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Steering System Principles

Chapter Objectives

At the conclusion of this chapter you should be able to:

- Identify the components and functions of the steering system.
- Describe the operation of the rack and pinion and recirculating ball gearboxes.
- Explain the various types of steering linkage arrangements and components.
- Explain the operation of power assist systems.
- Explain the operation of electric power assist systems.

KEY TERMS

collapsible steering column	multi-rib belts	recirculating ball gearbox
end-takeoff rack	parallelogram linkage	steering gear
flexible coupler	power steering pump	steering ratio
gearbox	rack and pinion	

Functions and Basic Principles

The steering system, along with the suspension system, allows the driver to safely and easily control the vehicle's direction while driving. To accomplish these goals the steering system works with components of the suspension to provide for the turning movement of the wheels. In addition to connecting the driver to the wheels, the steering system also provides feedback to the driver from the front tires. This feedback, called road feel, is used by the driver to determine how the vehicle is handling.

THE STEERING SYSTEM

The steering system consists of the components that allow the driver to turn the front wheels of the vehicle, and for a few vehicles, provides for a limited amount of steering by the rear wheels. The overall function of the steering system has not changed much since the earliest days of the automobile.

■ Functions of the Steering System. The most basic function of the steering system is to allow the driver to safely and precisely steer the vehicle. Beyond this, the steering system also provides a way to reduce driver effort by making the act of steering the vehicle easier. The components of the steering system also absorb some of the road shock before it gets to the driver. Very little has changed in the operation of the steering system or in some of the components since the earliest automobiles. The things that have changed primarily have to do with increased ease and effectiveness of operation and longer-lasting components that require less maintenance.

■ Steering Columns and Shafts. The basic operation and function of the steering column has not changed very much; the column gives the driver the ability to control the direction of the front wheels and provides some leverage to make steering a little easier.

Early steering columns contained the steering shaft, steering wheel, and often had the choke and ignition timing advance controls mounted on them for easy access. An early model car's steering wheel and column are shown in **Figure 8-1**.

Today's columns still perform the same steering functions and still have controls for other systems or components mounted to them for easy access by the driver, as shown in **Figure 8-2**. New vehicles sold in the United States are also required to have a **collapsible steering column** to help prevent driver injury in the event of a front-end collision.

Steering shafts transmit the motion of the steering wheel from the column to the **steering gear**. There is usually at least one coupler or joint between the column and gearbox to allow for changes in angles and to reduce



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FIGURE 8-1 The steering wheel in this vehicle is large in diameter and is not padded. The large steering wheel was necessary to increase leverage to turn the wheels.



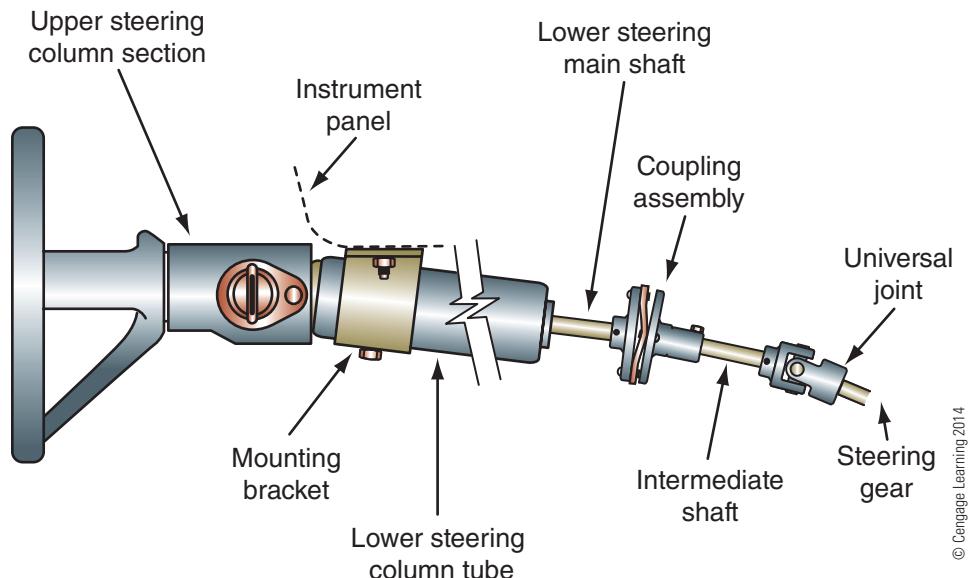
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FIGURE 8-2 Modern steering wheels contain many controls and are part of the overall safety design of the vehicle.

binding when turning the wheel. **Figure 8-3** shows how a steering shaft links the steering column and steering gearbox.

■ Manual Steering Systems. Cars and trucks built before the 1950s had manual steering systems, meaning that the effort needed to turn the steering wheel and the front wheels was supplied by the driver. Steering wheels were larger in diameter and steering gearbox ratios tended to be higher to help reduce driver effort, but turning the wheels still required a lot of muscle power, and drivers could become quickly fatigued when conditions required them to turn the wheels often.

■ Hydraulically Assisted Power Steering Systems. Chrysler offered the first power steering-equipped vehicle in 1951, and the other manufacturers soon offered power steering as an option. Today,



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FIGURE 8-3 An example of a column, intermediate shaft, and flexible joints. The joints allow for mounting the gearbox in different locations under the hood.

it would be difficult to find a new car or truck that does not have power steering as standard equipment.

Hydraulic power-assisted steering uses a belt-driven hydraulic pump, called the power steering pump, to supply pressurized fluid to the steering gear. The pressurized fluid then applies force to a piston inside the steering gear. With the addition of the force applied by the fluid, the effort required by the driver to turn the wheels is reduced.

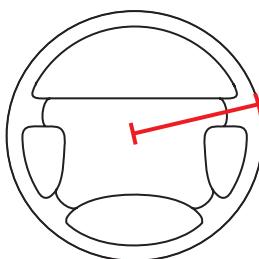
The power steering pump, which is belt-driven from the engine crankshaft, consumes a small amount of engine power to operate, which results in a slight loss in engine power and economy, but most agree that the benefits are well worth it.

Electrically Assisted Power Steering Systems. A recent change in power steering is the replacement of the belt-driven hydraulic pump by electric motor assist. There are currently three types of electric assist available: electrically powered hydraulic steering, column drive electric steering, and the electric motor-assisted rack and pinion steering gear.

Each of these systems offers the ability to provide variable amounts of assist based on driving conditions and driver preference. The completely electric types do not use any type of fluid, and so they are more environmentally friendly since no fluid loss can occur.

BASIC PRINCIPLES

Power steering systems use several basic principles to decrease driver effort. These include leverage, hydraulics, and in some systems, electricity.



The distance from the center to the outside acts as a lever to increase the force applied to the steering shaft running through the center of the column.

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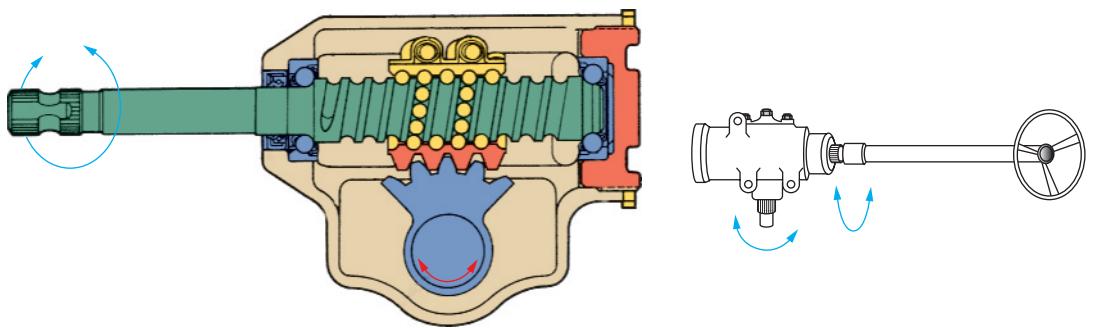
FIGURE 8-4 The steering wheel is a lever, used to increase the force applied by the driver.

Mechanical Advantage of the Steering System.

Leverage, or mechanical advantage, is used at the steering wheel and in the gearbox to increase the force supplied by the driver. The gears inside the gearbox act as levers, increasing mechanical advantage and reducing driver effort to turn the wheels.

Leverage is quite visible in the steering system. Think of the steering wheel as a lever, as in **Figure 8-4**. The force that you apply to the wheel while turning is applied over the radius of the steering wheel, which allows the steering wheel to act as a lever and to increase the force applied to the steering shaft.

The steering shaft in turn uses the force exerted on it by the steering wheel to act as the input for the steering gearbox. The gearbox uses two gears to further increase the mechanical advantage and decrease driver effort. The **gearbox** also converts the rotary motion of the steering wheel and shaft into a linear or back-and-forth motion that moves the wheels. **Figure 8-5** shows how a



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FIGURE 8-5 When the steering wheel is turned, the input to the steering gearbox turns. This motion is then converted into the turning of the front wheels.

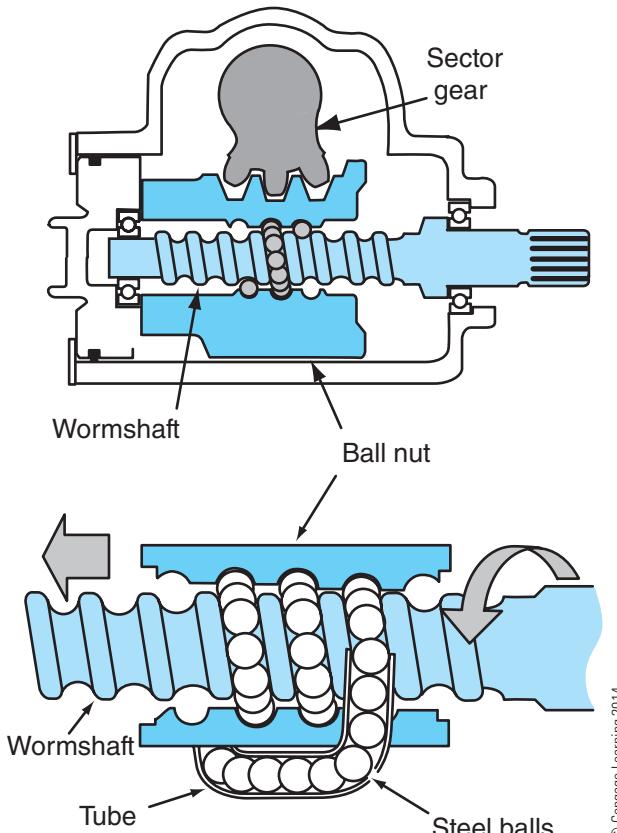
gearbox uses leverage and changes rotary motion into linear motion. Why is the use of leverage important in the steering system? Try this experiment: Ask your instructor to provide you with a lab vehicle. Turn the engine off but leave the steering column unlocked and the vehicle sitting normally on the shop floor. Next, try to push the front wheels side-to-side by yourself. How easy was this to do? Most likely, you were not able to move the wheels much, and the little bit they did move required a lot of effort. Moving the wheels takes effort which is why leverage is important to the steering system.

■ Manual Recirculating Ball Steering Gearbox

Operation. As discussed before, manual steering systems were standard and power steering was an added expense. While that is no longer true, the basic principles of manual steering are also the basic principles of most power steering systems, and they are important to understand.

Manual steering systems use either a recirculating ball gearbox design or a manual rack and pinion design. The rack and pinion system is discussed later in this chapter.

A **recirculating ball gearbox**, as shown in **Figure 8-6**, has three major components: the worm gear, the sector gear, and the ball nut. The steering shaft connects to the worm gear, usually with a splined and indexed clamp. The worm gear is like a large bolt, with very large and smooth threads. The sector gear forms the top of the sector shaft. The sector shaft is the output shaft and is connected to the steering linkage, which is connected to the tires. The ball nut threads over the worm gear and moves up and down the wormshaft just like a nut on a bolt. The outside of the ball nut has deep teeth cut into it to mesh with the sector gear. As the ball nut moves back and forth on the wormshaft, the rotary motion of the wormshaft is converted to a much smaller linear movement of the sector gear. The ball nut has passages cut into it to allow the ball bearings to travel through the nut and over the threads of the worm gear. The use of the ball bearings greatly reduces the friction between the worm gear and the ball nut, which makes the steering easier for the driver.

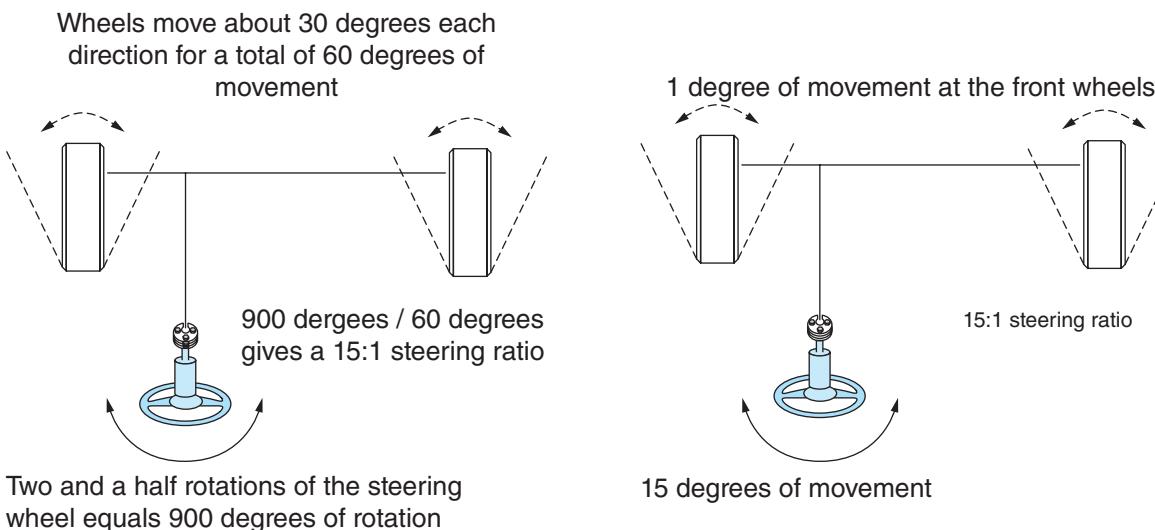


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FIGURE 8-6 An example of the recirculating ball gearbox design. The use of the ball bearings greatly reduces friction in the gearbox and allows for easier steering.

On very old vehicles, you may find a worm and sector gear steering gearbox that does not have the recirculating ball bearings to reduce friction.

■ Steering Ratio. On the average vehicle, the steering wheel will turn about two and a half to three times completely around, from the right steering lock to the left steering lock, but the front wheels do not turn nearly as much as the steering wheel. This is because the steering gearbox is using gear reduction to gain mechanical advantage. When the gearbox transfers the several turns



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FIGURE 8-7 Gearbox ratios vary depending on the type of vehicle. Slow ratios provide easy but imprecise steering, while fast ratios provide feedback and precision but increase driver effort.

of the worm gear into the smaller movement of the sector gear, driver effort is reduced. The number of complete turns of the steering wheel compared to the total amount of wheel and tire movement is called the steering ratio. An illustration is shown in **Figure 8-7**. The **steering ratio**, is found by dividing the total number of degrees the steering wheel turns by the total number of degrees of front wheel movement. The ratio determines how much advantage the gearbox will provide and how the steering will feel to the driver.

For example, you may have noticed that very large vehicles, such as school buses and semi trucks, have large-diameter steering wheels and require many turns of the steering wheel to go around a corner. This is because the steering gearbox has a very high numerical ratio. A high ratio provides easier steering but requires more turns of the steering wheel. A high ratio tends to have less feel or feedback to the driver and is not as responsive to driver input.

Sports cars usually have very responsive steering that also provides a lot of feedback to the driver. This is due to the gearbox having a lower gear ratio. The trade-off is that steering effort is increased as the gearbox ratio decreases.

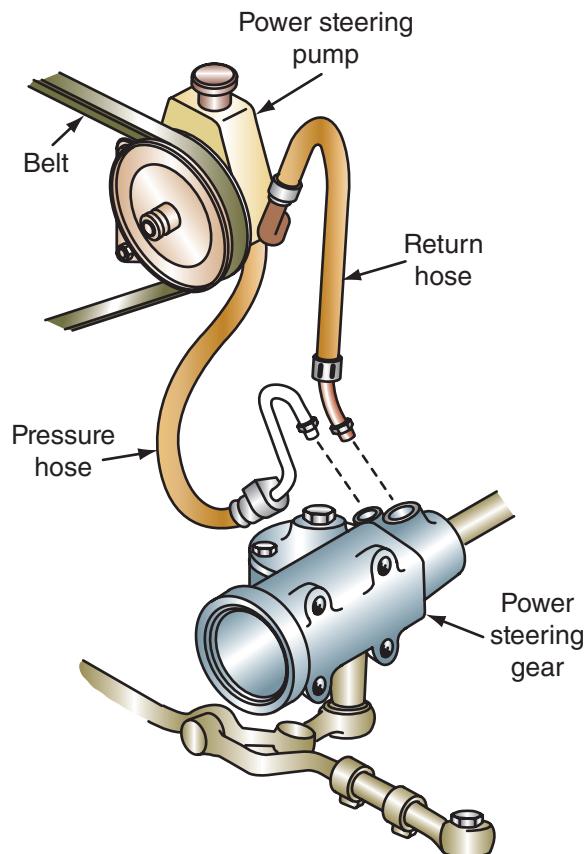
■ **Power Steering.** As stated before, power steering systems reduce driver effort, and can be either hydraulic or electric. Electric power steering systems are discussed later in this chapter.

Traditional hydraulic power steering systems use a belt-driven power steering pump, power steering fluid, lines and hoses, and a power steering gearbox, shown in **Figure 8-8**.

Power steering pumps are usually either a meshed-gear design or a vane type. In both, the power steering fluid enters the pump and is pressurized before being

sent to the gearbox. Power steering pumps are discussed in more detail later in this chapter.

Power steering fluid is a type of hydraulic oil used in the power steering system. Some older Ford products used automatic transmission fluid as their power steering fluid, but modern vehicles often have very specific fluid



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FIGURE 8-8 The hydraulic power steering system contains a pump, fluid lines, power steering gearbox, and hydraulic fluid.

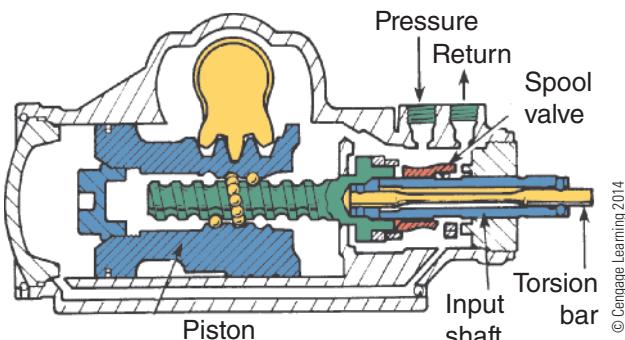


FIGURE 8-9 Inside the power steering gearbox, fluid is used to apply pressure against a piston, reducing the amount of effort required by the driver.

requirements, and the correct power steering fluid must be used for the system to function properly.

There are usually two power steering lines from the pump to the gearbox; the high-pressure supply and low-pressure return lines. Most vehicles use a combination of steel lines and rubber hoses to allow for movement of the engine during operation.

The gearbox can be either the recirculating ball or rack and pinion type. With either type, when the engine is running, power steering fluid is pressurized by the power steering pump and directed to the gearbox by the high-pressure supply hose. In the gearbox, the fluid is directed against a piston. The pressurized fluid pushes on the piston, which decreases the amount of effort needed by the driver. The fluid leaves the gearbox via a port and the power steering return or low-pressure hose return line, and returns to the power steering fluid reservoir. **Figure 8-9** shows a simplified power steering gearbox.

■ **Rack and Pinion Operation.** The traditional recirculating ball gearbox, which is a heavy piece of cast iron

and steel, has been replaced in most vehicles with a rack and pinion gearbox. Even though both types of gearboxes perform the same functions, they do so differently.

A **rack and pinion** assembly has two main components, the rack gear and the pinion gear, enclosed in an aluminum housing. **Figure 8-10** shows a basic manual rack and pinion gearbox. In a rack and pinion, the steering shaft is connected to the top of the pinion gear, which is held in the rack by a set of pinion bearings. The bottom of the pinion shaft has the pinion gear, which is meshed with the rack gear. The rack gear is a gear that has been flattened out with the teeth in a straight line. When the pinion gear turns, it moves the rack gear side-to-side. Just as in the recirculating ball gearbox, the rotary motion from the steering wheel is turned into a linear motion to move the wheels.

Benefits of the rack and pinion gearbox include the reduced weight of the component and the elimination of several pieces of steering linkage. The rack gear attaches to inner tie rods, which in turn connect to outer tie rods. The rack and pinion assembly eliminates the Pitman arm, idler arm, and center link found on parallelogram linkage systems.

Wheels, Tires, and Wheel Bearings as Part of the Steering System

Since the suspension and steering systems rely on the tires as the only contact point with the ground, it is important to remember that the wheels, tires, and wheel bearings also affect steering performance.

HOW WHEELS, TIRES, AND BEARINGS AFFECT STEERING

Like many systems on the vehicle, the steering system does not work by itself. The steering and suspension

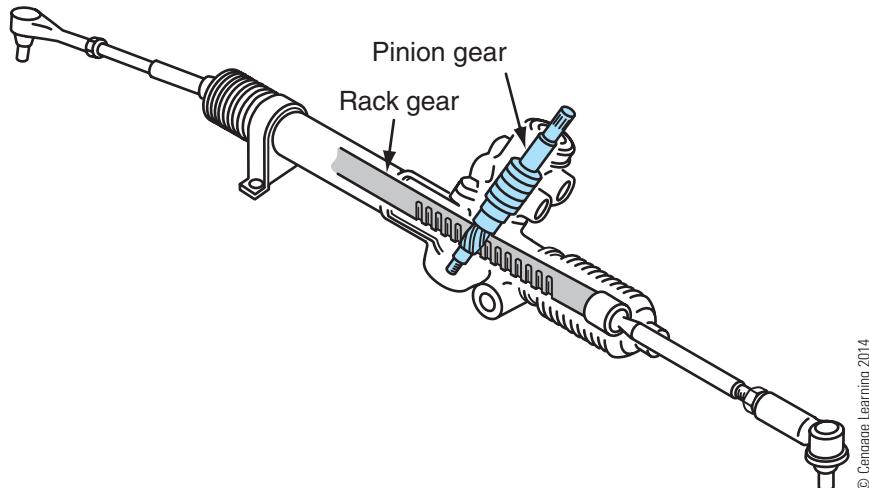


FIGURE 8-10 The rack and pinion gearbox is named for its two primary components, the rack gear and the pinion gear.

systems work together and share some components that are necessary for both to operate efficiently.

One of the biggest factors in vehicle ride and handling is the tires. Since the tires are the contact point between the car and the road, it only makes sense that tires play a big part in ride and handling, as discussed in Chapters 5 and 6. Sports cars typically have a low-ratio rack and pinion gearbox for increased feel and responsiveness, performance springs and shocks, and low-profile sport tires that maximize grip and cornering. If the tires are replaced with a poorer performing tire, the overall performance of the suspension and steering will be affected, and the performance of the car may be drastically reduced by the choice of tire.

Wheel and tire choices can affect the steering if a wider-than-stock tire is installed. A wider tire has more contact area, which will increase steering effort.

Loose wheel bearings affect the steering since the wheel and tire position changes due to the play in the bearing. This also means that the wheel alignment will always be incorrect.

Steering Columns

The steering column in modern vehicles does more than allow the driver to steer the front wheels. Today's columns contain an airbag and controls for many other components, such as the cruise control, radio, exterior lighting, and windshield wipers. Most columns provide a tilt function; some have the ability to telescope, and some vehicles have memory columns that move into a preset position based on driver preference.

BASIC OPERATION AND CONSTRUCTION

Modern steering columns are made of plastics and metals with a steel steering shaft. The column is bolted to the dash panel on a reinforcement brace that supports the dash. A coupler or joint is usually located where the column passes through the firewall. This joint allows the steering shaft to change angle to reach the steering gearbox.

Plastic covers, as shown in **Figure 8-11**, cover the switches and other electrical components that are attached to the column. These covers are usually held together by several screws, which are removed to gain access to the column and any attached components.

The steering wheel is secured to the top of the steering shaft with a nut or bolt. The steering wheel and steering shaft are usually aligned by a locating notch or splined groove that can only be installed in one location. This prevents the steering wheel from being installed incorrectly. A few vehicles, mostly older model 4WD trucks, do not have an alignment notch for the steering wheel. This is to center the steering wheel after a wheel alignment is performed.



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FIGURE 8-11 Covers around the steering column hide the electrical connections and wiring.

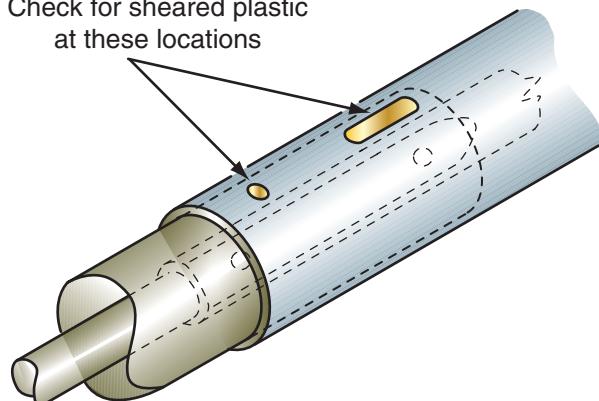
Wiring for the electrical controls runs through the column and down to connectors at the base of the column under the dash. Narrow channels are designed into the column to allow wiring and components to be removed and reinstalled if necessary.

COLLAPSIBLE COLUMNS

Collapsible steering columns have been standard equipment on cars and trucks for many years. The reason for a collapsible column is to help protect the driver from injury in the event of a head-on collision.

The column is often made of two tubes with a plastic layer between the inner and outer tube. **Figure 8-12** shows typical designs. In a frontal collision, the plastic that normally holds the two tubes rigidly together breaks, allowing the tubes to move in relation to each other. This prevents the column from being pushed into the driver's chest during impact. Once a column has collapsed, it must be replaced.

Check for sheared plastic
at these locations



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FIGURE 8-12 Collapsible columns compress in the event of a forward collision to help prevent injury to the driver.

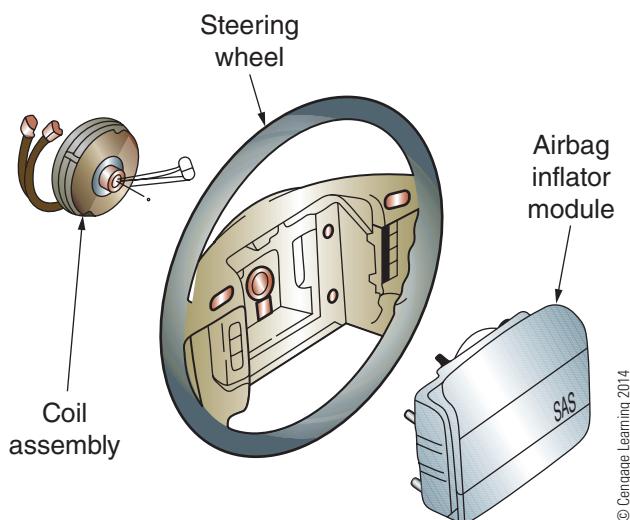


FIGURE 8-13 The driver's side airbag is mounted to the steering wheel.

Another method used to prevent injury from the steering during a collision is using a folding steering shaft. In this system, a section of the steering shaft may break or deform. This prevents the steering shaft and column from being pushed rearward toward the driver in a collision.

AIRBAGS

Airbags have been installed in steering wheels since the late 1980s. The purpose is to prolong or decrease the rate of deceleration of the driver during a collision and prevent him or her from being thrown through the windshield.

The airbag is mounted in the center of the steering wheel, beneath a cover that splits open when the bag is deployed. The airbag is bolted into brackets built into the steering wheel center section. The electrical connection for the airbag is maintained by a component called a clock spring. **Figure 8-13** shows how the components of the airbag system are positioned in the column.

If any service needs to be performed to the steering column, such as to the tilt mechanism, the airbag will have to be disabled and removed before the steering wheel can be removed. This is covered in detail in Chapter 9.

STEERING SHAFTS AND COUPLERS

Since the steering column is rarely perfectly aligned to the steering gearbox, an intermediate steering shaft and a coupler or joint is used to connect the column and the gearbox together. **Figure 8-14** shows a flexible coupler and a universal joint-equipped steering shaft.

TIIT AND TELESCOPING FUNCTIONS

Most modern vehicles have a tilt steering wheel as standard equipment. The tilt wheel allows the driver to adjust steering wheel position to increase comfort while driving. There are three types of tilt wheel, steering wheel tilt only, upper column and wheel tilt, and lower column and wheel tilt.



FIGURE 8-14 An example of a steering u-joint. Some of these designs are meant to collapse or break in a collision to prevent the column from injuring the driver.

All three change the position of the steering wheel by allowing a pivoting action inside the column. A release lever is mounted either on the side of the steering column or on the underside of the column. The release lever unlocks the tilt mechanism and allows the driver to adjust wheel position. Releasing the lever or pushing it back into its original position locks the column or wheel back into place.

Some vehicles are also equipped with a telescoping steering wheel. A telescoping wheel can move closer or farther from the driver's seat, again to increase driver comfort. **Figure 8-15** shows both tilt and telescoping column functions.

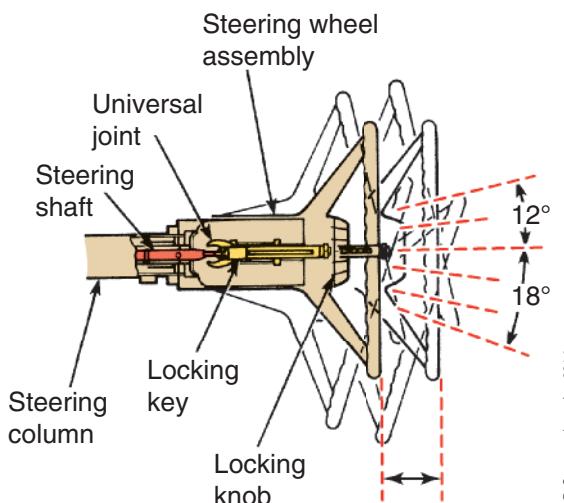


FIGURE 8-15 Tilt and telescoping steering wheels are common on modern cars and trucks. These adjustments allow for increased driver comfort.

POWER/MEMORY COLUMNS

A few vehicles offer power tilt and telescoping columns. Many of these cars have memory functions that save driver preferences for seat, steering wheel, and mirror positions. Vehicles equipped with a memory steering column have motors that move the column up, down, forward, and rearward to a preset position. These systems often move the steering column forward and up during vehicle entry and exit to make getting in and out of the driver's seat easier.

Steering Operation

The two basic types of steering systems, the recirculating ball and the rack and pinion, perform the same functions but in slightly different ways. The recirculating ball steering gearbox is usually only found on heavy-duty vehicles today since the rack and pinion is lighter and uses fewer linkage components.

RECIRCULATING BALL GEARBOXES

This design greatly decreases friction and steering effort compared to earlier gearbox designs. Driver input is through the wormshaft. When the wormshaft turns, it forces the ball nut to move either up or down the threads of the shaft. As the ball nut moves, its teeth move the sector gear and shaft. This movement is what the steering linkage transfers to the front wheels to turn the car.

The power-assisted version of this gearbox is basically the same as the manual gearbox with the exception of the operation of the ball nut. A power-assisted

gearbox has a torsion bar, piston, and control valve to control power steering fluid flow. **Figure 8-16** shows the internal components of the power steering gearbox. With the wheels pointed straight ahead, there is no torque on the torsion bar, and the ports inside the spool valve are all open and fluid enters and returns to the power steering pump. When the steering wheel is turned enough to twist the torsion bar, the ports in the spool valve realign, and fluid is directed to the piston within the ball nut. The pressure applied by the fluid on the piston makes moving the ball nut easier, which reduces the effort needed by the driver to turn the wheels.

Linkage Components. There are two basic linkage arrangements used to connect the recirculating ball gearbox with the steering knuckle, the parallelogram and the crosslink types.

The gearbox is connected to the front wheels by the steering linkage. The opposite end of the sector shaft, outside the gearbox, connects to a Pitman arm. The Pitman arm connects to a center link or drag link, which in turn connects to tie rods, which connect to the steering knuckles.

A common linkage arrangement, called the **parallelogram linkage**, is shown in **Figure 8-17**. The parallelogram linkage gets its name from the angles formed by the center link and the Pitman and idler arms as the wheels are turned. This type of linkage is used with the short/long arm type of suspension.

When the driver turns the steering wheel, the rotary motion of the wormshaft is reduced at the sector shaft.

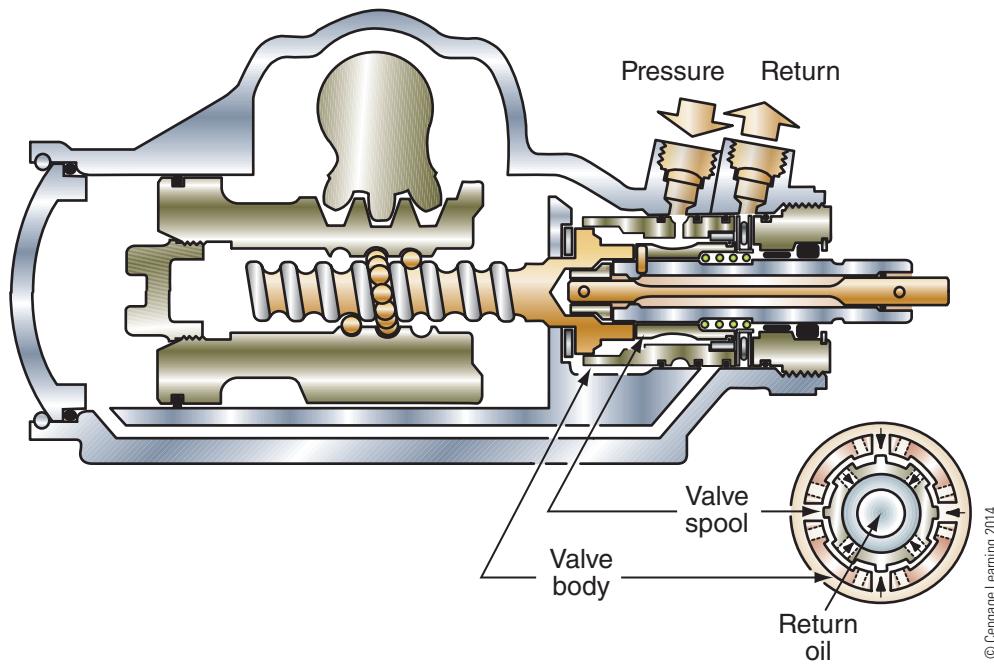


FIGURE 8-16 The spool valve inside the recirculating ball gearbox directs fluid against the piston for power assist.

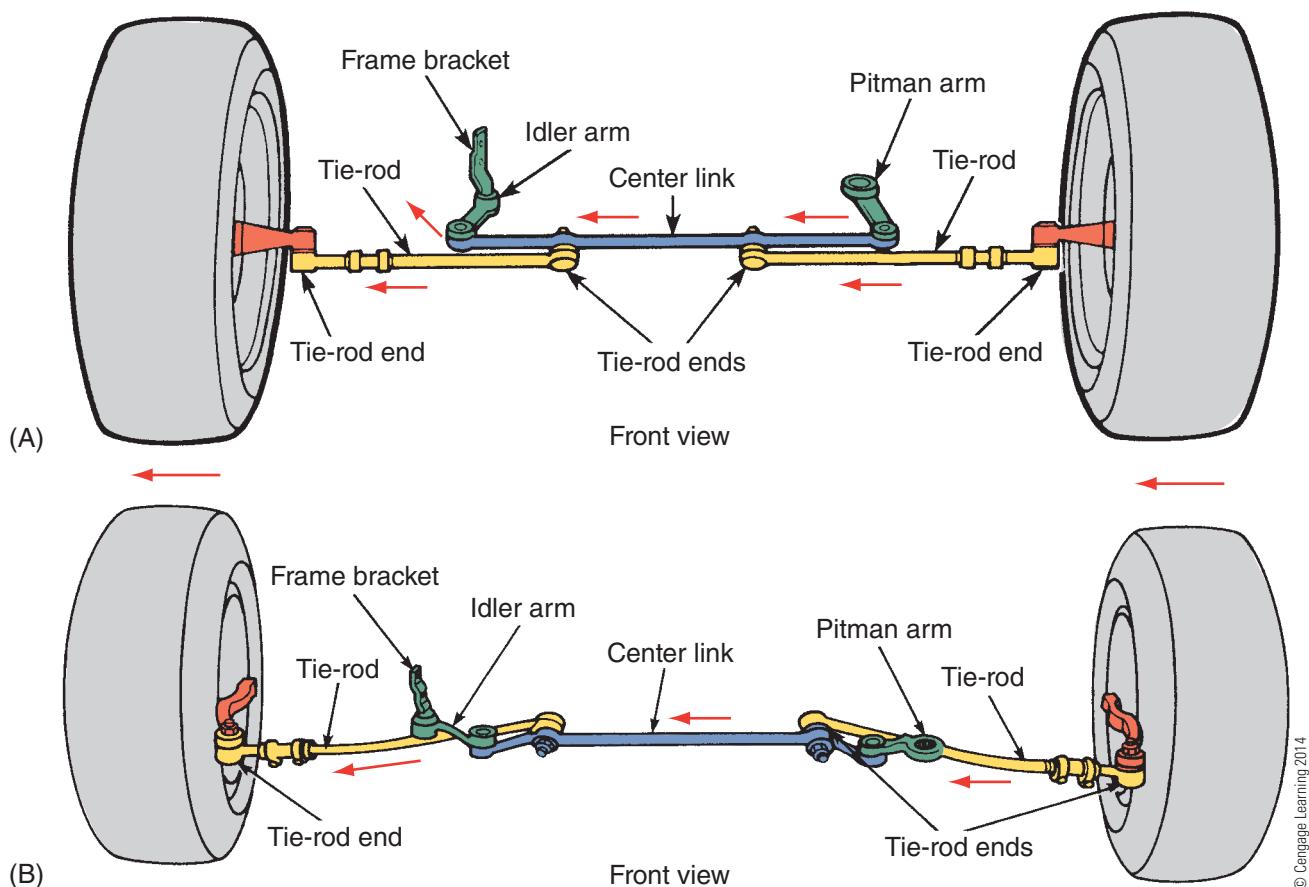


FIGURE 8-17 The parallelogram linkage allows the steering linkage to remain level as it moves side-to-side and allows the tie rods to travel with the movements of the lower control arms.



FIGURE 8-18 Pitman arms are splined to the gearbox and connect to the center link or relay rod.

As the sector shaft turns, it also turns the Pitman arm. An example of a Pitman arm is shown in **Figure 8-18**. One end of the Pitman arm is splined to match the splines on the sector shaft. **Figure 8-19** shows an example of a sector shaft. The other end of the Pitman arm is connected to the centerlink.

At the end of the centerlink opposite the Pitman arm is the idler arm. The centerlink can only move side-to-side since both the Pitman and idler arms prevent vertical movements. This is important because any vertical



FIGURE 8-19 The lower end of the sector gear is splined to fit the Pitman arm. The gear is in mesh with the nut on the worm gear.



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FIGURE 8-20 Idler arms keep the centerlink level as it moves side-to-side. This is to eliminate bump steer.



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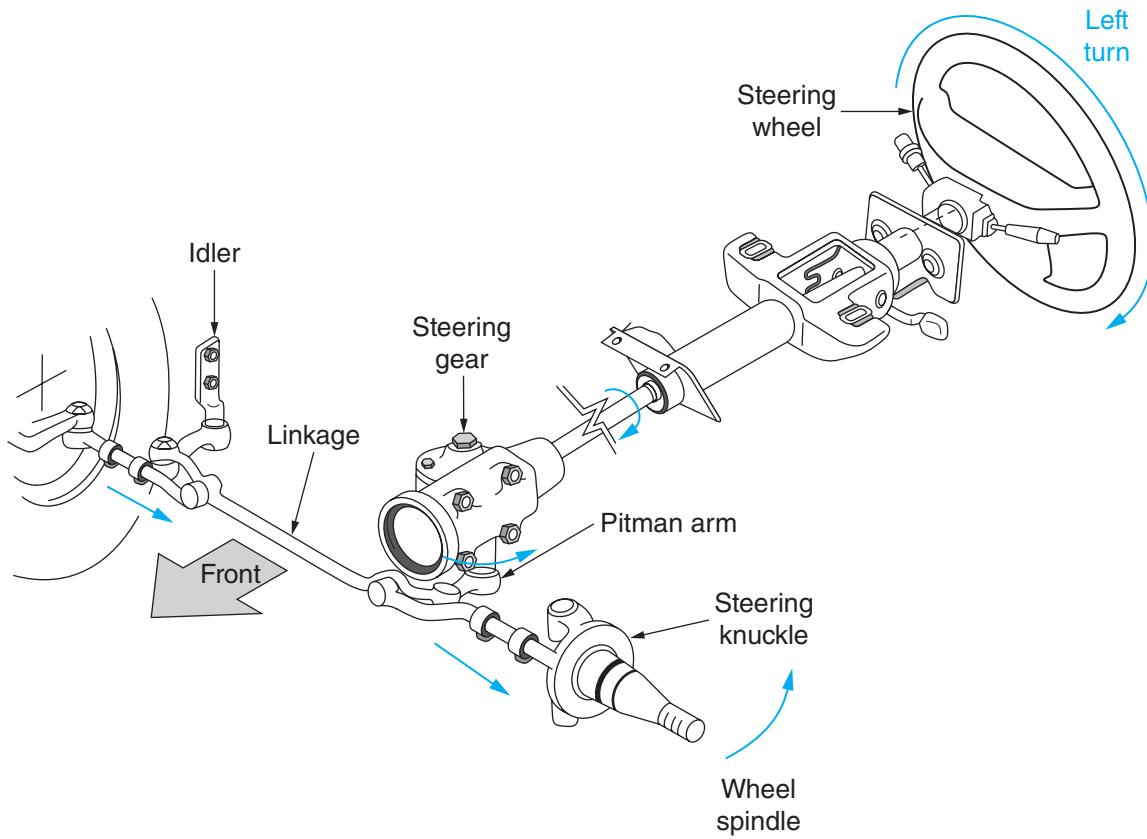
FIGURE 8-22 An example of an inner tie rod, tie rod sleeve, and outer tie rod.

movement of the steering linkage will result in changes to the toe angle and wheel position. An example of an idler arm is shown in **Figure 8-20**. This motion of the linkage is illustrated in **Figure 8-21**.

Two tie rod assemblies connect the centerlink of the steering knuckle, shown in **Figure 8-22**. These assemblies consist of an inner tie rod, a tie rod adjustment sleeve, and an outer tie rod. The inner tie rod is attached to the centerlink while the outer tie rod connects to the steering arm. The adjustment sleeve is used to connect the tie rods and allow for toe angle adjustment. The outer tie rod typically has right-handed threads, and the inner tie rod has left-handed

threads. The sleeve is placed between the tie rods, and when turned, the movement either shortens or lengthens the tie rod assembly.

To prevent bump steer, the tie rods are parallel with the lower control arms. Bump steer is the term used to describe the sudden darting of the vehicle to the left or right when a bump in the road is hit. The tie rods must travel in the same arc as the lower control arms while the arms respond to road conditions. This keeps the toe angle constant when the tire is moving up and down over bumps. If the tie rods do not travel exactly with the lower control arms, bump steer will occur.



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FIGURE 8-21 This illustrates the movements of the parallelogram linkage.

The parallelogram linkage has been in use for many years and is a very effective linkage arrangement, but it does not work with all types of suspensions. Since it relies on the tie rods following the movement of the lower control arms, it is not the best choice for all front suspensions, particularly those used on 4WD vehicles.

Crosslink Linkage. Vehicles with a twin I-beam or a live front axle do not have a control arm arrangement like the SLA suspension. Because of this, the parallelogram linkage will not work. **Figure 8-23** shows a crosslink arrangement as used on a 4WD truck with a live front axle.

This design still uses a Pitman arm connected to the steering gearbox but does not use a centerlink or idler arm. Instead, the Pitman arm connects to a drag link. The drag link looks like a very long inner tie rod since it connects to a tie rod sleeve and outer tie rod. The tie rod assembly is also connected to the drag link. This arrangement allows the tie rods to follow the movement of the axle without causing bump steer.



FIGURE 8-23 The crosslink system is used on 4WD trucks and Fords with the twin I-beam front suspension.

RACK AND PINION STEERING

Most cars and light trucks now use rack and pinion gearboxes. This is because the rack and pinion design is lighter and has fewer components.

A manual rack and pinion gearbox, as shown in **Figure 8-24**, contains the pinion shaft and gear and a

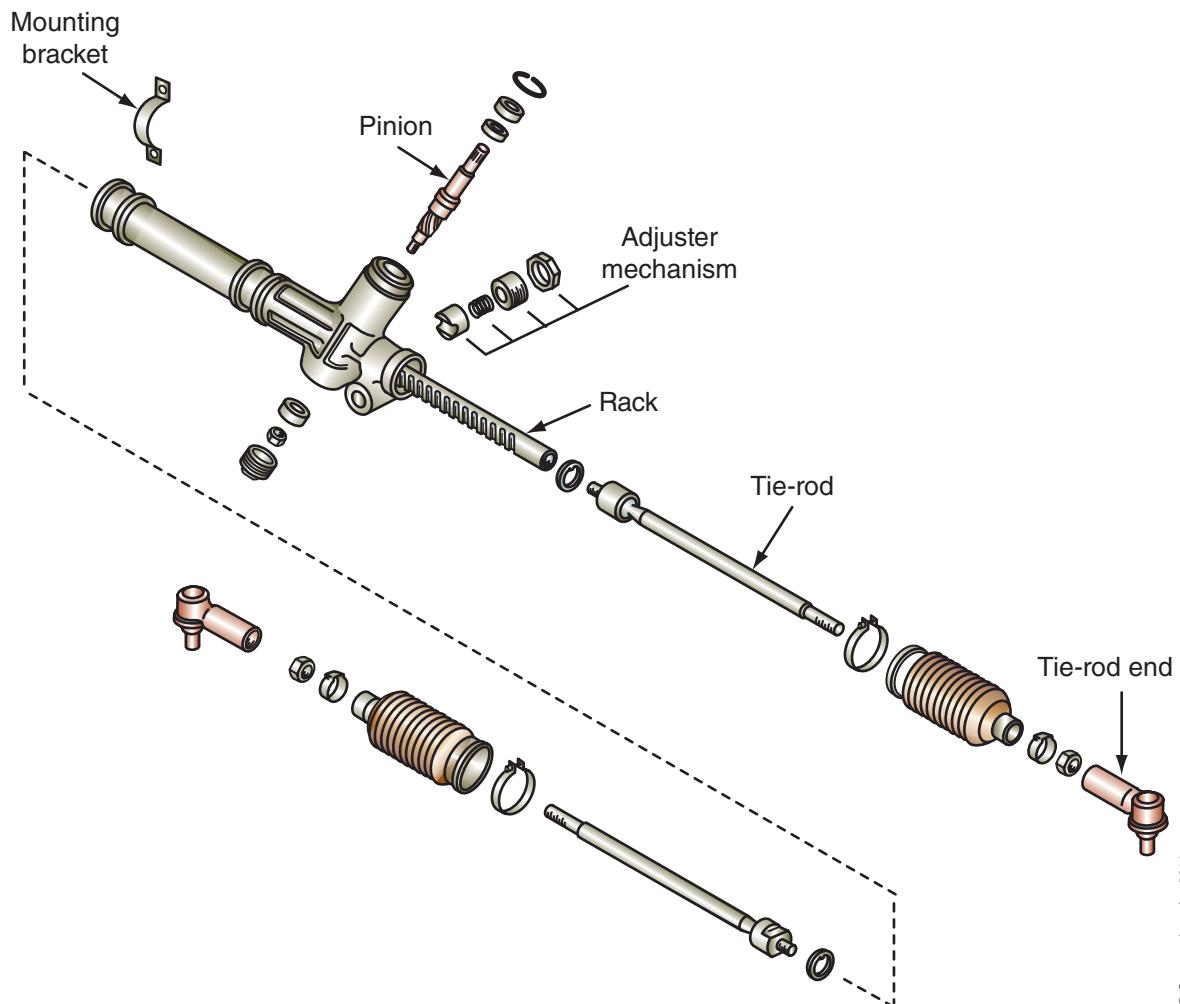


FIGURE 8-24 An example of a manual rack and pinion unit. Rack and pinion systems use only inner and outer tie rods, eliminating the centerlink, Pitman, and idler arms.

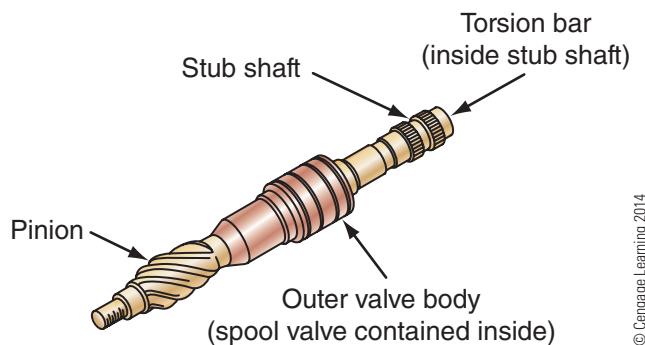


FIGURE 8-25 The pinion gear and spool valve are used in power steering rack and pinion units. The spool valve directs fluid through small passages and to the rack gear piston for power assist.

rack gear. When the steering wheel is turned, the pinion gear moves the rack gear side-to-side. Inner tie rods are connected to the rack gear, either at the ends of the rack or bolted to the center of the unit, and transfer the side-to-side motion to outer tie rods and the steering arms or strut assembly. When the inner tie rods are attached to the ends of the rack gear, it is called an end-takeoff rack. When the inner tie rods are bolted at the center of the rack, it is called a center-takeoff rack.

Power-assisted rack and pinion gearboxes use a spool valve that is integrated into the pinion gear, shown in **Figure 8-25**. Like the recirculating ball gearbox, a torsion bar is used. The lower end of the torsion bar is connected to the end of the pinion gear, which meshes with

the rack gear. As the driver turns the steering wheel, the top of the pinion gear begins to turn, but the lower end at the rack gear does not. This is because the weight on the front suspension makes the rack gear resist moving. This difference in torque between the top and bottom of the pinion causes the torsion bar inside to twist. As the torsion bar twists, ports align in the spool valve that allow fluid to pass through the valve and to one side of the piston attached to the rack gear, as shown in **Figure 8-26**. When the driver turns the wheel back, the process repeats and allows fluid to travel to the other side of the rack piston. When the wheels are straight ahead, the ports are not aligned, and the fluid returns to the power steering pump reservoir.

■ **Linkage Components.** End-takeoff rack and pinions use a ball socket inner tie rod that is threaded into the outer tie rod, as shown in **Figure 8-27**. A jam nut threaded onto the inner tie rod locks the inner and outer tie rods together. Examples of rack and pinion tie rods are shown in **Figure 8-28**. **Figure 8-29** shows a typical mounting location for end-takeoff rack and pinion units. The rack is typically mounted to the crossmember, near the front of the engine or behind the engine and transaxle.

Some vehicles use a center-takeoff rack, shown in **Figure 8-30**. This rack is usually mounted high on the firewall behind the engine due to space limitations around the frontcrossmember. The tie rods on center-takeoff racks connect to a steering arm made into the front strut.

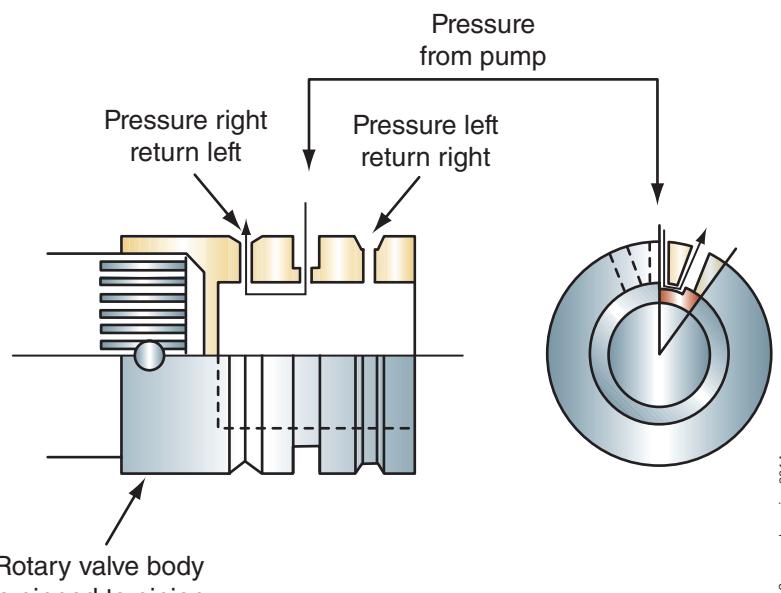
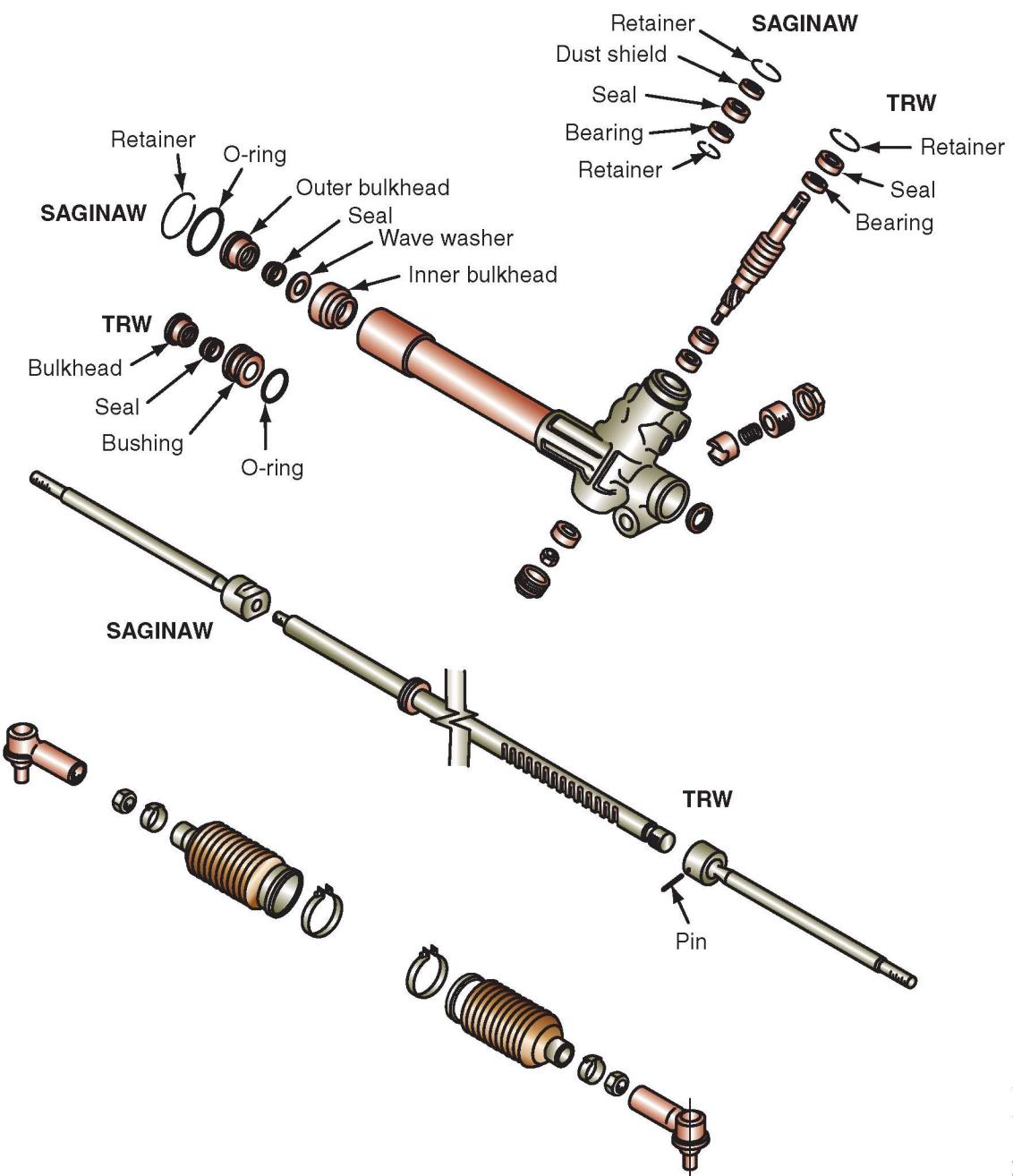
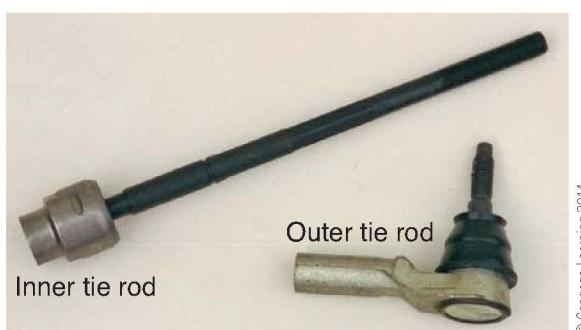


FIGURE 8-26 This illustrates the operation of the spool valve in a rack and pinion system.



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FIGURE 8-27 End-takeoff racks have the inner tie rods threaded to the ends of the rack gear.



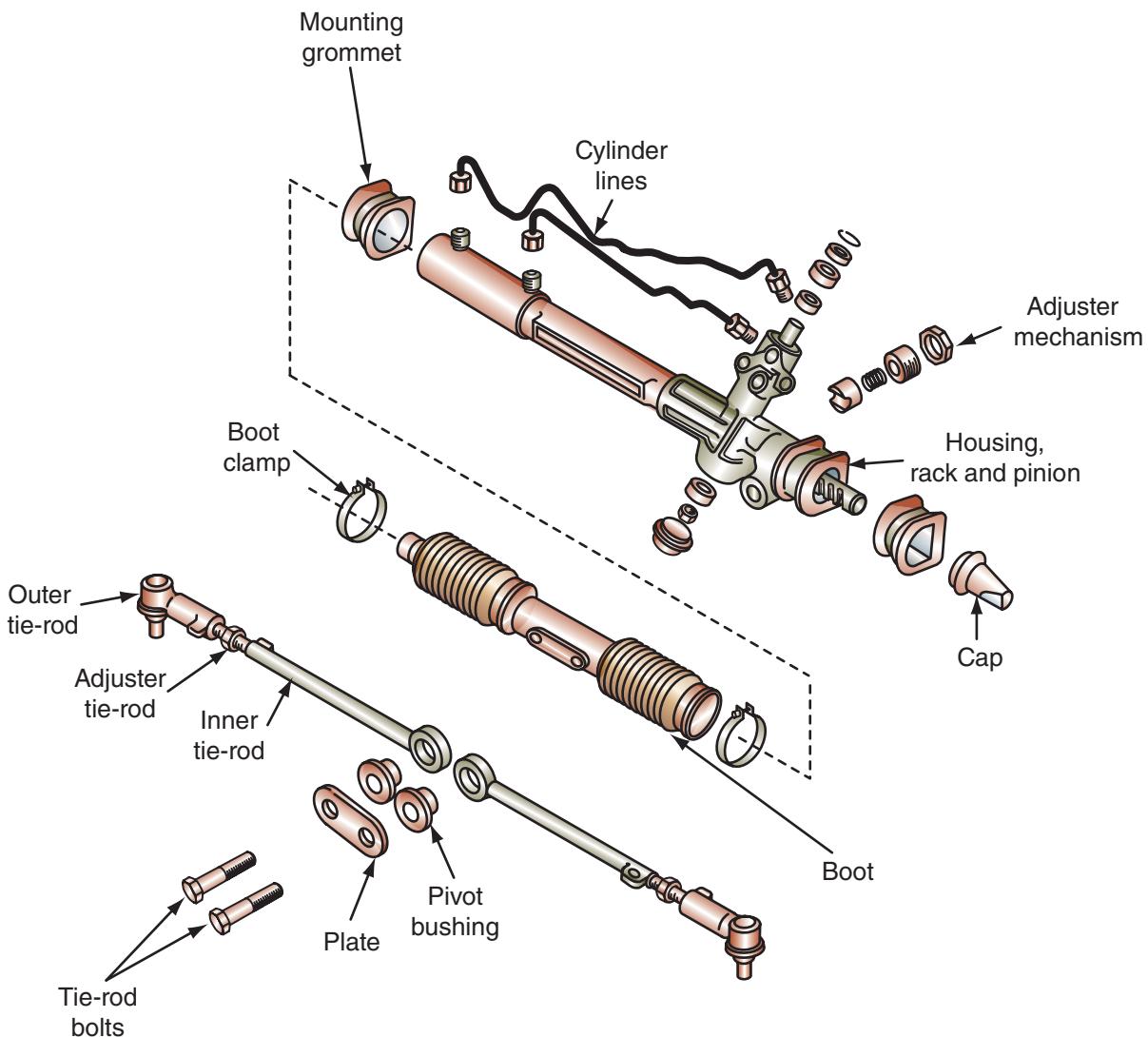
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FIGURE 8-28 Examples of rack and pinion tie rods.



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FIGURE 8-29 An example of a common rack and pinion location.



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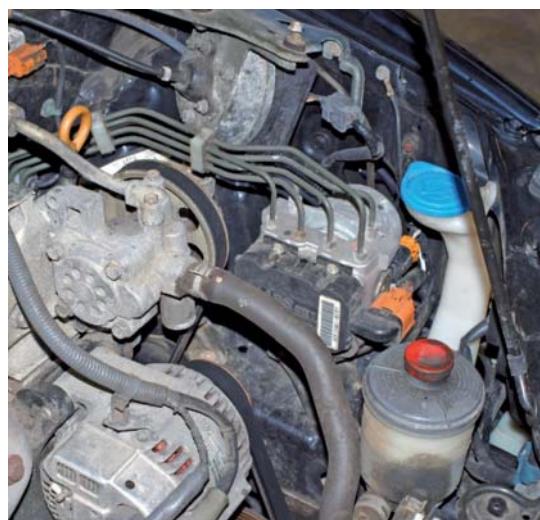
FIGURE 8-30 Center-takeoff racks have long inner tie rods that bolt to the middle of the rack gear.

HYDRAULIC POWER ASSIST

Hydraulic power steering assist has been available since the 1950s and has not changed significantly since then. Most hydraulic assist systems use a belt-driven pump to supply pressure to a piston in the gearbox.

■ **Power Steering Pumps.** The majority of power steering systems use a belt-driven hydraulic pump, as shown in **Figure 8-31**. When the engine is running, the crankshaft drives the accessory drive belt, which drives the power steering pump.

Power steering pumps are positive displacement pumps, meaning that they pump a specific volume of fluid for each revolution of the pump. All of the fluid that enters the pump is pressurized and exits the pump under pressure. The amount of fluid that can be pressurized at any time is based on the shape and size of chambers within the pump. The pump chamber's



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FIGURE 8-31 An example of a common power steering pump and remote reservoir system.

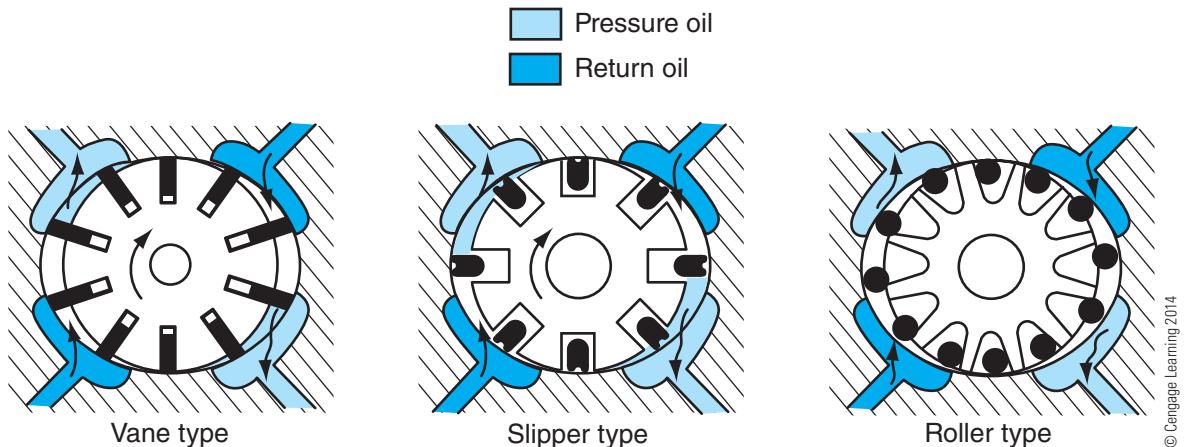


FIGURE 8-32 Even though the designs are slightly different, all three types of this power steering pump operate the same.

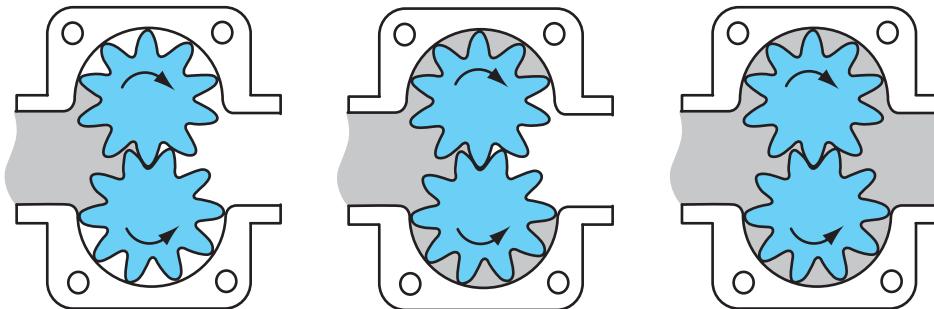


FIGURE 8-33 A gear-driven pump pressurizes the fluid between the teeth of the gears.

design and size depends on the type of pump used. The most common types of power steering pumps currently in use are the roller type, vane type, slipper type, and gear-to-gear type. **Figure 8-32** shows an example of three types of pumps. **Figure 8-33** shows an illustration of the gear-to-gear pump. In gear-to-gear pumps, fluid is drawn into the pump and forced in between the two gears that are meshed together. This pressurizes the fluid, which then exits the pump and is sent to the steering gearbox.

In the roller, vane, and slipper types of pumps, the power steering pulley drives a rotor, which is located in a ring. As the rotor spins, fluid is drawn into the space between the rotor and the ring. As the rotor continues to rotate, the rollers, vanes, or slippers reduce the area between the rotor and the ring. This decrease in volume places the fluid under pressure. An example of how this operates is shown in **Figure 8-34**.

A flow control valve, shown in **Figure 8-35**, is used to control fluid flow and maximum pressure. Since all of the fluid entering and exiting the pump is not needed at all times of the vehicle operation, the flow control valve will reroute fluid back to the reservoir at higher

pump rpm to reduce fluid flow and fluid temperature. An example of fluid flow in the system is shown in **Figure 8-36**.

Some vehicles control the flow of power steering fluid from the pump using an electrically operated

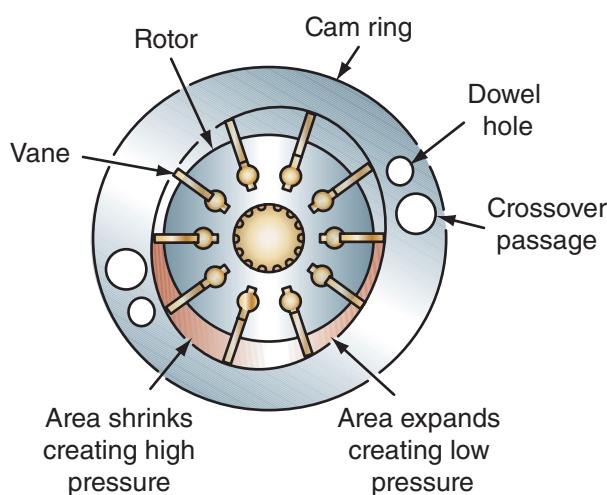
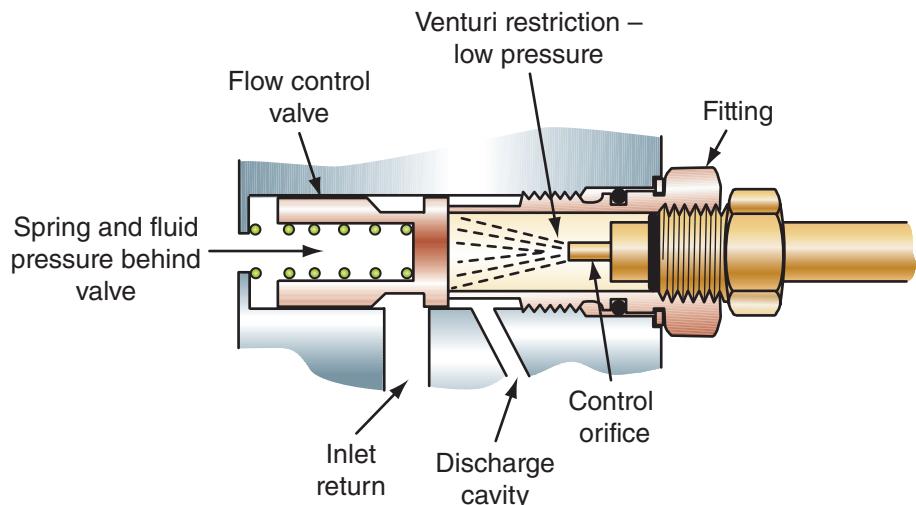
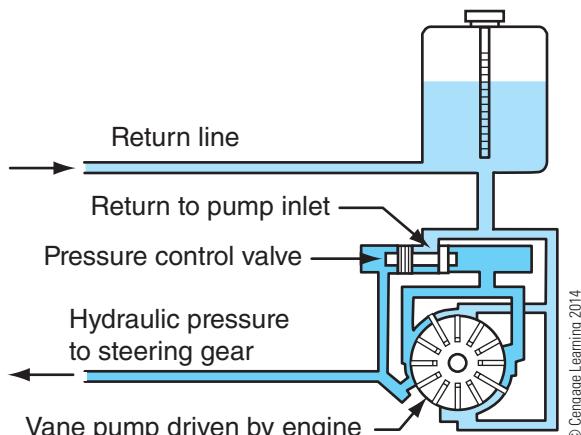


FIGURE 8-34 This illustrates how the fluid is pressurized in a vane type of power steering pump.

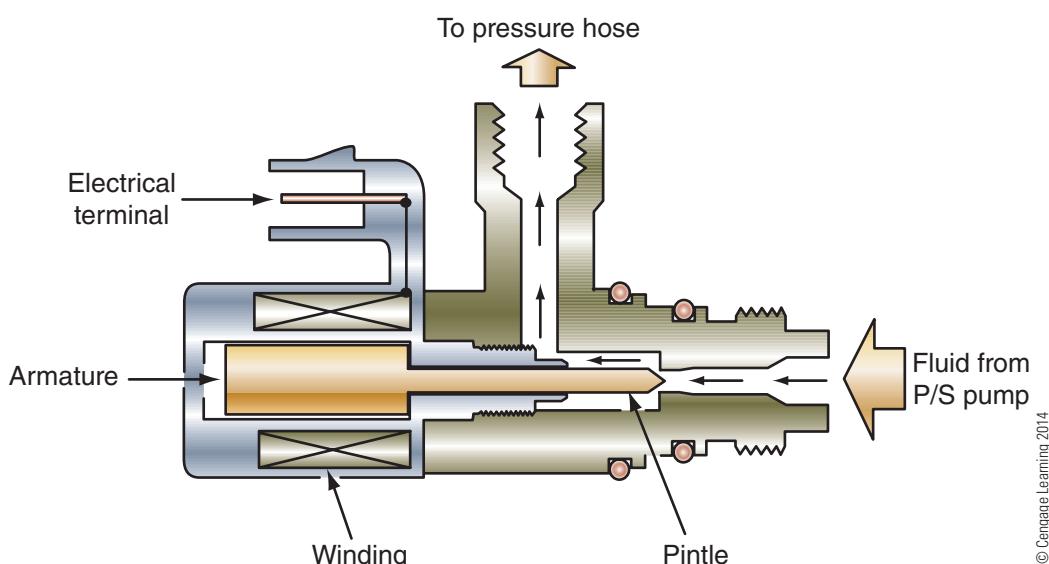


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FIGURE 8-35 An illustration of the flow control valve in a power steering pump.**FIGURE 8-36** An illustration of fluid movement through the power steering pump.

flow control valve, shown in **Figure 8-37**. This system opens or closes the fluid outlet based on power steering demand. When the vehicle is driving at low speed, such as when parking, fluid flow is increased for greater assist. At highway speeds, when less assist is needed, fluid flow is reduced. These systems are controlled by the engine control module (ECM) based on input from sensors in the steering column and various powertrain inputs.

■ Power Steering Pressure Sensors. Many power steering pumps have a pressure switch installed into them or the sensor may be installed into the power steering pressure hose, as shown in **Figure 8-38**. This sensor is used as an input for the engine control module (ECM).



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FIGURE 8-37 This shows how fluid flow from the pump is controlled by a small electric motor. This system is designed to provide variable power assist.



FIGURE 8-38 An example of a power steering pressure switch used by the ECM for idle speed control.

Because the power steering pump can place a significant load on the engine during low-speed driving, especially during parking, the ECM uses the input from the sensor to increase engine speed. This prevents engine speed from dropping too low during parking and causing the engine to stall.

■ **Electric Pump Hydraulic Assist.** Some vehicles use an electric pump instead of a belt-driven pump. This system takes the mechanical load of the pump off the engine, which increases fuel economy. This type of system can activate the pump only when needed and can provide a type of variable assist based on driving conditions and driver input.

■ **Power Steering Fluid.** Today, modern vehicles use power steering fluid in the power steering system, while some older vehicles still use automatic transmission fluid in the power steering system. Power steering fluid is low-viscosity hydraulic oil specially formulated for power steering systems. The low viscosity reduces the amount of power required to pump the fluid and reduces heat buildup in the system. Some vehicle manufacturers require special power steering fluids, and the use of general-purpose power steering fluid can result in system damage and the loss of power assist. Always refer to the manufacturer's service information for specific fluid requirements before servicing the power steering system.

■ **Power Steering Hoses.** Power steering systems have two hoses to connect the pump to the gearbox: a high-pressure supply hose and a low-pressure return hose. These hoses often have steel tubing and reinforced rubber sections, as shown in **Figure 8-39**.

The high-pressure hose has threaded fittings for connection to the pump and gearbox and high-pressure crimp connections to join the steel and rubber sections.

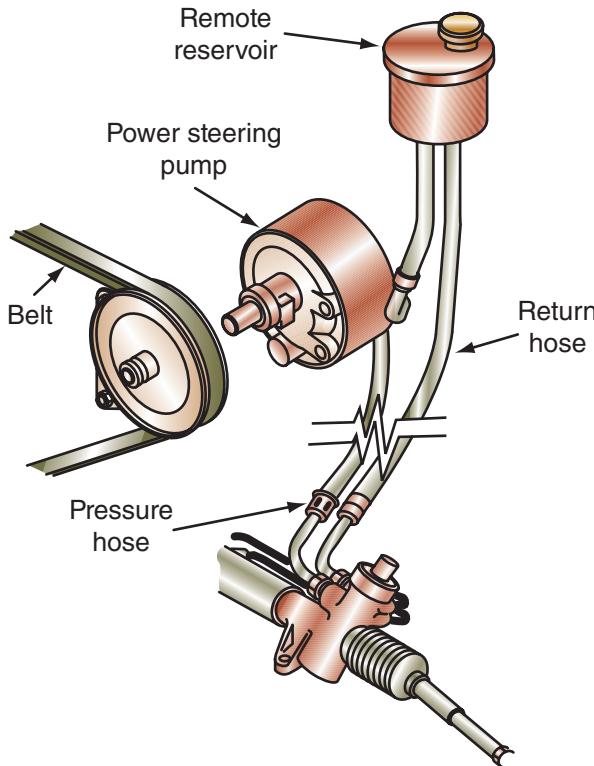


FIGURE 8-39 An illustration of power steering hoses supplying fluid through the system.

This is due to the high pressure the fluid is under during operation.

The low-pressure hose, while being a high-strength, reinforced design, does not carry high pressure like that of the supply hose, and as such does not usually have the same types of fittings. Many systems attach the return hose to the power steering pump return port with an ordinary worm or spring clamp.

■ **Power Steering Drive Belts.** For the power steering pump to operate correctly, the power steering drive belt must be installed and tensioned correctly. Older vehicles often use a V-belt design, while most newer vehicles use serpentine or **multi-rib belts**. Both are shown in **Figure 8-40**. An example of how a modern accessory drive belt is used is shown in **Figure 8-41**.

Correct tension must be maintained between the belt and the drive pulley. If the belt is loose, it can slip around the pulley instead of actually driving the pulley. This will cause the belt to make noise and cause the power assist to be erratic and jumpy, especially during low-speed operation and when parking. Inspecting and servicing the drive belt is covered in detail in Chapter 9.

ELECTRIC POWER-ASSISTED STEERING

A recent trend is the use of electrically assisted power steering. The advantages of electric assist are the

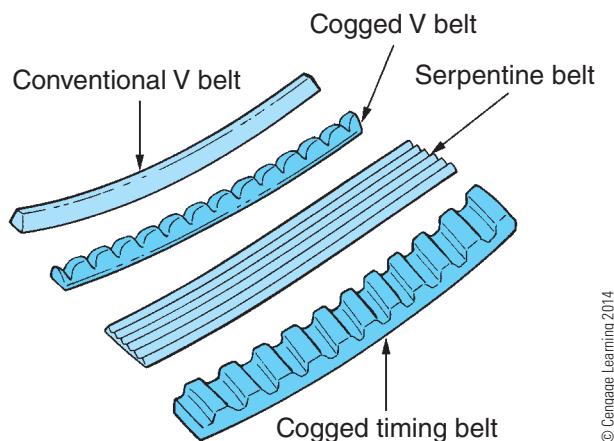


FIGURE 8-40 Serpentine drive belts are the most common, but many older vehicles are still in service that use V-belts.

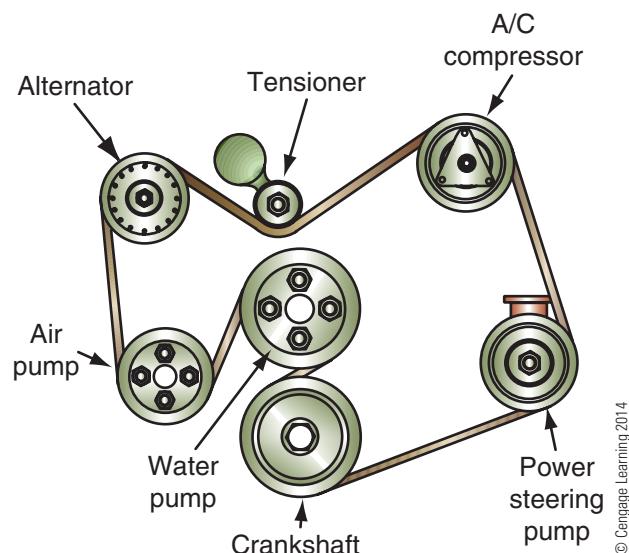


FIGURE 8-41 An example of an accessory drive belt routing.

elimination of a belt-driven pump and power steering fluid. Turning the power steering pump takes horsepower away from the engine, which decreases fuel economy. Power steering fluid leaks are also a concern. Vehicle manufacturers are under pressure to decrease the amount of fluid loss due to leaks as these leaks are harmful to the environment. Electric power steering eliminates the power steering fluid and the possibility of its leaking into the environment.

■ **Basic Principles.** There are currently three types of electric assist available: the electrically powered hydraulic steering discussed earlier in this chapter, column drive electric steering, and a motor-assisted rack and pinion steering gear.

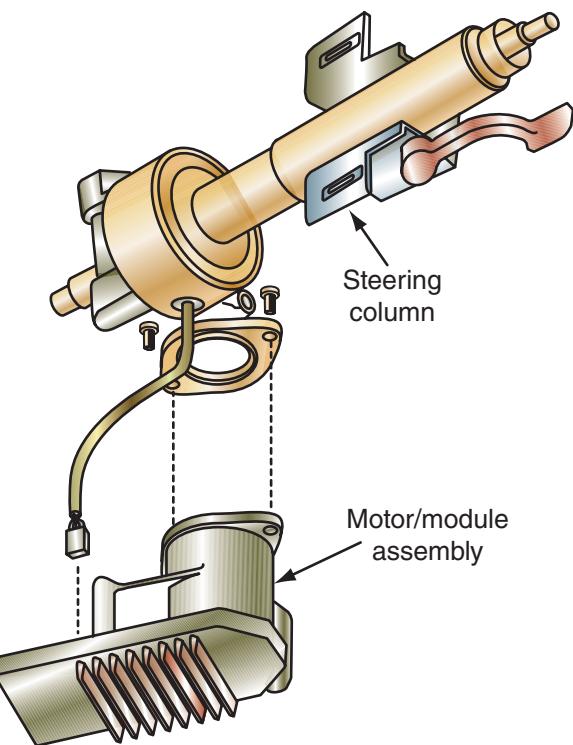


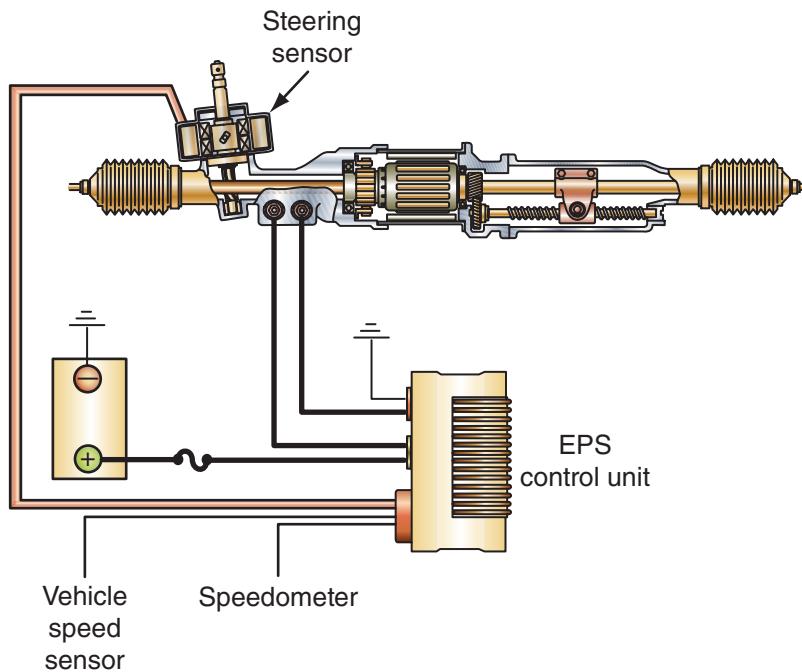
FIGURE 8-42 A column-mounted electric power steering system.

Many new vehicles from GM, Hyundai, BMW, and other manufacturers use a column-mounted electric power steering (EPS) system. An illustration of this is shown in **Figure 8-42**. Sensors mounted in the steering column determine steering wheel position, rate of movement, and torque on the steering shaft. A power steering control module receives these and other inputs and determines how much assist is needed. Assist can be tailored to suit driving conditions as necessary.

Some manufacturers place the electric motor in the rack and pinion. In this system, the electric motor applies torque to the rack gear to provide assist. This system also uses several sensors to determine how much assist is needed. An example of this type of EPS is shown in **Figure 8-43**.



FIGURE 8-43 An example of an electrically assisted rack and pinion system.



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FIGURE 8-44 An illustration of an electrically assisted rack and pinion system.

Both systems only operate the motors when assist is actually needed, so when the wheels are pointed straight ahead, no assist is necessary and the motor is not active. This saves power since the electrical system is not loaded.

Operation. In general, the electric power steering control module (PSCM) uses input from the torque sensor(s) to determine how much assist is needed. **Figure 8-44** shows an example of an electric rack and pinion system. In the EPS system used by GM, the input from the steering wheel, through the steering shaft, is transferred to the torque sensor. The output shaft from the torque sensor is attached to the steering coupler. The sensor uses a compensation coil, a detecting coil, and three detecting rings. The detecting rings have teeth in their edges that face each other. Detection ring 1 is attached to the output shaft, while rings 2 and 3 are fixed to the input shaft. As torque is applied to the steering shaft, the alignment of the teeth of the detection rings 1 and 2 change, which causes a voltage signal to be sent to the PSCM. The PSCM interprets the signal as steering shaft torque. The compensation coil is used for to allow for changes that occur from temperature changes during operation.

The EPS motor is a 12-volt DC motor and is located in the steering column. This type of motor can draw over 50 amps and can become quite hot in operation. Because of this high current demand, motor current draw is monitored by the PSCM. In the event the current flow

overheats the motor or draw becomes excessive, the PSCM has an overload protection mode, which limits current to the motor and decreases the amount of power steering assist.

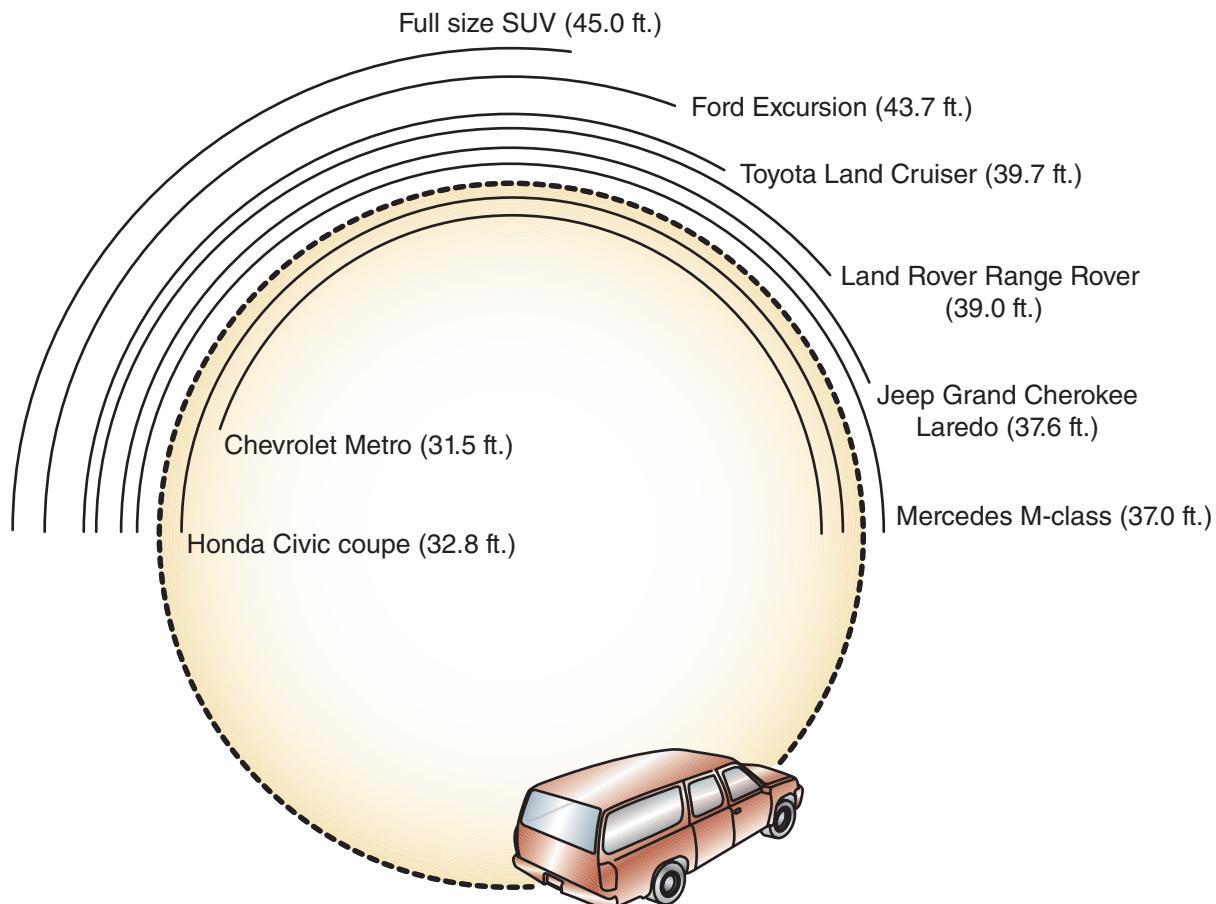
4WS SYSTEMS

Four-wheel steering, or 4WS, while not common, is available on vehicles ranging from the Chevrolet Silverado to certain Acura, BMW and Nissan models. Four-wheel steering systems improve both low- and high-speed maneuvering by allowing the rear wheels to either countersteer the front wheels at low speed or steer in the same direction as the front at higher speeds. This improves handling and decreases turning radius, shown in **Figure 8-45**.

Basic Principles. Allowing the rear wheels to turn in the opposite direction from the front wheels during low-speed turns and when parking enables the turning radius to be greatly reduced. That means a full-size truck can maneuver and park like a much smaller car. This is especially helpful when pulling a trailer. Low-speed operation is illustrated in **Figure 8-46**.

At higher speeds, the rear wheels turn in the same direction as the front wheels. This decreases the yaw of the vehicle when changing lanes and can greatly reduce the amount of wobble induced in a trailer when changing lanes. **Figure 8-47** shows the high-speed mode of 4WS operation.

Most vehicles equipped with 4WS use an electrically operated rack and pinion gearbox for the rear wheels,



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FIGURE 8-45 Four-wheel steering, decreases turning radius and improves maneuverability.

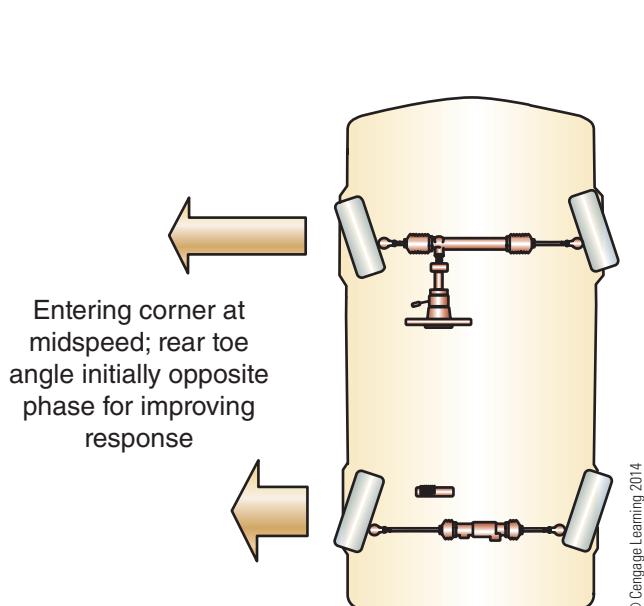


FIGURE 8-46 At low speed, the rear wheels turn opposite the front wheels to decrease turning radius.

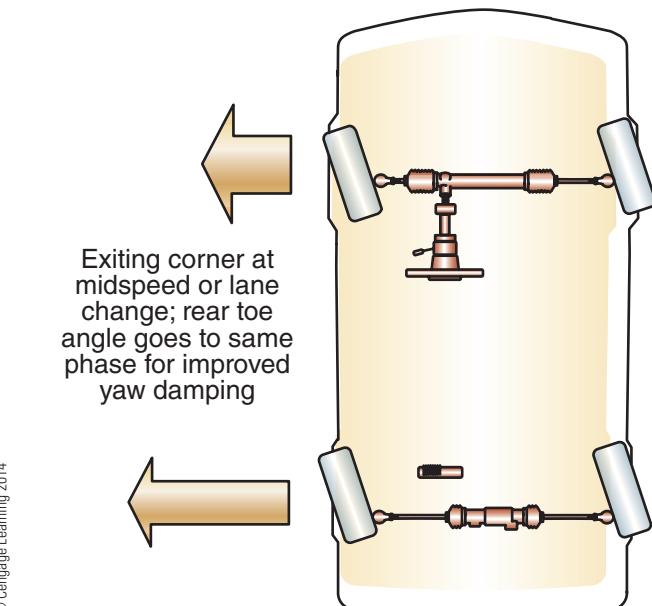
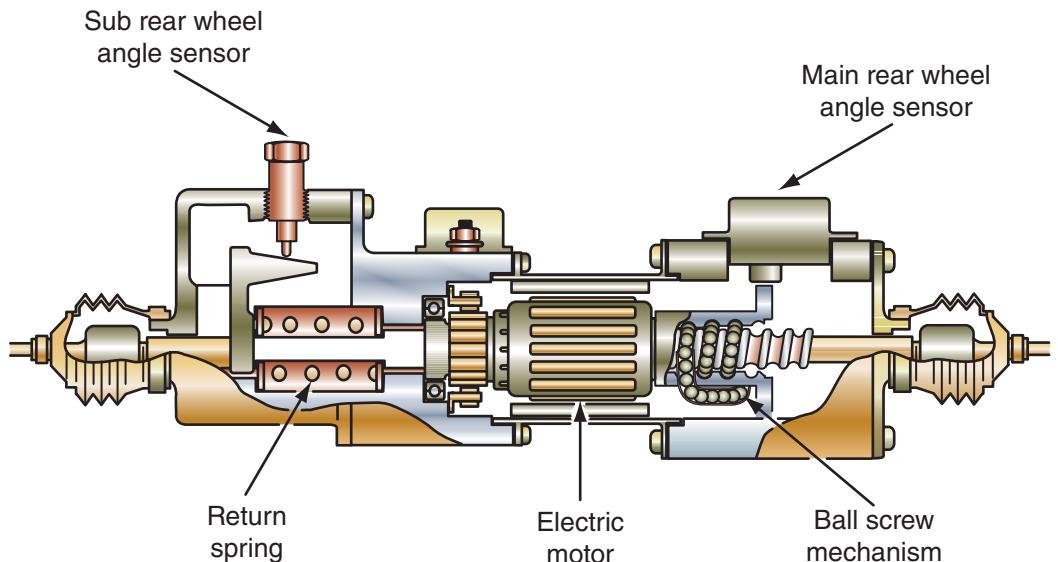


FIGURE 8-47 At higher speeds, the rear wheels turn in the same direction as the front wheels to improve stability.



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FIGURE 8-48 An illustration of an electric rear-wheel steering rack and pinion.

shown in **Figure 8-48**. This rear rack does not allow the same range of motion as the front. Rear turning radius is usually limited to about 12 degrees of movement.

■ **Operation.** Sensors in the steering column and data from the vehicle speed sensor are used to determine which way and how far to turn the rear wheels. At low speeds, usually less than 40 mph, the rear wheels are counter- or negative steered. At higher speeds the rear tires are turned in the same direction.

The system used on GM trucks, called Quadrasteer, has three main modes of operation; two-wheel mode,

four-wheel steer mode, and four-wheel tow mode. In two-wheel mode the rear wheels are held in their center position and rear wheel steering is disabled. Four-wheel steering below 40 mph is called negative phase steering. In negative phase, the rear wheels steer opposite the front wheels. Above 40 mph the rear wheels steer in positive phase, which is when the rear wheels follow the front wheels. Four-wheel tow mode allows for more positive phase steering than normal four-wheel steering at high speed and increased negative phase steering at low speeds.

SUMMARY

The steering system provides the safe and easy ability to control the vehicle's direction while driving.

The steering system also provides a way to reduce driver effort by using a power assist system.

Hydraulic power-assisted steering uses a belt-driven hydraulic pump, called the power steering pump, to supply pressurized fluid to the steering gear.

The number of degrees of the steering wheel from lock to lock compared to the total amount of wheel and tire movement is called the steering ratio.

The gearbox is connected to the front wheels by the steering linkage.

The rack and pinion system eliminates the Pitman arm, idler arm, and centerlink.

In a frontal collision, the two tubes of the steering column break, allowing the tubes to move in relation to each other.

The parallelogram is used with the short/long arm type of suspension.

Most cars and light trucks now use rack and pinion gearboxes.

Power steering pumps are positive displacement pumps.

Power steering systems have a high-pressure supply hose and a low-pressure return hose.

A recent trend is the use of electrically assisted power steering.

Four-wheel steering systems improve both low- and high-speed maneuvering.

REVIEW QUESTIONS

1. Two types of steering gearboxes in use are the reciprocating ball gearbox and the _____ gearbox.
2. The amount of turning of the front wheels compared to the amount of turning at the steering wheel is called the _____.
3. The _____ is often belt driven and is used to supply pressurized fluid to the gearbox.
4. Vehicles with memory steering columns may move both the _____ and the _____ functions as set by driver preference.
5. Four-wheel steering systems are used on trucks to decrease _____.
6. Technician A says all power rack and pinion gearboxes use hydraulic power assist. Technician B says some power steering gearboxes have electric motors to provide assist. Who is correct?
 - a. Technician A c. Both A and B
 - b. Technician B d. Neither A nor B
7. Technician A says universal power steering fluid can be used in all makes and models of vehicles. Technician B says power steering fluid and automatic transmission fluids can both be used in any power steering system. Who is correct?
 - a. Technician A c. Both A and B
 - b. Technician B d. Neither A nor B
8. Which of the following are not used in rack and pinion steering linkages?
 - a. Outer tie rod ends c. Inner tie rods
 - b. Idler arm d. All of the above
9. A vehicle has suffered heavy front-end damage in a collision: Technician A says the steering column may need to be replaced. Technician B says the steering column must be carefully inspected if being reused. Who is correct?
 - a. Technician A c. Both A and B
 - b. Technician B d. Neither A nor B
10. Technician A says a fast steering ratio requires many turns of the steering wheel to go around corners. Technician B says a fast steering ratio is common on sports cars because it increases road feel and feedback to the driver. Who is correct?
 - a. Technician A c. Both A and B
 - b. Technician B d. Neither A nor B