The Right Way to Lubricate Worm Gears

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Of all the different types of gear configurations, worm gear systems are considered some of the most problematic because they present unique lubrication challenges due to their distinct design. To overcome these challenges, you must understand not only the complexities of worm gears but also which qualities to take into account when choosing a worm gear lubricant.

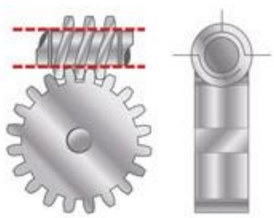

Figure 1. Non-throated (non-enveloping)

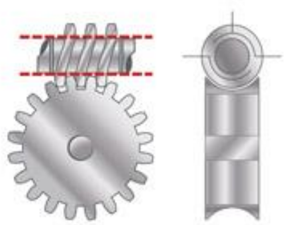

Figure 2. Single-throated (single-enveloping)

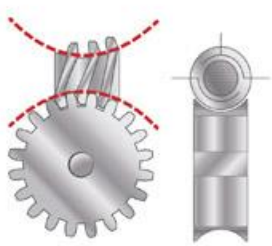

Figure 3. Double-throated (double-enveloping)

Worm Gear Designs

A worm gear is a non-parallel, non-intersecting axis design consisting primarily of two gear elements: the worm, which is the driving gear in the shape of a spiral or screw, and the worm gear or worm wheel, which is the driven gear in the shape of a common spur gear.

Technically, the entire worm gear system should be called a worm drive or worm gearset to avoid confusion. The worm always drives the worm wheel. This design characteristic is due to the extreme helical angle, which is nearly 90 degrees. The worm drive resembles the design of the crossed helical gear configuration, except the gear teeth on the worm of a worm drive will circle around the circumference of the worm at least once. Since the worm may have as little as one tooth that spirals radially around the helix, the number of teeth on the worm is more appropriately identified by the number of starts or threads.

There are three categories of worm drive designs that describe the degree to which the gears mesh together: non-throated (non-enveloping), single-throated (single-enveloping) and double-throated (double-enveloping or globoidal).

Non-throated or non-enveloping is the most basic design in which the worm and worm wheel are both cylindrical in shape. This allows for simplistic manufacturing, but the limited contact zone of a single point on one or two gear teeth can become problematic.

In single-throated or single-enveloping designs, one of the gear elements (most commonly the worm wheel) has concave helical teeth for contour or envelopment of the gear teeth onto the worm. This enables the contacting zone to increase to a line.

Double-throated (double-enveloping) or globoidal designs not only have concave helical teeth on the worm wheel, but the worm is also shaped like an hourglass so the two gear elements wrap around each other during motion. This results in nearly eight times more contact area (in the shape of a radial band) with three or more teeth in contact.

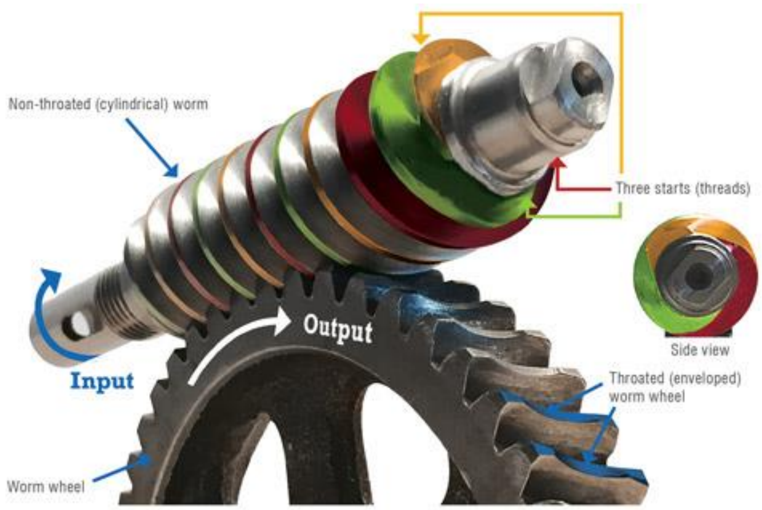

Figure 4. Single-throated (single-enveloping) worm drive

As the contact surface area increases, the torque capacity, load-holding ability (shock load resistance) and durability are improved. Enveloping gear designs also have a lower anticipated wear rate as a result of the load distribution. Worm drive manufacturers attempt to optimize this contact relationship between the two gear elements for improved reliability.

Other notable advantages of worm drives over potential gear system alternatives include:

- A worm drive can be designed with a gear ratio of more than 200-to-1, in comparison to that of a helical gear, which may be limited to 10-to-1 on a single reduction. The gear ratio for worm drives is the number of teeth on the worm wheel to the number of threads (or starts) on the worm.

- The high gear ratio and configuration of the two gear elements allow for a compact design, making the worm drive a great option for space-limited areas. In addition, the number of moving parts is reduced along with the opportunities for failure. However, this may be partially offset by a loss in efficiency from large increases in torque.
- Due to the extreme helical angle, switching the direction of power is nearly impossible. The worm wheel cannot easily be rotated independently to force movement on the worm. This self-locking ability eliminates the need for a backstop, which may be required in alternative gear systems.
- With the precise movement of worm drives, particularly in double-enveloping designs, backlash (play between gear teeth) can be greatly minimized. This is crucial in certain applications such as robotics.
- Low noise and vibration results from minimal moving components in worm drives in comparison to alternative gear designs.

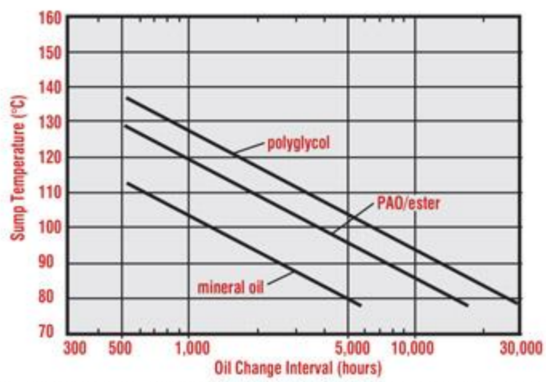

Figure 5. A comparison of lubricant life and oil change intervals for mineral oil, PAOs and PAGs over a range of oil sump temperatures

Lubrication Challenges

Worm drive designs have one major drawback: the relative motion between the mating teeth of the two elements is almost entirely sliding. This poses a significant challenge because the lubricant is continually scraped aside. The sliding friction losses result in elevated temperatures and inadequate hydrodynamic pressure development. Consequently, wear debris generation can increase. In many cases, the higher temperatures will be the limiting factor on the worm drive before the loading limitations are reached. The load distribution of enveloping gear designs can lessen this problem, but the challenge still persists.

Also, because of the sliding nature of the worm drive, metals with a low coefficient of friction are generally used. The worm wheel typically contains yellow metals, while the worm is usually made of steel. This results in more favorable wear characteristics, better loading ability and less heat generation not found in other metal combinations. Yellow metals like bronze that are used on the worm wheel can present unique lubrication challenges when selecting a compatible additive package. With this metallurgical combination, it is also expected that the worm wheel act sacrificially in comparison to the worm due to the relative effort and costs in worm drive rebuilds.

Lubrication Solutions

Gearing designs and materials have been modernized through the years to achieve better load-carrying capability, higher torque conversions and improved longevity. Sophisticated testing platforms and computerized methods have provided a better understanding of common worm drive failure modes and offered clues for optimizing the solutions. Lubricants are no exception to these enhancements for worm drives. Generally speaking, a high-quality worm drive lubricant will have low friction, high oxidation resistance, good anti-wear protection and high viscosity index.

The Right Base Oil

While using lubricants formulated with mineral oil is quite common within worm drives, employing synthetic base oils generally results in improved gear efficiency and lower operating temperatures. Figure 5 illustrates lubricant life and oil change interval expectations for polyalphaolefins (PAOs), polyalkylene glycols (PAGs) and mineral oils over a range of oil sump temperatures. This is supported by the Arrhenius Rate Rule, which states that for every increase of 10 degrees C in the average oil temperature, the chemical reactions double.

The energy transmission efficiency of the gear system's input and output can be significantly influenced by the lubricant selected. Figure 6 specifies the improved efficiency when choosing a synthetic over a mineral oil, particularly PAGs, which have an inherently low coefficient of friction. PAGs are also known to reduce operating temperatures and total losses. Additional comparisons between mineral and PAG base oils are seen in Figure 7.

PAGs do have some drawbacks, most notably their higher costs. They also are not compatible with some seal materials, plastics and paint coatings, so always confirm compatibility when switching to PAGs.

TYPES OF WORM DRIVE EFFECTS	ADVANTAGE OF A SYNTHETIC GEAR OIL OVER A MINERAL OIL
Reduction of total losses	30% or more
Improved efficiency	15% or more
Reduction of operating temperature	20˚C or more

Figure 6. Advantages of synthetic gear oil over mineral oil

The Right Additives

One of the most important jobs of a gear oil additive is to form a protective or sacrificial barrier between contacting surfaces when the conditions exceed that of the bulk oil's film strength. An additive package for a lubricant in a worm drive must be selected with care, since the yellow metals often contained within worm wheels can be adversely affected by corrosion from the activated sulfur within the extreme-pressure (EP) additive, particularly in the presence of heat. Nevertheless, advancements in additive formation with deactivated sulfur have helped to reduce or eliminate these corrosive attacks.

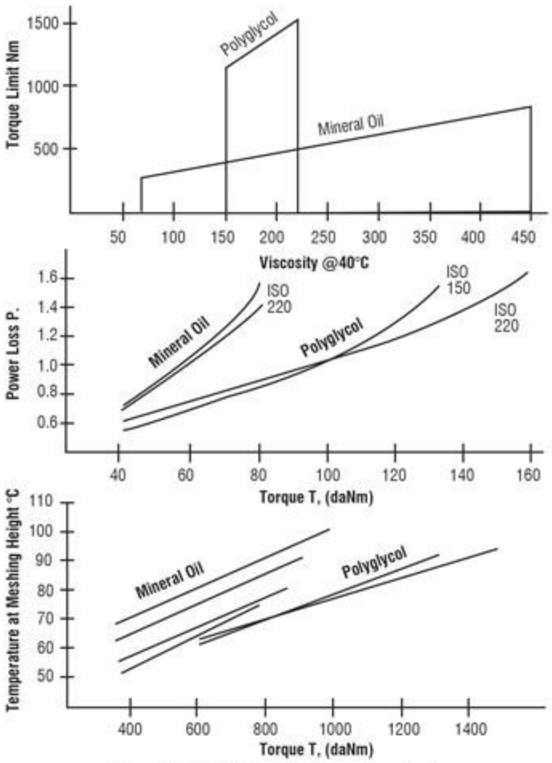

Figure 7. Polyalkylene glycol vs. mineral oil

Worm drives can present a unique boundary lubrication challenge, with the focus more on friction reduction than on the effects of wear. In these applications, a specific type of mineral-based lubricant known as a compounded oil can be used. This lubricant is formulated with up to 10 percent fatty acid (natural oil) or acidless tallow as the compounding agent along with rust and oxidation inhibitors and other additives. This results in improved lubricity, reduced friction and decreased sliding wear.

EP oils are still commonly used in worm drive applications where they are formulated with yellow metal compatibility. However, both compounded oils and EP gear oils have a working temperature limitation of approximately 80 degrees C before oxidation rates rapidly increase, resulting in acidic products that can attack cupric worm wheel materials.

The Right Viscosity

Aside from the ambient and operating temperature, the correct viscosity will depend on several variables of the final worm wheel, including the pitchline velocity, center distance and revolutions per minute. Figures 8 and 9 provide recommendations for the ISO viscosity grade selection on cylindrical and double-enveloped worm drives according to the American Gear Manufacturers Association (AGMA) 9005-E02 standard.

PITCHLINE VELOCITY OF FINAL REDUCTION STAGE	ISO VISCOSITY GRADES		
	AMBIENT TEMPERATURE (°C)		
	-40 TO -10	-10 TO 10	10 TO 55
Less than 2.25 m/s	220	460	680
More than 2.25 m/s	220	460	460
NOTES: Worm gear applications involving temperatures outside the limits shown above or speeds exceeding 2,400 rpm or 10 m/s sliding velocity should be addressed by the manufacturer. In general, for higher speeds, a pressurized lubrication system is required along with adjustments in the recommended viscosity grade. This table applies to lubricants with a viscosity index of 100 or less. For lubricants with a viscosity index greater than 100, wider temperature ranges may apply. Consult the lubricant supplier.			

Figure 8. ISO viscosity grade guidelines for enclosed cylindrical worm gear drives

CENTER DISTANCE OF FINAL REDUCTION STAGE	WORM SPEED OF FINAL REDUCTION STAGE (RPM)	ISO VISCOSITY GRADES			
		AMBIENT TEMPERATURE (°C)			
		-40 TO -10	-10 TO 10	10 TO 35	35 TO 55
UP TO 305 MM	<300	460	680	1000	1500
	300-700	320	460	680	1000
	>700	220	320	460	680
MORE THAN 305 MM TO 610 MM	<300	460	680	1000	1500
	300-500	320	460	680	1000
	>500	220	320	460	680
MORE THAN 610 MM	<300	460	680	1000	1500
	300-600	320	460	680	1000
	>600	220	320	460	680
NOTES: Worm gear applications involving temperatures outside the limits shown above or speeds exceeding 2,400 rpm or 10 m/s sliding velocity should be addressed by the manufacturer. In general, for higher speeds, a pressurized lubrication system is required along with adjustments in the recommended viscosity grade. This table applies to lubricants with a viscosity index of 100 or less. For lubricants with a viscosity index greater than 100, wider temperature ranges may apply. Consult the lubricant supplier.					

Figure 9. ISO viscosity grade guidelines for enclosed globoidal worm gear drives

As these recommendations and the oil change interval chart show, temperature has a significant impact on effective lubrication. Not only are the lubricant and machine longevity negatively affected by higher temperatures, but worm drives in particular have trouble with temperature spikes. As a result, if higher temperatures are expected, more effective alternatives for base oils and additives should be selected. Synthetic oils such as PAOs and PAGs perform better than mineral oils due to their naturally higher resistance to thermal degradation. Nevertheless, an increase of 32 degrees C above the ambient temperature in single-throated worm drives (37 degrees C for double-throated worm drives) is not considered excessive for the operating conditions.

POSITION	Worm-under (worm on the bottom)	Worm-over (worm on the top)	Vertical (worm on the side)
OIL LEVEL	Wheel immersed at approximately one-third of its diameter	Wheel immersed to approximately the center of the meshing zone	Half the wheel immersed to at least worm height

Figure 10. The three most common worm drive positions (Ref: *The Lubrication Engineers Manual*)

The Right Oil Level

As with most splash-lubricated gear systems, the oil level in a worm drive is essential to maintain accuracy. Depending on the position of the worm relative to the worm wheel, a small drop in oil level could be the difference between ideal lubrication and no lubrication. When monitoring the oil level in the three most common worm drive positions (Figure 10), adhere to the manufacturer's recommendations, which will often be in line with the standards for depth of oil immersion.

When the pitchline velocity of the worm elements exceeds 10 meters per second, particularly with double-enveloping worm drives, a force-feed lubrication system is recommended to spray the entire face of the worm.

The Right Visual Inspections

Besides monitoring the oil level, a sight glass should be regarded as a window into the oil's condition. This may include visual checks for unusual oil darkening (a sign of oxidation), visible sludge, solid particles and moisture. These inspections can be performed more efficiently when the sight glass is extended out from the gear housing so light can be passed through it, as in the sight glass shown on the left.

If possible, a bottom sediment and water bowl should also be used. This will help capture any solid particles or liquids that are heavier than the oil and provide a daily visual inspection point.

The Right Choice

The goal of any chosen lubricant should be to protect the worm drive from undesirable levels of friction, the dangerous effects of corrosion and inefficient operation. Assessing and achieving the optimum reference state for every style of worm drive in accordance with its operating and environmental conditions will come down to one thing: justifying the costs of improved lubrication practices to minimize the risk and potential consequences of failure. Fortunately, improving lubrication practices for worm drives should not be costly and may be as simple as confirming that the lubricant meets the minimum requirements while performing visual inspections and even oil analysis for effective condition monitoring. Just as worm drives are some of the most simplistic and beneficial gear designs, the lubrication practices that they require are equally unique and essential.

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