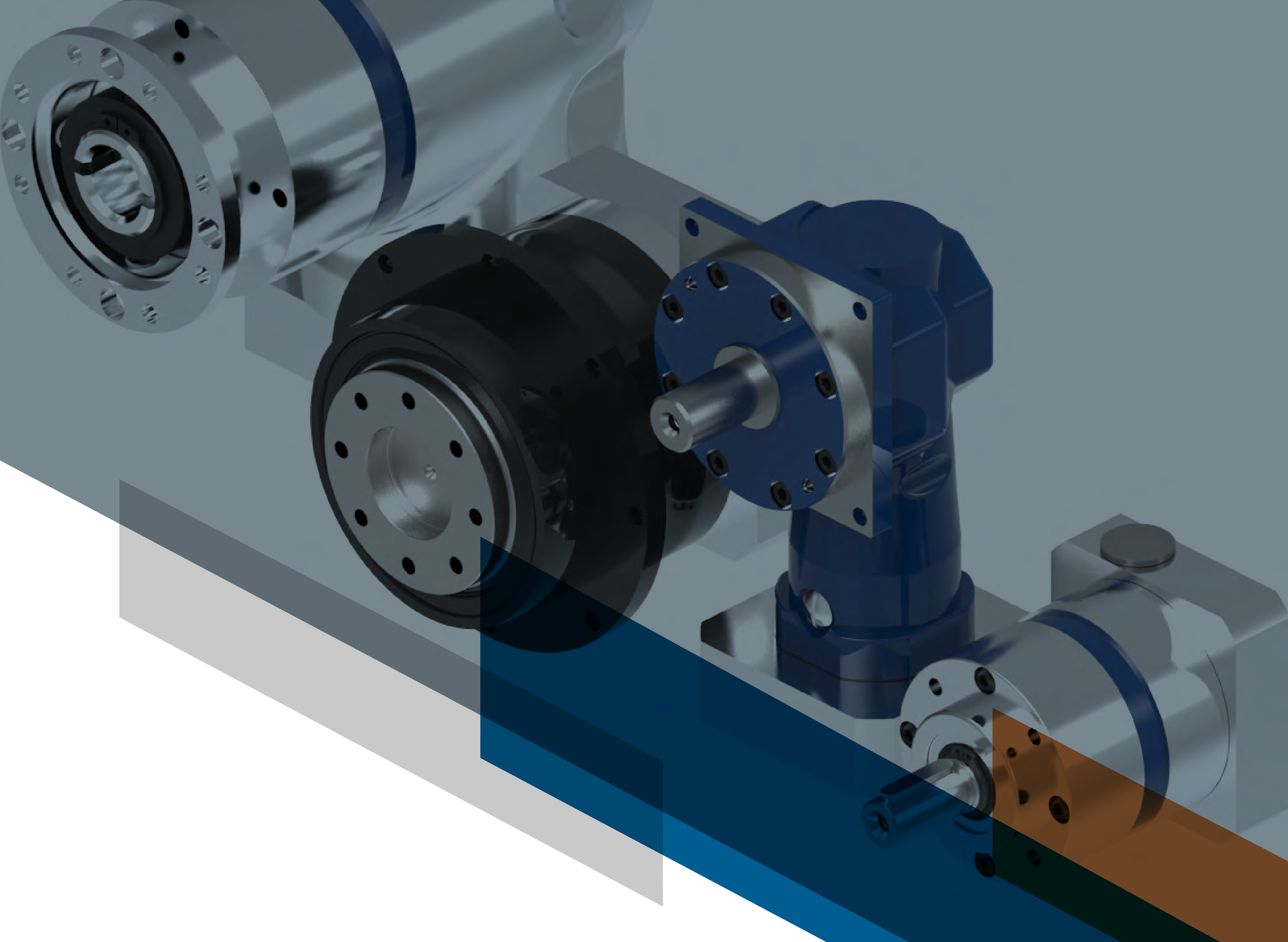

MOTION DESIGN GUIDE

GEARBOXES

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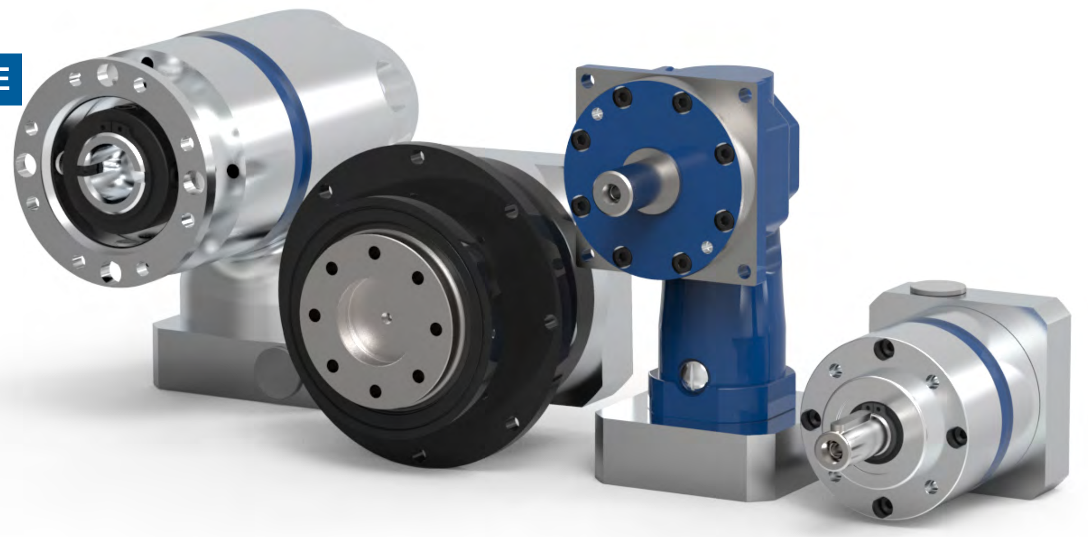
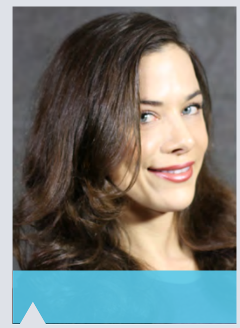


The function of gearing is to mesh with other gear elements to transmit altered torque and rotation. In fact, gearing can change the speed, torque and direction of motion from a drive source. In this Design Guide, the editors of Design World detail the most common gear types for precision applications — as well as the contained gear trains known as gearboxes (those mechanical components consisting of a series of integrated gears) and other iterations to simplify integration and servotuning.



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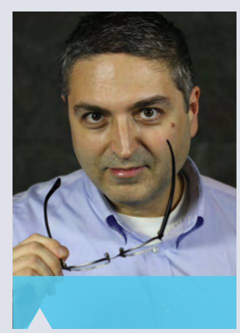

MILES BUDIMIR
Senior editor

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COMMON GEAR GEOMETRIES

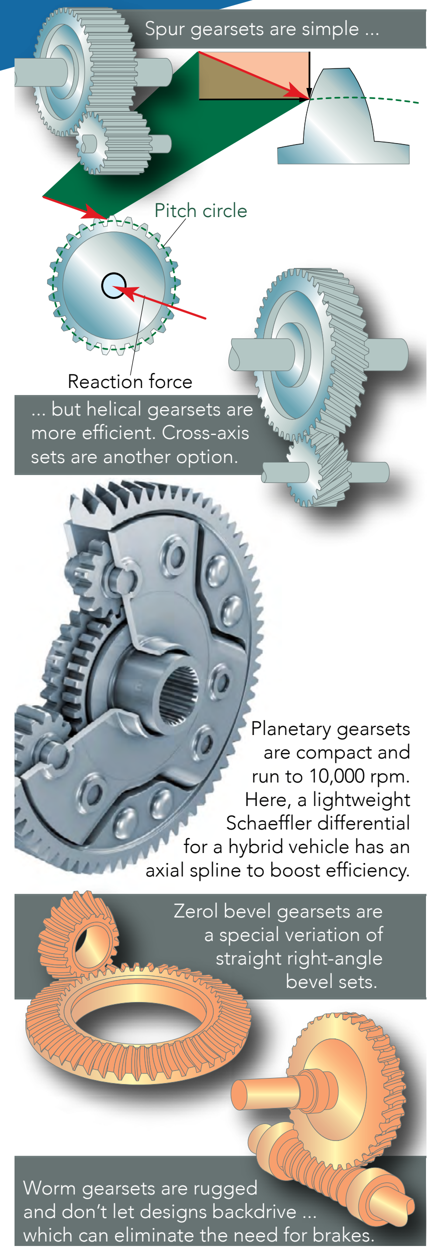
Recall a basic premise of gear function: When two gears with an unequal number of teeth or engaging elements mesh, the mechanical advantage makes their rotational speeds and torques different. In the simplest of setups, gears are flat with spur teeth — with edges parallel to the shaft — and the input gear's shaft is parallel to that of the output.

Spur gears mostly roll through meshing, so can be 98% or more efficient per reduction stage. However, there is some sliding between tooth surfaces, and initial tooth-to-tooth contact occurs along the whole tooth width at once, causing small shock loads that induce noise and wear. Sometimes lubrication helps mitigate these issues.

In slightly more complex setups, parallel-axis gearsets have helical gears that engage at an angle between 90° and 180° for more tooth contact and higher torque capacity.

Helical reducers are suitable for higher-horsepower applications where long-term operational efficiency is more important than initial cost. Helical gear teeth engage gradually over the tooth faces for quieter and smoother operation than spur gearsets. They also tend to have higher load capacities.

The ratio of a helical or bevel gearset is the number of teeth in the larger gear divided by the number of teeth in the smaller gear. Other gear types such as planetary gears have more complex ratio relationships.



Spur gearsets are simple ...

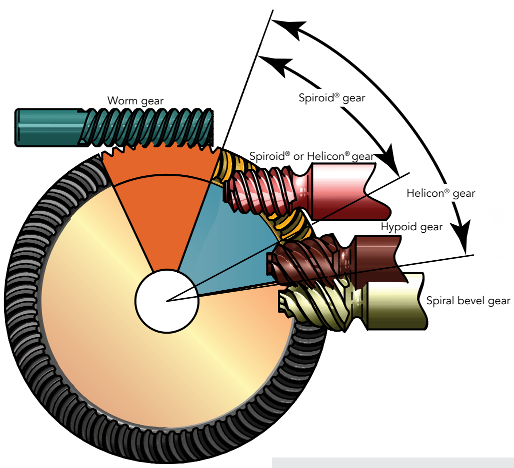
... but helical gearsets are more efficient. Cross-axis sets are another option.

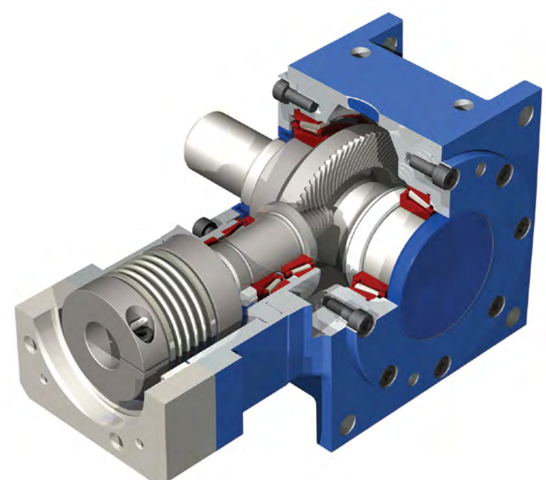
Planetary gearsets are compact and run to 10,000 rpm. Here, a lightweight Schaeffler differential for a hybrid vehicle has an axial spline to boost efficiency.

Zerol bevel gearsets are a special veriation of straight right-angle bevel sets.

Worm gearsets are rugged and don't let designs backdrive ... which can eliminate the need for brakes.

Compared to traditional right-angel bevel and worm gearing, the gear-centerline offset of Spiroid and Helicon branded gearing allows for more tooth-surface contact and results in higher contact ratios. This boosts torque capacity and smooths motion transmission. The gearsets are quiet, stiff, and compact ... delivering ratios from 3:1 to 300:1 and beyond.





Hypoid gearing, such as the GAM Dyna-Series, with its offset pinion, falls between bevel and worm gearing resulting in high efficiencies, high torque capability, and ratios up to 15:1. Image courtesy of GAM Enterprises, Inc.

(continued)

COMMON GEAR GEOMETRIES

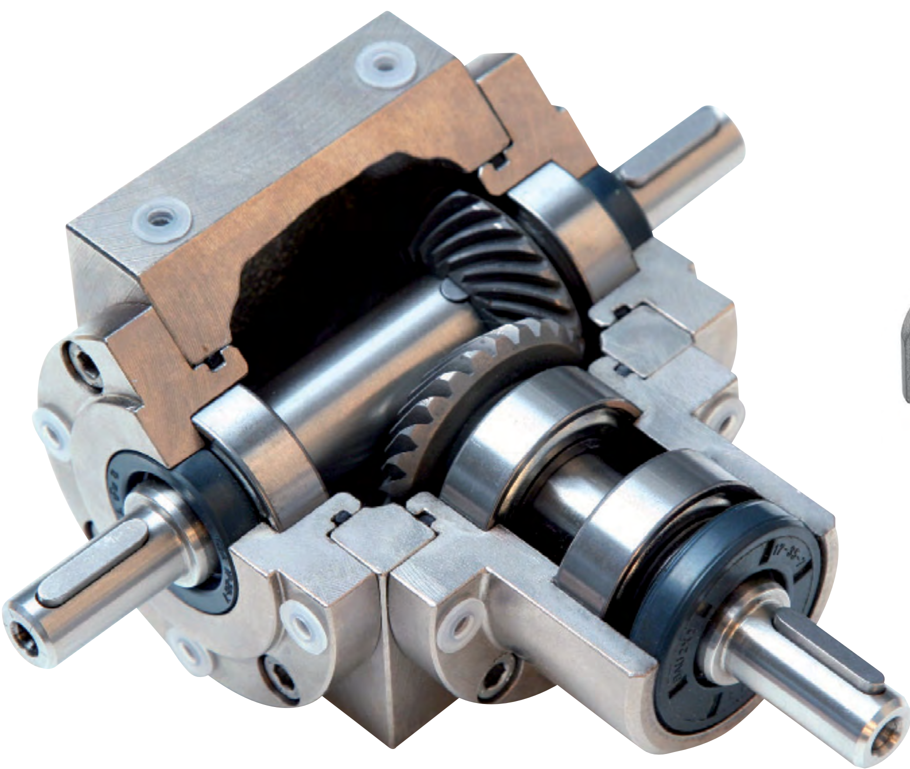
One caveat: Angled tooth contact generates thrust that the machine frame must resolve.

No matter the subtype, most parallel-axis gearsets have gear teeth with tailored involute profiles — customized versions of the rolled trace off a circle with an imaginary string. Here, mating gears have tangent pitch circles for smooth rolling engagement that minimizes slipping. A related value is the pitch point, is where one gear initially contacts its mate's pitch point. Involute gearsets also have an action path that passes through the pitch point tangent to a base circle.

Besides parallel-axis gearsets, there are non-parallel and right-angle gearsets. These have input and output shafts that protrude in different directions to give engineers more mounting and design options. The gear teeth of such gearsets are either bevel (straight, spiral, or Zerol), worm, hypoid, skewed, or crossed-axis helical gears. The most common are bevel gearsets with teeth cut on an angular or conical shape.

Hypoid gears are much like spiral-bevel gearsets, but the input and output shaft axes don't intersect, so it's easier to integrate supports. In contrast, Zerol gearsets have curved teeth that align with the shaft to minimize thrust loads.

GAM's V-Series Bevel Gearboxes use spiral bevel gearing for high efficiency (up to 98%) and precision of 10-30 arcmins suitable for motion control applications. Spiral bevel gearing allows these types of gearboxes to be highly configurable with many shaft arrangements including hollow output. Image courtesy of GAM Enterprises, Inc.



A planetary gerbox with helical gearing will have higher torque and quieter operation than straight gearing. In addition, machining the ring gear directly into the house, as with the GAM SPH helical planetary gearbox, maximizes stiffness. Image courtesy of GAM Enterprises, Inc.

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WHAT IS **A GEARBOX?**

When it comes to gearing components, things can get confusing quickly. There are many terms that gear manufacturers as well as engineers and designers use to talk about what sometimes is essentially the same thing. The term "gearbox" is one of those terms, often times used interchangeably with gearhead or gear reducer … even though they sometimes refer to slightly different physical arrangements of gears.

Inline and right angle gearboxes use different types of gearing and configurations to fit different types of motion control applications. L-to-R: Right-angle bevel with hollow output, helical planetary with flange output, hypoid with shaft output, planetary with shaft output. Image courtesy of GAM Enterprises, Inc.

The most basic definition of a gearbox is that it is a contained gear train, or a mechanical unit or component consisting of a series of integrated gears within a housing. In fact, the name itself defines what it is — a box containing gears. In the most basic sense, a gearbox functions like any system of gears; it alters torque and speed between a driving device like a motor and a load.

The gears inside of a gearbox can be any one of a number of types from bevel gears and spiral bevel gears to wormgears and others such as planetary gears. The gears are mounted on shafts, which are supported by and rotate via rolling element bearings. The gearbox is a mechanical method of transferring energy from one device to another and is used to increase torque while reducing speed.

Gearboxes are used in many applications including machine tools, industrial equipment, conveyors, and really any rotary motion power transmission application that requires changes to torque and speed requirements.

So it's clear — a gearbox is always a fully integrated mechanical component consisting of a series of mating gears contained in a housing with shafts and bearings (to support and resolve loads) and in many cases a flange for motor mounting. Most of the motion industry makes no differentiation between the terms gearhead and gearbox. But in a few contexts, the term gearbox specifically refers to housed gearing as described above while the more general term gearhead refers to assemblies otherwise open gearing that installs within some existing machine frame. The latter are targeted to compact or battery-powered mobile designs necessitating especially tight integration and omission of extra subcomponents. Here, a series of parallel plates might support the gear-train shafts (and their bearings) and allow bolting to a motor face.

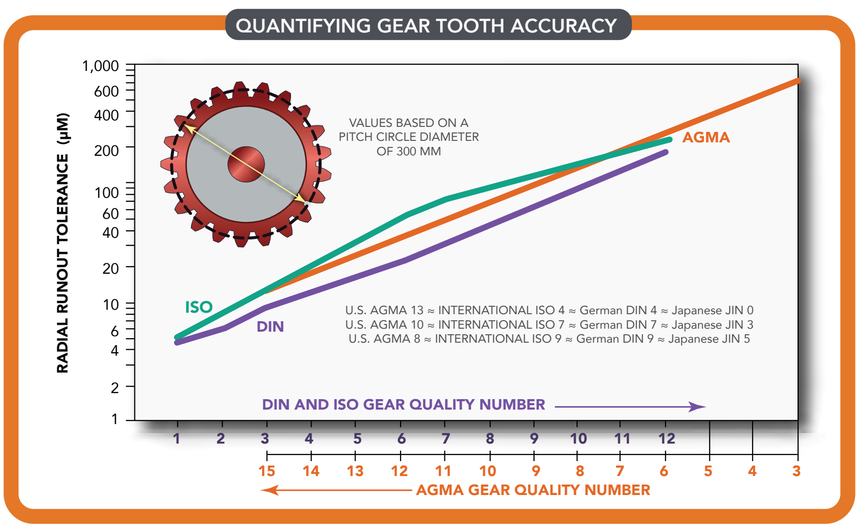
Though beyond the scope of this FAQ, other open gearing simply mounts to the electric-motor output and operates exposed to the environment. Some such open gearing is self-lubricating — constructed of dimensionally stable polyamides or similar materials engineered to meet stringent cleanliness, vibration, weight, and cost requirements.

SERVOGEARING AND THE SPECIAL CASE OF PLANETARY SETS

Servo systems are precision-motion setups with feedback and (in most cases) fairly stringent accuracy demands. So for these designs, engineers should pick servogear reducers with good torsional stiffness, reliable output torque, and minimal backlash. OEMs tasked with integrating servo systems should look for quiet reducers that easily mount to the motor and require little or (if possible) no maintenance. In fact, advanced machinery often integrates servogears into application-specific electromechanical arrangements … and several of these arrangements are common enough to have specific labels. Here is a look at some of the most widespread.

Gearmotor: This complete motion component is a gear reducer integrated with an ac or dc electric motor. Usually the motor includes the gears on its output (typically in the form of an assembled gearbox) to reduce speed and boost available output torque. Engineers use gearmotors in machines that must move heavy objects. Speed specifications for gearmotors are normal speed and stall-speed torque.

Gearbox: This is a fully integrated mechanical component consisting of a series of mating gears contained in a housing with shafts and bearings (to support and resolve loads) and in many cases a flange for motor mounting.



Gearing quality (in the form of tooth dimensional accuracy or tolerances) are quantified by ISO, DIN, and AGMA values plotted against radial runout. In some contexts, ratings and standards from the American Petroleum Institute (API) are also applicable.

The quality metric is somewhat controversial, because there is no universal system of accountability to ensure suppliers meet any given quality value. For this reason, it's recommended that design engineers require gear suppliers to disclose the manufacturing and measuring methods used for maintaining published quality values.

Gearhead: Most of the motion industry makes no differentiation between the terms gearhead and gearbox. But in a few contexts, the term *gearbox* specifically refers to housed gearing as described above while the more general term *gearhead* also refers to assemblies of otherwise open gearing that installs within some existing machine frame. The latter are often targeted to compact, consumer-grade, or battery-powered mobile designs necessitating especially tight integration and omission of potentially redundant subcomponents. In one variation, a series of parallel plates might support gear-train shafts (and bearings) and allow bolting to a motor face.

Though beyond the scope of this Design Guide, note that other open gearing simply mounts to the electric-motor output and operates exposed to the environment. Some such open gearing is self-lubricating — constructed of dimensionally stable polyamides or similar materials engineered to meet stringent cleanliness, vibration, weight, and cost requirements.

WHY ARE PLANETARY GEARBOXES PREFERRED FOR SERVO APPLICATIONS?

In a servo application — one in which a feedback device is used to control torque, position, or speed of a linear or rotary system — the ratio of the load inertia to the motor inertia is a critical factor in system performance. A lower inertia ratio allows the motor to more precisely control the load and avoid overshoot and oscillations, improving system responsiveness. If the actual inertia of the load cannot be changed, adding a gearbox to the system can reduce the amount of load inertia reflected back to the motor (essentially, making it seem to the motor as if there is less inertia to be

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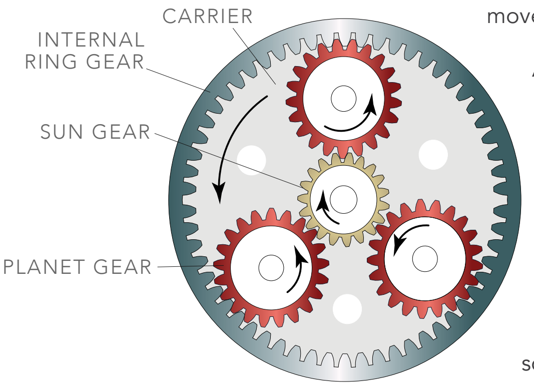
SERVOGEARING AND THE SPECIAL CASE OF PLANETARY SETS



moved).

A gearbox reduces the reflected load inertia (inertia the motor "sees") by the square of the gear ratio, so adding a gearbox can make a significant improvement in the system's inertia ratio. Gearboxes also multiply the torque from the motor to the load by an amount proportional to the gear ratio, while at the same time lowering the required motor speed by the same amount. In some applications, this means a smaller motor can be used, and the motor can be operated at a higher, more efficient speed.

J_L = *inertia of load reflected to motor*

J_M = *inertia of motor*

J_D = *inertia of drive (screw, belt & pulley, or actuator)*

J_E = *inertia of external (moved) mass*

J_C = *inertia of coupling*

J_G = *inertia of gearbox*

i = *gear ratio*

But any gearbox can reduce load inertia, multiply torque, and reduce speed, so why do many servo applications use planetary gearboxes? Because planetary gearboxes do all these things with higher stiffness, less backlash, better efficiency, and lower noise than other gear types.

SUMMARY OF HYPOID REDUCERS

Hypoid gearboxes are a type of spiral bevel gearbox — with the difference that hypoid gears have axes that are non-intersecting and not parallel. In other words, the axes of hypoid gears are **offset** from one another. The basic geometry of the hypoid gear is hyperbolic rather than having the conical geometry of a spiral bevel gear.

In a hypoid gearbox, the spiral angle of the pinion is larger than the spiral angle of the gear, so the pinion diameter can be larger than that of a bevel gear pinion. This provides more contact area and better tooth strength, which allows more torque to be transmitted and high gear ratios (up to 200:1) to be used.

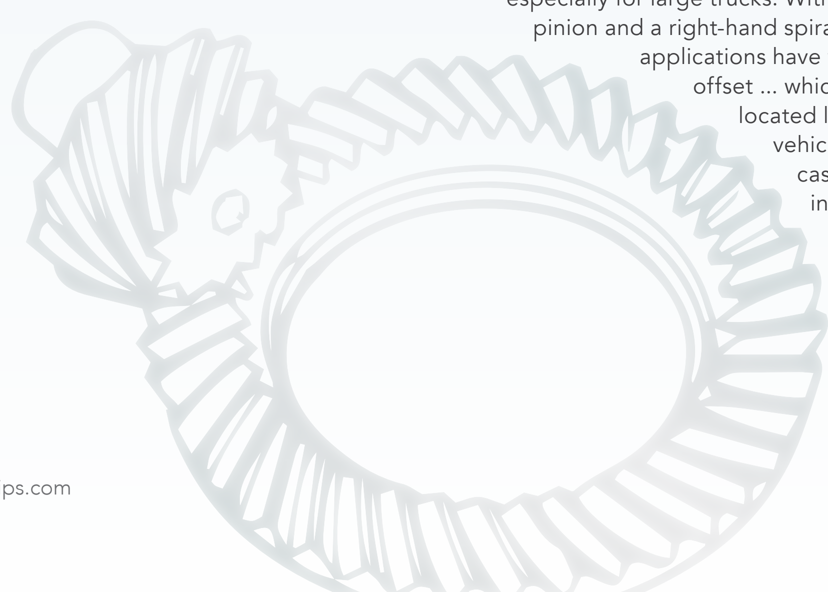
Because the shafts of hypoid gears don't intersect, bearings can be used on both sides of the gear to provide extra rigidity.

The difference in spiral angles between the pinion and the crown (larger gear) causes some sliding along the teeth, but the sliding is uniform, both in the direction of the tooth profile and longitudinally. This gives hypoid gearboxes very smooth running properties and quiet operation. But it also requires special extreme pressure (EP) gear oil to maintain effective lubrication due to the pressure between the teeth.

Hypoid gearboxes are generally used where speeds exceed 1,000 rpm ... although above 8,000 rpm ground gears are recommended.

However, hypoid gearing is also useful for lower speed applications that require extreme smoothness of motion or quiet operation. In multi-stage gearboxes, hypoid gears are often used for the output stage, where lower speeds and high torques are required.

The most common application for hypoid gearboxes is in the automotive industry, where they are used in rear axles — especially for large trucks. With a left-hand spiral angle on the pinion and a right-hand spiral angle on the crown, these applications have what is known as a below-center offset ... which allows the driveshaft to be located lower in the vehicle. This lowers the vehicle's center of gravity and in some cases reduces interference with the interior vehicle space.



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SERVOGEARING AND THE SPECIAL CASE OF PLANETARY SETS

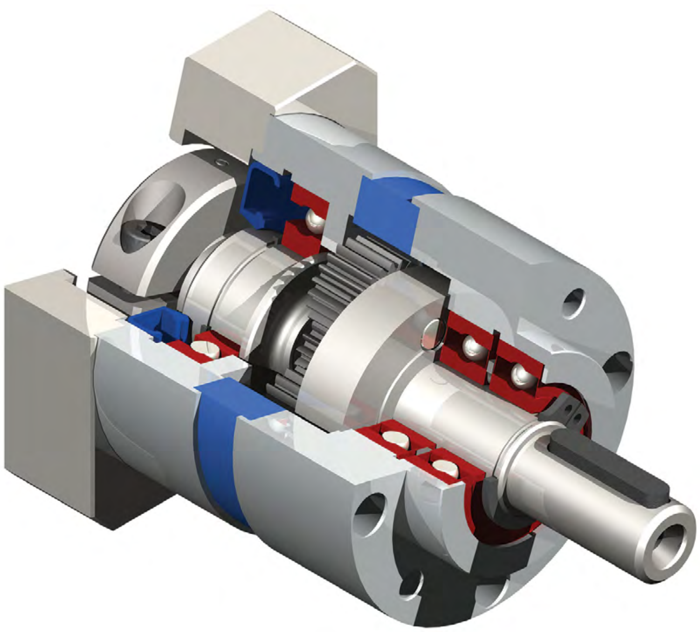
Planetary gearboxes use three gear types to transmit torque: planetary gears, a sun gear, and a ring gear. The attached motor drives the sun gear, which sits in the center of the gear assembly. Multiple planetary gears engage with both the sun gear and the ring gear, which is stationary and fixed inside the gearbox housing. As the sun gear rotates, it drives the planetary gears to spin on their own axes and revolve around the sun gear. The positions of the planetary gears are set by a carrier, which also incorporates the output shaft.

In this arrangement, the load is shared among multiple gear teeth, which gives planetary designs their high stiffness and contributes to low backlash — as low as 1 to 2 arcminutes in some designs. High stiffness is also important for applications that require frequent start-stop cycles or changes in rotational direction.

Planetary designs are compact, providing high reduction ratios in a small overall package. This compact design also means they have low inertia, which is especially beneficial in servo applications because the gearbox inertia adds directly to the load inertia that the motor must balance. And although planetary gearboxes, like other gearbox designs, can be lubricated with either grease or oil, most are lubricated by the manufacturer with grease and don't require re-lubrication or maintenance for the life of the gearbox.

Single-stage planetary gearboxes (as described above) can typically provide reduction ratios as low as 3:1 or as high as 10:1. Multi-stage gearboxes provide higher ratios by incorporating two or three planetary stages in a serial arrangement. To accomplish this, the length of the outer ring gear is increased, and the carrier of the first planetary stage drives the sun gear of the next stage. Because they're connected in a serial arrangement, the reductions of the individual stages are multiplied to get the final output reduction. For example, a multi-stage gearbox that incorporates a 5:1 stage and a 3:1 stage will have an output ratio of 15:1. Multi-stage designs provide an even better torque-to-size ratio than standard single-stage designs, but at the expense of efficiency.

The GAM EPL gearbox's modular design makes it easy to offer multiple shaft, flange, and hollow outputs, as well as custom assemblies. Image courtesy of GAM Enterprises, Inc.



In standard planetary gearboxes, the ring gear is stationary. By holding the planet gear carrier stationary instead, the outer ring gear rotates. This results in a gearbox with a rotating housing, such as the GAM GML gearbox. This is an ideal arrangment for an AGV or AMR wheel drive, with a large output for mounting the wheel, a pilot surface for centering the wheel, and the motor mounted inline with the wheel. Image courtesy of GAM Enterprises, Inc.

HOW TO SIZE AND **SELECT A GEARBOX**

Application-tailored and custom gearboxes are increasingly common, mainly because they're easier than ever to manufacture to specification. That's not to say that the design work isn't challenging. However, modern manufacturing lets some suppliers make gearboxes and components to meet specific application requirements.

New supplier approaches to giving engineering support (as well as new machine tools, automation, and design software) now let OEMs and end users get reasonably priced gearing even in modest volumes.

When enlisting help from a consultant or custom manufacturer, an engineer is more likely to get gearing that mounts properly and performs to specification after reviewing the following and answering as many of these questions as possible:

What's the input speed and horsepower? What's the gearbox target output speed or output torque? This partially defines the required gear ratio. What are the characteristics of use? How many hours per day will the gearbox run? Will it need to withstand shock and vibration?

How overhung is the load? Is there internal overhung load? Remember that bevel gears usually can't accommodate multiple supports, as their shafts intersect … so one or more gears often overhang. This load can deflect the shaft which misaligns the gears, in turn degrading tooth contact and life. One potential fix here is straddle bearings on each side of the gear.

Does the machine need a shaft or hollow-bore input … or a shaft or hollow-bore output? How will the gearing be oriented? For instance, if specifying a right-angle worm gearbox, does the machine need the worm over or under the wheel? Will the shafts protrude from the machine horizontally or vertically? Does the environment necessitate corrosion-resistant paints or stainless-steel housing and shafts?

Service factor: The starting point for most gearbox manufacturers is to define a service factor. This adjusts for such concerns as type of input, hours of use per day, and any shock or vibration associated with the application. An application with an irregular shock (a grinding application, for example) needs a higher service factor than one that's uniformly loaded. Likewise, a gearbox that runs intermittently needs a lower factor than one used 24 hours a day.

Class of service: Once the engineer determines the service factor, the next step is to define a class of service. A gearbox paired to a plain ac motor driving an evenly loaded, constant-speed conveyor 20 hours per day may have a service class 2, for example.

This information comes from charts from gearbox manufacturers that list classes of service. To use these charts, the design engineer must know input horsepower, application type, and target ratio. For instance, suppose that an application needs a 2-hp motor with a 15:1 ratio. To use the chart, find the point where 2 hp and 15:1 ratio intersect. In this case, that indicates a size 726 gearbox. According to one manufacturer's product-number system, size 726 defines a gearbox that has a 2.62 center distance. Such charts also work in reverse, to let engineers confirm the torque or speed of a given gearbox size.

Overhung load: After the designer picks a size, the gearbox manufacturer's catalog or website lists values for the maximum overhung load that is permissible for that sized unit. Tip: If the load in an application exceeds the allowed value, increase the gearbox size to withstand the overhung load.

Mounting: At this point, the designer or manufacturer has defined the gearbox size and capability. So, the next step is to pick the mounting. Common mounting configurations abound, and gearbox manufacturers offer myriad options for each unit size. A flanged input with hollow bore for a C-frame

Class II Service: Gear set with single reduction (a 1.25 service factor)

Reducer ratio	Output rpm	Input horsepower at 1,750 rpm													
		1/6	1/4	1/3	1/2	3/4	1	1.5	2	3	5	7.5	10	15	20
5	350	710	710	710	710	713	715	718	718	724	730	-	-	-	-
10	175	710	710	710	713	715	718	721	724	726	730	738	752	752F	760F
15	117	710	710	713	713	718	721	724	726	730	738	752	752	760	-
20	88	710	713	713	715	718	721	726	730	732	752	752F	760	-	-
25	70	713	713	713	718	721	724	726	730	732F	-	-	-	-	-
30	58	713	713	715	718	721	724	730	732	738F	752	760	-	-	-
40	44	713	713	715	721	724	726	732	732F	752	752F	760F	-	-	-
50	35	713	715	718	721	726	730	732F	738F	752	760F	-	-	-	-
60	29	713	718	721	724	730	732	738	752	752F	-	-	-	-	-

Most of the time, design engineers pair gearsets with electric motors. In some case, these setups get a roman-numeral service class number (I, II or III, for example) that equates to the standalone gearset service factor (in this case 1.0, 1.41, or 2.0).

(continued)

HOW TO SIZE AND SELECT A GEARBOX

motor combined with an output shaft projecting to the left may be the most common mounting, but there are many other choices. Options such as mounting feet for either above or below the body of the gearbox, hollow outputs, and input and output configuration are all possible. All gearbox manufacturers list their mounting options as well as dimensional information in catalogs and websites.

Lubricant, seals, and motor integration: Once unit size and configuration are complete, a few specifications remain. Most manufacturers can ship gearboxes filled with lubrication. However, most default to shipping units empty to let users fill them on site.

For applications where there is a vertical shaft down, some manufacturers recommend a second set of seals. Because many gearboxes eventually mount to a C-frame motor, many manufacturers also offer to integrate a motor onto the gearbox and ship the assembly as a single unit.

It's best to work with consultants and even use custom gear designs if the application needs a unique motor-gearbox combination. Some combinations are more efficient. In fact, working with manufacturers to get a pre-engineered gearmotor ensures that the motor-gearbox combination will work and deliver the specifications from calculations and testing performed by the manufacturer. Review the manufacturer's performance calculations to determine if the chosen gearmotor will cause any issues within the application.

Remember that today's custom and standard gearing aren't mutually exclusive. Where fully-custom gearboxes aren't feasible (if quantities aren't high enough, for example) consider working with manufacturers that sell gearboxes built to order from standard modular subcomponents. Otherwise, for small quantities of true custom gearboxes, look for manufacturers that leverage the latest CAD software, CAM software, and machine tools to streamline post-processing work and reduce the cost of one-offs.

One final tip: Once the gearmotor has been chosen and installed in the application, perform several testruns in sample environments that replicate typical operating scenarios. If the design exhibits unusually high heat, noise or stress, repeat the gear-selection process or contact the manufacturer.

Torque and speed output chart

Reducer ratio is 15	Output rpm is 116.7	Non-flanged reducers: Gear capacity: Output torque (lb-in.)	Horsepower IN	Horsepower OUT	Efficiency	Size	Flanged reducers (in a gearmotor): Ratings: Motor hp	Output (lb-in.)	Service class	Available styles: F	QC	FAN	HF	SF	HQC	RF	SS	Bore code
		552	1.13	1.02	0.90	718-15	1	489	I	•	•		•	•	•		•	B5
							0.75	367	II	•	•		•	•	•		•	B5
							0.50	244	III	•	•		•	•			•	B5
		841	1.72	1.56	0.90	721-15	1.5	733	I	•	•		•	•	•		•	B7
							1	489	II	•	•		•	•	•		•	B7
							0.75	367	III	•	•		•	•	•		•	B5
		1,159			0.92	724-15	2	990	I	•	•		•		•			B7
							1.5	743	II	•	•		•		•			B7
							1	495	III	•	•		•		•			B7
		1,466			0.92	726-15	3	1,466	I	•	•		•	•	•			B9
							2	994	II	•	•		•	•	•		•	B7
							1.5	745	III	•	•		•	•	•		•	B7

This chart provides values for C-face motor input (flanged) or directly coupled (non-flanged) motors. It lets the design engineer verify that with 15:1 reduction, a 726 flanged gearbox outputs 116.7 rpm … and when used with a 2-hp motor, outputs 994 lb-in. of torque.

Note that the efficiency value here is the complete gearbox efficiency.

PLASTIC GEARS OVERVIEW

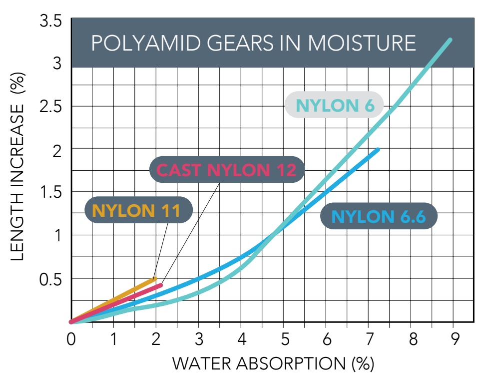
Electric-weapon geartrain image via Dreamstime

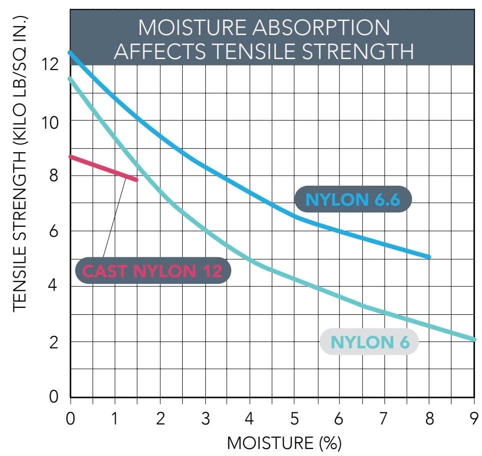
Plastic gears are primarily recognized for their quiet operation and resistance to rust — attributes that are important the food processing, medical equipment, and chemical processing industries, as well as in consumer applications. But plastic gears offer many other benefits, and advances in materials and manufacturing processes are helping to close the remaining performance gap between plastics and metals in gearing applications.

When determining whether a plastic gear will be suitable for a particular application, the most critical factor is environment. Some though not all plastics maintain less dimensional stability than metals ... and in a few cases, their strength and stiffness characteristics are dependent on temperature and exposure to water or chemicals. When properly specified, plastic gears will exhibit no swelling or shrinking.

Plastic and metal gears also experience different types of contact under load. Metal gears have primarily line contact, with one tooth in mesh at a time. But plastic gear teeth have an involute surface that deforms under load, distributing the contact pressure across a larger surface and allowing contact between adjacent teeth. This provides load sharing among teeth and helps to improve the life of plastic gears in some applications — especially those with high impact loads and relatively low continuous loads.

The lighter weight of plastic gears means they have lower inertia than their metal counterparts, which is essential for aerospace and some military applications. In addition, most plastic gears are capable of running without lubrication ... or can be embedded with lubricating materials such as graphite, silicone, or PTFE. However, some operating conditions benefit from (or even require) lubrication. Choosing a lubricant for plastic gears should take into consideration the environmental, load, and speed conditions in which the gears will operate. If the lubricant isn't compatible with the plastic material, stress cracking or even failure of the plastic can result.





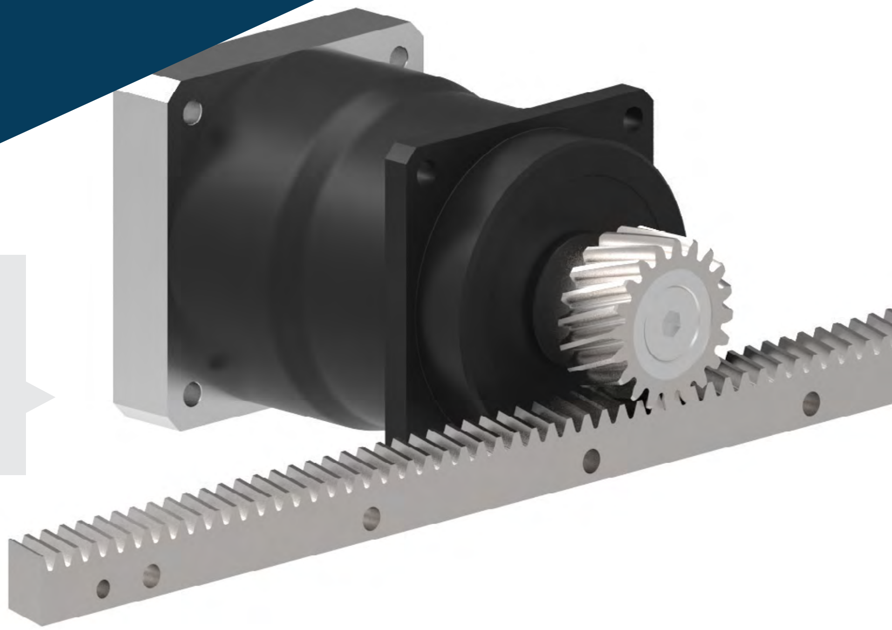
Due to sliding contact, plastic worm gears can in some cases experience heating which in turn decreases strength and accelerates wear. Speed capability is limited for such plastic worm gears, and lubrication is typically recommended.

The variety of plastics that are suitable for gear applications is extensive, but common choices include nylon, acetal, polycarbonate, polyphenylene sulfide, and polyurethane. The addition of glass fiber can improve the stiffness and heat conductivity of some materials, although it reduces the material's fatigue endurance. Plastic gears can processed by injection molding for lower cost than machined plastic gears. However, machined plastic gears typically offer better tooth strength and can be produced to meet higher AGMA quality levels than can be achieved with injection-molded versions.

A metal hub either molded into the gear or assembled after manufacturing can help in heat dissipation. It can also increase the rigidity of the gear and provide a secure surface for fastening the gear to the shaft.

Some plastics used in the construction of gears excel in wet settings. For example, cast nylon (Polyamide-12) gears submerged during operation never swell beyond a tenth of a percent. That's far less moisture absorption than other nylons used in constructing plastic gears — for maintenance of dimensions and rated tensile strength.

PITCH LINE VELOCITY IN **GEAR SIZING**



GAM helical rack along with a helical pinion mounted to a GAM SPH planetary gearbox. Using a smaller pinion requires less torque so a smaller gearbox can be used, despite requiring a faster rotational speed at the pinion for the same linear velocity.Image courtesy of GAM Enterprises, Inc.

In gearbox sizing, it's important to determine the required input speed in rpm and ensure that it doesn't exceed the gearbox maximum speed capability. The linear velocity of the gear teeth known as ***pitch line velocity*** also plays a significant role in gearbox performance.

Pitch line velocity is measured at the pitch line of the gear, which is midway along the length of the gear teeth. For circular gears, the pitch line is more correctly called the ***pitch circle*** — an imaginary circle that rolls without slipping when aligned with the pitch circle of the mating gear.

Strictly speaking, pitch line is the correct term when referring to a linear gear rack, and pitch circle is the correct term when referring to a circular gear. However, the term pitch line is often used when discussing the equivalent linear velocity of a circular gear — as in pitch line velocity.

Pitch line velocity is a function of the gear's pitch diameter and its rotational speed:

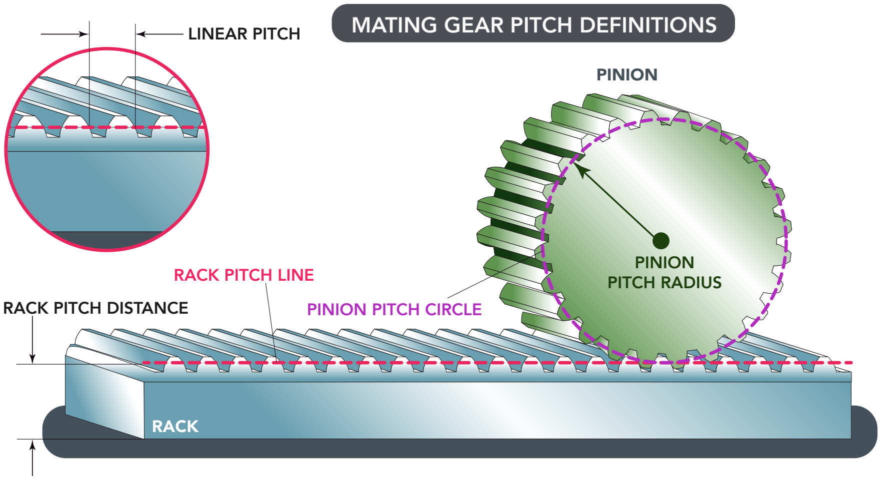
$$PLV = \frac{\pi d_p \omega}{60}$$

Where PLV = pitch line velocity (m/sec)
d_p = pitch diameter (m)
ω = rotational speed (rpm)

Pitch line velocity is important for gear design and selection for several reasons. The American Gear Manufacturers Association standard 9005-D94 Industrial Gear Lubrication specifies that a gear's pitch line velocity is one of the primary criteria for selecting gear lubrication.

Pitch line velocity also determines the contact time between gear teeth, which has a significant impact on the required oil viscosity.

High pitch line velocities are usually accompanied by light loads and short contact times, making low-viscosity oils suitable. However, low pitch line velocities are associated with high loads and long contact times, which make high-viscosity or even EP-rated oils necessary.



Technically speaking, a linear rack has a pitch line and a circular gear has a pitch circle.

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(continued)

PITCH LINE VELOCITY IN GEARBOX SIZING

In addition to lubrication considerations, pitch line velocity also affects the load capacity and service life of gear teeth. The ability of gears to transmit the required torque for the desired operating life depends on the ability of the gear teeth to withstand bending stress. Tooth bending stress is determined according to the Lewis formula:

$$\sigma = \frac{W_t P}{FY}$$

Where σ = tooth bending stress (MPa)
W_t = tangential force on tooth (N) and P = diametrical pitch (mm^{-1})
F = face width (mm) and Y = Lewis form factor

But as gear teeth come into initial contact, they experience greater stresses, based on the velocity of the gear. In order to account for these stresses, a velocity factor Kv was developed.

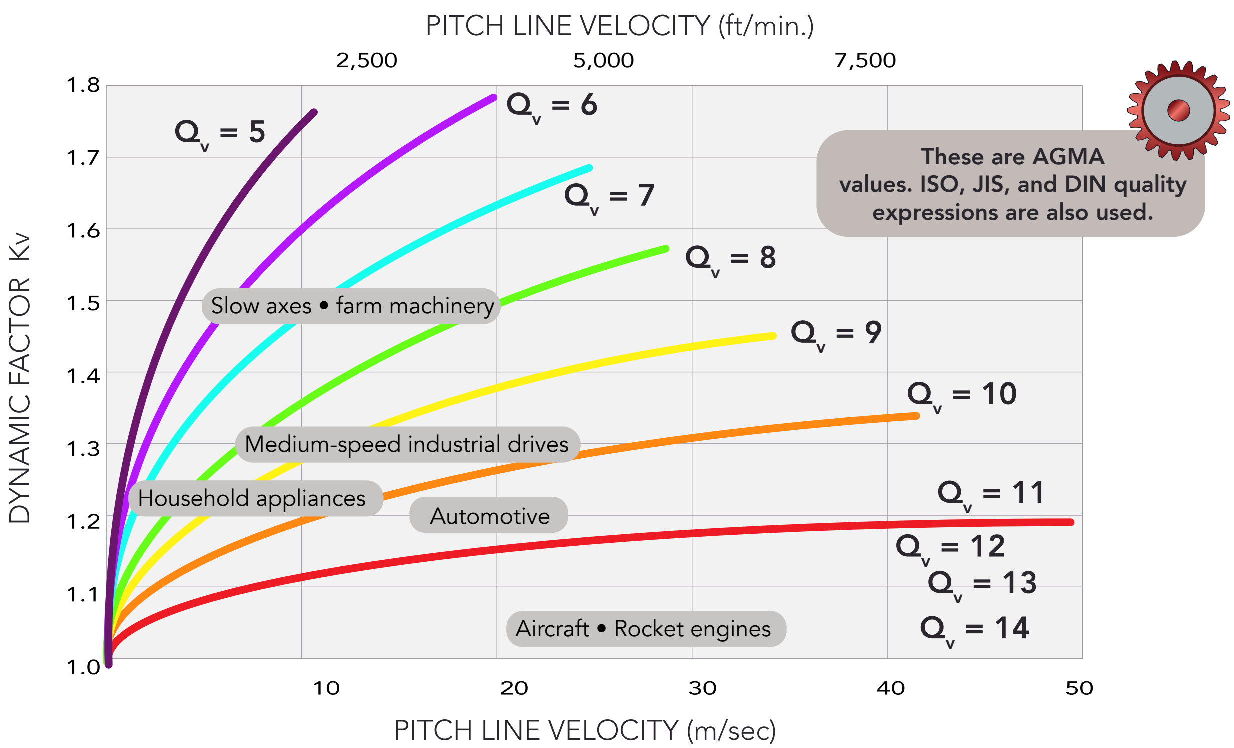
The velocity factor depends on both the pitch line velocity of the gear and the quality of the gear Qv and can be obtained from AGMA charts. This velocity factor Kv is used to modify the Lewis equation:

$$\sigma = \frac{W_t P K_v}{FY}$$

Thus the higher the pitch line velocity, the greater the bending stress on the gear teeth.

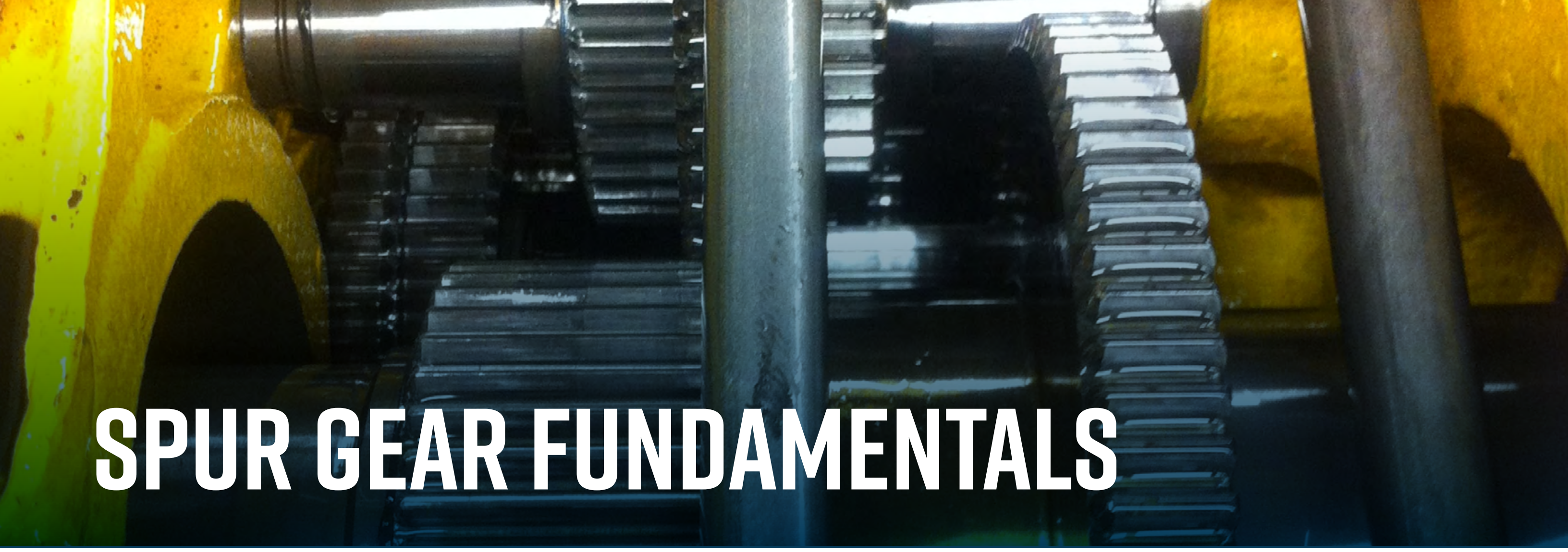
Note: The AGMA has developed an equation for bending stress that replaces the Lewis Form Factor with a geometry factor *J* and includes factors for other conditions that affect gear service life such as overload, load distribution, and mounting.

EXPRESSIONS OF GEAR QUALITY



The velocity factor depends on both the pitch line velocity of the gear and the quality of the gear (Qv) and can be obtained from AGMA charts as the one shown here.

Of course, design engineers should require their gear suppliers to disclose in detail the methods used to ensure published quality values.



SPUR GEAR FUNDAMENTALS

Spur gears are a type of cylindrical gearing with shafts that are parallel and coplanar ... and teeth that are straight and oriented parallel to the shafts. They're arguably the simplest and most common type of gear – easy to manufacture and suitable for a wide range of applications.

The teeth of a spur gear have an involute profile and mesh one tooth at a time. The involute form means that spur gears only produce radial forces (no axial forces), but the method of tooth meshing causes high stress on the gear teeth and high noise production. Because of this, spur gears are typically used for lower speed applications, although they can be used at almost any speed.

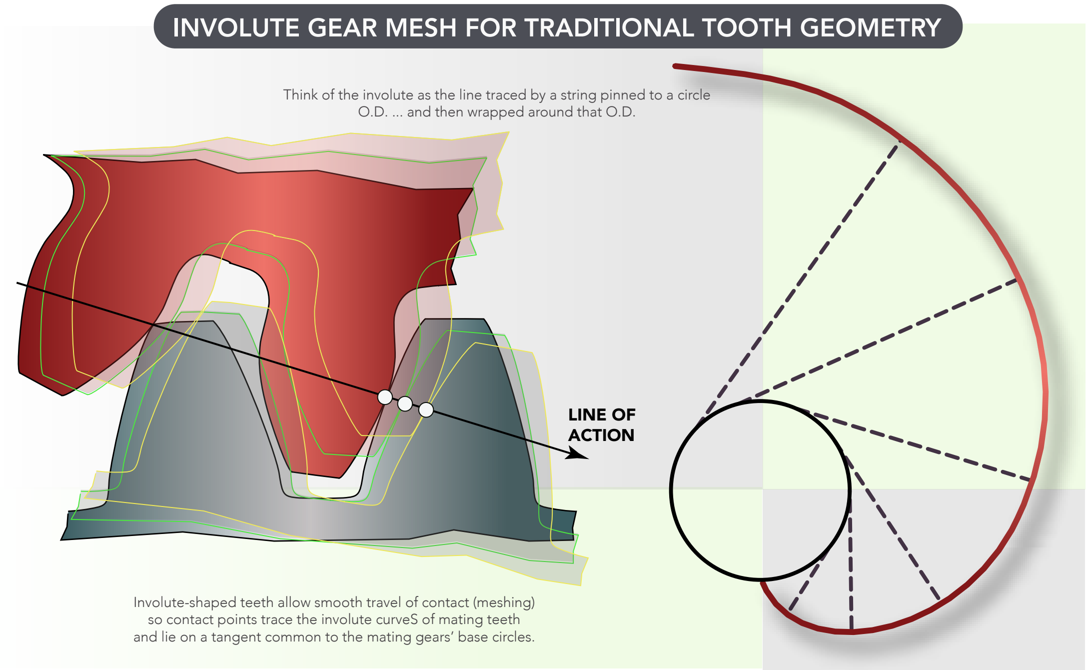
Involute gear teeth have a profile that is the involute of a circle. So as two involute gears mesh, they contact at a single point where the involutes meet. This point moves along the tooth surfaces as the gears rotate ... and the line of force (known as the line of action) is tangent to the two base circles. In this way, the gears adhere to the fundamental law of gearing — *that the ratio of meshing gears' angular velocities must remain constant throughout the mesh*.

Spur gears can be made from metals such as steel or brass or from plastics such as nylon or polycarbonate. Plastic gears are quiet but at the expense of strength and loading capability. Unlike other gear types, spur gears don't experience high losses due to slippage, so they generally have high transmission efficiency. Multiple spur gears can work in series (referred to as a gear train) to achieve large reduction ratios.

The two types of spur gears are external and internal. External gears have teeth that are cut on the outside surface of the cylinder. Two external gears mesh together and rotate in opposite directions. In contrast, internal gears have teeth cut on the inside surface of the cylinder. An external gear sits inside the internal gear, and the gears rotate in the same direction. Because the shafts are positioned closer together, internal gear assemblies are more compact than external gear assemblies. Internal gears are primarily used for planetary gear drives.

Spur gears are generally best for applications needing moderate speed reduction and torque multiplication — such as ball mills and crushing equipment. High-speed applications that use spur gears (despite their high noise levels) include consumer appliances such as washing machines and blenders. Though noise limits the use of spur gears in passenger automobiles, they're common in aircraft engines, trains, and even bicycles.

INVOLUTE GEAR MESH FOR TRADITIONAL TOOTH GEOMETRY



The majority of gears used in today's motion designs include teeth with an involute profile.

This shape is unique in that it lets gear teeth mesh with any number other gears' involute teeth — so long as the tooth counts are compatible and the pressure angle and pitch match.

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SUMMARY OF HELICAL GEAR DESIGNS

Inline helical gears image via Dreamstime

Helical gears and spur gears are two of the most common gear types and can be used in many of the same applications. Spur gears are simple and inexpensive to manufacture, but helical gears offer some important advantages over spur gears.

The teeth of a helical gear are set at an angle (relative to axis of the gear) and take the shape of a helix. This allows the teeth to mesh gradually, starting as point contact and developing into line contact as engagement progresses. One of the most noticeable benefits of helical gears over spur gears is less noise, especially at medium- to high-speeds. Also, with helical gears, multiple teeth are always in mesh, which means less load on each individual tooth. This results in a smoother transition of forces from one tooth to the next, so that vibrations, shock loads, and wear are reduced.

But the inclined angle of the teeth also causes sliding contact between the teeth, which produces axial forces and heat, decreasing efficiency. These axial forces play a significant role in bearing selection for helical gears. Because the bearings have to withstand both radial and axial forces, helical gears require thrust or roller bearings, which are typically larger (and more expensive) than the simple bearings used with spur gears.

The axial forces vary in proportion to the magnitude of the tangent of the helix angle. Although larger helix angles provide higher speed and smoother motion, the helix angle is typically limited to 45° due to the production of axial forces.

The axial loads produced by helical gears can be countered by using double helical or herringbone gears. These arrangements have the appearance of two helical gears with opposite hands mounted back-to-back, although in reality they are machined from the same gear. Note that the difference between the two designs is that double helical gears have a groove in the middle, between the teeth, whereas herringbone gears do not.

This arrangement cancels out the axial forces on each set of teeth, so larger helix angles can be used. It also eliminates the need for thrust bearings.

Besides smoother motion, higher speed capability, and less noise, another advantage that helical gears provide over spur gears is the ability to be used with either parallel or non-parallel (crossed) shafts. Helical gears with parallel shafts require the same helix angle but opposite hands —in other words, right-handed teeth versus left-handed teeth.

When crossed-axis helical gears are used, they can be of either the same or opposite hands. If the gears have the same hands, the sum of the helix angles should equal the angle between the shafts. The most common example of this are crossed helical gears with perpendicular (90°) shafts. Both gears have the same hand, and 90° is the sum of their helix angles. For configurations with opposite hands, the difference between helix angles should equal the angle between the shafts.

Crossed helical gears provide flexibility in design, but the contact between teeth is closer to point contact than line contact. That means they have lower force capabilities than parallel-shaft designs — so are not the most suitable for heavy loads or axes needing very dramatic speed reductions.

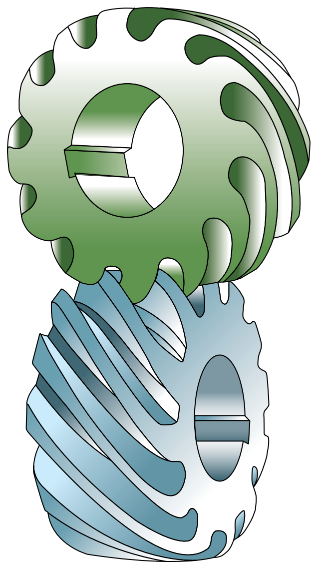
(continued)

SUMMARY OF HELICAL GEAR DESIGNS

Helical gears are often the default choice in applications that are suitable for spur gears but have non-parallel shafts. They are also used in applications that require high speeds or high loading. Plus regardless of the load or speed, they generally provide smoother, quieter operation than spur gears.

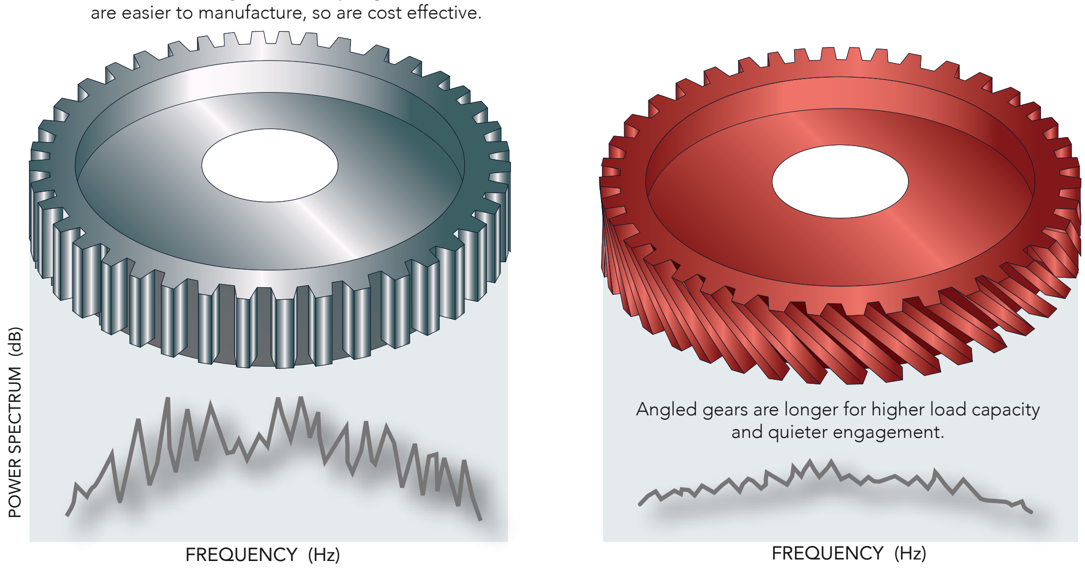
HELICAL GEAR TAKEHOME POINTS

- The axial loads produced by helical gears can be countered by using double helical or herringbone gears.
- Besides smoother motion, higher speed capability, and less noise, another advantage that helical gears provide over spur gears is the ability to be used with either parallel or non-parallel (crossed) shafts. Helical gears with parallel shafts require the same helix angle, but opposite hands (i.e. right-handed teeth vs. left-handed teeth).
- When crossed helical gears are used, they can be of either the same or opposite hands. If the gears have the same hands, the sum of the helix angles should equal the angle between the shafts.
- Crossed helical gears provide flexibility in design, but the contact between teeth is closer to point contact than line contact, so they have lower force capabilities than parallel shaft designs.
- Helical gears are often the default choice in applications that are suitable for spur gears but have nonparallel shafts. They are also used in applications that require high speeds or high loading.



Gears with parallel shafts have opposite hands. Gears with perpendicular shafts — as in these crossed-axis helical gears for power transmission through shafts at 90° — have the same hand.

SPUR GEAR VERSUS HELICAL GEAR



The teeth of a helical gear are set at an angle (relative to axis of the gear) and take the shape of a helix. This allows the teeth to mesh gradually ... starting as point contact and developing into line contact as engagement progresses.

WAVE & CYCLOIDAL GEAR APPLICATIONS

Many of today's precision applications necessitate gears capable of dramatic speed reductions, power densities, and transmission accuracies. Leading choices in these designs include trochoidal and cycloidal gearing as well as gearsets relying on wave-inducing subcomponents having an elliptical or Reuleaux or other polygonal shape.

Recall from geometry that trochoidal and cycloidal gearing includes elements that rotate and trace curves around some other element. More specifically, cycloids traced by a point on a rolling element's circumference include epicycloids (for which the element rolls along the outside of a sun gear or other reference component) and hypocycloids for which the element rolls within a ring or other reference component. In contrast, trochoids (and their subtypes) are traced not by a point on the rolling element's circumference but rather some point within or without. One particularly common subtype of epicyclic gearing is planetary gearing. Because we've covered planetaries in previous sections of this Design Guide, here we'll review other variations that are increasingly common in high-end machine tool, aerospace, material handling, and robotic applications requiring precision servo motion.

Consider the latter — in a robotic joint employing a motor (running at a few thousand rpm) fitted with gearing for output speeds to 100 times slower. Gearing in such designs also serves to boost acceleration torque for top power density — a priority design objective for SCARAs and collaborative robotics for which the total assembly is essentially a cantilevered mass.

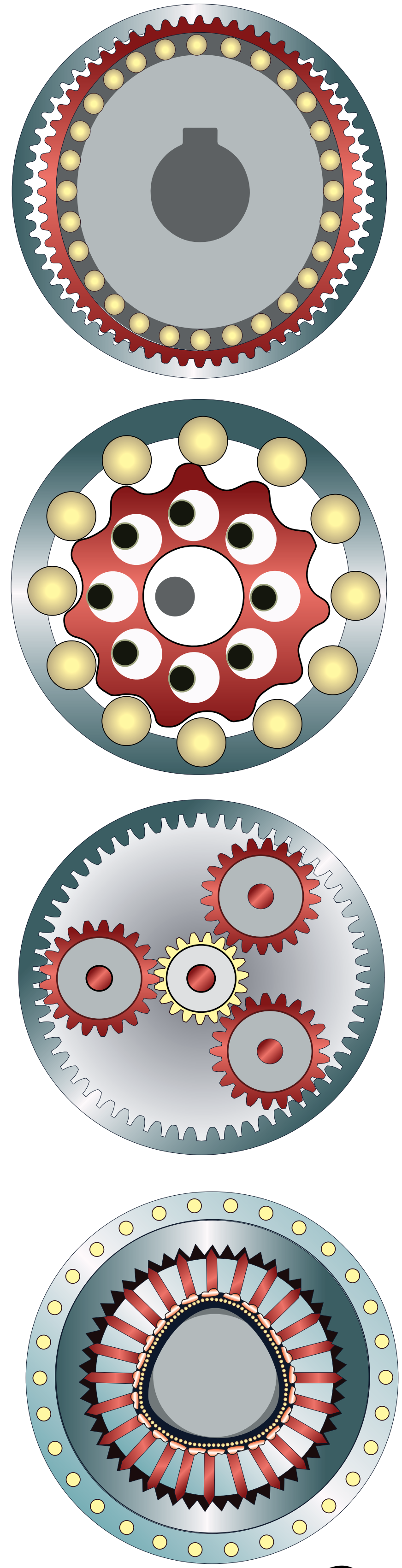
Recall that conventional gearing used in such designs (including some planetary gearsets) usually exhibit a very small amount backlash. This is often limited to only a few arc-min. (100ths of a degree) and serves to accommodate lubrication and thermal expansion. However, this backlash can in some cases degrade system accuracy by unacceptable amounts. So let's take a look at other gear options that avoid the issue.

STRAIN-WAVE GEARING

Strain-wave gearing uses the metal elasticity (deflection) of a gear to reduce speed. Key benefits of strain-wave gearing include zero backlash and high power density and positional accuracy.

A strain-wave gearset consists of three components: wave generator, flexspline, and circular spline. The wave generator is an assembly of a bearing and a steel disc with an elliptical shape machined to precise specifications. A specialty ball bearing fits around this disc and conforms to the elliptical shape. Most designs attach the wave generator to a servomotor — to serve as the motion input.

The flexspline is a thin-walled steel cup. These cup walls are radially compliant but remain torsionally stiff — because the cup has a large diameter. Manufacturers machine the gear teeth into the outer surface near the open end of the cup ... near what one might call the brim.



Wave and cycloidal gear options include (from top to bottom) strain-wave gearing, planocentric and cycloidal gearing, planetary gearing, and dynamic thrusted-tooth gearing.

(continued)

WAVE & CYCLOIDAL GEAR APPLICATIONS

Note that the gear types covered here are often associated with high-precision axes employing hollow shaft gear-output transmission to accommodate the feeding of hoses and cables through the center of the assembly. That's especially helpful where there is an end effector on the last axis in the design. Such hollow-shaft output also allows the installation of feedback devices.

The flexspline usually serves as the output.

The cup has a rigid boss at one end to provide a rugged mounting surface. The wave generator is inside the flexspline so the bearing is at the same axial location as the flexspline teeth. The flexspline wall near the brim of the cup conforms to the same elliptical shape of the bearing. This conforms the teeth on the outer surface of the flexspline to the elliptical shape. That way, the flexspline effectively has an elliptical gear-pitch diameter on its outer surface.

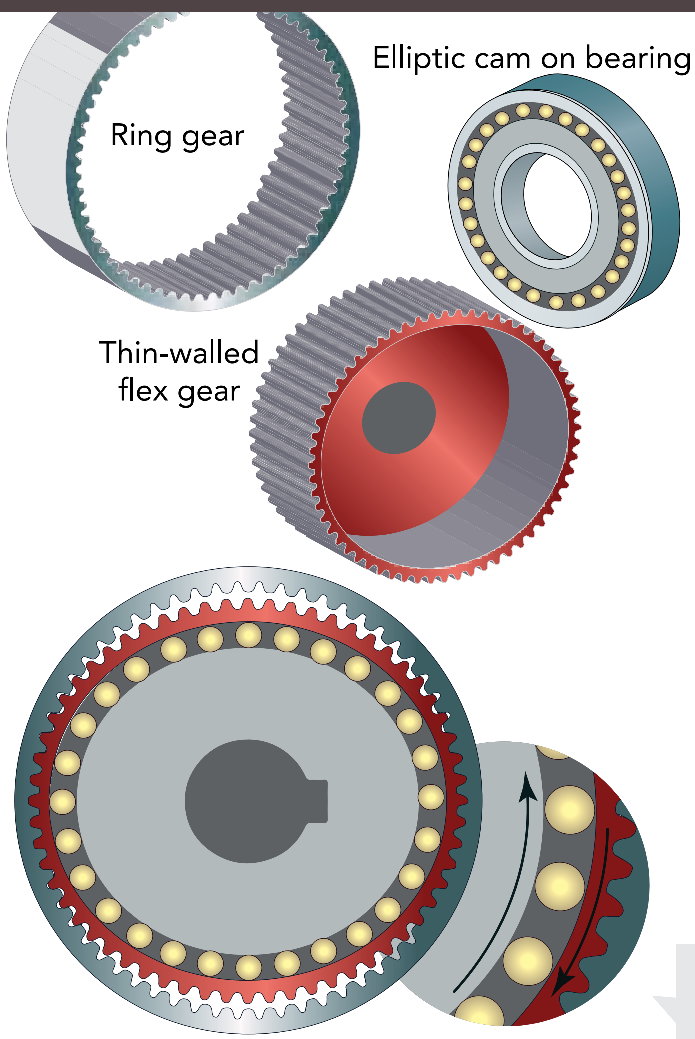
The circular spline is a rigid circular steel ring with teeth on the inside diameter. It is usually attached to the housing and does not rotate. Its teeth mesh with those of the flexspline. The teeth of the flexspline engage the teeth of the circular spline along the major (long) axis of the ellipse. So there are two areas of meshing made by the ellipse inscribed concentrically within the ring. Roughly 30% of the teeth are engaged at all times — in contrast with six or so teeth engaged at any time for an equivalent planetary-gear set, and one or two teeth for an equivalent spur-gear set.

Recall that backlash is the difference between the space to accommodate the teeth and the tooth width … and this difference is zero in strain-wave gearing. Elastic radial deformation of the strain-wave flexpline (preloaded by the manufacturer against those of the circular spline at the major axis) acts like a very stiff spring to compensate for space between the teeth that would otherwise cause backlash. Preload is set to keep stresses well below the material's endurance limit.

The pressure angle of the gear teeth transforms the output torque's tangential force into a radial force acting on the wave-generator bearing. The flexspline and circular spline teeth engage near the ellipse's major axis and disengage at the minor axis. The flexspline has two less teeth than the circular spline, so every time the wave generator rotates one revolution, the flexspline and circular spline shift by two teeth. The gear ratio is the number of flexspline teeth ÷ (number of flexspline teeth – number of circular spline teeth).

The lightweight construction and single-stage gear ratios (to 160:1) of strain-wave gearing let engineers use the gears in designs needing minimized weight and volume. Even small motors can leverage their large mechanical advantage. Certain tooth profiles (of convex and concave arcs) for strain-wave gearing let more teeth engage — for increased torsional stiffness and torque … as well as a longer MTBF.

STRAIN-WAVE GEAR-ASSEMBLY SUBCOMPONENTS



In traditional strain-wave gearing, a toothed flexspine engages a circular spline near the major axis of the ellipse — and disengages at the minor axis of the ellipse.

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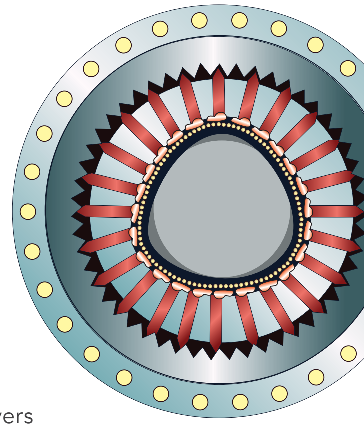
WAVE & CYCLOIDAL GEAR APPLICATIONS

THRUSTED-TOOTH GEARING

Now let's consider the thrusted-tooth design mentioned earlier. This newer high-torque gearbox offering offers extreme torsional rigidity and zero-backlash operation for applications that need superior precision in output motion. In contrast with other gear offerings that transmit power over lines of contact on gear teeth, meshing gears in the drive make almost full-surface contact. This allows for tooth contact that's up to 6.5 times that of certain types of conventional involute teeth.

How does it work? In short, the gearbox guides a large array of individual teeth along an internal ring gear. The tooth geometry follows a logarithmic spiral that lets multiple teeth transmit power at once through hydrodynamic contact — covering much larger surface areas than traditional line contact. The result is a gearbox with zero backlash even at the zero crossing. The logarithmic spiral path of the teeth allows for synchronization accuracy that outperforms traditional hollow-shaft drives with comparable outer diameters.



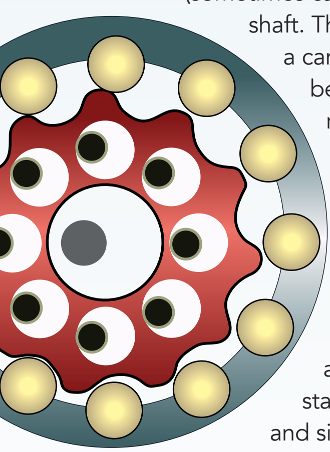
The gearbox also boasts up to 91% efficiency — 18 to 29% better than traditional strain-wave and cycloidal geared arrangements.

As part of a drive system, hydrodynamic tooth contact of the gear drive also delivers high overload capability. Emergency stop torque is 150 to 300% better than comparable systems, and torsional rigidity is to 580% higher ... so gearboxes of other designs might need to be up to three times larger to deliver the same torque as a given thrusted-tooth gearbox.

The gear design also allows for a very large hollow-shaft diameter in relation to the outer diameter — to 70% larger in some cases.

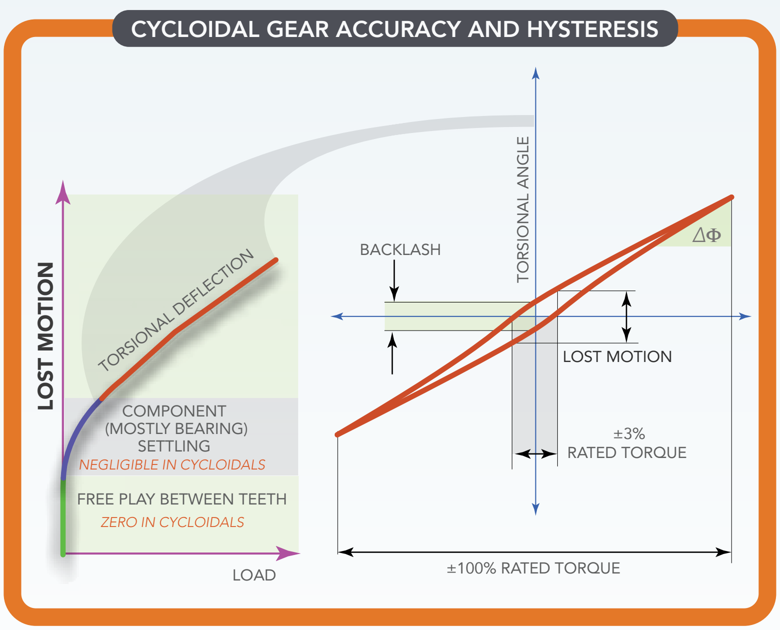
SUMMARY OF CYCLOIDAL GEARING

The eccentric rolling-mechanism gearheads known as cycloidal reducers are a type of servo gearing that has an input shaft that drives a bearing assembly. This in turn drives a cycloidal disc (sometimes called a cam) that connects to an output shaft. The cam has lobes or teeth that engage with a cam follower — typically with pin or needle bearings. The eccentric cam rotation induces rotation of an output shaft at a lower speed and higher torque than the input.



The main advantage of cycloidal reducers is their property of zero or near-zero backlash (to 1 arc-min.) which makes for high precision and high accuracy. This is especially in demand where highly precise and accurate positioning is required, for instance in robotic applications, machine tools, and similar applications. Cycloidal reducers also feature rolling as opposed to sliding contact, thus experiencing less overall wear. Some cycloidal speed reducers offer zero backlash by combining a compound reduction cam with a full complement of needle-bearing cam followers.

Because of the pin-and-gear structure, cycloidal gearing maintains continuous and distributed power-transmission contact for higher shock resistance than traditional reducers. In fact, some variations can withstand transitory exposure to quadruple their rated torque. High torque density makes for ratios to 185:1 in reasonable gearbox footprints.



Transmission error quantifies how accurately gearing transmits input to output. In cycloidal assemblies, material elasticity is the primary contributor of lost motion. Shown here is a typical hysteresis plot and $\Delta\Phi$ for cycloidal gearing.

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BEST METHODS FOR GEARBOX LUBRICATION

Like other types of rotating equipment, gearboxes rely on lubrication to reduce friction and provide cooling for optimal operation and life. Gearbox manufacturers provide recommendations for the type of lubrication to be used and the typical lubrication intervals, but the actual gearbox-lubrication requirements also depend on the environmental conditions to which the gearbox is exposed ... whether it is regularly maintained ... and whether it experiences overloading.

There are several methods for lubricating a gearbox, with the most common being grease lubrication, oil splash, and forced oil.

Grease lubrication is suitable for gearing in a wide variety of sizes and speeds. However, grease provides less cooling than oil and is not recommended for continuous-duty or very heavily loaded applications — even at low speeds. With any lubrication, using the proper quantity of lubricant is important, and this is especially critical with grease. Using too little lubrication prevents an adequate lubrication film from forming, but too much lubrication (especially grease) adds viscous drag and results in power loss.

Oil splash lubrication is often used for helical, spur, and bevel gearboxes. This method is also referred to as an oil bath, because it uses a reservoir is filled (or partially filled) with oil. As the gears rotate, they dip into this oil bath and splash the oil onto the other gears and bearings. But if the gear teeth are fully submerged, a condition known as *churning* occurs.

Essentially, churning is when the gears or bearings must work harder to push through the lubricant. A good analogy is walking along the edge of the water at the beach: Walking through ankle-deep water is relatively easy, but if you move to knee-deep water, walking requires much more effort. The effectiveness of oil splash lubrication is heavily dependent on the speed of the gears. A common rule of thumb is that a tangential speed of at least 3 m/sec is required for splash lubrication to be effective.

Forced oil lubrication is preferred for high-speed applications, and includes methods such as oil mist, oil spray, and oil drop. In the oil mist method, oil is atomized so that it saturates all areas of the gears and other internal components. In contrast, the oil-spray method applies oil lubricant directly to the gears and other components, but this method is not always effective, as high centrifugal forces affect the direction of the oil spray.

The **oil drop method** pumps or drops oil directly onto the surfaces where it's needed. A pump takes lubrication from a reservoir and delivers it to the gears or bearings via an internal piping system. This method can often be found in conjunction with the splash (otherwise known as the oil bath) method — where some components may be difficult to reach via oil splash.

Regardless of the lubrication method used, the right type of lubrication is critical to gearbox performance. Of the parameters involved in selecting a lubricant, viscosity is the most important ...

A lubricant with a viscosity that is too high for the application (in other words, lubricant that is too thick) won't sufficiently flow as the gear teeth engage ... so won't fully protect mating surfaces from wear and heat accumulation. On the other hand, lubrication with a viscosity that's too low won't provide a sufficient film thickness to prevent metal-to-metal contact between the mating surfaces.

(continued)

BEST METHODS FOR GEARBOX LUBRICATION

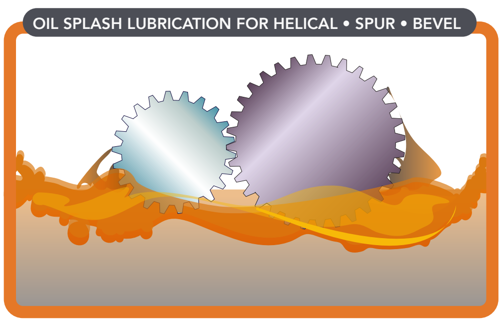
WHAT'S UNIQUE ABOUT WORM-GEAR LUBRICATION

Worm gears are used in various types of applications for their ability to provide very high reduction ratios and, in many cases, for their self-locking properties. But choosing the right worm gear lubrication involves more than just selecting the right viscosity.

Most gear types including helical, bevel, and spur experience both sliding and rolling contact as the teeth engage and mesh. But worm gears operate with mostly sliding contact between the worm and the gear … also referred to as the *worm wheel*. This predominantly sliding contact results in significant friction and very high operating temperatures. It also makes the formation of a hydrodynamic lubrication wedge or film difficult, so the gears predominantly operate under boundary-lubrication conditions. A result of these combined operating factors is that worm gears require lubricants that can operate under significant heat and pressure, in addition to providing excellent lubricating properties.

Lubricants with extreme pressure (EP) additives seem to fit the bill, but there's a catch: EP additives often contain activated sulfur or chlorine, both of which can damage yellow metals through softening or etching. After all, most worm gears are made of a steel worm and a bronze gear. To reduce these harmful effects, some EP lubricants now use deactivated sulfur.

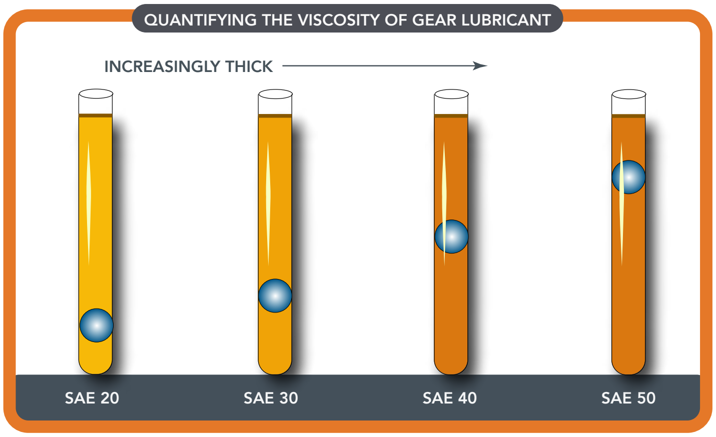
In the quest to find a lubrication that can withstand the operating conditions of worm gear assemblies, without reacting with the bronze gear, some manufacturers and lubrication specialists recommend using compounded oils, which are made from a mineral oil base with acidless tallow or fatty acid, and with rust and oxidation inhibitors added. Compounded oils provide better lubricity, which reduces friction and wear. However, they have a temperature limit of approximately 80° C. Above this temperature, oxidation increases rapidly and produces acidic products that can damage the bronze gear.



Oil splash is a common mode of lubrication … especially in gearbox assemblies completed with an enclosed housing.

Synthetic lubricants are another alternative, and although they have a higher up-front cost, they can noticeably improve the efficiency and operating life of worm gear assemblies. These usually fall into two categories:

- **Polyalphaolefin (PAO) oils** have lower viscosity and a high viscosity index, so they can be used in a wider range of temperatures. Most have anti-wear additives … and PAOs are available with EP additives as well.
- **Polyalkylene glycol (PAG) synthetic oils** have a high viscosity index and a wide operating temperature range. They also have superior lubricity properties when compared to other types of lubrication. PAGs contain anti-wear additives, but unlike PAOs, PAG synthetic oils are not available with EP additives. What's more, they tend to be incompatible with paints, seals, and polycarbonates.



*Oils with lower viscosity (such as the SAE 20 oil on the left) are often referred to as **thinner**. Lower viscosity lets oil flow over surfaces but may not provide a film thickness sufficient to prevent metal-to-metal contact.*

Using the wrong type of lubrication and not providing sufficient lubrication are two of the most common causes of worm gear failure.

In addition to choosing the right type of lubricant, ensuring that the worm gear has the right quantity of lubricant is critical to proper operation. Worm gears are typically lubricated by the splash method, and another unique characteristic of worm gear lubrication is that the mounting orientation plays a significant role in determining how much lubrication is needed. Case in point: Worm gears are most commonly mounted in the worm-over orientation, where the worm sits above the gear, but they can also be mounted in a worm-under orientation. To ensure that it's properly lubricated in the worm-under orientation, the gear assembly requires up to 50% more lubricant than in the worm-over orientation.

LUBRICANT MAINTENANCE RECOMMENDATIONS

If gear lubricant is left in service beyond its useful life, the gear assembly will exhibit excessive wear, diminished efficiency, and eventual failure. End users should follow published relubrication guidelines — and plant personnel should execute more frequent lubrication if the application is particularly challenging. A first sign of lubricant trouble is elevated operating temperatures due to the decreased ability of the oil or grease to minimize friction.

(continued)

BEST METHODS FOR GEARBOX LUBRICATION

In some instances, some end users include gearbox oil monitoring in their preventative maintenance schedules. That's especially true where the designs employs a circulating oil or oil sump system. In short, oil samples from the gearboxes in question are sent to laboratories for analysis. Returned are data sheets that include details about the lubricant's pH levels, viscosity, additives, and contaminants — whether in the form of dirt, metal component shavings, or water. Lubricant replacement is indicated where such oil monitoring indicates:

- A viscosity increase beyond 10% or so of the expected values
- The presence of shavings beyond the allowable parts per million
- Contamination with water or (especially for off-highway equipment) hydraulic fluid

In contrast, wear-particle analysis tracks the quantity, type, and size of contaminant in gearbox lubricant. Though less exhaustive than oil monitoring, it's indispensable where a design is subject to shock loading, vibration, and accelerated wear due to other unavoidable mechanical challenges.

Where a gearset employs grease, the lubricant analysis is somewhat more complicated. No wonder greases are more common in lubed-for-life gearbox offerings to serve in inaccessible or remote machinery.

In contrast with oil lubricants, grease's apparent dynamic viscosity can increase threefold or more before it's a concern … and in some designs, a slight amount of water ingress is tolerable. However, grease lubricant is usually far less forgiving of the ingress of solid contaminants.

Example gearbox-grease grades

	GB M0	GB H0	GB A2	GB C2
NLGI grade	0	0	2	2
Penetration • ASTM D217	355 to 385	355 to 385	265 to 295	265 to 295
Thickener chemistry	PTFE	PTFE	PTFE	PTFE
Dropping point (°C)	Greater than 290	Greater than 290	Greater than 290	Greater than 290
Base oil viscosity (at 40 °C)	100	500	100	500
Estimated useful temperature range (at °C)	-40° to 210°	-4° to 270°	-40° to 210°	-4° to 270°
Appearance	Grey and creamy	Grey and creamy	Grey and creamy	Grey and creamy
Specific gravity	2.1	2.1	2.1	2.1

Shown here is a listing of DuPont Krytox fluoropolymer greases for the lubrication of gearboxes (and their gears, bearings, and seals) destined for extreme-temperature settings. These greases resist oxidation due to heat — even to 270° C. Such greases are often used in lubed-for-life gearboxes ... and resist lubricant leakage from seal failure better than oil alternatives. Chart courtesy DuPont Performance Lubricants

GEAR DESIGN FEATURES FOR WASHDOWN ENVIRONMENTS

Washdown processes are common in the food and beverage and pharmaceutical industries, where cleanliness of the manufacturing and handling equipment plays an important role in the quality and safety of the product.

In fact, the US Food and Drug Administration (FDA) and the European Hygienic Engineering and Design Group (EHEDG), along with other government and industry-specific agencies, provide regulations and standards for the safe and hygienic processing, handling, and packaging of food, beverage, and pharmaceutical products. However, these standards often address overall machine or process design and leave the choice of individual components, such as bearings, motors, and gearboxes, up to the equipment designer and manufacturer.

Washdown applications introduce two significant hazards to the performance and life of a gearbox. The first being that the washdown solution could make its way inside the gearbox and damage the internal gears and bearings, and the second being the possibility of corrosion due to exposure to water and chemicals — specifically alkalines, chlorine, and acids.

Fortunately, gearbox manufacturers have found ways to address these hazards, and it's now common to see ***washdown*** and ***hygienic*** designs among gearbox manufacturers' standard offerings. But what features make a gearbox suitable for washdown or hygienic applications?

Gear materials for washdown: First and foremost, the materials used for the housing and other external components, such as the output shaft and hardware, are critical to making a gearbox suitable for washdown duty. While some equipment manufacturers choose to use gearboxes with epoxy painted housings for washdown applications, these can chip and need to be repainted periodically. In most cases, stainless steel is a better alternative than painted options.

The GAM SSP gearbox is designed for washdown applications with all stainless steel housings, shafts, and hardware, Viton(R) seals, and minimal holes and crevices. Image courtesy of GAM Enterprises, Inc.

(continued)

GEARBOX FEATURES FOR WASHDOWN ENVIRONMENTS

Both 304 and 316 series stainless are suitable for washdown and hygienic applications, although 316 has better resistance against pitting, especially when exposed to the caustic chemicals found in many washdown solutions. But the use of stainless steel presents a higher up-front cost than painted designs, and 316 series stainless even more so than 304. To mitigate the cost, some manufacturers use 316 stainless for the housing and 304 stainless for other components with less exposure (such as shafts and some hardware).

Geometry to maximize gear-design cleanability: Another important design aspect of washdown or hygienic gearboxes is their shape. The purpose of washdown is to clean the equipment and prevent bacteria from growing, but if the gearbox has crevices, seams, or grooves where particles can be trapped, thorough cleaning will be difficult or even ineffective. This is why many gearboxes designed for these applications have a round housing with smooth surfaces and no external seams. And if corners are necessary in the design, they're executed with a radius rather than sharp angles.

Gearbox lubrication and seals: In the ideal world, lubrication would never make its way out of the gearbox and into the process. However, in the real world such leaks can (and do) happen. To prepare for this possibility, applications that pose the risk of incidental contact with the product should be lubricated with NSF H1 food-grade grease or oil.

The primary task of gearbox seals is to keep lubrication inside the gearbox and keep liquids and contamination out. Washdown conditions make this especially difficult, since the seals must withstand the high pressure of the washing operation and be impervious to harsh chemicals. This is why it's common to find gaskets or o-rings on the input side of the gearbox and two-part seals on the output shaft. Most gearboxes for washdown and hygienic applications use seals made of Viton due to its broad chemical compatibility, ability to withstand high temperatures, and excellent mechanical properties.

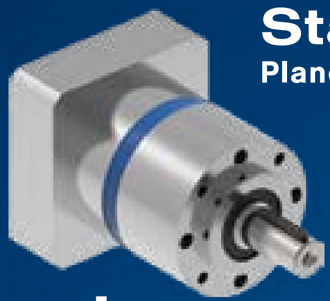
The most common system used to classify a product's washdown compatibility is the IP rating, which is published by the International Electrotechnical Commission (IEC). IP stands for International Protection but is sometimes referred to as Ingress Protection. IP ratings that convey suitability for washdown are:

- IP65 — protection against water jets
- IP66 — protection against powerful water jets
- IP67 — protection against immersion up to 1 meter
- IP69k — protection against powerful high-temperature water jets

Heavy washdown applications should consider products that are IP69K rated.

The National Electrical Manufacturers Association (NEMA) has also developed and published protection ratings, but NEMA ratings are used almost exclusively in the US, while IP ratings are used internationally. It's important to note that there is no direct correlation between NEMA and IP ratings.

The GAM Advantage



Standard
Planetary Gearbox

Broad Product Line

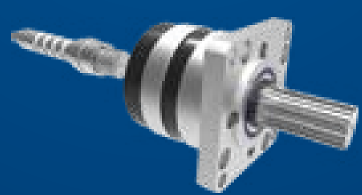
Flexible Manufacturing

Engineering Collaboration

Modified

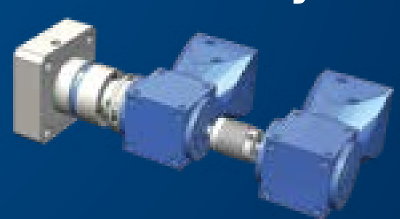
Modified Standard Gearbox
Standard planetary gearbox modified for the demanding shock and reversing loads of the wheel drive of an automated parking robot

Custom



Custom Planetary Gearbox
GAM produced a custom motor rotor shaft with an integral sun gear for a motor manufacturer . This drives a customized planetary gearbox with a spline output shaft to directly mount and drive an AGV Wheel

Assembly



Integrated Assembly
Standard Planetary Gearbox, with hollow output, drives dual spiral bevel gearboxes connected with a servo coupling for a solution to drive two linear ball-screws in unison from a single servo motor

GAM®

GAM offers a full range of robotic and servo gearboxes, along with rack & pinion, couplings, and linear mount products for motion control and robotic applications.
With our broad product offerings in the gearbox market, as well as the in-house engineering design experts and manufacturing capabilities to develop customized solutions, we can help with your application.

GAM Can.

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