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Gear efficiency — key to lower drive cost

Motion System Design

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Efficiency of a speed reducer is an important selection factor that is often overlooked. It shouldnít be. In many cases, high-efficiency gearing cuts the cost of drives and their operation

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Because they are widely used with industrial equipment, speed reducers and gearmotors can significantly impact your drive costs. Therefore, you should know how efficiently the various types of reducers use incoming motor power to drive a load.

Reducer type determines efficiency

Though reducer efficiency may vary slightly from one manufacturer to another, the way in which the gears intersect and mesh mainly determines speed reducer efficiency. This efficiency ranges from 49 to 98%, depending on the type of reducer and number of reduction stages it contains, Figure 1. Here's a brief description of some common types and their relative efficiencies.

Worm gear. In these widely used speed reducers, a worm gear drives a worm wheel to provide output motion at a right angle to the motor shaft, Figure 2. The worm gear and worm wheel have non-intersecting, perpendicular axes, and the meshing action between gears occurs over a relatively large contact area. This meshing action consists primarily of a sliding motion that creates friction between the gears.

Efficiency of a worm-gear speed reducer depends (in part) on its speed-reduction ratio. High-ratio units have a smaller gear-tooth lead (helix) angle, which causes more surface contact between them. This higher contact causes higher friction and lower efficiency. Typical worm-gear efficiencies range from 49% for a 300:1, double-reduction ratio, up to 90% for a 5:1, single-reduction ratio. For this reason, these units are usually more suitable for low ratios.

Helical worm. The arrangement of gear stages in a speed reducer also affects its efficiency. In helical-worm speed reducers, a set of helical gears connected to the motor shaft drives a worm-gear set, Figure

3. The helical-gear set reduces input speed (from the motor) to the wormgear set. This keeps the worm-gear reduction ratio (and size) low to maximize its efficiency.

The combined efficiency of helical and worm gears ranges from 79% for a 300:1 speed-reduction ratio to 90% for a 5:1 ratio.

Helical bevel. As with worm and helical- worm units, the output shaft of this reducer type is at a right angle to the motor shaft, Figure 4. And like helical-worm speed reducers, a set of helical gears usually makes the first speed reduction.

Here, spiral-bevel gears are mounted with intersecting axes, an arrangement that minimizes friction between the gears to provide 94 to 97% efficiency.

The primary drawback to helical-bevel speed reducers is their higher cost than worm-gear units, especially for small ratios such as 5:1 or 10:1. But the added cost is sometimes offset in high-reduction-ratio units because their high efficiency allows the use of either a smaller reducer, motor, or both.

In-line helical. These speed reducers are often the best value for applications in which the motor and reducer are coupled in-line with the driven shaft, Figure 5. Their efficiency usually ranges between 95 and 98%, regardless of speed ratio. Cost is competitive with worm-gear speed reducers where the center distance is 2-in. or more.

Helical-gear sets have parallel axes between gear teeth and small contact areas, which keeps power-robbing friction and heat low.

Calculating efficiency

To compare differerent types of speed reducers, first calculate the required load for your application and the efficiencies of the reducers being considered.

Load requirement. The key to proper speed-reducer selection is to determine the actual torque or power required to drive the load. First measure the torque (lb-in.) or power (hp) needed to drive the load at its input shaft.

Next, multiply the torque or power value by appropriate service factors to compensate for unusual operating conditions such as shock loads, frequent stopping and starting, and high temperature. These service factors are normally listed in manufacturers' catalogs. The American Gear Manufacturers Association (AGMA) also publishes service factors for different classes of service in their standards.

For example, if a driven equipment shaft requires 2 hp, and it's subject to moderate shock loads, apply a 1.4 service factor. If the ambient temperature is between 100 and 115 F, use a 1.15 service factor. Thus:

$$\begin{aligned} P_R &= P_0 \times SF_S \times SF_T \qquad (1) \\ &= 2 \times 1.4 \times 1.15 = 3.22 \text{ hp} \end{aligned}$$

Once you've applied the recommended service factors to compensate for loading and temperature, compare the efficiency of the speed-reducers being considered based on the actual load requirement.

Efficiency. Unfortunately, many speed-reducer manufacturers do not publish efficiency ratings. If their catalog lists the input power, torque, or wattage

as well as comparable output values, you can calculate efficiency by:

$$E = \frac{P_I}{P_O} \qquad (2)$$

If you need to convert power, torque, or wattage values to make a comparison, use these formulas:

$$P_m = \frac{T \times S}{63{,}025} \qquad (3)$$

$$P_e = P_m \times 0.75 \qquad (4)$$

Input power requirement

Once the service-factored power and the gear efficiency are known, determine the required motor power by:

$$P_M = P_O \times \frac{1}{E_{SR}} \qquad (5)$$

$$= 2 \times \frac{1}{0.95} = 2.1 \text{ hp}$$

As a rule of thumb, choose the nextlarger motor, in our example, a 3-hp motor.

Energy consumption

Nomenclature:

- P_R = Power required, hp
- P_O = Output power, hp (or lb-in. or kW)
- SF_S = Service factor for shock load
- SF_T = Service factor for high temperature
- E = Efficiency, %
- P_I = Input power, hp (or lb-in. or kW)
- P_m = Power (mechanical), hp
- T = Torque, lb-in.
- S = Speed, rpm
- P_e = Power (electrical), kW
- P_M = Motor power, hp
- E_{SR} = Speed reducer efficiency, %
- P_C = Power cost, $
- H = Time, hr
- C_K = Cost, $/kW-h

To estimate the cost of power consumed by a reducer, convert the motor power requirement to kW. Then multiply this value by the annual number of operating hours and the local cost per kW-h:

$$\begin{aligned} P_C &= P_M \times 0.75 \times H \times C_K \qquad (6) \\ &= 2.1 \times 0.75 \times 4{,}000 \times 0.08 \\ &= \$504 \end{aligned}$$

Because this calculation doesn't consider motor efficiency and power factor, use it only to compare the energy consumption of different speed reducers, not the motor-reducer combination.

Costs

Gear efficiency affects both drive component (speed reducer and motor) costs and operating costs, as demonstrated by examining two common speed-reducer types: a concentric or in-line helical-gear unit and a right angle worm-gear unit. Both units provide a 60:1 ratio and are rated with a 1.0 service factor for uniform loads and normal ambient temperature. They are driven by a 1,750-rpm, 230/460- V, 3-phase TEFC motor.

As Table 1 shows, the higher efficiency of the in-line helical reducer enables using a ½-hp smaller motor.

Component costs are shown in Table 2. Though gear efficiency can cut costs through the use of a smaller reducer and motor, it also minimizes energy costs. Table 3 compares the energy cost of the units in our example, based on 4,160 hr annual operation at a cost of $0.08/kW-h.

The in-line unit's higher efficiency gives an annual energy savings of $143 compared to the right-angle worm unit. Combined with the in-line unit's lower cost of $139, the total first year savings is $282.

Not every application produces the same results. For example, worm-gear speed reducers with ratios up to 30:1, or those with 2-in. center distances or less, are often a better value than helical reducers. Such worm-gear units offer about 78% efficiency, compared to 62% in our example, because the worm gear and wheel are smaller and generate lower friction losses.

Environmental benefit

Efficient speed reducers can achieve significant savings, both in drive component costs and energy costs. But there is another good reason to use them: to reduce health risks from greenhouse gases in our environment. According to the U.S. Dept. of Energy, industrial electric motor systems account for 1/12 of all greenhouse gas emissions from fossilfuel power plants. Therefore, cutting motor power consumption with efficient speed reducers will help to ease this global problem.

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