After studying this chapter, you will be able to:

- Identify and explain the operation and components of steering wheels, columns, and related parts.
- Explain the operation of conventional steering systems.
- Identify the components of conventional steering systems.
- Explain the operation of rack-and-pinion steering systems.
- Identify the components of rack-and-pinion steering systems.
- Explain the operation of power steering systems.
- Identify the components of power steering systems.
- Identify the major types of power steering systems.
- Explain the operation of four-wheel steering systems.
- Identify the components of four-wheel steering systems.

### Technical Terms

| Road feel | Telescoping steering columns | Reservoir |
| Steering wheel | Steering arm | Power steering pump |
| Master spline | Steering stops | Flow regulator |
| Horn switch | Ball sockets | Pressure regulator |
| Air bag | Tie rod ends | Power piston |
| Clockspring | Steering ratio | Rotary valve |
| Steering shafts | Rack-and-pinion steering | Linear control valve |
| Collapsible shaft | Conventional steering systems | Four-wheel steering |
| Telescoping shafts | Pitman arm | Hydraulic/electronic four-wheel steering system |
| Steering coupler | Relay rod | Electromechanical four-wheel steering |
| Universal joints | Drag link | |
| Adjustable steering columns | Connecting rod | |
| Tilt steering wheel | Idler arm | |
Introduction

The steering system components are a common source of driver complaints. Tire wear is almost completely dependent on the condition and adjustment of the steering components. This chapter covers the construction and operation of both conventional and rack-and-pinion steering systems. Study this chapter carefully.

Note: Chapters 13 and 14 will cover electronically controlled steering systems.

The Job of the Steering System

The steering system is a group of parts that transmit the movement of the steering wheel to the front, and sometimes the rear, wheels. The primary purpose of the steering system is to allow the driver to guide the vehicle. When a vehicle is being driven straight ahead, the steering system must keep it from wandering without requiring the driver to make constant corrections.

The steering system must also allow the driver to have some road feel (feedback through the steering wheel about road surface conditions). The steering system must help maintain proper tire-to-road contact. For maximum tire life, the steering system should maintain the proper angle between the tires both during turns and straight-ahead driving. The driver should be able to turn the vehicle with little effort, but not so easily that it is hard to control.

Common Steering System Parts

All steering systems contain several common parts. Every steering system, no matter what type, will have a steering wheel, a steering shaft and column, a flexible coupler, universal joints, steering arms, and ball sockets. These parts are discussed below.

Steering Wheels

The only part of the steering system the average driver is familiar with is the steering wheel. Older wheels are made of hard plastic, are larger in diameter, and are relatively thin when compared to modern steering wheels. The modern steering wheel is generally padded. Most steering wheels have two or three spokes or a large center section that connects the wheel portion to the hub. To prevent slippage, the steering wheel hub has internal splines, which match external splines on the steering shaft. Some shafts and steering wheels have a master spline, which is larger than the others. The master spline prevents the installation of the wheel in the wrong position. A large nut holds the hub to the steering shaft, Figure 9-1.

A horn switch has electrical contacts that connect the rotating steering wheel components to the rest of the vehicle’s electrical system. Stationary brass or copper rings in the steering column touch sliding or rolling contacts in the wheel assembly. The sliding or rolling contacts brush against the rings as the wheel is turned, maintaining electrical contact at all times.

Air Bag

In most late-model vehicles, the center of the steering wheel also contains an air bag, Figure 9-3. An air bag is a general term given to devices that inflate to protect the vehicle’s occupants during a collision. In most manufacturers’ service literature, however, an air bag is referred to as a supplemental inflatable restraint, or SIR. The air bag inflates rapidly (within \( \frac{1}{60} \) of a second) if the vehicle is involved in a collision. Air bag inflation is often called deployment.

In addition to the steering wheel-mounted air bag, many vehicles have an additional air bag mounted in the dashboard on the passenger side of the vehicle. Some modern vehicles are equipped with side air bags, which will deploy if the vehicle is struck from the side.

Most air bag systems are designed to deploy only if the vehicle is involved in a frontal collision (within a certain number of degrees of its centerline). During an impact, electronic impact sensors, which are often mounted in the front portion of the vehicle, tell the air bag control module that a collision has occurred. The control module then sends a current to an air bag squib. The squib generates heat, igniting a flammable substance in the bag. As the flammable substance burns, it creates a large amount of a harmless gas. The gas expands and causes the bag to inflate. The sequence of events that results in air bag inflation is shown in Figure 9-4.

To prevent unnecessary air bag deployment, at least two impact sensors must indicate a collision. Most vehicles have at least one primary impact sensor, as well as a saving sensor, which confirms a collision has taken place. On some newer vehicles, the impact sensors are mounted in the air bag control module in the passenger compartment.

Air bag control modules often contain a reserve power supply that allows the air bag system to operate even if the rest of the vehicle loses electrical power. The reserve power supply can retain power for up to 30 minutes after the ignition is switched off.

Most steering wheel-mounted air bags use a clockspring to provide an electrical connection between the steering wheel and the steering column. See Figure 9-5. The clockspring consists of a flat wire, sometimes called a ribbon wire, wound into a coil. The wire coil is called a clockspring because it resembles the mainspring of a mechanical clock. One end of the clockspring is attached to the air bag system electrical connector in the stationary steering column. The other end of the clockspring is attached to the air bag electrical connector in the steering wheel. The clockspring coils and

![Figure 9-1. A large nut holds the steering wheel hub to the steering shaft. (General Motors)](image1)

![Figure 9-2. The horn buttons or pad is mounted on the steering wheel. (Jeep)](image2)

![Figure 9-3. A horn switch has electrical contacts that connect the rotating steering wheel components to the rest of the vehicle’s electrical system. Stationary brass or copper rings in the steering column touch sliding or rolling contacts in the wheel assembly. The sliding or rolling contacts brush against the rings as the wheel is turned, maintaining electrical contact at all times.)](image3)

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uncoils as the steering wheel is turned. Using a clockspring ensures that there is always a complete electrical circuit between the air bag squib and the rest of the air bag system, regardless of the position of the steering wheel.

Steering Columns and Shafts

The steering shaft is installed in the steering column. Bearings are generally used to hold the shaft in position. The shaft and column assembly is usually removed and replaced as a unit. However, individual parts are often replaced without removing the shaft or column. In this section, we will discuss the individual parts that make up the steering column and shaft assembly.

**Shaft Design**

Modern steering shafts are made of two sections of steel rod. One section is hollow and the other is solid. The solid section slides into the hollow section. See Figure 9-6.

This design allows the steering shaft to collapse when the vehicle is in a collision. For this reason it is called a collapsible shaft. Collapsible shafts are often referred to as telescoping shafts, since the shaft length is reduced as one section of the shaft slides into the other in the same way a portable telescope is collapsed.

During normal driving, the two halves of the steering shaft are held in position by shear pins. Shear pins are purposely made of a relatively weak material, usually plastic. Their purpose is to break when sufficient pressure is placed on them, preventing injury to the driver. If a collision occurs that is severe enough to cause the driver to strike the steering wheel, the shear pins break, allowing the shaft to collapse.

**Steering Universals**

On many newer cars, there is not enough clearance to allow the steering shaft to make a straight connection with the steering gear. Therefore, the upper and lower shafts must be offset through the use of universal joints. Steering shaft universal joints allow the shaft to turn through an angle. Universal joints consist of a center cross that connects two yokes. Each yoke is connected to one part of the steering shaft. The yokes can twist as they rotate. This allows the centerline of the steering shaft to change. Figure 9-8 shows a typical universal joint installed on a steering shaft.
Column Design

The steering column is the support and cover for the steering shaft and other steering wheel-mounted components and wiring. Shaft bearings are ball or roller bearings installed at the top and bottom of the steering column to allow the steering shaft to turn with no resistance. The steering column is attached to the underside of the dashboard, usually through studs and nuts. Many of the column attachment holes are slotted to allow for steering column adjustment. On some vehicles, the bottom of the column is attached to the firewall.

The upper part of the steering column is usually somewhat larger in diameter to hold the driver-operated components, as well as the air bag clockspring. The steering column usually contains the turn signal indicator stalk. In addition to controlling the turn signals, the modern turn signal stalk may also be used to operate the cruise control, the windshield wipers, and the high-beam selector.

On most modern vehicles, the ignition switch is installed inside the steering column. The ignition lock assembly is installed on the column and connected to the switch by a metal rod. On some vehicles, the steering column contains the gearshift indicator and selector lever. Neutral safety switches and vacuum parking brake release switches may also be located on the lower portion of the steering column.

The steering column is collapsible, although its design is somewhat different from that of the steering shaft. The lower section of the steering column is perforated and resembles a heavy screen. If the driver hits the steering wheel during an accident, the perforated area will bend, allowing the column to collapse.

Adjustable Steering Columns

Some steering columns can be adjusted to change the position of the steering wheel. Adjustable steering columns make driving more comfortable for people who are shorter or taller than average. Changing the wheel position can also make long trips more comfortable.

On a tilt steering wheel, the steering column is sectioned at the top and can pivot. The upper part of the steering shaft is equipped with a universal joint. There may be an extra bearing at the tilt mechanism to further support the shaft. A lock holds the steering column in position as the vehicle is driven. A lever mounted on the steering column releases the lock when the driver wants to change the steering wheel position. The design of a typical tilt steering column is shown in Figure 9-11.

Telescoping steering columns are designed so that the steering wheel can be moved either toward or away from the driver. The telescoping parts of a steering column include a solid steering shaft section inside a hollow shaft section. This assembly is called a telescopic shaft. During normal driving, a locking mechanism holds the telescopic shaft in position. Moving a lever on the steering column allows the driver to release the lock and move the steering wheel. When the lever is released, the column is locked in the new position. See Figure 9-12.
steering stops are adjustable, but most are not. See Figure 9-16. A few manufacturers locate the steering stops on the pitman arm, Figure 9-17.

**Ball Sockets**

Since many parts of the steering linkage move in relation to each other, it is necessary to have a flexible connection between them. **Ball sockets** are used to make this flexible connection. The internal parts of the ball socket resemble those of a ball joint, Figure 9-18. The bearing surfaces of the ball socket form a sliding surface for the transfer of motion. To reduce wear and vibration, ball sockets are preloaded (placed under tension). A small spring or rubber ring is installed under one of the bearing surfaces to create this tension.

Like ball joints, ball sockets are used to transfer loads while rotating and moving both horizontally and vertically. Unlike ball joints, ball sockets do not transfer vehicle weight downward. Instead, they transfer steering effort sideways. Therefore, the loads placed on a ball socket are horizontal (side to side) rather than vertical (up and down).

Some ball sockets are self-contained units, such as the assembly shown in Figure 9-19. The ball socket is attached to the steering knuckle by a threaded and tapered stud. The other end is a threaded section, which is installed into matching threads in another part of the steering linkage. The threaded section can have internal or external threads, depending on the linkage design. Ball sockets used to connect the steering linkage to the steering knuckle are called **tie rod ends**.

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**Steering Arms and Ball Sockets**

All vehicles use steering arms and ball sockets to transmit motion from the steering gear, through the steering linkage, and into the steering knuckles.

**Steering Arm**

The **steering arm** converts the linear (back-and-forth) motion of the steering linkage to the rotating motion of the steering knuckle. See Figure 9-13. The steering arms on each side of the vehicle are shaped to allow the relative position of the wheels to change as the vehicle is turned. This position change, called toe out on turns, will be discussed in more detail in Chapters 15 and 16. A steering arm can be bolted to the steering knuckle, Figure 9-14, or may be cast as an integral part of the steering knuckle, Figure 9-15.

The steering arm usually contains the **steering stops**, or **tie stops**. These are projections on the arm that keep the steering stops are adjustable, but most are not. See Figure 9-16. A few manufacturers locate the steering stops on the pitman arm, Figure 9-17.

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Ball sockets are used on other parts of the steering linkage. The ball and socket section is often part of the linkage component, and the entire component must be replaced when the ball socket wears out.

**Types of Steering Systems**

Two main types of steering systems are used on modern cars and light trucks: the rack-and-pinion system and the conventional, or parallelogram linkage, steering system. On automobiles, the conventional system was the only type used until the 1970s. It has been almost completely replaced by rack-and-pinion steering. Many light trucks continue to use the conventional system. The two types of systems are discussed below.

**Steering Ratio**

Steering ratio is the relative number of turns of the steering wheel compared to the movement of the wheels. If the steering wheel must be turned one revolution to turn the front wheels one sixteenth of a turn, the steering ratio is 1 to 1/16. Reversing the numbers gives a ratio of 16 to 1; 1/16 to 1, or 16:1. Although the steering ratio is not as critical on modern vehicles with power steering, it must be carefully selected as a compromise between handling and steering effort. The average steering ratio on modern vehicles ranges from 12:1 to 24:1. A heavy vehicle will have a higher ratio than a lighter vehicle. If the vehicle has power steering, the ratio will be lower than that on the same vehicle with manual steering.

Steering ratio affects the response of the front wheels to the movement of the steering wheel (handling) and the ease of turning the wheel. A small steering ratio means that slight steering wheel movement will turn the front wheels, but the effort required to turn the steering wheel will be relatively high. A large steering ratio means that more turns of the steering wheel are needed to turn the front wheels, but that the steering effort is less. A relatively high steering ratio also helps to absorb shocks from the road. If for instance the steering ratio is 16:1, road shocks are transmitted to the steering wheel at 1/16 of their original intensity.

Steering ratio, as well as overall handling and ease of steering, is determined by many factors. The size of the steering wheel was already mentioned. The relative size of the gears in the steering gear, the size and shape of the steering arms, and the angles formed by the linkage all affect the steering action. The percentage of vehicle weight placed on the front wheels and whether the vehicle has front- or rear-wheel drive are also factors.

**Rack-and-Pinion Steering**

Rack-and-pinion steering is a simple system that directly converts the rotation of the steering wheel to straight line movement at the wheels. Figure 9-20 illustrates the principle of the rack-and-pinion steering gear. The steering gear consists of the rack, pinion, and related housings and support bearings. Turning the steering wheel causes the pinion to rotate. Since the pinion teeth are in mesh with the rack teeth, turning the pinion causes the rack to move to one side. The rack is attached to the steering knuckles through linkage, so moving the rack causes the wheels to turn.

**Steering Ratio**

The size of the pinion gear and the number of teeth on the gear determine the rack-and-pinion steering ratio. A large pinion gear with many teeth would turn quickly but would require a large steering effort. A small gear with a few teeth would turn easily, but require many revolutions of the steering wheel to make a turn.

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**Figure 9-17.** Adjustable pitman arm stop bolts and lock nuts. This setup calls for a 0.20" (5 mm) clearance for the proper steering angle. (General Motors)

**Figure 9-18.** Cutaway view of a typical ball socket. Note the internal components. (General Motors)

**Figure 9-19.** Typical self-contained ball socket. Note the tapered ball stud. (Moog)

**Figure 9-20.** A—Rack-and-pinion steering system cutaway showing the pinion shaft and the rack. B—Steering rack reaction in relation to the direction the pinion shaft and teeth are turned. This particular unit is powered with hydraulic fluid. (Honda)
**Rack-and-Pinion Construction**

The body of a rack-and-pinion steering gear is usually an aluminum casting. The rack is often held to the vehicle body or frame by two U-shaped brackets that are bolted in place. Other units are bolted directly to the vehicle with a series of bolts and nuts that pass through holes in the rack body and the vehicle’s frame. The pinion assembly is a hardened steel gear supported by bearings at the top and bottom. The rack is also made of hardened steel and moves in slide bearings. Seals keep the steering gear lubricant from leaking out of the rack-and-pinion assembly. Figure 9-21 shows a typical manual rack-and-pinion gear. Power rack-and-pinion gears will be discussed later in this chapter.

**Rack-and-Pinion Linkage**

Rack-and-pinion linkage connects the gear to the steering knuckles. Rack-and-pinion linkage is simple, consisting of inner and outer tie rods. Figure 9-22. Design of the outer tie rod was discussed earlier in this chapter. One end of the inner tie rod is inside the steering gear and is usually threaded into the end of the rack. A plastic or metal shear pin keeps the tie rod from loosening. Some tie rods are held in place by a crimp on the inner part of the tie rod assembly. The inner tie rod is protected from the elements by a flexible rubber bellows, sometimes called a bellows boot or a boot. The outer part of the inner tie rod is a threaded shaft. The outer tie rod is threaded onto this shaft and held in place by a locknut, Figure 9-23.

**Conventional Steering**

Conventional steering systems are sometimes referred to as parallelogram steering. Figure 9-24. The conventional steering system has more components than the rack-and-pinion system. The basic design and components of the conventional steering system are discussed below.

**Conventional Steering Gears**

All steering gears used on conventional steering systems appear similar when viewed from the outside. All contain a worm shaft, or worm gear, which is turned by the steering shaft, and a sector gear, which is turned by the worm gear. The interaction of the worm and sector gear converts the rotation of the worm into movement at the pitman arm while turning the steering effort 90°.

One difference between conventional and the rack-and-pinion steering gears is that the conventional gear can be adjusted. There are two adjusting devices built into the conventional gearbox, as shown in Figure 9-25. The adjuster at the top of the sector shaft is used to adjust the clearance between the sector gear and worm gear. The worm gear adjuster is used to adjust the bearing preload of the worm gear. The worm gear adjuster can also be...
steering gear because the ball bearings move in a loop, or circuit, as the worm gear moves the ball nut. The ball bearings can recirculate because of ball guides installed on top of the ball nut assembly.

The worm and sector gears ride on ball or roller bearings to reduce friction. The steering gear may be lubricated by 90–140 weight gear oil, or it may require automatic transmission fluid. Seals at the input shaft and sector shaft keep lubricant from leaking out of the steering gear. The worm and sector gears contain thrust washers and spacers for proper clearance.

Worm-and-Roller Steering Gear

The worm-and-roller steering gear is found on Asian vehicles, as well as some older Jeep vehicles and European cars. Figure 9-28 is an illustration of a typical worm-and-roller steering gear. Unlike the recirculating-ball steering gear, the worm-and-roller steering gear does not use a ball nut. Instead, the worm gear turns against a roller installed in the sector gear. Turning the worm gear causes the sector gear to move. The rolling action between the worm gear and the sector roller reduces friction. Note that the worm gear is tapered, with the end sections being larger than the center. This worm gear design results in constant full contact between the worm and roller, no matter what the sector position. The worm-and-roller steering gear may have a provision for adjustment.

Worm-and-Follower Steering Gear

The worm-and-follower steering gear is found on older European cars. Figure 9-29 shows a typical worm-and-follower steering gear. This design may be...
called the worm-and-peg, worm-and-cam, or worm-and-pin steering gear. Note that the worm gear works directly on the follower, causing the sector shaft to turn as the follower moves on the turning worm gear.

**Pitman Arms**

The pitman arm is attached to the sector gear at the steering gear. It converts the turning movement of the sector gear to linear (back-and-forth) motion and transfers this motion to the steering linkage.

Note: The sector gear shaft is sometimes called the pitman shaft.

The pitman arm has internal splines, Figure 9-30. These splines match the external splines on the bottom of the sector gear shaft. The splines are slightly tapered to create a tight fit. The pitman arm is held to the sector shaft by a large nut and a lock washer. The linkage end of the pitman arm may contain the ball socket. Other pitman arms have a hole to accept the ball socket shaft.

**Relay Rods**

The relay rod, or drag link, is used to transmit the steering motion from the pitman arm to the inner tie rods on each side of the vehicle. Figure 9-31 shows the arrangement of a typical relay rod. The relay rod may have ball sockets permanently installed, or may have holes for installation of the ball socket studs attached to other linkage parts.

Some vehicles have an additional piece of linkage called a connecting rod. The connecting rod attaches the relay rod to the pitman arm, Figure 9-32.

Another system uses two long pieces of linkage instead of a center relay rod and tie rods. This design is shown in Figure 9-33.

**Idler Arms**

If the linkage were not supported on the side of the vehicle opposite the pitman arm, the linkage would flex instead of moving the wheel on that side. To prevent unwanted flexing, an idler arm is installed on the frame across from the pitman arm. One end of the idler arm is attached to the frame through a metal bushing, which allows the arm to turn. The other end of the idler arm is attached to the relay rod through a ball socket. Figure 9-34 shows an idler arm as it is installed on most vehicles. Some large vans and pickup trucks have two idler arms. The idler arm will usually have grease fittings on both the ball socket and the bushing ends. Some vehicles have two idler arms, Figure 9-35.

**Tie Rods**

A tie rod assembly is attached to each end of the relay rod. The tie rod assembly consists of inner and outer tie rods that are usually connected through an adjusting sleeve. See Figure 9-36.

Some vehicles have a hydraulic damper installed between the relay rod and the frame or axle, Figure 9-37. The hydraulic damper resembles a shock absorber. Its function is to absorb road shocks. A hydraulic piston inside the damper allows small amounts of hydraulic fluid to pass through calibrated holes. This absorbs the energy from road shocks before they reach the steering gear.

**Hydraulic Damper**

Hydraulic steering damper

Power steering is a steering system feature that reduces driver effort by providing extra force to steer the vehicle. The use of power steering has increased to the point that all but the smallest cars are equipped with power steering as standard equipment. Power steering systems are used on both rack-and-pinion and conventional steering systems. Principles of power steering are discussed in the following sections.

**Power Steering Systems**

Pressurised hydraulic fluid is used to amplify the driver’s effort, and thus reduce the force needed to turn the steering wheel. Power steering systems use a hydraulic pump or motor to generate hydraulic pressure, which is then directed to the hydraulic steering control valve. The steering wheel is connected to the valve by a hydraulic hose, which transfers the hydraulic pressure to the steering gear. The steering gear is a mechanism that translates the hydraulic pressure into mechanical force, which is then transmitted to the steering linkage. The steering linkage, in turn, moves the steering wheel, which turns the wheels of the vehicle. The power steering system is designed to provide the necessary force to turn the wheels, while also reducing the effort required by the driver.

**Pressure Development and Control**

The basic operating principle of power steering is that liquids (in this case power steering fluid) cannot be compressed. Therefore, liquids can be used to transmit pressure and movement. Systems that make use of liquids to transfer pressure are called hydraulic systems, and the pressure exerted by the liquid is called hydraulic pressure. Observe the closed hydraulic system in Figure 9-38. Hydraulic pressure is transmitted through the hose to one side of the piston. This pressure causes the piston to move.
In a power steering system, pressure is created by a pump and transmitted to the steering gear or, in a few cases, a separate power piston. This pressure is used to help the driver move the wheels. Pressures in a power steering system can rise to over 2000 psi (13,450 kPa) during hard turns.

**Power Steering Fluid**

The average power steering system contains less than two pints (0.95 liters) of hydraulic fluid. A few systems use slightly more. This fluid must transfer pressure, lubricate parts, and remove heat. Most power steering fluid is intended to last the life of the vehicle, providing lubrication without breaking down into sludge or acids.

Many older power steering systems used automatic transmission fluid as hydraulic fluid. Newer systems, however, are filled with special power steering fluids. These fluids contain additives designed to increase the smoothness of power steering system operation and prolong the life of the power steering parts. Specific fluid requirements vary from one manufacturer to the next. Due to the extreme forces placed on the fluid, it is important that the correct fluid be used.

**Power Steering Reservoir**

The power steering system must be full of fluid at all times. Any air that enters the system will cause malfunctions. The power steering reservoir stores extra fluid for use by the other system components. Some reservoirs are installed around the pump assembly. Figure 9-39. The pump draws fluid directly from the reservoir. A large O-ring is used to seal the pump and reservoir mating surfaces. Other reservoirs are separate from the pump and are connected by low-pressure hoses, as in Figure 9-40. A filler cap installed on the top of the reservoir allows fluid to be added when necessary.

**Power Steering Pump**

The engine operates the power steering pump. A pulley on the engine crankshaft turns a belt that turns a pulley on the power steering pump, Figure 9-41. The engine may have to provide as much as 5 horsepower to create pump pressure during maximum power assist.

Most power steering pumps are vane-type pumps, Figure 9-42. This type of pump has an internal chamber with suction and pressure sides. Flat metal vanes turn inside the chamber to draw in and pressurize fluid. To keep the vanes in contact with the chamber walls, pressure is directed to the area at the center of the pump. This pressure enters behind the vanes and pushes them against the walls of the chamber.

Refer to Figure 9-43 as you read the following section. In the suction chamber, the vanes move apart and the area between the vanes increases. This creates a partial vacuum that sucks fluid into the chamber from the reservoir. The fluid is carried around to the pressure side of the chamber. On the pressure side, the area between the vanes becomes smaller and the fluid is pressurized. The pressurized fluid then exits to the other parts of the system.

A similar type of pump is the slipper pump. The operating principles are similar to those of the vane pump, but spring-tensioned slippers are used instead of vanes. The spring tension keeps the slippers in contact with the pump wall. Figure 9-44 shows a typical slipper pump. An older design uses rollers in place of the slippers. See Figure 9-45.

A few vehicles have dual gear power steering pumps. The dual gear pump, Figure 9-46, creates pressure using two gears. As the gear teeth move apart on one side of the pump housing, they create a suction that draws in fluid. The fluid is carried around with the pump gears and then compressed as the gear teeth move together.

Some late-model vehicles are equipped with hydro-boost brake systems. In these systems, the power steering pump produces power assist for both the steering system and the brake system.
To control the output of the pump, a **flow regulator** and a **pressure regulator** are used. Each has a separate function. A few pumps have only one regulator.

**Flow and Pressure Regulators**

The flow control valve allows the pump to produce maximum flow for assist at low speeds, while reducing flow at high speeds to preserve road feel. Allowing the pressurized fluid to enter the inlet also reduces pump wear and fluid temperatures. The goal of the flow control valve is to keep the flow constant as the pump speed and the fluid demands of the system change.

The flow control valve consists of a tapered pin inserted into a small orifice. A spring holds the valve in the closed position, Figure 9-47. Note that in the closed position, fluid can still flow to the power steering gear.

As the engine and pump speed increases, excess fluid flow through the orifice causes a low-pressure condition (called the **venturi effect** on the spring side of the valve. Lower pressure on the spring side causes the valve to compress the spring and begin moving. Valve movement uncovers a passage to the pump inlet, and fluid is returned to the pump. With more fluid bypassing back to the pump, less flows through the steering gear, reducing sensitivity. The tapered pin helps to control the amount of venturi action, allowing the valve to move more or less depending on the amount of fluid flowing. This helps to avoid sudden changes in flow.
Pressure Regulator

The purpose of the pressure regulator is to bleed off high pressures that could damage power steering components. The pressure regulator is a check ball or a small valve that is held closed by a spring. The pressure regulator may be built into the pump housing or may be part of the flow regulator. If system pressure becomes greater than the spring tension, the ball is pushed away from its seat. This opens a passage to the reservoir and allows fluid to return to the reservoir.

The spring holds the valve closed during normal operation. However, if the steering wheel is turned completely left or right, fluid cannot flow through the steering gears and dead ends in the pump. When flow stops, fluid pressure increases and overcomes valve spring pressure. The valve opens and fluid is dumped into the reservoir, reducing the pressure. When pressure returns to normal, the spring pushes the valve closed.

Power Steering Hoses

Since the power steering pump is installed on the engine and the power steering gear is mounted on the vehicle’s frame, there will be relative motion between the pump and the gear when the engine moves on its mounts. To supply the steering gear with fluid, flexible hoses are needed. The hose that directs the pressurized fluid to the steering gear is called a high-pressure hose. High-pressure hoses are made of several layers of reinforced rubber, with tubing fittings solidly attached to each end. The ends of the tubing are double-flared fittings or ISO (International Standards Organization) fittings to withstand high system pressures. Some high-pressure hoses use banjo-type fittings. See Figure 9-48.

The return hose is used to return fluid to the reservoir and is usually a low-pressure hose. Most low-pressure hoses have much less reinforcement than high pressures. Instead of using high-pressure threaded fittings, low-pressure hoses are usually clamped to tubing that is brazed or threaded into the steering gear and the reservoir cover, Figure 9-49.

Power Steering Pressure Switch

Some vehicles have a pressure switch installed on the power steering high pressure hose, Figure 9-50, or on the gearbox. This on-off-type pressure switch sends signals to the ECM. This switch and the ECM work together to raise the engine idle when the power steering system puts an extra load on the engine. The switch contains a flexible diaphragm and two electrical contacts. When the wheels
are turned to lock (their maximum turning position in either direction), the power steering pump produces maximum pressure. This pump pressure increases the load in the engine. When maximum pressure is reached, the pressure switch diaphragm deflects enough to close the contacts and the switch sends an electrical signal to the ECM. The ECM then compensates for the extra load by raising engine idle. On some vehicles, the ECM may also deactivate the air conditioning compressor when signaled by the pressure switch.

**Power Steering Coolers**

Pressurizing the power steering fluid creates heat. If this heat is not removed, it will overheat the fluid, causing oxidation and sludge formation. Excessive heat will also cause hardening of the hoses and other rubber parts. Power steering systems used on smaller vehicles generate less heat than those used on larger vehicles, and the fluid temperature does not become dangerously high. Many larger vehicles have enough airflow through the engine compartment to remove excess power steering system heat.

However, some vehicles develop high power steering system temperatures and have cramped engine compartments with low airflow. On these vehicles, an oil cooler is used to prevent fluid overheating. Some oil coolers are simply extra lengths of aluminum tubing installed on the bottom of the frame where air can pass over them, as shown in Figure 9-51. Other coolers are finned heat exchangers installed ahead of the radiator, Figure 9-52.

**Rack-and-Pinion Power Steering**

A rack-and-pinion power steering gear is similar in design to a conventional system. A self-contained power piston is added to the rack assembly. The power piston creates two pressure chambers in the rack-and-pinion housing. A control valve is installed in the pinion section. The operation of each of these units is explained in the following sections.

Pressure passages may be built into the rack assembly, or the unit may have external piping to deliver the pressure where it is needed. Seals are more complex and stronger to seal under power steering pressures and to hold in the thinner power steering fluid.

**Power Piston**

The rack-and-pinion power piston is installed inside the rack housing and is directly connected to the rack assembly, Figure 9-53A. Seals prevent pressure from crossing between the two sides of the piston. When the vehicle is not being turned, there is no pressure on either side of the power piston.

When the driver begins a turn, pump pressure is directed to one side of the power piston. This causes a pressure differential, meaning that there are unequal amounts of pressure on each side of the piston. The piston will move toward the side with the least pressure, taking the rack with it. This provides the power assist. Fluid on the side of the power piston that is not pressurized is exhausted into the pump reservoir.

During a left turn, pressure enters the left turn side of the power piston, Figure 9-53B. No fluid pressure is delivered to the right side. This causes the power piston to move the rack, assisting with steering effort in that direction. During a right turn, Figure 9-53C, fluid pressure is delivered to the right turn side of the power piston, causing it to move.

**Control Valve**

The power steering control valve is called a rotary valve. It is composed of a spool valve inside a valve body. Since the valve body turns in the rack-and-pinion gear housing, it is equipped with sealing rings. The turning effort from the steering wheel passes through the valve assembly before reaching the pinion gear. The spool valve is connected to the valve body through a torsion bar that allows the valve to rotate slightly inside the valve body before transferring motion to the valve body. Figure 9-54 is a cross section of a typical control valve. Note the relationship of the fluid passages in the spool valve and valve body. Fluid flows through the rotary valve depends on how the passages in the spool valve and the valve body are aligned.

When the steering wheel is in the straight ahead position, or central position, pressure from the pump circulates through the valve assembly and returns to the reservoir. When the steering shaft turns the valve assembly, the spool valve moves in relation to the valve body before the turning effort passes through the valve body to the pinion gear. Note in Figure 9-55A the spool valve has turned slightly to the left. Fluid passages in the spool valve are aligned with passages in the valve body that direct fluid to the side of the power piston that assists a left turn. Pressurized fluid enters the left turn side of the power piston, assisting the driver with a left turn. Fluid on the right turn side of the power piston exhausts through the valve and valve body passages to the pump reservoir.

In Figure 9-55B the spool valve has turned slightly to the right. Fluid passages in the spool valve are aligned with holes in the valve body that direct fluid to the right turn side of the power piston. Pressurized fluid enters the right turn side of the power piston, assisting the driver with a right turn. Fluid on the left turn side of the power piston returns to the pump reservoir through the valve passages. When the driver returns the steering wheel to the straight ahead position, the spool valve returns to its central position inside of the valve body and fluid pressure is exhausted from the power piston.

**Conventional Linkage Power Steering**

Two kinds of power steering are used on conventional linkage steering systems. The self-contained steering gear design is in almost universal use. Linkage types are found on a few vehicles.
Self-Contained Steering Gear

The self-contained power steering gear is a conventional recirculating-ball steering gear that contains a power piston and a control valve.

Power Pistons

A piston with Teflon® seals is attached to the ball nut, dividing the interior of the steering gear into upper and lower chambers, Figure 9-56. Pressure directed to either of the power chambers causes it to move the ball nut. Moving the ball nut moves the sector gear.

When the driver makes a left turn, pressure is directed to the upper chamber, creating a pressure differential between the upper and lower chambers. This pressure differential assists the driver effort in moving the ball nut down. See Figure 9-57A. The fluid in the lower chamber exhausts through the passages in the rotary valve.

In Figure 9-57B the vehicle is making a right turn. Pressure is directed to the lower chamber, causing the ball nut to be assisted in moving up. Fluid in the lower chamber exits through the rotary valve to the pump reservoir.

Rotary Control Valve

Most self-contained power steering gears use a rotary valve similar to that used on rack-and-pinion power steering. The valve assembly consists of a spool valve inside a valve body. The spool valve can turn a small amount inside of the valve body. Passages in the valve and valve body direct fluid to the power chambers. The outer valve spool turns the stationary steering gear housing, and Teflon® sealing rings seal the pressure passages.

The series of illustrations in Figure 9-58 shows the action of the rotary valve. Note that when the steering wheel is in the straight ahead position, fluid circulates through the valve with no effect on either power chamber. When the steering wheel is turned to the left, fluid passages in the valve align with passages in the valve body to direct fluid to the upper chamber. This pressurizes the power piston. Fluid in the lower chamber exhausts through the valve passages to the pump reservoir.

When a right turn is begun, the valve moves slightly to the right. Fluid passages in the valve and valve body align to direct fluid to the lower chamber. Pressurized fluid against the lower end of the power piston assists the driver with the turn. Fluid in the upper chamber returns to the pump reservoir through exhaust passages in the rotary valve.

When the driver returns the steering wheel to the straight ahead position, the valve twists to the straight ahead position inside of the valve body and fluid pressure is exhausted from the power chambers.

Linear Control Valve

Another power steering gear uses a linear control valve. The linear control valve assembly is a small spool valve that can move in a linear direction (back and forth) in a valve bore. A lever connected to the steering shaft moves the linear valve. A typical linear valve steering gear is shown in Figure 9-59. The operation of the power chambers and pistons is identical to the operation of the power pistons and pistons used in the rotary valve power steering gear. This steering gear was used on some older cars and on pickup trucks until the early 1990s.

When the steering wheel is turned, the resistance of the sector gear against the ball nut causes the shaft to move either up or down according to whether the wheel is being turned right or left. This causes the lever to pivot and move the valve in its bore. The valve then directs fluid to the proper power chamber as necessary. Turning the steering wheel in the opposite direction causes the lever to pivot and return the valve to the centered position.

Linkage-Mounted Power Steering

Linkage-mounted power steering is a conventional steering system with a separate power piston and control valve mounted on the linkage. The steering gear is a manual design, although it may have a different steering ratio than one used with manual steering. Linkage power steering was the first kind of power steering, but it has not been used on cars since the late 1980s. Pressure from the power steering pump is delivered to the valve assembly through high-pressure hoses.

Power Cylinder

The power cylinder is a machined cylinder containing an internal piston connected to an output rod. The power cylinder is attached to the steering linkage, usually at the center of the relay rod. The cylinder output rod is attached to the vehicle frame, usually through a double bushing. Hydraulic fluid enters the power piston through high pressure hoses from the valves. See Figure 9-60.