WORMS AND WORM GEARS
Now that you have an understanding of two of the more common types of gears – spur gears and helical gears – let’s learn about two additional and highly versatile types of gears that are used to transmit motion and power at various speeds and speed ratios: **worms and worm gears**.

A **worm** is a gear with one or more cylindrical, screw-like threads (also referred to as “starts”) and a face width that is usually greater than its diameter. A worm has a center hole (bore) for mounting the worm on a shaft.

**Worm gears**, like worms, also are cylindrical and bored for mounting on a shaft. However, unlike a worm, a worm gear’s diameter is usually much larger than the width of its face.

**Note**: Worm gears differ from spur gears in that their teeth are somewhat different in shape and are always formed on an angle to the hole (axis) in order to mate with worms. (See Figure 4.1).

In order to transmit motion and power at various speeds and speed ratios, worms and worm gears work in sets, rotating on shafts at right angles to one another. The worm usually drives the worm gear. Accordingly, the worm gear is usually the driven member. (See Figure 4.1A)

**Important**: In worms and worm gear sets, both the worm and worm gear are of the same hand. Right-hand sets are considered standard. As a result, right-hand sets will always be furnished unless otherwise specified.

**COMMON APPLICATIONS:**
Worm and worm gear sets are used in many, everyday products including: electrical mixers, hubometers, right angle speed reducers and medical equipment.

**CATALOG CHECK:**
Boston Gear carries a full line of standard stock worms and worm gears for use in open and enclosed drives. Check them out starting on page 73 of the Gears catalog.
WHEN TO USE WORMS AND WORM GEARS

Worms and worm gears provide solutions to a wide range of drive problems, particularly when the following factors need to be considered:

• High ratio speed reduction
• Space limitations
• Right angle shafts
• Non-intersecting shafts

Now that you have been introduced to worms and worm gears, let's take a closer look at each, starting with the worm.

WORMS - IDENTIFYING THE NUMBER OF THREADS

Boston worms are cut with single, double, triple or quadruple threads. To determine the number of threads on a worm, look at an end view so you can see the “start” of each thread. One start means that you have a single thread, two starts a double thread, three starts a triple thread, and four starts, a quadruple thread. (See Figure 4.1B)

DIAMETRAL AND CIRCULAR PITCH

As you learned from our lessons on spur gears and helical gears, diametral pitch and circular pitch are two systems used to designate the size of a gear's teeth. Boston Gear stock worms and (worm gears) are listed in the Gears catalog according to their diametral pitch.

Diametral pitch (also referred to as pitch) is the relationship between the number of teeth in a gear and each inch of the gear's pitch diameter (PD). For example, a worm gear with 16 teeth (T) and a one-inch pitch diameter is a 16-diametral pitch (DP) gear.

\[
DP = \frac{T}{PD} \text{ or } DP = \frac{16 \text{ teeth}}{1 \text{ PD}} = 16 \text{ DP}
\]

Note: Diametral pitch can be measured using a gear gauge.

Important: Diametral pitch can also be determined using the following formula: \( DP = 3.1416 \div \text{Circular (linear) pitch} \)

Figure 4.1B
CIRCULAR (LINEAR) PITCH

With a worm, circular (also referred to as linear) pitch is a distance measured along the pitch line of the gear. It can be determined by measuring – with an ordinary scale – the distance between any two corresponding points of adjacent threads parallel to the axis. (See Figure 4.1)

With a worm gear, circular pitch is a distance measured along the pitch circle of the gear. It can be determined by measuring – with an ordinary scale – the distance between any two corresponding points of adjacent teeth. As noted above, this measurement should be taken on the pitch circle, which is approximately halfway down a tooth. (See Figure 4.2)

WORMS–THREAD DIMENSIONS

The dimensions of a worm thread are important because they provide valuable information when determining a customer’s needs.

As noted earlier, a worm thread is the part of the worm that wraps (spirals) around the cylindrical base of the worm, similar to the way the threads of a screw are configured.

The following terms are used when describing the dimensions of a worm-thread.

- Addendum – the part of the thread from the pitch line of the worm to the outer edge of the thread. (See Figure 4.3A)

- Dedendum – the part of the thread from the pitch line of the worm to the bottom of the thread. The dedendum is equal to one addendum plus the working clearance (defined below). (See Figure 4.3A)

- Working Clearance – the distance from the working depth (defined below) to the bottom of the thread. (See Figure 4.3A)

- Working Depth – the space occupied by the mating worm gear tooth. It is equal to twice the addendum. (See Figure 4.3A)

- Whole Depth – the distance from the bottom of the thread to its outside diameter.
WORMS—PITCH DIAMETER

The pitch diameter of a worm is the diameter of the pitch circle (the “imaginary” circle on which the worm and worm gear mesh). There is no fixed method for determining the pitch diameter of a worm. (See Figure 4.3B)

Important: Pitch diameters can vary, but sound engineering practice dictates that they be as small as possible for the most efficient performance. Why? A small pitch diameter reduces the sliding velocity and, therefore, the efficiency of the worm.

WORMS—BASIC FORMULAS

The following formulas will be useful as you determine your customers’ needs with regard to the selection of the correct worms.

- Diametral pitch = \( \frac{3.1416}{\text{circular (linear) pitch}} \)
- Circular (linear) pitch = \( \frac{3.1416}{\text{diametral pitch}} \)
- Pitch diameter = outside diameter - 2 (addendum)
- Bottom diameter = outside diameter - 2 (whole depth)
- Outside diameter = pitch diameter + 2 (addendum)

\[ \text{Figure 4.3B,} \]
\[ \text{Pitch Diameter Worm} \]
WORMS—HAND

Boston worms and worm gears are manufactured with right- or left-hand threads and teeth. The hand of a worm or worm gear may be determined by noting the direction in which the threads or teeth lean when the worm or worm gear is held with the hole facing up. (See Figure 4.4)

In a worm gear set, the worm and gear must have the same hand, pitch, number of threads, and tooth dimensions. They also must have the same pressure angle and lead angle (terms you will learn about below).

Reminder: Right hand worm and worm gear sets are considered standard. As a result, right-hand sets will always be furnished unless otherwise specified.

WORMS—LEADS AND LEAD ANGLE

The lead of a worm is the distance any one thread advances in a single revolution. The lead may be calculated using either one of the following formulas:

- Lead = (Number of worm threads x 3.1416) ÷ diametral pitch
- Lead = Circular pitch x number of worm threads

The following information also will come in handy when determining the lead of a worm:

- The lead and circular (linear) pitch are equal on single-thread worms.
- The lead is twice the circular pitch on double-thread worms.
- The lead is three times the circular pitch on triple-thread worms.
- The lead is four times the circular pitch on quadruple-thread worms.

WORMS—LEAD ANGLES

The lead angle of a worm is the angle formed by the worm thread and a line perpendicular to the worm axis. (See Figure 4.5)
LEAD ANGLE VS. EFFICIENCY

The lead angle is an important factor in determining the efficiency of a worm and worm gear set. The efficiency increases as the lead angle increases.

For a given pitch, the lead angle is controlled principally by two factors: (1) the number of threads and (2) the pitch diameter of the worm. The lead angle can be determined from the lead and pitch diameter by using a formula in concert with a table of cotangents (as follows).

\[
\text{(Pitch diameter of worm } \times 3.1416) \div \text{lead} = \text{Cotangent of lead angle}
\]

(See Figure 4.4)

**Important:** The mating worm and worm gear must have the same:

- Pitch
- Number of threads
- Tooth dimensions
- Hand
- Pressure angle
- Lead angle

(See Figure 4.4)

WORMS—PRESSURE ANGLE

The pressure angle is the angle at which a force is transmitted from the worm thread to the worm gear tooth. It determines the relative thickness of the base and top of the thread.

(See Figure 4.6)
WORMS—PHYSICAL DIMENSIONS

When ordering special (made-to-order) worms, the pitch, pitch diameter, pressure angle, number of threads and hand should always be specified, as should the physical dimensions illustrated in 4.7.

Note: Sometimes a pinhole through the hub is required (rather than a keyway). If this is the case, be sure to specify the pin dimensions and location.

WORMS GEARS—BASIC DIMENSIONS

As noted in our discussion of spur gears, gear dimensions are important because they provide valuable information when determining how best to meet a customer’s needs. Here are definitions you need to know in order to determine the basic dimensions of worm gears. (See Figure 4.8)

- Pitch Diameter – the diameter of the pitch circle (which, you will remember, is the “imaginary” circle on which the worm and worm gear mesh.
- Working Depth – the maximum distance the worm thread extends into the tooth space of the gear.
- Throat Diameter – the diameter of the throat circle at the center line of the worm gear face (the lowest point on the tooth face).
- Outside Diameter – the largest diameter of the worm gear teeth. It is equal to the diameter of the outside circle.
- Root Diameter – the smallest diameter of the worm gear. It is equal to the diameter of the root circle.
Now let’s look at the dimensions of the teeth on a worm gear.

**WORMS GEARS—TOOTH DIMENSIONS**

- **Addendum** – the distance from the pitch circle to the throat circle. (See Figure 4.9)
- **Dedendum** – the distance from the pitch circle to the base of the tooth. It is equal to the addendum plus the working clearance.
- **Whole Depth** – the distance between the throat and the base of the tooth. It is equal to the addendum plus the dedendum.
- **Working Clearance** – the space between the top of the worm thread and the bottom of the worm gear tooth when properly meshed.

**SPECIAL ORDER WORM GEARS—PHYSICAL DIMENSIONS**

When ordering special order worm gears, the pitch, number of teeth, pressure angle, number of threads, and the pitch diameter of the mating worm should always be specified.

**ROTATION AND RATIO**

Figure 4.10 indicates the various directions worms and worm gears will rotate depending on their position and hand.

- Changing the position of the worm (above or below the worm gear) changes the relative rotation of the worm gear.
- The direction of rotation using right-hand gearing is shown at the top.
- The direction of rotation using left-hand gearing is shown at the bottom.

The ratio of a mating worm and worm gear is determined by dividing the number of teeth in the worm gear by the number of threads in the worm or:

\[
\text{Ratio} = \frac{\text{Number of teeth in the worm gear}}{\text{Number of threads in worm}}
\]
**THRUST**

When a worm drives a worm gear, there is a tendency for the worm to “back out” or push forward (depending upon the direction it is rotating) due to the action of the thread. This is known as “thrust action”. To counteract the friction caused by this thrust action, thrust bearings should be used. Thrust bearings should also be used on the worm gear shaft, although thrust is considerably less on the shaft (due to the slower gear rotation.)

Figure 4.11 shows the direction of thrust when worms and worm gears are rotating in various directions. Thrust bearings are shown in their proper position to absorb the pushing force (thrust).

**CENTER DISTANCE**

The center distance of a worm and worm gear in mesh is the distance between the center of the two shafts. When mounted on the proper center distance, the worm and worm gear will mesh correctly. (See Figure 4.11A)

**Important:** For proper operation, the center distance should be equal to one-half the pitch diameter of the worm plus one-half the pitch diameter of the worm gear.

All Boston gears are cut to run with the correct backlash (see the explanation of “backlash” below) if exact center distances are maintained. If the exact center distance cannot be maintained, it is better to increase the center distance than it is to decrease it.

**BACKLASH**

Backlash (See Figure 4.11B) is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles. Backlash may be determined in the tranverse, normal, or axial-planes, and either in the direction of the pitch circles or on the line of action. Such measurements should be corrected to corresponding values on tranverse pitch circles for general comparisons. (See Figures 4.11C)

**Important:** The operation of Boston gears at proper center distances assures the correct degree of backlash for greatest efficiency and longest life.
VELOCITY

The velocity of a worm gear or worm is the distance that any point on the pitch circle will travel in a given period of time, generally expressed in feet per minute (FPM).

(See Figure 4.12)

Formula: Velocity (FPM) = Pitch Diameter (in inches) \times 0.262 \times RPM

WORM AND WORM GEAR EFFICIENCY

The worm and worm gear drive is never 100% efficient as there is always some power loss due to the friction (rubbing action) between the worm and worm gear. The following factors have an impact on the friction and, therefore, the efficiency of a drive:

• Lubrication
• Speed of worm
• Material of worm and gear
• Load
• Finish of surface on worm thread
• Accuracy of cutting worm and gear
• Lead angle of worm

See for yourself: Take a look at figure 4.12A. Note how the efficiency of a worm and worm gear drive increases as the teeth wear in.

FIGURING OUTPUT HORSEPOWER

In order to determine the actual maximum output horsepower of any worm and worm gear, you need to know:

• The maximum amount of load in horsepower from the power source
• The efficiency (in terms of a percentage) of the gears

These factors can then be applied to the following formula:

• Output horsepower = Input horsepower \times \text{efficiency}

Now let’s apply the formula to a sample problem.
Problem: What is the actual maximum output horsepower available from a quad thread worm and worm gear drive using a 0.5 horsepower motor?

- Output = Input horsepower (HP) x Efficiency
- Output = 0.5 x .90% = .45 Horsepower
- (See figure showing efficiency of a quad thread worm and worm gear after run-in as 90% efficient)

(See Figure 4.12, Page 4-11)

### WORM AND WORM GEAR FORMULAS

<table>
<thead>
<tr>
<th>To Obtain</th>
<th>Having</th>
<th>Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular Pitch</td>
<td>Diametral Pitch</td>
<td>Divide 3.1416 by the Diametral Pitch.</td>
</tr>
<tr>
<td>Diametral Pitch</td>
<td>Circular Pitch</td>
<td>Divide 3.1416 by the Circular Pitch.</td>
</tr>
<tr>
<td>Lead (of Worm) or Linear Pitch</td>
<td>Number of Threads in worm &amp; Circular Pitch</td>
<td>Multiply the Circular pitch by the number of threads.</td>
</tr>
<tr>
<td>Circular Pitch or Linear Pitch</td>
<td>Lead and number of threads in worm</td>
<td>Divide the lead by the number of threads.</td>
</tr>
<tr>
<td>Addendum</td>
<td>Circular Pitch</td>
<td>Multiply the Circular pitch by .3183.</td>
</tr>
<tr>
<td>Addendum</td>
<td>Diametral Pitch</td>
<td>Divide 1 by the Diametral Pitch.</td>
</tr>
<tr>
<td>Pitch Diameter of Worm</td>
<td>Outside Diameter and Addendum</td>
<td>Subtract twice the Addendum from the Outside Diameter.</td>
</tr>
<tr>
<td>Pitch Diameter of Worm Select Standard Pitch Diameter when Designing</td>
<td></td>
<td>Worm Gears are made to suit the mating worm.</td>
</tr>
<tr>
<td>Pitch Diameter of Worm Gear</td>
<td>Circular Pitch and Number of Teeth</td>
<td>Multiply the number of teeth in the gear by the Circular Pitch and divide the product by 3.1416.</td>
</tr>
<tr>
<td>Pitch Diameter of Worm Gear</td>
<td>Diametral Pitch and No. of Teeth</td>
<td>Divide the number of teeth in gear by the Diametral Pitch.</td>
</tr>
<tr>
<td>Center Distance between Worm and Worm Gear</td>
<td>Pitch Diameter of Worm and Worm Gear</td>
<td>Add the Pitch Diameters of the worm and worm gear then divide the sum by 2.</td>
</tr>
<tr>
<td>Whole Depth of Teeth</td>
<td>Circular Pitch</td>
<td>Multiply the Circular Pitch by .6866.</td>
</tr>
<tr>
<td>Whole Depth of Teeth</td>
<td>Diametral Pitch</td>
<td>Divide 2.157 by the Diametral Pitch.</td>
</tr>
<tr>
<td>Bottom Diameter of Worm</td>
<td>Whole Depth and Outside Diameter</td>
<td>Subtract twice the whole depth from the Outside Diameter.</td>
</tr>
<tr>
<td>Throat Diameter of Worm Gear</td>
<td>Pitch Diameter of Worm Gear and Addendum</td>
<td>Add twice the Addendum to the pitch diameter of the Worm Gear.</td>
</tr>
<tr>
<td>Lead Angle of Worm</td>
<td>Pitch Diameter of the Worm and the Lead</td>
<td>Multiply the Pitch Diameter of the Worm by 3.1416 and divide the product by the Lead, the Quotient is the cotangent of the Lead Angle of the Worm.</td>
</tr>
<tr>
<td>Ratio</td>
<td>Number of Starts (or threads) in the Worm and the number of teeth in the Worm Gear</td>
<td>Divide the number of teeth in Worm Gear by number of starts (or threads) in worm.</td>
</tr>
</tbody>
</table>

### WORM AND WORM GEAR SELECTION

Boston Gear manufactures standard stock worms made from high quality steel (both hardened and unhardened). Depending on pitch, hardened worms are available with polished only threads as well as with ground and polished threads. Standard stock worm gears are available – depending on pitch – in fine grain cast iron and bronze.
Approximate input horsepower and output torque ratings for Boston stock worm and worm gear combinations – ranging from 12 to 3 DP – are always illustrated in your Boston Gears catalog.

The ratings shown on chart C.1 (page 4-14) are for hardened, ground, and polished worms operating with bronze worm gears. For other combinations, multiply the listed ratings by the following percentages:

- Hardened, ground, and polished steel worms with cast iron gears: 50%
- Unhardened steel (.40 Carbon) worms with cast iron gears: 25%

Take note: These ratings are listed at selected worm speeds. Ratings for intermediate speeds may be estimated, or interpolated from the values indicated.

The ratings reflected on the chart should be satisfactory for gears: 1) operated under normal conditions, 2) properly mounted in accordance with good design practice, and 3) continuously lubricated with a sufficient supply of oil, carrying a smooth load (without shock) for 8 to 10 hours a day. These ratings were established using a mineral oil compounded with 3-10 percent of acid-less tallow. This is a recommended lubrication for worm and worm gear drives.

Important: Extreme Pressure (E.P.) lubricants are not recommended for use with bronze worm gears.

SELECTING A WORM AND WORM GEAR—A SAMPLE PROBLEM

Let’s see if we can select a worm and worm gear set using the following information:

- Torque at machine to be driven: 3,211 inch lbs.
- Speed of shaft to be driven: 18 RPM
- Drive motor: 1-1/2 H.P.
- Drive motor speed: 1800 RPM
- Center Distance: 7.000"
- Duty Cycle: 8-10 hrs./day smooth load
**STEP 1—FINDING A RATIO**

Use the following formula to find the ratio:

- \( \text{Ratio} = \frac{\text{RPM of Motor}}{\text{RPM of Driven Shaft}} = \frac{1,800 \, \text{RPM}}{18} = 100 \) to 1

**STEP 2—SELECTING THE RIGHT WORM AND WORM GEAR**

Using the ratings chart, found in the Boston Gear Open Gearing Catalog, find a worm gear set that meets the following specifications: (Example chart below)

- Center Distance: 7.000"
- Ratio: 100 to 1 (as determined above)
- Output Torque: 3,711 inch lbs.
- Input Horsepower: 1-1/2 H.P.

When we check the chart, we find that a GB 8100 bronze worm gear and an H1076 hardened worm with threads ground and polished will satisfactorily meet our specifications.

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Center Distance</th>
<th>Input HP</th>
<th>Output Torque</th>
<th>Input HP</th>
<th>Output Torque</th>
<th>Input HP</th>
<th>Output Torque</th>
<th>Input HP</th>
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<th>Input HP</th>
<th>Output Torque</th>
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<th>Output Torque</th>
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<td>3</td>
<td>1.500</td>
<td>1.39</td>
<td>109</td>
<td>0.52</td>
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<tr>
<td></td>
<td>1.500</td>
<td>1.39</td>
<td>109</td>
<td>0.52</td>
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<tr>
<td>4</td>
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<td></td>
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<td>159</td>
<td>0.58</td>
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<tr>
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<td>223</td>
<td>0.61</td>
<td>100</td>
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<td>0.13</td>
<td>134</td>
<td>H1618</td>
<td>DB12</td>
<td></td>
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</tr>
</tbody>
</table>

*Torque in Lb. Ins.
†Cast Iron Gear Rating with Hardened Worm shown.
Keypoints

- Worm gears are used only on 90 degree non-intersecting shafts
- Worm gears are excellent when higher ratios are needed
- Worm gears become more efficient after a run in period
- Most worm gear sets are available both right and left hand; right hand is considered standard
- Boston Gear worm gear sets can be selected by ratio
Quiz

CLICK HERE or visit http://www.bostongear.com/quiz to take the quiz