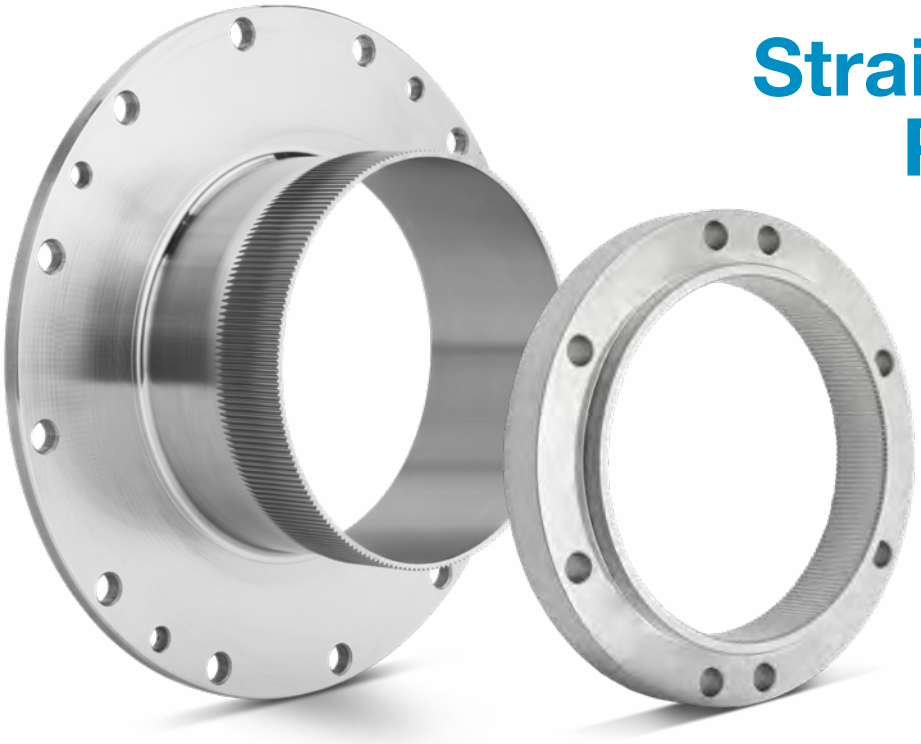


Strain wave gearbox with internal and external gears, both cut on 80PS.
(All Images: Gleason Corp.)

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.

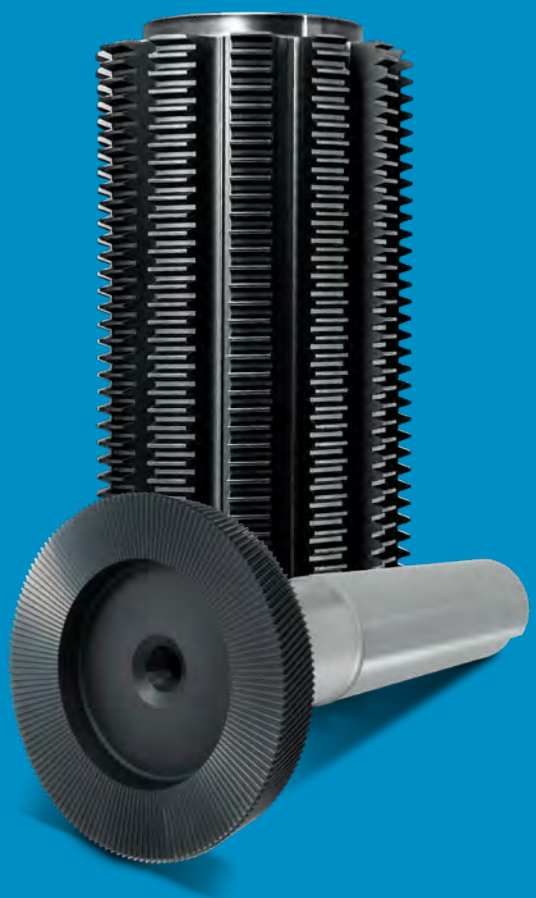
The world's leading robotics manufacturers have been quick to recognize the benefits of strain wave gears and are now gearing up to meet demand. Naturally, strain wave gears for these applications vary in size and complexity. In general, they consist of three main components: a wave generator that delivers 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.

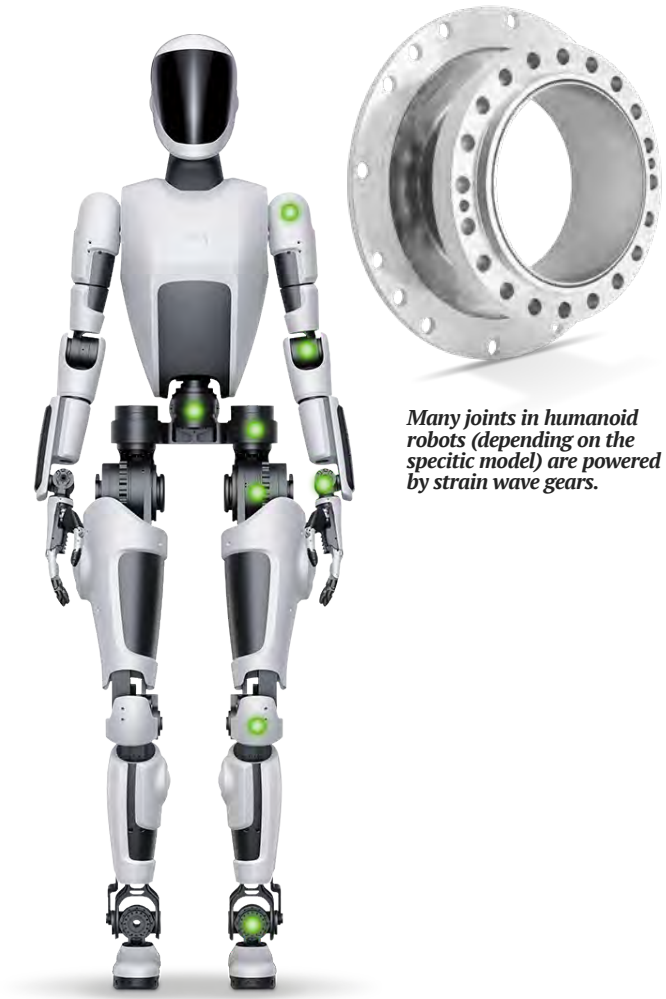


Case in Point

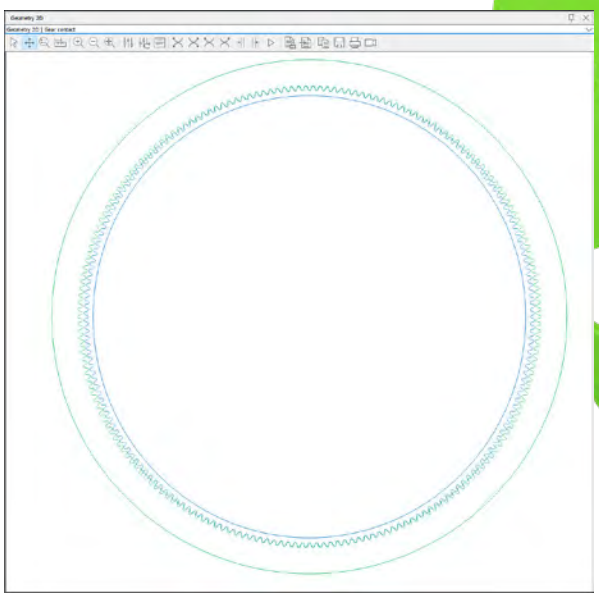
Production of a strain wave circular spline internal gear with 320 teeth. In the case of this small-module internal gear (about module 0.25 mm) with a high number of teeth, power skiving proves to be the perfect solution to achieve significant improvements in productivity and quality. For this application, 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 specitic 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, $K_{H\alpha}$, 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.

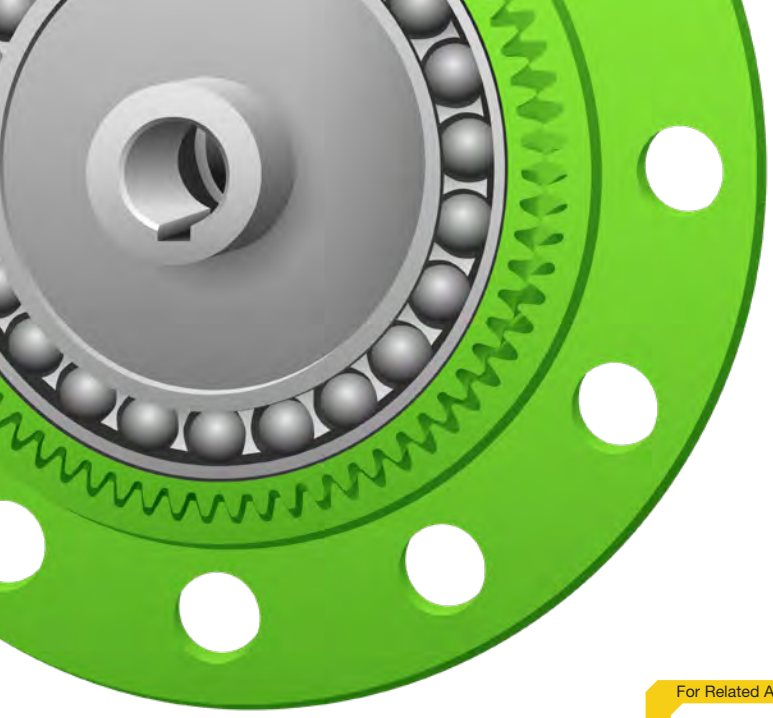
Manufacture: Single Platform, Multiple Processes

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 hobbed, 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

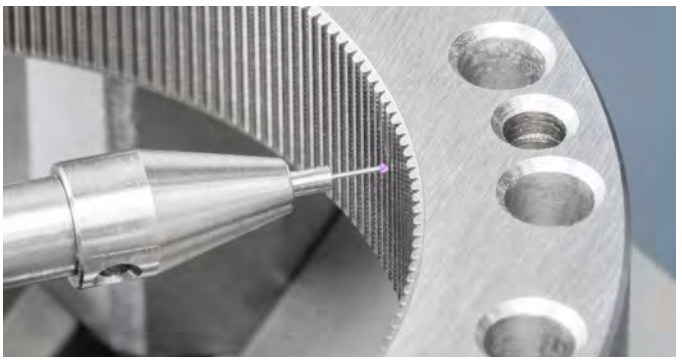
Strain wave gears place particularly demanding requirements on gear metrology. In addition to their small module design, which is essential to the functionality of the gearbox, they require the highest levels of measurement, quality and reliability. For small gears, Gleason offers the 175GMS nano metrology 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.

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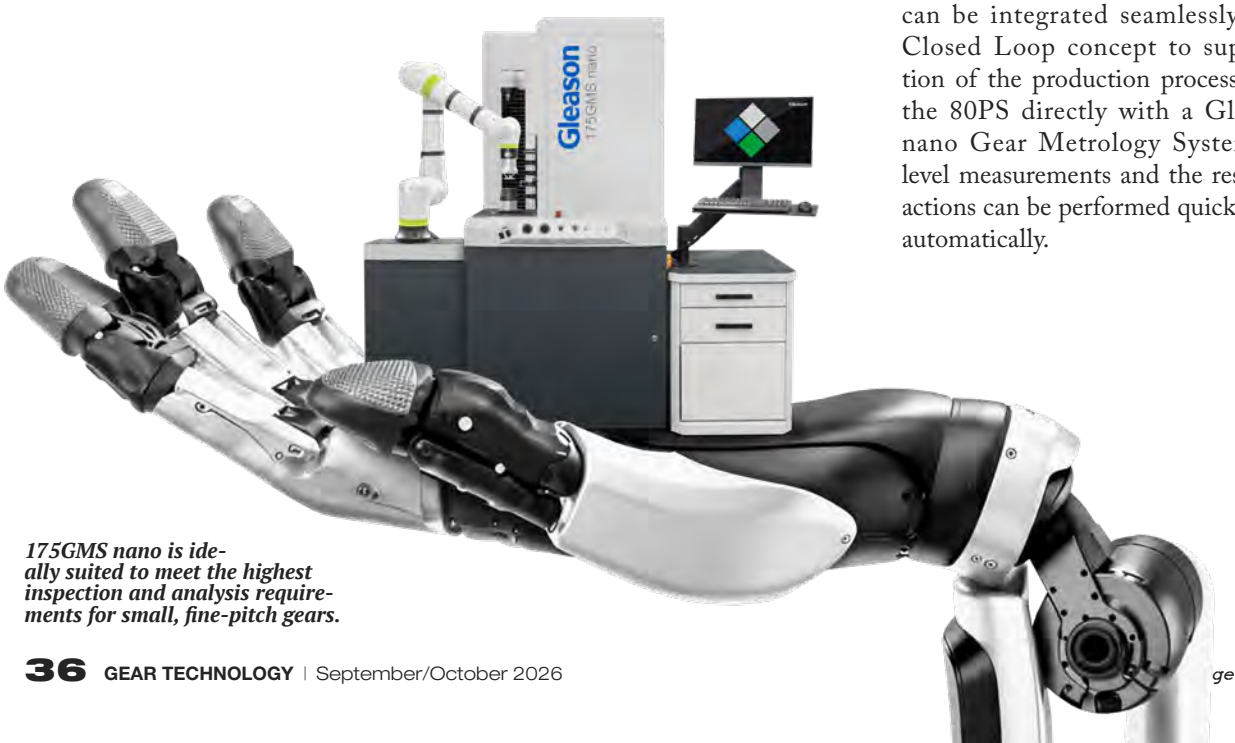

175GMS nano is ideally suited to meet the highest inspection and analysis requirements for small, fine-pitch gears.