CHAPTER 11

DRIVE AXLES

OBJECTIVES

After studying Chapter 11, the reader should be able to:

1. Identify the parts of a RWD drive axle assembly.
2. Explain the purpose for each of these parts.
3. Identify the parts of a gear tooth.
4. Discuss the power flow through a hypoid gear.
5. Identify the different types of limited slip differentials.
6. Explain how the limited slip differentials operate.
7. Identify the different styles of axle shafts.
8. Explain how the different axle shafts are retained.
9. Discuss the requirements for good drive axle operation.

KEY TERMS

Backlash (p. 305)
Bearing-retained axle (p. 323)
Carrier bearings (p. 309)
C-lock retained (p. 323)
Coast side (p. 305)
Dead axle (p. 305)
Differential (p. 313)
Drive side (p. 305)
Electronic traction control (ETC) (p. 316)
Extreme pressure (EP) (p. 324)
Face (p. 305)
Final drive (p. 305)
Flank (p. 305)
Float (p. 305)
Friction modifier (p. 324)
Full-floating axle (p. 323)
Gear contact pattern (p. 312)
Heel (p. 305)
Hunting (p. 305)
Hydra-Lok (p. 320)
Hypoid gear set (p. 305)
Independent rear suspension (IRS) (p. 325)
Integral carrier (p. 309)
Limited slip differential (p. 314)
Live axle (p. 305)
Locked differential (p. 314)
Nonhunting (p. 305)
Open differential (p. 313)
Overhung pinion (p. 309)
Partial nonhunting (p. 305)
Pinion depth (p. 309)
Pinion gear (p. 305)
Pitch line (p. 305)
Positraction (p. 314)
Removable carrier (p. 309)
Ring gear (p. 305)
Semifloating axle (p. 321)
Side bearings (p. 309)
Side gears (p. 316)
Straddle mounting (p. 309)
Toe (p. 305)
Torque bias ratio (TBR) (p. 314)
Torsen® (p. 320)
Vari-Lock (p. 320)

INTRODUCTION

All RWD vehicles use a drive axle assembly to transfer power from the driveshaft to the drive wheels. Because it is powered, it is sometimes called a **live axle**; FWD cars use a **dead**, nonpowered rear axle. The major parts of a drive axle are the ring and pinion gears, differential, and axle shafts (Figure 11-1). Many 4WD vehicles use a similar axle at the front, the major difference being steerable drive wheels.

RING AND PINION GEARS

The **ring** and **pinion gears** are the **final drive** reduction gears. Their ratio and tire size are normally selected to provide the proper engine rpm for cruise speed. Sometimes the ratio must be selected so that it will provide sufficient torque for low-speed operation. Many people consider the reduction for low-speed operation the transmission ratio's job, and the reduction for cruising speed the drive axle ratio's job. With today's fuel mileage and emission requirements, the axle ratio has come under federal control, and ratio changes are done only for off-road situations. With these requirements and today's lower-profile tires, the rear axle ratio of most 1990 cars is between 2.7:1 and 3:1. Fifty years ago, the driving situations were slightly different and taller tires were used; the average ratio for a 1950s vehicle was around 4:1.

Besides determining the gear ratio, the ring and pinion gear set must also turn the power flow from the driveshaft 90° to align with the axles. The ring and pinion gear set is a hypoid type. These are similar to spiral bevel gears except for the height position of the pinion gear (Figure 11-2). In a spiral bevel set, a line drawn through the pinion shaft will intersect the center of the ring gear. In a **hypoid gear set**, the pinion gear is below center. This accomplishes two things: (1) to lower the driveshaft so that the tunnel or hump in the floor of the vehicle can be smaller, and (2) to create a longer, larger, and stronger drive pinion gear in which the pinion gear teeth slide across the teeth of the ring gear. This also makes a hypoid gear set quieter. The sliding, wiping action of the gear teeth requires a special GL-4 or GL-5 lubricant. Most gear oils sold in the United States are of hypoid quality (Figure 11-3).

As a gear set is made, after the gears have been cut, hardened, and ground to shape, the ring and pinion are run against each other in a machine with abrasive compound on their teeth. This laps or wears them to match each other perfectly. At this point, they become a matched set, and damage to one will require replacement of both with another matched set. There is normally a mark etched on the head of the pinion gear and on the side of the ring gear to identify a particular set. There is often a stamping that indicates the gear ratio or part number, and sometimes there will also be a marking that indicates the pinion gear depth (Figure 11-4).

Gear Tooth Terminology

When a gear set is adjusted, reference is often made to particular parts of the gears and their teeth. The outer ends of the ring gear teeth are called the **heel** and the inner ends the **toe** (Figure 11-5). The **pitch line** is the design center of contact between the two gears and is about halfway up the tooth. The **face** of the tooth is above the pitch line, and the **flank** is below it.

The **drive side** of the ring gear teeth is the more vertical, *convex* side of the tooth. This is the side of the tooth that contacts the pinion gear while the engine is driving the vehicle forward (Figure 11-6a). At this time there should be a clearance at the coast side of the tooth; this is called **backlash**. The **coast side** of ring gear teeth is the slanted, *concave* side of the tooth. This surface receives pressure while the vehicle is coasting; the vehicle is driving the engine (Figure 11-6b). While coasting, the backlash will be at the drive side of the tooth. The third tooth-load condition is called **float** (Figure 11-6c). During float there is no load on the gear teeth, and backlash will be on both sides.

Most hypoid gear sets are classified as **hunting** gears. This term refers to the pattern of tooth contact between the gears; think of it as a pinion gear tooth hunting for a mate. If the pinion gear has 11 teeth and the ring gear 24 teeth, the ratio will be 2.182:1. This gear set is identified as hunting, where a single pinion tooth will contact every tooth on the ring gear. If the drive pinion has 10 teeth and the ring gear 40 teeth, the gear set will be **nonhunting**. With a ratio of 4:1, 1 pinion tooth contacts 4 different ring gear teeth on one revolution and then the same 4 teeth on the next revolution. It will always mate with the same 4 teeth. If the pinion gear has 10 teeth and the ring gear has 25 teeth, the ratio will be 2.5:1 and the gear set is classed as **partial nonhunting** (Figure 11-7a). In the first revolution a single pinion tooth will contact 2 ring gear teeth (or 3, depending on which one starts); during the second revolution, it will contact 3 (or 2) different ones; and the third revolution will be a repeat of the first. The 1 tooth of the pinion will always contact the same 5 teeth on the ring gear.

Nonhunting gearsets can produce a cyclic noise if one of the gear teeth become damaged. This noise repeats at every

TECH TIP

Nonhunting and partial nonhunting gear sets have index marks that are like timing marks (Figure 11-7b). These marks indicate the relationship of the two gears during the lapping stage of the manufacturing process. These marks must be aligned when a gear set is assembled.

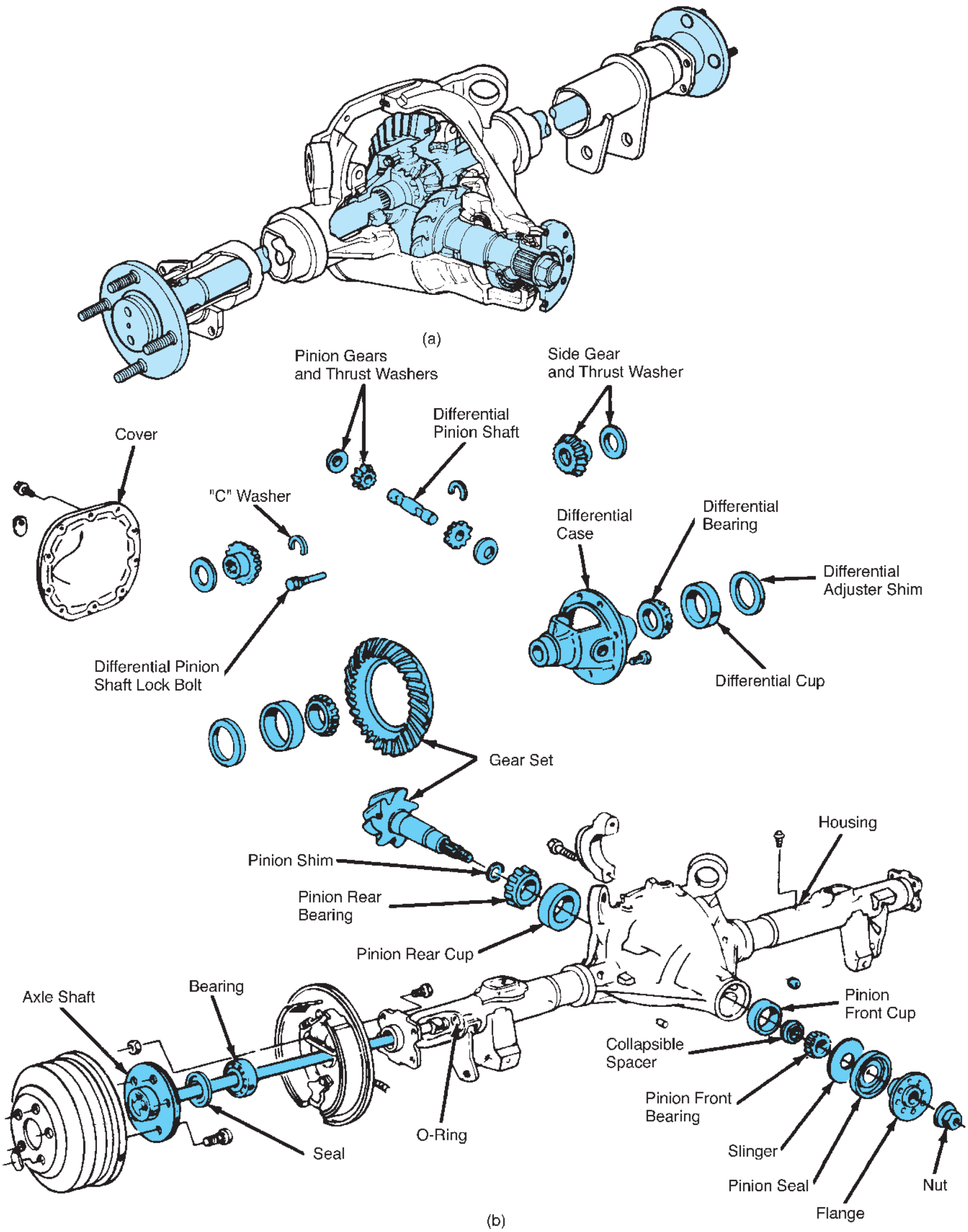


FIGURE 11-1 Cutaway (a) and exploded (b) views of a rear axle assembly. *(Courtesy of Ford Motor Company)*

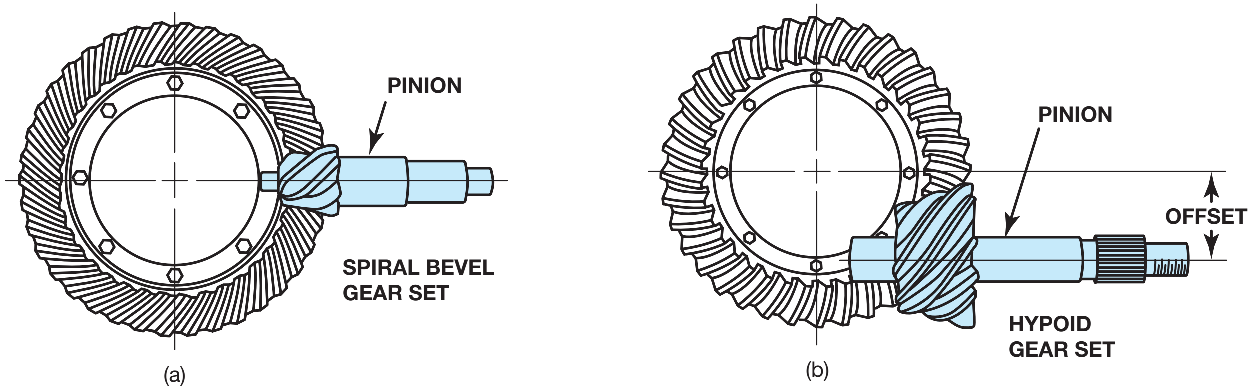


FIGURE 11-2 Spiral bevel (a) and hypoid (b) gear sets; hypoid gears are used in most drive axles. Offset is a design factor.

FIGURE 11-3 Two gear oil containers (left); the container should indicate that the oil is suitable for hypoid use or GL-4 (right). *(Courtesy of Sta-Lube, a division of CRC Industries)*

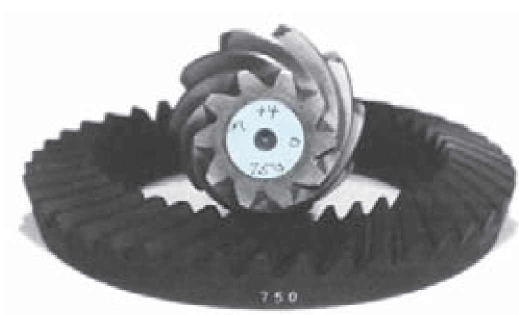


FIGURE 11-4 Hypoid ring and pinion gear set; the 750 etched on each gear indicates a matched gear set. This pinion gear will operate properly only with this ring gear. *(Courtesy of Dana Corporation)*

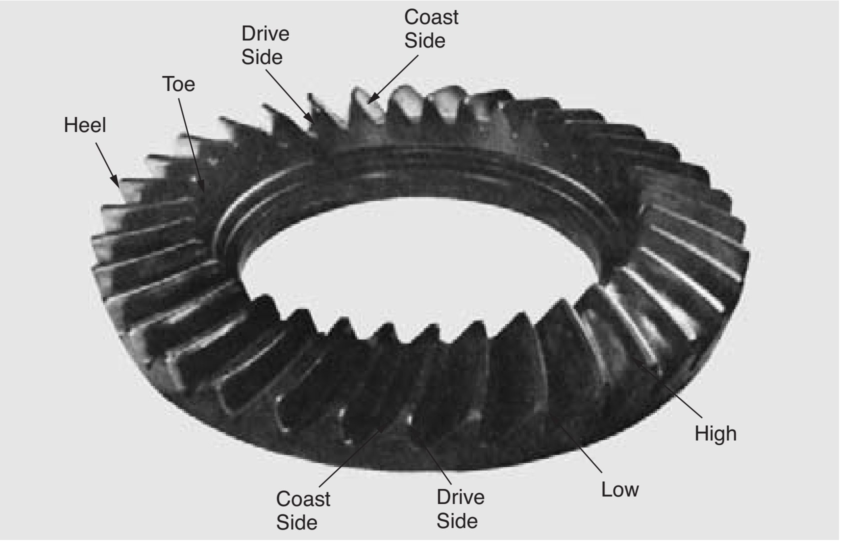


FIGURE 11-5 Ring gear showing the terms used to identify certain sections of the gear. *(Courtesy of Ford Motor Company)*

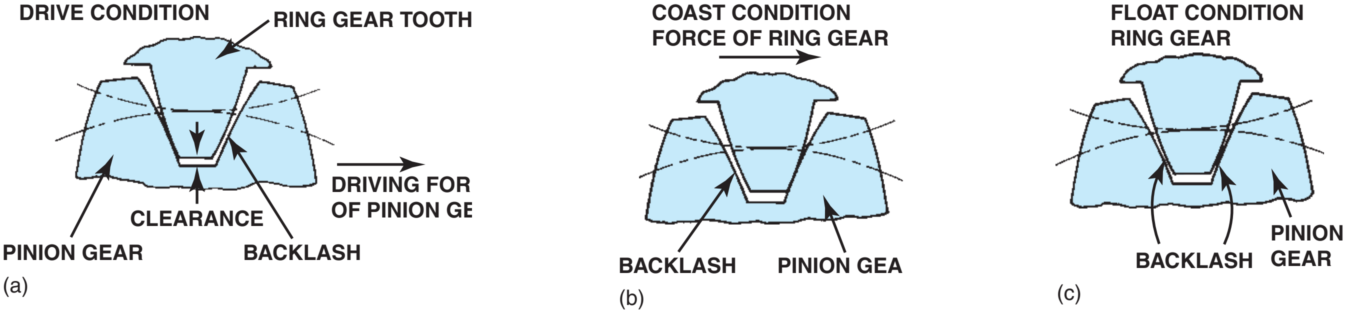


FIGURE 11-6 During a drive condition, the pinion gear is driving the ring gear, and there is backlash at the coast side of the ring gear tooth (a). During a coast condition, this action is reversed (b); and during a float condition, lash is split between both sides of the tooth (c).

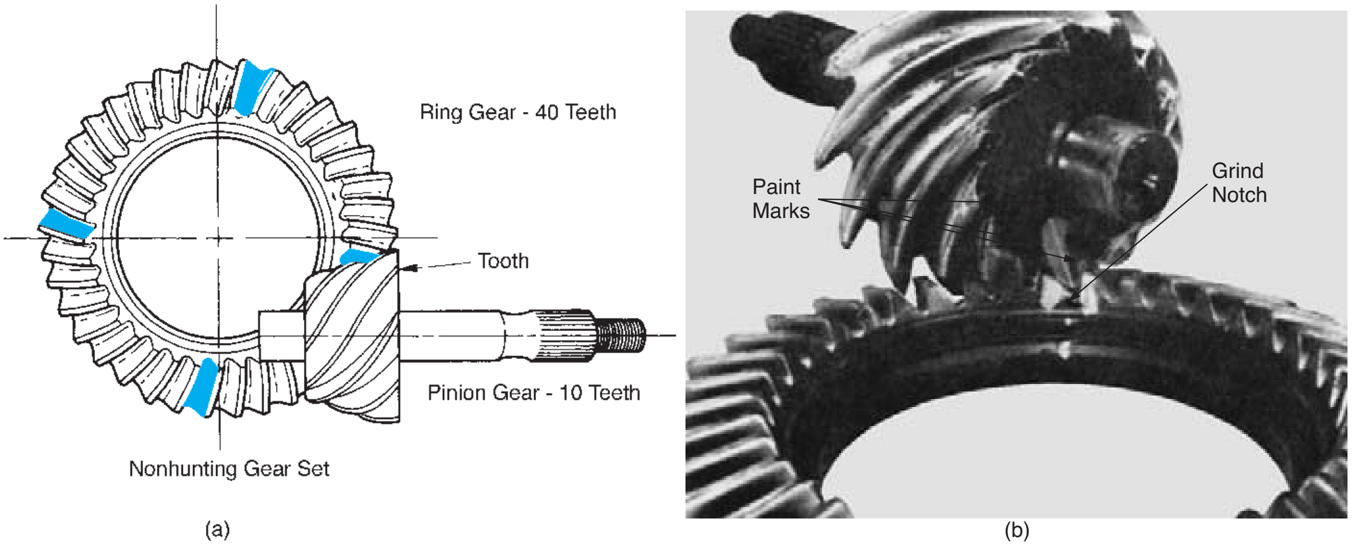


FIGURE 11-7 In this nonhunting gear set (4:1 ratio), one pinion gear tooth will contact the same four teeth on the ring every revolution (a). These gear sets have timing marks so that the gear teeth can be located correctly (b). *(b is courtesy of Ford Motor Company)*

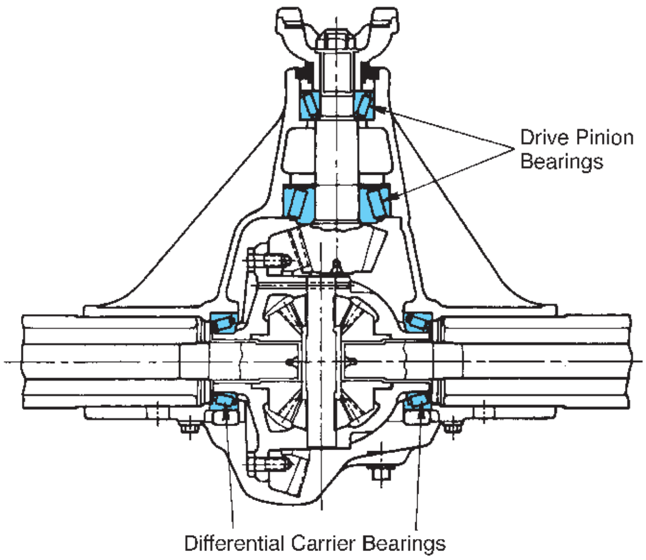


FIGURE 11-8 A pair of tapered roller bearings called carrier bearings are used to locate the drive pinion gear and the differential case and ring gear. Another pair of bearings locates the drive pinion gear. *(Courtesy of Dana Corporation)*

time the damaged teeth meet. The noise can be very objectionable. With a hunting gearset, there will be long intervals before the noise will repeat so it is usually not very noticeable. If possible, engineers design gearsets so the ratio will be slightly away from an even number; and example is 3.93:1 or 4.11:1 instead of 4:1.

Mounting

The ring and pinion gears must be mounted securely because of the large torque load involved. Gear separation forces try to move the gears away from each other. The ring gear is bolted or riveted to the differential case. Rivets provide a secure and permanent mounting, but they make it harder to remove the ring gear. The differential case is mounted on a pair of tapered roller bearings, which are commonly called **carrier bearings** or **side bearings** (Figure 11-8). The differential carrier is the heavy cast-iron portion of the rear axle assembly that provides mounting points for the drive pinion shaft bearings and the carrier bearings. Many carriers have special reinforcing webs to contain the gear separation forces of the ring and pinion gear set.

Most trucks, and early passenger vehicle drive axles had **removable carriers**, and the carrier (also called a *third member, drop-out,* or *pumpkin*) can be unbolted and removed from the housing for service (Figure 11-9). Most RWD passenger vehicles and light trucks use **integral carriers**, and the axle tubes are welded to extensions of the carrier (see Figure 11-1). An integral carrier is stronger in the areas around the carrier bearings. An integral carrier axle assembly, sometimes called a *Salisbury* or *Spicer axle*, has a removable rear cover for access to the differential and other internal parts.

The pinion shaft is also mounted on a pair of tapered roller bearings. There are two common styles of mounting the shaft and gear (Figure 11-10). In the first and most common style, called an **overhung pinion**, the pinion gear hangs over from the rear bearing. The two tapered roller bearings are positioned as far apart as practical to hold the pinion shaft rigid and not allow any movement of the pinion gear as it tries to climb or move away from the ring gear. In the second style, called **straddle mounting**, the pinion gear is straddled by two bearings: the rear tapered roller bearing in front of the gear and a pilot bearing behind the gear. The pilot bearing is usually a smaller roller bearing. Straddle mounting is the strongest, in that the pilot bearing prevents any flexing of the pinion shaft. It also eliminates any gear-to-bearing leverage effects and allows the two tapered roller bearings to be placed fairly close to each other.

The drive pinion gear bearings are located in the carrier. With an overhung pinion, they are mounted directly in the carrier. With a straddle-mounted pinion, they are mounted in a separate casting that is bolted to the front of the carrier.

Adjustments

A hypoid gear set must be aligned precisely if it is to operate correctly. Improper adjustments will produce a noisy gear set that might fail early. Four adjustments are normally made when an axle is serviced; two of them are for gear positioning and two for bearing preload (Figure 11-11). Each pair of bearings, carrier, and drive pinions must be adjusted to a light preload, which means slightly tighter than free running; the bearings have a load on them while at rest. *Drive pinion bearing preload* is normally adjusted by tightening the pinion nut to the point where it collapses or shortens a spacer between the bearings (Figure 11-12). Bearing preload becomes greater as this space becomes shorter. In some axles, fixed-length spacers and shims are used.

Depending on the axle, *carrier bearing preload* is adjusted by either threaded adjusters or shim packs alongside the bearings. Most integral carriers use shim packs (see Figure 11-1), while most removable carriers use threaded adjusters (see Figure 11-9). Turning the threaded adjuster inward or increasing the size of the shim packs increases carrier bearing preload.

Too little preload will allow the gears to move partly out of mesh during high-torque conditions, and this could cause noise or gear failure. Too much preload increases the drag and power loss and might lead to early bearing failure.

Drive pinion gear position, normally called **pinion depth**, is usually adjusted with selective shims (Figure 11-13). With an overhung pinion, the shims are normally positioned between the gear and the rear bearing; a thicker shim will

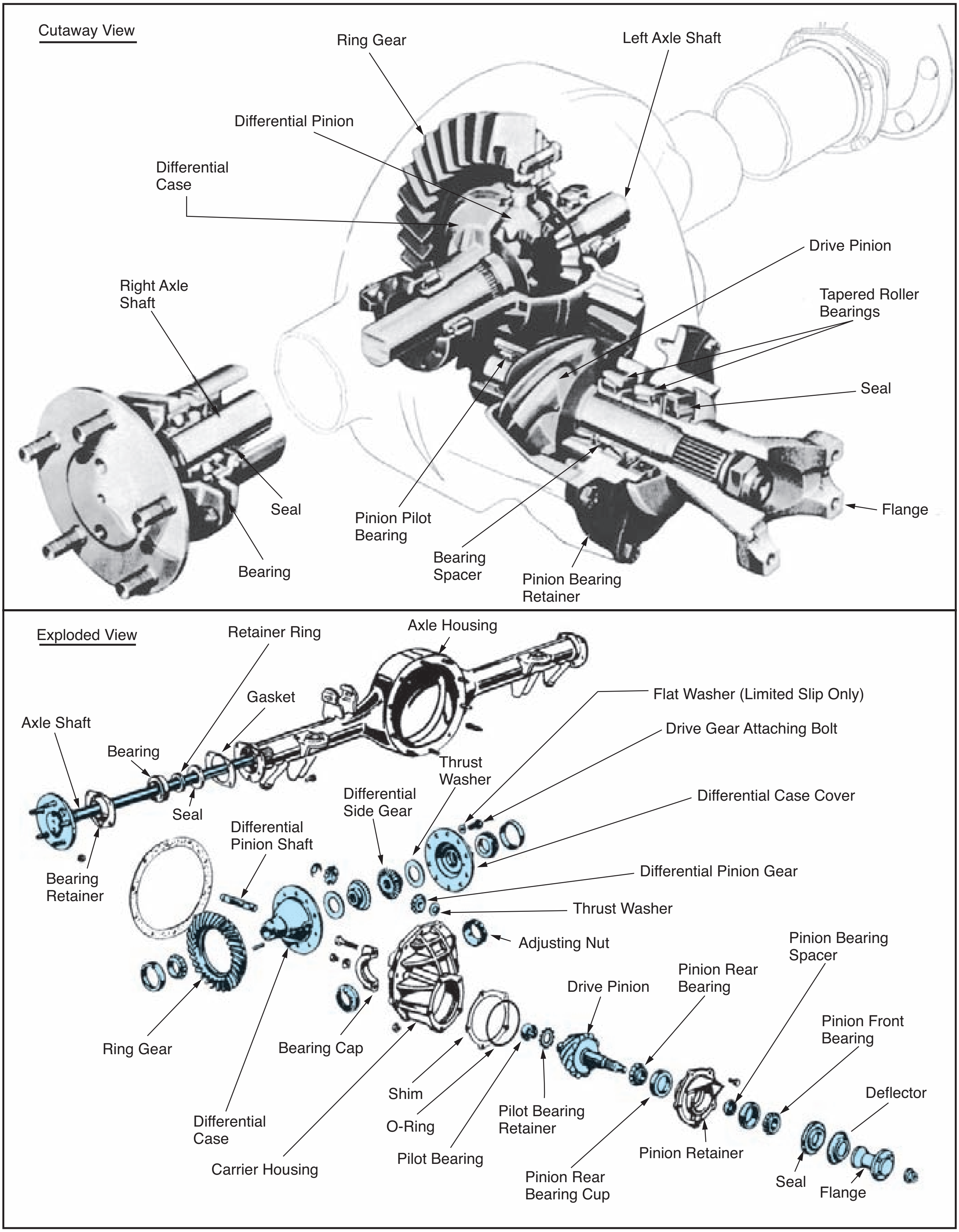


FIGURE 11-9 Cutaway and exploded views of a removable carrier axle. *(Courtesy of Ford Motor Company)*

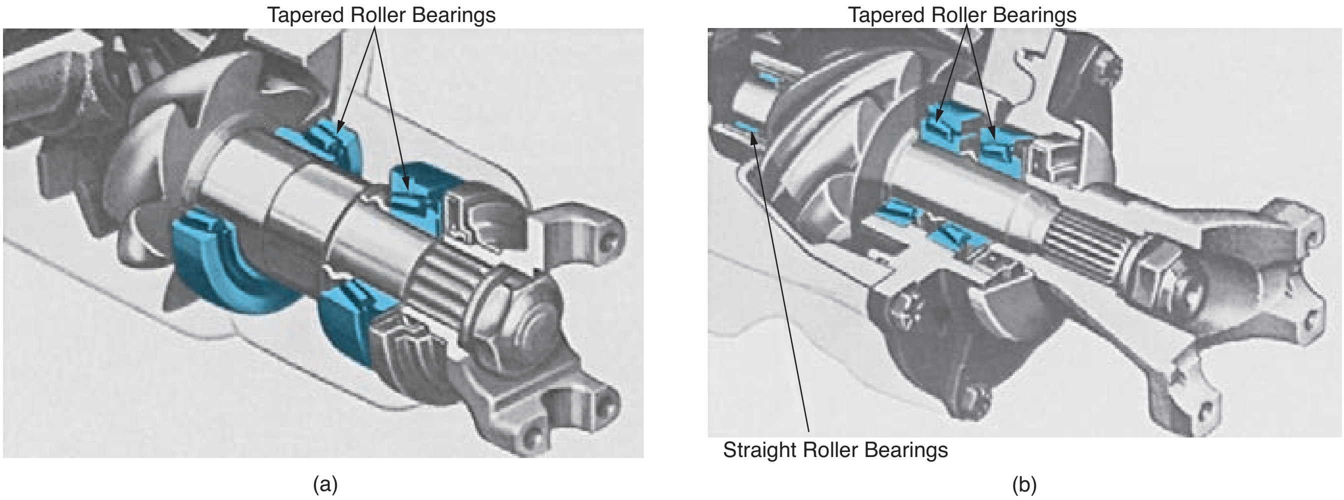


FIGURE 11-10 An overhung-mounted pinion gear uses a pair of tapered roller bearings and locates them several inches apart (a). A straddle-mounted pinion gear uses a straight roller bearing in addition to the pair of tapered roller bearings (b). *(Courtesy of Ford Motor Company)*

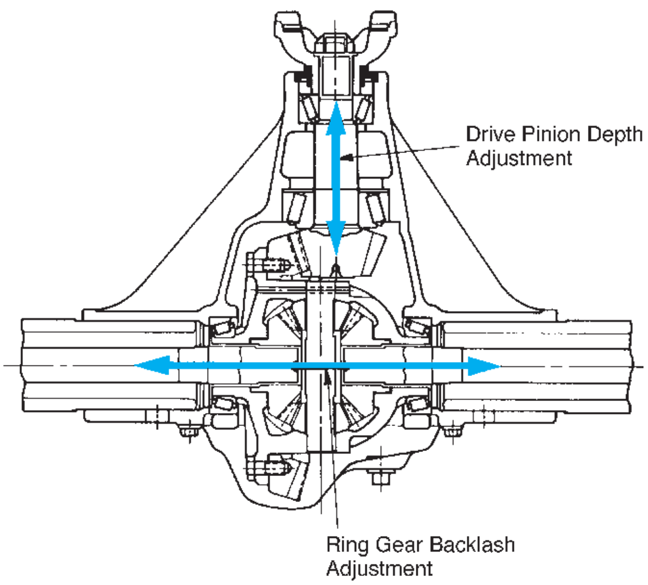


FIGURE 11-11 When a hypoid gear set is assembled, pinion depth and ring gear backlash, as well as bearing preload on each bearing set, must be adjusted.

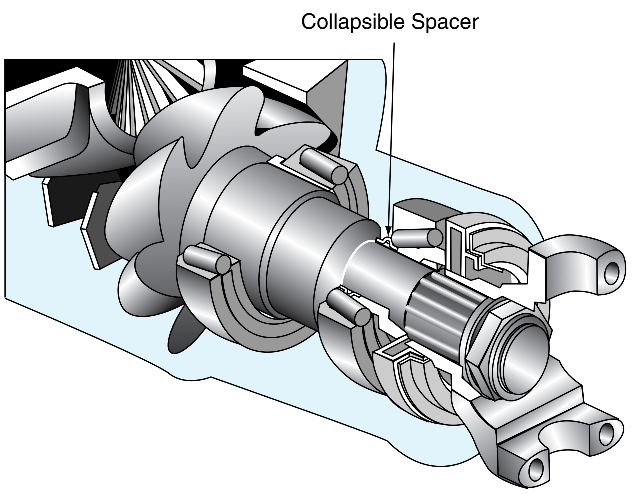


FIGURE 11-12 The collapsible spacer is compressed during the drive pinion bearing preload adjustment to get the correct amount of preload on the bearings. Some axles use solid spacers and shims for this adjustment. *(Courtesy of Ford Motor Company)*

move the gear deeper into mesh with the ring gear. Straddle-mounted pinions have the shim positioned between the bearing housing and the carrier; a thicker shim will move the pinion gear away from the ring gear for a shallower mesh.

Ring gear position is adjusted at the carrier bearings. Loosening the left- or ring-gear-side bearing while tightening the right-side bearing moves the ring gear away from the pinion gear and will increase lash (Figure 11-14). Doing the opposite will move the ring gear into the pinion gear and reduce lash. Lash and carrier bearing preload are usually adjusted at the same time.

The manufacturer determines proper gear position as the gears are operated in a machine. A load is placed on the gears, and the operator listens to the gear noise and watches the contact pattern. Pinion depth and lash are adjusted to produce the quietest operation. This position is then marked on the gears.

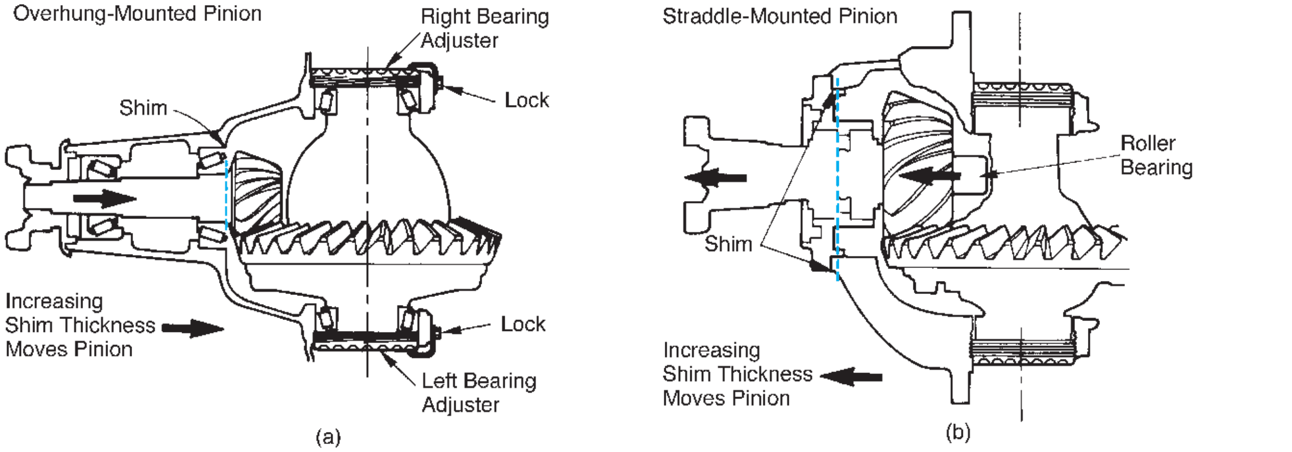


FIGURE 11-13 The shim used to adjust pinion depth is located between the pinion gear and rear bearing in most axles (a) and between the pinion retainer and carrier in some axles (b). *(Courtesy of Ford Motor Company)*

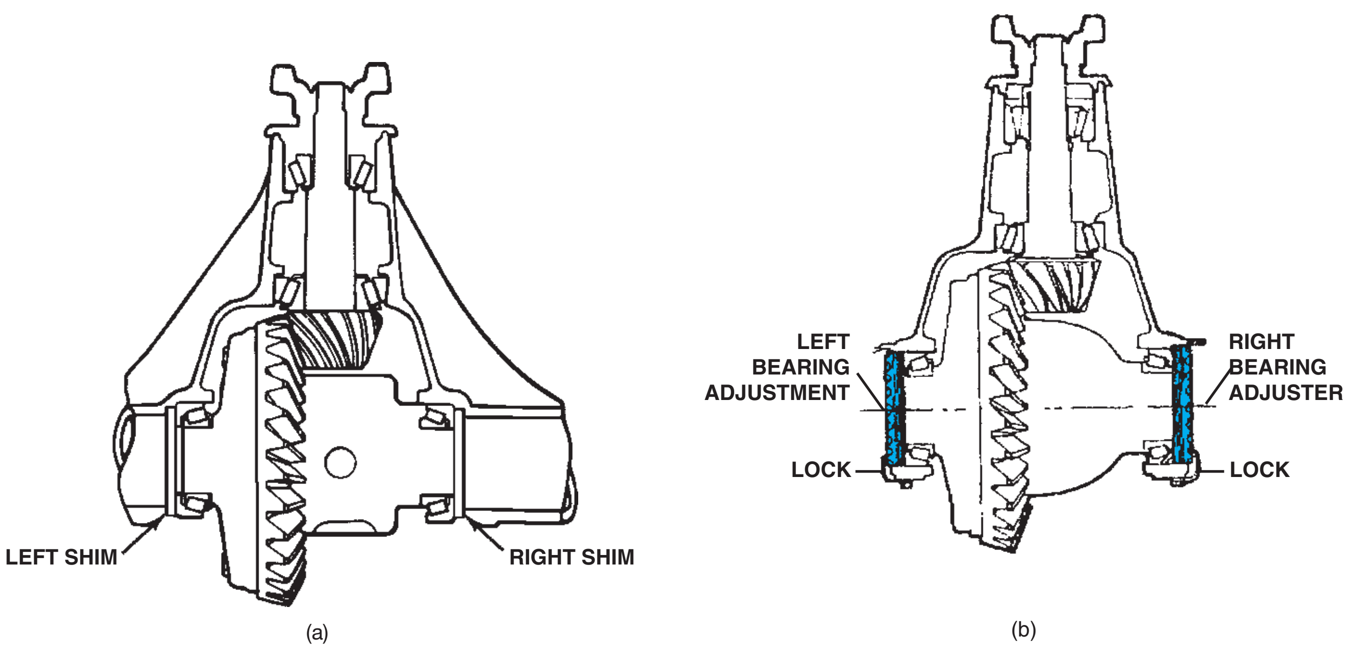


FIGURE 11-14 Reducing the size of the left shim and increasing the size of the right shim will move the ring gear away from the pinion and increase backlash (a). Turning the left adjuster outward and the right adjuster inward will do the same thing (b). *(Courtesy of Ford Motor Company)*

During a drive axle repair, a technician will usually coat the ring gear with a marking compound so that a **gear contact pattern** can be made and then examined. A good pattern indicates proper ring and pinion gear positioning, which should result in a quiet gear set that will operate for a long time (Figure 11-15). Other patterns indicate a need for further adjustment. Complete adjustment of a gear set is described in Chapter 12.

ABS

Most RWD vehicles with ABS mount the rear wheel speed sensor(s) to the rear axle assembly. Some vehicles will use a single-speed sensor mounted to the driveshaft flange, drive pinion shaft, or ring gear; others will use a pair of sensors near the end of the axle at each wheel hub (Figure 11-16). Since

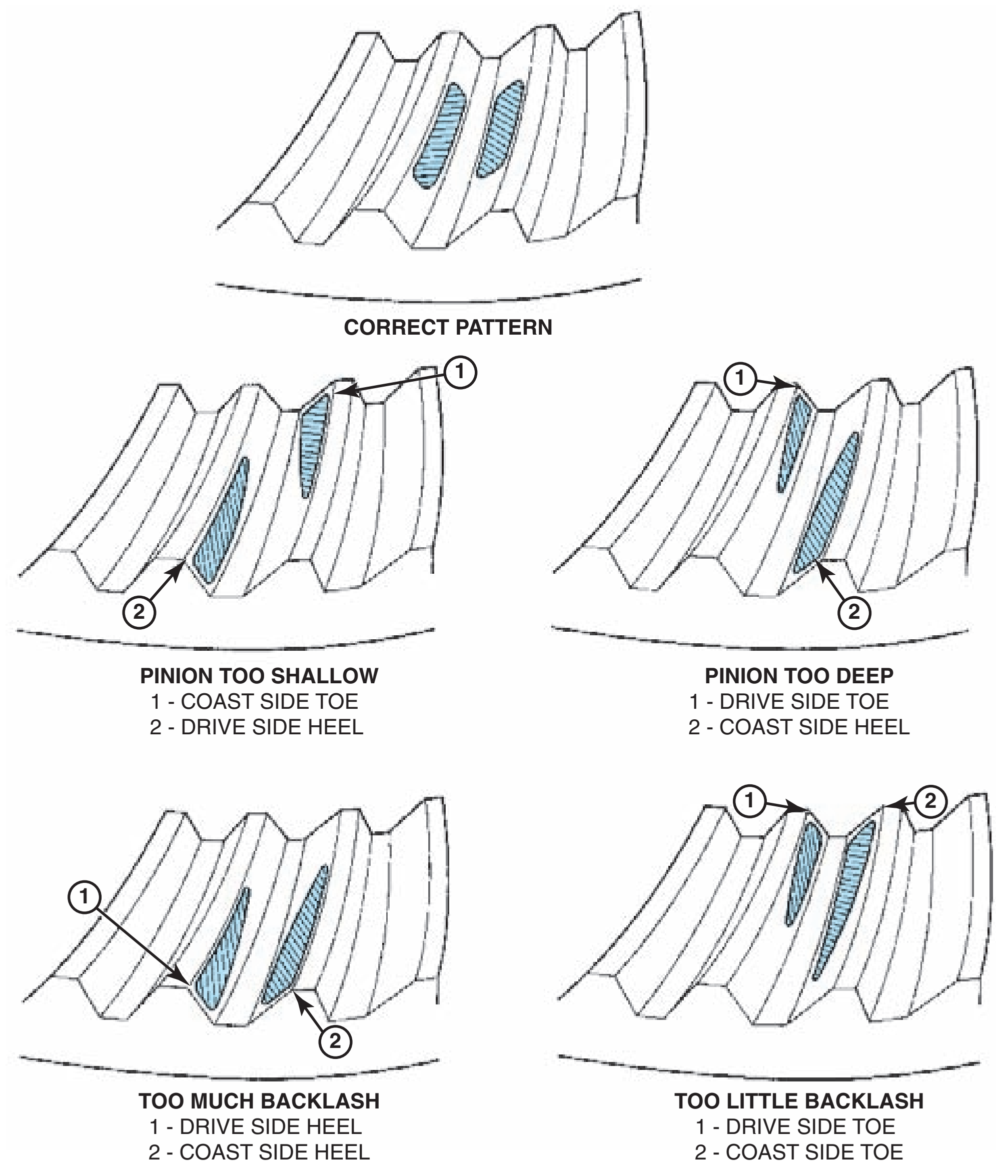


FIGURE 11-15 Good ring gear contact pattern (top) and patterns that require further adjustment. The location of the gear contact shows the technician what adjustment is needed. *(Courtesy of DaimlerChrysler Corporation)*

they include a magnetic core, sensors that are in the axle housing can be affected by metal particles worn from the gears or bearings. Sensors at the axle shafts can be affected by worn axle bearings.

DIFFERENTIAL

A drive axle assembly must include a **differential** to allow the drive wheels to rotate at different speeds on corners. The differential used in most drive axles includes two or more differential pinion gears mounted on a differential pinion shaft(s) and two side or axle gears that are splined to the axle shafts. It is the same as that described in Chapter 7, on page 159. When used with larger engines and heavier vehicles, some differentials use four pinion gears for increased strength (Figure 11-17).

Pickups and RWD vehicles encounter more single-wheel traction problems than FWD vehicles. They encounter more driving conditions in which the **open differential** action is not suitable. Remember that a differential splits torque equally to the drive wheels. The amount of torque that can be delivered

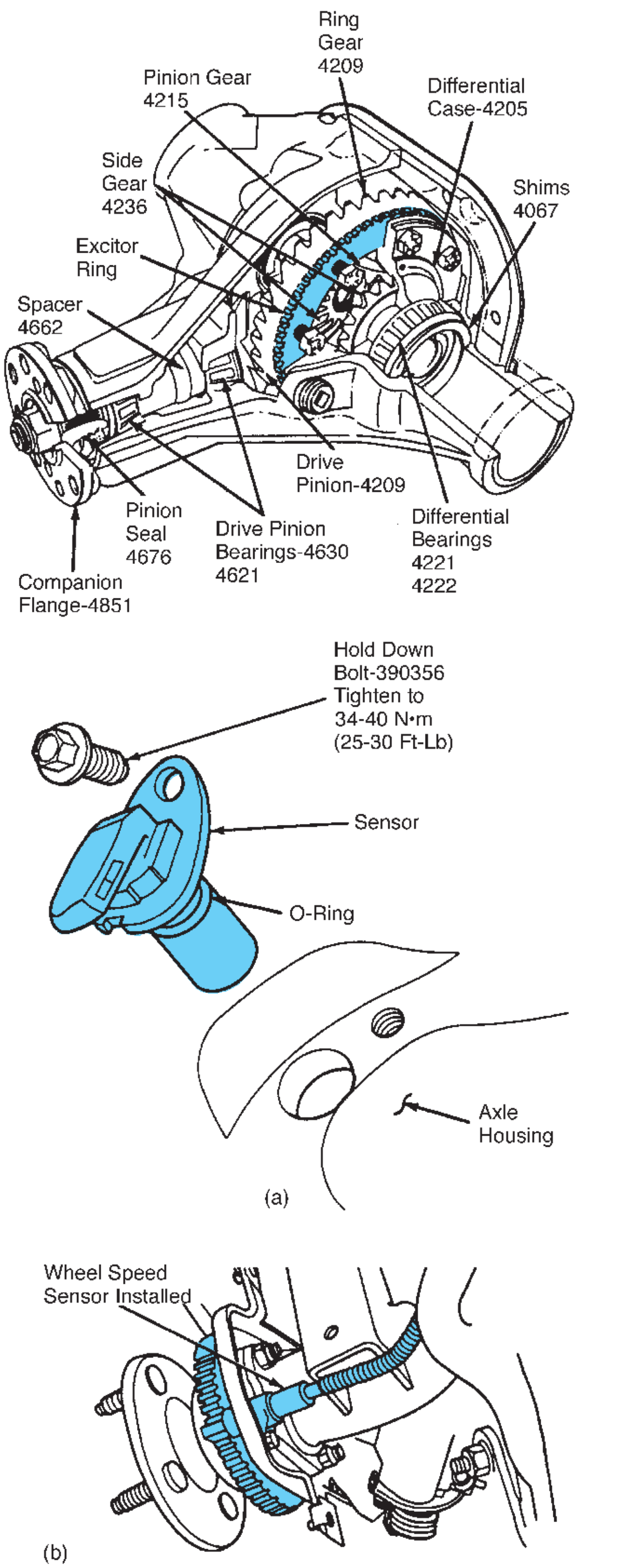


FIGURE 11-16 Vehicles with ABS will have a single rear-wheel speed sensor at the ring gear (a) or a speed sensor at each axle shaft (b). Some will use a sensor similar to (a) at the drive pinion shaft. *(Courtesy of Ford Motor Company)*

is a product of tire traction as well as engine torque times gear multiplication. One tire cannot receive more torque than either tire can transmit to the ground. A **limited slip differential (LSD)** is designed to deliver a minimum amount of torque to each drive wheel as well as to provide differential action on turns. A **locked differential** is one in which differential action cannot occur, and this is not suitable for driving around corners on pavement.

The three major differential types are:

- **Open**, which are used in most passenger cars.
- **Limited Slip**, traction-control differentials that can send more torque to the wheel with traction than the wheel with poor traction.
- **Locked**, connects both axle shafts together to eliminate differential action, rarely used in OEM applications.

Differential Torque Bias Ratio

An open differential has a **torque bias ratio (TBR)** of 1:1 (Figure 11-18). A 1:1 TBR indicates that each wheel receives the same amount of torque. But this means that the amount of torque that can be sent to the two wheels is twice that of the tire with the least traction. Any more torque than this will cause the tire with poor traction to spin, and the vehicle could be stuck. If the poor-traction tire spins at 50 ft-lb of torque, only 50 ft-lb of torque can be sent to the good-traction tire, which could transfer more torque.

Limited slip and Torsen® differentials can send as much as five times the torque to the tire with good traction; this would be a TBR of 5:1. If the differential has a TBR of 2.5:1 and 50 ft-lb of torque can be sent to the poor traction tire, then 50×2.5 or 125 ft-lb of torque can be sent to the good traction tire. A total of 175 ft-lb of torque can be sent to both tires. The limited slip differential designs that use preloaded clutches will tend to bind up on turns during normal driving because the clutches are forced to slip.

Limited Slip Differentials (LSD)

Limited slip differential is a generic name for a group of specific vehicle-line units. Many people use the term *Positraction* to refer to all limited slip differentials, but **Positraction** is the specific name of the limited slip differential used in Chevrolet vehicles. Other manufacturers have their specific names, such as Equa-lok or Traction-lok for a Ford and Sure-grip for a DaimlerChrysler.

LSDs are *torque biasing devices (TBD)* that have been traditionally used to improve traction for both off-road and on-road driving. These devices are also used with the modern all-wheel-drive (AWD) vehicle where on-road handling in both good and bad traction conditions is a major priority (Figure 11-19). Electronic wheel speed, steering, and yaw sensors determine what

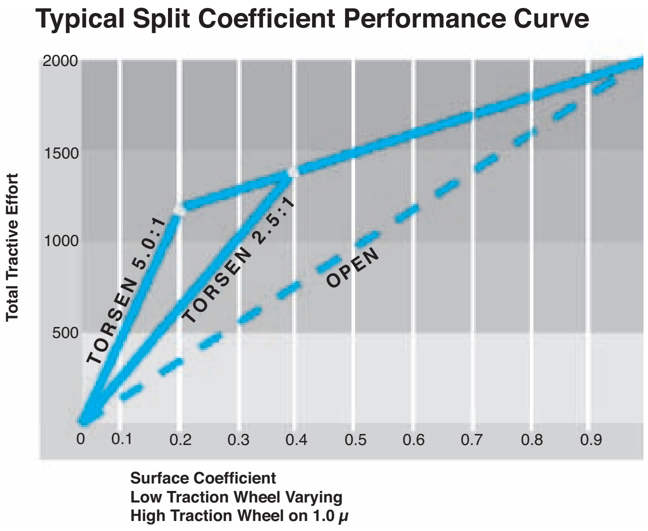
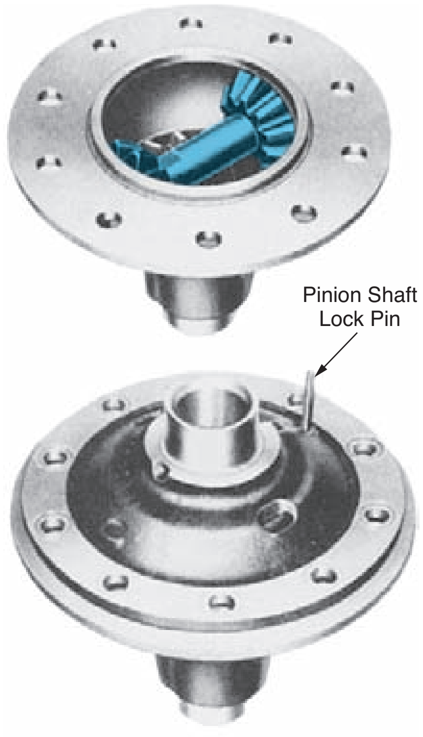


FIGURE 11-18 This curve shows the torque bias ratio, the increased amount of torque that can be sent to the tire with good traction. *(Courtesy of Zexel Torsen, Inc.)*



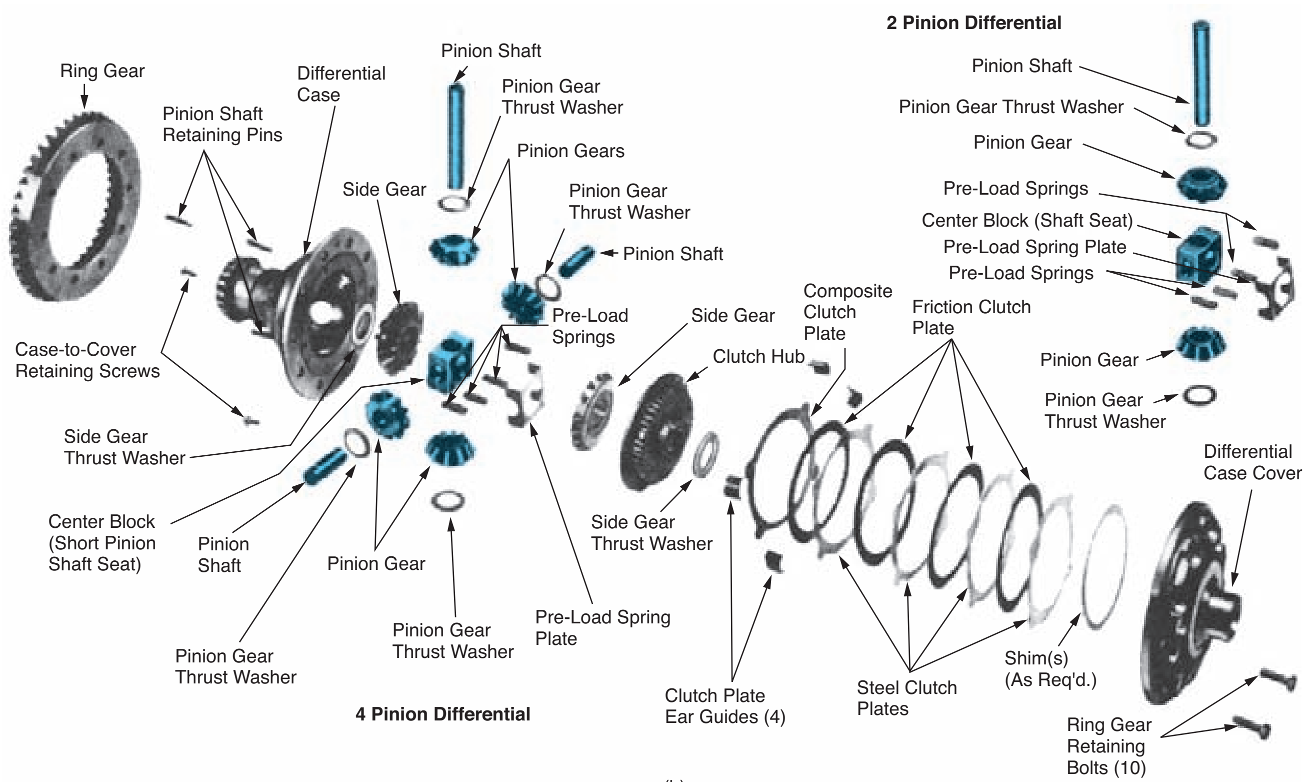


FIGURE 11-17 Most differentials use a single differential pinion shaft with two pinion gears (a). Some use four pinion gears for increased torque capacity (b); also note that this unit is a limited slip differential. *(Courtesy of Ford Motor Company)*

Differential Type	Traction	Handling	Actuation
Open	Ok	Ok	None
Passive Torque Sensing	Better	Better	Bevel gear separation forces and multiplate or cone clutches, parallel helical gear friction
Passive Speed Sensing	Better	Better	Viscous coupling, hydraulic pump actuated clutch, flyweight triggered multiplate clutch
Manually Selected Locking	Best	Ok	Manual cable, air, electronic, or hydraulic operated clutch
Active/Electro-Actuated	Best	Best	Electronically controlled electro-magnetic clutch, shift motor, or air
Permanently Locked	Best	Worst	None

FIGURE 11-19 A variety of differentials/torque biasing devices are used to improve vehicle traction and/or handling.

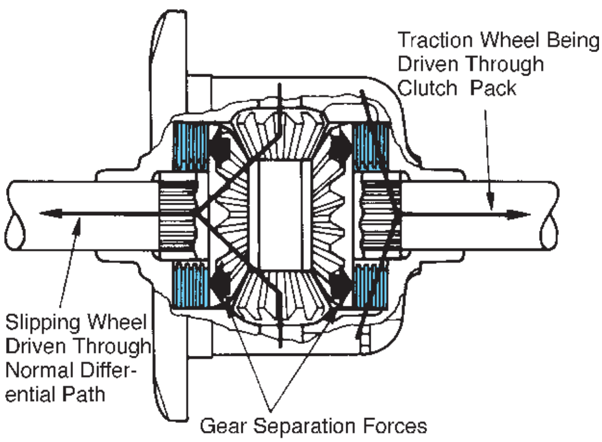


FIGURE 11-20 A limited slip differential transfers most of the torque through the pinion shaft and gears like a conventional differential. Some torque is also transferred through the clutch pack going from the case through the clutch to the side gear (right).

the vehicle is doing relative to what the driver is requesting it to do, and the TBD is electronically actuated to send more torque to the tire most able to improve the situation.

Many modern vehicles use **electronic traction control (ETC)** to prevent single-wheel spin. ETC uses the wheel speed sensors, control module, and hydraulic modulator of the antilock brake system (ABS) to sense wheel spin and, if spin occurs, to apply the brake on that wheel. This will transfer torque to the other drive wheel.

There are seven different styles of limited slip differentials: preloaded clutches, self-applying clutches, viscous couplings, Eaton locker differential, hydraulic applied clutches, mechanical ratcheting mechanism, and worm gears. Of these, only the first six are commonly used in passenger cars and pickups, so they will be described here. The others are intended more for racing and off-road use and are described in Chapter 16. Each style has different operating principles.

Preloaded Clutch Differential. Differentials with a preloaded clutch(es) provide two different differential power paths (Figure 11-20). One path is through the differential gears as in other differentials, and the other path is directly through the clutch pack(s). Most of these units use two clutch packs, one on each side, but a few designs use a single clutch pack. The operation is essentially the same (Figure 11-21).

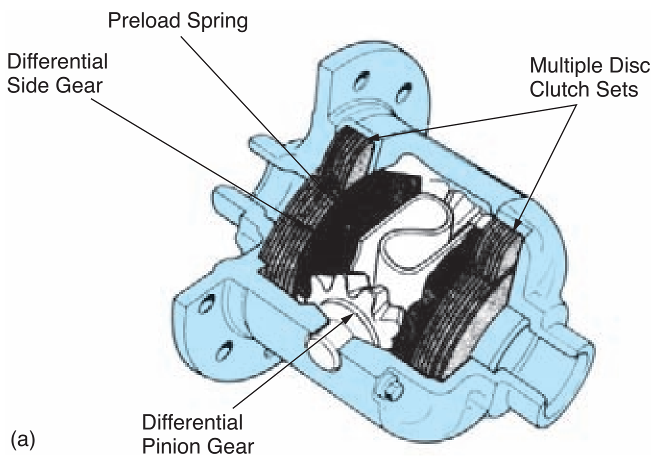
Flat, hardened-steel plates with various-shaped oiling grooves are used for the clutch plates. Half of them are splined to the axle gear and the other half are splined to the differential case. To provide the preload pressure to apply the clutch, spring pressure forces the axle gear against the clutch pack. The spring can be a single coil spring, a group of coil springs, an S-shaped spring, or one or more Belleville springs.

Lubrication of the plates is critical because the plates have to slip across each other every time the vehicle turns a corner or rounds a curve. A special friction modifier additive is required in the gear oil to make it slippery enough for these differentials (Figure 11-22). Most filler openings or plugs will be marked to indicate the proper fluid. A common problem encountered with these differentials is a stick/slip condition in which the plates stick together, break apart, stick together, and so on, instead of sliding smoothly over each other. This problem shows up as a series of clunks or chuckle sounds as a vehicle rounds a corner. It is very important to keep the drive tires the same diameter with these differentials. Having tires of different diameters will cause the clutch stacks to slip continuously, which, in turn, will cause early failure.

This style of differential has a tendency to lock up under high-torque conditions like hard acceleration because of the gear separation force between the differential pinions and the **side gears**. Applied torque will try to move the side gears away from the differential pinion gears. The separation force, also called torque loading, will increase the applied pressure at the clutch packs. Some limited slip differentials use a pair of cone clutches in place of the clutch plates (Figure 11-23). A cone is splined to each axle shaft, and the differential case is machined to form the mating cone surface.

Eaton Locker Differential. The Eaton "locker" differential used in some pickups and light trucks includes a governor, latching mechanism, and differential cam gear (Figure 11-24). Normally, this unit will operate as a limited slip differential, but if a wheel-to-wheel speed difference of 100 rpm or more occurs, the unit will lock up. Lockup occurs because the spinning cam in the case turns the governor weights fast enough to fly outward; this, in turn, causes the latching operation, which, in turn, causes the cam gear to rotate relative to the cam side gear, which, in turn, locks up the clutch pack.

Self-applying Clutch Differential. Some limited slip differentials use self-applying clutches. They do not maintain a constant preload on the clutch packs, so differential action



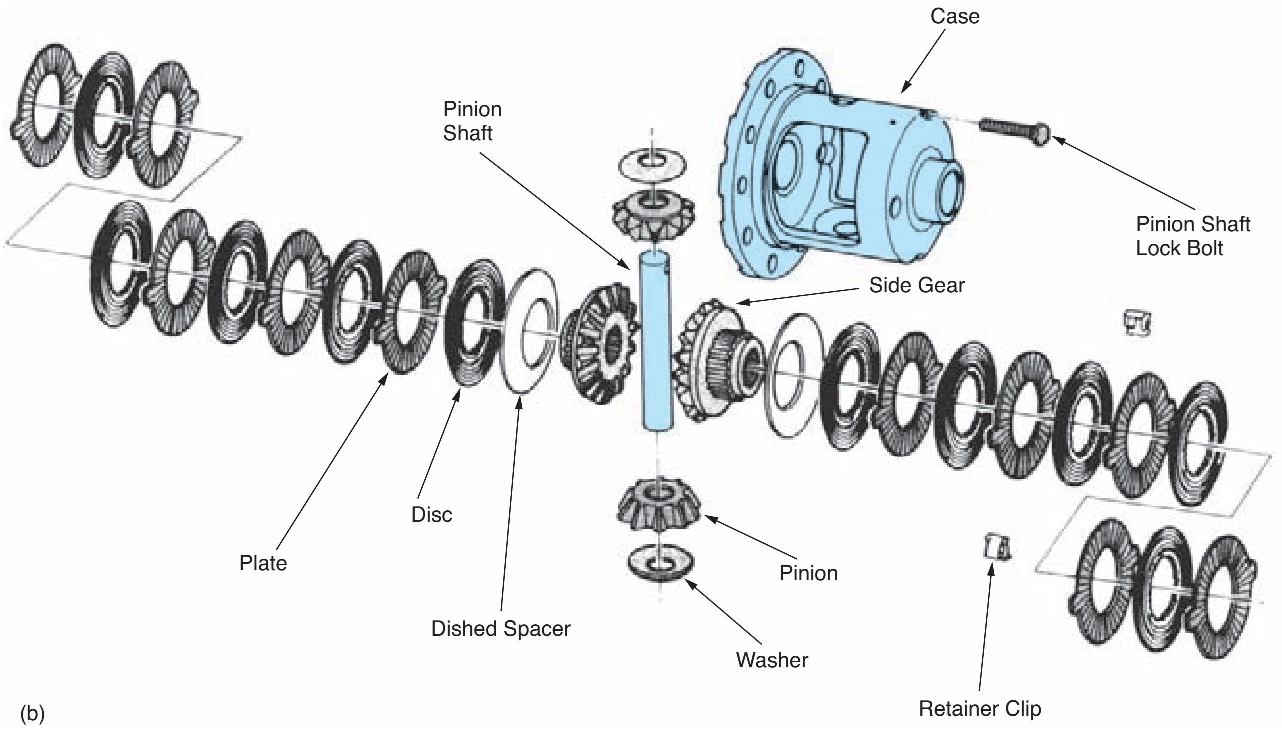


FIGURE 11-21 Cutaway (a) and exploded (b) views of a limited slip differential using clutch plates. *(Courtesy of Ford Motor Company)*

during normal driving is free of clutch drag. These differentials used a four-pinion differential with two separate differential pinion shafts. The two shafts called mate shafts, are fitted into the case in an opposing manner, with ramplike attachments to the case (Figure 11-25). While going down the road, the two shafts stay centered by pushing toward each other with equal force because of the equal driving loads and differential gear separation forces. If one wheel loses traction, the driving load on one of the pinion shafts drops off. The load on the other pinion shaft causes it to lag behind the differential case and move sideways because of the case ramps. This pressure from the differential pinion gears through the axle gear applies the clutch on the side with good traction. The result is that this differential applies the clutch needed to drive the other wheel from the one with poor traction.

Viscous Coupling Differential. Viscous coupling differentials use a stack of intermeshed clutch plates that run in a bath of silicone fluid and are not spring loaded (Figure 11-26). The thickness of the fluid causes a drag that tries to keep the two sets of plates at the same speed. A unique feature of silicone fluid is that the drag increases as the slip speed of the

FIGURE 11-22 Limited slip additive and fluid must be used in axles with LSD. *(Courtesy of James Halderman)*

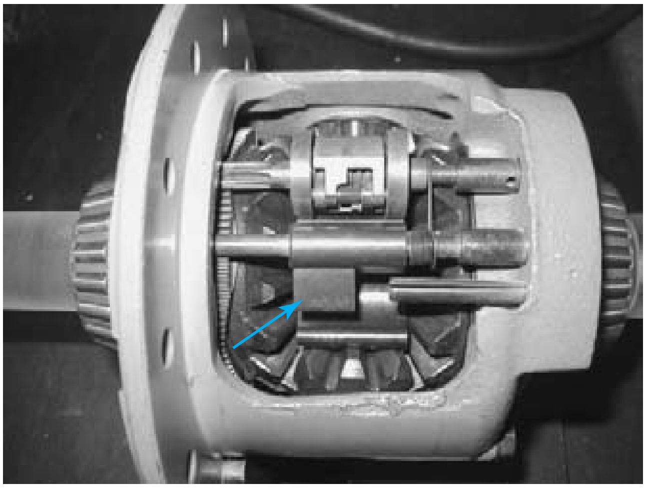


FIGURE 11-24 This locker-type differential operates as a limited slip differential until there is a wheel-to-wheel speed difference of 100 rpm or more. At that point, the governor weights (arrow) move outward and cause the mechanism to lock the clutch pack. *(Courtesy of James Halderman)*

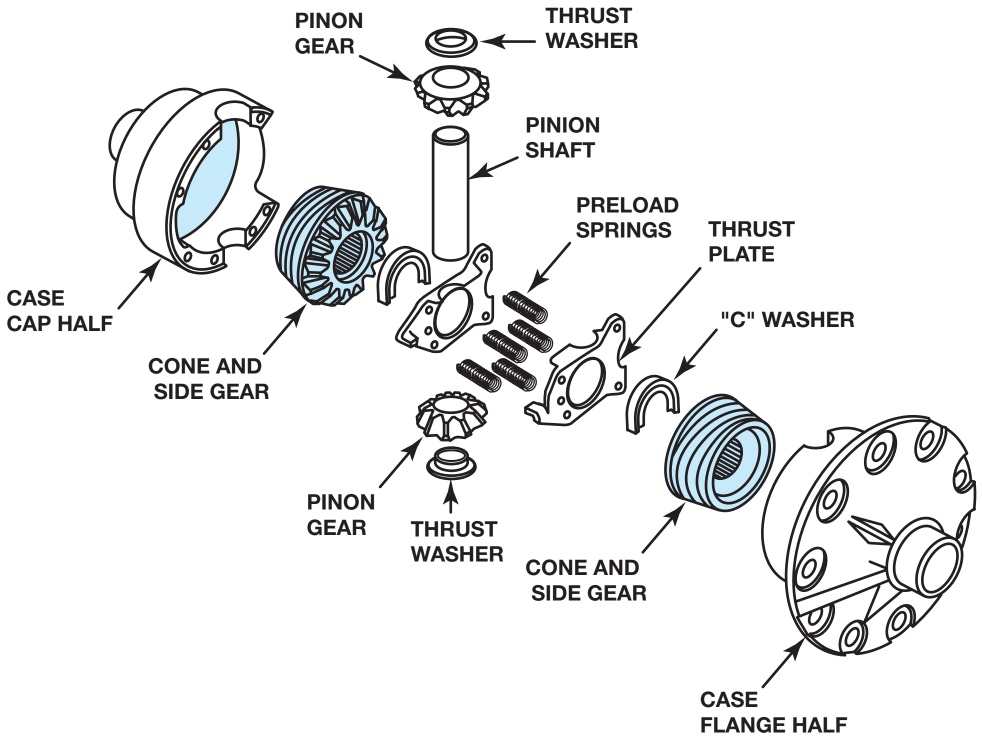


FIGURE 11-23 Exploded view of a limited slip differential using cone-type clutches.

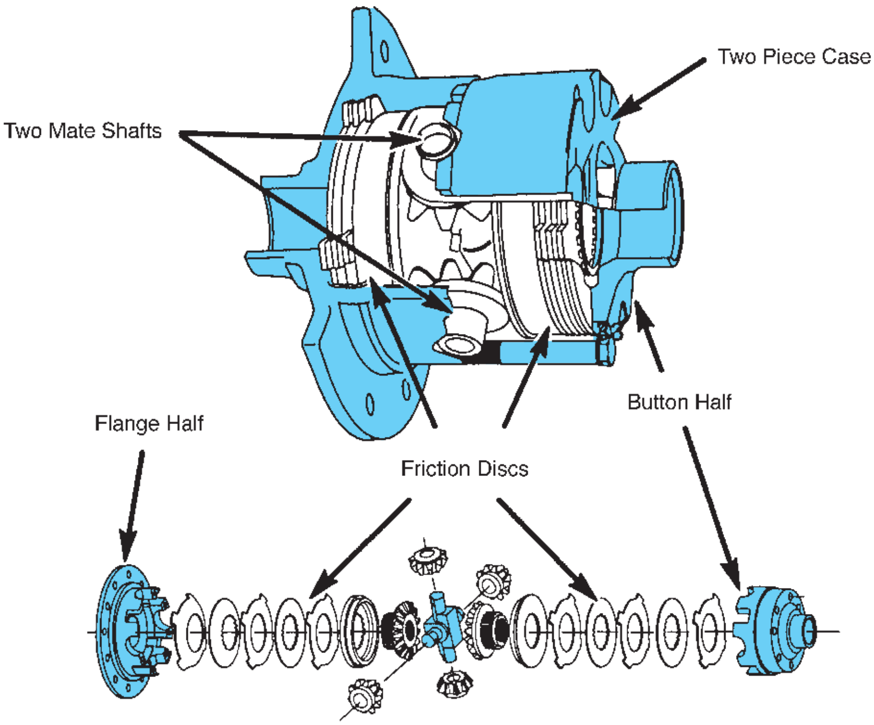


FIGURE 11-25 This limited slip differential uses the action of the pinion mate shafts and ramps in the differential case to apply pressure on the clutch pack and send torque to the wheel with traction. *(Courtesy of DaimlerChrysler Corporation)*

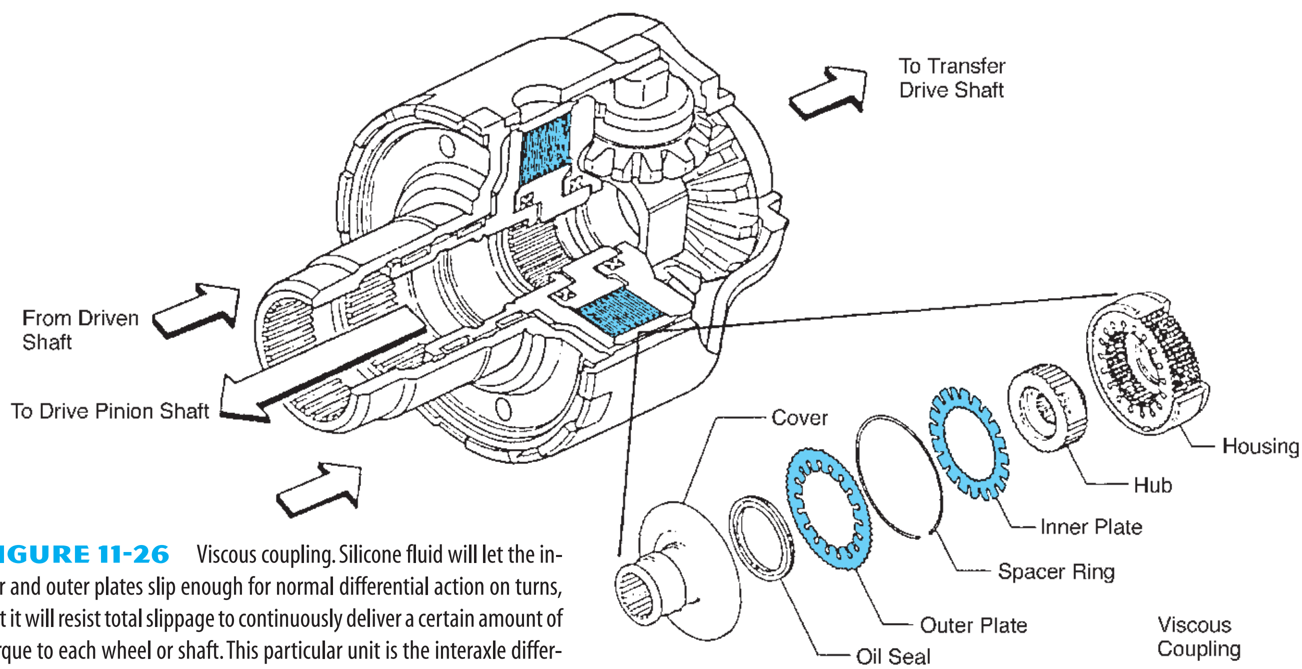


FIGURE 11-26 Viscous coupling. Silicone fluid will let the inner and outer plates slip enough for normal differential action on turns, but it will resist total slippage to continuously deliver a certain amount of torque to each wheel or shaft. This particular unit is the interaxle differential for an AWD vehicle. *(Courtesy of Subaru of America, Inc.)*

plates increases. Single-wheel spinning tends to lock up the differential. The plates and silicone fluid must be isolated within a chamber inside the differential case and must be kept separate from the gear oil in the axle.

Hydraulic Applied Clutch Differential. Normally, a limited slip differential cannot be used on the front axle. If both front wheels turn at the same speed, the vehicle cannot turn; it will travel straight ahead. A recent development is the **Hydra-Lok** differential from Dana-Spicer (Figure 11-27). Jeep uses the name **Vari-Lock** for this differential. This differential uses a set of clutch plates between one axle gear and the differential case, and these clutch plates have a clearance for free running. There is also a gerotor oil pump built into the differential case. The fluid pressure developed is dependent on the speed difference between the axle gear and the case. The fluid pressure applies the clutch plates so torque will be transferred to both drive axles. The Hydra-Lok differential can be tuned to operate in both a front and rear drive axle.

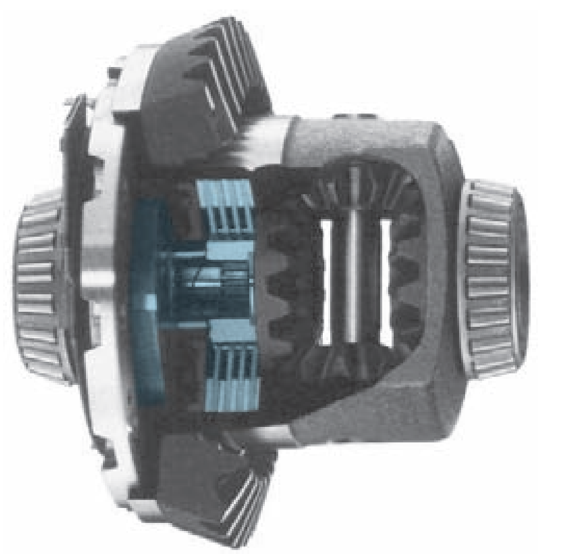


FIGURE 11-27 A Vari-Lock (Hydra-Lok) differential includes a gerotor oil pump that is driven when the axles operate at different speeds. If there is too much speed differential, the fluid pressure can apply the internal clutch to reduce wheel spin. *(Courtesy of DaimlerChrysler Corporation)*

Torsen® Differential. The **Torsen®** differential is a pure mechanical worm gear differential (Figure 11-28). The name is derived from "torque sensing." Two helical gears, called "side gears," are connected to the axle shafts. Three pairs of worm gears are mounted in the differential case, and these are called "element gears." Each element gear has the worm gear in the center and a spur gear at each end. The spur gears mesh with the spur gears of the mating element gear. If one of the element gears rotates in the case, its mate must rotate in the opposite direction. Note that all three pairs of element gears must rotate at the same time. Gleason, the company that developed Torsen® differentials, calls the element and side gears *Invex gearing.*

Electric Locking Differentials. A locking differential eliminates any differential action by coupling two of the differential parts together. When the axle shaft or side gear is connected to the differential case, the differential becomes locked (Figure 11-29).

Electric locking differnentials use an electric motor or magnetic clutch assembly to move the locking mechanism. Current flow to the motor can be electronically controlled, or by a simple switch as in some aftermarket systems.

Locking differentials are used in both rear and front axles. If used in the front, they must be released when steering maneuvers are necessary.

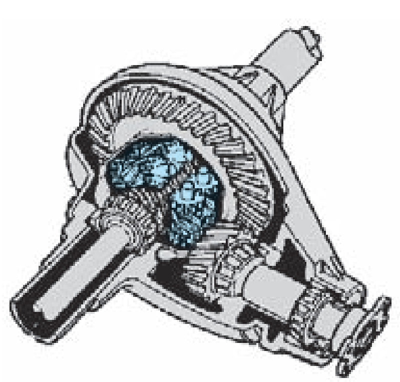


FIGURE 11-28 A cutaway view of an axle with a Torsen® differential (left), the Torsen® Invex gear train (center), and an exploded view of a Torsen® differential. *(Courtesy of Zexel Torsen, Inc.)*

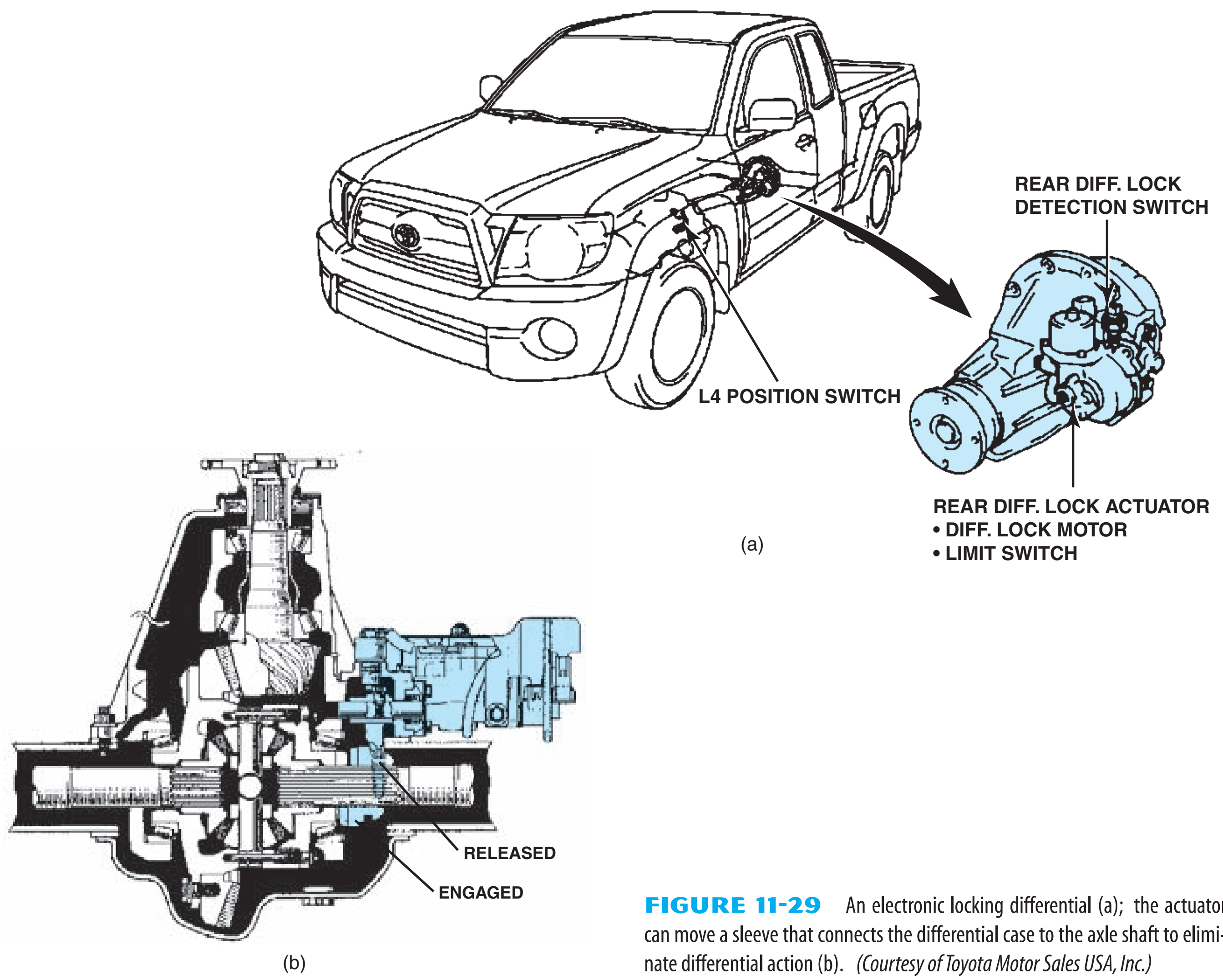


FIGURE 11-29 An electronic locking differential (a); the actuator can move a sleeve that connects the differential case to the axle shaft to eliminate differential action (b). *(Courtesy of Toyota Motor Sales USA, Inc.)*

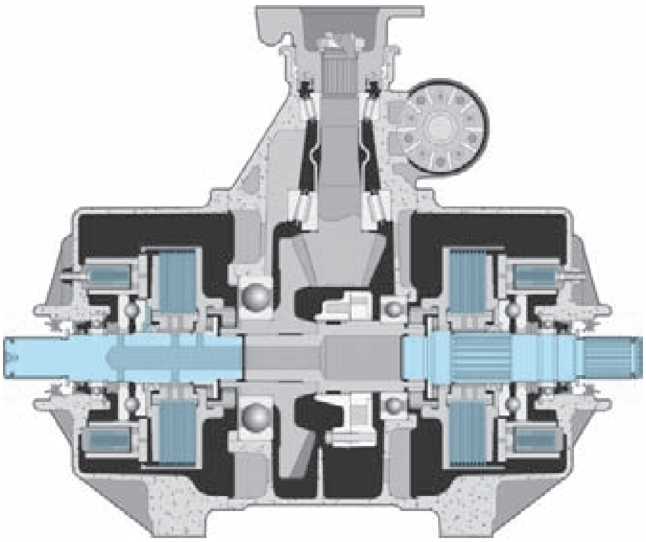
Electronic Torque Management. Some vehicles are using a variable torque rear drive axle. These are basically FWD vehicles that have a rear drive axle with no differential; the ring gear is mounted on a spool to drive two clutches (Figure 11-30). The pair of electronically controlled wet clutch packs are used to send power to the rear axle shafts. The clutches can be engaged at times of poor traction for AWD or they can be engaged to provide high-speed vehicle stability. The latter is called automatic yaw control (AYC) and it drives one or both rear wheels as needed to keep the vehicle under control. Clutch control comes from an electronic control module (ECM), which receives signals from front and rear wheel speed sensors and engine speed and load sensors.

The Honda Super Handling All Wheel Drive system, SH-AWD, uses a similar rear drive axle that includes an eletronically controlled gear assembly to increase wheel speed. This feature is for automatic yaw control (AYC). When necessary, AYC drives one or both rear wheels as needed to keep the vehicle under control during cornering maneuvers.

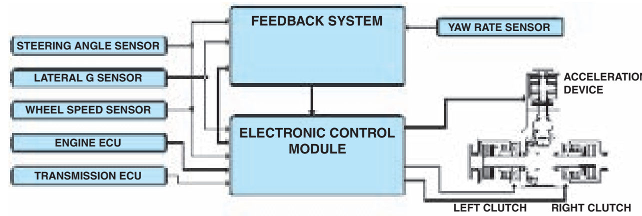
AXLE SHAFTS

The axle shafts transfer the torque from the differential side gears to the drive wheels, and support the weight of the vehicle on most passenger vehicles and pickups. Axles are forged steel to give them the necessary strength to transfer the torque. The inner ends are splined to match the splines of the differential side gears. Axle shafts can be classified into two categories: the way the axle is loaded and how the axle is retained in the housing.

All modern RWD passenger vehicles use **semi-floating axles**. The inner end floats because it is supported by a gear, not a bearing (Figure 11-31). The outer end uses a bearing in



(a)



(b)

FIGURE 11-30 A cutaway view of an InterActive Torque Management II™ (ITMII™) rear drive axle showing the left and right clutches (a). The clutches are electronically controlled (b); the control circuit for a SH-AWD system is shown. *(a is courtesy of BorgWarner Inc.)*

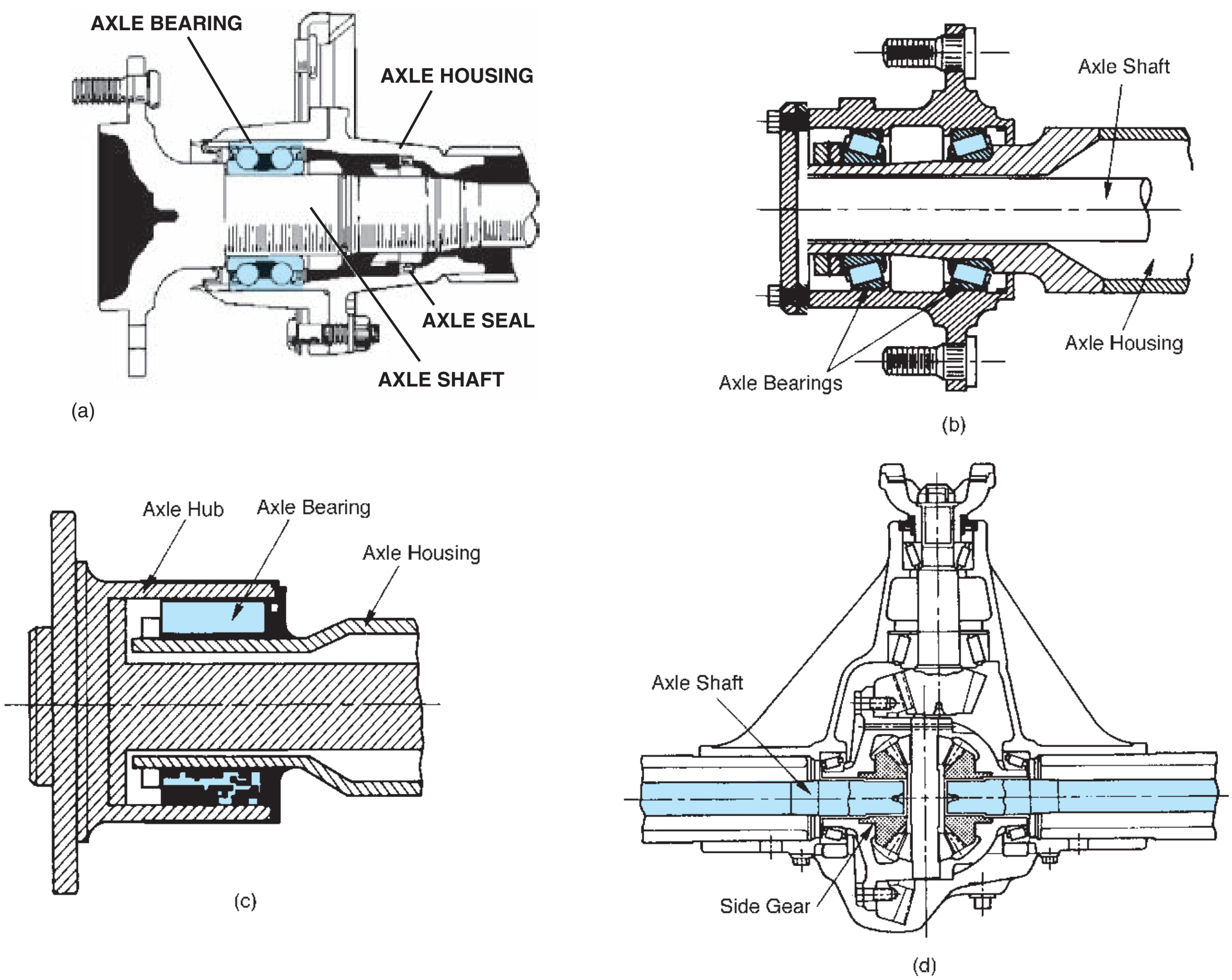


FIGURE 11-31 Modern passenger vehicles use semi-floating axles (a). Most trucks use full-floating axles (b). Some older vehicles use three-quarter-floating axles (c). In all cases, the inner end of the axle floats in the differential side gear (d). *(a is Courtesy of Toyota Motor Sales USA, Inc.)*

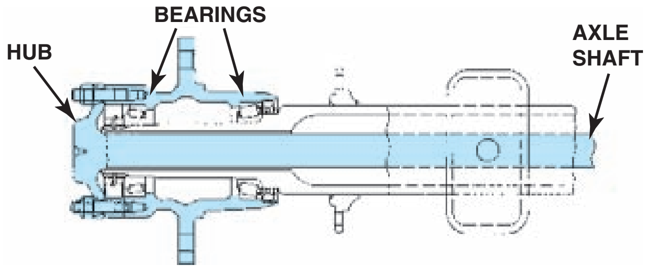


FIGURE 11-32 Cutaway view of a full-floating axle and hub. Note the bearings supporting the hub and the axle attachment. *(Courtesy of DaimlerChrysler Corporation)*

the end of the housing. This bearing transfers the load of the vehicle to the axle, which, in turn, transfers it to the wheel. If the axle were to break outboard of the bearing, the wheel would fall off and the vehicle would drop.

All heavy trucks use a **full-floating axle** design. The wheel hub uses a pair of large tapered roller bearings that transfer all of the vehicle loads except torque from the axle housing to the wheel (Figure 11-32). The axle shaft slides into mesh with the axle gear and is bolted to the hub. The axle shaft can be removed, and the vehicle will still roll down the road.

A few older vehicles used three-quarter-floating axles. This design uses a single roller or ball bearing between the hub and axle housing. Vertical loads pass from the hub through this bearing to the housing, but cornering loads, which try to pull the axle out of the housing, act on the axle. If the axle breaks, it can slide out of the housing.

Axle Retention

Semi-floating axle shafts in passenger vehicles are either **bearing retained** at the outer end of the housing or **C-lock retained** at the inner end. In a bearing-retained axle, the inner race of the axle bearing and a retaining ring are pressed onto the axle. The retaining ring ensures that the axle cannot slide out of the bearing (Figure 11-33). The bearing is held in place in the housing by a retainer plate that is bolted to the end of the axle housing. The brake backing plate is usually secured with the same bolts.

With a C-lock-retained axle, the axle shaft has a hardened surface to serve as the inner race for the bearing; the outer race with a group of rollers is pressed into the end of the housing (Figure 11-34). The inner end of the axle has a groove for the C-lock and a hardened end where it contacts the differential pinion shaft. The axle gear has a recess that the C-lock fits into. The differential pinion shaft must be removed to allow the axle to be slid inward so that the C-lock can be removed or replaced in its groove. Sliding the axle outward positions the C-lock into the recess of the axle gear, and sliding the differential pinion shaft into place locks the assembly together. The C-lock limits

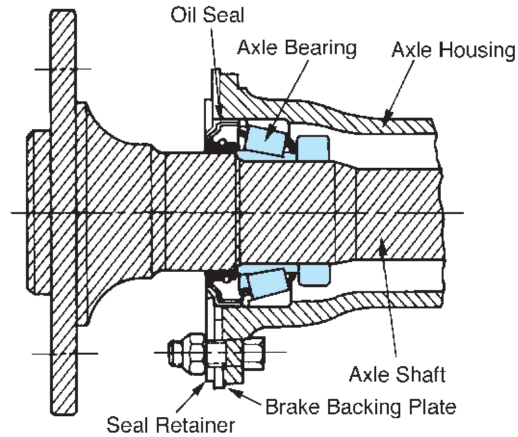


FIGURE 11-33 This bearing-retained axle is held in the axle housing by the seal retainer.

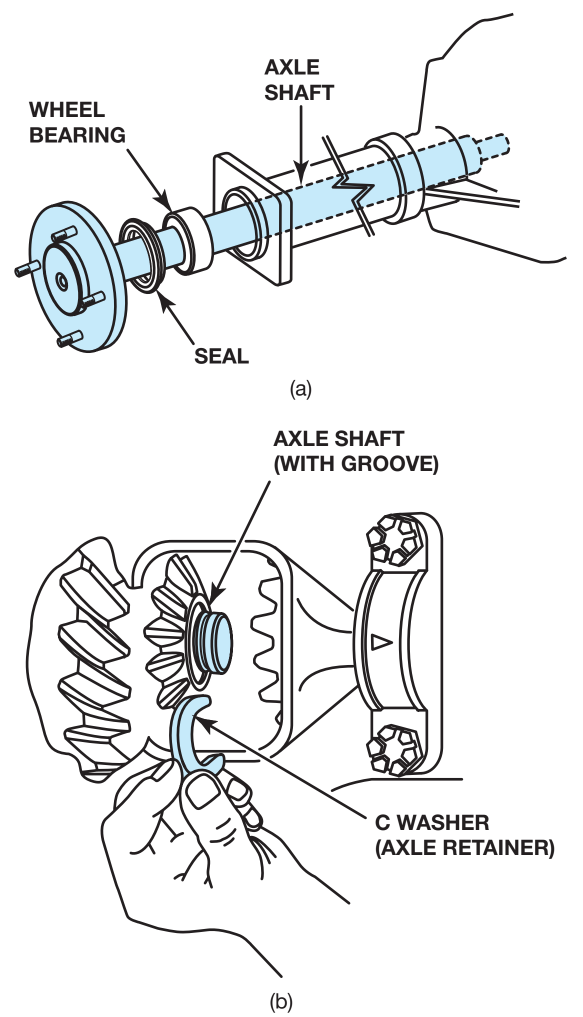


FIGURE 11-34 The outer end of the axle is supported by a straight roller bearing (a), and a C-washer/lock holds the inner end in the side gear (b).

the outward movement of the axle, and the differential pinion shaft limits the inward movement. This axle style will have a slight end play; a bearing-retained axle should have no end play. If a C-lock axle breaks anywhere from the C-lock groove outward, the axle can slide out of the rear axle housing.

LUBRICATION

A drive axle is normally filled with gear oil to a point just below the filler opening (Figure 11-35). A few axles, however, are filled at a level lower than this. The action of the ring gear running in the bath of oil distributes the oil through the housing. Many carriers provide a trough to ensure adequate oiling of the front pinion shaft bearing. A vent is installed in the housing to relieve pressures generated as the gears and oil warm up.

The gear oil is kept in the housing by one or more grease seals in each end of the axle housing and at the drive pinion shaft (Figure 11-36). The pinion shaft seal normally seals against the surface of the driveshaft flange, and the axle seals against the machined surfaces of the axle. In some cases, the axle seal is part of the axle bearing.

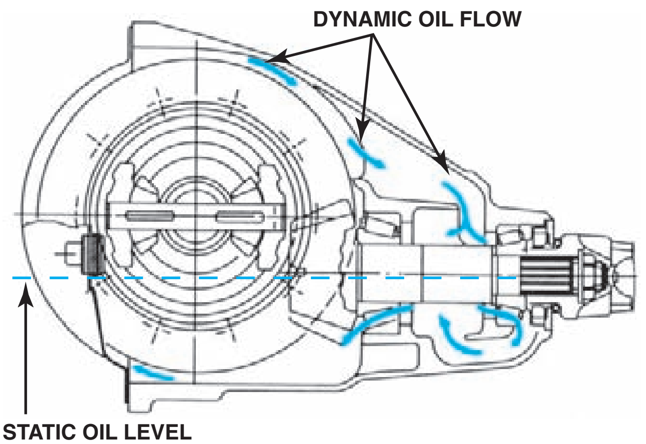


FIGURE 11-35 In most axles the gear oil level is at the bottom of the filter opening. When the axle operates, the ring gear will produce a dynamic oil flow to lubricate all the parts. *(Courtesy of DaimlerChrysler Corporation)*

Drive Axle Lubricants

The gear oils used in drive axles are very similar to those described in Chapter 6 on page 138; the major differences are the **extreme pressure (EP)** additives and friction modifiers. The gear oil used with hypoid gear sets must be GL-4 or GL-5; GL-5 has about twice as much EP additive as GL-4. This additive forms a wear-resistant coating on the metal surface of the teeth to prevent metal-to-metal contact as the pinion gear slides across the ring gear tooth. EP additives give the gear oil a sulfur-like smell.

The gear oil used in drive axles with limited slip differentials must have a friction modifier. The **friction modifier** increases the slipperiness of the lubricant to prevent the stick/slip problem. A friction modifier reduces the load-carrying ability of the lubricant; normally, no more of this additive is used than is necessary.

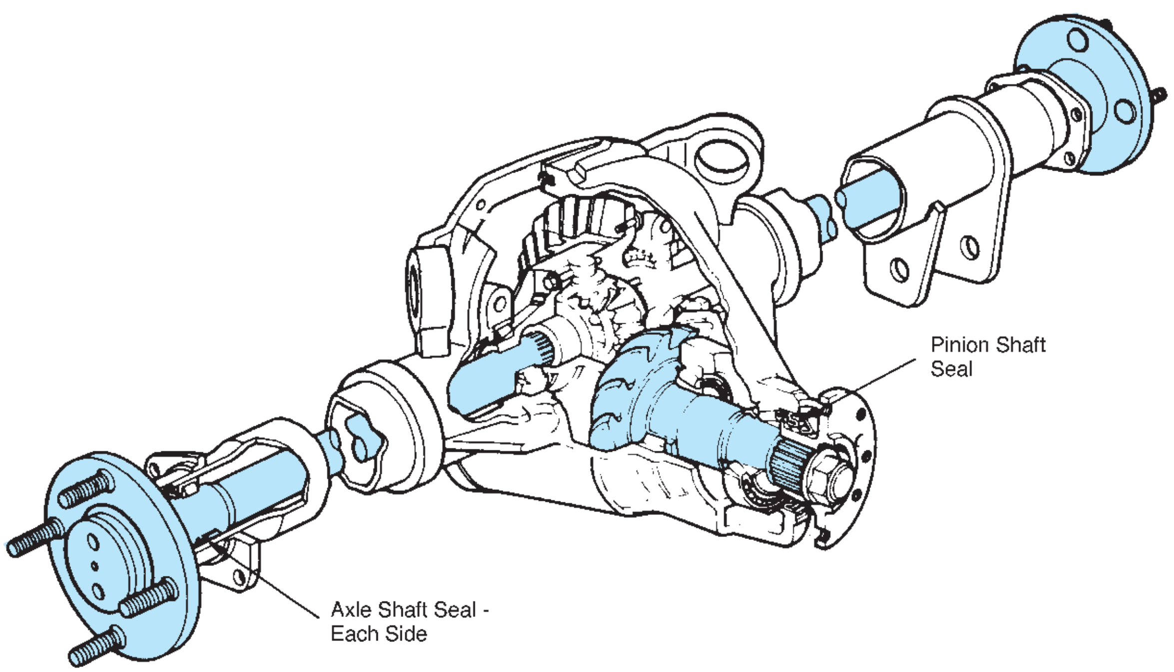


FIGURE 11-36 The gear oil is kept in the housing by seals at each axle shaft, the drive pinion shaft, and gaskets or sealant at each cover. *(Courtesy of Ford Motor Company)*

INDEPENDENT REAR SUSPENSION

Vehicles with **independent rear suspension (IRS)** have the wheels which are supported by the suspension system; driveshafts, also called halfshafts, connect them to the axle assembly (Figure 11-37). The axle housing is very short, slightly bigger than the carrier, and short output shafts are used to connect the axle gears to the U-joint halfshaft flanges.

AXLE IDENTIFICATION

Occasionally, a technician needs to identify the particular axle that is used in a vehicle. Many manufacturers build axle assemblies of differing torque capacity and install the one most suited for the engine size and vehicle weight. The diameter of the ring gear is often used to classify the various axle assemblies. The Ford 9-in. axle is larger and can carry more torque than the smaller 8-in. axle used in smaller vehicles with smaller engines. Ford's integral carrier axle assemblies are built in 6.75-in., 7.5-in., and 8.5-in. sizes. The 6.75-in. axle assembly is used in compact and subcompact installations, the 8.5-in. axle is used in full-size vehicles, and the 7.5-in. axle is used for vehicle sizes between these two. The size number refers to the rough-cut diameter of the gear blank.

In some cases, the axle assembly can be identified by looking at the shape of the cover or by counting the number of mounting bolts. The GM 10-bolt and 12-bolt axle assemblies illustrate this—if the rear cover has 10 mounting bolts, the ring gear also has 10 bolts. In most cases, a more precise identification can be made from the numbers or letters on a

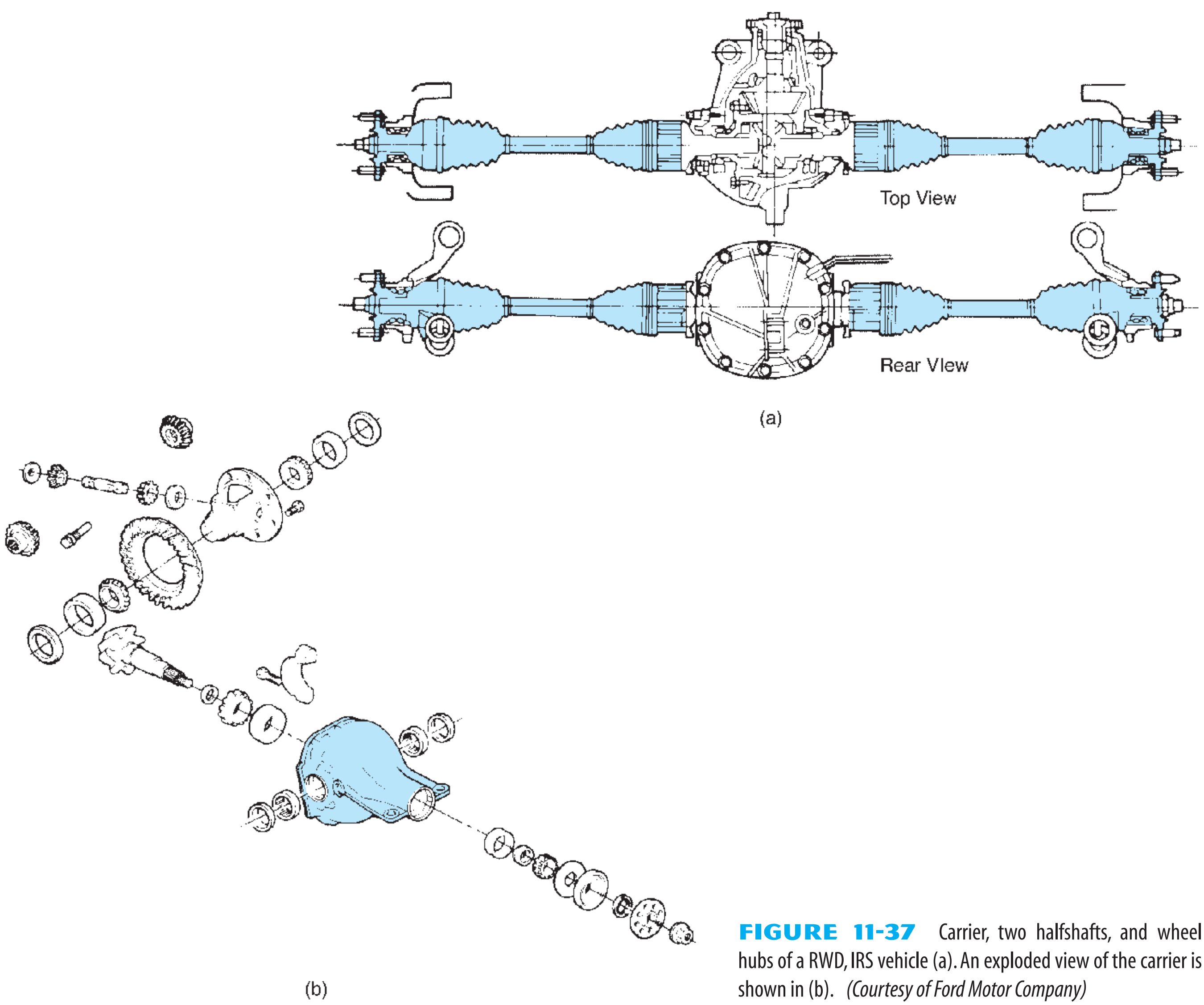


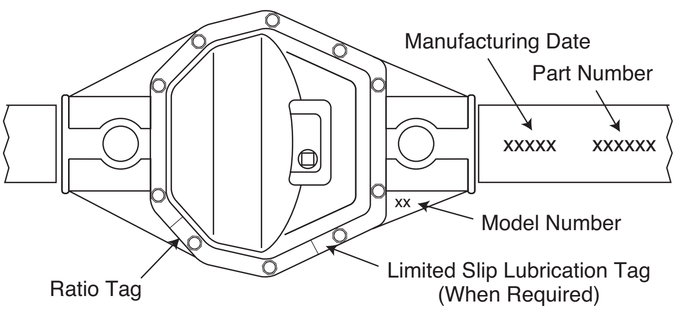
FIGURE 11-37 Carrier, two halfshafts, and wheel hubs of a RWD, IRS vehicle (a). An exploded view of the carrier is shown in (b). *(Courtesy of Ford Motor Company)*

tag retained by one of the rear cover mounting bolts or stamped into the axle housing (Figure 11-38).

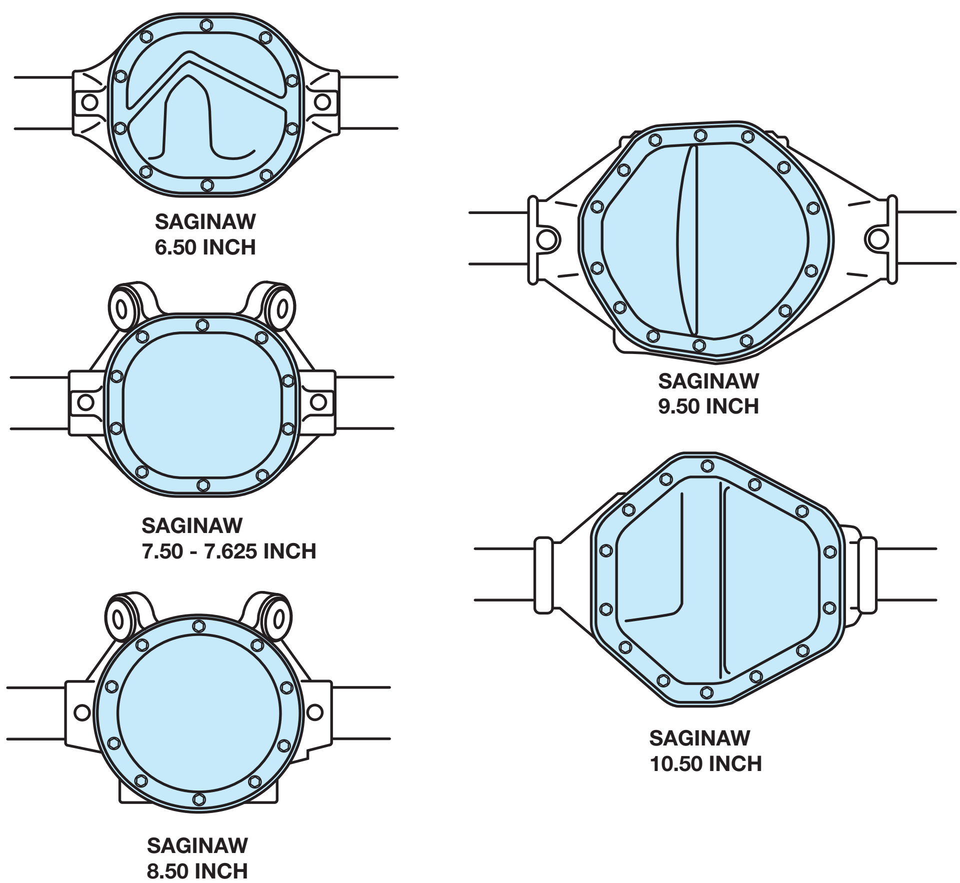
The axle ratio can be determined from this tag or by counting the number of turns the driveshaft makes to get one turn of the tires. On limited slip differential axles, this is easier because both tires will rotate together; but on an open differential the tires will rotate unevenly and make accurate counting difficult.

TECH TIP

The most accurate method of determining gear ratios, if the ring and pinion gears are exposed, is to read the tooth number markings on the ring gear or count the number of teeth on the two gears. Now divide the tooth count of the ring gear by that of the pinion gear, and the result is the ratio.



(a)



(b)

FIGURE 11-38 A drive axle can be identified by a tag or markings on the housing (a). A quick identification is often made by the shape of the cover and number of mounting bolts (b). *(a is courtesy of Dana Corporation)*

TECH TIP

The axle ratio can often be identified from the tag attached to the axle housing or by the coding on some axles.

TECH TIP

The axle ratio can be determined by counting the number of revolutions of the driveshaft that are required to turn the wheels one revolution. The most accurate method of doing this is to lock one of the tires using the parking brake or a block (Figure 11-39). Now, turn the driveshaft until the free tire turns 20 revolutions, and divide the driveshaft revolutions by 10. For example, if you count 23 1/3 turns of the driveshaft to 20 turns of the free tire, the gear ratio is 2.33:1. Remember that with one wheel locked, the differential will cause the other wheel to turn twice as fast.

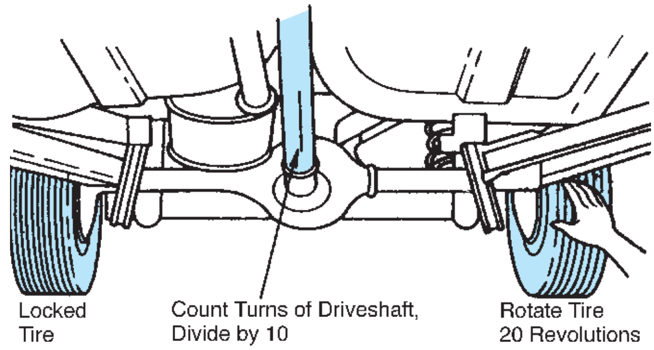


FIGURE 11-39 The quickest and most accurate method of determining a rear axle ratio is shown here. If the driveshaft rotates 37 1/3 turns while the free tire rotates 20 turns, the ratio is 3.73:1.

SUMMARY

1. A drive axle combines the hypoid final drive gears with the differential and two axle shafts.
2. Hypoid ring and pinion gears must be adjusted correctly for long, quiet operation.
3. The pinion gear and shaft are supported by two pinion bearings, and the ring gear and differential case are supported by two carrier bearings.
4. Differentials allow a vehicle to drive two wheels at different speeds.
5. Limited slip differentials increase torque bias to send more torque to the tire with good traction.
6. Several bearing styles are used at the axle wheel ends. Axle shafts can be retained by the axle bearing, a C-clip in the differential, or a full-floating axle is bolted to the hub.
7. Drive axles require the proper type and amount of lubricant.

REVIEW QUESTIONS

1. Another name for a drive axle is a ____________.
2. The ring and pinion gears are machined as a ____________ set. If one of the gears needs replacement, the other must also be replaced.
3. The outer ends of the ring gear teeth are called the ____________ and the inner ends are known as the ____________.
4. The ____________ of the ring gear tooth is above the pitch line and the ____________ is below it.
5. The ____________ side of the ring gear tooth is the drive side and the ____________ side is the coast side.
6. The clearance between the ring gear and the drive pinion gear teeth is called ____________.
7. ____________ and ____________ gear sets normally have index marks that are used to time the gears during installation.
8. The two common ways that a drive pinion is mounted in the carrier are ____________ ____________ and ____________ mounted.
9. The four adjustments that are typically done during a drive axle overhaul are
   a. drive pinion ____________
   b. drive pinion bearing ____________
   c. ____________
   d. carrier bearing ____________
10. The drive pinion bearing preload is typically adjusted by tightening the ____________ ____________ nut, which crushes a collapsible spacer.
11. Most removable carriers use ____________ adjusters and integral carriers use ____________ for backlash and carrier bearing preload adjustments.
12. The differential allows the two drive wheels to rotate at different ____________ when turning a corner.
13. The axle shaft used in passenger vehicle drive axles are ____________ ____________ and the axles used in heavy-duty trucks are of the ____________ ____________ design.
14. ____________ ____________ axles are held in the drive axle by ____________ or a bearing ____________.
15. The gear oil used in most limited slip differentials must have a ____________ ____________ to prevent the stick/slip problem common with these differentials.

CHAPTER QUIZ

1. In a rear axle, the drive pinion gear works with
   a. a ring gear to change the direction of the power flow.
   b. side gears to provide differential action.
   c. a ring gear to provide a gear reduction.
   d. all of these.
2. Two students are discussing the hypoid gears. Student A says that the concave side of the ring gear tooth is called the drive side. Student B says that the heel is the smaller, inner end of the ring gear tooth. Who is correct?
   a. Student A
   b. Student B
   c. Both A and B
   d. Neither A nor B
3. An overhung pinion uses (A) three pinion bearings; (B) a wide spacing between the two tapered roller bearings. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
4. Which of the following is not true about a hypoid gear set?
   a. The pinion gear is mounted below the ring gear centerline.
   b. A special type of gear oil is required.
   c. This is an efficient gear set with very little friction.
   d. Special procedures are required to adjust it.

5. Two students are discussing axle shafts. Student A says that a broken axle will cause a no-drive condition. Student B says a broken semi-floating axle can let a wheel fall off. Who is correct?
   a. Student A
   b. Student B
   c. Both A and B
   d. Neither A nor B
6. A ring and pinion with a 3.76:1 ratio is classified as
   a. hunting.
   b. nonhunting.
   c. partial nonhunting.
   d. Neither A nor B
7. A straddle-mounted pinion uses (A) three pinion bearings; (B) a wide spacing between the two tapered roller bearings. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
8. The differential case
   a. provides a mounting point for the ring gear.
   b. encloses the differential gears.
   c. is supported by the carrier bearings.
   d. all of these.
9. An integral carrier axle assembly
   a. is stronger than a comparable removable carrier assembly.
   b. is easier to service than a removable carrier assembly.
   c. uses full-floating axles in most cases.
   d. all of these.
10. Most limited slip differentials transfer torque through (A) the differential gears; (B) one or two clutch stacks. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
11. Limited slip differentials require a special lubricant to prevent the plates from (A) sticking; (B) wearing. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
12. As a rear axle assembly is put together, the carrier bearings are adjusted to get the correct amount of (A) backlash between the ring and pinion gears; (B) clearance at the bearings. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
13. Two students are discussing the assembly of a rear axle center section. Student A says that with an overhung pinion gear, a thicker shim between the gear and its rear bearing will increase the load on the bearing. Student B says that this will move the pinion gear deeper into the ring gear. Who is correct?
   a. Student A
   b. Student B
   c. Both A and B
   d. Neither A nor B
14. When a car with a limited slip differential turns a corner, the (A) clutch plate surfaces must slide across each other; (B) pressure on the plates is reduced because of the differential gear action. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
15. Full-floating axles are (A) not designed to carry heavy loads; (B) normally bolted to the drive wheel hub. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. none of these.
16. The ring and pinion gear set has 11 teeth on the pinion and 41 teeth on the ring gear. What is the ratio?
17. What would the ratio be if the pinion gear had 11 teeth and the ring gear had 42?
18. While checking the axle ratio, you find that it takes 34 1/2 turns of the driveshaft to produce 20 turns of one rear tire; the other one is locked. What is the gear ratio?