CHAPTER 24

Brakes

Outcomes

After studying this chapter, you will be able to:

- ✓ Describe the basic principles used for brake hydraulic system operation.
- ✓ Identify common braking ratios.
- ✓ Describe the components and operation of the master cylinder.
- ✓ List control valves commonly used in brake systems.
- ✓ Explain the purposes of brake lines and hoses.
- ✓ Describe the operation of disc brake calipers.
- ✓ Explain the function of the wheel cylinders in drum brakes.
- ✓ Identify the purpose of brake friction members.
- ✓ Describe the operation of a disc brake assembly.
- ✓ Describe the operation of a drum brake assembly.
- ✓ Explain the differences between vacuum-assisted and hydraulically assisted power brake systems.
- ✓ Understand the operation of anti-lock brake systems.
- ✓ Explain the operation of traction control systems, including electronic stability control and hill holders.
- ✓ Explain the principle of regenerative braking in hybrid vehicles.

This chapter covers the components and operation of modern disc and drum brake systems. The brake system is subdivided into the hydraulic system (master cylinder, wheel cylinders, calipers, lines and hoses, and valves), and friction system (brake shoes and drums, disc brake rotors and pads). This chapter also covers drum and disc parking brakes, vacuum and hydraulic power brake assists, and anti-lock brake and traction control systems. After studying this chapter, you will understand the operating principles and components of modern brake systems.

Warning

Brake friction materials may contain asbestos—a known carcinogen. Brake assemblies can produce small airborne particles of asbestos during cleaning, which are easily inhaled. Breathing these particles may cause emphysema or cancer. The following safety rules should be observed at all times:

- Wear appropriate respiratory protection when servicing brake components.
- Never use compressed air to blow brake assemblies clean. Use a contained vacuum cleaning system or flush with cleaner or water.

Hydraulic Basics

Early cars used complex linkages to operate the brakes. Modern vehicles use the principles of ***hydraulics*** to transfer power to the brakes. Hydraulics is the practical application of the principles of liquids in motion.

Liquids can include water, oil, transmission fluid, and for our purposes in this chapter, brake fluid. Brake fluid, confined in a hydraulic system, is used to transmit both motion and pressure from the brake pedal to the wheels. A liquid under confinement can be used to:

- Transmit pressure.
- Increase pressure.
- Decrease pressure.
- Transmit motion.

Air Is Compressible, Liquids Are Not

Air confined under pressure will compress, thereby reducing its volume, **Figure 24-1**. When a liquid is confined and placed under pressure, it cannot be compressed. **Figure 24-2A** shows a cylinder filled with oil. A leak-proof piston is placed on top of the oil. When a downward force is applied, as shown in **Figure 24-2B**, the force will not compress the oil.

Pascal's Law

A French scientist, Blaise Pascal, discovered that when pressure was exerted on a confined fluid, the pressure was transmitted undiminished throughout the fluid. **Figure 24-3** illustrates ***Pascal's law***. Note that the original pressure (force) placed on the liquid is the same at all outlets.

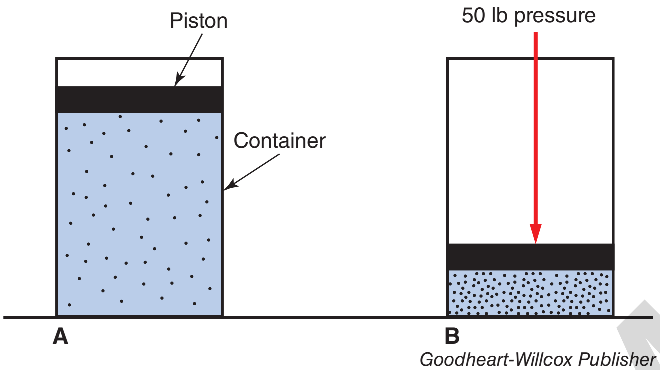

Figure 24-1. Air is compressible. A—There is no pressure on the piston. B—Pressure has forced the piston down, compressing the air trapped in the container.

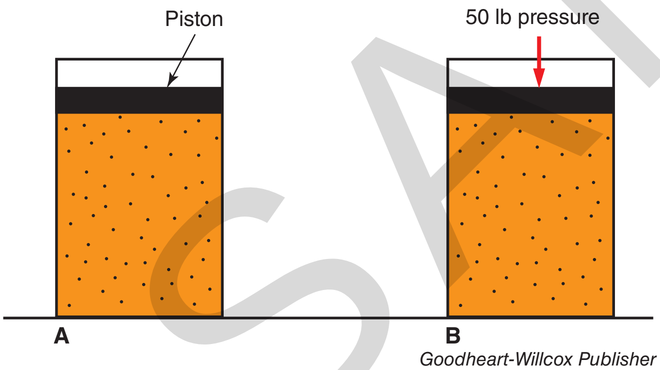

Figure 24-2. Liquids cannot be compressed. A—No pressure is applied to the piston. B—When pressure is applied to the piston, it does not compress the liquid.

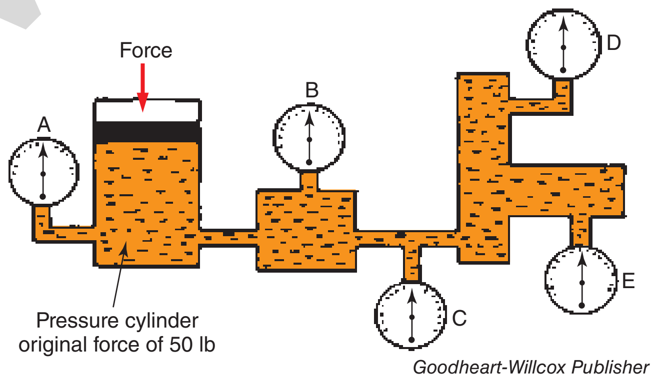

Figure 24-3. When pressure is exerted on a confined liquid, it is transmitted undiminished. Force on the piston has created a pressure of 50 psi (pounds per square inch) upon the liquid in the pressure cylinder. Note that all gauges read the same throughout the system. If gauge A reads 50 psi, gauges B, C, D, and E will also read 50 psi.

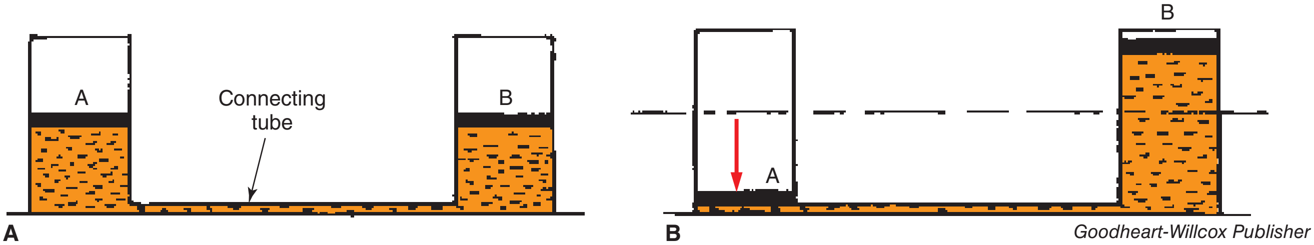

Figure 24-4. Liquids can transmit motion. A—Both pistons are at rest. B—Piston in left cylinder has been forced down. When one piston travels down, it forces liquid into the other cylinder. Since the other cylinder is the same size, the distance that the piston is raised is equal to the distance that the other piston was lowered.

Liquids Can Transmit Motion and Force

In **Figure 24-4**, you will see that any movement of piston A will cause piston B to move an equal amount. This is a transmission of motion through a liquid. If a 200 lb force is placed on piston A in **Figure 24-5**, piston B will support 200 lb. Both pistons are the same size. In a hydraulic system, this force is usually expressed as hydraulic pressure.

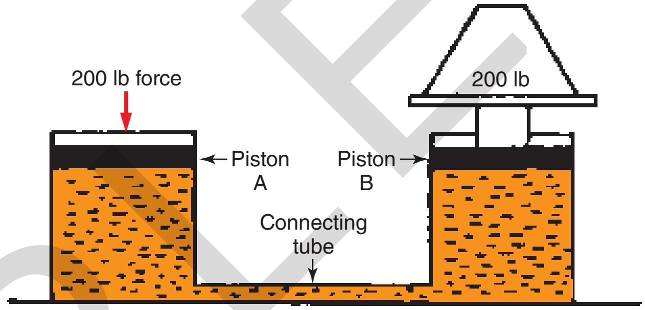

Figure 24-5. Using a liquid to transmit force. A 200 lb force on piston A is transmitted, via liquid, to piston B.

Liquids Can Increase Force

When a force is applied to piston A in **Figure 24-6**, it can be increased if it is transmitted to a larger piston B. If piston A has a surface area of 1 in^2, the 200 lb force on piston A represents a pressure of 200 lb/in^2. According to Pascal's law, this 200 lb/in^2 force will be transmitted undiminished.

If piston B has a surface area of 20 in^2, piston A will exert a 200 lb force on each square inch of piston B. This would produce a mechanical advantage (MA) of 20, and the original 200 lb force would be increased to 4000 lb. The force may be further increased by either making piston A smaller or piston B larger.

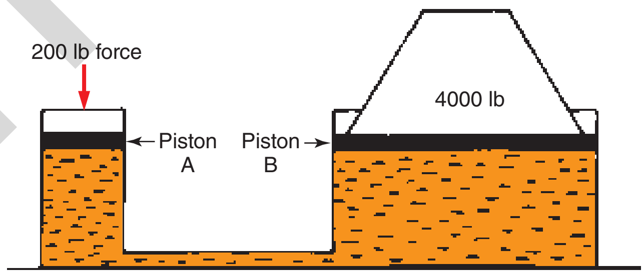

Figure 24-6. Liquids can be used to increase force. A 200 lb force on piston A with an area of 1 in^2 is increased to 4000 lb on piston B with an area of 20 in^2.

Liquids Can Decrease Force

In order to produce a pressure of 4000 lb on piston A with a surface area of 1 in^2, 80,000 lb of force would need to be applied to piston B with a surface area of 20 in^2. By applying the force to the large piston, the force increase has been reversed and the original force, with regard to the smaller piston, will be diminished.

This force's ability to produce pressure can be increased or decreased by applying it to a larger or smaller area. Note in **Figure 24-7** that pressures in the pump and lifting pistons are the same. However, the force applied to the pump piston has been increased many times on the head of the lift.

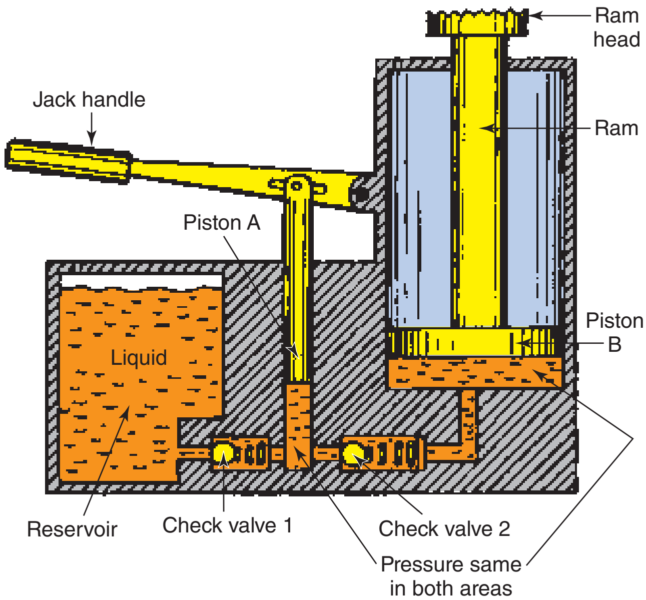

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Figure 24-7. Simple hydraulic jack. If piston B has an area 100 times greater than piston A, the ram will lift 100 times more than the pressure generated by piston A.

A Hydraulic Jack

Figure 24-7 shows how a fluid can be used to produce a powerful lifting force using the principles of hydraulics. When the jack handle raises piston A, piston A will form a vacuum. This will draw check valve 1 open and close check valve 2. When the handle is depressed with a force that exerts 200 lb pressure (or any force) on piston A, check valve 1 will close, check valve 2 will open and 200 psi will be transmitted to piston B. If piston B has a surface area 100 times greater than the 1 in^2 area of A, piston B will raise a weight of 20,000 lb.

Hydraulic Principles in Vehicle Brake Systems

When the driver depresses the brake pedal, the force is transmitted undiminished to each caliper or wheel cylinder. The caliper pistons or wheel cylinders transfer this force (increased or decreased, depending on piston area) to the friction linings.

When the master cylinder piston moves, the caliper pistons or wheel cylinders will move until the brake friction components are engaged. Further movement is impossible as any attempt to depress the master cylinder piston beyond this point will transmit additional pressure, not motion.

Brake Fluid

Brake fluid is used to transmit motion and pressure through the hydraulic system. Not just any fluid can be used in a brake system. Some of the more important characteristics of quality brake fluid are:

- Maintains even viscosity throughout a wide temperature variation.
- Does not freeze at the coldest possible temperature that the vehicle may encounter.
- Boiling point is above the highest operating temperature of the brake system parts.
- Is hygroscopic (has the ability to absorb and retain moisture) to prevent internal freezing of parts.
- Acts as a lubricant for pistons, seals, and cups to reduce internal wear and friction.
- Must not corrode the brake system's metal parts.
- Must not swell or deteriorate the brake system's plastic and rubber parts.

Many brake fluids contain alcohol, glycerin, and other non-petroleum ingredients. The latest Department of Transportation–approved (DOT-approved) brake fluid is marked DOT 3 or DOT 4. These fluids have a boiling point of about 400°F (200°C). DOT 4 has a higher boiling point and is usually recommended for vehicles where high heat may be generated. DOT 3 continues to be used in many vehicles. Some vehicles use silicone brake fluid, labeled DOT 5, which has a boiling point of about 500°F (260°C). DOT 5 fluid should never be used in anti-lock brake systems (ABS) or mixed with other types of brake fluid.

Although named similarly, glycol-based DOT 5.1 brake fluid should not be confused with silicone-based DOT 5 brake fluid. DOT 5.1 brake fluid is a glycol-based fluid, similar to DOT 3 or DOT 4 fluid, but with additional chemical compounds which allow it to meet DOT 5 standards. The DOT 5.1 fluid is also safe to use in ABS systems.

It is important to use only top-quality, DOT-approved brake fluid in an automobile brake system. The brake fluid should meet or exceed current SAE recommendations. Although makers of DOT 3, DOT 4, and DOT 5.1 fluid state that their fluid can be mixed with other types of DOT 3, 4, and 5.1 fluid, do *not* mix different fluids without first checking the vehicle manufacturer's service information.

Under no circumstances should any fluid besides brake fluid be put into the brake system. Any mineral or petroleum-based oils such as motor oil, transmission fluid, power steering fluid, kerosene, or gasoline in even the smallest amounts will swell and destroy the rubber cups and seals in the system.

Since DOT 3, DOT 4, and DOT 5.1 brake fluids are extremely hygroscopic (able to absorb water), the brake fluid can absorb enough water to seriously lower the fluid's boiling point. To remove water-contaminated fluid, the brake hydraulic system should be periodically flushed with fresh fluid. Do not reuse old brake fluid and keep brake fluid containers tightly capped. Test strips and electronic devices can be used to test the fluid moisture content.

Warning

Brake fluid is poison. Keep it away from skin and eyes. Do not allow brake fluid to splash on painted surfaces.

Hydraulic System Vapor Lock

Fresh, quality brake fluid will remain liquid at any brake system temperature. Old, low-quality brake fluid or fluid that is contaminated can boil at normal braking temperatures. If brake fluid begins to boil, it becomes a gas, which can be compressed.

Since the brake hydraulic system depends on having uncompressible fluid, vaporized brake fluid will make it impossible to transmit the proper braking force from the brake pedal to the wheels. Boiling brake fluid has caused many accidents. After the accident, the fluid will cool off and recondense, making it impossible to locate as the problem. This is another reason why high-quality brake fluid should always be used.

Braking Ratio

When a vehicle is stopped, there is a transfer of weight to the front of the vehicle due to its inertia. This forces the vehicle's weight against the front tires while it relieves weight off the rear tires somewhat.

To compensate for and to take advantage of this effect, the front brakes usually are designed to produce more stopping power than the rear. This is called the vehicle's ***braking ratio***. Typically, 55–60% of the stopping power is provided by the front brakes and 40–55% of the stopping power is provided by the rear brakes. This ratio will vary depending on the type and size of vehicle, vehicle loading, and whether the vehicle uses front- or rear-wheel drive. The hydraulic system may also be designed to modify the braking ratio for increased braking efficiency.

Master Cylinder

The ***master cylinder*** is the central unit in which hydraulic pressure is developed. Pressure from the driver's foot pressing on the brake pedal is transmitted to the master cylinder pistons. As the pistons are forced forward in the cylinder, they push brake fluid ahead of them. Since the system is airtight, the pistons are acting on a solid column of fluid.

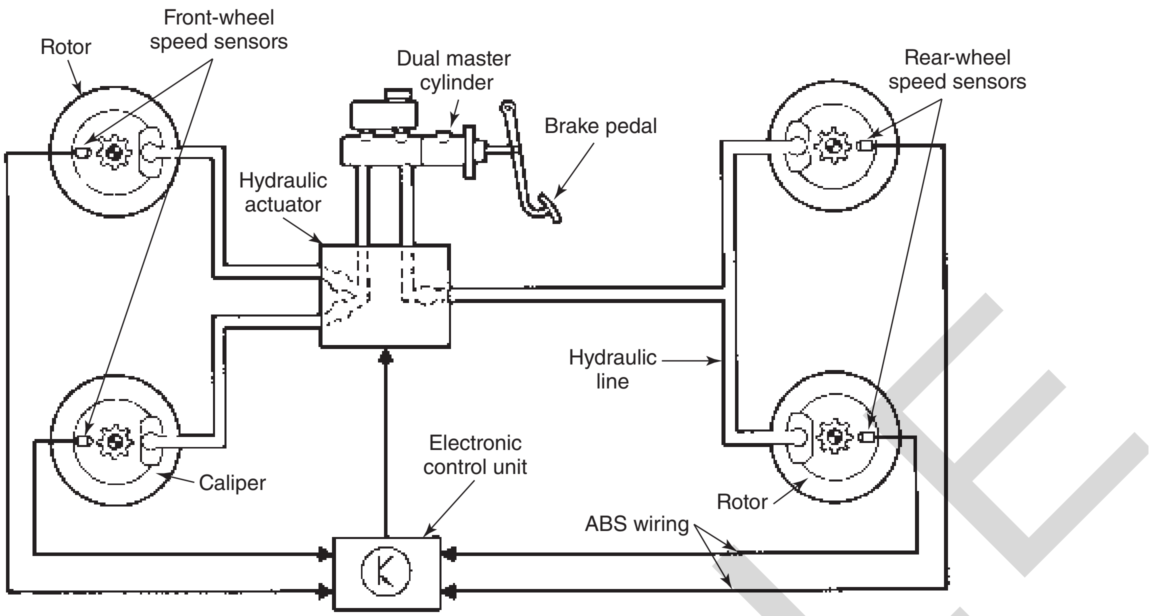

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Figure 24-8. Schematic of a four-wheel disc brake system that incorporates four-wheel anti-lock braking (ABS).

When the friction members have moved far enough to fully apply, the fluid movement ceases and pressure rises in response to the amount of force on the master cylinder pistons. **Figure 24-8** illustrates brake pedal linkage, master cylinder, hydraulic lines, and brake assemblies. All of these components will be discussed later in this chapter.

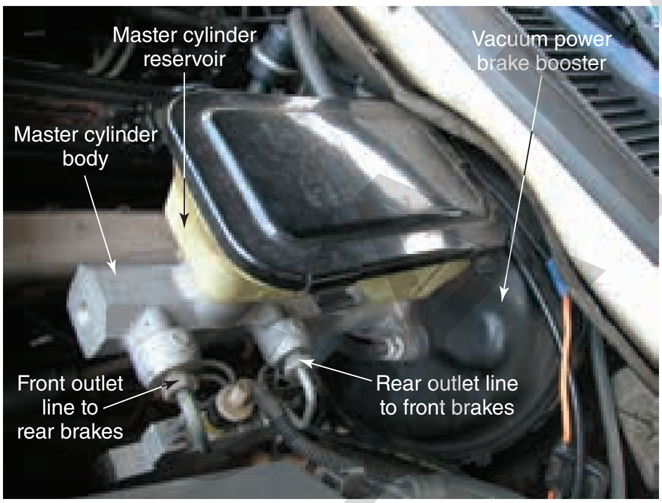

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Figure 24-9. This master cylinder is mounted to the vacuum power brake booster, which is in turn attached to the vehicle firewall. The front outlet line goes to the rear brakes and the rear line goes to the front brakes.

Master Cylinder Construction

Most master cylinders are manufactured of cast iron or aluminum. The master cylinder has a drilled bracket as part of the casting for mounting. Modern master cylinders are installed on a vacuum or hydraulic power booster mounted to the vehicle's firewall, **Figure 24-9**. With the master cylinder in this location, it can be inspected and serviced easily, and the chances of contamination by water, oil, or dirt are reduced.

Brake Fluid Reservoir

The master cylinder has a reservoir for brake fluid. This will provide additional fluid to compensate for minute leaks or lining wear. The reservoir cover is vented (has an air hole in it) to allow fluid expansion and contraction without forming pressure or vacuum. A rubber diaphragm contacts the fluid and follows the level up and down. The diaphragm seals out dust and moisture.

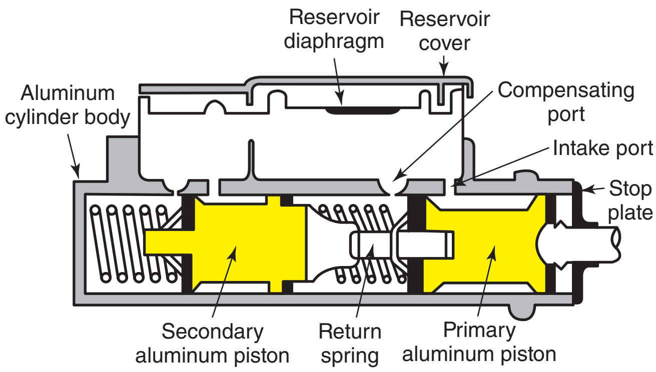

Figure 24-10. Typical dual master cylinder setup. This master cylinder uses an aluminum cylinder body and pistons. The reservoir diaphragm sits below the reservoir cover and keeps air from entering the system as the fluid level fluctuates.

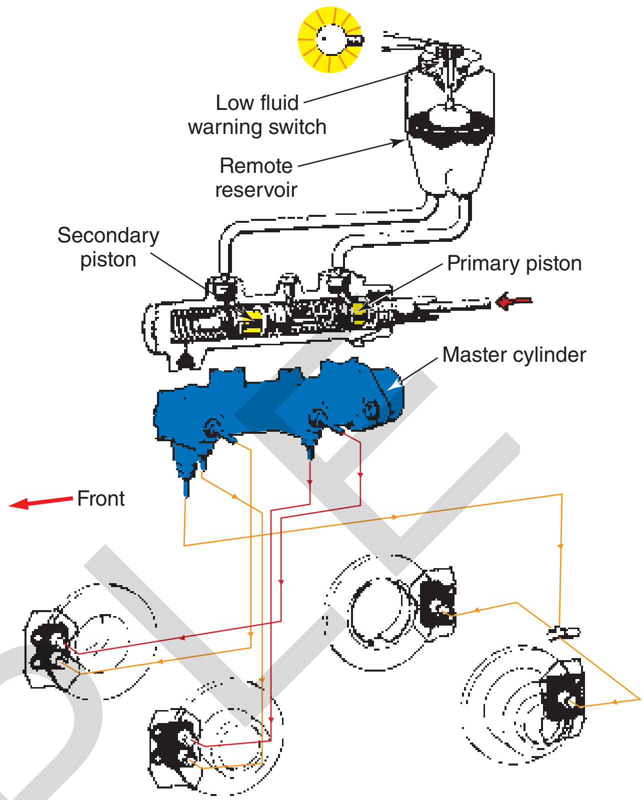

Figure 24-11. Split braking system employing dual (separate) front and single rear hydraulic lines. Some braking is always possible unless both master cylinder pistons fail.

Reservoir Construction

Some reservoirs are made of clear plastic, or have clear windows so the fluid level can be checked without removing the cover. A typical reservoir cover is illustrated in **Figure 24-10**. A few master cylinders have a remote (separately located) reservoir, such as the one in **Figure 24-11**. A separate reservoir is used when the master cylinder is in a location that would be difficult to reach. Note that the reservoir in **Figure 24-11** has a low fluid warning switch. This switch illuminates a dashboard light to warn the driver if the fluid level drops below the safe point.

Reservoir Fluid Level

The master cylinder reservoir should be filled to within 1/4″ to 1/2″ (6.35–12.7 mm) of the top of the reservoir, depending upon manufacturer's recommendations, **Figure 24-12**. Depending on the design of the dual master cylinder, one reservoir with an internal separator is used for both piston intake ports or a separate reservoir is used for each piston intake port, **Figure 24-13A**.

Figure 24-12. Fill the master cylinder with the correct type of brake fluid. Air space is important so that reservoir fluid can expand without leaking or creating pressure in the master cylinder. Do not overfill. An internal separator splits the reservoir between each piston intake port but allows fluid to pass over the top of it.

Pressure Cylinder

A cylinder with a very smooth wall is provided in the master cylinder. This cylinder contains two close-fitting aluminum pistons. Some older vehicles use a single piston design. The cylinder is connected to each reservoir by two ports (holes): the compensating port and intake or breather port, **Figure 24-13B**. Pressure is developed in this cylinder for use in the rest of the brake system.

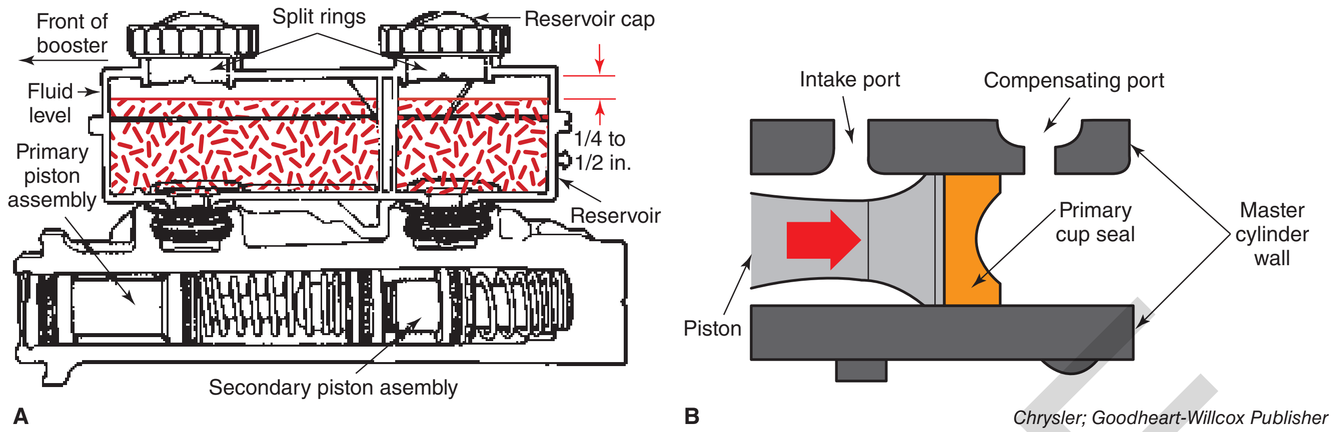

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Figure 24-13. A—Master cylinder with a separate attached reservoir for both the primary and secondary piston. Note the double-piston construction. B—The intake port is always located behind the primary cup seal. Brake fluid enters this port to reach the back section of each piston cylinder. The compensating port lets pressurized brake fluid flow back into the reservoir when the brake pedal is released.

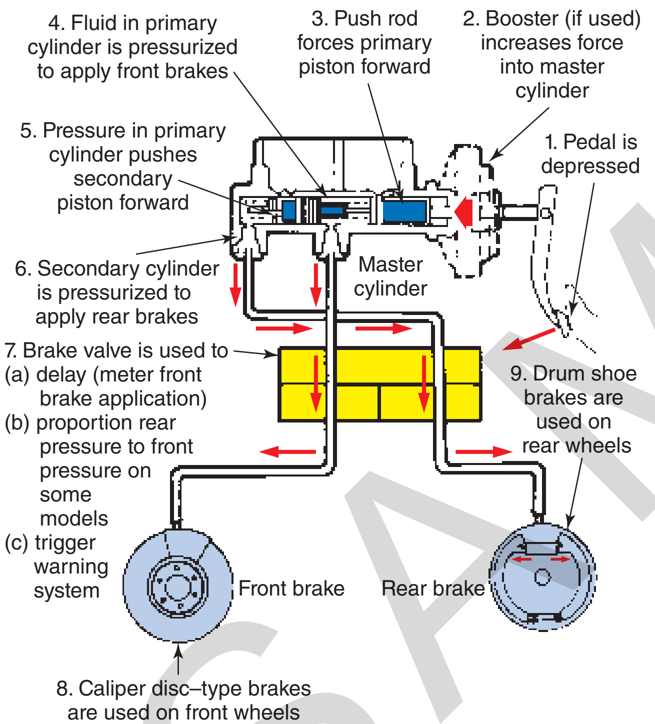

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Figure 24-14. A dual master cylinder in the applied position. There is fluid pressure in the master cylinder due to the operation of the push rod in Step 3. The fluid reservoir is not shown.

Piston Assembly

The inner face of each piston presses against a rubber ***primary cup***. This cup prevents fluid leakage past the piston. The outer piston end has a rubber ***secondary cup*** to prevent fluid from leaving the master cylinder. The inner piston head has several small ***bleeder ports*** that pass through the head to the base of the rubber primary cup.

Both piston assemblies rest in the cylinder. They are retained by a stop plate and/or a snap ring in the end of the cylinder. Pressure is applied to the pistons by means of a push rod that connects to the brake linkage, **Figure 24-14**. The ***piston return springs*** reposition the pistons when the brakes are released.

Dual Brake System

Master cylinders with two pistons provide two separate (often called "split" or "twin") braking systems. This is often called a ***dual brake system***. If one part of the system loses its hydraulic fluid from a leaking seal, ruptured hose, or cracked line, the other system will still provide some braking. Although braking performance is significantly reduced, the dual system provides an important margin of safety.

The dual brake system uses a ***dual master cylinder*** (also referred to as a tandem or double-piston master cylinder). A disassembled view of a dual master cylinder is shown in **Figure 24-15**. The action of the cylinder when either the front or rear hydraulic system loses pressure is explained later in the chapter.

Systems may be arranged so that one master cylinder piston provides pressure for the front brakes, while the other piston provides pressure for the rear brakes. See **Figure 24-16A**. Another arrangement is the ***diagonal split brake system***, in which one master cylinder piston operates one front brake and one rear brake on opposite sides, **Figure 24-16B**.

Note

Modern brake dual master cylinders may have four outlet lines, with one connecting to each wheel.

Figure 24-17 shows the configuration and operation of a typical dual master cylinder under normal conditions. Note that movement of the push rod applies both the front and rear brakes.

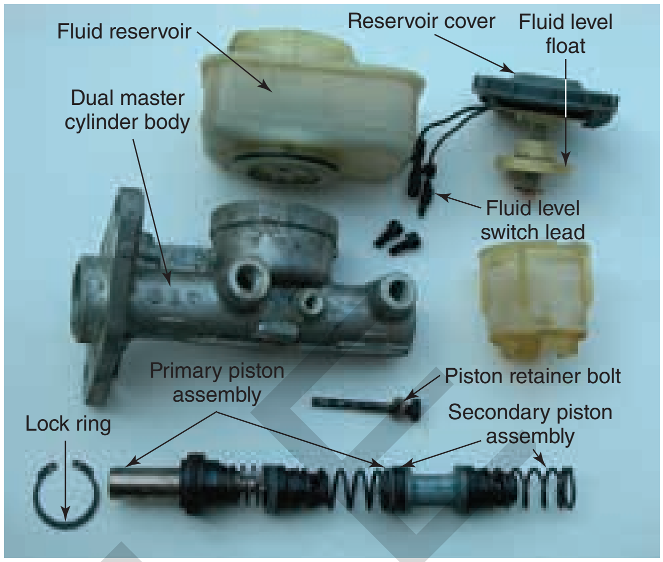

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Figure 24-15. Disassembled view of a master cylinder. Note the fluid level float and switch lead.

Master Cylinder Operation

The following sections explain the operation of the master cylinder in the released position (brake pedal not being pressed by the driver) and applied positions (brake pedal being pressed by the driver). Also covered is master cylinder operation as the brake pedal is released.

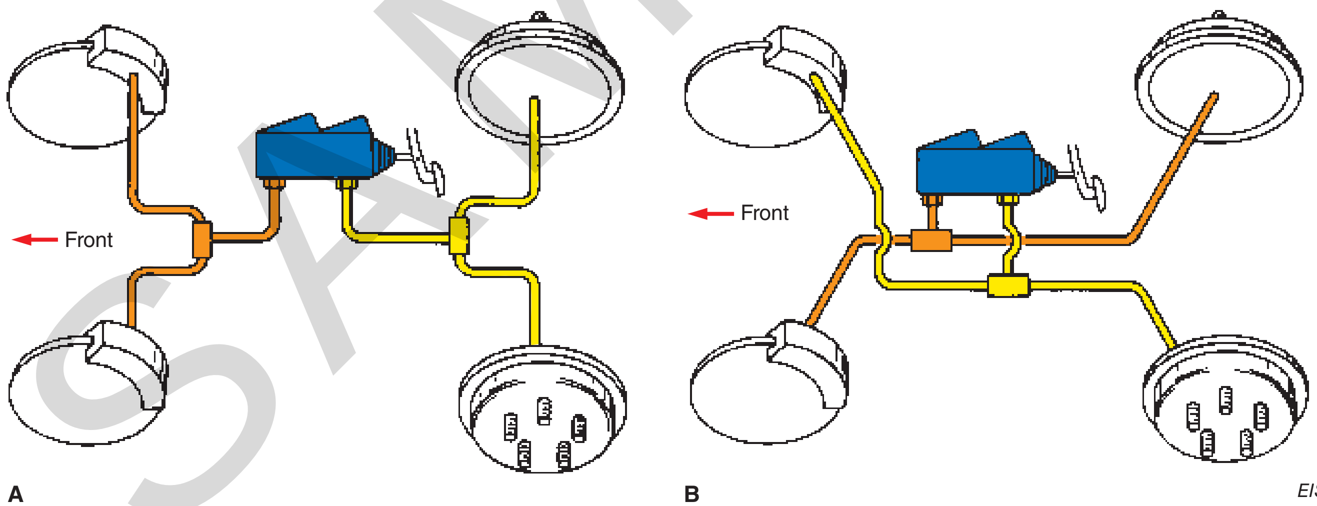

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Figure 24-16. Two dual or "split" braking system designs. A—Typical front and rear setup is widely used. Note how each master cylinder piston serves only one set of brakes. B—Diagonal setup where each piston serves one front and one rear brake on opposite sides. Other designs, such as right side-left side or dual front-dual rear, have been used.

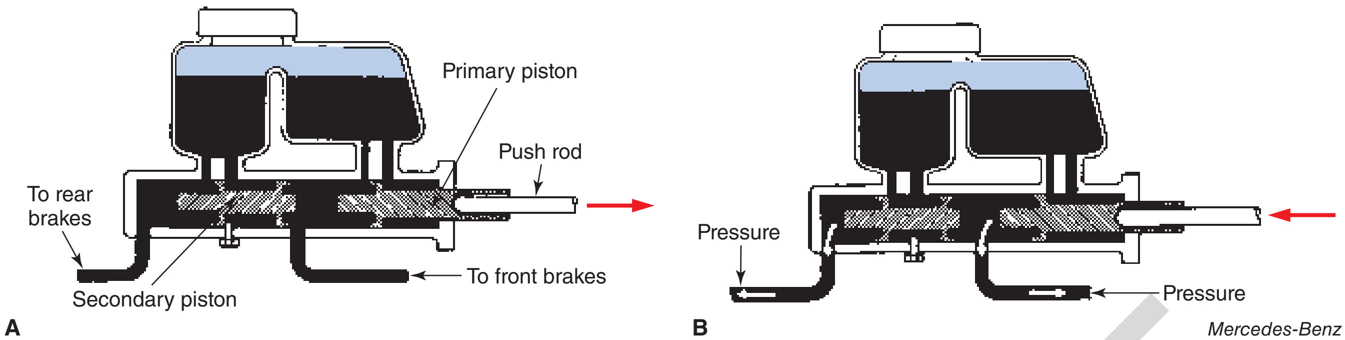

Figure 24-17. Dual master cylinder operation. A—Released position. B—Applied position.

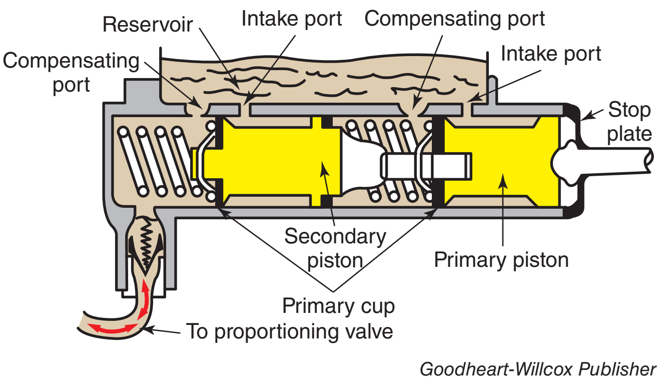

Figure 24-18. Dual master cylinder in the fully released position. The primary piston is against the stop plate and there is no pressure in the master cylinder.

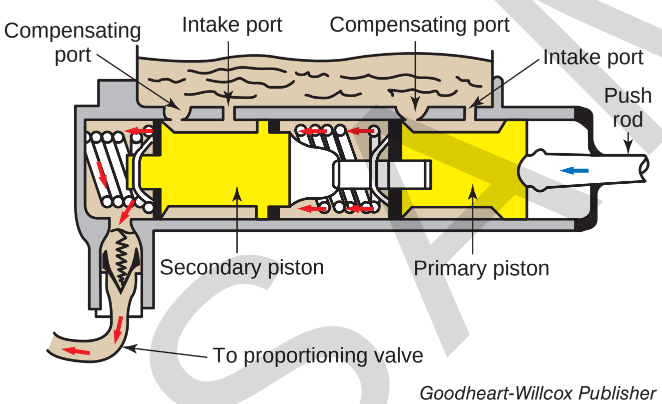

Figure 24-19. A dual master cylinder in the applied position. Pressure is being generated in the brake lines, forcing the caliper and wheel cylinder pistons out.

Brake Pedal Released

Figure 24-18 shows the master cylinder in the released position. The primary piston is pushed back against the stop plate. If the vehicle has rear drum brakes, there is residual, or static, pressure in the brake line and wheel cylinder. The primary cups are free of the compensating ports and the intake port is open to the center section of the primary piston. No pressure is present within the master cylinder itself.

Brake Pedal Applied

When pedal pressure is applied to the primary piston, it moves forward and blocks off the compensating port, sealing the fluid in front of it. Refer to **Figure 24-19**. As the piston continues to move forward, it will transmit fluid pressure to the front calipers and to the base of the secondary piston. This causes the secondary piston to move forward, blocking off its compensating port and applying pressure to the rear calipers or wheel cylinders. Note that the pedal pressure has moved both pistons and has created pressure to both chambers.

Brake Release, Start

When the driver removes his or her foot from the brake pedal, push rod pressure is removed from the pistons, **Figure 24-20**. As the pistons start to move outward in the cylinder, they will move faster than the fluid can return through the lines. This creates a mild vacuum in the pressure chambers and fluid will flow through the bleeder holes in the head of the pistons. This fluid pressure will bend the lips of the cups away from the cylinder wall, and fluid will flow into the cylinder ahead of the pistons.

This action also allows the brakes to be pumped. Pumping is the repeated application of the pedal in quick movements. It is used when one full application fails to expand the friction members or when stopping on slick or icy roads. Pumping the brakes should not be necessary under normal driving conditions and usually indicates a hydraulic system leak or part failure, faulty brake adjustment, or worn brake linings. The brakes should be serviced whenever pumping becomes necessary. The flow of fluid through the bleeder holes will also prevent the possible entry of air by keeping the cylinder filled at all times.

Brake Release, Finish

When pressure drops in the master cylinder, the friction linings begin to retract. As the linings retract, they force the brake fluid to flow back into the master cylinder. See **Figure 24-21**. As the pistons return to their fully released position against the stop plate, the primary cups uncover the compensating ports and any excess fluid will flow into the reservoir.

The small valve shown in the insert in **Figure 24-21** shows the ***residual pressure valve*** used when the vehicle has drum brakes. The residual pressure valve is a spring-loaded valve that remains open until there is only a small amount of pressure in the drum brake lines and wheel cylinders. Once pressure is reduced below a small amount, the valve is closed by spring pressure. Trapping a small amount of pressure in a drum brake system helps the hydraulic system overcome return spring pressure the next time that the brakes are applied.

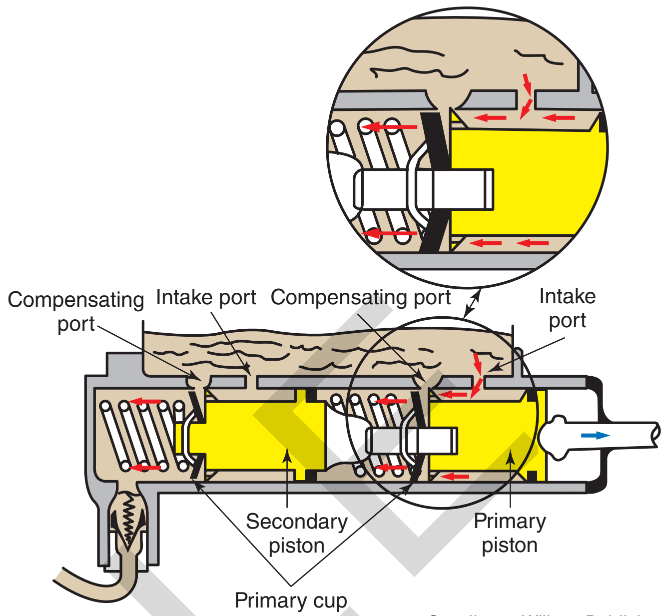

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Figure 24-20. A master cylinder at the start of fast release. Note how the fluid flows through the bleeder holes in the head of the piston. This forces the rubber seal cup away from the cylinder wall. It helps to prevent a mild vacuum from retarding (holding back) the piston withdrawal.

Quick Take-Up Master Cylinder

The quick take-up master cylinder is used with the diagonal split brake system. Opposed front and rear brakes are both operated by the primary or secondary piston only. The quick take-up master cylinder allows the brake system to be designed with extra clearance between the disc brake pads and rotor. The extra clearance eliminates contact between the pads and rotor, increasing mileage and reducing wear. If a conventional master cylinder were used, this extra clearance would cause a low brake pedal.

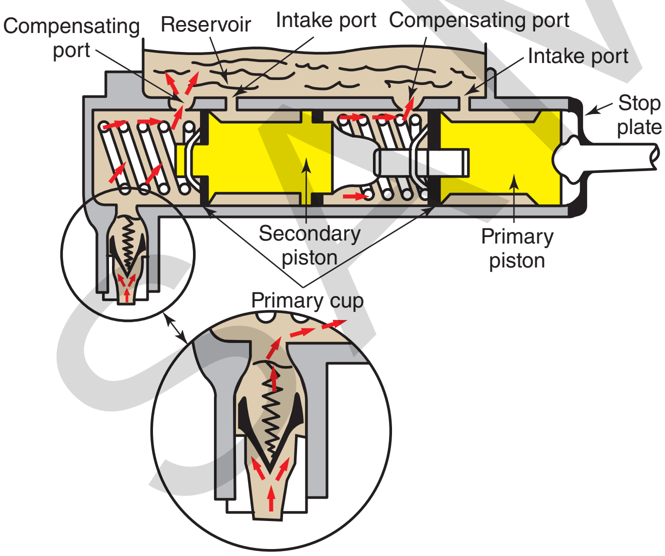

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Figure 24-21. Master cylinder at the finish of brake release. Both pistons have uncovered their compensating ports. As the brake shoes are retracted, they squeeze the wheel cylinder pistons together and the fluid is forced back through the lines, into the master cylinder reservoir. The small valve on the insert maintains residual pressure when drum brakes are used.

A quick take-up master cylinder has a large diameter piston installed at the rear of the cylinder bore, **Figure 24-22.** When the brake pedal is pressed, the large diameter piston is moved before the other pistons. The large diameter piston slightly pressurizes the fluid in the brake caliper pistons. This low pressure fluid causes the pistons to move just enough to remove the clearance from between the pads and rotor. Once the clearance is removed, the other master cylinder piston takes over and tightens the pads against the rotor and the normal braking process begins. When the brakes are released, the ***quick take-up valve*** allows a large amount of fluid to return quickly to the chamber containing the large piston. This allows the brakes to be applied again immediately if necessary.

Brake System Hydraulic Control Valves

The brake hydraulic system of modern vehicles contains many valves to provide even braking and warn of problems. The most common valves are the proportioning valve, the metering valve, and the pressure differential switch. These valves are sometimes installed in a single housing, called a *combination valve.*

Proportioning Valve

A ***proportioning valve*** is normally used in brake systems using disc brakes in the front and drum brakes in the rear. Under mild stops, braking effort is about equal front and rear. As pedal pressure is increased, the proportioning valve controls (and finally limits) pressure to the rear wheels. This reduces the possibility of rear wheel lockup during heavy braking. The proportioning valve can be a separate unit or it can be incorporated into a combination valve, **Figure 24-23**.

Some vehicles utilize a diagonal split brake system with a ***dual proportioning valve***. The master cylinder is connected directly to the valve. From there, the system is divided diagonally.

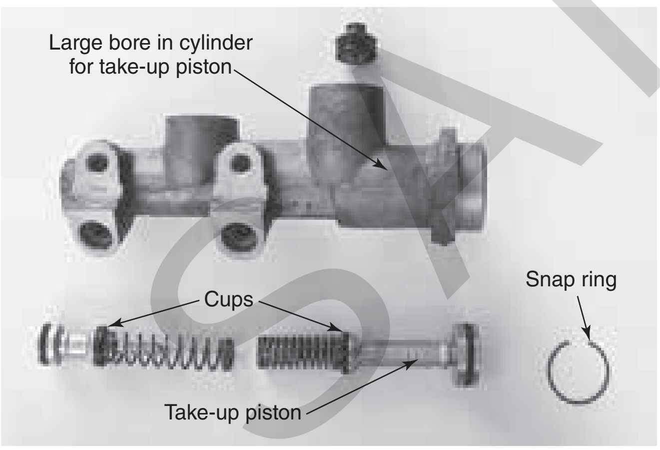

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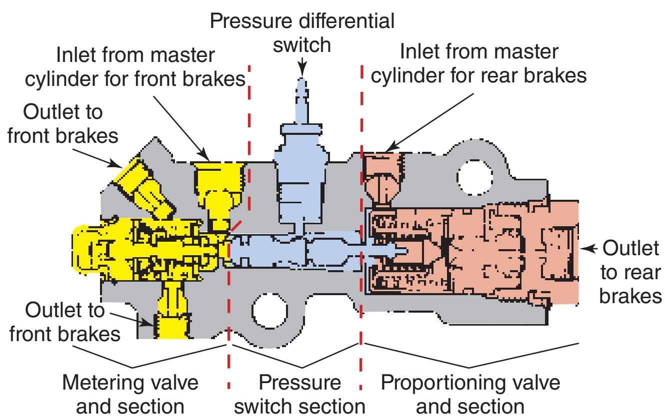
Figure 24-22. Disassembled view of a "quick take-up" master cylinder. Note the large piston at the right side of the photo. This is the take-up piston, and it installs into the large bore in the cylinder body.



Allied-Signal

Figure 24-23. A proportioning valve inside a three-function combination valve assembly. Note the location of the inlet ports from the master cylinder and the outlet ports to the front and rear brake assemblies.

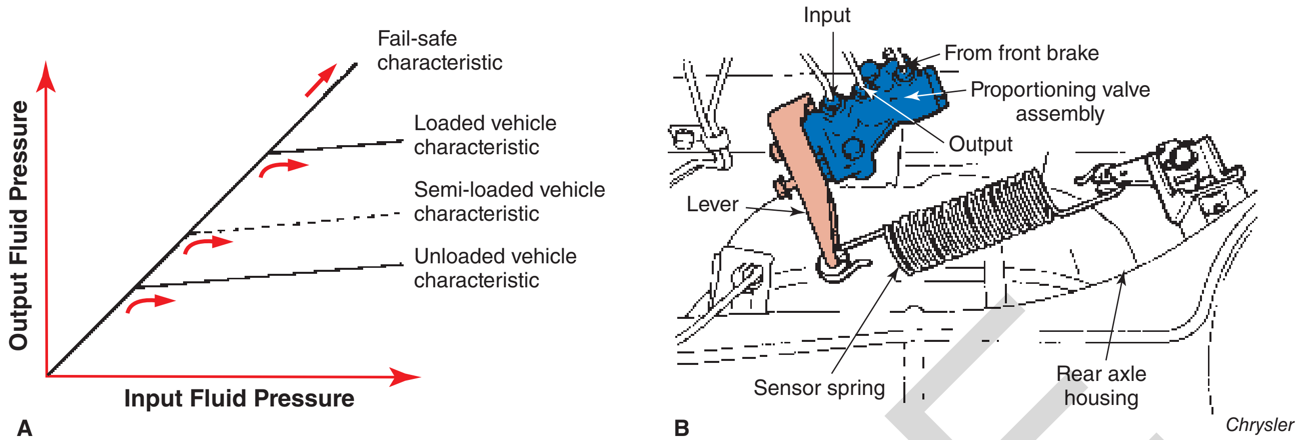


Figure 24-24. Height-sensing proportioning valve assembly. A—Vehicle loaded (body height-to-ground) fluid output and input pressures. B—Proportioning valve and sensor springs shown in their mounting positions on the frame and rear axle housing. The sensor spring will pull the valve operating lever in farther, which increases brake fluid pressure to the rear brakes, helping them overcome and stop the heavier-than-normal load.

Height-Sensing Proportioning Valve

The ***height-sensing proportioning valve*** uses a variable pressure range feature, which increases the pressure to the rear brakes as the vehicle's weight (cargo) increases. This pressure will diminish as the vehicle's weight decreases. Most valves are located on the vehicle's chassis and are connected to the rear axle with a calibrated tension spring or a rod-type linkage, **Figure 24-24**.

Vehicle weight transfer during a stop will cause chassis height-to-axle distance to change. The spring or rod linkage will also change in length. This, in turn, adjusts the valve, limiting pressure to the rear brakes. Loading the vehicle (wood in the bed of a truck, for example) will also actuate the valve.

Disc Brake Metering Valve

Vehicles with front disc and rear drum brakes require the use of a metering valve. See **Figure 24-25**. The ***metering valve*** closes off pressure to the front disc brakes until a specified pressure is developed in the hydraulic system. This allows pressure to force the back brake shoes to overcome retracting spring pressure and move into contact with the drum. Pressure beyond this opens the metering valve, sending fluid to both front and rear brakes.

Pressure Differential Switch

On systems with a dual master cylinder, failure of either the front or rear hydraulic system will allow the brake pedal to travel closer to the floorboard before applying the brakes. In addition, braking power is significantly reduced. Any hydraulic system failure must be corrected as soon as possible.

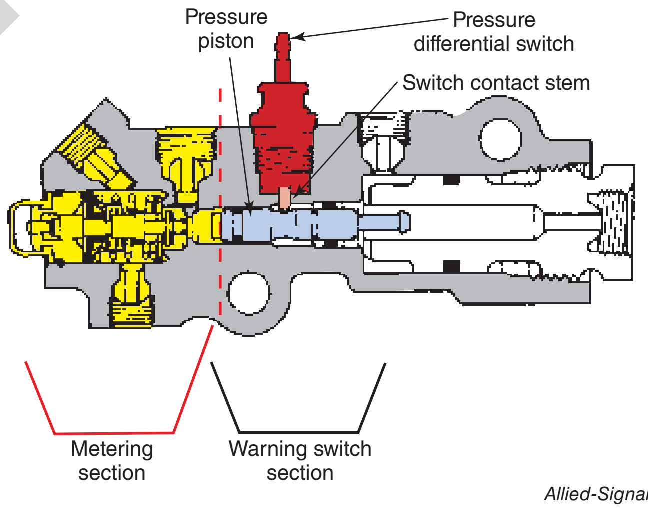


Figure 24-25. A cross-sectional view of a metering valve and pressure differential switch. The metering section limits hydraulic fluid pressure to the front brakes until a certain predetermined rear brake apply pressure is obtained. The pressure is equalized when the brakes are not applied. The electrical switch turns on a dashboard brake warning light if there is a loss of fluid pressure in the front or rear system.

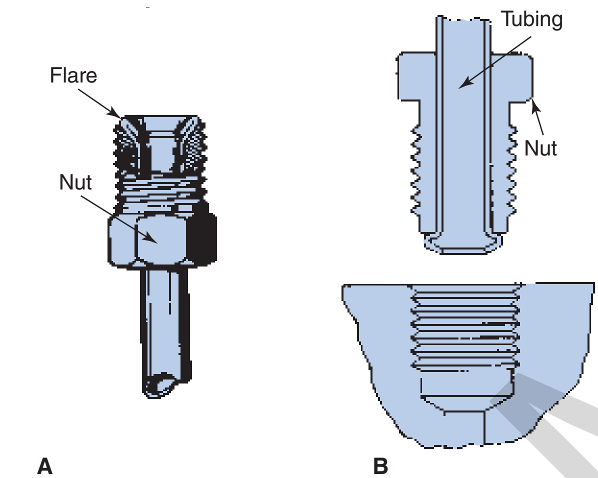
All dual brake systems use a ***pressure differential switch*** to warn the driver that one-half of the split brake system has failed, **Figure 24-25.** A small piston floats in a cylinder separating two pressure chambers. One side of each chamber is connected to one side of the master cylinder. The piston is centered by a spring on each end. An electrical switch is placed in the center of the piston. The switch will be grounded whenever the piston moves to one side. This completes an electrical circuit through the instrument panel brake warning light.

The pressure differential switch in **Figure 24-25** is in the normal open or "light out" position. Each side has equal pressure and the piston remains centered. When one side of the system develops a leak, the pressure drops on that side of the valve. The piston is forced toward the low pressure side. It then touches the electrical switch contact stem and provides the ground needed to light the warning light.

Combination Valve

A ***combination valve*** contains either two or three of the valves discussed above. They are called the *two-function valve* and the *three-function valve*. The two-function valve combines the metering valve and the brake warning light switch in one unit. Some units may contain a proportioning valve instead of the metering valve.

The three-function valve houses the metering valve, the proportioning valve, and the brake warning light switch. These valves cannot be adjusted or repaired. If they are defective, the entire valve must be replaced.



Bendix

Figure 24-26. Brake tubing flares. A—Flare with nut in place. B—I.S.O. flare.

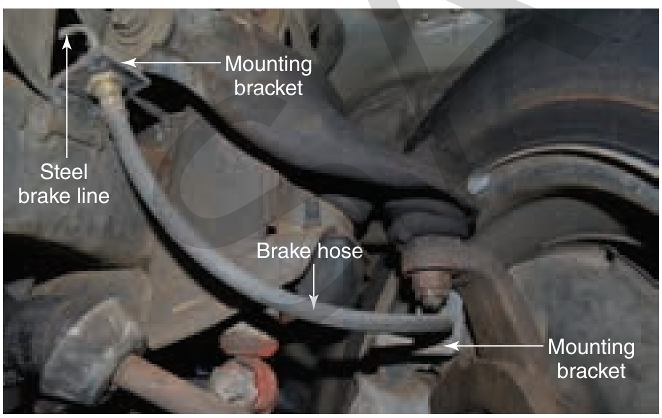


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Figure 24-27. Flexible brake hose. The hose connects the steel brake line to the wheel brake assembly.

Brake Lines and Hoses

The master cylinder is connected to the wheel cylinders by brake lines made of high-quality, double-walled steel tubing. The tubing is copper-plated and lead-coated to prevent rust and corrosion. Where brake tubing is connected, it uses a double lap flare or a special I.S.O. flare. See **Figure 24-26**.

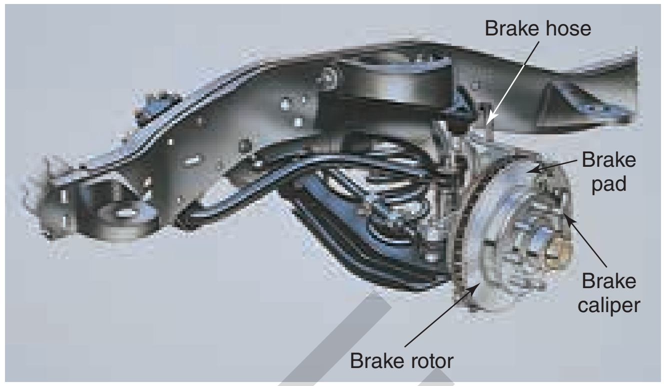
Brake lines must be replaced with high-quality double-walled steel tubing only. Use of poor quality or incorrect materials such as copper tubing or standard steel tubing can result in a potentially fatal accident.

Since the wheels move up and down in relation to the body, flexible, high-pressure brake hoses are used to carry fluid to each wheel cylinder or caliper piston. Using flexible hoses prevents line breakage as the wheels move up and down. **Figure 24-27** shows a flex hose leading from the brake line on its way to the wheel brake cylinder. Note that the line and hose, where connected, are securely held in a bracket.

All brake lines and hoses must be secured by brackets or clips. At no point must they be free to rub or vibrate. This will cause wear and fatigue with resulting line or hose failure.

Disc Brake Calipers

On modern vehicles equipped with disc brakes on the front and rear wheels, a ***disc brake caliper*** having one or more hydraulic cylinders is used, **Figure 24-28**. The caliper is bolted securely to the spindle. ***Caliper pistons***, which can be constructed from cast iron, aluminum, or ceramic materials, are fitted to the caliper cylinders with the outer ends resting against the friction linings. A bleeder screw is connected to the cylinder. Rubber boots exclude the entry of dirt and moisture.



Dodge

Figure 24-28. One particular front-wheel disc brake assembly as used on a rear-wheel-drive truck. Disc brakes have excellent cooling characteristics, making them very resistant to brake fade.

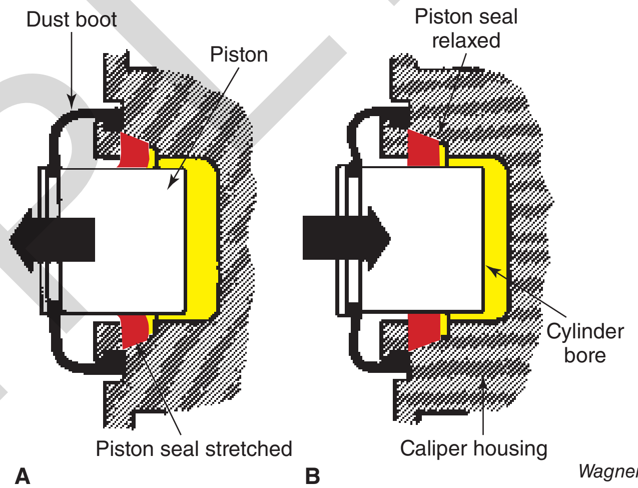
Caliper Operation

The caliper piston shown in **Figure 24-29** operates against a seal ring installed in a groove in the cylinder wall. On some calipers, the seal ring may be installed on the piston. When the brake is applied, the piston moves outward. In so doing, it stretches the seal to one side, **Figure 24-29A**.

When brake pressure is released, the seal returns to its normal position, **Figure 24-29B**. This seal roll action pulls the piston back around 0.005″ (0.13 mm), providing a small amount of lining-to-rotor clearance. As the linings wear, the piston moves out through the seal, automatically keeping the proper clearance.

Modern disc brake calipers are called ***floating calipers***. The caliper can slide, or "float," on its mounting surface. When the piston pushes the inside pad into contact with the rotor, the entire caliper slides back, causing the outside pad to contact the rotor. As long as the caliper can slide, both pads will be applied whenever the brake pedal is depressed.

Non-floating brake calipers usually have two or four pistons. Most pistons in multiple arrangements are of equal size on each side of the rotor. **Figure 24-30** is a comparison of sliding and non-sliding disc brake calipers. All modern vehicles have disc brakes on the front axle. A decreasing number of vehicles have drum brakes on the rear because many models are offered with disc brakes on all four wheels.



Wagner

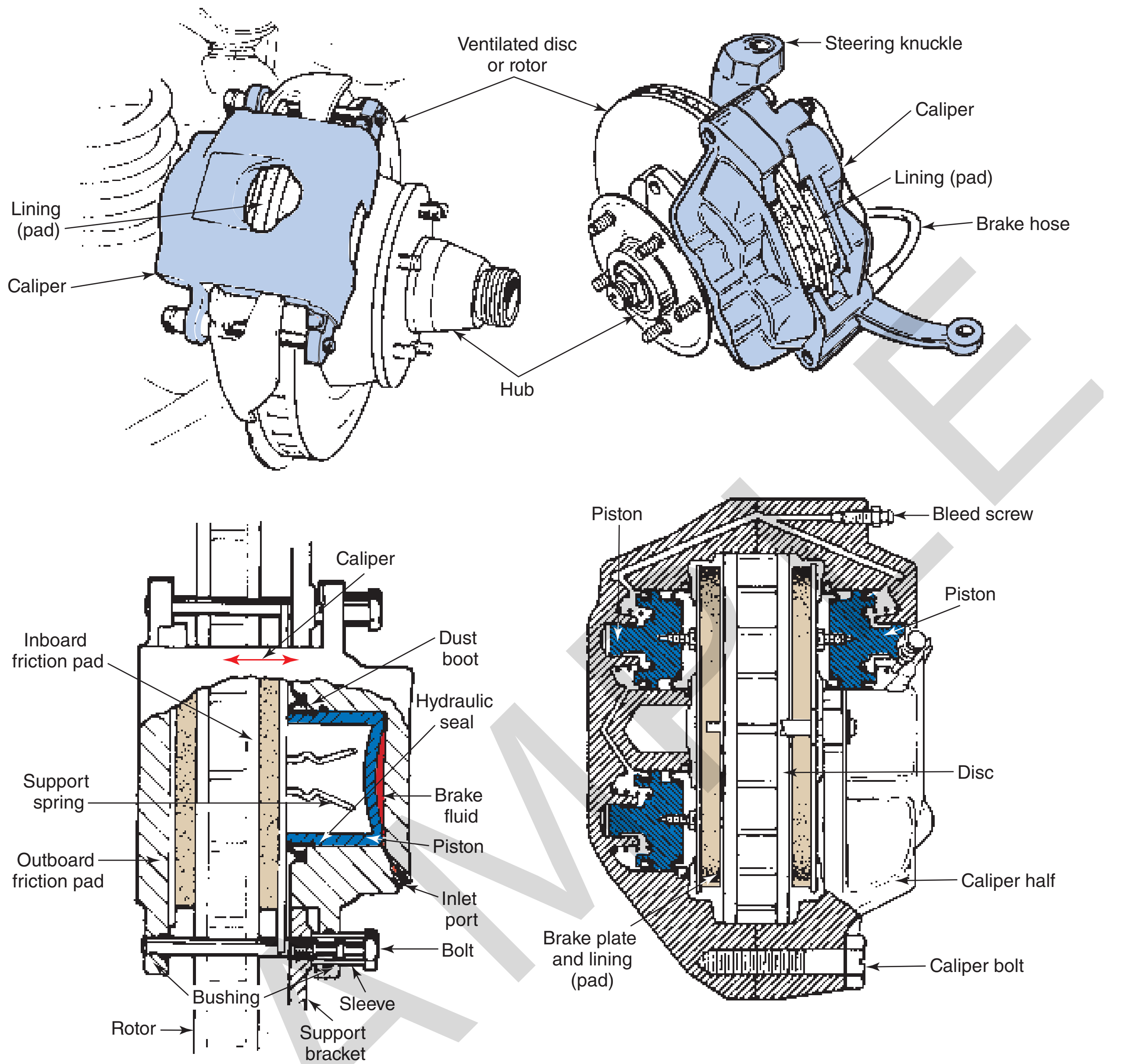
Figure 24-29. Piston seal pulls the piston back, providing pad-to-disc clearance. A—Brake piston applied. The piston moves outward and stretches the seal. B—Brake piston released. The seal rolls back to original shape, drawing the piston back with it.

Other Caliper Parts

Some calipers slide on separate pins that also serve to attach the caliper to the spindle assembly. Many calipers have clips that keep the pads from rattling when the brakes are not applied. These clips are usually attached to the inner pad and piston. Dampening devices are sometimes placed between the pad and caliper piston or housing to reduce the possibility of brake squealing.

Wheel Cylinders

Wheel cylinders are used with all drum brakes. The wheel cylinder is used to transmit the master cylinder pressure to the friction linings and force them outward against the drum. One wheel cylinder is used in each drum brake assembly.



FMC Corp.

Figure 24-30. Two different disc brake assemblies. A—A sliding (floating) caliper that uses one piston. B—A non-sliding (fixed) caliper that uses four pistons.

Wheel Cylinder Construction

The wheel cylinder assembly is of rather simple construction. It consists of a cast iron housing, two aluminum wheel cylinder pistons (iron pistons are sometimes used), two rubber cups, cup expanders, a lightweight coil spring, two push rods, and two rubber dust boots. These parts are shown in the cross-section in **Figure 24-31**. On some systems, the cup expanders and push rods are not used. The cylinder is drilled to provide for a bleeder screw (covered later) and the brake line connection. The cylinder is usually bolted to the brake backing plate (covered later).

Single-piston cylinders were used on a few older vehicles in which two wheel cylinders per wheel were used. Since each cylinder operated only one of the shoes, it was necessary to direct the pressure in only one direction. Another design sometimes used was the ***stepped wheel cylinder***, in which one half of the cylinder was one size, and the other half was another size.

Wheel Cylinder Operation

When the master cylinder forces fluid into the wheel cylinder, the two pistons move apart. Push rods, or links, connect each piston to a brake shoe. On some newer systems, the shoe is connected directly to the piston. As the pistons move outward, they force the shoes against the drum. Study the simplified illustration in **Figure 24-32**, which shows fluid action on the piston.

The cup design in the wheel cylinder is similar to the primary cup in the master cylinder. When the fluid exerts pressure against the cup, the flanged edges are pressed tightly against the cylinder. See **Figure 24-33**.

Hydraulic System Failure

A leak in the front wheel portion of the system would allow fluid to escape from the system and prevent pressure buildup. Note in **Figure 24-33A** that the primary piston moves in, forcing fluid from the burst portion of the system until the primary piston strikes the secondary piston. Additional pedal movement will cause the primary piston to physically move the secondary piston forward, transmitting normal brake pressure to the rear wheels.

If the rear brake system fails, the primary piston will force the secondary piston in until it strikes the end of the cylinder. The primary piston will then apply normal pressure to the front system as in **Figure 24-33B**. By providing separate systems for the front and rear brakes, the dual master cylinder will provide some braking force regardless of line failure. Although both front and rear systems could fail at the same time, such an event is highly unlikely.

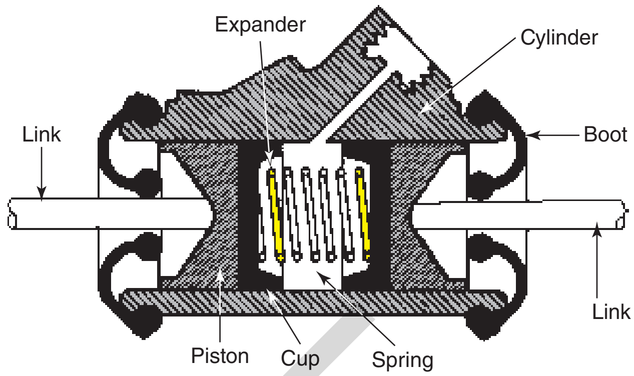


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Figure 24-31. Cross-section of a typical double-piston wheel cylinder. Stamped metal expander cups at each end of the spring tend to keep the lips of the rubber cups in constant contact with the cylinder wall.

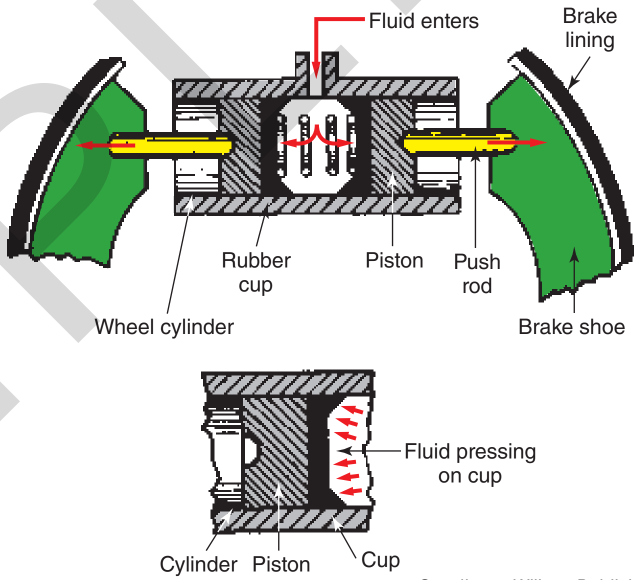

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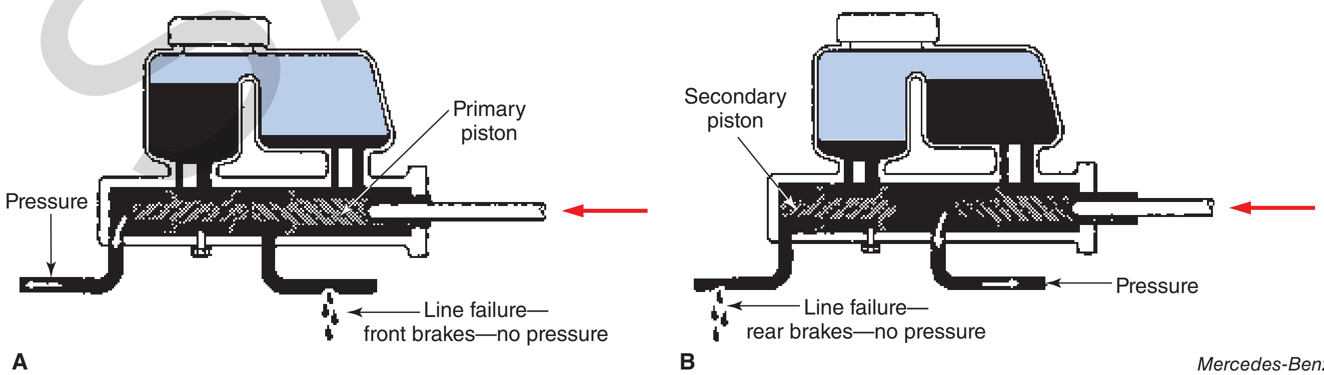
Figure 24-32. Simplified wheel cylinder action. Fluid under pressure enters the wheel cylinder and forces the pistons and push rods outward by pressing on the rubber cups.



Mercedes-Benz

Figure 24-33. Hydraulic failures can be disastrous. With the dual hydraulic system, some braking force can be maintained. A—A line failure in the front brakes will allow fluid to escape; however, the rear brake system retains its supply of fluid and braking action is maintained at a reduced level. B—If the rear brakes lose pressure, the hydraulic system can still apply the front brakes.

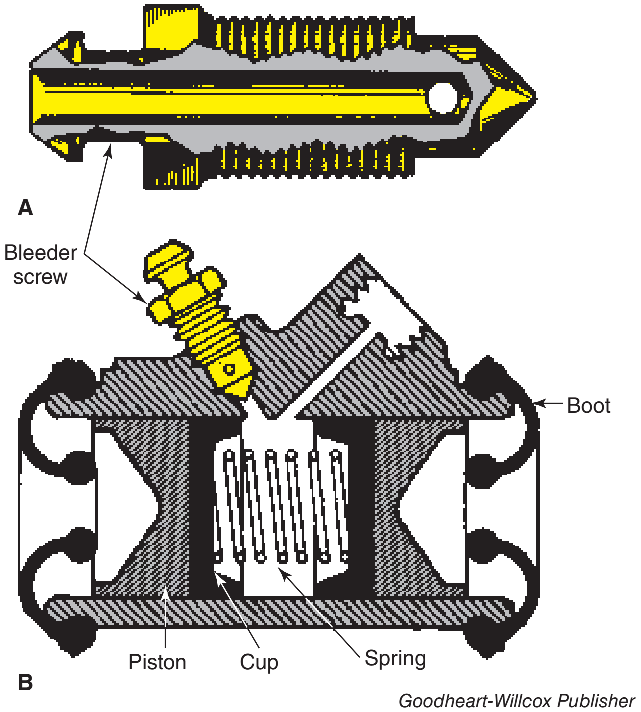


Figure 24-34. A—Cutaway of bleeder screw. B—Wheel cylinder showing bleeder screw.

Bleeder Screw

Since air is compressible, any air in a hydraulic system would render the system unfit for service. Air must be removed, so each caliper and wheel cylinder is equipped with a ***bleeder screw***. The bleeder screw is threaded into an opening leading into the center of the caliper or wheel cylinder. A bleeder screw installed in a wheel cylinder is shown in **Figure 24-34**.

The brake pedal is pumped several times and held to apply pressure on the master cylinder. The bleeder screw is loosened, allowing trapped air to escape. Then the bleeder screw is tightened before pressure is removed from the master cylinder. This process is repeated at each wheel until all of the air in the system is removed. When the screw is loosened, the tapered point uncovers the bleeder hole. This permits air to move up around the point, through the cross hole, and out the center passageway. When the screw is tightened, the point seals the opening.

Brake Friction Members

The purpose of the brake ***friction members*** is to physically stop the vehicle. These units, including disc brake pads and rotors and brake shoes and drums, change physical movement into heat by the use of friction. Every wheel contains either a disc or drum brake assembly.

The kinetic energy (energy in a moving object) in the moving vehicle is converted into heat by the brakes. A fast-moving vehicle has tremendous energy. To bring it to a stop will produce a great amount of heat. Most of the heat is given off by the friction members to the surrounding air.

Coefficient of Friction

Friction is created whenever two objects are rubbed together. The ability of materials to slide across each other is called the ***coefficient of friction***. The coefficient of friction is calculated by dividing the force needed to push a load across a given surface by the weight of the load.

For example, if it takes 5 pounds (2.25 kg) of force to move a 10 pound (4.5 kg) block across a smooth surface, the coefficient of friction between the two surfaces is 5 divided by 10 (2.25 kg divided by 4.5 kg) or 0.5. If it takes 10 pounds (4.5 kg) of pressure to move the same block across another surface, then the coefficient of friction is 10 divided by 10 (4.5 kg divided by 4.5 kg) or 1. This system is used to determine how various friction materials will act in combination with a brake rotor or drum to stop a vehicle.

To determine the coefficient of friction for a brake system, change weight to pressure and change sliding force to momentum. For instance, a 3000 pound (1359 kg) vehicle traveling at 25 mph (45 kph) has a momentum of 62,700 foot-pounds (85,000 Nm). Pressing the brake pads against the rotors with a steady pressure of 500 psi (3450 kPa) brings the vehicle to a stop. Dividing the applied pressure by the momentum gives a coefficient of friction of about 0.008. While this does not seem like much, it occurs with every revolution of the wheels. The coefficient of friction can never be more than 1, or the brakes would lock the wheels.

Friction Linings

Brake linings are made from materials that will produce friction with the rotor or drum and withstand the high temperatures developed during braking. In the past, brake linings were made from ground asbestos fibers pressed into shape. Since asbestos has been shown to cause respiratory problems and cancer, most modern brake pads and shoes are made without asbestos.

Current linings are made from synthetic and steel fibers, and iron, ceramic, and metallic powders. Linings made from these materials are usually referred to as ***semi-metallic***. For heavy-duty braking, special metallic linings, which are very resistant to brake fade, are used.

Brake Fade

Each time the brake friction members slow or stop vehicle movement, tremendous heat is created. If some method were not incorporated to dissipate this heat, the brake components would become so hot that they would cause other parts to catch fire. Therefore, brake friction materials are designed to melt at a certain temperature. When heat causes the friction material to melt, the rotor or drum slides over the melted friction material. No more friction is available to produce more heat. This is called ***brake fade***.

With no friction, braking is reduced, or even vanishes entirely. Even hard pedal pressure will not produce fast, even stops. If the brakes fade under normal driving, the cause must be found and corrected. Vehicles used in high-speed and heavy-duty applications have metallic linings that have great resistance to fade.

Disc Brake Assembly

The disc brake uses a ***rotor*** as its friction surface. The rotor is bolted to and revolves with the wheel hub. ***Disc brake pads*** are installed in the caliper that surrounds the rotor. The rotor is stopped when the brake pads are pressed against it by the caliper piston (discussed earlier). Most calipers are single piston types.

Older designs allowed the brake pads to drag very lightly against the rotor at all times. To reduce drag and improve fuel economy, modern disc brake systems operate with only a minimal pad-to-disc clearance (about 0.005″ or 0.13 mm). The disc brake pads are self-centering and press on each side of the rotor with equal pressure.

Disc brakes resist brake fade because the rotor's larger surface area is exposed to the open air. Rotors are made of cast iron for maximum heat absorption. Some high-performance rotors have an aluminum core with cast iron core braking surfaces. The rotor may be solid or have fins and/or drilled holes for cooling, **Figure 24-35**. Despite the fact that the rotor is exposed to water and dirt, the disc brakes work well during wet or dry operation without grabbing. Due to the relatively small friction area and the lack of servo or self-energizing action common in drum brakes, disc brakes require a higher operating hydraulic pressure.

Brake Pad Construction

Brake pads consist of friction materials bonded (glued) or riveted to a metal plate. Past friction materials included asbestos, which has been replaced with various high temperature compounds. These compounds are mixed with metallic compounds into a matrix to make a semi-metallic friction material. Some heavy-duty. high-temperature brake applications use friction materials made up almost entirely of various metals.

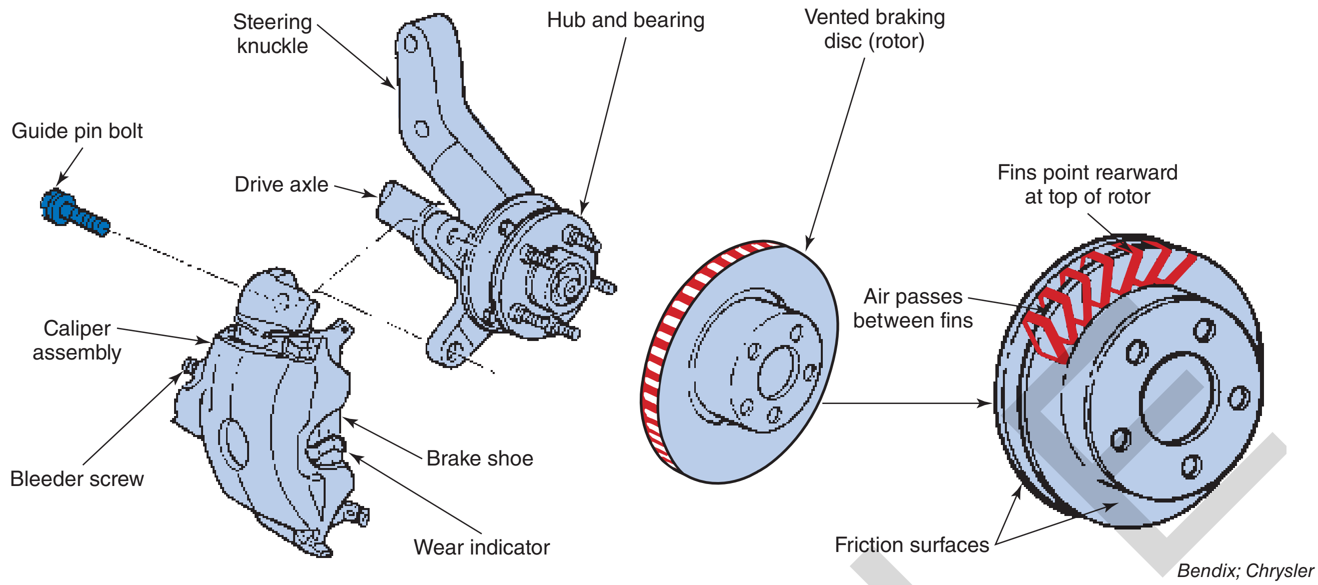


Figure 24-35. A disc brake assembly from a front-wheel-drive vehicle equipped with finned brake rotors. Air that passes between the rotor fins while the vehicle is moving helps to dissipate the heat.

Figure 24-36. The tab on this type of pad wear indicator contacts the rotor when the pads have worn excessively. The contact with the tab and rotor produces a squeal that warns the driver of pad wear.

Figure 24-37. This pad wear indicator alerts the driver of worn pads by illuminating a warning light on the instrument panel. Note the electrical connector.

Pad Wear Indicators

If the brake pads wear down until the metal backing contacts the rotor, stopping power will be poor and the rotor will be ruined. To warn the driver when the pads are excessively worn, two kinds of ***pad wear indicators*** are used.

The mechanical wear indicator is a metal tab that extends from the surface of one pad, **Figure 24-36.** As long as the pads are above a minimum thickness, the tab cannot contact the brake rotor. When the pads wear down to the replacement point, the tab contacts the rotor when the brakes are applied. The contact between the stationary tab and spinning rotor creates a high-pitched noise, warning the driver that the pads are worn. Eventually the tab will contact the rotor at all times, producing a squeal whenever the rotor is turning.

The second kind of wear indicator warns the driver by completing an electrical circuit to illuminate a warning light. This design uses sensor wires imbedded in the pad material. The wires are connected to a positive current source through a warning light on the instrument panel. When the pads are above the minimum thickness, the sensor wires are insulated from the rotor by the pad material. Once the pads are worn down to the replacement depth, the sensor wires contact the rotor when the brakes are applied. This completes an electrical circuit through the rotor, spindle, and frame, and illuminates the warning light. This type of pad can be identified by the presence of an electrical connector, **Figure 24-37.**

Backing Plate

A round, stamped sheet metal or steel plate is bolted to the front spindle, or to the end of the rear axle housing. This ***backing plate***, when used for disc brakes, serves as a shield for the caliper and rotor. When it is used for drum brakes, it serves as the foundation upon which the wheel cylinder and brake shoe assembly is fastened. The backing plate is rigid and cannot move in any direction.

Drum Brake Assembly

Each drum brake assembly consists of the brake backing plate, a set of brake shoes, shoe retainer clips and return springs, and a brake drum. These components are covered in the following sections.

Brake Shoe Assembly

All drum brake assemblies use two ***brake shoes***. These shoes are made of stamped steel and have brake linings either riveted or bonded to the outer surface. Although of similar design, there are some minor differences in the shapes of the shoes. All utilize a T-shape cross-section, **Figure 24-38**. A web is used to give the shoe rigidity. When forced against the drum, it will exert braking pressure over the full lining width and length.

The brake shoe ends may be free-floating or they may have one end fastened to an anchor. The primary (front or leading) brake shoe faces toward the front of the vehicle. It often has a different size lining than the other shoe. The secondary (rear or trailing) brake shoe faces the rear of the vehicle. Some newer drum brake assemblies use brake shoes that can be mounted in either position.

Brake return or retracting springs are used to pull the shoes together when hydraulic pressure is released. Small spring clips of various designs are used to keep the shoes against the backing plate to ensure shoe alignment and prevent rattle. Study the typical arrangement of parts shown in the exploded view of a drum brake assembly in **Figure 24-39**.

Brake Drum

The ***brake drum*** fits between the wheel and hub and completely surrounds the brake shoe assembly. It comes very close to the backing plate so that water and dust cannot enter easily. The center section is constructed of stamped steel, with an outer cast iron braking rim.

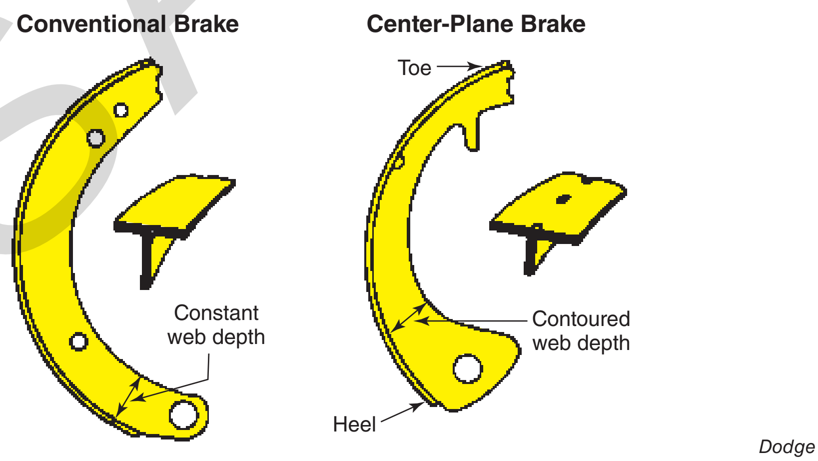


Figure 24-38. Two brake shoe designs.

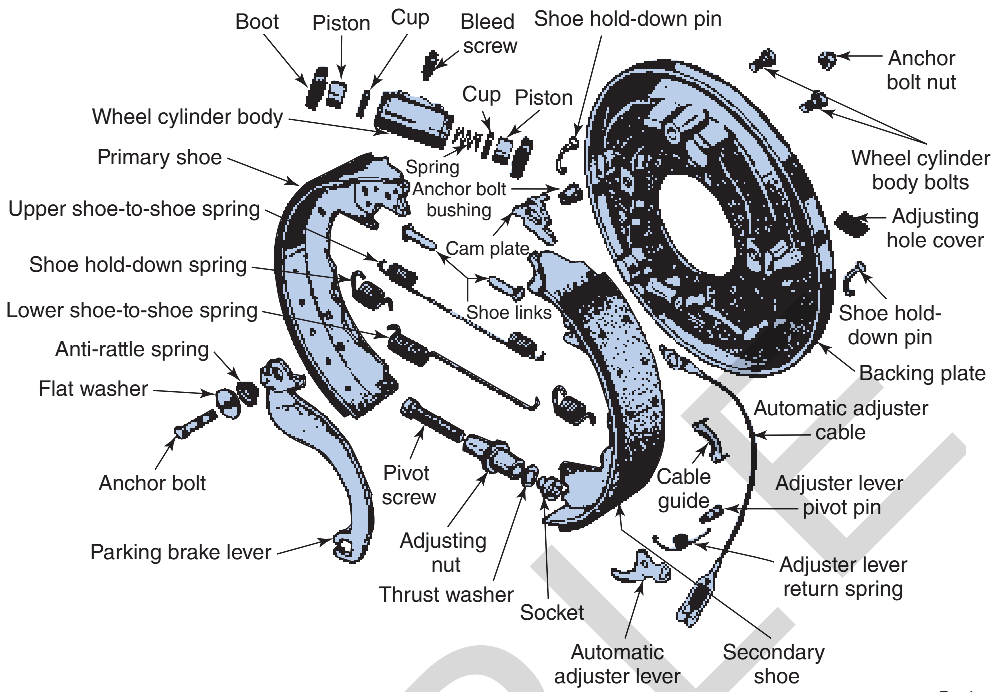


Figure 24-39. Exploded view of a backing plate and brake shoe assembly.

The heavy casting enables the drum to absorb and dissipate heat from the braking process without distorting. Cooling fins are often cast into the rim to assist in heat dissipation. The braking area of the drum must be smooth, round, and parallel to the shoe surface. When the wheels turn, the drum revolves around the stationary brake shoes.

Drum Brake Operation

When hydraulic system operation creates pressure in the wheel cylinder, the wheel cylinder pistons and links move the brake shoes outward into contact with the revolving brake drum. Since the shoes cannot revolve, they will stop the drum and wheel.

Drum Brake Arrangement

There are many arrangements used in mounting drum brakes. Several popular ones are illustrated in this chapter. Drum brakes on larger vehicles utilize ***servo action*** (one shoe helps to apply the other), as well as ***self-energizing action*** (using frictional force to increase shoe-to-drum pressure). Drum brakes on smaller vehicles use ***non-servo action***.

Servo Action, Self-Energizing Brakes

Servo and self-energizing action is produced by hooking the heel of the primary shoe to the toe of the secondary shoe. When the wheel cylinder forces the top ends of the shoes against the revolving brake drum, it will try to carry the forward shoe around. As the primary shoe attempts to revolve, it will jam the secondary shoe against the single anchor pin. This stops both shoes and produces a binding effect that actually helps the shoes apply themselves. This servo and self-energizing action reduces the amount of pedal pressure needed.

Note how the primary shoe in **Figure 24-40** attempts to rotate in the direction of the drum. Since the adjusting screw connects it to the toe of the secondary shoe, the heel of the secondary shoe is jammed against the anchor pin. The arrows illustrate the braking force direction. When the vehicle is traveling in reverse, the secondary shoe applies the primary shoe.

The primary shoe lining on self-energizing brakes generally is smaller and of a different composition. The secondary shoe does more of the braking, so less lining material is needed on the primary shoe. A servo action, self-energizing brake assembly is shown in **Figure 24-41**. Note that the primary shoe has less lining. The star wheel at the bottom is used to adjust the shoes to keep them close to the drum.

Non-Servo Brakes

Non-servo brakes have a fixed anchor in place of the star wheel adjuster at the bottom of the brake shoe assembly. The front shoe is applied by wheel cylinder pressure and contacts the drum. The turning drum forces it into contact with the fixed anchor point. The rear shoe is also applied by the wheel cylinder and contacts the drum. Drum rotation causes it to push against the rear wheel cylinder piston. Front and rear non-servo brake shoes are usually the same size.

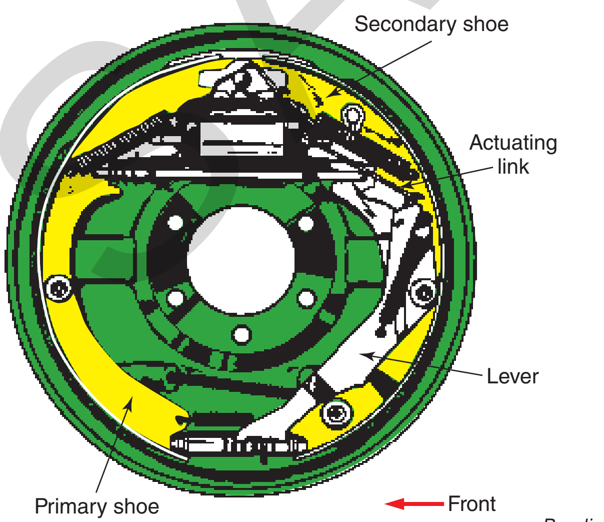
Self-Adjusting Brakes

Modern drum brake systems are self-adjusting. Each uses a series of springs, levers, and cables that automatically adjusts the drum-to-lining clearance as the linings wear down. Manual adjustment is provided by turning the star wheel with a special adjusting tool.

The adjustment systems are of three general types. Some systems operate only when braking in reverse, others in a forward direction, and others when braking in either direction.

Lever Adjuster

An adjustment lever is attached to one of the brake shoes in such a manner that it is free to pivot back and forth. One end engages the teeth in the star wheel, while the other is attached to a link, as in **Figure 24-42**. The link is attached either to the anchor (adjustment will take place



Bendix

Figure 24-42. Lever-type automatic brake adjuster. This unit functions only when braking in reverse.

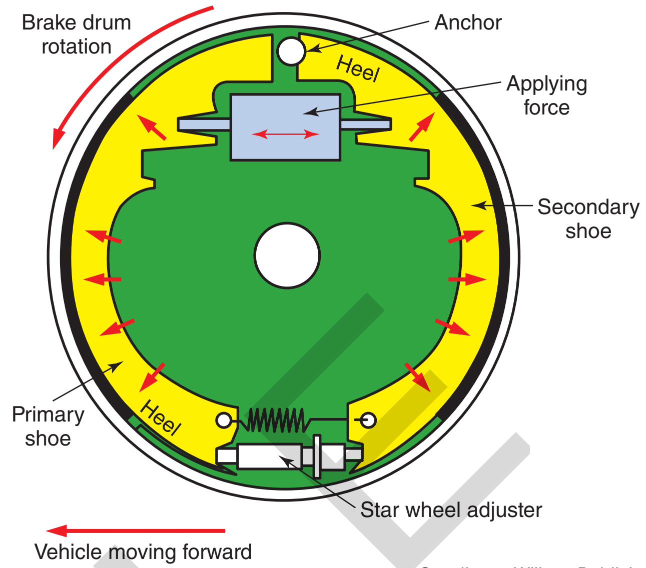


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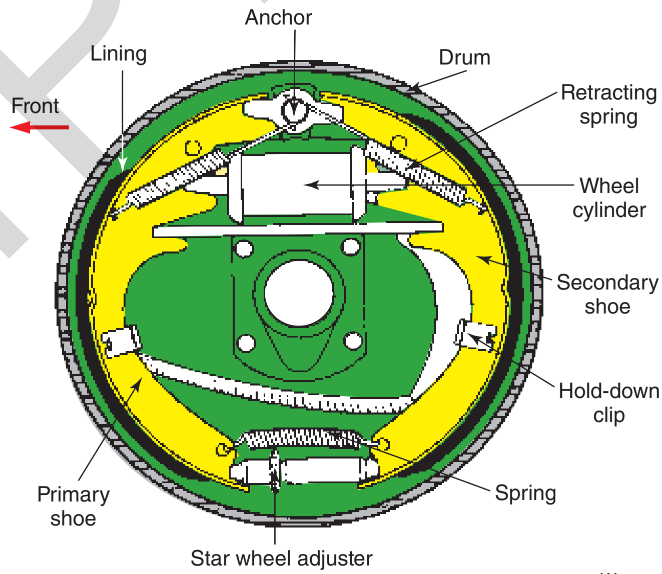
Figure 24-40. Servo action, self-energizing drum brake. When actuated, the primary shoe starts to move with the drum and in so doing, applies the secondary shoe.



Wagner

Figure 24-41. Servo action, self-energizing drum brake. The primary shoe (left) has a short lining when used in this setup.

when braking in one direction only) or to the other brake shoe (will function when braking in either direction).

A spring holds the adjustment lever in a downward position. Since the actuating link is attached to the anchor, it will operate only in one direction. On brake assemblies where the lever is pivoted to the secondary shoe, it will function only during reverse braking.

Cable Adjuster

A cable adjuster mechanism is shown in **Figure 24-43**. This particular unit passes the actuating cable up over the anchor and attaches it to the secondary shoe, causing it to function when braking in either direction.

When the brakes are applied, the shoes move out until they contact the rotating drum. They will then move around with the drum until the secondary shoe heel engages the anchor. The small out-and-around movement tightens the actuating cable and pulls it upward on the adjustment lever a small amount. When the brakes are released, the shoes are retracted, causing the actuating cable to become slack, and the return spring pulls the adjustment lever back down. This action is repeated during each brake application.

Since the amount of lever movement is very small, the cable will not normally draw the lever up far enough to engage a new tooth on the star wheel. However, when sufficient lining wear has taken place, the cable movement will be enough to draw the lever up to the next tooth on the star wheel. When the brakes are released, the return spring will draw the lever down, forcing it to rotate the star wheel one tooth. This adjustment action will take place during the entire life of the lining.

Link Adjuster

The link adjuster is very similar to the cable type. Instead of using a cable, it uses two separate links that perform the same task. The use of links instead of the cable is the basic difference, **Figure 24-44**.

Parking Brakes

On most modern vehicles, the ***parking brakes***, sometimes called the ***emergency brakes***, are part of the rear brake assemblies. This basic system is used with both drum and disc rear brakes. In most parking brakes, a foot pedal or hand-operated lever is connected through linkage and cables to both rear brake assemblies. When the emergency brake is applied, the cables pull a lever in each rear brake assembly.

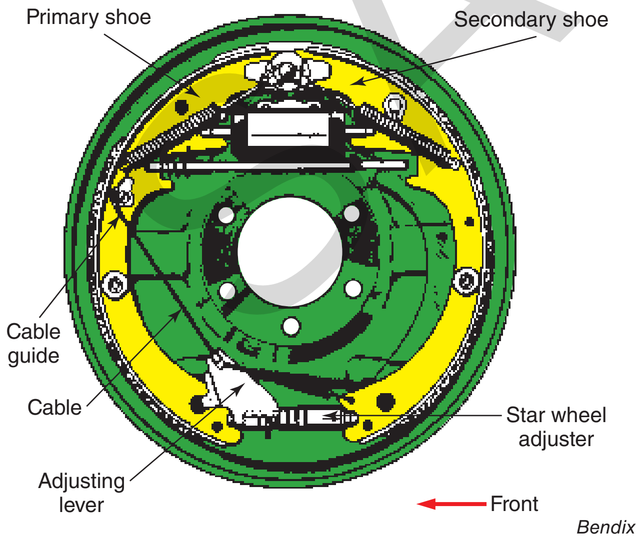


Figure 24-43. Cable-type automatic brake adjuster. This specific drum brake setup works when braking in either direction.

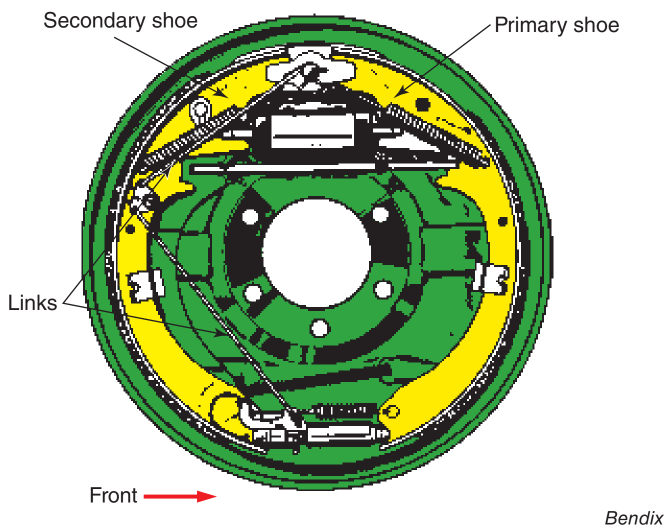


Figure 24-44. Link-type automatic brake adjuster. This type of adjuster functions during reverse braking.

Drum Parking Brake Operation

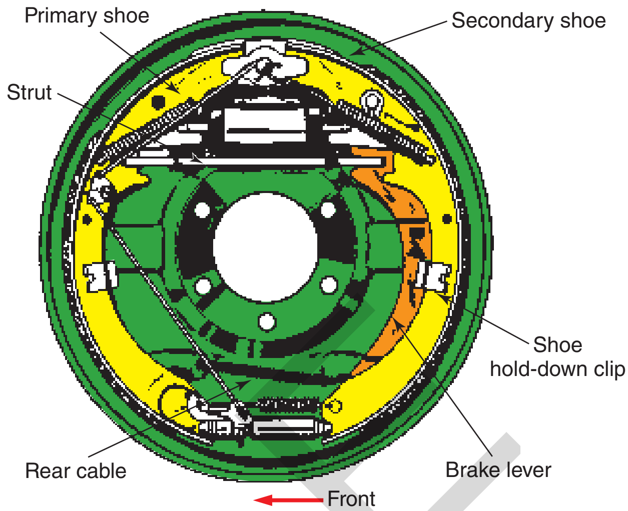
The top of the lever is bolted to one shoe and one end of a strut (steel bar) is notched into the lever below the top bolt. The other end of the strut is notched into the opposite shoe. The emergency brake cable is attached to the lower end of the lever. See **Figure 24-45**.

When the cable pulls the bottom of the lever toward the left, the lever forces the strut to the left until it presses the shoe against the drum. At this point, continued movement of the lever causes it to pivot on the strut. This moves the lever and shoe to which it is bolted to the right until it engages the drum. Any further lever movement will now apply force to both shoes.

Caliper Parking Brake Operation

Vehicles equipped with rear disc brakes incorporate an integral thrust screw mechanism in the caliper piston. This caliper is similar to the front caliper in design and operation. The parking brake is actuated by a lever located on the inboard side of the caliper. The lever is moved by the parking brake cable.

As the lever is applied, it rotates the thrust screw, which forces the piston assembly against the shoe and lining. Continued application moves the caliper, bringing the outboard shoe and lining into contact with the rotor, firmly holding it in position. An exploded view of this caliper setup is shown in **Figure 24-46**.



Bendix

Figure 24-45. Rear-wheel parking brake assembly. Rear cable pulls on brake lever, thus causing strut to spread and apply the brake shoes.

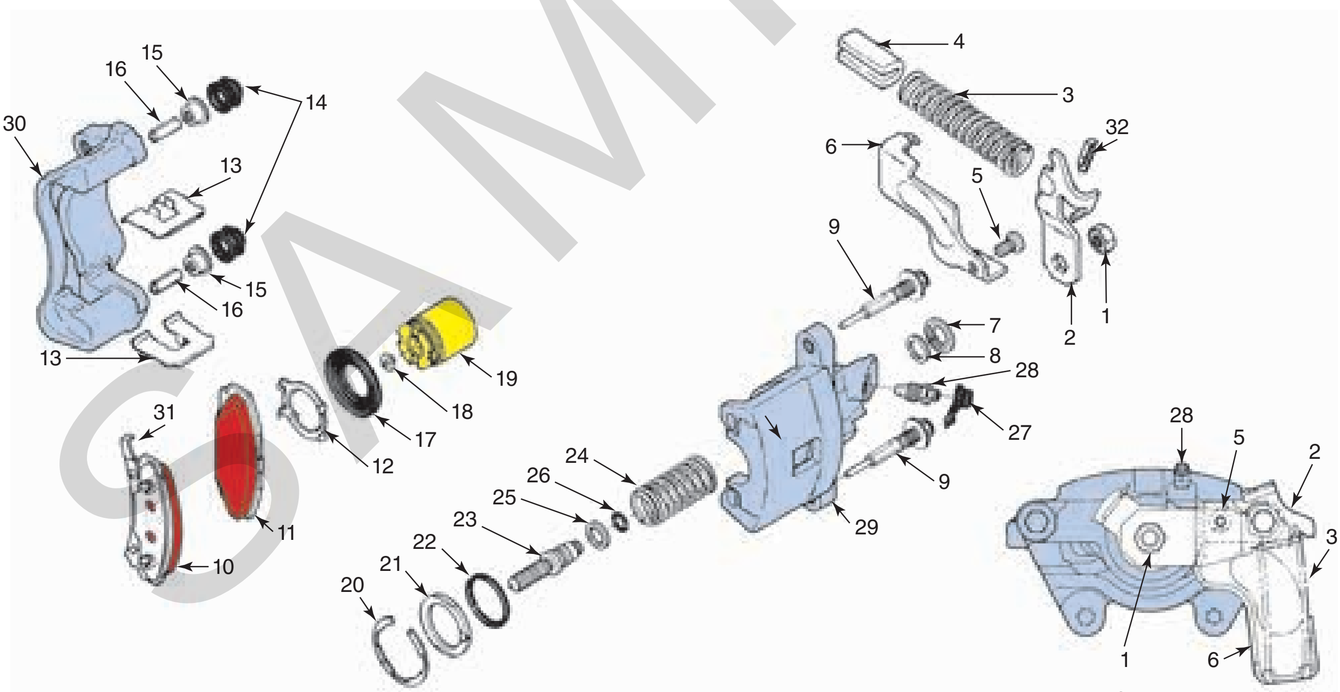


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Figure 24-46. Exploded view of a rear disc caliper assembly. Note that this unit incorporates an integral parking brake setup. 1—Nut. 2—Parking brake level. 3—Return spring. 4—Damper. 5—Bolt. 6—Bracket. 7—Lever seal. 8—Anti-friction washer. 9—Mounting bolt. 10—Outboard shoe and lining. 11—Inboard shoe and lining. 12—Shoe retainer. 13—Insulator. 14—Bolt boot. 15—Support bushing. 16—Bushing. 17—Caliper piston boot. 18—Two-way check valve. 19—Piston assembly. 20—Retainer. 21—Piston locator. 22—Piston seal. 23—Actuator screw. 24—Balance spring and retainer. 25—Thrust washer. 26—Shaft seal. 27—Cap. 28—Bleeder valve. 29—Caliper housing. 30—Bracket. 31—Wear sensor. 32—Retaining clip.

Electrically Operated Parking Brakes

An increasingly common parking brake is the ***electric parking brake***. There are two types of electric parking brakes. One design uses an electric motor to pull the conventional emergency brake cable. The other type has two computer-controlled motors attached to each rear brake caliper. Most of these systems are controlled by the ECM. Some control systems are designed so the emergency brake applies when the vehicle stops and releases when the accelerator pedal is pressed. This keeps the vehicle from rolling on inclines. The vehicle operator can turn off the system when necessary.

Power Brake Systems

Most modern vehicles are equipped with ***power brakes*** as standard equipment. The power brake unit is an additional part that operates with the hydraulic system. Power brakes reduce the amount of pedal pressure necessary to stop the vehicle. Pedal travel (distance from release position to full brake application) can also be shortened. Power brakes can be vacuum or hydraulically assisted.

Vacuum-Assisted Power Booster

The ***vacuum power brake booster*** is a closed cylinder with a piston inside. One side of the piston is connected to the master cylinder piston. The other side is connected to the brake pedal. A ***vacuum control valve*** is placed between the brake and the piston.

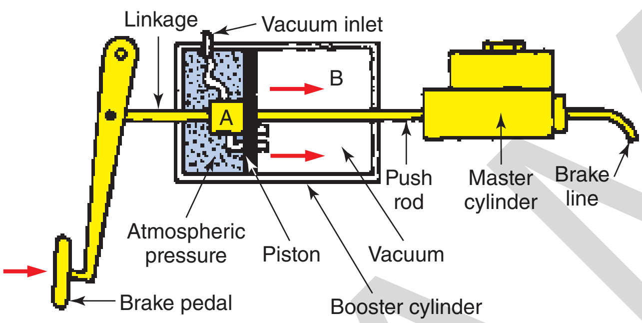

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Figure 24-47. Schematic of a simplified power brake booster. Engine vacuum is admitted through the vacuum inlet. Control valve A can apply either vacuum or atmospheric pressure to the B section of the booster cylinder. When the brake pedal is being applied, the pedal linkage causes control valve A to cut off atmospheric pressure and to apply vacuum to the B side. Atmospheric pressure is forcing the piston and push rod to the right, which builds pressure in the master cylinder.

Vacuum Power Booster Construction

A power brake booster operates from the vacuum produced in a gasoline engine. If the vehicle has a diesel engine, an engine-driven or electrically driven vacuum pump is used, because diesel engines do not provide sufficient vacuum for efficient brake booster operation. Vacuum pumps are used on some gasoline engines.

The vacuum control valve admits vacuum to one side of the piston, while the normal atmospheric pressure is allowed to exist on the other. This valve can also allow atmospheric pressure to reach both sides of the piston, **Figure 24-47**.

Vacuum- and Atmospheric-Suspended Booster

The ***vacuum-suspended booster*** has a vacuum on both sides of the diaphragm or piston when the booster is in the released position. When the booster is applied, atmospheric pressure is admitted to one side to cause the necessary movement of the piston. See the schematic in **Figure 24-48A**. An ***atmospheric-suspended booster*** has atmospheric pressure on each side of the piston in the released position. To cause booster action, vacuum is admitted to one side, **Figure 24-48B**. Most modern brake systems use the vacuum-suspended booster.

Vacuum Power Booster Operation

When the driver presses the brake pedal down, the vacuum control valve closes off the atmospheric pressure to the brake cylinder side of the piston. Further movement of the brake pedal opens a vacuum inlet passage to this same side. As there is atmospheric pressure on one side of the piston and a partial vacuum on the other, the piston will be

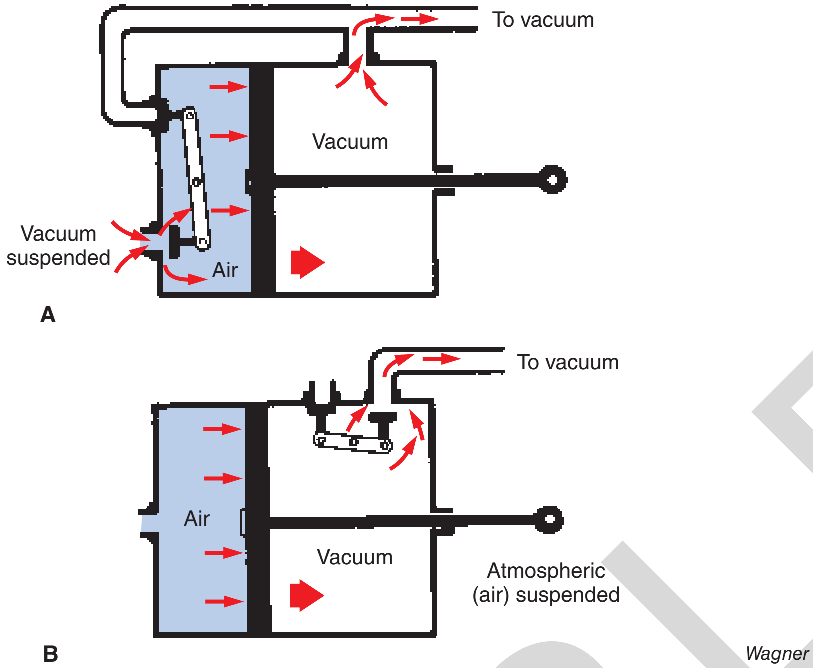

Figure 24-48. Power brake boosters. On both designs, the difference in pressure between the two sides moves the piston. A—Vacuum-suspended design. B—Atmospheric-suspended type.

forced toward the vacuum side. Since the piston is connected to the master cylinder piston, it will apply pressure to the brake system. The vacuum power brake has four stages of operation:

- Released position (brake pedal not being depressed).
- Applied position (brake pedal being depressed).
- Holding position (brake pedal with driver applying constant pressure).
- Releasing position (brake pedal being released).

These stages of operation are discussed in the following sections. Refer to the operational cross-sections in **Figure 24-49**.

Released Position

With the engine running and the brake pedal fully released, the valve operating rod and plunger are moved to the right by the return spring, **Figure 24-49A**. This presses the right end of the valve plunger against the face of the poppet valve, closing off the atmospheric port. The vacuum port is open, which allows vacuum to form on both sides of the diaphragm plate. The left side of the diaphragm is subjected to constant vacuum, regardless of plunger position. With a vacuum on both sides, the diaphragm return spring moves the diaphragm plate to the right, releasing all pressure on the master cylinder.

Applied Position

When the driver depresses the brake pedal, the valve operating rod is moved to the left, **Figure 24-49B**. This causes the valve plunger to move to the left. As the plunger moves, it will compress the return spring and move the poppet valve into contact with the vacuum port seat in the valve housing. This closes the vacuum port leading to the right side of the diaphragm.

Further application of the brake pedal will cause the valve rod to force the valve plunger away from the poppet, opening the atmospheric port. As the port is opened, atmospheric air will rush into the right side of the diaphragm (control vacuum area) and force the diaphragm plate to the left. This applies pressure to the master cylinder push rod.

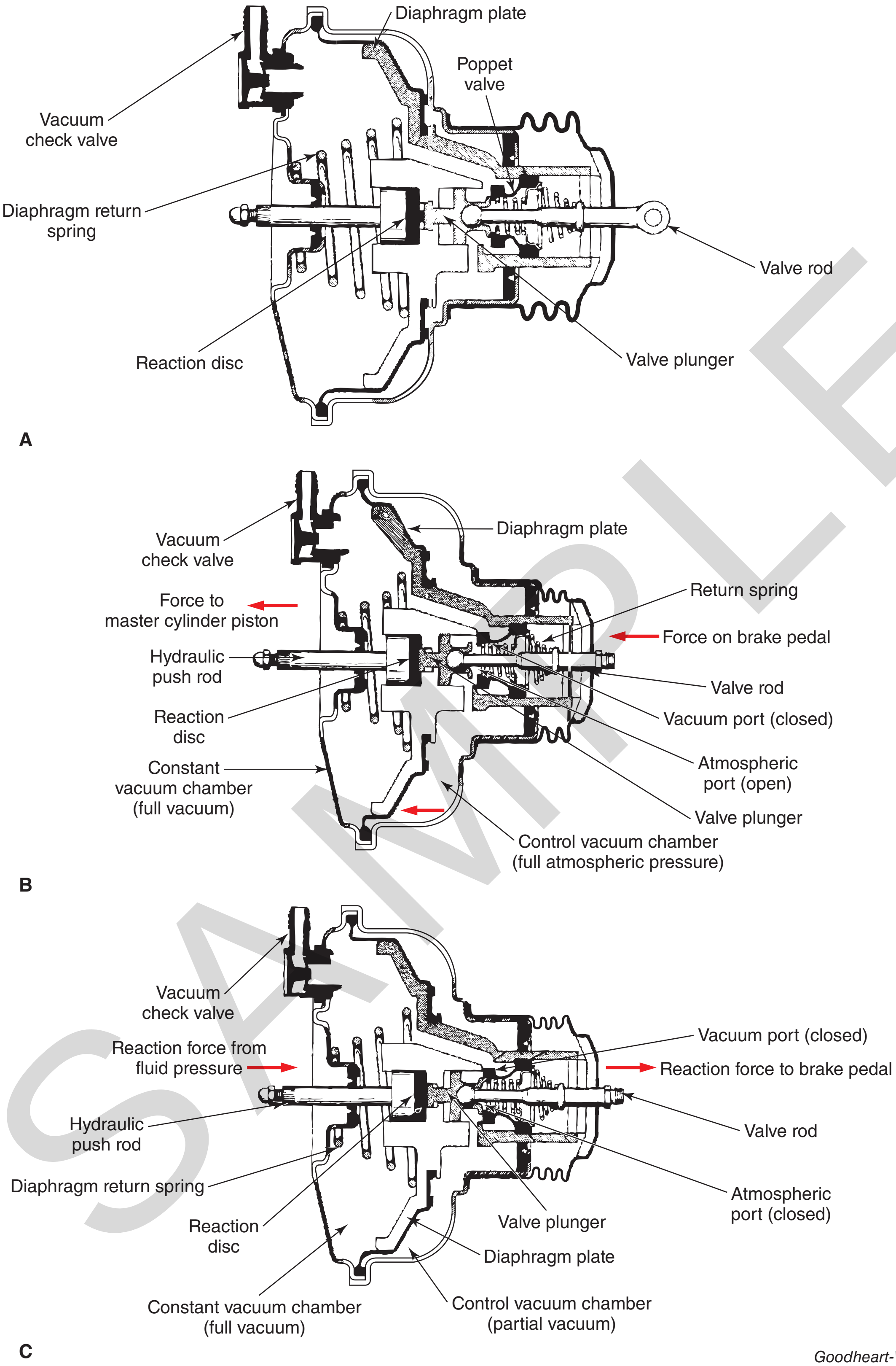

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Figure 24-49. Typical vacuum power booster action. A—Released position. Vacuum is on both sides of the diaphragm. The spring moves the diaphragm to the right. Pressure is not applied to the master cylinder. B—Applied position. The poppet valve closes the vacuum port and the valve plunger moves to the left, opening the atmospheric port. Atmospheric pressure forces the diaphragm plate toward the vacuum side. C—Holding position. Both vacuum and atmospheric ports are closed. This will retain the desired amount of braking.

Note in **Figure 24-49A** how the rubber reaction disc is compressed when the brakes are applied. As the master cylinder piston builds up hydraulic pressure in the brake system, a reaction pressure is transmitted back through the master cylinder push rod. The compressed rubber reaction disc transmits this pressure to both the diaphragm plate and the valve plunger. The pressure on the plunger valve tends to force it to the right (without moving the diaphragm plate), causing the valve to close off the atmospheric port.

The movement of the valve plunger is transmitted to the valve operating rod and on to the brake pedal. This provides the driver with brake feel to determine the amount of braking effort being exerted. This reaction force is directly proportional to pressure created within the master cylinder. Some power boosters use a reaction plate, levers, and diaphragms instead of the rubber disc. Note that the reaction disc in **Figure 24-49A** is not compressed and that a portion engages the valve plunger. Compare this with the compressed reaction disc shown in **Figure 24-49B**.

The ***vacuum runout point*** occurs when vacuum has built up the maximum pressure possible on the power piston or diaphragm plate. If more pressure than full vacuum can produce is desired, additional pressure must be exerted by the driver on the pedal. This will hold the vacuum port wide open and transmit all of the driver's effort directly to the master cylinder piston. Wheel lockup (tires will stop revolving and slide) or anti-lock cycling will usually occur before the vacuum runout point is reached.

Holding Position

As long as the driver increases pedal pressure, the valve plunger will move to the left. When the driver exerts the desired amount of pressure, plunger movement will cease. The reaction force, transmitted to the reaction disc, will move the valve plunger (without moving the diaphragm plate) a slight amount to the right. This shuts off the atmospheric port. The vacuum port also remains shut.

When this balanced condition occurs, the right side of the diaphragm plate will be subjected to a specific and unchanging amount of atmospheric pressure. This maintains a constant pressure in the brake system. If more pedal force is applied, the atmospheric valve is reopened, causing the diaphragm plate to exert additional pressure on the master cylinder. It will maintain this pressure until pedal and reaction forces are again balanced.

Figure 24-49C shows a power booster in the holding position. Both vacuum and atmospheric ports are closed. Note how the reaction disc has moved the valve plunger a little to the right (in relation to diaphragm plate), as compared with the applied position in **Figure 24-49B**. This action closes the atmospheric port.

Released Position

When the pedal is released, the atmospheric port closes and the vacuum port opens, exposing both sides of the diaphragm plate to vacuum. As the force is removed from the plate, the diaphragm return spring will push the plate and valve assembly to the right of the booster cylinder.

Tandem Booster

The ***tandem booster***, shown in **Figure 24-50**, uses two diaphragm plates to increase booster-to-master cylinder pressure. This has the effect of doubling the force of the vacuum in the same size booster. Tandem boosters are often found on larger cars, vans, and light trucks.

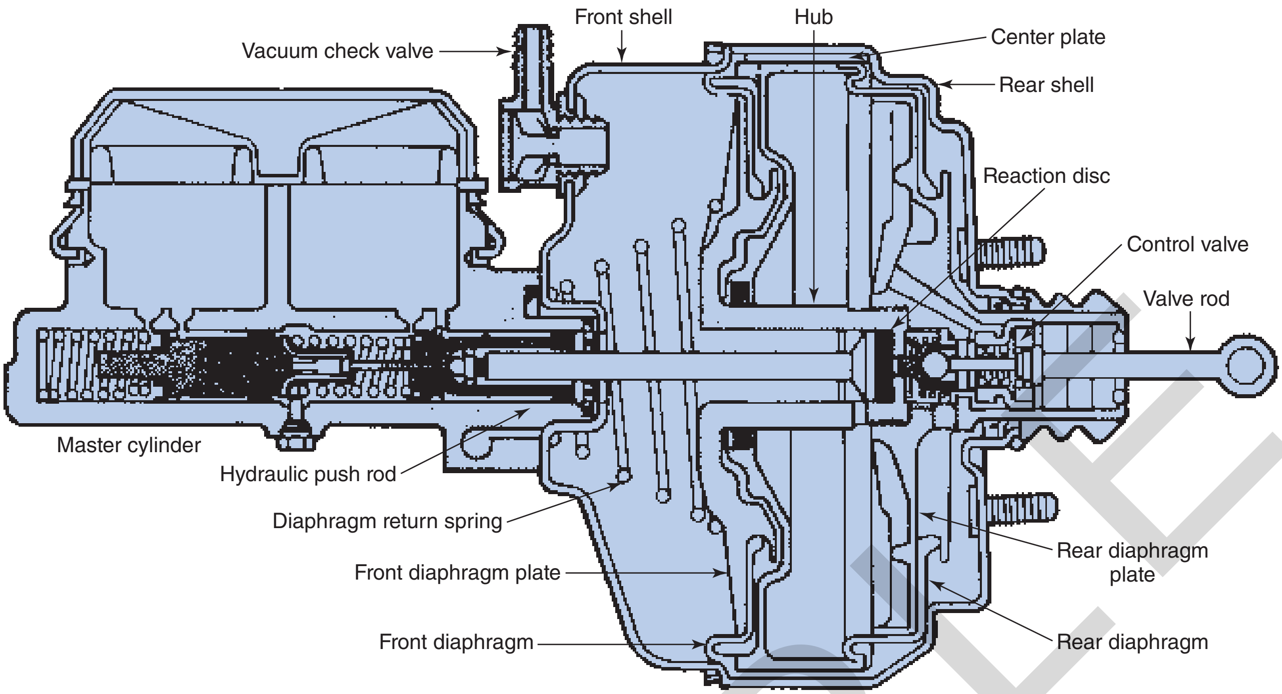

Figure 24-50. A cross-sectional view of a tandem (dual) vacuum power booster unit with attached master cylinder.

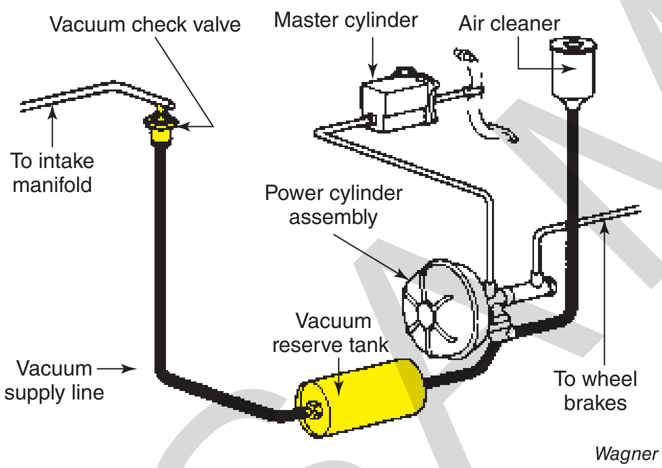

Figure 24-51. Vacuum reservoir tank. Reservoir allows one or two brake applications after engine vacuum is gone.

Vacuum Reservoir

As long as the engine is running, vacuum is available for the booster. When the engine stops, vacuum is gone. To provide several brake applications without engine vacuum, the booster is designed to maintain a ***vacuum reservoir***. Even though engine vacuum may be lost, enough vacuum will be retained in the booster body to provide one or more power-assisted stops.

Most modern vacuum booster systems have a check valve in the booster body itself. Note the check valve position in **Figure 24-50**. A separate reservoir, with a vacuum check valve, may be found on some older cars and a few large trucks. One type is shown in **Figure 24-51**.

Booster Failure

In the event the booster or the vacuum supply fails, the brakes may still be applied by foot pressure alone. It will require somewhat more pressure than when the booster is working, but the system will still function. Stopping distance will be greatly increased. Engine performance may also be affected if the failure is due to the loss of vacuum.

Hydraulic Pressure-Operated Power Booster

The ***hydraulic power brake booster*** (such as a Hydro-Boost®) is used on some vehicles, usually larger trucks and SUVs, and on cars with diesel engines. The hydraulic power booster is operated by hydraulic pressure developed by the power steering pump. Power steering pump pressure is delivered to the booster by high-pressure hoses. Some heavy-duty trucks employ an electro-hydraulic emergency pump as a backup source if the power steering pump becomes inoperative.

The hydraulic power booster system consists of a hydraulic pressure source and the hydraulic booster. **Figure 24-52** shows a typical pressure supply from the power steering pump. As with the vacuum booster, the hydraulic booster is coupled directly to the master cylinder. Movement of the brake pedal operates the booster valve, causing the booster to exert pressure on the master cylinder primary piston.

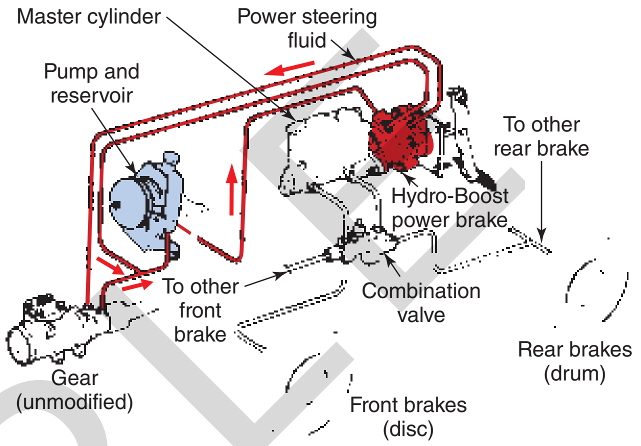

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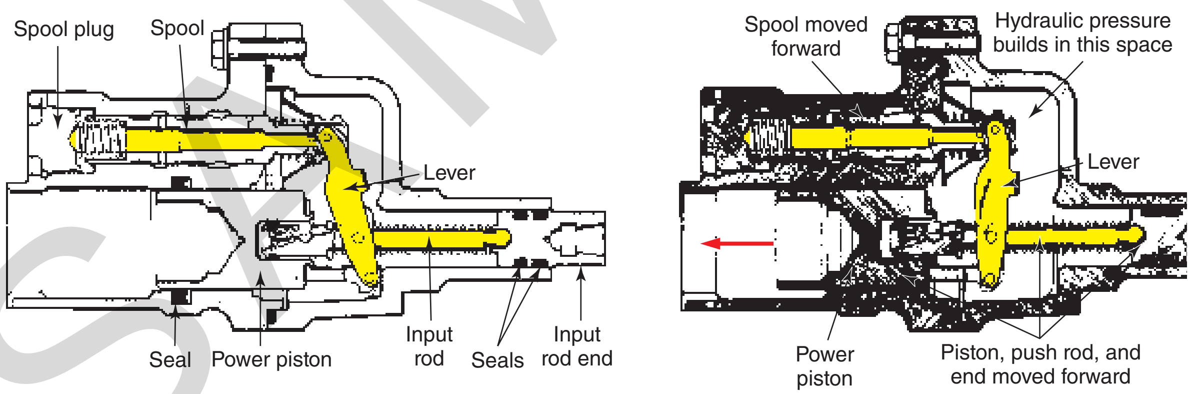
Figure 24-52. Hydraulic booster system. The pressurized fluid from the power steering pump is directed to the steering gear and then to the master cylinder. The brake and power steering fluid are separate from each other.

Hydraulic Power Booster Operation

In the fully released position, **Figure 24-53A**, power steering fluid flows through the booster power section on to the steering gearbox. No pressure is built up by the booster.

As the brake pedal is depressed, **Figure 24-53B**, the input rod and piston are forced forward. This action causes the lever to move the spool valve forward (toward the master cylinder), admitting more fluid into the space behind the power piston. As pressure builds, the power piston is forced forward, actuating the master cylinder.



Bendix

Figure 24-53. A—Cross-sectional view of one hydraulic power brake booster design. This booster is in the fully released position. B—Hydraulic booster in applied position. The lever has moved the spool forward, raising the fluid pressure behind the power piston. The piston moves forward to exert pressure on the master cylinder piston.

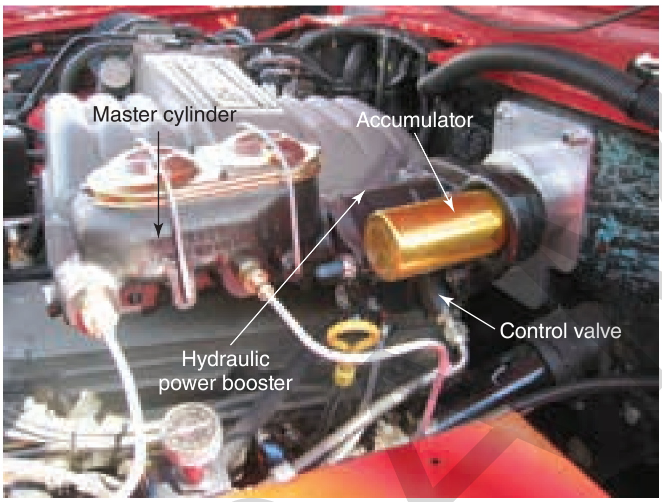
The amount of pressure exerted by the booster (up to its maximum output) is proportional to the pressure exerted on the brake pedal. Brake feel is provided by fluid pressure generated in the space between the inboard end of the input rod and the power piston. This fluid pressure attempts to force the input rod back against pedal pressure. This gives the driver the needed pedal feel so that correct foot pressure may be exerted. Excess hydraulic fluid pressure is first vented to the accumulator; any remaining pressure goes back to the power steering pump reservoir.

Hydraulic Accumulator

All hydraulic ***accumulators*** are either spring-loaded or contain gas under pressure. The accumulator is filled with fluid by the power steering pump and is pressurized whenever the brakes are applied. If the engine stalls or a problem occurs, such as a power steering pump failure or leak, or if the drive belt breaks, the accumulator will contain enough pressurized fluid to provide between one and three power-assisted brake applications. **Figure 24-54** shows an accumulator installed against a vehicle firewall.

Note

Some hydraulic brake boosters do not have an accumulator. Instead, an electric pump provides pressure if the power steering system fails.



Hydratech

Figure 24-54. A hydraulic power booster and accumulator installed between the master cylinder and vehicle firewall. The accumulator retains pressure for one or more brake applications in the event pump pressure is lost.

Even after the accumulator charge has been depleted, the brakes can still be operated by using pedal pressure only. As with all boosters that become inoperative, pedal resistance and stopping distance will be noticeably increased.

Warning

Accumulators contain strong springs or pressurized gas and can fly apart with lethal force. Special training is recommended before servicing these units.

Do not apply heat to an accumulator. For proper disposal, follow manufacturer's instructions.

Electric Power Booster

Some aftermarket brake parts manufacturers offer an electric power booster, designed to be installed between the brake pedal and the master cylinder. It is commonly used for racing and heavy-duty applications. Other high-performance suppliers offer an electric vacuum pump to produce additional vacuum when manifold vacuum is low.

Anti-Lock Brake Systems (ABS)

Most vehicles are equipped with ***anti-lock brake systems (ABS)***. Most ABS systems used on automobiles are similar to the one shown in **Figure 24-55** and control all four wheels. The ABS systems used on some older vehicles operate only the rear wheels (rear-wheel anti-lock or RWAL). These systems, whether two- or four-wheel, use electronic and hydraulic components to help prevent wheel lockup during hard braking.

Anti-lock brakes allow the driver to maintain directional control while providing maximum braking efficiency. The ABS system does this by pulsing (applying and releasing) the brakes much more quickly than the driver could. This keeps any of the wheels from locking and causing a skid.

Anti-Lock Brake System Components

Anti-lock brake systems use an electronic control system to modify the operation of the brake hydraulic system. The electronic and hydraulic components work together to prevent wheel lockup during periods of hard braking.

In the past, many kinds of ABS devices were tried. Some used pressure from the power brake or power steering system, while others were self-contained, electrically operated units independent of the base brake system. The modern ABS is connected to the base brake system and is a combination of:

- Hydraulic valves that control brake fluid pressures.
- Position motors and/or control solenoids.
- Electronic controls, usually a dedicated module and various sensors.

These parts work together to reduce brake hydraulic pressure when one or more wheels are about to lock up. Systems often contain other hydraulic components, such as pumps and accumulators. On newer vehicles, the ABS is combined with traction and stability controls.

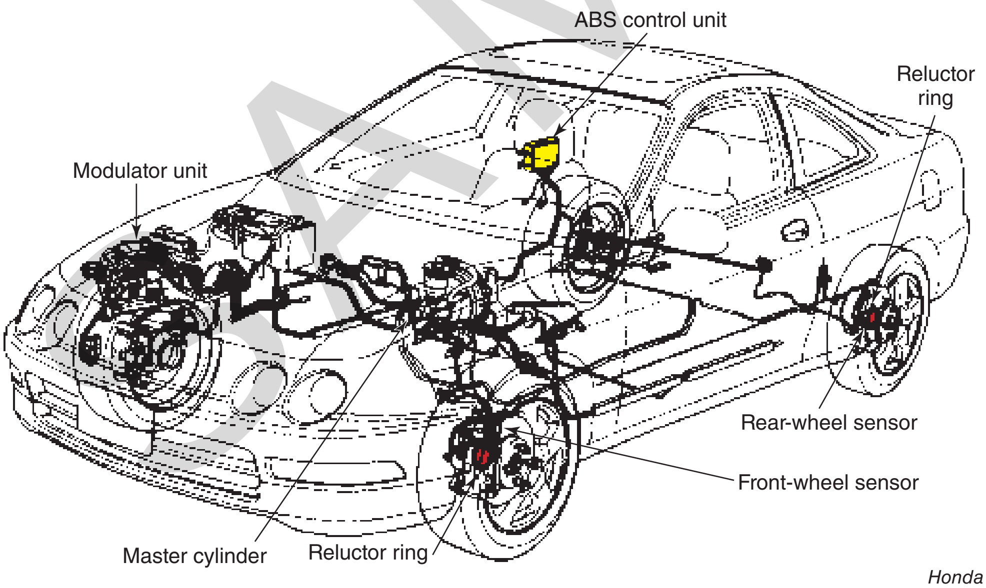


Figure 24-55. Overall view of a vehicle which is equipped with a four-wheel anti-lock brake system.

Most anti-lock brake systems, no matter who manufactures them, contain several common components. These components include ***wheel speed sensors***, a control module, and various hydraulic devices. The speed sensors can use a magnetic sensor that is acted on by a toothed tone ring, or, on some newer vehicles, a magnetic encoder with alternating positive and negative segments. Some vehicles also use G-force sensors and a pedal travel switch. Modern anti-lock brake systems have self-diagnostic capabilities.

Note that the brake friction components and most of the hydraulic components, such as wheel cylinders, caliper pistons, master cylinder, hydraulic lines, and power brake system components, are the same as those used on vehicles without ABS. When discussing ABS systems, the other friction and hydraulic components are referred to as the ***foundation brakes***, or the ***base brakes***.

Anti-Lock Brake System Operation

Refer to **Figure 24-56** as you read the following paragraphs. This figure illustrates the operation of a typical modern anti-lock brake system. The images are simplified to show basic ABS operation on one wheel only. An actual ABS has speed sensors at each wheel and a more complex hydraulic control valve assembly. **Figure 24-56A** shows normal brake operation as pressure is developed in the master cylinder and then is delivered to the brake caliper. The caliper piston moves the brake pads into contact with the rotor. In this figure, the ABS system has no effect on brake operation. The wheel speed sensors, however, are monitoring wheel rotation and communicating with the control unit at all times.

In **Figure 24-56B**, the wheel speed sensor and control module have determined that the wheel is about to lock up. The module causes the valve position motor to move the ABS valve, closing the passage between the master cylinder and the caliper. This prevents any additional pressure from reaching the caliper piston. The chance of wheel lockup is reduced. The original pressure is held in the line to the caliper piston and continues to apply the caliper.

If the wheel is still in danger of locking up, the wheel speed sensor input causes the control module to operate the position motor again. The position motor moves the ABS valve further in its bore, **Figure 24-56C**. Moving the valve opens a passage between the caliper line and the master cylinder reservoir. Pressure is released into the reservoir, reducing the braking force of the caliper piston.

When the wheel speed sensor indicates that there is no longer a danger of wheel lockup, the ABS control module returns the system to normal non-ABS operation. The process shown in **Figure 24-56** repeats many times per second until the driver releases the brake pedal.

Traction Control Systems

To reduce wheel spin when accelerating on slippery surfaces, some vehicles are equipped with a ***traction control system (TCS)***, also called *acceleration slip regulation*. These systems are able to reduce engine power and operate the brake system to increase vehicle acceleration and stability on wet, icy, or uneven road surfaces. Traction control systems also provide higher levels of cornering performance.

The traction control system can apply the brakes on the drive axles. On a two-wheel-drive system, it will control only the driving wheels. On a full-time four-wheel-drive system, it can apply any one of the four brakes. If the system detects one drive wheel spinning at a faster rate than the others, it will apply the appropriate amount of braking force to slow the wheel to the correct speed.

If the system determines that one or more drive wheels are spinning excessively, it can close the throttle or briefly retard ignition timing to prevent further spinning. Most vehicles with traction control also have an anti-lock brake system and are usually controlled by a single electronic control unit, **Figure 24-57**.

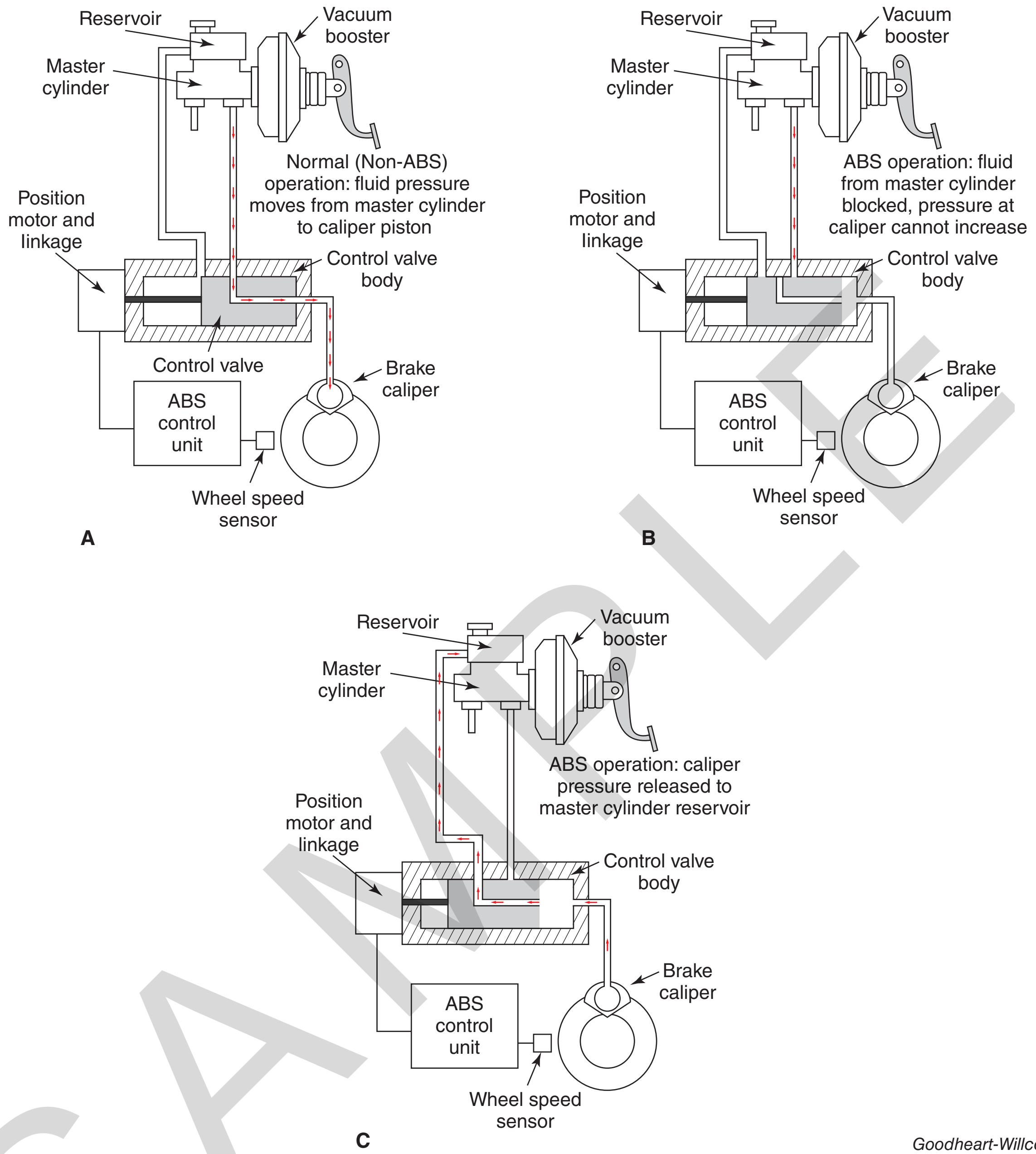


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Figure 24-56. ABS operation. A—The ABS is inactive and pressure developed in the master cylinder flows to the caliper piston with no restriction. The speed sensor signal indicates to the control module that no ABS action is necessary. B—The control module decides from speed sensor input that the wheel is about to stop turning (lockup). The control module activates the position motor, which moves the valve to block off the fluid passage between the master cylinder and caliper. The pressure in the caliper cannot increase or decrease. C—Based on speed sensor input, the ABS control module determines that more action is needed to prevent lockup. It again activates the position motor to move the valve. Valve movement opens a passage between the caliper line and reservoir, exhausting caliper pressure.

Electronic Stability Control

Vehicle operators must occasionally make a severe change in direction when driving, often to avoid a collision. Turning the steering wheel sharply changes the vehicle handling characteristics, and the vehicle will lose traction and steering control. When this happens, the vehicle may spin out of control, often sliding into another vehicle or a stationary object. Loss of steering control can sometimes cause the vehicle to roll over. ***Electronic***

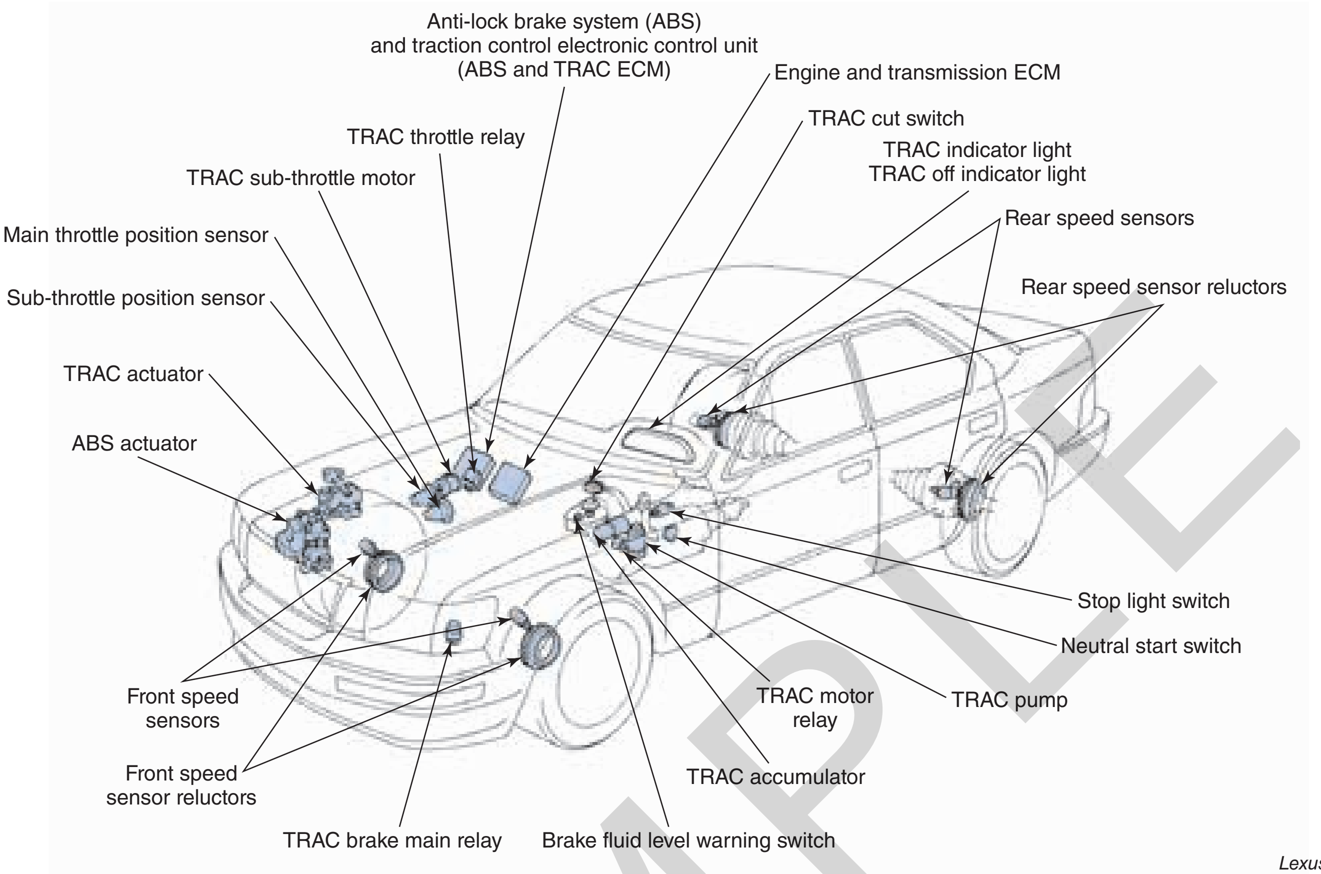

Figure 24-57. One particular traction control system and components. This traction control system manages the engine torque and braking of the drive wheels. Tire slippage (spinning) during takeoff on slippery road surfaces is carefully controlled. The traction control and anti-lock brake electronic control units are combined into one control unit on this system.

stability control (ESC) uses the ABS system components, plus some other sensors, to detect and prevent loss of traction. When the ESC system detects loss of steering control, it automatically applies one or more of the individual wheel brakes to help turn the vehicle in the direction and angle that the driver wants to steer. If, for example, the vehicle begins to oversteer, the outer front wheel brake will be applied. If the vehicle begins to understeer, the inner rear wheel brake will be applied.

Electronic stability control does not operate during normal driving, even under hard cornering. It constantly monitors steering and vehicle direction, and operates only to correct a loss of steering control. In addition to the speed sensors on each wheel, the ESC control system receives inputs from sensors that monitor steering wheel angle and vehicle rotation around the vehicle center. It may also use input from a yaw sensor that indicates the angle of the vehicle in relation to horizontal. The ECM uses these inputs to determine that the vehicle is traveling in a direction different from the one indicated by steering wheel position. The ABS ECM then automatically applies the brakes on the appropriate wheel to help the driver maintain control. The ECM also may reduce engine power and usually turns on an instrument panel warning light.

Hill Holder

In the past, many manufacturers installed a ***hill holder*** feature to prevent vehicles from rolling backward when stopped on an incline. Some new vehicles are again using a hill holder feature. Early hill holders were mechanically operated devices that prevented reverse movement. Modern hill holders use hydraulic brake pressure to hold the vehicle.

The hill holder control system is part of the chassis or body computer(s) and must detect the following:

- The vehicle brakes are applied.
- The vehicle is not moving.
- The vehicle is on an incline.
- Engine torque is below a certain value.

When the driver releases the brake pedal, the control system continues to apply the brake until it decides that engine torque can overcome vehicle weight and road angle. Once this is established, the control system releases the brakes.

Note

Some vehicles with electric parking brakes use the parking brake as a hill holder.

Regenerative Braking

Most hybrid vehicles use a ***regenerative braking system***. The primary purpose of regenerative braking is to help recharge the vehicle's high-voltage battery as the vehicle is slowing to a stop. Kinetic energy that would be turned into heat by the conventional braking system is turned into electricity. This is done by controlling electrical flow through the vehicle motor-generators. A motor-generator is an electrical device that can switch from changing electricity into motion (motor) to changing motion into electricity (generator).

Every hybrid vehicle has at least one electric motor-generator. During acceleration or cruising, the vehicle high-voltage battery energizes the motor-generator to move the vehicle. The internal combustion engine recharges the batteries and helps to move the vehicle when extra power is needed.

To help keep the batteries charged, the control system switches electrical flow through the motor-generator circuitry to generate electricity when stopping. The electricity created is sent to the high-voltage battery. In addition to recharging the battery, the motor-generator provides a braking effect. Since motion is being changed into electricity, the charging motor-generator creates a drag that helps to slow the vehicle. Under heavy braking, the hydraulic brake system aids regenerative braking efforts for added stopping power.

Note

The vehicle brake lights are operated either by a hydraulically operated switch placed somewhere in the brake line, or by a mechanically operated switch actuated by the brake pedal. The mechanical switch is the most common switch on newer vehicles. Newer vehicles usually have separate tail and brake lights. These lights may be filament bulbs or LEDs. Brake lights on older vehicles use dual filament bulbs, one filament for the tail lights, and a brighter filament for the brake lights. Brake lights and switches were covered in more detail in Chapter 18, *Chassis Electrical*.

Summary

- Liquids, under confinement, can be used to transmit motion and to increase or decrease pressure. Air is compressible; liquids are not.
- Pascal's law states that when pressure is exerted on a confined liquid, the pressure is transmitted undiminished throughout the liquid.
- A brake system is divided into two main parts: the hydraulic system and the friction members.
- When the brake pedal is depressed, the master cylinder pistons compress brake fluid in the master cylinder, which causes fluid to move in the brake lines. The fluid movement expands the calipers or wheel cylinders, causing them to apply the brake pads or shoes against the brake rotors or drums.
- Use only the manufacturer recommended Department of Transportation–approved (DOT-approved) brake fluid in a brake system and never mix different brake fluid types.
- The front brakes generally provide somewhat more braking force than the rear brakes. This is to compensate for the transfer of weight to the front during stops.
- All modern vehicles use a double-piston or dual master cylinder, which provides a brake fluid source to a separate system for the front and rear brakes.
- Hydraulic control valves (metering valve, proportioning valve, and pressure differential switch) are used to provide maximum braking power under all conditions.
- Brake lines are made of double-walled steel tubing.
- Flexible, high-pressure brake hoses carry fluid to each caliper piston or wheel cylinder.
- In a disc brake system, a caliper attached to the spindle or axle applies caliper pistons that press the brake pads against the rotor to stop it from turning.
- In a drum brake system, a single or double-piston wheel cylinder presses brake shoes against the brake drum to stop it from turning.
- Brake system friction members (brake pads or shoes) are used to physically stop the vehicle.
- A disc brake assembly consists of a backing plate, a caliper, brake pads (two per wheel), and a brake rotor.
- The caliper surrounds the brake rotor and a caliper piston applies the brake pads against the rotor to stop the wheel.
- A drum brake assembly consists of a backing plate, brake shoes (one primary shoe and one secondary shoe per wheel) and springs, and a brake drum.
- The brake shoes are attached to the backing plate and are arranged so they may be expanded by the wheel cylinders. As the shoes expand, they stop the brake drum and wheel.
- Some brake shoes are arranged so that servo action assists in applying the brakes. Brake shoe servo action is when one shoe helps apply the other. Self-energizing shoes are arranged so that shoe-to-drum friction helps apply the shoe.
- Some brake shoes are self-adjusting, while others may be adjusted periodically to compensate for shoe lining wear.
- An older parking brake system uses a drive line brake. Newer designs control the operation of the parking brake with computer-controlled electric motors.
- A power brake system is essentially a regular brake system with a vacuum or hydraulic power booster added to reduce the braking effort by the driver.
- Some vacuum power brake boosters used with diesel engines provide an engine-driven or electrically driven pump to produce sufficient vacuum for brake application.
- The diaphragm-type vacuum power booster is in common use today and is categorized as either vacuum- or atmospheric-suspended.

- Atmospheric pressure is applied to one side of the vacuum power booster diaphragm upon application of the brake pedal.
- With atmospheric pressure on one side and vacuum on the other, the diaphragm is forced to move in the direction of the vacuum. As it moves, it applies force either to the master cylinder piston or to the brake pedal itself.
- A power booster is designed to provide a braking “feel” for the driver, which is essential in controlling the amount of brake pressure.
- Hydraulic power brake boosters employ pressure from the power steering pump and are used on large vehicles and on vehicles with diesel engines.
- An anti-lock brake system (ABS) is a combination of electronic and hydraulic components which pulse the brakes quickly to prevent wheel lockup during hard braking.
- Traction control systems (TCS) are able to reduce engine power and operate the brake system to increase vehicle acceleration and stability on wet, icy, or uneven road surfaces. They also provide higher levels of cornering performance.
- Electronic stability control uses the ABS system components, plus some other sensors, to detect and prevent loss of traction and to improve vehicle control under difficult or emergency handling.
- A “hill holder” feature prevents a vehicle from rolling backward when stopped on an incline by using hydraulic brake pressure or an electric parking brake to hold the vehicle.
- Hybrid vehicle regenerative braking uses the motor-generator to change the kinetic energy of the moving vehicle into electricity during braking. The electricity charges the hybrid high-voltage battery.

Technical Terms

accumulators
anti-lock brake system (ABS)
atmospheric-suspended booster
backing plate
base brakes
bleeder ports
bleeder screw
brake drum
brake fade
brake fluid
brake shoes
braking ratio
caliper pistons
coefficient of friction
combination valve
diagonal split brake system
disc brake caliper
disc brake pads
dual brake system
dual master cylinder
dual proportioning valve
electric parking brake
electronic stability control (ESC)
emergency brakes
floating calipers
foundation brakes
friction members
height-sensing proportioning valve
hill holder
hydraulic power brake booster
hydraulics
master cylinder
metering valve
non-servo action
pad wear indicators
parking brakes
Pascal’s law
piston return springs
power brakes
pressure differential switch
primary cup
proportioning valve
quick take-up valve
regenerative braking system
residual pressure valve
rotor
secondary cup
self-energizing action
semi-metallic
servo action
stepped wheel cylinder
tandem booster
traction control system (TCS)
vacuum control valve
vacuum power brake booster
vacuum reservoir
vacuum runout point
vacuum-suspended booster
wheel cylinders
wheel speed sensors

Review Questions

Answer the following questions using the information provided in this chapter.

1. *True or False?* Unlike air, liquids confined under pressure cannot be compressed.
2. According to Pascal's law, the original pressure placed on a confined liquid is _____ throughout the liquid.
   A. transferred with increased pressure
   B. transferred with decreased pressure
   C. transferred undiminished
   D. transferred with an increase or decrease, depending on the shape of the container
3. If a 100 lb (46 kg) force is applied to a piston with 1 in^2 (6.5 mm^2) of area, how much pressure would a piston with an area of 10 in^2 (65 mm^2) exert, if both of these pistons rested with an airtight seal on a column of oil? Assume that both cylinders or columns are connected via a pipe.
   A. 10 psi (69 kPa).
   B. 100 psi (689 kPa).
   C. 500 psi (3447 kPa).
   D. 1000 psi (6895 kPa).
4. All of the following are characteristics of high-quality brake fluid, *except*:
   A. must not swell or deteriorate the brake system's plastic and rubber parts.
   B. can safely be mixed with any other type of DOT-approved brake fluid.
   C. maintains even viscosity throughout a wide temperature variation.
   D. acts as a lubricant for pistons, seals, and cups to reduce internal wear and friction.
5. To compensate for the transfer of weight to the front wheels due to inertia when a vehicle is stopped, the vehicle's brake system is designed with a(n) _____.
   A. braking ratio
   B. additional brake pad on each front wheel
   C. emergency brake
   D. larger rear brake shoe assembly
6. All of the following statements regarding the fluid reservoir for a brake system's master cylinder is true, *except*:
   A. has a vented cover for brake fluid expansion and contraction.
   B. provides extra brake fluid to compensate for lining wear and minute leaks.
   C. is attached to the bottom of the master cylinder in all vehicles.
   D. is often manufactured with clear plastic.
7. In a dual brake system, the dual master cylinder _____.
   A. locks up one wheel on each axle when braking
   B. applies pressure to separate front and rear brake hydraulic systems
   C. works the transmission clutch also
   D. has two master cylinders, with one positioned on top of the other
8. Which of the following valves controls brake hydraulic pressure to a vehicle's rear wheels?
   A. Proportioning valve.
   B. Master cylinder check valve.
   C. Pressure differential switch.
   D. Metering valve.
9. The _____ valve closes off pressure to the front disc brakes until the hydraulic system pressure can overcome rear brake shoe retracting spring pressure.
   A. proportioning
   B. variable pressure
   C. disc brake metering
   D. master cylinder check
10. Which of the following valves warns the driver that one side of a split hydraulic system has failed?
    A. Proportioning valve.
    B. Master cylinder check valve.
    C. Pressure differential switch.
    D. Metering valve.
11. Brake lines must be made of _____.
    A. double-walled steel
    B. thin-walled brass
    C. thin-walled copper
    D. bendable plastic

12. Metal brake lines and _____ are connected together at certain points on a vehicle and are securely held with brackets or clips.
    A. steering system components
    B. flexible, rubber coolant hoses
    C. parking brake linkage
    D. flexible, rubber brake hoses
13. *True or False?* Compared to a non-floating caliper, a floating disc brake caliper uses one "U-shaped" brake pad to contact both the inner and outer sides of the brake rotor.
14. All of the following are parts of a wheel cylinder, *except*:
    A. two rubber cups.
    B. caliper pins.
    C. cast iron housing.
    D. two cylinder pistons.
15. *True or False?* Trapped air within a brake hydraulic system causes the brake system to respond faster and apply with stronger force.
16. Synthetic and steel fibers as well as iron, ceramic, and metallic powders are the materials currently used to manufacture _____.
    A. brake hoses
    B. wheel cylinder dust boots
    C. the brake master cylinder fluid reservoir
    D. the friction linings for brake pads and shoes
17. To prevent potential damage to the rotor, many brake pads have a mechanical or electrical sensor-type of _____.
    A. caliper piston
    B. pad wear indicator
    C. directional installation sleeve
    D. friction lining grid
18. All of the following statements about brakes are true, *except*:
    A. brake fluid is poisonous.
    B. brake fluid can damage vehicle paint.
    C. brake dust can damage the lungs.
    D. brake dust can damage aluminum vehicle parts.
19. In a servo action, self-energizing drum brake arrangement, the secondary brake shoe jamming against the ____ stops both shoes and produces a binding effect that helps both shoes apply themselves.
    A. anchor pin
    B. retracting spring
    C. star wheel adjuster
    D. caliper
20. The three general types of self-adjusting drum brake systems are the cable, link, and _____ adjuster designs.
    A. electric sensor
    B. lever
    C. solenoid
    D. spherical
21. An electric parking brake may use an electric motor to pull the conventional emergency brake cable, or it may have two computer-controlled motors attached to each _____.
    A. rear wheel hub
    B. rear brake caliper
    C. front steering knuckle
    D. front brake caliper
22. *True or False?* The components and operation of a vacuum power brake booster are the same for both gasoline and diesel engines.
23. *True or False?* In a vacuum-suspended power booster, the booster has a vacuum on both sides of the diaphragm or piston when the booster is in the released position.
24. Which of the four stages of vacuum-suspended power booster operation occurs when both the vacuum and atmospheric port are closed and the near side of the diaphragm plate is subjected to a specific and unchanging amount of atmospheric pressure?
    A. Released position.
    B. Applied position.
    C. Holding position.
    D. Releasing after application position.
25. A _____ allows for several power-assisted brake applications after vacuum ceases when the vehicle's engine is shut off.
    A. vacuum reservoir
    B. tandem booster
    C. master cylinder check valve
    D. hydraulic power brake booster

26. A hydraulic brake booster uses pressure generated by the _____ system.
   A. cooling
   B. power steering
   C. engine lubrication
   D. brake hydraulic
27. A hydraulic brake booster uses a(n) _____ to provide reserve pressure in case the regular hydraulic system fails.
   A. engine-driven pump
   B. vacuum pump
   C. accumulator
   D. vacuum back-up booster
28. *True or False?* Anti-lock brake systems (ABS) allow the driver to maintain directional control while providing maximum braking efficiency by locking up the wheels during emergency braking.
29. All of the following are components of an anti-lock brake system (ABS), *except*:
   A. quick take-up valve.
   B. control module.
   C. wheel speed sensors.
   D. hydraulic modulator.
30. Reducing engine power and operating the brake system to increase vehicle acceleration and stability on wet, icy, or uneven road surfaces is the task of a _____.
   A. regenerative braking system
   B. hydraulic power brake booster
   C. tandem brake booster
   D. traction control system (TCS)
31. *True or False?* An electronic stability control (ESC) system constantly monitors steering and vehicle direction, but operates only to correct a loss of steering control.
32. What does a "hill holder" feature do?
   A. Lightly applies the vehicle brakes when traveling up an incline.
   B. Prevents a vehicle from reaching excessive speeds when rolling down an incline.
   C. Disengages any power assist from the system when braking on an incline.
   D. Prevents a vehicle from rolling backward when stopped on an incline.
33. *True or False?* A hybrid vehicle's regenerative braking system takes the kinetic energy that would be turned into heat by the conventional braking system and turns it into electricity to recharge the vehicle's high-voltage battery.
34. Controlling the electrical flow through a hybrid vehicle's _____ is the key operational aspect of a regenerative braking system.
   A. power splitter
   B. motor-generator
   C. converter/inverter
   D. 12-volt battery
35. A mechanically operated switch actuated by the brake pedal is one of two methods to operate a vehicle's _____.
   A. transmission clutch
   B. brake lights
   C. hydraulic power brake booster
   D. parking brakes

Critical Thinking Questions

1. Explain how hydraulic principles and concepts are used in the operation of a vehicle's hydraulic brake system. Describe how the different parts within the system and the system as a whole functions as a hydraulic circuit to successfully stop a vehicle.
2. What do you believe will be the future of automotive brakes? Will regenerative braking systems be incorporated into non-hybrid vehicles? Will electronic brake systems replace the current hydraulic brake systems sometime in the future? Or will an entirely new concept be developed? Do some brief research into the topic.