Pairing Gearheads with Servo Motors

Machine designers are increasingly turning to gearheads to take advantage of the latest advances in servo motor technology. Essentially, a gearhead converts high-speed, low-torque energy into low-speed, high-torque output. A servo motor provides highly accurate positioning of its output shaft. When these two devices are paired with one another, they enhance each other's strengths, providing controlled motion that is precise, robust, and reliable.

As servo technology has evolved—with manufacturers producing smaller, yet more powerful motors —gearheads are becoming increasingly essential partners in motion control. Finding the optimal pairing must take into account many engineering considerations. Before addressing those, a short review of gearhead basics may be helpful.

Gearhead Basics

So how does a gearhead go about providing the power required by today's more demanding applications? Well, that all goes back to the basics of gears and their ability to change the magnitude or direction of an applied force. Gearheads can accomplish this in a few different ways:

- **Torque multiplication.** The gears and number of teeth on each gear create a ratio. If a motor can generate 20 in-lbs. of torque, and a 10:1 ratio gearhead is attached to its output, the resulting torque will be close to 200 in-lbs. With the ongoing emphasis on developing smaller footprints for motors and the equipment that they drive, the ability to pair a smaller motor with a gearhead to achieve the desired torque output is invaluable.

- **RPM reduction.** A motor may be rated at 2,000 rpm, but your application may only require 50 rpm. Trying to run the motor at 50 rpm may not be optimal based on the following;

  - If you are running at a very low speed, such as 50 rpm, and your motor feedback resolution is not high enough, the update rate of the electronic drive may cause a velocity ripple in the application. For instance, with a motor feedback resolution of 1000 counts/rev you have a measurable count at every .357 degree of shaft rotation. If the electronic drive you are using to control the motor has a velocity loop of .125 milliseconds, it will look for that measurable count at every .0375 degree of shaft rotation at 50 rpm (300 deg/sec). When it does not see that count it will speed up the motor rotation to find it. At the speed that it finds the next measurable count the rpm will be too fast for the application and then the drive will slow the motor rpm back down to 50 rpm and then the whole process starts all over again. This constant increase and decrease in rpm is what will cause velocity ripple in an application.

  - A servo motor running at low rpm operates inefficiently. Eddy currents are loops of electrical current that are induced within the motor during operation. The eddy currents actually produce a drag force within the motor and will have a greater negative impact on motor performance at lower rpms.

About the author:

Jeff Nazzaro

Based at the New Ulm facility, Jeff Nazzaro is product manager for gearheads and motors in Parker's Electromechanical and Drives Division.

- An off-the-shelf motor's parameters may not be ideally suited to run at a low rpm. When an application runs the aforementioned motor at 50 rpm, essentially it is not using all of its available rpm. Because the voltage constant (V/Krpm) of the motor is set for a higher rpm, the torque constant (Nm/amp)—which is directly related to it—is lower than it needs to be. As a result, the application needs more current to drive it than if the application had a motor specifically designed for 50 rpm.

A gearhead's ratio reduces the motor rpm, which is why gearheads are sometimes called gear reducers. Using a gearhead with a 40:1 ratio, the motor rpm at the input of the gearhead will be 2,000 rpm and the rpm at the output of the gearhead will be 50 rpm. Operating the motor at the higher rpm will allow you to avoid the concerns mentioned in bullets 1 and 2. For bullet 3, it allows the design to use less torque and current from the motor based on the mechanical advantage of the gearhead.

As an example, consider a person riding a bicycle, with the person acting like the motor. If that person tries to ride that bike up a steep hill in a gear that is designed for low rpm, he or she will struggle as they attempt to maintain their balance and achieve an rpm that will allow them to climb the hill. However, if they shift the bike's gears into a speed that will produce a higher rpm, the rider will have a much easier time of it. A constant force can be applied with smooth rotation being provided. The same logic applies for industrial applications that require lower speeds while maintaining necessary torque.

- **Inertia matching.** Today's servo motors are generating more torque relative to frame size. That's because of dense copper windings, lightweight materials, and high-energy magnets. This creates greater inertial mismatches between servo motors and the loads they are trying to move. Using a gearhead to better match the inertia of the motor to the inertia of the load allows for using a smaller motor and results in a more responsive system that is easier to tune. Again, this is achieved through the gearhead's ratio, where the reflected inertia of the load to the motor is decreased by $1/\text{ratio}^2$.

Recall that inertia is a measure of an object's resistance to change in its motion and is a function of the object's mass and shape. The greater an object's inertia, the more torque is needed to accelerate or decelerate the object. This means that when the load inertia is much larger than the motor inertia, sometimes it can cause excessive overshoot or increase settling times. Both conditions can decrease production line throughput.

On the other hand, when the motor inertia is larger than the load inertia, the motor will need more power than is otherwise necessary for the particular application. This increases costs because it requires paying more for a motor that's larger than necessary, and because the increased power consumption requires higher operating costs. The solution is to use a gearhead to match the inertia of the motor to the inertia of the load.

System Cost Savings

Gearheads allow using smaller motors and drives, which can help lower a system's cost. Because smaller servo systems draw fewer amps they reduce operating costs. Power savings are greatest when applications demand high torque and low speed because direct-drive servo motors need to be considerably larger than servo motors coupled to gearheads.

Gearheads often drive long mechanisms, such as material-feed systems that move lengths of wire, wood, or metal, where high speed is not essential but high torque and highly repeatable accuracy are critical. Pairing a servo motor with the appropriate gearhead in this type of application can provide flexibility that cannot be matched with a traditional direct-drive motor. The servo-gearhead combination will cost less to operate, take up less space, and will provide an inertia match for better motion control.

Additional applications for which servo-gearhead combinations are particularly well-suited typically fall into the same high-torque, lower-speed category as material feed systems. For instance, industrial robotics rely heavily on gearheads. Pick and place systems, which are widely used in applications such as automotive manufacturing, injection molding, and heavy equipment manufacturing, all require the highly accurate output provided by a servo motor. Adding a gearhead to that motor provides the torque needed to deal with the inertia involved in these demanding applications.

Applying Gearheads: So Many Choices

Machine designers have a variety of options when evaluating gearheads for an application:

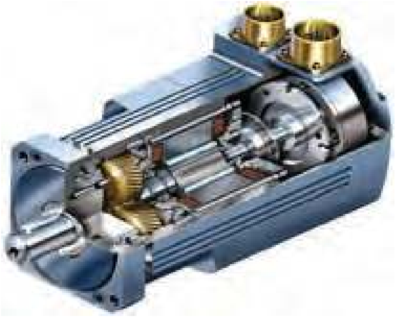
- **In-line gearheads.** These are commonly used for motion control applications because they have lower backlash and cost less than right-angle gearheads. In-line gearheads have an output shaft that is in line and centered with the motor shaft.

- **Right-angle gearheads.** This type is commonly used when the servo motor must fit into a tight space. The gearhead's output shaft is at a 90-degree angle to the motor shaft; therefore, most of the gearhead housing, and all of the motor housing, is parallel to the side of the machine, providing a smaller machine envelope.

- **Separate motors and gearheads.** Most motion control systems that employ gearing use separate motors and gearheads. This allows choosing the motor and gearhead most appropriate for the application, even when they come from different manufacturers. Typically, gearheads can be mounted to just about any servo motor. All that is required is a mounting kit, which is typically provided by the gearhead manufacturer, to attach the gearhead to the motor flange and shaft. This configuration is more flexible than an integrated gearmotor and it's easier to maintain.

- **Integrated gearmotors.** This is the best choice for certain applications. One advantage is that the overall length of the assembly can be considerably shorter than an assembly with a separate gearhead and motor. System design is also simpler because only one speed and torque curve is needed to determine if a gearmotor will provide the necessary performance to power the motion control system.

- **Flange-face gearheads.** A somewhat newer trend is the use of flange-face gearheads. The machine being driven mounts directly to the flange, which eliminates the need for a flexible couple and all of its associated problems.



Integrated gearmotors are often more compact than an assembly with a separate gearhead and motor.

For space-constrained applications, right-angle gearheads offer significant space savings over in-line gearheads.

In-line gearheads have an output shaft that is in line and centered with the motor shaft.

Choosing the Right Gear Drive

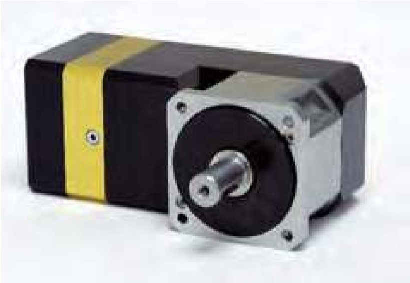
There are several gear technologies available in today, including spur, planetary, worm, harmonic, and cycloidal gearheads. Some criteria to consider in the selection process are torque density, backlash, torsional stiffness, and efficiency.

- **Torque density.** The higher the torque density, the more torque (rotational force) relative to the size of the gearhead is generated. Planetary, harmonic, and cycloidal gearheads are comparable to one another and can have torque densities up to 5 times greater than worm or spur designs. This value is expressed in units of torque per volume such as in-lbs force per inch^3.

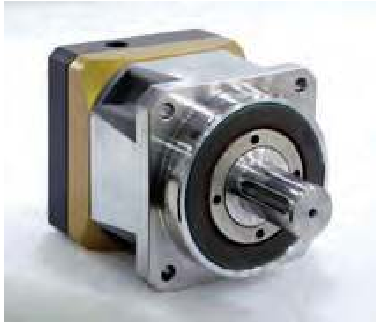
- **Backlash** is the amount of motion generated at a gearheads output shaft when the input is fixed, specified in arc min (1 arc min = 1/60 of a degree). Typically, it is measured by applying 2% of the rated output torque to its output shaft while the input is locked. For high precision, lower backlash is better. Harmonic drive gearheads are rated at zero backlash due to the pre-load that exists between its flexible spline and outer ring gear. Planetary, worm and cycloidal designs can achieve 1 to 3 arc min. on their high precision models. Some worm gear manufacturers also pre-load for zero-backlash capability.

- **Torsional stiffness** measures torsional stability (rotational displacement) of the output shaft and gear train while the input is fixed and after backlash is removed (any continued displacement after the 2% of rated torque called out in the aforementioned backlash definition). With torsional stiffness, the higher the number the better, as that will be the amount of torque required to displace the shaft an extra arc min. With higher torsional stiffness, settling time is reduced as a gearhead starts and stops while driving the application. This helps to support higher throughputs. Planetary and cycloidal designs offer the highest values relative to the size of the gearhead. Worm and spur designs provide lower values, with harmonic gearheads offering low stiffness due to the springiness of its flexible spline. This value is measured in in-lb/arc min.

- **Efficiency** is a measurement of lost power transmitted through the gearhead, stated as a percentage of input power. If a gearhead is rated 95% efficient at nominal torque, then 5% of the motor's torque will be lost by the time it reaches the output shaft. If a gearhead is too inefficient, then it may require a larger motor to make up for this loss. Spur and planetary gearheads are typically 90 to 95% efficient. Worm gearheads range from 70% at higher ratios (50:1) to 90% at lower ratios (5:1). Cycloidal gearhead efficiencies typically range from 65 to 80%. Harmonic gearheads may suffer in efficiency also due to the constant pre-load of the flex-spline against its ring gear.



For applications that require low backlash, high stiffness and high accuracy, helical planetary technology, like that found in Parker Generation II's Stealth® gearhead line is ideal for high- and medium-level performance tasks.



Helical gears like those in this Parker Generation II PS90 Helical Planetary Gearhead have greater face width and more tooth contact than spur gears. This results in smoother tooth engagement, higher torque capability, quieter operation and lower backlash.

Put Your Engineering in Gear

Virtually any controlled motion application that requires high torque and lower speed can be improved with the right combination of servo motor and gearhead. Combining these two technologies often offers lower operating cost, smaller size, and higher reliability than direct-drive motors can provide. As servo motors become smaller and stronger, gearheads will keep evolving as well. Together they'll provide the controlled motion that tomorrow's applications will demand.

800.866.4568 crossco.com

Parker Hannifin Corporation
Electromechanical & Drives Div.
9225 Forsyth Park Dr.
Charlotte, NC 28273
Phone 704-588-3246
parker.com/emdusa