The functionality and efficiency of a particular AC or DC type gearmotor is a factor of both the motor and the gearhead. This Chapter will focus on the mechanical aspects of the various types of gears and gear trains, which are employed in fractional horsepower gearmotors to control motor speed and output torque.

6.1 GEARING

Over time and because of varying application demands, gears have evolved from one form to another. They can be categorized into five basic types: spur, helical, bevel, hypoid and worm. Gears facilitate power transmission by providing a positive means to engage the output of machine drives. The direction of rotation, speed of rotation, output torque, environmental conditions and efficiency requirements of a specific application determine which type of gear should be used.

**Spur Gears:** A typical spur gear is shown in Fig. 6-1a. Its teeth are cut paral-
Fig. 6-2: Spur rack and pinion.

Spur gear pairs can be external-toothed (teeth cut on the outer edge) or internal-toothed (teeth cut on the inner edge, see Fig. 6-1b).

The pair of external-toothed spur gears in Fig. 6-1a makes up a single reduction stage. The output rotation of such a stage is opposite the input rotation. When multiple gear stages are combined, larger speed reductions can be achieved.

A single stage made up of an internal-toothed “ring” gear and an external-toothed spur gear produces an output rotation that is in the same direction as the input (Fig. 6-1b). Ring gears are employed in planetary gear trains which will be discussed in the next section.

A special spur gear configuration is the rack and pinion, where the rack is simply a flat bar with teeth cut in it, which meshes with a conventional cylindrical spur gear. See Fig. 6-2.

**Helical Gears:** Helical gears are similar to spur gears except that their teeth are cut at an angle to the shaft axis. See Fig. 6-3. Several teeth make contact at any point in time which distributes the load and reduces wear. The noise and vibration associated with spur gears is also reduced with helical gears.

Fig. 6-3: Helical gears.

Fig. 6-4: Double helical and herringbone gears.
Helical gears have more stringent lubrication requirements because of the inherent sliding action between the gear teeth. Thrust bearings may be needed to absorb the side thrust which helical gears produce.

Double helical gears (two helical gears mounted side-by-side on the shaft) and a variation called herringbone gears (Fig. 6-4) are sometimes employed to eliminate the net thrust load on the shaft. In both cases, the side thrusts produced by each gear cancel each other.

**Bevel Gears:** Bevel gears are employed in applications where an intersection of the input and output shaft centerlines occurs. Teeth are cut from a conical or angular surface and at an angle so that the shaft axes intersect, usually at 90°. See Fig. 6-5a.

Bevel gears are available in straight and angular or “spiral” cut versions. Straight bevel gears are usually noisier than spiral cut and create side thrusts which tend to separate the two gears. Spiral bevel gears function much like helical gears. See Fig. 6-5b.

**Hypoid Gears:** Hypoid gears are similar to spiral bevel gears with one major distinction. The shafts to which they are connected do not intersect as in bevel gear configurations. This allows end bearings to be installed on each shaft for additional support. See Fig. 6-6.

**Worm Gears:** Worm gears have screw-like threads that mesh with a larger cylindrical gear. See Fig. 6-7. It takes several revolutions of the worm to cause one revolution of the gear. Therefore, a wide range of speed ratios can be achieved from a single stage reduction. The worm is usually the driving member although reversible worm gears are available. An advantage of worm gear drives is less wear and friction due to an inherent sliding action. However, the same sliding action decreases the overall efficiency of the system.
6.2 GEAR TRAINS

The inherent characteristics of gear types have an overall effect on the power, efficiency and torque ratings of a drive when combined in different configurations. In this section, we’ll take a look at how various gear trains can be used to adapt fractional horsepower motors to specific applications.

**Parallel Shaft Gear Trains:**
The term “parallel shaft” applies to gear trains with shafts facing the same direction as the motor shaft. In other words, the axis of the gear train shaft is parallel to the motor shaft axis.

Although the gear train shafts are parallel they can be either in-line with (concentric with) or offset from (parallel to) the motor shaft. See Fig. 6-8. The offset configuration is generally more compact than in-line designs because it eliminates the axial space needed for the bearing support of the inboard end of the driveshaft. The offset output shaft makes it possible to locate the shaft in a 3, 6, 9 or 12 o’clock position, providing greater versatility in mounting. The shaft location, however, may necessitate changing the location of oil level and oil fill plugs.

Fractional horsepower parallel shaft gearmotors usually employ spur and/or helical gearing. Both types provide high efficiency within a small axial space. Spur and helical gears commonly provide ratios up to 6:1 per gearing stage. Spur gearing is easier to manufacture and is therefore less expensive.

Besides slightly higher cost, helical gearing often requires additional constructional features to accommodate its inherent axial thrust. The magnitude of the axial thrust forces is proportional to the load transmitted and the tooth angle of the helical gearing. Because of the greater overlapping or “load-sharing” of helical gear teeth, the transmission of power is usually smoother and quieter with helical than with spur gearing. Gear quietness is also dependent upon rotational speed. It is common in parallel shaft gearmotors for high speed stages to be helical and slower speed stages to be spur (for economy).

The efficiency of spur or helical gearing alone is about 97% per stage. Additional losses result from bearing friction and circulation of lubricant. These losses, in typical fractional horsepower parallel shaft gearmotors, reduce efficiency to about 92% per stage.

**Right Angle Gear Trains:** In right angle gear trains the axis of the output shaft is at a right angle (90°) to the motor shaft axis. See Fig. 6-9. They are frequently used in applications where space restricts the use of parallel shaft gear trains of comparable strength. Right angle gearmotors are especially desirable where a vertical output shaft is required.
Right angle gearmotors can be configured with vertical shafts without mounting the gear train above the motor (an undesirable arrangement due to the risk of gear train lubricant leakage into the motor).

Various types of worm, bevel and spiral bevel gearing are used in right angle gear trains from about 1/100 to 40 hp. The cylindrical worm is by far the most popular type used in right angle designs. Ratios up to approximately 72:1 per stage are common in fractional horsepower worm gearmotors. Both single and double stage reductions are possible, and overall reductions of over 2000:1 can be achieved in two stages (with high single stage reductions). Because of the limited reduction possible with bevel gearing, it is normally used only when necessary to provide an output shaft at a right angle, but not offset from the motor shaft axis.

Precision, simplicity and reliability are some of the benefits of using worm and spiral bevel gearing. However, “self-locking” characteristics can also be achieved. Self-locking prevents external torque applied to the driveshaft from “backdriving” the motor, and depends upon tooth angles and the coefficient of friction between the worm and gear. Generally, worm gear sets are self-locking if the lead angle is less than 5°. Gearmotors may start out being self-locking when new, but become non-self-locking as the parts wear in and efficiency improves. The manufacturer should be consulted if the self-locking feature is necessary for positioning or hoisting applications over the life of the motor.

Because the worm and gear teeth are under crushing (rather than cantilever) loads and many teeth are usually in contact, worm gears have higher resistance to shock loads than spur or helical gearing.

The sliding tooth action of worm gears offers minimal noise in comparison with spur and helical types. However, sliding tooth action is more difficult to lubricate and, as previously mentioned, less efficient than the rolling action of spur and helical gearing. The lower efficiency of worm gearing is more pronounced in the higher ratios. Worm gear efficiency also decreases with a decrease in speed. It is most critical during starting conditions where the torque multiplication may be as much as 20% less than under running conditions. This factor must be considered if the torques required by the application approach the gearmotor rating.

Thrust loads are always present with right angle gearing, and many right angle
gearmotors use rolling element bearings for severe duty conditions. Right angle gearmotors also impose relatively high thrust loads on the rotor shaft bearings, which can be a limiting factor in overall gearmotor life. Spiral bevel gearing has different efficiencies depending upon the direction of rotation. This should be considered if the torques required by the application are close to the gearmotor’s maximum torque rating.

**Combination Gear Trains:**
Some applications can benefit from a combination of parallel and right angle gear trains. This is especially true in situations where large reductions are required and space is at a minimum. Combination gear trains accommodate right angle turns in the drive and can often result in a reduction of bearings and other system components. The right angle reduction is usually added as the first or last stage.

**Epicyclic Gear Trains:** Another type of gear train is the epicyclic or planetary gear train. It is comprised of three stages:
1) a central “sun” gear,
2) several “planets” which engage the sun gear and rotate around it, and
3) a large ring gear or “annulus” which surrounds the entire assembly and engages the planets.

Because the points on the rotating planets trace epicycloidal curves as they turn, the term “epicycloidal” is used. The term “planetary” is also applicable because the rotating action of the entire assembly about the central sun gear mimics the movement of a solar system. Epicyclic gear trains are being used increasingly as actuators in applications where more torque is required from a smaller drive train package. A typical application in the aviation industry is where a small motor must produce high torque output to control the wing flaps on an airplane. Epicyclic gear trains are also used for differential systems and applications where very low reduction ratios are required. The input, output and auxiliary shafts can be connected to any of the three stages to achieve the speed/torque requirements of the application.

Epicyclic gear trains can be configured in three arrangements:
1) planetary,
2) star, and
3) solar.

See Fig. 6-10. The number of planet gears required depends on the ratio desired. The ratio also determines the type of system to be used. Each epicyclic gear train configuration can be further categorized as:
1) simple,
2) compound, and
3) coupled.

The simple epicyclic gear train has already been described in detail.

Compound versions consist of a common shaft with two planet members connected to it. Coupled epicyclic gear trains combine two or more simple epicyclic trains so that two elements of one train are common to the other train.

### 6.3 GEARMOTOR LUBRICATION

Both metallic and nonmetallic gearing are used in the gear trains of small multiple reduction gearheads. A nonmetallic gear is often used in the first stage for noise reduction and a metallic gear used in subsequent stages for strength. For reliable service life, both types of gear materials must be properly lubricated.

Long service life (10,000 hours and up) requires a fluid lubricant which is circulated throughout the gearhead. Oils or semi-fluid
Fig. 6-10: Simple epicyclic gear trains: a) planetary (top), b) star (middle), and c) solar (bottom).
Greases provide the best combination of lubrication properties and is nearly always used in gearmotors larger than 1/10 hp designed for industrial applications.

Despite its advantages, oil is not always used in smaller fractional horsepower gearmotors because of sealing problems. Gearmotors under 1/10 hp do not always have adequate surface area for gaskets and more importantly, may not have sufficient power to overcome the friction of a contact seal on the rotor shaft. Therefore, in many small fhp gearmotors, grease is used as a compromise to achieve lubrication without oil leakage.

Shorter service intervals are required when grease is used as a lubricant, primarily because of reduced lubrication circulation. The wear rate of gear train parts is higher when grease is used as a lubricating agent and the wear rate increases with the stiffness of the grease. Moderate service life of approximately 2,000 hours can be achieved with grease lubrication.

Gearhead inefficiencies (frictional losses) are converted into heat. Because of their inherent low efficiency, gearmotors with worm or spiral bevel gearing require careful attention because their lubricants reach higher operating temperatures. Worm gear lubricants generally have high viscosity and contain "extreme pressure" additives as well as other additives.