Chapter 8

Gears

Chapter Objectives

When you have finished Chapter 8, "Gears," you should be able to do the following:

1. Understand the purpose of gears and drives.
2. Identify five gear design categories and their orientation types.
3. Describe and compare various gear types, including: spur helical, herringbone, straight bevel, spiral bevel, cylindrical worm, double-enveloping worm, cycloidial, and hypoid.
4. Define the most common gear terms.
5. Explain the application requirements when selecting gears.
6. List the important specifications needed when ordering gears.
7. List five causes for gear tooth failure.
8. Name the associations that standardize gear classification.
9. Describe and compare the basic types of enclosed gear drives.
10. Explain the function and importance of seals and breathers for enclosed gears.
11. Describe the purpose and the lubrication essential for gear life.
12. Explain gear rating standards.
13. Explain the major factors for selecting and installing gear drives.

Introduction

A **gear** is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a *transmission* and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, torque, and direction of a power source. The most common situation is for a gear to mesh with another gear; however, a gear can also mesh with a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

The gears in a transmission are analogous to the wheels in a pulley. An advantage of gears is that the teeth of a gear prevent slipping.

When two gears of an unequal number of teeth are combined, a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship.

Where called upon, gears can change both speed and direction of rotation. Gears can be mounted on shafts, and their centerlines can be parallel or at any angle relative to each other and in one or more planes. Gears are supplied either unassembled, which is referred to as open gearing, or assembled as part of an enclosed gearbox or speed reducer.

Open Gears

Gears are grouped into five design categories: spur, helical, bevel, hypoid, and worm. They are also classified according to the orientation of the shafts on which they are mounted, either in parallel or at an angle. Generally, the shaft orientation, efficiency, and speed determine which type should be used for a specific application. Table 8-1 compares the different gear types.

Parallel Shaft Gearing

Spur Gears

Spur gears, or straight-cut gears, are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, and although they are not straight-sided in form, the edge of each tooth is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel shafts. Figure 8-1 shows a typical spur gear. When a pair of gears rotate, the teeth mesh with a combined sliding and rolling motion. To avoid excessive wear of the sliding motion and forces, proper lubrication is important.

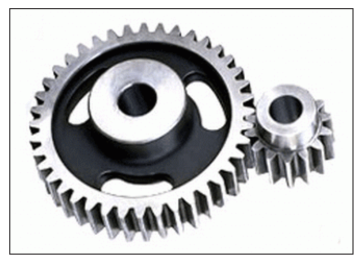

Figure 8-1:
Spur gears have straight teeth and are parallel to the shaft axis

Because the teeth are parallel to the shaft axis, spur gears produce reaction loads only radially

TABLE 8-1 – Comparison of gear types				
			Maximum pitch line Velocity, fpm	
Gear type	Approximate range of efficiency, %	Range of reduction ratio	High-precision	Commercial
Spur	97-99	1:1-10:1	20,000	4,000
Helical or double helical	97-99	1:1-9:1	40,000	5,000
Straight bevel	97-99	1:1-10:1	10,000	1,000
Spiral bevel	97-99	1:1-10:1	25,000	5,000
Cylindrical worm	50-90	3:1-100:1	10,000	5,000
Double-enveloping worm	50-98	3:1-100:1	10,000	4,000
Hypoid	90-98	1:1-10:1	10,000	4,000

to the shaft. They do not produce axial thrust loads, as do some other types of gears.

Spur gears are applied in moderate speed applications such as mill drives, hoisting equipment, and general machinery. Spur gears at high speeds can be very noisy and exhibit higher-wear performance. Spur gears are the most widely used gear type due to their low cost, lack of end thrust, and low maintenance.

When two gears have the same number of teeth, the speed of one matches the other, but the two rotate in opposite directions. When two meshing gears have different numbers of teeth, the gear with the least number of teeth is called the pinion and the larger is called the gear. In this case, the two gears rotate in opposite directions as before, but now the gears rotate at different speeds. The speed ratio equals the number of teeth in the larger gear divided by the number of teeth in the smaller pinion gear.

If an idler or an intermediate gear is inserted between the driving pinion and driven gears (see Fig. 8-2), the pinion and gear rotate in the same direction. This configuration does not affect the speed ratio, which is still equal to the number of teeth in the driven gear divided by the number of teeth in the pinion.

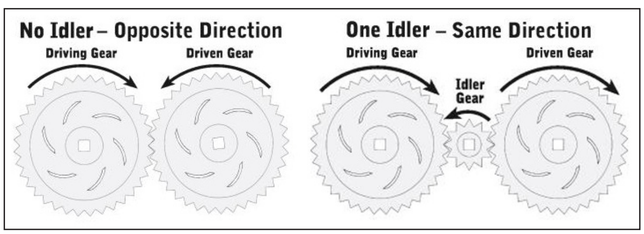

Figure 8-2:
Using Idler Gear to Change Gear Rotation

Many types of spur gears are available. Pinions come with or without a hub, and gears are available with solid, webbed, or spoked bodies.

Tooth Forms

The shape of a spur gear's teeth is based on an involute tooth form (see Fig. 8-3), which produces a rolling contact rather than a sliding contact between mating teeth. Common tooth forms for spur gears are defined in terms of pressure angle (the angle of contact between the teeth) and diametrical pitch (the number of teeth given per inch

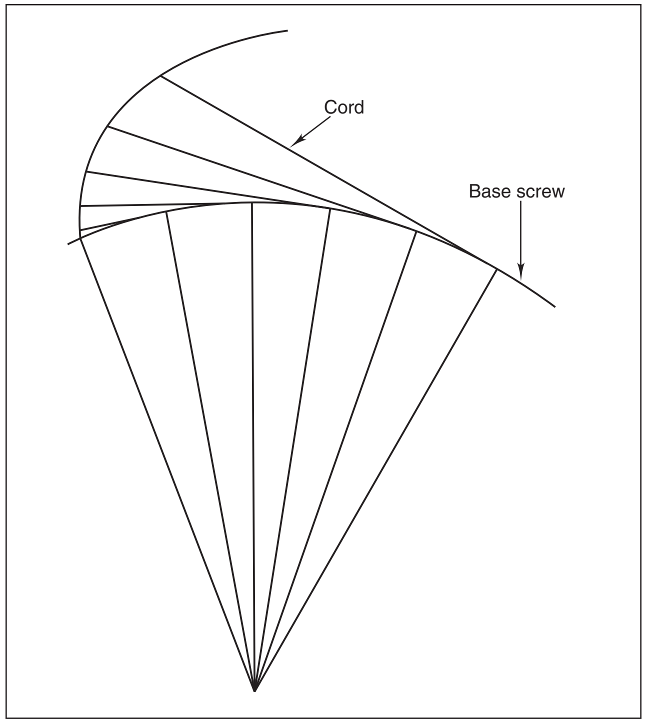

Figure 8-3: Involute form is generated by unwrapping a cord from a circle

of a gear's pitch diameter). Diametrical pitch can be either coarse (one to 19 diametral pitch) or fine (20 diametral pitch or higher).

The American Gear Manufacturers Association (AGMA) has established standards for gear teeth. These standards include the following:

- 14 ½ degree course pitch (former standard – not recommended for new designs)
- 20 degree coarse pitch
- 20 degree fine pitch

The low pressure angle, 14 ½ degrees, provides smooth, quiet meshing between mating teeth. However, for gears that have fewer than 32 hobbed teeth, each tooth is undercut at its base, thereby weakening it. Thus, this tooth form is no longer an AGMA standard, although it is still used for replacement gears and special design. For teeth formed by other methods, this undercutting does not apply.

The larger 20 degree pressure angle produces stronger teeth that have higher load capacities. These larger angles also minimize undercutting of hobbed teeth. Thus, undercutting shows up in the 20 degree tooth form only when the number of teeth is fewer than 18. Of major importance is the fact that 14 ½ degree pressure angles cannot be used with gears of 20 degree pressure angles and vice versa.

Helical Gears

Helical gears are capable of carrying more load than spur gears. They have teeth that are oriented at an angle, when compared to the shaft's axis. This is called the helix angle (see Fig. 8-4). This arrangement provides an overlapping tooth engagement, which results in smoother, quieter operation. Helical gears are quieter with less vibration and run at higher speeds than spur gears.

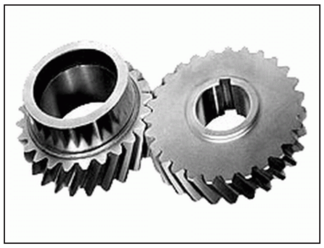

Figure 8-4: Helical gears have teeth across the face at an angle

Helix angles range from a few degrees to about 45 degrees. However, tooth bending-load capacity drops off at large angles, generally those above 20 degrees. The teeth in mating helical gears that are operating on parallel shafts must have the same helix angle, but must be oriented in opposite directions such that a right-handed gear meshes with a left-handed pinion. Unlike spur gears, helical gears require bearings designed to take thrust loads.

Double Helical Gears

A double helical gear is a variation of the helical gear. A double helical gear has two sets of teeth on one gear with opposing tooth angles (see Fig. 8-5). A groove separates the two sets, which have identical helix angles and tooth pitches.

Figure 8-5: Double helical gear sets use two pairs of opposed gear teeth to eliminate thrust load

Unlike single helical types, these double helical gears exhibit no side thrusts because the thrust of one side cancels out the opposing side. For this reason, the teeth can be cut at a greater helix angle, providing greater tooth overlap and smoother operation. Double helical gears are particularly effective when shock and vibration are present. Double helical gears are also used for applications that require high speed and high ratio in a single stage (one pair of gears).

Herringbone Gears

Similar to double helical gears, herringbone gears have two sets of teeth that are joined in the middle (see Fig. 8-6). The continuous tooth form allows herringbone gears of commercial quality to operate at pitch line velocities up to 5,000 feet per minute. Herringbone gear sets are also well suited for shock and vibration applications or applications where a high single reduction is needed. In general, the terminology for helical gears is the same as that for spur gears. In some instances, the design formulas are different because they depend on the helix angle.

Figure 8-6: Herringbone gears have opposite teeth joined in the middle

Internal Gears

Internal gears have teeth on the inside (see Fig. 8-7). These gears are available with either spur or helical-type teeth. In either case, an internal gear meshes with a pinion that has external teeth.

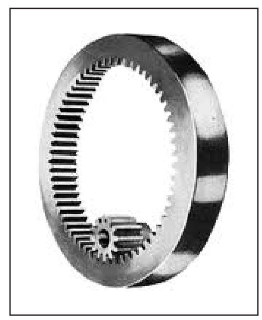

Figure 8-7: Internal spur gear set

Internal gears allow a closer center distance with their mating pinions than do external gears of the same size. This allows for a more compact design and also provides a protective guard over the meshing gear teeth. Internal gears and pinions rotate in the same direction; as a result, an idler gear may not be required.

Although more compact, internal gears cannot be used in all cases. The number of teeth in the pinion and the gear cannot be equal because of interference between the tips of the mating teeth. As a general rule, the difference in tooth count must be at least 8 teeth for a 20 degree stub-tooth form and 10 teeth for a 20 degree full-depth form.

Internal gears are typically used in planetary gear systems (see Fig. 8-8). In this example, the sun gear, or center pinion,