mu\text{m}$ )   |
| Lead Slope              | Left  | 9 $\mu\text{m}$    | 21 $\mu\text{m}$ (-30 $\mu\text{m}$ –30 $\mu\text{m}$ ) |
| Tip Relief              | Left  | 7 $\mu\text{m}$    | 4 $\mu\text{m}$ (0 $\mu\text{m}$ –10 $\mu\text{m}$ )    |
| Lead Slope              | Right | -9 $\mu\text{m}$   | -9 $\mu\text{m}$ (-30 $\mu\text{m}$ –30 $\mu\text{m}$ ) |
| Tip Relief              | Right | 7 $\mu\text{m}$    | 10 $\mu\text{m}$ (0 $\mu\text{m}$ –10 $\mu\text{m}$ )   |

Table 1—Microgeometry parameters before and after optimization. The scope of microgeometry parameters considered by the optimizer is given in brackets.

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## Optimization Performance

The optimization begins by training an ML surrogate model on a set of initial samples, which is typically set to a power of two to set up a low-discrepancy Sobol' sequence to achieve good coverage over the high-dimensional input space. After the initial surrogate model has been fit to the data, this surrogate model is used to select a new microgeometry for analysis that is likely to meet the constraints, achieve a better target, or explore unseen regions of the problem space. For the optimization of eight microgeometry parameters, we use 32 initial samples followed by 168 optimization technique steps for a total of 200 LTCA analyses (see Figure 1), taking between 15 and 20 minutes on a desktop with an Intel Core i9-14900K with 128GB of RAM.

The lowest target found was 0.22  $\mu\text{m}$ , which is lower than the manually optimized baseline microgeometry, which had a target value of 0.28  $\mu\text{m}$ . To demonstrate the effectiveness of the optimization technique, we compare this to a 100,000-sample Monte Carlo simulation using uniform bounds over the optimization space, which took roughly three days to complete across two high-performance desktops. In Figure 1, it can be seen that the lowest target value found within the Monte Carlo study was 0.26  $\mu\text{m}$ , with the 0.1 percentile of microgeometries that met constraints taking the value 0.52  $\mu\text{m}$ . The ML optimization technique found 23 microgeometries that met the constraints with a target value less than this target value, demonstrating that the optimization technique is capable of finding many one-in-a-thousand microgeometries in a matter of minutes. By only performing LTCA analyses that are likely to either yield an improved solution or rule out less-explored regions of the problem space, the ML microgeometry optimization technique is highly data efficient and can thus achieve optimization in a significantly reduced timeframe.

## Results and Comparison to Baseline

The optimization technique found a range of promising microgeometries; each one is then manually checked by an engineer who selects for a combination of: a low WHSTE across both meshes, a preferentially low first harmonic of TE across both meshes, and a good contact patch across both meshes. Manually looking through the lowest results found by the optimization technique revealed iteration 163 to be a good trade-off between these targets. These microgeometry parameters were then rounded to the nearest micrometer and re-evaluated against the baseline microgeometry. The optimized microgeometry has a broadly improved set of TE harmonics (see Figure 2) and displays a similar contact patch to the baseline design with better centralization on the left input gear to idler mesh (see Figure 3). This can be reflected by comparing the optimized microgeometry parameters in Table 1; the manually and automatically optimized microgeometries have many features in common, such as the parabolic reliefs (lead crowning and profile barreling) taking their minimum values of two. The main difference between the two microgeometries is the increased lead slope on the left input gear from 9  $\mu\text{m}$  to 21  $\mu\text{m}$ , in which the ML optimization decreased the edge stress, thereby achieving a slightly more centralized contact patch (see Figure 3) whilst also resulting in improved TE. The similarity between the manual and ML-optimized microgeometries emphasizes that the original microgeometry was already very successfully manually optimized; putting the small performance improvements aside, the main benefit of the ML optimization technique was the drastically reduced run time totaling about 20 minutes.

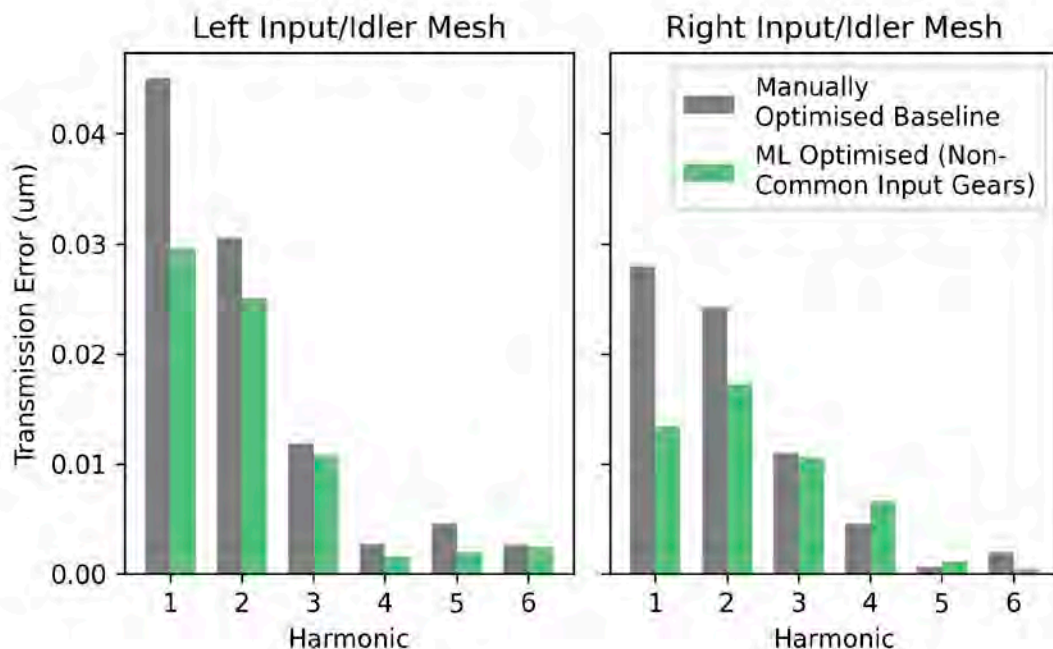


Figure 2—TE harmonics for each gear mesh before and after optimization.

## Manually Optimised Baseline

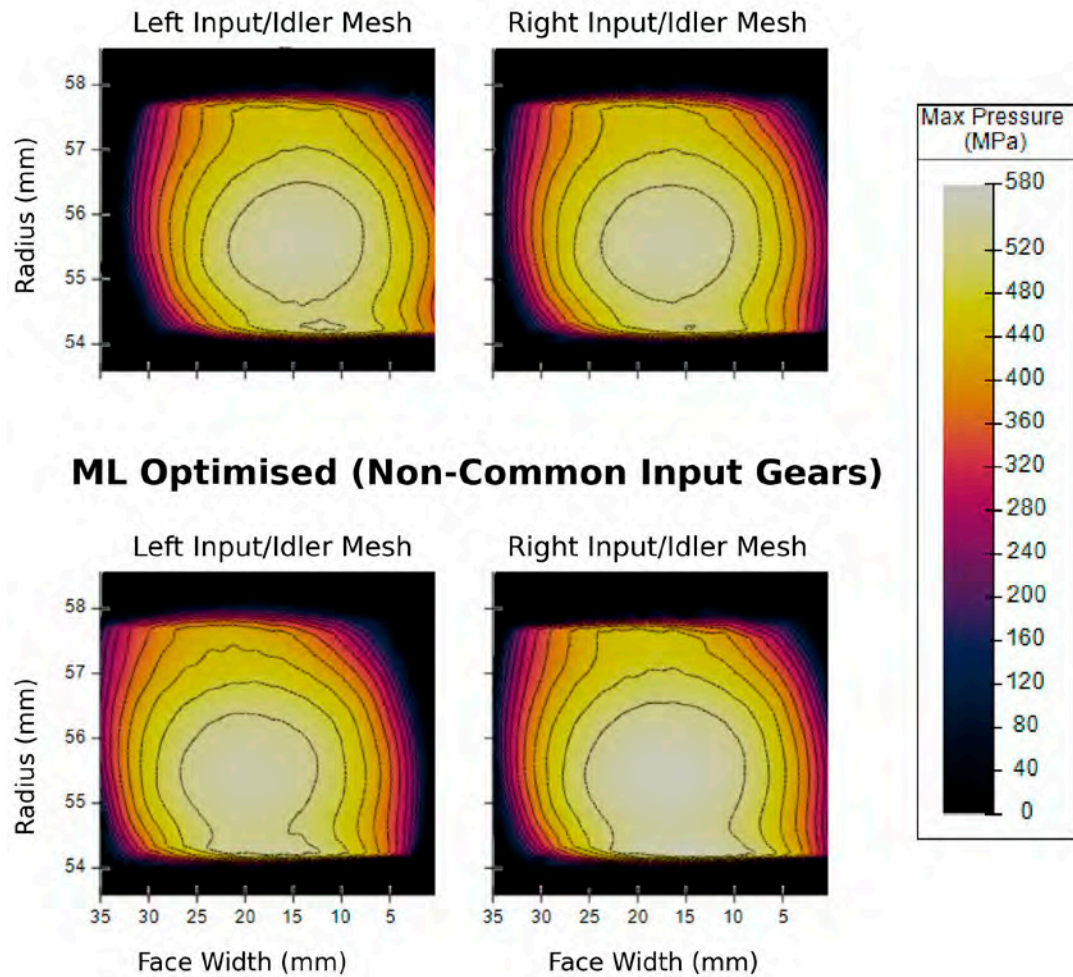


Figure 3—Contact patches for each gear mesh before and after optimization.

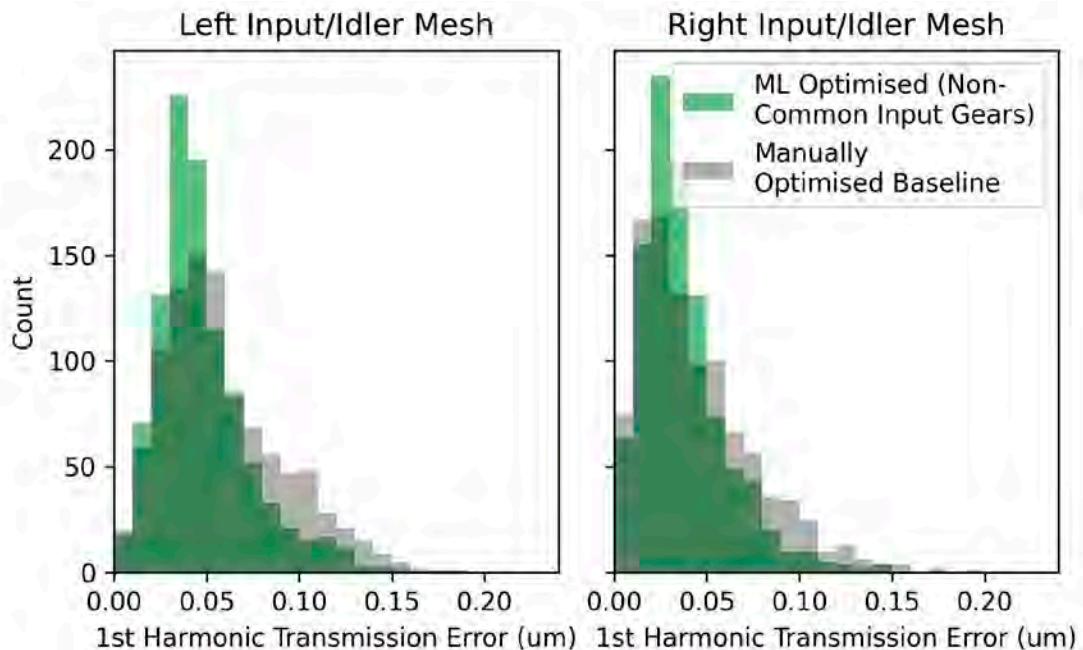


Figure 4—Robustness of the first harmonic of TE for the manually and ML-optimized microgeometry.

## Robustness to Manufacturing Deviations

So far, we have compared the baseline and ML-optimized microgeometries assuming that each parameter is known exactly; we refer to these as the nominal microgeometries. To simulate manufacturing deviations, we apply independent Gaussian tolerances to each microgeometry parameter, with lead slope, lead crowning and profile barreling having a standard deviation of 0.6  $\mu\text{m}$  and profile slope and tip relief having a standard deviation of 0.9  $\mu\text{m}$ . The robustness is evaluated by a Monte Carlo simulation requiring 1,000 samples per microgeometry, taking approximately one and a half hours using the previously mentioned hardware. It should be noted that these definitions of microgeometry tolerances were chosen to match the original manual optimization study; however, manufacturing deviations arising from any specific gear manufacturing process can be chosen. After optimization of the nominal microgeometry, we check the robustness. If the robustness is not satisfactory, the user can select a different solution from the optimization to check again for robustness. In Figure 4, we compare the robustness of the manually optimized baseline and optimized microgeometry, observing an improved average first harmonic of TE across both gear pair meshes.

By optimizing the nominal microgeometry, we have also indirectly optimized for a low average TE across both meshes when considering manufacturing tolerances. It should be expected that finding robust microgeometries through optimization of the nominal becomes less effective as the manufacturing tolerances are increased. Given that a typical robustness study requires on the order of  $10^3$  function evaluations, optimization thereafter is likely to take over  $10^5$  function evaluations (assuming an outer optimization loop requiring one hundred iterations). As demonstrated in this paper, efficient optimization of nominal microgeometry allows engineers to find high-performing candidates in a reduced timeframe; these microgeometries can then be checked for robustness as a post-processing step. The authors are conducting further research into microgeometry optimization techniques that directly consider robustness; however, it is emphasized that optimization of the nominal will remain a practical first step before further robust optimization.

## Optimization With Common Input Gears

The previous optimization study closely followed the original optimization procedure by allowing the microgeometry on the two input gears to differ; this decision maximizes the optimization potential but does so with an increased cost associated with manufacturing two distinct sets of input gears. Using the microgeometry optimization technique, we will now explore the optimal performance that can be achieved using common input gears. We now vary most microgeometry parameters on the common input gears, varying only the tip relief on the idler (see Tables 2 and 3), with optimization targets, constraints, and load case unchanged from the initial optimization. The optimization was run for two different ranges of tip relief parameters; for each optimization run, a single solution that balanced TE and contact patch quality was selected by an engineer.

| Microgeometry Parameter | Gear       | Machine Learning Optimized Common Input 1 (Scope)      |
|-------------------------|------------|--------------------------------------------------------|
| Lead Slope              | Left/Right | 9 $\mu\text{m}$ (-30 $\mu\text{m}$ –30 $\mu\text{m}$ ) |
| Lead Crowning           | Left/Right | 2 $\mu\text{m}$ (2 $\mu\text{m}$ –20 $\mu\text{m}$ )   |
| Profile Slope           | Left/Right | 1 $\mu\text{m}$ (-30 $\mu\text{m}$ –30 $\mu\text{m}$ ) |
| Profile Barreling       | Left/Right | 2 $\mu\text{m}$ (2 $\mu\text{m}$ –20 $\mu\text{m}$ )   |
| Tip Relief              | Left/Right | 0 $\mu\text{m}$ (0 $\mu\text{m}$ –10 $\mu\text{m}$ )   |
| Tip Relief              | Idler      | 9 $\mu\text{m}$ (0 $\mu\text{m}$ –10 $\mu\text{m}$ )   |

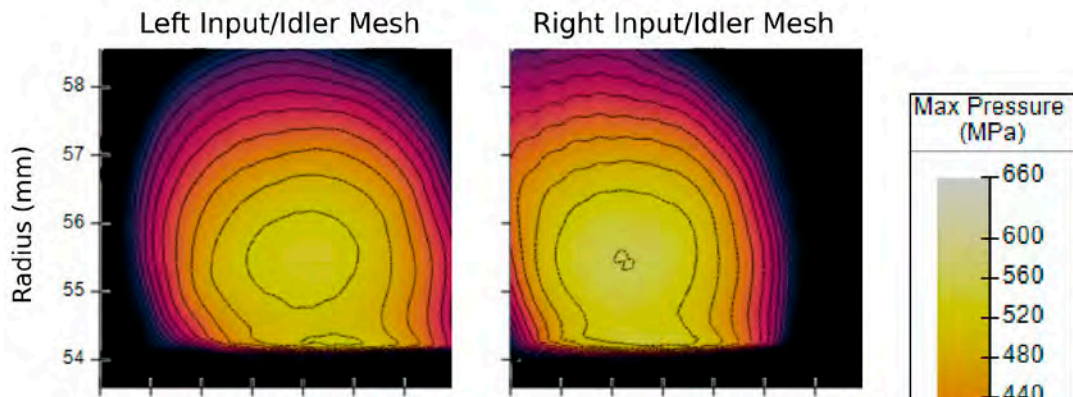
**Table 2—Microgeometry parameters for the first common input gear optimization, with tip relief limited to 0  $\mu\text{m}$ –10  $\mu\text{m}$ . The scope of microgeometry parameters considered by the optimizer is given in brackets.**

| Microgeometry Parameter | Gear       | Machine Learning Optimized Common Input 2 (Scope)     |
|-------------------------|------------|-------------------------------------------------------|
| Lead Slope              | Left/Right | 12 $\mu\text{m}$ (same as Table 2)                    |
| Lead Crowning           | Left/Right | 3 $\mu\text{m}$ (same as Table 2)                     |
| Profile Slope           | Left/Right | 2 $\mu\text{m}$ (same as Table 2)                     |
| Profile Barreling       | Left/Right | 0 $\mu\text{m}$ (same as Table 2)                     |
| Tip Relief              | Left/Right | 0 $\mu\text{m}$ (0 $\mu\text{m}$ –20 $\mu\text{m}$ )  |
| Tip Relief              | Idler      | 20 $\mu\text{m}$ (0 $\mu\text{m}$ –20 $\mu\text{m}$ ) |

**Table 3—Microgeometry parameters for the second common input gear optimization, with the tip relief scope extended to 0  $\mu\text{m}$ –20  $\mu\text{m}$ . All other parameter scopes are unchanged from Table 2.**

For each optimization, a total of 150 iterations (16 initial samples and 134 optimization technique steps) were performed, resulting in a combined runtime of approximately 30 minutes. One solution from each run was selected, and the microgeometry parameters were rounded to the nearest micrometer. Perhaps the most noticeable difference between the two common input gear solutions and the previous non-common input gear microgeometries is the stress distribution; it is noted that the first of the two common input gear optimization results has smaller stress concentrations (see Figure 5) but at the cost of higher TE. The root sum of squares WHSTE across both meshes takes values of 0.32  $\mu\text{m}$  and 0.34  $\mu\text{m}$  for the two microgeometries; these values are higher than the baseline (0.28  $\mu\text{m}$ ) and noncommon input gear optimization (0.22  $\mu\text{m}$ ), but still low when compared to the Monte Carlo study (0.1 percentile with value 0.52  $\mu\text{m}$ ). Furthermore, the difference in TE between noncommon and common gears reduces when comparing the average TE over tolerances instead of the nominal values (see Figure 6); it would be up to the engineer as to whether this is an appropriate increase in TE for the reduced manufacturing costs. As seen in this section, it is possible to use the optimization technique to find optimal microgeometries under different design constraints; using several runs of the microgeometry optimization technique, a Pareto set of optimal microgeometries can be found from which an engineer can select the most appropriate solution.

## ML Optimised (Common Input Gears 1)



## ML Optimised (Common Input Gears 2)

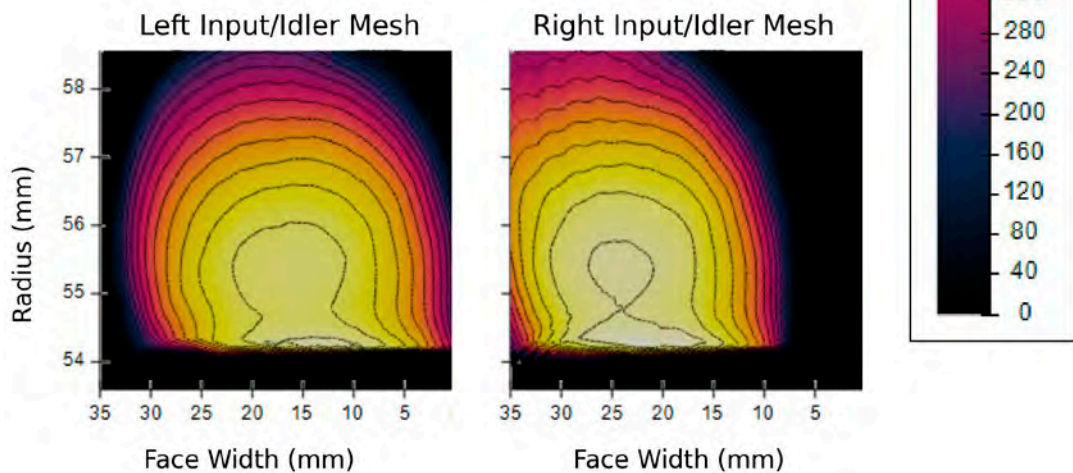


Figure 5—Contact patches for each gear mesh for two common input gear optimizations.

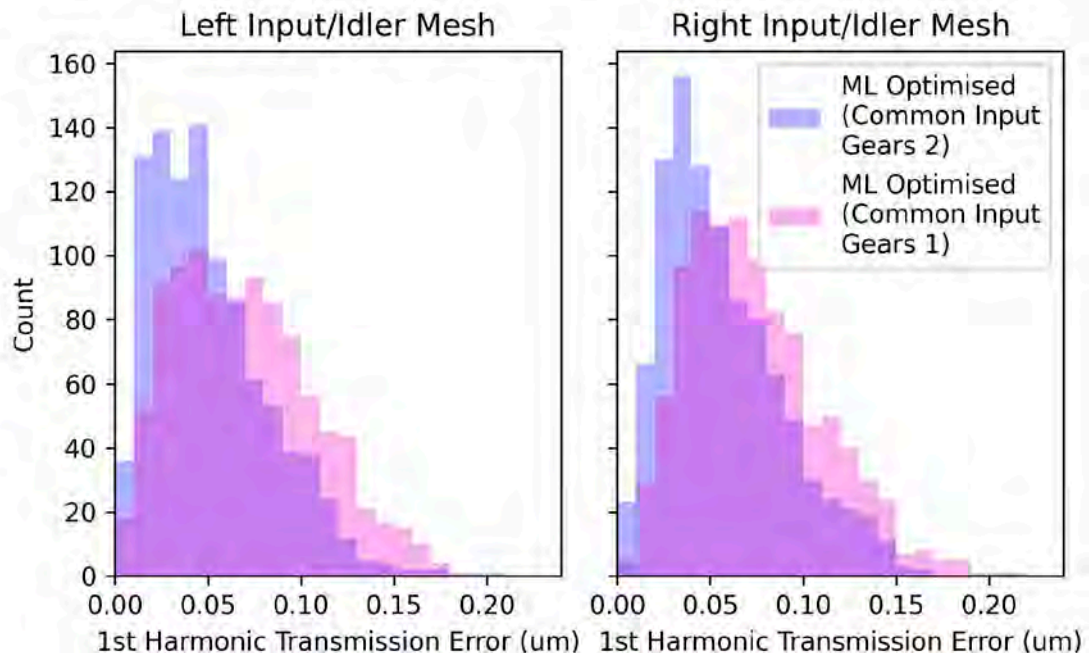


Figure 6—Robustness of the first harmonic of TE for the two optimized common input gear microgeometries.

## Optimization for Torque Robustness

In previous sections, the ML microgeometry optimization technique has been used to reduce the WHSTE whilst considering durability through contact patch constraints across both meshes at a single torque of 90 Nm. After successfully optimizing considering a single torque, we now expand the optimization to improve NVH under multiple operating conditions. By reducing TE at other torques, we will search for a torque-robust microgeometry and compare it to the previously obtained optimized microgeometries.

To optimize NVH under multiple operating conditions, we now define the WHSTE as  $WHSTE_{m,\tau}$  for each mesh  $m$  and torque  $\tau$ . The root-sum-of-squares target then combines the WHSTE across both meshes and multiple torques:

$$\text{Target} = \sqrt{\sum_{\tau \in T} (WHSTE_{L,\tau}^2 + WHSTE_{R,\tau}^2)}, \quad (3)$$

where  $T$  is a set of torques. Three torque-robust optimizations are considered:

- A.  $T=\{50 \text{ Nm}, 90 \text{ Nm}, 150 \text{ Nm}\}$ ,
- B.  $T=\{10 \text{ Nm}, 50 \text{ Nm}, 90 \text{ Nm}, 150 \text{ Nm}\}$ ,
- C.  $T=\{10 \text{ Nm}, 50 \text{ Nm}, 90 \text{ Nm}, 150 \text{ Nm}, 300 \text{ Nm}\}$ .

In all cases, the contact patch constraints remain unchanged from the previous optimizations, considering only a single torque of 90 Nm. Furthermore, we explore the same range of microgeometry parameters as seen in the noncommon input gear optimization as outlined in Table 1.

In Figure 7, the RMS of the WHSTE combined over both meshes for a given torque is plotted for a range of torques for each microgeometry. Torque-robust optimizations B and C have significantly improved NVH performance at very low torques (roughly less than 25 Nm) due to their active targeting of the 10 Nm load case. Furthermore, torque-robust optimization C has a clear reduction in TE at higher torques through its consideration of the 300 Nm load case. Interestingly, torque-robust optimization A, which targeted torques of 50 Nm, 90 Nm and 150 Nm, outperformed the noncommon input gear optimized solution at its individual target torque of 90 Nm. In optimization, we cannot guarantee that the global minimum has been found, and two separate optimizations can have similar solutions if their objectives do not contradict. Whilst the torque-robust optimization A indeed found a better solution at 90 Nm than the noncommon input gear optimization, it is emphasized that both solutions are actually very similar; this can be seen by comparing them both against random samples from the Monte Carlo covering the optimization, as seen in the inset of Figure 7.

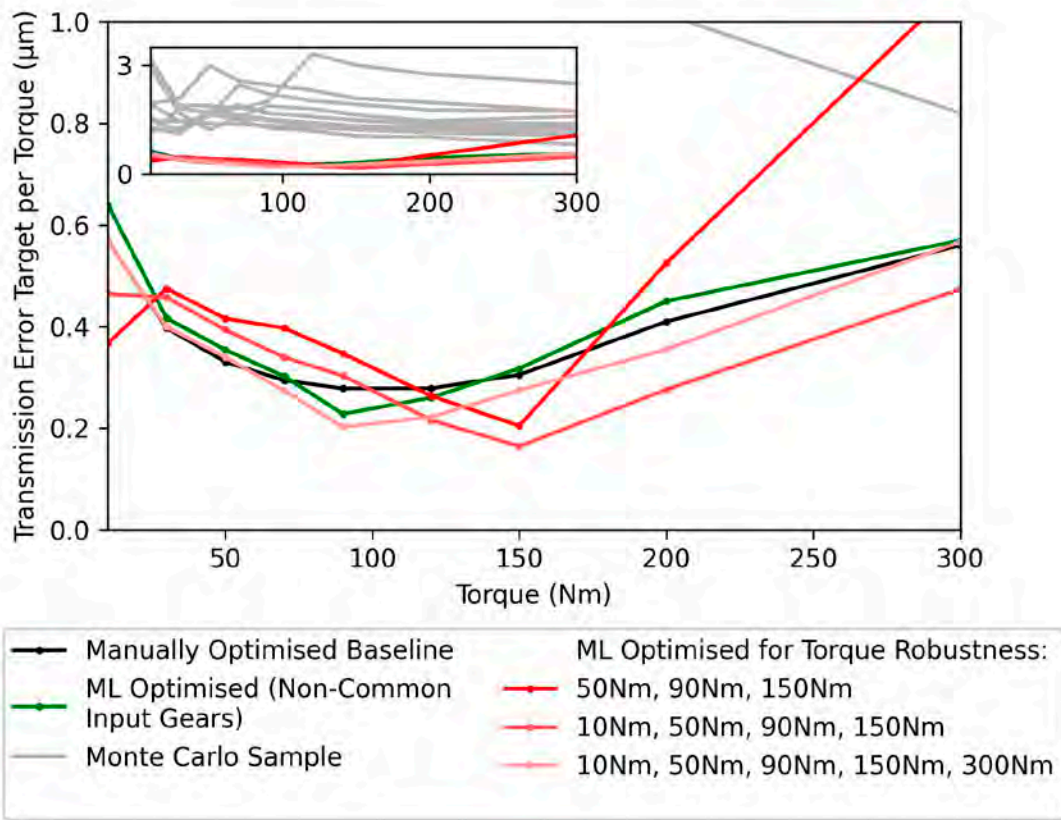


Figure 7—WHSTE (root sum of squares over both meshes) is plotted for a range of torques and microgeometries. Inset: The optimality of all solutions is highlighted by comparing to 10 microgeometries from a Monte Carlo study of the optimization space.

## Conclusion

The optimization of gear microgeometry is a challenging process often carried out by experienced engineers who often balance competing optimization objectives against lengthy calculation times arising from high-fidelity loaded tooth contact analyses. In this work, we have seen how ML microgeometry optimization can be used to achieve efficient optimization of microgeometries, balancing noise, vibration and harshness with other metrics such as durability on a computational budget. By recreating a past manual microgeometry optimization study, we have validated that the optimization technique can yield similar performance to a gear specialist but doing so in a drastically reduced timeframe; providing this powerful tool to an engineer allows them to optimize for a variety of different objec-

tives from which an ideal solution can be selected. Robustness of microgeometries identified by the optimization technique was quantified through computationally expensive Monte Carlo studies. Although the microgeometries identified in this study were robust, direct robust optimization that guarantees performance over manufacturing tolerances has been identified as an area for future research. It is emphasized that the efficient nature of the optimization technique allows it to identify high-performing microgeometries quickly, allowing engineers to identify a varied set of microgeometries for downstream robustness verification and allowing this process to be used as an inner optimization loop alongside gear macrogeometry or wider powertrain optimization.



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**Shinya Sudo** manages the CAE team for all drivetrain systems at Hino Motors, where he has worked since 1988, for close to four decades. A specialist in cylindrical gear durability and vibration, he now leads the CAE-based development process for drivetrain units, working to visualize all physical phenomena inside each unit.



**Dr. Paul Langlois** is SMT's CTO, with more than 20 years' experience and technical oversight of its Software, Research, and Customer Support teams. A main contributor to loaded tooth contact analysis, NVH, and electric machine software, he holds a Ph.D in Mathematical Physics from Nottingham and contributes to ISO gear standards.



**Jaekwon Lee** is currently an Assistant Manager at Hino Motors, where he actively supports the development of trucks and buses within the Drivetrain Department. His primary responsibilities center on the use of CAE simulation to reduce development lead times and improve product quality across all of Hino's drivetrain unit programs.

## References

1. D. Miler and M. Hoic, "Optimisation of cylindrical gear pairs: A review," *Mechanism and Machine Theory*, Vol. 156, pp. 104156, 2021, doi: 10.1016/j.mechmachtheory.2020.104156.
2. D. Ghribi, J. Bruyère, P. Velez, M. Oetue, and M. Haddar, "A contribution to the design of robust profile modifications in spur and helical gears by combining analytical results and numerical simulations," *Journal of Mechanical Design*, Vol. 134, pp. 061011, 2012, doi: 10.1115/1.4006740.
3. M. Gabiccini, A. Bracci, and M. Guiggiani, "Robust optimization of the loaded contact pattern in hypoid gears with uncertain misalignments," *Journal of Mechanical Design*, Vol. 132, pp. 041010, 2010, doi: 10.1115/1.4001485.
4. Akash Pavan S., S. Periyasamy, Vikram Karthik S. S., and A. Gopalakrishnan, "Microgeometry Optimization of Spur Gear for Electric and Hybrid Vehicle Applications," *2019 IEEE Transportation Electrification Conference (ITEC-India)*, pp. 1–5, Dec. 17–19, 2019, doi: 10.1109/ITEC-India48457.2019. ITECINDIA2019-155.
5. C. Brecher, C. Löpenhaus, and J. Brimmers, "Function-oriented tolerancing of tooth flank modifications of beveloid gears," *Procedia CIRP*, Vol. 43, pp. 124–129, 2016, doi: 10.1016/j.procir.2016.02.155.
6. M. Trippe, A. Lemmer, C. Löpenhaus, and C. Brecher, "Optimizing the operational behavior of bevel gears using a tolerance field-based approach," *Gear Technology*, pp. 68–73, Aug. 2019.
7. S. Lahoti, P. Patil, and J. Wagner, "Gear whine noise reduction by transmission error and contact pattern optimization: Simulation and testing correlation," SAE Technical Paper 2021-01-1103, 2021, doi: 10.4271/2021-01-1103.
8. G. Bonori, M. Barbieri, and F. Pellicano, "Optimum profile modifications of spur gears by means of genetic algorithms," *Journal of Sound and Vibration*, Vol. 313, pp. 603–616, 2008, doi: 10.1016/j.jsv.2007.12.013.
9. K. Deb and S. Jain, "Multi-Speed Gearbox Design Using Multi-Objective Evolutionary Algorithms," *Journal of Mechanical Design*, Vol. 125, pp. 609–619, 2003, doi: 10.1115/1.1596242.
10. P. Garambois, J. Perret-Liaudet, and E. Rigaud, "NVH robust optimization of gear macro and microgeometries using an efficient tooth contact model," *Mechanism and Machine Theory*, Vol. 117, pp. 78–95, 2017, doi: 10.1016/j.mechmachtheory.2017.07.008.
11. D. J. Fonseca, S. Shishoo, T. C. Lim, and D. S. Chen, "A genetic algorithm approach to minimize transmission error of automotive spur gear sets," *Applied Artificial Intelligence*, Vol. 19, pp. 153–179, 2005, doi: 10.1080/08839510590901903.
12. B. Blanco, J. L. Escalona, R. Lambert, R. Ling, and O. Balling, "On the definition and effect of optimum gear microgeometry modifications for the gearbox of an offshore 10-MW wind turbine," *Wind Energy*, Vol. 26, pp. 717–740, 2023, doi: 10.1002/we.2825.
13. V. V. Simon, "Multi-objective optimization of hypoid gears to improve operating characteristics," *Mechanism and Machine Theory*, Vol. 146, pp. 103727, 2020, doi: 10.1016/j.mechmachtheory.2019.103727.
14. E. Ben Younes, C. Changenet, J. Bruyère, E. Rigaud, and J. Perret-Liaudet, "Multi-objective optimization of gear unit design to improve efficiency and transmission error," *Mechanism and Machine Theory*, Vol. 167, pp. 104499, 2022, doi: 10.1016/j.mechmachtheory.2021.104499.
15. V.-T. Dinh, H.-D. Tran, T.-D. Bui, D.-B. Vu, D. Vu, N.-P. Vu, and T.-T.-H. Truong, "Multi-Objective Optimization of a Two-Stage Helical Gearbox with Second Stage Double Gear-Sets Using TOPSIS Method," *Processes*, Vol. 12, pp. 1160, 2024, doi: 10.3390/pr12061160.
16. C. Choi, H. Ahn, Y.-J. Park, G.-H. Lee, and S.-C. Kim, "Influence of gear tooth addendum and dedendum on the helical gear optimization considering mass, efficiency, and transmission error," *Mechanism and Machine Theory*, Vol. 166, pp. 104476, 2021, doi: 10.1016/j.mechmachtheory.2021.104476.
17. Y. Lei, L. Hou, Y. Fu, J. Hu, and W. Chen, "Research on vibration and noise reduction of electric bus gearbox based on multi-objective optimization," *Applied Acoustics*, Vol. 158, pp. 107037, 2020, doi: 10.1016/j.apacoust.2019.107037.
18. K. Tamboli, S. Patel, P. M. George, and R. Sanghvi, "Optimal Design of a Heavy Duty Helical Gear Pair Using Particle Swarm Optimization Technique," *Procedia Technology*, Vol. 14, pp. 513–519, 2014, doi: 10.1016/j.protcy.2014.08.065.
19. M. Sedak and B. Rosic, "Multi-Objective Optimization of Planetary Gearbox with Adaptive Hybrid Particle Swarm Differential Evolution Algorithm," *Applied Sciences*, Vol. 11, pp. 1107, 2021, doi: 10.3390/app11031107.
20. A. Artoni, M. Gabiccini, M. Guiggiani, and A. Kahraman, "Multi-Objective Ease-Off Optimization of Hypoid Gears for Their Efficiency, Noise, and Durability Performances," *Journal of Mechanical Design*, Vol. 133, pp. 121007, 2011, doi: 10.1115/1.4005234.
21. A. Artoni, M. Guiggiani, A. Kahraman, and J. Harianto, "Robust Optimization of Cylindrical Gear Tooth Surface Modifications Within Ranges of Torque and Misalignments," *Journal of Mechanical Design*, Vol. 135, pp. 121005, 2013, doi: 10.1115/1.4025196.
22. P. Qiu, N. Zhao, and F. Wang, "Optimum microgeometry modifications of herringbone gear by means of fitness predicted genetic algorithm," *Journal of Vibroengineering*, Vol. 18, pp. 4964–4979, 2016, doi: 10.21595/jve.2016.17179.
23. I. Park, "Multi-objective optimization of the tooth surface in helical gears using design of experiment and the response surface method," *Journal of Mechanical Science and Technology*, Vol. 24, pp. 823–829, 2010, doi: 10.1007/s12206-010-0117-x.
24. H. Wang, D. Chen, F. Pan, and D. Yu, "Multi-objective Optimization Design of Helical Gear in Centrifugal Compressor Based on Response Surface Method," *IOP Conference Series: Materials Science and Engineering*, Vol. 423, pp. 012040, 2018, doi: 10.1088/1757-899X/423/1/012040.
25. Z. Tang, M. Wang, Z. Chen, J. Sun, M. Wang, and M. Zhao, "Design of Multi-Stage Gear Modification for New Energy Vehicle Based on Optimized BP Neural Network," *IEEE Access*, Vol. 8, pp. 199034–199050, 2020, doi: 10.1109/ACCESS.2020.3035570.
26. B. Haefner, M. Biehler, R. Wagner, and G. Lanza, "Meta-Model Based on Artificial Neural Networks for Tooth Root Stress Analysis of Micro-Gears," *Procedia CIRP*, Vol. 75, pp. 155–160, 2018, doi: 10.1016/j.procir.2018.04.031.
27. O. D. Mohammed, A. D. S. Bhat, and P. Falk, "Robust multi-objective optimization of gear microgeometry design," *Simulation Modelling Practice and Theory*, Vol. 119, pp. 102593, 2022, doi: 10.1016/j.simpat.2022.102593.
28. J. A. Korta and D. Mundo, "Multi-objective micro-geometry optimization of gear tooth supported by response surface methodology," *Mechanism and Machine Theory*, Vol. 109, pp. 278–295, 2017, doi: 10.1016/j.mechmachtheory.2016.11.015.
29. J. A. Korta and D. Mundo, "A population-based meta-heuristic approach for robust micro-geometry optimization of tooth profile in spur gears considering manufacturing uncertainties," *Meccanica*, Vol. 53, pp. 447–464, 2018, doi: 10.1007/s11012-017-0737-7.
30. U. Urbas, D. Zorko, and N. Vukašinović, "Machine learning based nominal root stress calculation model for gears with a progressive curved path of contact," *Mechanism and Machine Theory*, Vol. 165, pp. 104430, 2021, doi: 10.1016/j.mechmachtheory.2021.104430.
31. P. Langlois, B. Al, and O. Harris, "Hybrid Hertzian and FE-based helical gear-loaded tooth contact analysis and comparison with FE," *Gear Technology*, pp. 54–63, Jul. 2016.

# MPT Expo 2027

ISSUES A SAVE THE DATE



The countdown is officially on—October 26–28, 2027, Huntington Place, Detroit; mark your calendar now—and this one comes with a milestone attached. In just one year, the gear and bearing industries return to Detroit for the Motion + Power Technology Expo (MPT Expo), and 2027 marks the show's 40th anniversary. It started in 1985 as Gear Expo, back when exhibitors worked out of tabletop displays rather than full booths. Four decades later, it's still the one event where gear and bearing manufacturers, suppliers and the OEMs who depend on them show up in the same room, at the same time.

## Why Save the Date

MPT Expo isn't a generic manufacturing trade show, and it never set out to be one. It has stayed a niche event built around the core of this industry, the traditional mechanical power transmission sectors like mining, oil and gas, agriculture and industrial manufacturing that have always relied on gears, bearings and drivetrain technology. What's changed is what else now shows up alongside them: robotics and automation, electric and hybrid vehicles, urban air mobility, and a growing presence from aerospace, space and defense, all welcomed into the same show floor as the traditional base that built this event. It happens once every two years, which is part of what makes it feel less like a trade show and more like a homecoming. It's where 2025's Power Breakfasts sparked some of the most talked-about conversations of the year on supply chain, workforce, and the pressures facing gear and bearing manufacturers today, and where the next round of white papers, standards

releases and product debuts happen live, not in a press release.

It's also, at its core, a chance to see the whole industry in one place, something that matters more as the show enters its fifth decade. The people designing humanoid robots and the people machining the gearboxes that drive them. The suppliers watching air mobility move from concept to certification and the manufacturers building the components that get it there. But the innovation on display isn't only coming from the companies building the next humanoid robot or the next air mobility vehicle. It's the suppliers behind them, the ones pushing forward on cutting tools, lubrication, heat treat techniques, and the dozens of other disciplines that make those end products possible, who have quietly been doing just as much of the hard work. MPT Expo is where that work finally gets seen.

Aerospace, space and defense deserve their own mention here. As drone technology, next-generation propulsion, and space hardware place new demands on precision components, gear and bearing manufacturers are being asked to meet requirements once reserved for a narrow slice of the industry. MPT Expo is where those buyers and the suppliers who can meet those requirements find each other.

Attendees leave with something a webinar can't give them: face time with the people actually shaping where this industry goes next. Save the date, block the travel and plan to be in the room.

## What to Expect on the Floor

Expect the same mix that made 2025 memorable, just bigger, and with four decades of history behind it. Panel discussions in the style of our Power Breakfasts, tackling the supply chain, workforce, and manufacturing challenges facing this industry head-on. A show floor where the machine tool companies that have anchored this industry for decades stand alongside the people designing the robots, vehicles and aircraft that are newest to it. Sessions covering everything from established mechanical power transmission topics to robotics, air mobility, electric vehicles, and the fast-growing needs of aerospace, space, and defense, each grounded in a year of real

research rather than headlines. And we will not forget the traditional craft needed for agriculture, automotive, mining, oil and gas and industrial applications that have built our industry. And plenty of the unscripted, coffee-line conversations that tend to be where the most useful information actually changes hands.

Bring your team, not just yourself. The show rewards people who wander the floor as much as those who stick to a fixed agenda.

## Papers and Presentations: The Call Is Coming

This year, our Fall Technical Meeting (FTM) made a notable shift: it became a dual-track event, adding a presentation track built around emerging technologies, innovative solutions, and real-world applications alongside its traditional technical program. That format is returning, this time as part of MPT Expo 2027 itself, giving the show an even stronger technical backbone alongside the exhibit floor.

The call for papers and presentations opens later this year. If your team has research, case studies, or real-world applications worth putting in front of this audience, start thinking now about what you would want to present. Submission details will be available soon.

## A Note for Exhibitors

If your company has exhibited before, you know this floor is less about foot traffic and more about the specific conversations that happen there. If you haven't yet, a 40th-anniversary show is a good place to start. Reach out whenever you're ready to talk through options; there's no rush.

## How to Get Started

Join us as we celebrate 40 years of driving the gear industry forward. Save the date: October 26–28, 2027, Huntington Place, Detroit, MI. Go to [motionpowerexpo.com](http://motionpowerexpo.com) and sign up for show alerts now to stay on top of everything as the show approaches, exhibitor news, education opportunities, speaker announcements, and more. To reserve exhibit space, request the prospectus, or ask about sponsorships, contact Katie Mulqueen at [mulqueen@motionpower.org](mailto:mulqueen@motionpower.org).

[motionpowerexpo.com](http://motionpowerexpo.com)

# Star Cutter and Star SU

UNIFY BRAND IDENTITY



Star Cutter Company and Star SU have introduced a new brand identity as Star Cutter approaches its 100th anniversary. The rebrand updates the visual identities of both companies and brings them together under a single identity. Since its founding in 1927, Star Cutter has grown into a group of companies that supplies cutting tools, grinding machines, gear manufacturing technologies, application engineering and technical support.

“For nearly 100 years, we’ve built our reputation by working alongside manufacturers to solve complex production challenges,” said Jeff Lawson, CEO. “Our new brand reflects who we are today: a unified organization built on American craftsmanship, trusted partnerships and a relentless drive to help our customers succeed.”

The new identity is built around three principles: the company’s manufacturing heritage dating back to 1927, long-standing customer partnerships and continued investment in advanced manufacturing technologies. Over the coming year the brand will roll out across the companies’ websites, digital platforms, product literature, advertising, trade show exhibits and customer communications.

“As manufacturing continues to evolve, so do we,” said Andreas Blind, chief commercial officer of Star Cutter and president of Star SU. “This new brand honors where we’ve come from while positioning us for the next century of innovation.”

Star Cutter Company is headquartered in Farmington Hills, MI, and has more than 700 employees working in 15 manufacturing facilities. Each facility focuses on one product line: carbide blanks and preforms, solid carbide

cutting tools, gundrills, PCD tooling, gear cutting tools, or 5-axis CNC tools and cutter grinding machines.

[starcutter.com](http://starcutter.com)

## Piselli Enterprises

WELCOMES NICK PISELLI  
TO SALES TEAM



Nick Piselli

Nick Piselli recently joined the sales team at Piselli Enterprises located in Statesville, NC. He joins his father Richard and his brother Matthew to serve the gear industry with high-quality new and used gear machinery equipment.

“I’m very excited to start the next chapter of my career working with both my father and my brother,” Piselli said. “I started working on blogs for the website as well as social media for networking and I’m currently learning the technical aspects of the gear industry as I approach my new role in sales.”

Blogs on topics such as Barber Colman hobbing machines, rebuilds vs.

CNC retrofits and the advantages of guideless helical gear shaping can be found online here: ([pisellient.com/blog](http://pisellient.com/blog)).

Piselli graduated from Colgate University in New York with a degree in finance. He spent the last six years working in the finance industry before joining the family business in North Carolina.

“My father’s work ethic and determination have always been an inspiration and really instilled similar goals for both my brother and I,” Piselli added. “He set that standard and we look forward to continuing the legacy he started 30-plus years ago.”

Piselli said he is eager to learn about all the unique markets where gears play a critical role in manufacturing. “Everything from aerospace to automotive to general industrial applications, there are so many opportunities to see where these gears are utilized and how the technology is adapting to market demands. It is an amazing opportunity to be a part of this business today.”

The used gear machinery market is an area that Nick is looking forward to strengthening from a legacy standpoint.

“We walk into some of these machine shops and they have the most incredible, state-of-the-art hobbing machines working side by side with 1946 Barber Colman machines,” Piselli said. “There is a real art to being a gear machinist and sometimes they cannot do the things they need to do on a brand-new machine—they cannot make the same cuts as they can with the older equipment. We can offer some older equipment that offers repeatable gear cutting, better cycle efficiency and dependable production on a wide range of parts.”

Piselli Enterprises specializes in giving manufacturing shops clear options when critical equipment goes down.

“Instead of investing in a new machine tool, customers can find some used and refurbished options from us, or they can bring their gears to us for a test run before they make that initial capital machine investment,” Piselli said.

As a leading supplier of used gear machinery, Piselli Enterprises delivers reliable solutions backed by decades of expertise. Inventory includes hobbers, shapers, grinders and inspection equipment from top manufacturers (more than 500 machines in stock). Inquire about the “Give Back Program” to MPMA members.

[pisellient.com](http://pisellient.com)

[geartechnology.com](http://geartechnology.com)

NOVEMBER 24–26

**SPS Smart Production Solutions 2026**

*SPS (Nuremberg, Germany) highlights smart and digital automation solutions. Around 1,000 exhibitors from across the globe present forward-looking technologies and high-impact solutions for industrial applications. Industrial AI is the driving focus topic of SPS 2026 demonstrating how automation, in combination with solutions from drive technology, sensor technology, software and industrial communication, is shaping the future. Four stages will present current trends, technologies and practical applications offering insights for decisionmakers, developers and young talent.*

**[geartechnology.com/events/sps-smart-production-solutions-2026](https://geartechnology.com/events/sps-smart-production-solutions-2026)**

DECEMBER 8–9

**CTI Symposium Berlin 2026**

*CTI Symposium Berlin offers active discussions on the latest technologies and strategies on automotive transmissions and HEV & EV drives for passenger cars and commercial vehicles. At CTI Symposium Berlin, more than 650 senior experts and decisionmakers from OEMs, Tier 1 suppliers, technology companies, and research institutions come together to discuss the latest developments in electrified drivetrains, hybrid technologies, energy systems, software integration and future mobility strategies. The CTI Symposium is neutral, international and insight driven. It is not guided by any corporate or political agenda – but by the shared commitment to innovation, technical excellence, and open exchange across the global powertrain community.*

**[geartechnology.com/events/cti-symposium-berlin-2026](https://geartechnology.com/events/cti-symposium-berlin-2026)**

JANUARY 6–9

**CES 2027**

*Attracting a diverse range of professionals, including executives, engineers, designers and entrepreneurs, CES (Las Vegas) is an excellent opportunity to connect, collaborate and grow your professional network. The broad range of exhibits and industries represented at the show can inspire innovative solutions. Industries include 3D printing, AR/VR/XR, AI, cloud computing/data, construction tech, cybersecurity, robotics, e-Mobility, AI, vehicle tech and more. Stellantis CEO, Antonio Filosa, will deliver a keynote on the opening day of CES 2027 on January 6. Filosa will highlight how Stellantis is integrating advanced technologies across its vehicles, software and digital ecosystems to create a more seamless and intuitive customer experience. With 14 automotive brands serving customers around the world, Stellantis brings a unique global perspective on how innovation can be human and smart improving the way people move.*

**[geartechnology.com/events/ces-2027](https://geartechnology.com/events/ces-2027)**

JANUARY 20–22

**PowerGen 2027**

*PowerGen (Salt Lake City) is the premier networking and business hub for power generation professionals and solution providers. It unites power producers, utilities, EPCs, consultants, OEMs and large-scale energy users. As the industry evolves toward cleaner and more sustainable energy, PowerGen fosters a progressive environment for both established professionals and new energy leaders driving the transition to a more sustainable future. A surge in data centers, industrial expansion and electrification is reshaping power generation planning across North America. Utilities are under mounting pressure to maintain reliability and add new capacity. IPPs are accelerating project development to capture the opportunity. EPCs and OEMs are finding innovative ways to build faster, smarter and stronger amid supply chain and permitting headwinds.*

**[geartechnology.com/events/powergen-2027](https://geartechnology.com/events/powergen-2027)**

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# If We Ain't Got It, It's Gonna Be Hard to Find!

Matthew Jaster, Director, Editorial Content



*The Whoopee Bowl reopened in 2025 and recently celebrated its one-year anniversary on October 3. (Image: Whoopee Bowl Clarkston)*

My grandfather's favorite pastime in the 1980s was to toss my brother and I into his pickup truck and tell our grandmother we were running errands. The Silverado would disappear into a labyrinth of dirt roads cruising past rundown golf courses, odd sculpture parks and miles of empty forests. The old man would smoke a carton of cigarettes along the way.

Although he had safely navigated the Solomon Islands during World War II, he would act like he had no idea where we were or where we were going. A ruse, of course, the kind of practical joke a grandfather plays on his young and naïve grandkids simply to shake up a Saturday afternoon during summer vacation.

Every trip ended the same way. The great forest would eventually disappear, and we would pop back into civilization in front of a large orange warehouse in Clarkston, MI, known as The Whoopee Bowl.

Yes, this was its official name.

During the 1980s, The Whoopee Bowl was a gigantic surplus store full of junk. It was a magical place where collectors and treasure hunters could spend hours rifling through boxes searching desperately for knickknacks, trinkets and doodads.

If a customer was searching for antique road signs, vintage board games, mechanical components, tools, military weapons, light fixtures, furniture or go-kart supplies—this was the place to be. Retro toys pinned to corkboards looked like they belonged in an insidious Toys R Us where every doll followed you as you walked down the dimly lit aisles, nightmare fuel for those with relentless imaginations.

My grandfather spent hours at the Whoopee Bowl, years before anything like *Antiques Roadshow* or *American Pickers* slipped into the pop culture vernacular. Upon arrival, he would give my brother and I \$10 each to spend in the store. You would not believe the bounty a kid could produce at a Walmart-sized flea market back in 1985 with \$10.

The shop would eventually become an iconic local landmark operating under the slogan, "If We Ain't Got It, It's Gonna Be Hard to Find."

The memories of that giant, pumpkin-looking warehouse still make me smile when I think of the treasure I pulled from the shelves and storage bins. Comic books, miniature gears, pulleys, toy robots, a giant barrel of marbles, weird art; whatever you wanted was hidden somewhere in the superstore's dark, congested corners.

My appreciation for gears, bearings, pumps, electronics, motors, vintage computers, metal parts and old machinery—consistently featured in the background of most Terry Gilliam films—probably stems from aimlessly walking the Whooping Bowl aisles and imagining a beautiful mechanical world of junk-deco art, steam-powered machinery and never-ending ductwork.

The store would eventually shut down, and Michigan residents would refer to the old building as a "colossal eye sore, falling into a permanent state of disrepair. My brother and I, however, have wonderful memories of scavenging the building for anything mechanical, tangible, quirky yet modestly priced.

I was thrilled to hear residents had reopened the Whoopee Bowl site in October 2025 as a new destination for antique collectors and treasure hunters. After 17 sets of blueprints and four and a half years of construction, the Whoopee Bowl triumphantly returned to the area with a deeper shade of orange paint. It also features Rusty Relics Vintage Antiques, with more than 100 vendors across 16,000 square feet of space.

Though my kids are young adults at this point, I am looking forward to tossing them in the SUV, getting lost in the woods and finding out how far \$10 will go at the Whoopee Bowl in 2026—my guess is not very far at all.





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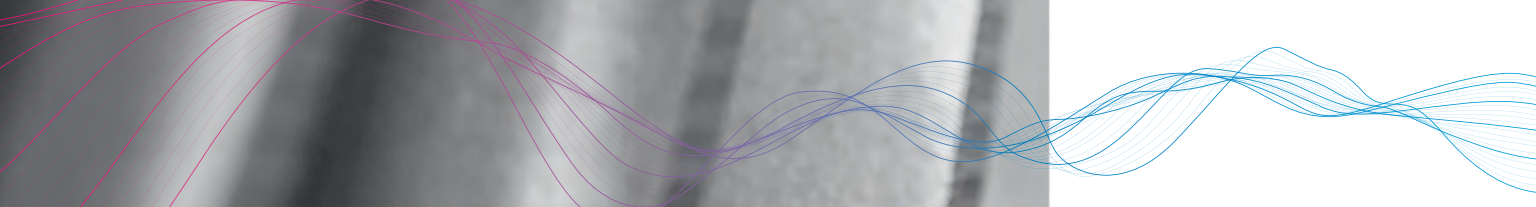
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