Considering Energy-Efficient Motors? Don't Forget the Gearbox

David. W. Conrad

The mechanical components of your drive system play a major role in overall system efficiency. Don't cut corners.

Most manufacturing facilities are trying to reduce their energy usage today. Average cost-per-kWh has more than tripled in the past two decades due to increased demand and less development of energy resources. Those manufacturing processes utilizing numerous power transmission applications (motors/gearboxes) are particularly concerned with energy consumption. These operations include—among others—warehouse distribution centers, food processing and bottling plants—i.e., anywhere automated conveyance is needed and often requires a right-angle change of power transmission.

In recent years much emphasis has been placed on high-efficiency NEMA premium motors—and with good reason. Higher-efficiency motors can play an important role in your energy conservation efforts. Yet today, it is estimated that half of all U.S. manufacturers still use outdated right-angle gearing technology that may have low initial cost, but is inefficient, wears quickly, wastes energy and fails prematurely—limiting the effectiveness of your new premium motor.

Generally, there are two common indicators in gearing that most of us intuitively understand indicate inefficiency: high noise and vibration, and high heat generation.

Rotating machines that generate high noise and high vibration can have any number of quality issues: e.g., rotating components may not be balanced properly; mating components may be not be machined precisely enough regarding perpendicularity, concentricity and true position; or components may not be rigid enough, flexing under load, which can result in misalignment.

High heat generation (Fig. 1) is always the result of low efficiency in rotating machines, which can also have many causes, including inefficient design, misalignment and poor product selection.

In general, gearboxes that generate excessive noise and vibration—or regularly run at temperatures >75°F above ambient—are poorly designed, poorly manufactured or poorly selected.

Design. Although traditional worm-only, right-angle gearboxes are widespread and relatively inexpensive, they are also quite inefficient. Worm gears operate mainly by sliding contact, resulting in high friction and inefficient operation (25-80 percent). The worm set is not only performing the function of changing the torque transmission direction, but is also bearing the burden of all of the speed reduction and torque increase, thus requiring more turns in the worm gear. The efficiency of the worm set depends on the number of turns on the worm—the more turns, the larger the ratio and the lower the efficiency. Helical gear sets, although not used to change torque transmission direction, are very efficient (> 98 percent-per-stage). Decreased tooth loading is a chief advantage of helical gears, allowing operation with high speed and torque changes with minimal rolling friction and minimized heat generation. Helical gearing is much more ef-

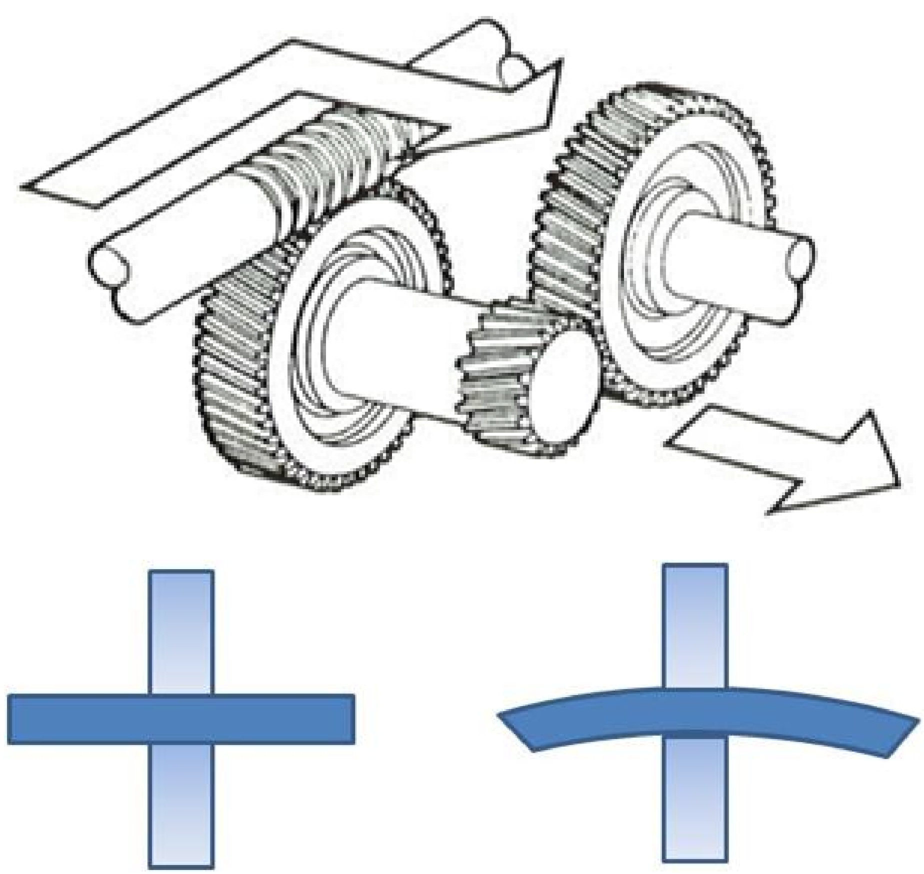


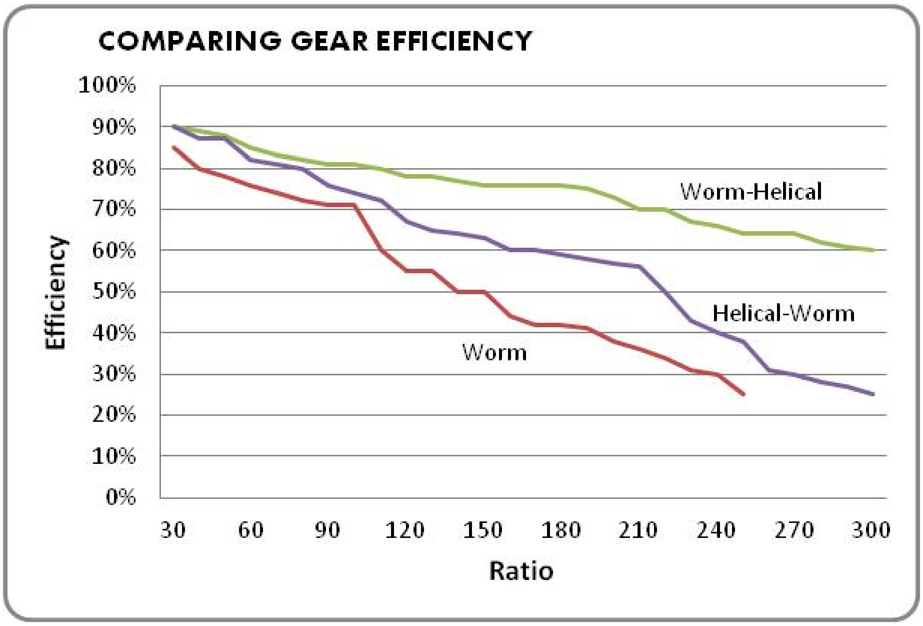
Figure 1 Inefficient gearing generates high heat losses that in turn elevate pressure inside the gear reducers that require venting to the outside environment.

ficient than worm gearing, so even for a single, one-HP motor running in a 24/7 operation, that can mean hundreds of dollars per year in energy savings. A well-designed, precisely manufactured and effectively applied helical gearbox can last many years under normal operating conditions.

Understanding that worm gearing alone is relatively inefficient and helical gearing is very efficient, some gear manufacturers offer right-angle gearboxes that include worm *and* helical gearing (Fig. 2). The worm portion of the gearbox serves to achieve the right-angle direction change of power transmission and the helical portion provides very efficient speed reduction. These types of gearboxes can be obtained with a helical input and worm output (helical/worm) or with a worm input and helical output (worm/helical). In most cases the latter (worm/helical) is the more efficient option. When the worm gear is used as the input (first stage), its primary function is the right-angle change in direction of power transmission. Very little speed reduction is required, so fewer turns are required on the worm gear, sliding friction is reduced, efficiency loss minimized. The helical portion of the gearbox (second stage) bears the primary load of torque increase and speed reduction. This results in a right-angle gearbox offering considerably higher efficiencies—especially at high-reduction ratios.

When the helical gear set is the first stage or input, the size of the shaft—and, therefore, the gear set—are limited, because input shaft size and torque are low, and input speed is high. The result is less of the speed reduction and torque increase can be counted on from the first-stage helical set and the second-stage worm set must make up the difference. This makes the total gear train less efficient and generates more heat. The result is a right-angle gearbox offering efficiencies of 65–70 percent.

When right-angle gear reduction is required, worm/helical gearboxes are generally the best-suited for applications that require an efficient right-angle solution with low output speed and high output torque. Typical applications include conveyor systems, food processing equipment, medical equipment and factory automation.



EFFICIENCY COMPARISON

40:1 RATIO

REDUCTION	EFFICIENCY
Worm/Helical	87%
Helical/Worm	80%
Single Worm	77%

200:1 RATIO

REDUCTION	EFFICIENCY
Worm/Helical	68%
Helical/Worm	59%
Single Worm	55%

Figure 2 Efficiency comparison based on worm set ratio; as ratios increase, savings decrease.

Manufacture. Well-manufactured helical gearing is machined with angled teeth that are hardened and then ground—a complex but necessary process to achieve the high-efficiency gear mesh. The teeth are cut across each gear at an angle, such that the gears gradually mesh. Because of the angled teeth, two or three teeth of each gear are always in contact with other gears. This alleviates the load on each tooth and creates a smooth transition of forces from one tooth to the next. The result: less vibration, wear, noise and longer life.

Many gear reducers are designed and manufactured to limit size and weight in an effort to claim higher "power density." The result is a smaller, lighter gearbox that is less rigid. Robustly designed

Table 1 Energy savings are there for the taking—if you have the right gearbox

SYSTEM	ENERGY SAVINGS POTENTIAL
Mechanical Power Transmission	60%
Variable Speed and Energy Controls	30%
High Efficiency NEMA Premium Motors	10%

and manufactured gearboxes are compactly designed to fit easily into new and existing applications, but maintain the mass of the housing to provide a more structurally stable and rigid product. The resulting housing stiffness and rigidity keeps shafts and gears precisely aligned—even at high loads. Adherence to tight tolerances on the machining of the housings is critical as well, to ensure the optimal radial meshing of the gears and optimal perpendicularity of gears to each other.

Inefficient gearing generates high heat losses that in turn elevate pressures inside the gear reducers that require venting to the outside environment. Venting lets air out, but it also lets air in. Incoming air contains contaminants and adds moisture, which breaks down the oil inside the gear reducers. Well-designed and precisely manufactured worm/helical gearboxes are very efficient and do not generate much heat. This, along with high-quality synthetic oil, allows these gear reducers to be completely sealed, thus preventing moisture and contaminants from entering the oil chamber and breaking down the oil. Oil, under normal operation, should not break down and should not need to be changed for the life of a gearbox designed and manufactured in this manner, even in the harshest environments.

Seal surfaces run at high speed against metal surfaces, thus making them the wear items that often determine the life of a gear reducer. The highest quality designs, materials, handling and assembly practices are required to ensure that oil seals perform to the level required for long-life gear reducers. This is another area where a worm/helical input/output gearbox usually functions better than a simple worm or helical/worm combination gearbox. Because the worm input is used primarily for changing the direction of torque (leaving most of the heavy lifting to the helical gears), the input shaft diameter can be smaller, resulting in less linear speed between the seal lip and the shaft. This results in less seal lip friction, which is especially important on the input side of the gear train, which is closer to the heat generated by the motor and the worm gear mesh. Small shaft diameters are less important on the output as speeds are lower and the seals are further away from heat sources (motor and worm mesh).

Finally, bearings—whether ball, spherical or tapered—are the other wear items within gear reducers with high-speed, metal-to-metal rolling contact under various load conditions. Proper selection and sizing, correct handling and assembly are all critical to ensure long life in gear reducers. Minimized bearing spans, rigid housing construction and well-controlled housing tolerances are very critical to the life of bearings in an enclosed gearbox.

Proper selection. Even industry-leading designs and manufacturing practices cannot prevent failure if a gearbox is improperly sized or applied. It is imperative that the application power requirements and demands are clearly understood. Utilization of the appropriate service factor for the speed of the reducer must be taken into consideration and applied. If the gearbox is unnecessarily oversized and the power capacity of the gearbox greatly exceeds the power of the applied motor, much of the motor horsepower will be used to overcome the constant losses within the gearbox, thereby leaving little additional, usable power and torque for the application itself. As such, this would be a situation where the speed reducer is yielding a very low efficiency. Conversely, a gearbox undersized for an application runs the risk of low life expectancy due to overload conditions, despite a seemingly high efficiency.

Conclusion

The initial cost of a well-designed, precisely manufactured and properly selected right-angle gearbox will be higher than the lowest initial cost solution, but that investment is returned many times over during the life of the application. The temptation to cut corners to lower initial cost is always present. Price competition in the market is fierce; many companies attempt to lower costs in areas that result in a compromise of design and quality. Robust and efficient right-angle gear solutions are manufactured by companies that focus cost control efforts on areas like design and manufacturing efficiency, waste reduction and continuous improvement. The quality and durability of the gear reducers should never be compromised. **PTE**

For more information:
David W. Conrad
VP Engineering
Master Power Transmission
Phone: (864) 312-5102
dwconrad@master-pt.com
www.master-pt.com

David Conrad's career began with several management-level positions at Dodge (Rockwell Automation), including, engineering manager, director of lean enterprise and plant manager. He moved on in 2007 to Richmond Gear/Velvet Drive (Regal Beloit Corp.), assuming the role of VP/general manager. He now serves as VP of engineering at Master Power Transmission in Greenville, SC–a manufacturer of quality industrial mechanical power transmission products. Conrad is a licensed professional engineer, with a Master of Science in mechanical engineering from the University of South Carolina. He holds a number of U.S. patents related to industrial mechanical power transmission and is the author of several articles on related topics.