BRIAN DENGEL
GENERAL MANAGER • KHK-USA

Worms and worm wheels – a primer

Worm gear pairs are an excellent design choice when you need to reduce speeds and change the directions of your motion, and they have many other applications as well.

First published in 1973, the novel *How to Eat Fried Worms* by Thomas Rockwell tells the story of Billy and his desire to win a bet by eating a worm a day for 15 days. Although the thought of eating worms is not something most of us would consider doing, Billy finds a way to ingest a nightcrawler each day. Much like this children's story, most mechanical engineers know about worms, but are not comfortable designing them into their systems.

Worm pairs or worm drives are interchangeable terms for a set of mechanical components that consist of a worm and a worm wheel. The worm is the drive mechanism in this set and has a shape like that of a screw. The worm has several critical dimensions which define how it will function in the set. The critical values are the outside diameter of the worm, the lead angle of the threads, the direction of the threads, and the number of starts of the threads. For the worm shown, the thread direction is clockwise; this corresponds to a right-hand thread. Although available in both left-hand and right-hand threads, the right-hand thread is the most common choice. This worm also has two starts to the threads. This is important in determining the reduction ratio of the pair.

Worm drive

Worm wheel

The worm wheel, also known as the worm gear, is simplistically a helical gear that matches the pitch, pressure angle, and helix angle of the worm. The significant difference between a worm gear and a helical gear is the throat. This is an indent in the tooth form that allows the worm to be properly seated with the centerline of the worm wheel. The speed ratio of a worm gear pair is determined by the number of teeth on the worm wheel and the number of thread starts on the worm. For worms with a single thread, very high-speed ratios can be developed. Since the speed ratio is the ratio of the number of teeth to the number of thread starts, it is possible to change the reduction ratio by replacing the worm pair with another set which is produced with additional starts. With the addition of more thread starts, the helix angle needs to increase if the center distance is to remain the same.

There are several types of worm gear pairs. The set detailed above is known as a single enveloping set. It is designated as such because there is only one set of threads on the worm that engage the teeth on the worm wheel. Because the worm pair is a friction drive and one set of threads repeatedly engages the worm gear, the material of the worm needs to be significantly harder than that of the wheel. For this reason, worms are typically produced from steel and worm wheels are typically produced from bronze alloys. It is common to harden and grind worms specifically when they are going to be used under high load or operating at high speeds such as inside a reduction drive gearbox.

Another type of worm gear set is the double enveloping pair. In this set, the worm is not straight but has a concave tooth shape which matches the curvature of the worm wheel. This permits more of the threads of the worm to engage with the worm wheel. This additional contact allows for greater torque transmission.

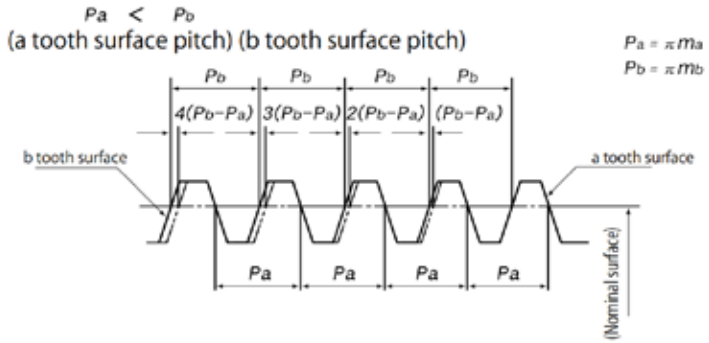
A third type of worm gear set is the duplex pair. This type of worm pair uses a single enveloping worm which has a variable pitch across its length. As the pitch profile changes, the tooth form is increased, and the backlash is decreased. Using this type of worm gear pair, a near-zero backlash worm gear assembly can be produced (Figure 1).

Other variations of worm gearing that have been developed to reduce backlash include the use of a spring loaded, split worm (known as the Ott worm), or the use of spring loaded windows in the worm gear.

Worm gear pairs are friction drive mechanisms. As such, they require lubrication to remove the heat built up by friction. Due to the limits of most lubricating fluids, the input speed of the worm needs to be less than 1800 rpm. At higher speeds, most lubricants do not have the ability to pull the heat from the mesh and will froth inside the gearbox. In most cases, open worm gearing should be lubricated with recirculating splash lubrication. However, when enclosed in a housing, the suggestions in Figure 2 should be followed.

Due to the friction, some designers will choose a worm gear pair to act as a brake to prohibit reversing motion in their mechanism. This idea develops from the concept that a worm gear pair becomes self-locking when the lead angle is small and the coefficient of friction between the materials is high. Although not an absolute, when the lead angle of a worm gear pair is less than 4 degrees and the coefficient of friction is greater than 0.07, a worm gear pair will self-lock.

Since worm gears have a lead angle, they do produce thrust loads. These thrust loads vary on the direction of rotation of the worm and



[CAUTION] The amount of change in backlash (△j mm) in relation to the axial movement of the duplex worm shaft (V mm) can be calculated from the formula below.

$$\Delta j = 2V \frac{m_b - m_a}{m_a + m_b}$$

Where

m_a = Nominal Axial Module − (0.01 × Nominal Axial Module)

m_b = Nominal Axial Module + (0.01 × Nominal Axial Module)

Figure 1: Worm gear backlash calculations.

the direction of the threads. A right-hand worm will pull the worm wheel toward itself if operated clockwise and will push the worm wheel away from itself if operated counter-clockwise. A left-hand worm will act in the exact opposite manner.

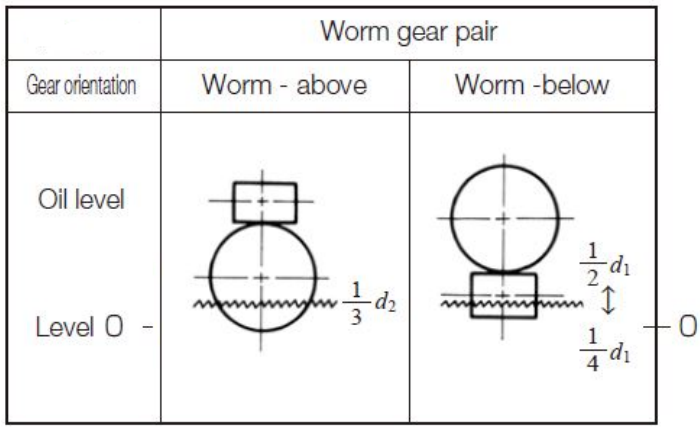


Figure 2: Worm gear lubrication when enclosed in a housing.

Worm gear pairs are an excellent design choice when you need to reduce speeds and change the directions of your motion. They are available in infinite ratios by changing the number of teeth on the worm wheel and, by changing the lead angle, you can adjust for almost any center distance. I don't recall what Billy did with his $50 for eating all 15 worms, but I do know I won't be taking up that challenge any time soon.

ABOUT THE AUTHOR

Brian Dengel is general manager of KHK-USA, which is based in Mineola, New York. Go online to www.khkgears.us