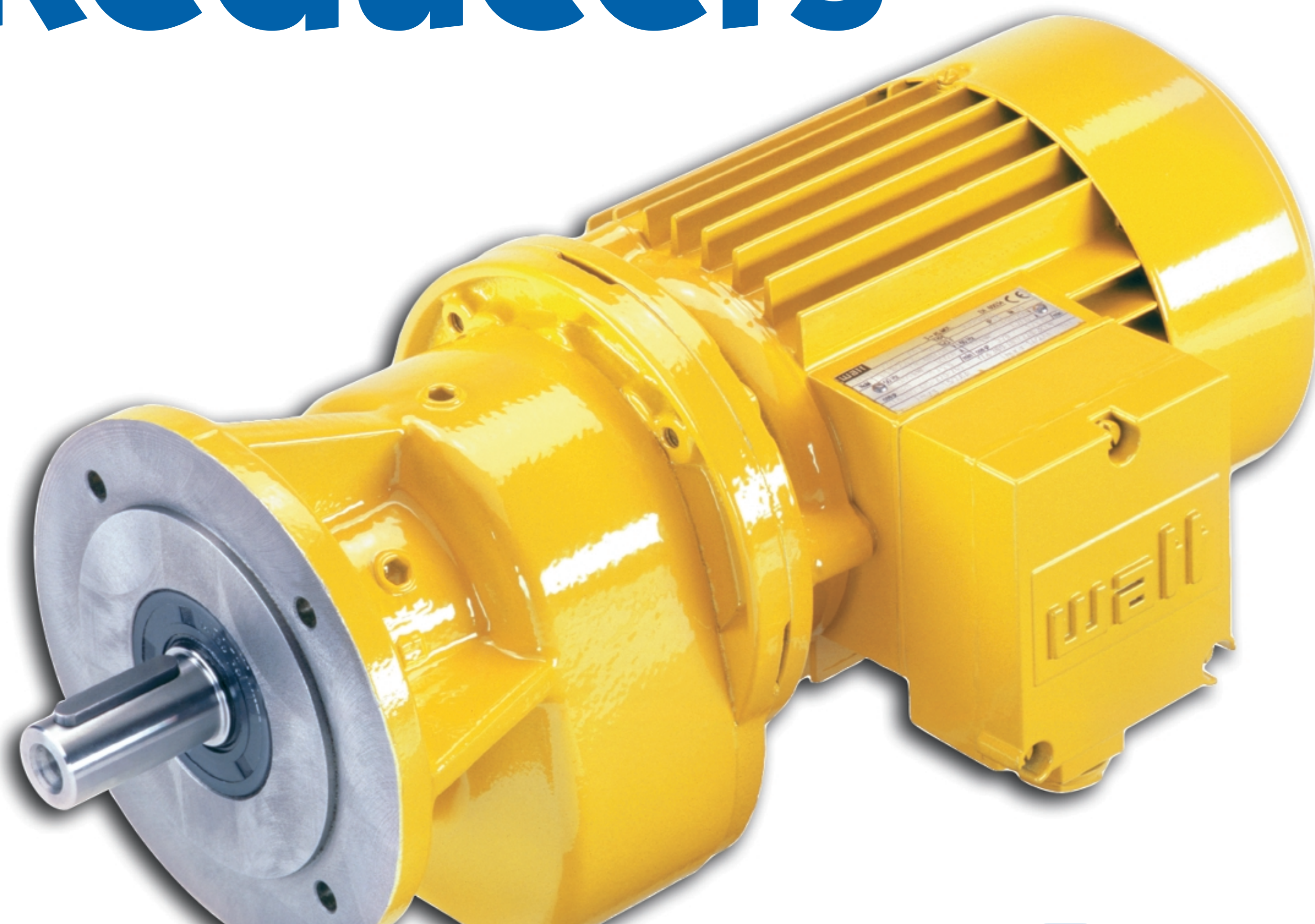
Selecting and Applying Speed Reducers



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Things you should know about sizing and applying

Speed Reducers

Speed reducers are mechanical devices generally used for two purposes. The primary use is to multiply the amount of torque generated by an input power source to increase the amount of usable work. They also reduce the input power source speed to achieve desired output speeds.

The selection and integration of speed reducers entails much more than simply picking one out of a catalog. In most cases the maximum torque, speeds, and radial loads published cannot be used simultaneously. Proper service factors must be applied to accommodate a wide range of dynamic applications. And, once the appropriate speed reducer is selected, proper installation and maintenance are the keys to maximizing life.

Speed reducer categories

The wide variety of mechanical speed reducing devices includes pulleys, sprockets, gears, and friction drives. There are also electrical products that can change the motor speed. This discussion will focus on enclosed-drive speed reducers, also known as gear drives and gearboxes, which have two main configurations: in-line and right angle. Each can be achieved using different types of gearing. In-line models are commonly made up of helical or spur gears, planetary gears, cycloidal mechanisms, or harmonic wave generators. Planetary designs generally provide the highest torque in the smallest package. Cycloidal and harmonic drives offer compact designs in higher ratios, while helical and spur reducers are generally the most economical. All are fairly efficient.

Right angle designs are typically made with worm gearing or bevel gearing, though hybrid drives are also available. Worm gears are perhaps the most cost effective reduction solution, but usually have a minimum 5:1 ratio and lose considerable efficiency as ratios go higher. Bevel reducers are very efficient but have an effective speed reduction upper limit of 6:1. The type of application dictates which speed reducer design will best satisfy the requirements.

Before choosing any reducer, specifications must be collected to properly size and install the unit: torque, speed, horsepower, reducer efficiency, service factor, mounting position, connection variable, and life required. In some applications the amount of backlash, transmission error, torsional rigidity, and moment of inertia are also important.

The torque, speed, horsepower relationship

The amount of torque needed is perhaps the most important criteria, as this translates to the amount of work the speed reducer must perform. Although in simple applications determining the torque can be relatively straightforward, it can be difficult in complex machinery. Inertia, friction, and gravity – the physical phenomena that tend to resist motion – have to be identified so that enough torque can be generated to overcome them. Considering coefficients to friction and the acceleration and deceleration of inertial masses is important when calculating required torque. A more detailed discussion of these elements can be found in the Machinery's Handbook, Motion System Design Handbook, and other machine design publications.

A shortcut in finding an existing machine's required torque is to take amperage readings from the motor by identifying the current draw. Then calculations can be made to find the required horsepower. Finally, by using a standard torque formula and considering the various ratios, the ultimate torque value can be realized.

Once the required power is identified, the service factor, must be considered to properly size the unit. The service factor takes into account other operational parameters, including length of work days, numbers of starts and stops, load characteristics, and power sources. Most reducers are rated for a maximum torque at a given number of lifetime hours. The limiting factor in these ratings is not the gear of shaft strength, but the bearing life. Because bearings must support the separation forces of the gears under load, loading less than the maximum rating increases gearbox life. Conversely, by increasing the load variable as highlighted above, a decrease in gearbox life will result. Therefore, to arrive at the effective torque

Service Factors

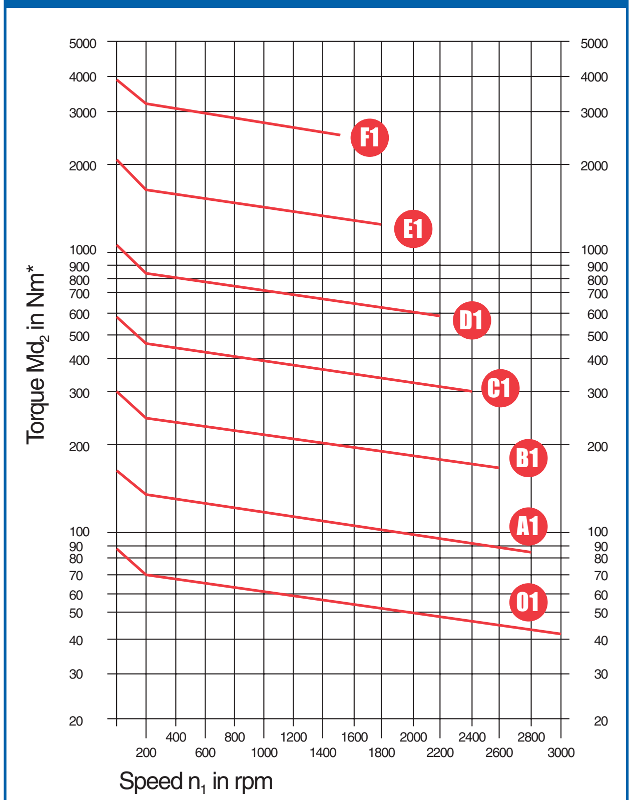
Degree of shock of the driven machine	Electric motor - running time in hours per day				Piston engine, hydraulic motor - running time in hours per day				Single cylinder piston engine - running time in hours per day			
	0.5	3	8	24	0.5	3	8	24	0.5	3	8	24
I	0.5	0.8	1.0	1.25	0.8	1.0	1.25	1.5	1.0	1.25	1.5	1.75
II	0.8	1.0	1.25	1.5	1.0	1.25	1.5	1.75	1.25	1.5	1.75	2.0
III	1.25	1.5	1.75	2.0	1.5	1.75	2.0	2.25	1.75	2.0	2.25	2.5

I Almost shock-free, e.g., electric generators, conveyor screws, light elevators, electric trains, ventilators, stirrers.
II Moderate shock, e.g., heavy elevators, crane turrets, piston pumps, mine ventilators, cable winches.
III Heavy shock, e.g., punch presses, shears, steel rolling machines, mills, looms.

requirement, the appropriate service factors need to be applied.

At this stage the speed reducer and motor can be selected. Typically a main power source such as a motor or engine has been selected, which operates at a specific speed. Arriving at the correct speed reducer ratio and the resulting torque multiplication is merely a matter of dividing the motor speed by the driven element speed. Then, the proper motor size can be found by plugging in the various factors and values in a standard horsepower formula.

Gear Ratio of 5:1 and 6:1



A typical reducer selection chart shows the relationship of torque capacity to speed. Lower speeds allow for higher torque capacity.

Integrating speed reducers

After selection, the next issue is how the gearbox will be integrated into the machine. The main concerns are how the gearbox will be mounted and how it will be connected to the driver and driven load.

Shaft orientation is one of the first considerations. In many applications it is desirable to have either the input or output shaft vertically oriented. In this situation great care must be taken to assure proper lubrication. The oil or grease in a gearbox does not only provide protection against gear wear, but also for reducing bearing wear. So, when one of the shafts is mounted vertically, the uppermost support bearing may not get the lubrication it needs. In certain gearbox designs the splash and misting created by the gears rotating through the oil reservoir are enough to provide the proper lubrication, but in low-speed types it is necessary to install pre-greased, sealed bearings. In still other high-speed applications it may be necessary to provide internal or external pumps to deliver the lubrication to the appropriate location. Whenever a shaft needs to be vertically mounted, it is important to determine if an alternate lubrication method is necessary.

The next consideration is how the speed reducer will be connected to the power source and to the driven load. Options include driving with a pulley, sprocket, or gear, connecting with a coupling, line shaft, or universal joint, and shaft mounting directly on the driven shaft.

When connecting with a pulley, sprocket, or gear, the main issue is radial load, commonly known as overhang load. Shaft bearings are not only designed to support gear separation forces but to accommodate a certain amount of radial and thrust loading on the shafts themselves. When driving with pulleys and sprockets, a radial force occurs as the belt or chain tries to rotate the shaft. The magnitude of this force can be calculated as the torque transmitted divided by the radius of the pulley or sprocket. This usually isn't the only side force exerted, however. The pulley or chain is tight on the driving side, but has some slack on the back side. To reduce the resulting noise and prevent belt slip or tooth jumps, it is common to install a tension device. When the belt or chain is tightened, additional radial loading occurs. The combination of radial load due to torque and tension must be considered when selecting a gear drive.

When connecting a speed reducer with a coupling, and to a lesser extent, line shafts and u-joints, alignment is the main concern. Because of machining tolerances on gearbox housings and mounting plates, flexible couplings are recommended. Without exact alignment, using a rigid coupling could create excessive side loads on the shaft bearings. Even with flexible couplings proper alignment is necessary, as most couplings will only allow parallel misalignments of 0.005 to 0.010 in. and angular misalignments of 1 to 3°. Many coupling designs are appropriate for different applications, but for maximum reducer life, the coupling should suit the job.

The third option for connecting the gearbox is to mount it directly on the driven shaft with a hollow bore output shaft. This reduces the concerns regarding alignment and radial loads and conserves space. A support arm from the gearbox to the machine frame keeps the gearbox from rotating about the shaft.

Common Formulas

$$T = \frac{63{,}025 \times P \times i}{N}$$

$$T = F \times r$$

$$P = \frac{T \times N}{63{,}025 \times i}$$

$$F = \frac{T}{r}$$

T = output torque (lb-in.)
P = power (hp)
i = reducer ratio
N = input speed (rpm)
F = force (lb)
r = radius (in.)

Cost Cutting Tips

When a selected speed reducer or drive package is just too expensive for the application parameters, a different approach should be considered. Because all speed reducer types come in a variety of quality levels, it should be determined how much gearbox is really needed. However, you usually get what you pay for. There are several other "tricks" that can be implemented to shave costs.

One is to consider changing the mating drive components. Although most speed reducers can handle higher torque at lower speeds, the relationship is not linear. Instead of trying to get an entire speed reduction out of the gearbox and therefore the entire torque multiplication, a smaller reducer can be selected by getting some of the ratio and torque from less expensive pulleys or gears. For example, instead of choosing a 10:1 speed reducer driving a 1:1 belt, select a 5:1 reducer driving a 2:1 belt. The gearbox only has to do half the work.

When at first glance it seems that a larger reducer is required to handle excess overhang load, consider changing the pulley size. Radial forces can be reduced in direct proportion to increases in pulley, sprocket, or gear diameters. When accelerating and decelerating inertial loads, the torque required is also in direct proportion to the time required to achieve the desired speeds. Altering the acceleration profiles can lead to reduced torque requirements. Instead of sizing reducers to handle all torque resulting from e-stops or machine jams, install brakes to assist in deceleration and torque limiters to protect against extreme shocks. Saving up to 50% can be realized.

Some motor manufacturers offer designs that provide full torque to 3,600 rpm. By doubling the reducer ratio, the same output torque and speed can be achieved with a less expensive motor. Lowering operating expenses can also reduce costs. When high speeds are required, consider oil circulation systems or external cooling options. Although initially more expensive maintenance and down time will be reduced and gearbox life will be extended.

Use higher efficiency speed reducers. For example, select a helical or worm design instead of a standard worm reducer. Although the unit may cost 20 to 30 percent more, the high efficiency may allow for a smaller motor and result in less power consumption for payback in only a few months.

Many gearbox designs allow for the motor to be directly mounted to the reducer. These designs incorporate either extremely precise flanges to allow the motor to be directly plugged into the reducer or other adapters with integral couplings. This eliminates the need for separate mounting of the motor, but is usually only practical with smaller motors.

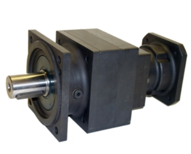
Although this completes the major considerations of speed reducer selection and integration into the machine, other elements are important in certain applications. For instance, with reversing or intermittent load applications, the amount of backlash should be reduced. The second element that should be considered is transmission error, or the positional variance of output motion relative to input motion. This is usually a function of gear and assembly quality and is important when precise and predictable motion is required. The third design element is torsional rigidity, which is a reducer's resistance to twist under load. This is an especially important consideration when precise motion must be maintained during acceleration and deceleration. The final design element is moment of inertia. In fast acceleration applications, such as servo systems, the gearbox inertia increases the motor torque required to move the load. All of these speed reducer elements can be supplied in varying levels of precision or durability with increasing cost for more stringent requirements.

Maintenance and failure analysis

In spite of well-engineered designs and intense selection analysis, speed reducers are subject to wear and eventual failure. To maximize life, proper maintenance procedures should be established. The most important element is the routine oil change. Oil and grease molecules break down under the extreme pressure of mating gear teeth under load. The shearing effect of gears cutting through the oil and high temperatures inside the box also contribute to oil breakdown. When oil and grease lose their lubricating properties, reducer wear rapidly follows.

Although a certain number of failures can be attributed to problems with materials or workmanship, usually operating conditions or application dynamics are to blame when a speed reducer fails prematurely. When overload causes failure, it is usually because the original design criteria has changed, the proper service factors were not applied, the oil was not changed, or there was a major shock load. When bearings fail it is usually the result of excess overhand load, shaft misalignment, or too much heat. When seals fail, it is most likely because something came between the seal and shaft, or because bearing wear has allowed the shaft to deflect.

This article first appeared in the October 2001 issue of Motion Systems Design magazine. DieQua Corporation offers a wide range of speed reducing solutions. Contact your DieQua Representative to find out how your machine drive system can be improved!



Servo Gearhead

Spiral Bevel Gearboxes

Helical Inline Reducers

Parallel Shaft Reducers

Helical Worm Reducers

Helical Bevel Reducers