Drive Sprockets. The sprocket, as shown in *Figure 9-32,* is not mounted to the track frame but is attached to the final drive. Its job is to transfer drive torque to the track. The teeth on the outside of the sprocket act as gear teeth. They engage the track links and propel the equipment on the continuous track loop. Older track equipment often has a one-piece sprocket assembly; the use of individual bolts on segments showed up more recently. On the older models, the old sprocket had to be cut off and a new one welded in its place. Often, the welded version was replaced with a welded-on adapter, which allowed for the bolted, segmented type of sprocket, saving considerable time for future changes.

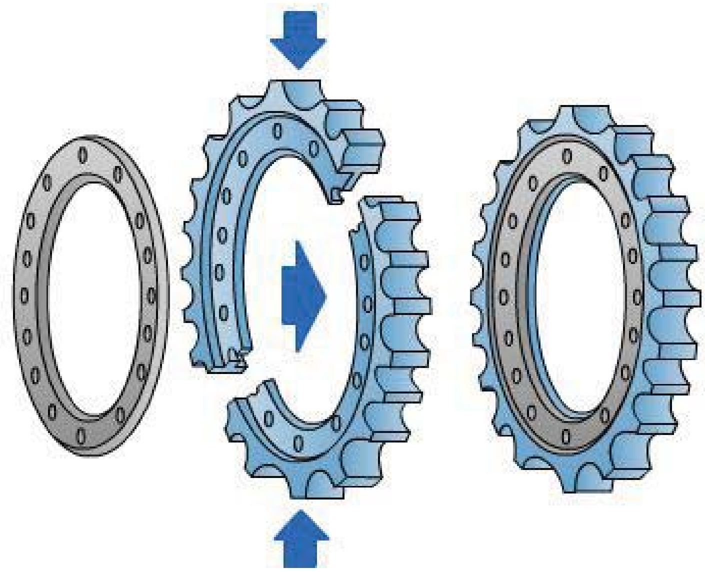

Figure 9-32 – Drive sprocket.

Changing sprocket segments is quick and easy. Position the track so the segment that requires changing is on the inside (away from the track links), unbolt the old segment, and bolt in and torque the new one. Rotate the track a few feet and repeat the procedure until all segments are replaced.

By design, the sprocket has an odd number of teeth to provide a change in tooth-to-sprocket contact every revolution of the sprocket. This is commonly called "tooth hunting." This design allows for the even distribution of wear among the sprocket teeth.

Figure 9-33 – Mechanics working on a bulldozer with an elevated sprocket.

Elevated Sprockets. Improvement in track equipment design has led to the inception of the elevated track design, which offers a few major advantages over a conventional track sprocket arrangement. The major benefit of this design is that it isolates the final drive from excessive shock loads. The position of the final drive also creates a better balance arrangement that also provides better traction, as shown in

Figure 9-33. This design requires the use of two idlers and a separate roller frame for the front and rear.

There is always a down side to any design, and this one is no exception. Compared to a conventional undercarriage design, which has one travel loaded flex point, the elevated sprocket undercarriage has three flex points where loading takes place during operation. Therefore, in the long run, the conventional undercarriage with only one load point during forward travel will likely last longer.

The two rear track frames are connected together with a pivot shaft that allows the shock loads to be absorbed by the main frame. The front roller frames fit inside the rear roller frames and are connected to each other with an equalizer bar that is pinned in the center with limited movement from side to side. A recoil spring provides track tension.

Track Rollers and Carrier Rollers. Current track design utilizes two different types of track rollers to maintain track alignment. The bottom rollers are called track rollers. They support the weight of the equipment and ensure that the weight of the equipment is distributed evenly over the bottom of the track. The track rollers are spaced closely together, and there are generally a large number of them mounted to the bottom side of the track frame. The track rollers maintain track alignment as well as distribute the weight of the equipment evenly over the length of the track.

There are two types of track roller designs: single flange and double flange. Single flange rollers are used closest to the sprockets. Double flange rollers maximize track stability and alignment. The surface of the track rollers is hardened to the same Rockwell scale as the track links. Lubrication and cooling are provided by oil sealed in the housing. Because of the twin flanges, double flange track rollers are used to maximize track alignment.

There are several different design configurations of track rollers. Always refer to the specific shop manual of the equipment on which you are working for detailed instructions. *Figure 9-34* shows the parts breakdown of a typical track roller.

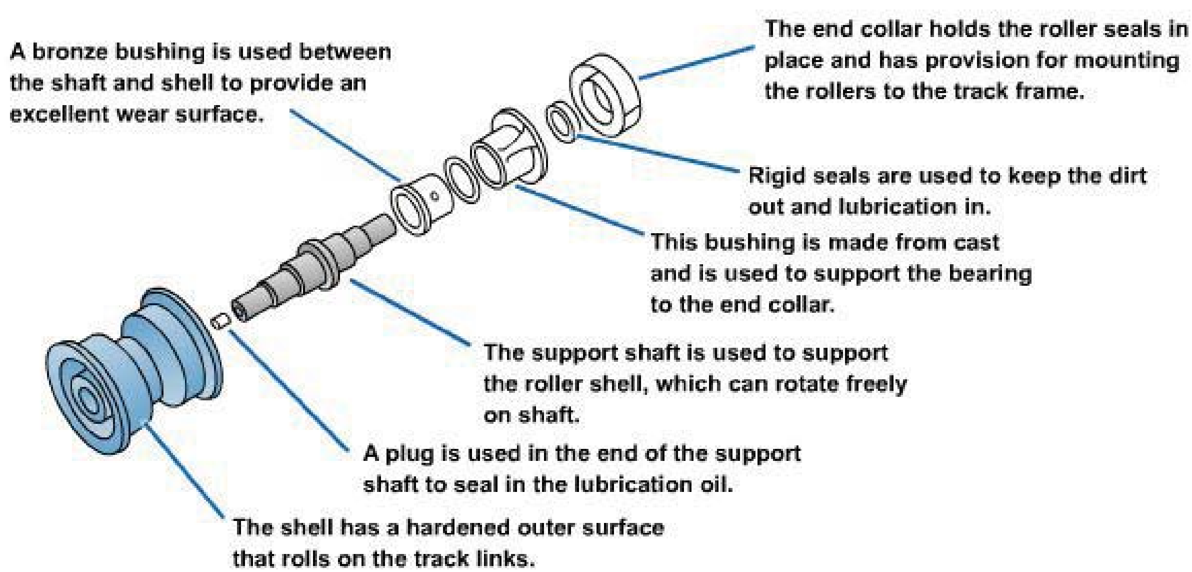

Figure 9-34 – Track roller.

Carrier rollers are located above the frame rail. Their purpose is to support the weight of the top section of track as it rolls between the idler and the sprocket. These rollers generally have a single flange that aids in controlling track sag and whipping during operation. A secondary function of the carrier rollers is to maintain alignment on the upper portion of the track between the idler and sprocket. These rollers also have a hardened surface that is equal in hardness to the track link surfaces. This hardness can have a slight negative effect on the life of the track links. Some manufacturers cantilever mount the carrier rollers to minimize material buildup.

Figure 9-35 shows an exploded view of a typical carrier roller. The retaining ring on a roller fastens the end collar to the roller shell and is held in position on the support shaft by a groove. The bearings are held in place in the carrier shell by the end collar and seals, which also prevent oil from leaking out of and dirt getting into the bearings. The two roller bearing assemblies allow the carrier roller to roll freely on the shaft. The shaft has mounting points to secure the carrier roller to the track frame. A plug and O-ring seal the lubrication opening in the shaft. The retainer plate, which mounts to the shaft, holds the tapered roller bearings inside the carrier housing. A roller cover provides a seal on one end and is fastened with bolts to the end of the carrier shell.

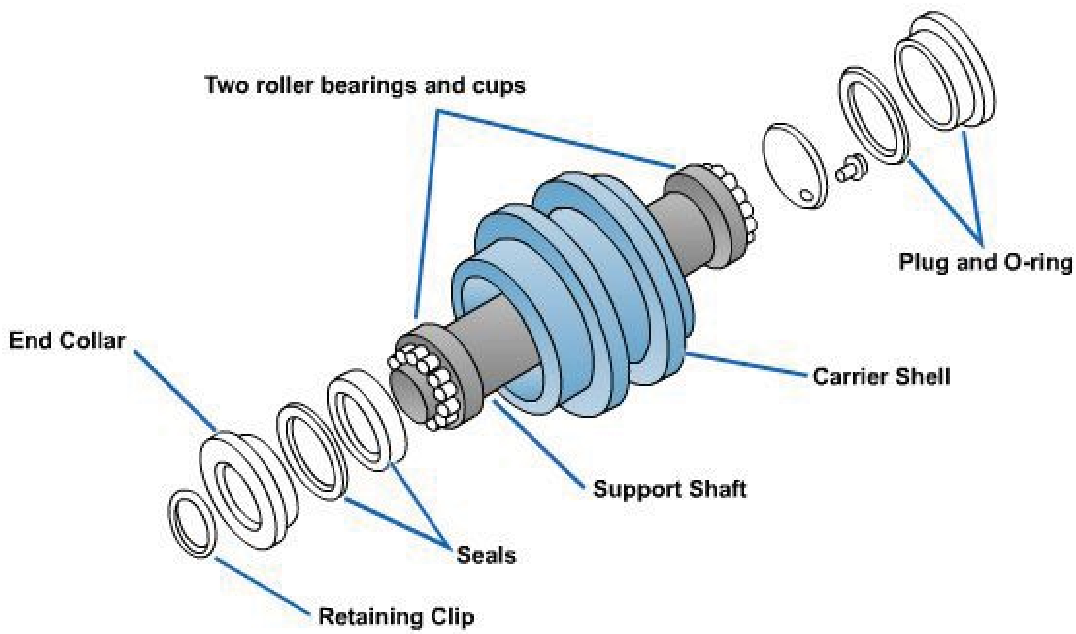

Figure 9-35 – Carrier roller.

Seals. Tracks operate in extremely abrasive conditions and quickly wear out the pins and bushings if they are not protected with seals. Seals keep lubrication in and dirt out, providing a much longer service life. Not only do seals keep dirt out, but they also carry a certain amount of side load, preventing unnecessary wear of the track links' counterbore. Conventional track seals use Bellville washers that are capable of maintaining sealing pressure as they wear, which helps keep dirt out.

Some manufacturers use rigid seals, which consist of two individual parts similar to those used on lubricated tracks. These parts are made up of a lip seal and stiff wear-resistant material on the inside, called the "can." The seal shape integrity is maintained by an extremely durable urethane material. The seal holds the bushings by a load ring. These seals are capable of withstanding operating temperatures as high as 170°. The seal is protected from thrust loads by a steel thrust ring, which limits seal compression.

This type of seal system is considerably more costly than conventional Bellville washer design, but the result is a much longer pin and bushing life. Over the long haul, this type of seal system will yield lower operating costs. Wear is generally not an issue with this type of seal system, and operation is quieter due to the lubricated pins and bushings. Frictional losses are reduced more with a lubricated track than with a conventional track, resulting in lower operating fuel costs.

Track Guards. To keep the tracks from getting packed with dirt, roller guards are often used to keep the rocks and foreign debris from getting between the track rollers and track links. The track guard also helps guide the track. Good practice requires that the area around the track guard be cleaned regularly, especially after operating in muddy conditions. Operating equipment with packed debris in the track mechanism results in a track condition that is too tight, which greatly accelerates wear. Track tension should be checked periodically during and after operations in mud, clay, fractures or quarry rock, and heavy vegetation or roots. All of these objects have the potential to enter the track assembly.

Frame. The frame is the backbone of the tack assembly. It holds the front idler in place, and the track rollers and guards are bolted to its underside. The recoil assembly and the track carrier roller(s) are all mounted to the frame. Generally, the frame causes very few problems when compared to the rest of the track components.

Equalizer Bar. The track frames on each side of the equipment are connected together through an equalizer bar near the front of the machine and are mounted to the sprocket that is part of the final drive at the rear of the machine. All the weight of the equipment is carried by the track rollers and frame. With this type of mounting, each side can move independently on uneven terrain to maintain contact with the ground. Diagonal braces are used to maintain track alignment when on uneven terrain. One end of each brace is welded to the track frame, while the other end is mounted to the sprocket shaft and swivels on a bearing. These bearings must be lubricated at regular intervals.

Older track loading equipment does not have a pivoting equalizer bar; therefore, independent track movement is not possible. Instead, this older type of equipment has a rigid frame, and as a result, is unable to operate on uneven terrain effectively . Typically, older track loading equipment is best suited to operate on flat, hard surfaces, such as quarries and pits.

Some manufacturers have added an oscillating undercarriage, as shown in *Figure 9-36,* as an alternative to independent track movement. This design has the added benefit of being able to pivot from the front to rear, which can increase stability when the equipment is operating on uneven ground. The track frames have an equalizer bar mounted between to allow each track frame to pivot independently on a pivot shaft. With this design, an idler swing link is used to permit the idler to move horizontally to absorb any shock loads it may encounter

Figure 9-36 - Oscillating undercarriage for a track loader.

during operation. This ensures that the correct amount of track tension is always maintained. Pins are used to prevent the equalizer bar from having excessive oscillating travel. Rubber pads are used to dampen vibration between the equalizer bar and the main frame.

7.1.1 Track Roller Frame Alignment with Sprocket

For the following example, refer to *Figure 9-37*:

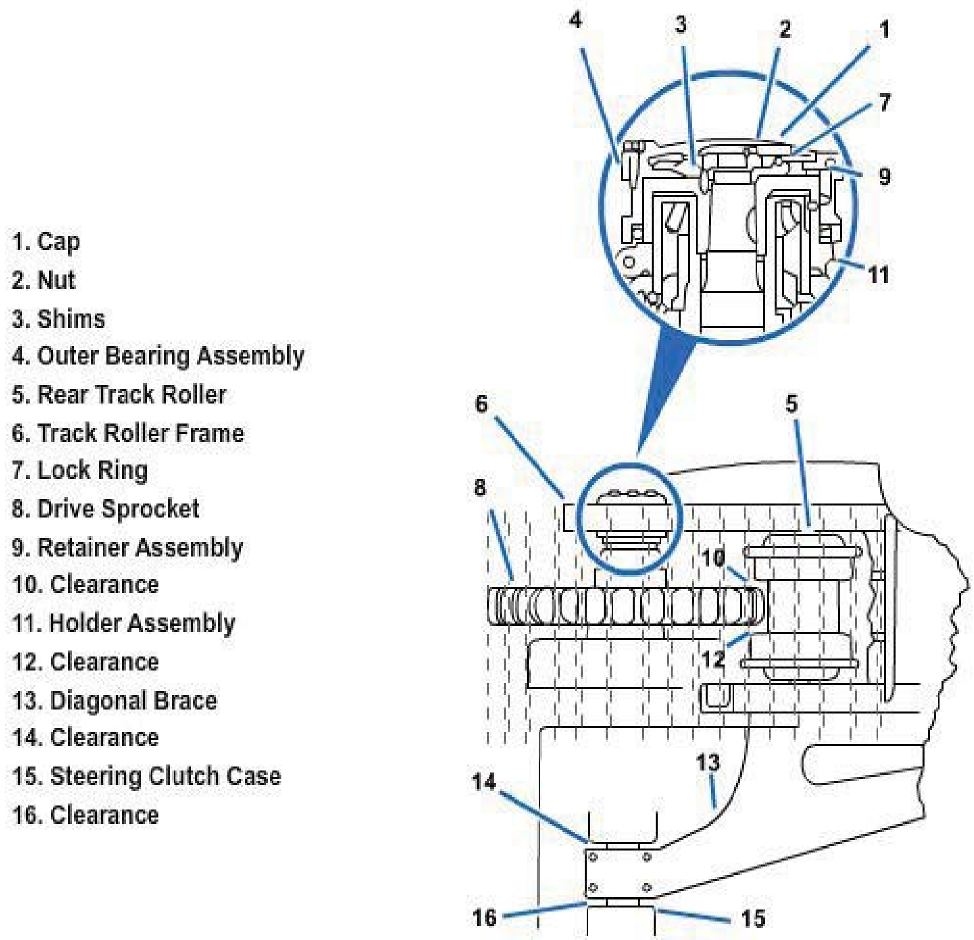

Figure 9-37 - Aligning track roller frame with sprocket.

1. For the track to lead straight off the rear roller (5) onto the drive sprocket (8) and not rub against either the sides of the sprocket or the rims of the track roller, the center of the roller should be centered with the sprocket.
2. The drive sprocket (8) should be centered with the rear roller (5) so the area (10) and (12) between the outer face of the sprocket and the inner edge of the track roller rim is equal.
3. In the recess in the steering clutch case (15), check the clearance of the diagonal brace (13) at points (14) and (16).
4. To make this adjustment, remove the cap (1) from the outer bearing assembly (4) and take off the lock ring (7), nut (2), and retainer assembly (9).

5. To move the roller frame out, add shims (3) between the retainer assembly (9) and the holder assembly (11). This will decrease the clearance (12) at the roller and at the diagonal brace (14), and increase the clearance at (10) and (16).
6. To move the roller frame closer to the tractor, remove shims (3). This decreases the clearance at (10) and (16) and increases the clearance at (12) and (14).

7.2.0 Adjustment of the Front Idler

Depending on the track design, the equipment could have one or two idlers per track section. If the equipment has an elevated sprocket system, there will be two idlers: a front idler and a back idler. Equipment that has a conventional oval track requires only one idler (*Figure 9-38*). The purpose of an idler is to help guide the track through the track rollers and to help support part of the weight of the equipment. Besides providing alignment, the idler's job is to maintain the correct tension and slack on the track. The tension on the track is adjusted by moving the idler back and forth on the track frame. This is accomplished with the use of hydraulic pressure to compress a high-tension spring mechanism to tighten the track.

Figure 9-38 – Front idler.

Equipment with oval tracks can have a two-position idler, with one position that is used when drawbar work is required. This position minimizes the amount of track that is in contact with the ground, resulting in less track wear. When equipment must operate with heavy implements attached to the front, the use of the lower mount for the idler places more track on the ground, making the equipment more stable but causing more track wear. Too much track tension is a contributing factor to accelerated wear because of increased loading on the track components.

Figure 9-39 shows an exploded view of a typical idler assembly. The bearing used between the idler shaft and shell is a plain bimetallic bearing with excellent load and wear characteristics. A retainer ring holds the end collar to the idler shell. The end collar holds the seals and the other parts inside the assembly. The outer circumference of the idler, as with all track components, is the same as the track links.

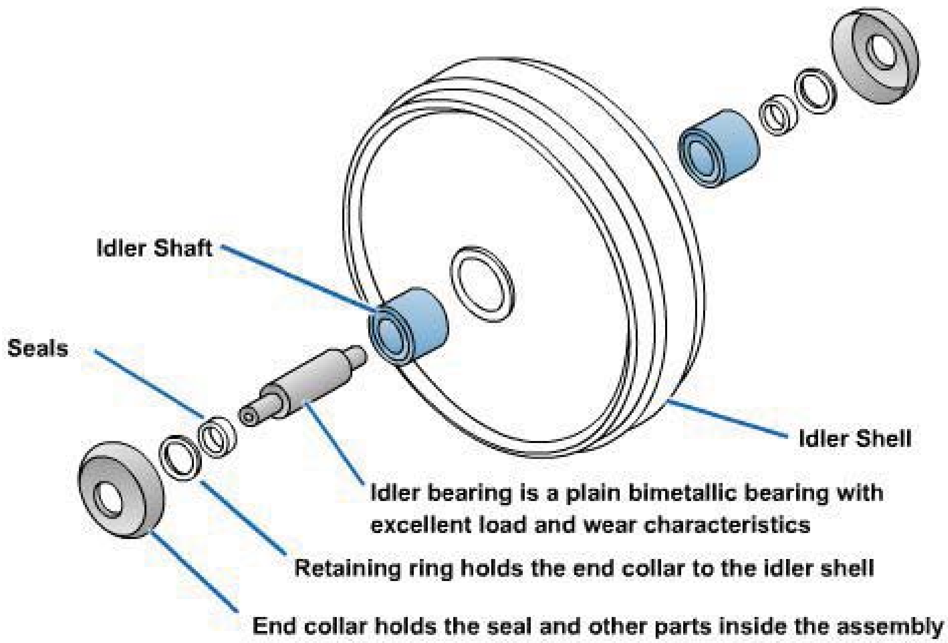

Figure 9-39 – Exploded view of an idler.

The tensioning mechanism connects to the idler to maintain the correct track tension. On older equipment, the tensioning mechanism uses a coil spring with a mechanically adjusted rod to adjust track tension (*Figure 9-40*). On newer equipment, you will find the use of hydraulic pressure to balance spring equipment.

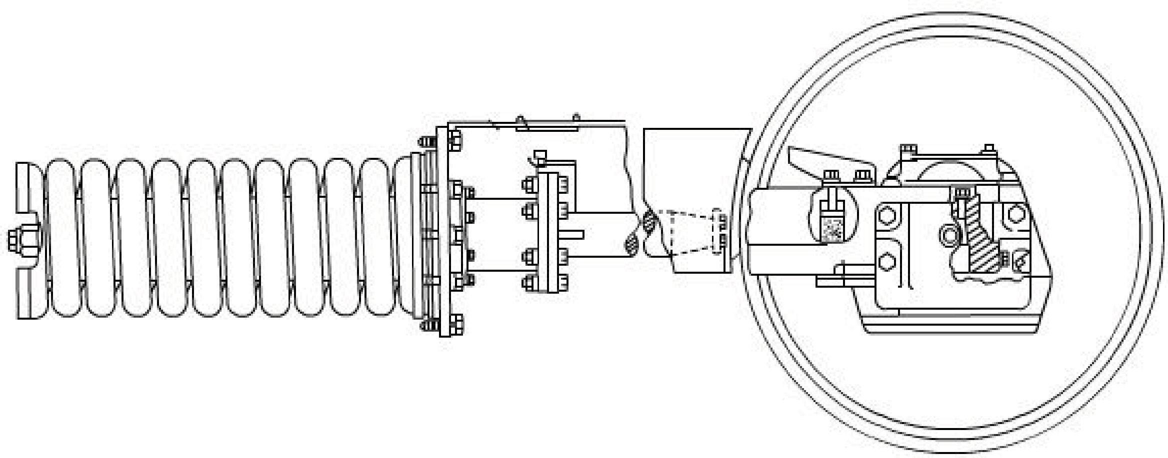

Figure 9-40 - Idler with coil spring and adjustable tension rod.

7.2.1 Track Tension and Sag

The most important controllable factor in undercarriage wear is correct track-chain adjustment. Correct track sag for all conventional crawlers is two inches (± 1/4 inch). Tight tracks can increase wear up to 50 percent. For example, a crawler in the 80-horsepower range with 1/2-inch track-chain sag results in approximately 5,600 pounds of chain tension when measured at the track adjuster. The same machine with the suggested 2-inch track chain sag results in approximately 800 pounds of chain tension when measured at the track adjuster. A tight track magnifies the load, which results in more wear on the track bushings to sprocket teeth contact areas and the track-link-to-idler roller contact areas. Increased wear also occurs at the track-link-to-idler contact point and track-link-to-roller contact points. More load means more wear on the entire undercarriage system. Also, a tight track requires more horsepower and more fuel to do the job. Follow this method to adjust track-chain tension:

Figure 9-41 demonstrates the proper procedure for track adjustment and sag. Always adjust track sag in the actual underfoot working condition and check sag often. To adjust track-chain tension, move the machine forward slowly and let the machine roll to a stop, centering the track pin over the carrier roller, as shown in *Figure 9-41, View A*. Put a straight edge over the track, as shown in *Figure 9-41, View B,* and measure the sag at the lowest point, as shown in *Figure 9-41, View C.*

Figure 9-41 -Track sag.

Figure 9-42 provides a quick reference for troubleshooting track problems.

Problem	Possible cause
Accelerated wear is on one side of the final drive sprocket teeth.	• Track misalignment • Loose track • Sprocket misalignment due to improper installation
Accelerated wear is on one side of the idler(s) or rollers.	• Track misalignment • Idler misalignment due to improper installation
There is accelerated wear to track pins, bushings, and track links.	• Track adjustment too tight • Misaligned track • Excessively worn sprocket teeth • Excessive high-speed operation
There is excessive wear to the final drive bearing.	• Track adjustment too tight • Misaligned track
Operator complains of loss of drawbar power.	• Improper track adjustment • Track adjustment too tight
Operator complains that the dozer drifts either to the right or left while being driven in a straight direction.	• Improper track adjustment • One track is tighter than the other • Track misalignment
There is frequent packing of the track during operation.	• Improper track adjustment • Track adjusted too loose
The track is noisy during operation.	• Improper track adjustment • Track adjustment too loose
The track whips excessively during operation.	• Improper track adjustment • Track adjusted too loosely • Idler seized in the retracted position
The track is thrown off during operation.	• Improper track adjustment • Track adjustment too loose

Figure 9-42 - Troubleshooting track problems.

Summary

Wheel alignment is the process of repositioning the suspension and steering parts to compensate for normal wear and the effects of replacing parts to compensate for normal wear. Correct wheel alignment should be checked after parts replacement and periodically during the life of the vehicle.

Wheel alignment is a series of angles that position the tires in relation of the vehicle's body, road, and the other tires. The angles for a particular wheel are interrelated, and the angles are related between each of the vehicle's wheels. Camber is the inward or outward tilt of the top of the wheels when viewed from the front of the vehicle. Caster is the tendency of the tire to follow behind the center of movement formed by the steering axis. Kingpin inclination is the amount in degrees that the top of the kingpin inclines away from the vertical, viewed from the front of the vehicle. Toe is the relative position of the tires on the axle. When the front of the tires is closer together than the rear, the tires are toed in. When the front of the tires is farther apart than the rear, the tires are toed out. Turning radius or angle is the degree of movement from a straight-ahead position of the front wheels to either an extreme right or left position. Ackerman geometry is the means used to steer a vehicle so that the tires track freely during a turn. During a turn, the inboard wheel on a steer axle has to track a tighter circle than the outer wheel.

All vehicles are built around a geometric centerline that runs through the center of the chassis from the back to the front. The thrust line is the direction the rear axle travels if unaffected by the front wheels. This condition is called tracking. An ideal alignment has all wheels running parallel to the centerline, making the thrust line parallel to the centerline. Not only is this true with vehicles, but it also is true with trailers.

The most common cause of accidents is carelessness. Many mechanics become rushed and forget to do the job safely. An accident may result in personal injury, long-term bodily harm, or damage to equipment or property. Accidents are also caused when personnel fail to correct hazardous conditions and take shortcuts instead of following proper procedures. Many suspension parts are under spring tension. The mechanic must be sure that all spring tension is removed from any part before trying to remove it.

There are a number of specialty tools required for frontend alignment, and using the proper tools is vital to doing the job properly and safely. Mechanical alignment testers include caster-camber testers, toe gauges, and turning plates. Alignment machines have alignment heads that are attached to the wheels of the vehicle. Electronic alignment machines use infrared or laser beams to send signals to a computer that displays the alignment on a screen.

Conduct pre-alignment checks, to include talking to the operator; road testing; checking height, tire, and wheel damage; and checking for worn parts and underbody damage. To set up the vehicle for wheel alignment, the wheels must be free to turn. The vehicle must be at its correct curb weight. After obtaining alignment specifications, install the alignment heads to the rim and compensate it.

After all pre-alignment procedures have been accomplished, check camber, caster, and toe. Also check SAI and toe out on turns, if required.

Adjustable suspension angles are caster, camber, and toe. Follow the prescribed specifications and procedures for measuring caster and camber. Nonadjustable wheel alignment angles are turning radius, steering axis inclination, or SAI. The included angle is the combination of SAI and camber.

Many vehicle defects can affect the alignment of the suspension and steering. These include defective parts, bent frames, defective tires, road crown and irregularities, vehicle load, acceleration and braking, and turning forces.

The chain section of the track is made up of track links, pins, and bushing. Several components together form a track system, to include the drive sprocket, front idler, track rollers, tension mechanism, roller guards, and frame.

Improvement in track design has led to the inception of the elevated track design, which has a few advantages over the conventional track sprocket arrangement. The major benefit of this design is that it isolates the final drive from excessive shock loads. The elevated track design requires the use of two idlers.

Tracks utilize two different types of track rollers to maintain track alignment. The bottom rollers support the weight of the equipment and ensure that the weight of the equipment is distributed evenly over the bottom of the track.

Carrier rollers are located above the frame rail. The purpose is to support the weight of the top section of the track as it rolls between the idler and the sprocket.

The purpose of the idler is to help guide the tack through the track rollers and to support the weight of the equipment. Besides providing alignment, the idler's job is to maintain the correct tension and slack on the track. A tension mechanism connects to the idler to maintain the correct track tension. The track tensioning mechanism uses either a recoil spring with a mechanically adjusted rod or a hydraulically tensioning cylinder to adjust track tension.

Correct track adjustment is necessary to maintain long track life. Nothing shortens the life of the tack faster than incorrect adjustments. If the track is adjusted too tightly, excessive loads are placed on the mating components, which accelerate track component wear. If the track is adjusted too loosely, it will cause the track whip at higher speeds and lead to excessive wear of undercarriage components.

Review Questions {Select the Correct Response)

1. Abnormal wear on the side of the tire tread is caused by what?

    A. Incorrect caster
    B. Incorrect camber
    C. Incorrect toe-in
    D. Incorrect kingpin

2. When the lower ball joint is ahead of the top ball joint or strut mounting, to which angle are you referring?

    A. Negative caster
    B. Positive camber
    C. Positive caster
    D. Positive canter

3. **{True or False)** One of the advantages of positive caster is that it makes it easy to turn the wheels from the straight-ahead position when entering a turn.

    A. True
    B. False

4. What is the name of the angle that, when in conjunction with camber angles, places the approximate center of the tire tread footprint in contact with the road?

    A. Kingpin inclination
    B. Axle inclination
    C. Toe-in
    D. Caster

5. What should you do to the suspension prior to measuring toe angle?

    A. Neutralize
    B. Deactivate
    C. Naturalize
    D. Activate

6. Within the steps for adjust turning radius, what is adjusted to make proper contact with the axle stop?

    A. The axle
    B. Wheel stop screw
    C. Front tire
    D. Wheel angle stop

7. What allows the inner and outer wheel to turn at different angles so that both wheels can negotiate the turn without scrubbing?

   A. Scrubbing
   B. Toe-in
   C. Wheel geometry
   D. Ackerman geometry

8. The length and angle of the steering control arms and length of the cross tube determine the actual toe-out during what maneuver?

   A. Braking
   B. Driving straight
   C. Acceleration
   D. Turning

9. When all the axles are following in line with each other and perpendicular to the to the vehicle centerline, this is known as what?

   A. Wheel hunting
   B. Tracking
   C. Axle tracing
   D. Thrustline

10. In trailer tracking, what is it called when the drive axles are not parallel?

   A. Scrub angle
   B. Scribe angle
   C. Thrust angle
   D. Tracking angle

11. What will you plug into when working with electrical tools in wet conditions?

   A. Ground-fault circuit interrupter
   B. Extension cord
   C. Grounded electrical cord
   D. Three-pronged adapter

12. To ensure your safety, what should you do with a jack stand when working outside, repairing a vehicle that is parked on asphalt?

   A. Place a hydraulic jack with wheels.
   B. Use a forklift to hold vehicle.
   C. Remove the jack and use lumber cribbing.
   D. Place lumber underneath the jack.

13. **{True or False)** Spring tension is no concern because once you raise the vehicle, all tension is removed.

    A. True
    B. False

14. What is the purpose of the tool that sometimes is referred to as a pickle fork?

    A. Adjust tie rod
    B. Remove ball joint stud
    C. Remove coil springs
    D. Remove pickle stud

15. Which of the following hammers should never be used when working on vehicles?

    A. Carpenter's hammer
    B. Ball peen
    C. Soft face
    D. Rubber mallet

16. Which tool arm that typically attaches to the control arm and frame would be used to move the control?

    A. Lever-type adjusting tool
    B. Inner tie-rod tool
    C. Toe gauge
    D. Ball peen hammer

17. Of the different methods to remove a spot weld, which one is the most expedient?

    A. Air chisel
    B. Grinder
    C. Rotary cutter
    D. Spot weld cutter

18. What type of torque wrench is considered the most accurate?

    A. Extendable
    B. Click
    C. Dial
    D. Beam

19. After conducting the road test, check_________before beginning alignment procedures.

    A. Underbody, height, tires, and rims
    B. fuel level, oil, and height
    C. steering, underbody, and fluid levels
    D. Height, weight, and model number

20. When you inspect the tires, all tires should be_________?

A. New
B. Same age
C. Same size
D. Recently rotated

21. All rims have some runout, so when installing the alignment head, what might you have to do for this situation?

A. Nothing
B. Remove the rim
C. Compensate for it
D. Use different equipment

22. What is your next step after installing the alignment heads and lowering the vehicle?

A. Place on the turning plates.
B. Remove turning plates.
C. Remove heads.
D. Compensate wheels.

23. What is the other procedure that is conducted along with the caster checking process?

A. Checking brakes
B. Checking camber
C. Checking toe
D. Checking steering axis inclination

24. Which angle(s) cannot be checked on trucks with solid front axles?

A. Caster only
B. Camber only
C. Caster and camber
D. Toe

25. At what position should caster be measured?

A. On a lift
B. Level floor
C. Jack stands
D. None of the above

26. When measuring caster angle with a protractor and it tilts toward the rear, it is what?

A. Negative
B. Positive
C. Zero
D. Alignment

27. When measuring caster using a radius gauge, how many degrees do you turn the front wheel?

A. 10
B. 15
C. 20
D. 25

28. How many shims can you use on each side when changing the caster angle?

A. As many as it takes
B. One only
C. No more than two
D. Two only

29. Which is the most important setting regarding tire life?

A. Toe in
B. Camber
C. Caster
D. Inclination

30. When you are adjusting toe and the steering wheel, and the vehicle has two sleeves, what adjustment is made first?

A. Wheel center
B. Camber
C. caster
D. Toe

31. **{True or False)** Steering axis inclination is a nonadjustable angle.

A. True
B. False

32. What does steering axis inclination use to improve tracking?

A. Weight
B. Toe-in
C. Toe-out
D. Thrust

33. Which of the following components is not part of the track system?

A. Chain
B. Idler
C. Tension mechanism
D. Torque converter

34. What is the type of track system that has the pin and bushing already lubricated on assembly and is designed to eliminate internal wear?

A. Closed
B. Manual
C. Sealed
D. Lubricated

35. What is the purpose of the drive sprocket?

A. To clean the chain links
B. To transfer drive torque to the track
C. To transfer thrust to the idler
D. To transfer weight to the rollers

36. What component has seen Improvement in design on some bulldozers?

A. Track
B. Track rollers
C. Sprocket
D. Idler

37. Along with distributing the weight of the equipment, what else do track rollers accomplish?

A. Alignment of the track
B. Cleaning the track
C. Keeping the track tight
D. Lubrication of the link pins

38. On a typical carrier roller, the bearings are held in place in the carrier shell by which component(s)?

A. Shaft
B. Retaining ring
C. End collar and O-ring
D. End collar and seals

39. What do conventional seals use that maintains sealing pressure as they wear and helps keep dirt out?

A. Bellville springs
B. Bellville bearings
C. Bellville seals
D. Bellville washers

40. Rigid seals, although more costly than Bellville washers are able to withstand temperatures up to_________degrees.

A. 150
B. 160
C. 170
D. 180

41. Which component allows the track frame to pivot independently on a pivot shaft?

A. Frame
B. Equalizer
C. Track Guards
D. Idler connector

42. Which component of tracked equipment adjusts the track tension and guides the track through the track rollers?

A. Front idler
B. Sprocket
C. Rear idler
D. Equalizer

43. **{True or False)** A tight track is essential to distribute the load evenly over the rollers and to prevent throwing the track.

A. True
B. False

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Auto Suspension and Steering, Chris Johanson and Martin T. Stockel, The Goodheart-Wilcox Company, Inc., 2004. (ISBN: 1-59070-261-1)

Heavy Duty Truck Systems, 4th Edition, Sean Bennett and Ian Andrew Norman, Delamar Cengage Learning, 2006, (ISBN: 1-4018-7064-3)

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Chapter 10

Hydraulic Systems

Topics

1.0.0 Basic Principles of Hydraulics and Pneumatics

2.0.0 Components

3.0.0 Hydraulic Systems

To hear audio, click on the box.

Overview

As a CM, you will be responsible for the maintenance, repair, and troubleshooting of hydraulic systems. You must be able to analyze the malfunctions of these systems and supervise your personnel in the required corrective action. To be able to do this, you must thoroughly understand the basic system, the operational principles, and the components of the system.

This chapter will discuss the basic principles associated with hydraulics, followed by coverage of various system components. The purpose of this information is to give you an analytical understanding of the interrelationships of principles and components in an operating system. When you understand the operation of a system, it is much easier to analyze a malfunction and make the proper repairs.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the basic principles of hydraulics and pneumatics.
2. Identify components of hydraulic systems.
3. Understand how to troubleshoot hydraulic systems.

Prerequisites

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air Conditioning Systems	↑	C M
Air Compressor Overhaul		
Inspecting and Troubleshooting Brake Systems		
Hydraulic Systems		A D V A N C E D
Wheel and Track Alignment		
Troubleshooting Transmissions, Transfer Cases and Differentials		
Clutches and Automatic Transmissions		
Troubleshooting Electrical Systems		
Fuel System Overhaul		
Engine Troubleshooting and Overhaul		
The Shop Inspectors		
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 BASIC PRINCIPLES OF HYDRAULICS and PNEUMATICS

In automotive and construction equipment, the terms hydraulic or pneumatic describe a method of transmitting power from one place to another through the use of a liquid or a gas. Several kinds of gases are used in the various hydraulic systems; however, certain physical laws or principles apply to all liquids and gases. As a CM, you should be aware of this. You should also be familiar with the following terms as they are associated with hydraulic and pneumatic systems.

- HYDRAULICS is that branch of science that deals with the study and use of liquids as related to the mechanical aspects of physics.
- PNEUMATICS is that branch of science that deals with the study and use of air and other gases as related to the mechanical aspects of physics.
- ***FORCE*** is the push or pull on an object. In hydraulics and pneumatics, force is usually expressed in pounds.
- ***PRESSURE*** is the amount of force distributed over each unit on the area of an object. In hydraulics/pneumatics, pressure is expressed in pounds per square inch (psi).

A fluid is defined as any substance made up of small particles or molecules that have the ability to flow or move easily (conforms to the outline of its container); this includes both liquid and gas. The terms liquids and fluids are often used interchangeably; however, fluids have a much broader meaning. All liquids are fluids, but not all fluids are liquid; fluids can be liquid, but they can also be air and other gases that are not liquid. In support equipment, hydraulics mean liquids, and pneumatics mean air or other gases.

1.1.0 Incompressibility and Expansion of Liquids

For all practical purposes, fluids are ***incompressible***. Under extremely high pressures, the volume of a fluid can be decreased somewhat, though the decrease is so slight that it is considered to be negligible except by design engineers.

Liquids expand and contract because of temperature changes. When liquid in a closed container is subjected to high temperatures, it expands. This exerts a pressure on the walls of the container; therefore, it is necessary that pressure-relief mechanisms and expansion chambers be incorporated into hydraulic systems. Without these precautionary measures, the expanding fluid might exert enough pressure to rupture the system.

1.2.0 Compressibility and Expansion of Gases

A gas is a substance in which the molecules are separated by relatively large spaces. The two major differences between liquids and gases are their compressibility and expansion. While liquids are incompressible, gases are highly compressible because of these large spaces between the molecules.

Gases, like liquids, expand and contract because of temperature change; but unlike liquids, a gas expands to till completely any closed container in which it is contained; a liquid fills the container only to the extent of its normal volume.

1.3.0 Pascal's Law

Pascal was a noted French physicist who discovered that a closed container of fluid could be used to transfer force from one place to another or to multiply forces by its transmission through a fluid. Pascal's law may be stated as follows: pressure applied anywhere on a confined fluid is transmitted undiminished in every direction. The force thus exerted by the confined fluid acts at right angles to every portion of the surface of the container and is equal upon equal areas. It should be noted that Pascal's law applies to fluids--both gas and liquid. It is the use of Pascal's law that makes today's hydraulic and pneumatic systems possible.

According to Pascal's law, any force applied to a confined fluid is transmitted in all directions throughout the fluid regardless of the shape of the container. Consider the effect of this in the systems shown in *Figure 10-1, Views A* and *B*. If there is a resistance on the output piston (View A, piston 2) and the input piston is pushed downward, a pressure is created through the fluid, which acts equally at right angles to surfaces in all parts of the container.

If the force 1 is 100 pounds and the area of input piston 1 is 10 square inches, then the pressure in the fluid is 10 psi (100 + 10). It must be emphasized that this fluid pressure cannot be created without resistance to flow, which in this case is provided by the 100-pound force acting against the top of the output piston 2. This pressure acts on piston 2 so that for each square inch of its area it is pushed upward with a force of 10 pounds. In this case, a fluid column of uniform cross section is considered so that the area of the output piston 2 is the same as the input piston 1, or 10 square inches; therefore, the upward force on the output piston 2 is 100 pounds--the same as was applied to the input piston 1. All that was accomplished in this system was to transmit the 100-pound force around a bend; however, this principle underlies practically all mechanical applications of fluid power.

At this point, it should be noted that since Pascal's law is independent of the shape of the container, it is not necessary that the tube connecting the two pistons be the full area of the pistons. A connection of any size, shape, or length will do so long as an unobstructed passage is provided. Therefore, the system shown in *Figure 10-1, View B* (a relatively small bent pipe connects two cylinders) will act exactly the same as that shown in *View A*.

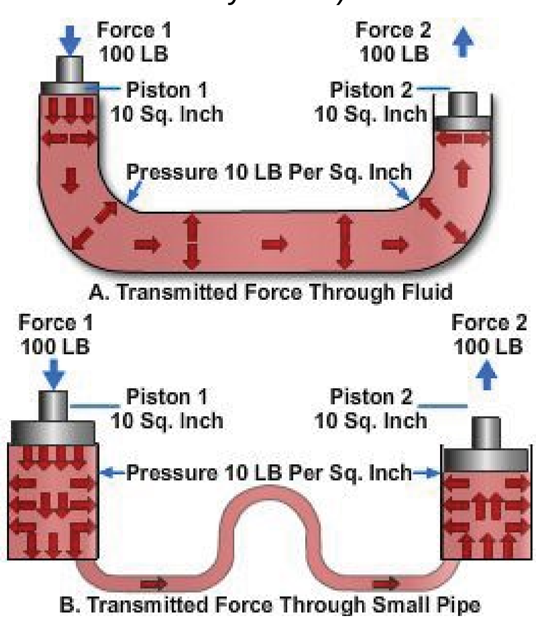

Figure 10-1 - Force transmitted from piston to piston.

1.3.1 cation Forces

In *Figure 10-1*, the systems contain pistons of equal area wherein the output force is equal to the input force. Consider the situation in *Figure 10-2* where the input piston is much smaller than the output piston. Assume that the area of the input piston 1 is 2 square inches. With a resistant force on piston 2, a downward force of 20 pounds acting on piston 1 creates 10 psi (20+2) in the fluid. Although this force is much smaller than the applied forces in *Figure 10-1*, the pressure is the same because the force is concentrated on a relatively small area.

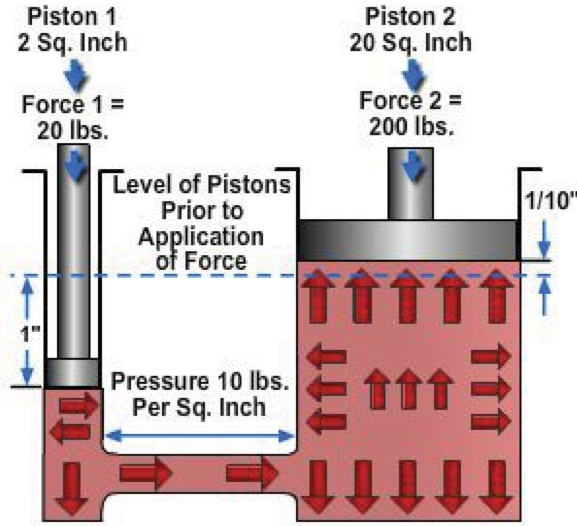

Figure 10-2 – Multiplication of force in a hydraulic system.

This pressure of 10 psi acts on all parts of the fluid container, including the bottom of the output piston 2; therefore, the upward force on the output piston 2 is 10 pounds for each of its 20 square inches of area, or 200 pounds (10 x 20). In this case the original force has been multiplied tenfold while using the same pressure in the fluid as before. In any system with these dimensions, the ratio of output force to input force is always 10 to 1 regardless of the applied force; for example, if the applied force of the input piston 1 is 50 pounds, the pressure in the system is increased to 25 psi. This will support a resistant force of 500 pounds on the output piston 2.

The system works the same in reverse. Consider piston 2 as the input and piston 1 as the output; then the output force will always be one-tenth the input force. Sometimes such results are desired.

Therefore, the first basic rule for two pistons used in a fluid power system-that the force acting on each is directly proportional to its area, and the magnitude of each force is the product of the pressure and its area--is totally applicable.

1.3.2 Volume and Distance Factors

In the systems shown in *Figure 10-1*, the pistons have areas of 10 square inches. Since the areas of the input and output pistons are equal, a force of 100 pounds on the input piston will support a resistant force of 100 pounds on the output piston. At this point, the pressure of the fluid is 10 psi. A slight force, in excess of 100 pounds, on the input piston will increase the pressure of the fluid, which in turn will overcome the resistance force. Assume that the input piston is forced downward 1 inch. This displaces 10 cubic inches of fluid. Since liquid is practically incompressible, this volume must go some place. In the case of a gas, it will compress momentarily but will eventually expand to its original volume at 10 psi. This is provided, of course, that the 100 pounds of force is still acting on the input piston. Thus this volume of fluid moves the output piston. Since the area of the output piston is likewise 10 square inches, it moves 1 inch upward to accommodate the 10 cubic inches of fluid. The pistons are of equal areas; therefore, they will move equal distances, though in opposite directions.

Applying this reasoning to the system in *Figure 10-2*, it is obvious that if the input piston 1 is pushed down 1 inch, only 2 cubic inches of fluid is displaced. The output piston 2 will have to move only one-tenth of an inch to accommodate these 2 cubic inches of fluid because its area is 10 times that of the input piston 1. This leads to the second basic rule for two pistons in the same fluid power system: the distances moved are inversely proportional to their areas.

Test your Knowledge (Select the Correct Response)

1. In regard to hydraulics and pneumatics, what are the two major differences between liquids and gases?

    A. Weights and temperatures
    B. Colors and weights
    C. Temperatures and compressibility
    D. Expansion and compressibility

2.0.0 COMPONENTS

Since fluids are capable of transmitting force and at the same time flow easily, the force applied to the fluid at one point is transmitted to any point the fluid reaches. Hydraulic and pneumatic systems are assemblies of units capable of doing this. They contain a unit for generating force (pumps), suitable tubing and hoses for containing and transmitting the fluid under pressure, and units in which the energy in the fluid is converted to mechanical work (cylinders and fluid motors). In addition, all operative systems contain valves and restrictors to control and direct the flow of fluid and limit the maximum pressure in the system.

Because of the similarities of hydraulic and pneumatic systems (that is, from a training point of view), only the components of hydraulic systems are covered in this section. Remember that most of the information is also applicable to pneumatic systems and their components.

2.1.0 Pumps

The heart of any hydraulic system is its pumps; it is the pump that generates the force required by the actuating mechanisms. The pump causes a flow of fluid; thus, the amount of pressure created in a system is not controlled by the pump but by the workload imposed on the system and the pressure-regulating valves.

Basically, pumps may be classified into two groups based on performance: (1) fixed delivery when running at a given speed and (2) variable delivery when running at a given speed. Pumps may further be divided into types, based upon the design used to create force (fluid flow). Practically all hydraulic pumps fall within three classifications of design-rotary, reciprocating, and centrifugal. The centrifugal style pumps find little use in CESE hydraulic systems used in the Naval Construction Force and will not be covered here. Pumps may be driven by air pressure, electric motors, gas turbine engines, or the conventional internal combustion engines (gasoline and diesel).

2.1.1 Rotary Pumps

All rotary pumps operate by means of rotating parts that trap the fluid at the inlet (suction) port and force it through the discharge port into the hydraulic system. Gears, lobes, and vanes are commonly used as elements in rotary pumps. Rotary pumps operate on the positive displacement principle and are of the fixed displacement type.

There are numerous types of rotary pumps and various methods of classification. They may be classified as to shaft position-either vertically or horizontally mounted; the type of drive-electric motor, internal combustion engine, and so forth; manufacturer's name;

or service application. However, classification of rotary pumps is generally made according to the type of rotating element. A few of the most common types of rotary pumps are covered in the paragraphs below.

2.1.1.1 Gear Pumps

Gear pumps are classified by their method of meshing together (*Figure 10-3*). This style pump is simple in design and finds wide use in low-pressure hydraulic systems. A gear pump delivers a constant volume of fluid at any given rpm.

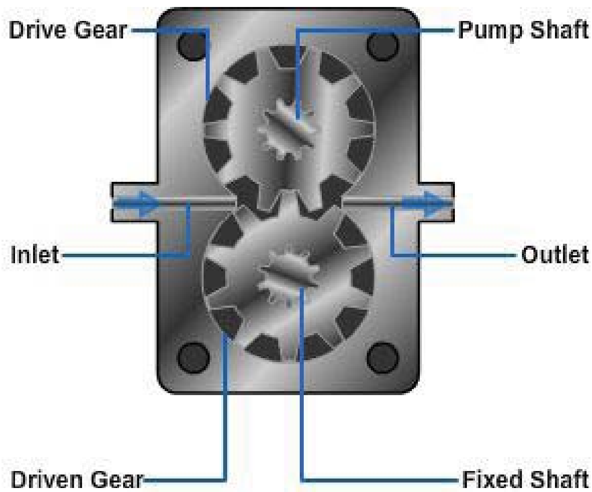

Figure 10-3 – Gear-driven hydraulic pump.

The pump shown is known as a spur tooth and consists of two meshed gears that revolve alongside each other in one housing. The drive gear in the illustration is turned by a drive shaft that engages the power source. The clearances between the pump housing and the gear teeth as they mesh are very small.

The inlet port is connected to the fluid supply line, and the outlet port is connected to the pressure line. Referring to the figure, note that the drive gear is rotating in a counterclockwise direction, and the driven gear (idler gear) is rotating in a clockwise direction. As the teeth pass the inlet port, fluid is trapped between the teeth and the housing; this liquid is carried around the housing to the outlet port. As the teeth mesh again, the liquid between the teeth is displaced into the outlet port. This action produces a positive flow of liquid into the system. A shear pin or shear section is incorporated in the drive shaft to protect the power source or reduction gears if the pump fails because of excessive load or binding of parts.

A variation of the spur tooth pump is the lobe pump, which is also used on many diesel-powered types of equipment for an intake blower as well as in a variety of hydraulic systems (*Figure 10-4*). The principle of operation of this pump is exactly the same as that of the spur tooth. The lobes are so constructed that there is a continuous seal (vane) at the point of juncture at the center of the pump and also on the housing.

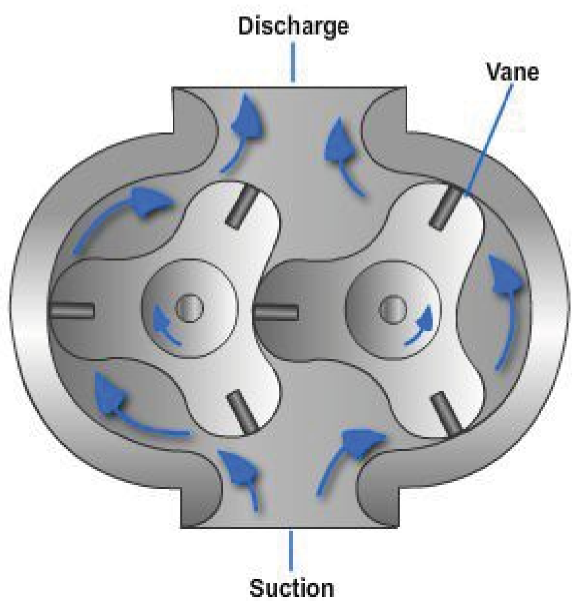

Figure 10-4 – Lobe-driven hydraulic pump.

Another popular style of gear pump is the internal gear (*Figure 10-5*). This pump consists of a pair of gear-shaped elements (one within the other) located in the pump chamber. The inner gear is connected to the drive shaft of the source of power.

Note that the inner gear has one less tooth than the outer gear has spaces. The tooth force of each gear is related to that of the other in such away that each tooth of the inner gear is always in sliding contact with the surface of the outer gear.

Each tooth of the inner gear meshes with the outer gear at just one point during each revolution. At one side of the point of mesh, pockets of increasing size are formed as the gears rotate, while on the other side the pockets decrease in size.

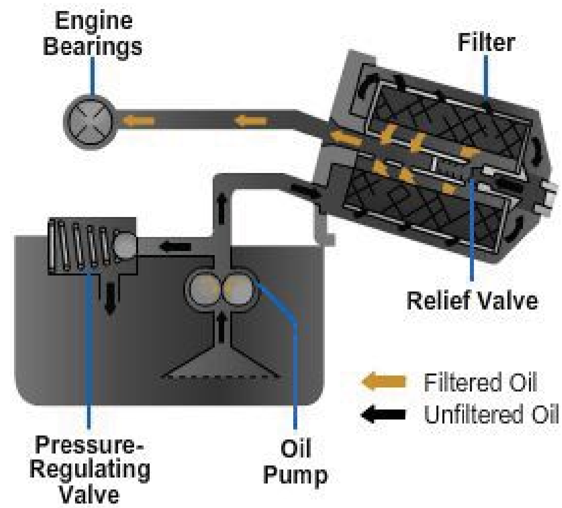

Figure 10-5 – Internal gear hydraulic pump.

2.1.2 Vane Pump

Figure 10-6 illustrates a vane pump of the unbalanced design. The rotor is attached to the drive shaft and is rotated by an outside power source, such as an electric motor or gasoline engine. The rotor is slotted, and each slot is fitted with a rectangular vane. These vanes, to some extent, are free to move outward in their respective slots. The rotor and vanes are enclosed in a housing, the inner surface of which is offset with the drive axis.

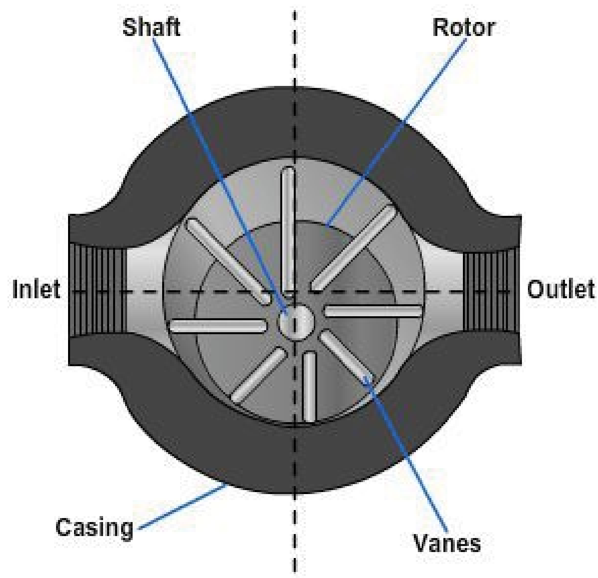

Figure 10-6 – Vane-driven hydraulic pump.

As the rotor turns, centrifugal force keeps the vanes snug against the wall of the housing. The vanes divide the area between the rotor and housing into a series of chambers. The chambers vary in size according to their respective positions around the shaft. The inlet port is located in that part of the pump where the chambers are expanding in size so that the partial vacuum (low-pressure area) formed by this expansion allows liquid to flow into the pump. The liquid is trapped between the vanes and carried to the outlet side of the pump. The chambers contract in size on the outlet side, and this action forces the liquid through the outlet port and into the system.

The pump is referred to as unbalanced because all of the pumping action takes place on one side of the shaft and rotor. This causes a side load on the shaft and rotor. Some vane pumps are constructed with an elliptical-shaped housing that forms two separate pumping areas on opposite sides of the rotor. This cancels out the side loads; therefore, such pumps are used quite extensively in power steering units in CESE to provide the flow.

2.1.3 2.1.3 Reciprocating Pumps

Reciprocating pumps are most commonly used for applications requiring high pressures and accurate control of the discharge volume. There are many variations of this pump, which is normally referred to as a piston pump in support equipment; however, they are generally based on the axial piston or hand pump principle. There are also radial piston pumps, but they are hardly ever used in design of support equipment systems. Whenever you are working with these types of pumps, refer to the manufacturer's technical manual for repair.

2.1.3.1 Axial-Piston Pumps

Axial-piston pumps are classified as either constant volume or variable volume. The paragraphs below explain the overall operation of the pump and the means designed into the variable volume pump to provide stroke reduction.

2.1.3.2 Constant Volume Piston Pump

The constant volume piston pump produces a constant flow of fluid for any given rpm (*Figure 10-7*). The pistons, usually about nine (always an odd number), are fastened by a universal linkage to a drive shaft. The universal link in the center drives the cylinder block; it is held at an angle to the drive shaft by the pump housing. Everything within the pump housing rotates with the drive shaft. As the piston is rotated to the upper position, its movement forces fluid out of the pressure port. As the same piston moves from the upper position to the lower position, it draws in fluid through the intake port. Since each piston is always somewhere between the upper and lower position, constant intake and output of fluid results. The volume output of the pump is determined by the angle between the drive shaft and the cylinder block, as the degree of angle decreases or increases the piston stroke. The larger the angle, the greater the output per revolution.

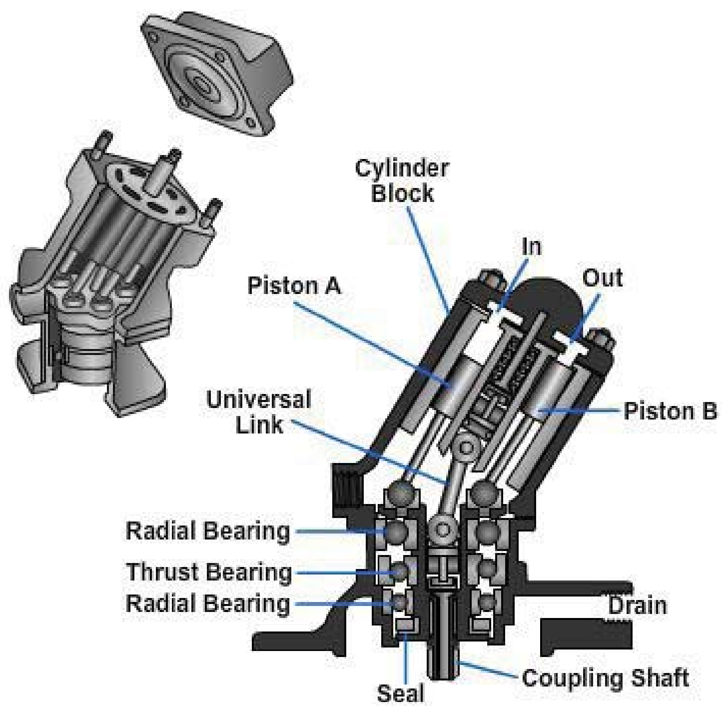

Figure 10-7 - Constant volume piston pump.

If you follow one piston through one complete revolution, you can see how the pump operates. Start with the piston at the top of its cylinder. It has just completed its pressure stroke and is ready to begin its intake stroke. As the cylinder starts its rotation from this point, the piston immediately aligns with the intake port as it moves toward the bottom of the cylinder. The partial vacuum created by the movement of the piston in the cylinder and the gravity pressure (in some cases, boost pressure) on the fluid cause the space above the piston to fill with fluid. When the cylinder has gone through 180 degrees or one-half revolution, the piston reaches the bottom of the cylinder; the cylinder is now full of fluid.

As rotation continues beyond this point, the piston now aligns with the outlet port slot. Thus, when the last 180 degrees have been completed, the piston will have moved forward in the cylinder, and the fluid will have been forced into the outlet line. At this point, the piston and cylinder are again ready to start another cycle. There are several pistons performing the same function just described. Since the pump rotates rapidly, there is a constant flow of fluid through the outlet port.

This pump normally uses case pressure and fluid flow for cooling and lubricating. Fluid seeps by the pistons in the cylinder block and fills all the space inside the pump. The fluid is prevented from escaping through the drive end of the pump by a drive shaft seal. Excessive case pressure is prevented by routing the fluid back to the inlet port of the pump through one or more relief valves. These valves are usually set at about 15 psi; this ensures circulation of fluid in the pump.

The piston pump discussed is a constant displacement type, that is, for any given rpm, the volume output is constant. However, there is another version of the piston pump used more extensively than the constant volume pump--the variable volume pump.

2.1.3.3 Variable Volume Piston Pump

There are many versions of the variable volume pump (*Figure 10-8*); several different control methods are used to vary the fluid flow through the pump. Some of the pumps vary the volume by controlling the inlet fluid, some by changing the angle between the pump drive shaft and the piston cylinder block, and others by using a system bypass within the pump to vary volume output.

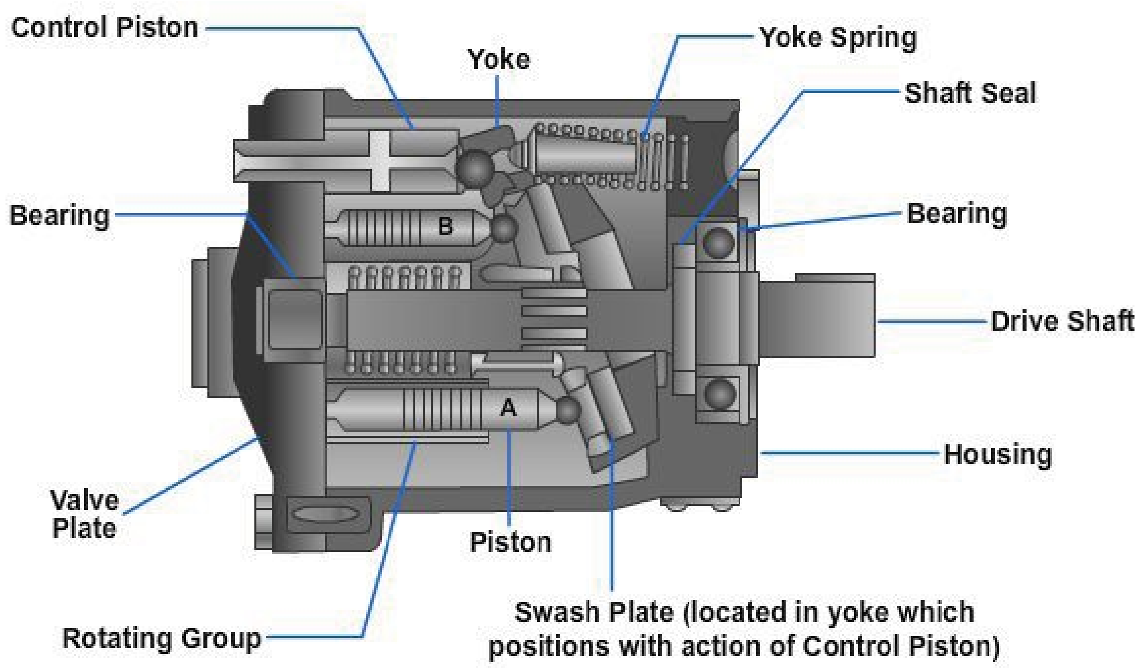

Figure 10-8 - Variable volume pump.

One advantage of the variable volume pump is that it eliminates the need for a system pressure regulator. A second advantage is that it provides a more stable pressure, thus reducing pressure surges and the need for a system accumulator; however, they are retained for use during peak load occurrences.

As stated previously, the output of the constant volume pump is determined by pump rpm and the fixed angle between the drive shaft and the rotating cylinder block. If the angle was not fixed and could be varied, the piston stroke would be changed, thus varying the pump output. Changing the pump piston stroke is the method used on most variable volume pumps found in support equipment.

The stroke reduction pump is a fully automatic variable volume pump. The pressure compensating valves shown in both figures use system pressure to control and vary the piston stroke of the pump, thus changing the output.

The pumps may also be configured to allow manual volume control of the pump. Manual volume is controlled by a handwheel to vary the piston stroke, or manual pressure compensating valves may be used, such as those used on many hydraulic test stands.

2.1.4 Hand Pumps

The hand pump normally serves as a substitute for the main power pump on most hydraulic systems; however, the hand pump is widely used as the only power source in some equipment. Examples are hydraulic jacks, hydraulically actuated workstands, and similar equipment.

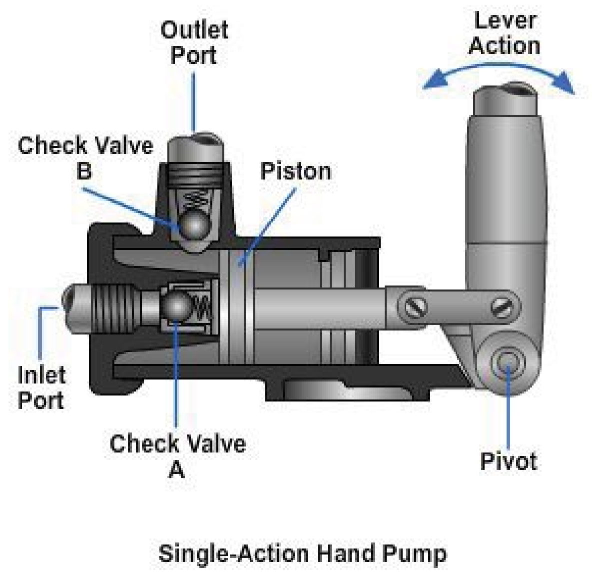

Figure 10-9 – Hand pumps.

The two designs of hand pumps you will be using are single action (*Figure 10-9, View A*) and double action (*Figure 10-9, View B*). The double-action hand pump creates the flow of fluid with each stroke of the pump handle; two strokes are required for the single-action pump. There are several versions of single- and double-action hand pumps, but all operate on the reciprocating piston principle. The unit shown in *Figure 10-9, View A* consists of a cylinder, a piston, an operating handle, and two check valves--check valve A and check valve B. The inlet port is connected to the reservoir, and the outlet port is connected to the pressure system. As the piston is moved to the right by the pump handle, fluid from the reservoir flows through check valve A into the pump cylinder. As the piston is moved to the left, check valve A closes and check valve B opens. The fluid in the pump cylinder is forced out of the outlet port into the pressure line. Thus, with each two strokes of the hand, a single pressure stroke is produced.

The double-action hand pump consists of a cylinder, a piston containing a built-in check valve A, a large piston rod, an operating handle, and check valve B at the inlet port (*Figure 10-9, View B*).

When you move the piston to the right, check valve A closes and check valve B opens. Fluid from the reservoir then flows into the cylinder through the inlet port. When you move the piston to the left, check valve B closes. The pressure created in the fluid then opens check valve A, admitting fluid behind the piston. (Note that the large piston rod takes up much of the space behind by the piston rod.) Because of the space occupied by the piston rod, there is room for only part of the fluid; thus, the remainder of the fluid is forced through the outlet port into the pressure line. This is one pressure stroke. Again, if you move the piston to the right, check valve A closes. The fluid behind the piston is forced through the outlet port. At the same time fluid from the reservoir flows into the cylinder through check valve B. This pump has a pressure stroke for each stroke of the handle.

2.2.0 Actuators

The purpose of hydraulic actuators is to transform fluid pressure into mechanical energy. They are used where linear motion or rotary motion is required. Actuators are generally of the cylinder or motor design.

2.2.1 Cylinders

An actuating cylinder is a device that converts fluid power to linear or straight-line force and motion. Since linear motion is a back-and-forth motion along a straight line, this type of actuator is sometimes referred to as a reciprocating or linear motor. The cylinder consists of a ram or piston operating within a cylindrical bore.

Actuating cylinders for pneumatic and hydraulic systems are similar in design and operation. Some of the variations of ram- and piston-type actuating cylinders are described in the paragraphs below.

2.2.1.1 Ram Type of Cylinder

The ram type of cylinder is used primarily for push functions rather than pull. Some applications simply require a flat surface on the external part of the ram for pushing or lifting the unit to be operated. Other applications require some mechanical means of attachment, such as a clevis or eyebolt. The design of ram-type cylinders varies in many other respects to satisfy the requirements of different applications. Two designs of the ram type cylinders are the single-acting and the double-acting rams.

- The single-acting ram applies force in only one direction (*Figure 10-10*). Fluid directed into the cylinder displaces the ram and forces it outward. Since there is no provision for retracting the ram by the use of fluid power, the retracting force can be gravity or some mechanical means, such as a spring. This type of actuating cylinder is often used in the hydraulic jack.

Figure 10-10 - Single-acting piston type cylinder.

- A double-acting ram type of cylinder is illustrated in *Figure 10-11*. In this cylinder, both strokes of the ram are produced by pressurized fluid. There are two fluid ports-one at or near each end of the cylinder. To extend the ram and apply force, fluid under pressure is directed to the closed end of the cylinder through one port.

To retract the ram and reduce force, fluid is directed to the opposite end of the cylinder through a different port.

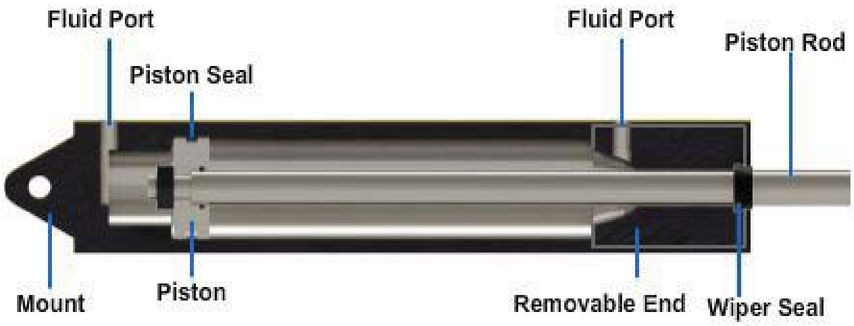

Figure 10-11 - Double-acting piston type cylinder.

2.2.1.2 Piston Type of Cylinder

The piston type of cylinder is normally used for applications that require both push and pull functions. Thus, the piston type serves many more requirements than the ram type, and therefore is the most common type used in fluid power systems.

The housing consists of a cylindrical barrel that usually contains either external or internal threads on both ends. End caps with mating threads are attached to the ends of the barrel. These end caps usually contain the fluid ports. The end cap on the rod end contains a hole for the piston rod to pass through. Suitable packing must be used between the hole and the piston rod to prevent external leakage of fluid and the entrance of dirt and other contaminants. The opposite end cap of most cylinders is provided with a fitting for securing the actuating cylinder to some structure. For obvious reasons, this end cap is referred to as the anchor end cap.

The piston rod may extend through either or both ends of the cylinder. The extended end of the rod is normally threaded for the attachment of some type of mechanical connector, such as an eyebolt or a clevis, and a locknut. This threaded connection of the rod and mechanical connector provides for adjustment between the rod and the unit to be actuated. After correct adjustment is obtained, the locknut is tightened against the connector to prevent the connector from turning. The other end of the eyebolt or clevis is connected to the unit to be actuated, either directly or through additional mechanical linkage.

To satisfy the many requirements of fluid power systems, you may get piston type cylinders in various designs. Two of the more common designs are the single-acting piston and the double-acting piston.

2.2.1.2.1 gle-Acting Piston

The single-acting piston-type cylinder (*Figure 10-12, View A*) is similar in design and operation to the single-acting ram-type cylinder previously covered. The single-acting piston-type cylinder uses fluid pressure to apply force in only one direction. In some designs of this type, the force of gravity moves the piston in the opposite direction; however, most cylinders of this type apply force in both directions. Fluid pressure provides the force in one direction, and spring tension provides the force in the opposite direction. In some single-acting cylinders, compressed air or nitrogen is used instead of a spring for movement in the direction opposite that achieved with fluid pressure.

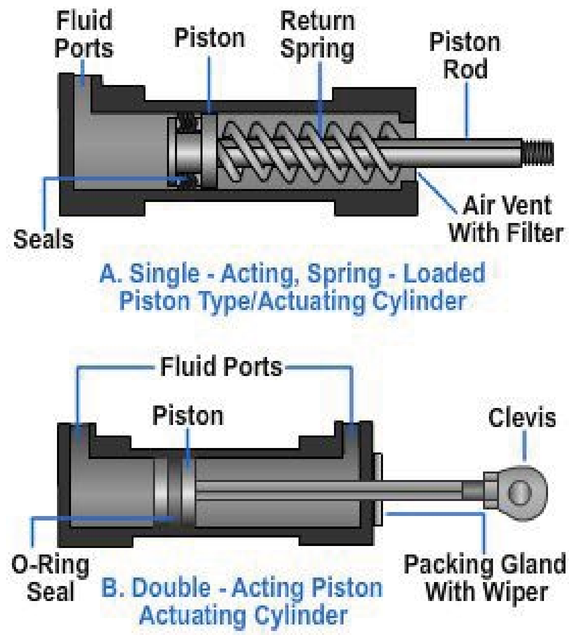

Figure 10-12 – Piston type cylinders.

The end of the cylinder opposite the fluid port is vented to the atmosphere. This prevents air from being trapped in this area. Any trapped air would compress during the extension stroke, creating excess pressure on the rod side of the piston. This would cause sluggish movement of the piston and could eventually cause a complete lock, preventing the fluid pressure from moving the piston.

You should note that the air vent ports are normally equipped with an air filtering attachment to prevent ingestion of contaminates when the piston retracts into the cylinder.

A three-way directional control valve is normally used to control the operation of this type of cylinder. To extend the piston rod, fluid under pressure is directed through the port and into the cylinder. This pressure acts on the surface area of the blank side of the piston and forces the piston to the right. This action, of course, extends the rod to the right through the end of the cylinder. This moves the actuated unit in one direction. During this action, the spring is compressed between the rod side of the piston and the end of the cylinder. Within limits of the cylinder, the length of the stroke depends upon the desired movement of the actuated unit.

2.2.1.2.2 -Acting Piston

Most piston-type actuating cylinders are double-acting, which means that fluid under pressure can be applied to either side of the piston to provide movement and apply force in the corresponding direction.

One design of the double-acting piston type actuating cylinder is illustrated in *Figure 10-12, View B*. This cylinder contains one piston and piston rod assembly. The stroke of the piston and piston rod assembly in either direction is produced by fluid pressure. The two fluid ports, one near each end of the cylinder, alternate as inlet and outlet, depending upon the direction of flow from the directional control valve.

This is referred to as an unbalanced actuating cylinder, that is, there is a difference in the effective working areas on the two sides of the piston. Assume that the cross-sectional area of the piston is 3 square inches and the cross-sectional area of the rod is

1 square inch. In a 2,000-psi system, pressure acting against the blank side of the piston creates a force of 6,000 pounds (2,000 x 3). When the pressure is applied to the rod side of the piston, the 2,000 psi acts on 2 square inches (the cross-sectional area of the piston less the cross-sectional area of the rod) and creates a force of 4,000 pounds (2,000 x 2). For this reason, this type of cylinder is normally installed in such a manner that the blank side of the piston carries the greater load, that is, the cylinder carries the greater load during the piston rod extension stroke.

A four-way directional control valve is normally used to control the operation of this type of cylinder. The valve can be positioned to direct fluid under pressure to either end of the cylinder and allow the displaced fluid to flow from the opposite end of the cylinder through the control valve to return/exhaust.

2.3.0 Motors

A fluid power motor is a device that converts fluid power to rotary motion and force. Basically, the function of a motor is just the opposite as that of a pump; however, the design and operation of fluid power motors are very similar to pumps. In fact, some hydraulic pumps can be used as motors with little or no modifications; therefore, your having a thorough knowledge of the pumps will be extremely helpful to you in understanding the operation of fluid power motors.

Motors serve many applications in fluid power systems. In hydraulic power drives, pumps and motors are combined with suitable lines and valves to form hydraulic systems. The pump, commonly referred to as the A-end, is driven by some outside source, such as a diesel or gasoline engine. The pump delivers fluid to the motor. The motor, referred to as the B-end, is actuated by this flow, and, through mechanical linkage, conveys rotary motion and force to the work.

Fluid motors are usually classified according to the type of internal element which is directly actuated by the flow. The most common types of elements are the gear, vane, and piston. All three of these types are adaptable for hydraulic systems, while only the vane type is used in pneumatic systems.

2.3.1 Gear Type

The gears of the gear-type motor are of the external type and may be of the spur, helical, or herringbone design. These designs are the same as those used in gear pumps.

The operation of a gear-type motor is illustrated in *Figure 10-13*. Both gears are driven gears; however, only one is connected to the output shaft. As fluid under pressure enters chamber A, it takes the path of least resistance and flows around the inside surface of the housing, forcing the gears to rotate as indicated. The flow continues through the outlet port to return. This rotary motion of the gears is conveyed through the attached shaft to the work unit.

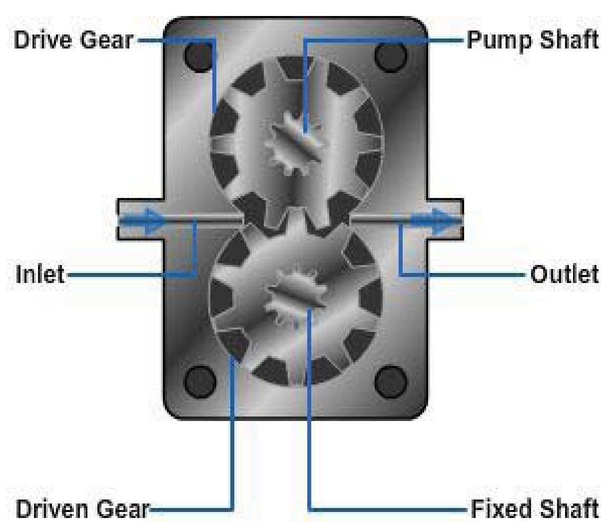

Figure 10-13 – Gear-type hydraulic pump.

Although the motor illustrated in *Figure 10-13* shows operation in only one direction, the gear-type motor is capable of providing rotary motion in either direction. The ports alternate as inlet and outlet. To reverse the direction of rotation, the fluid is directed through the port-labeled outlet into chamber B. The flow through the motor rotates the gears in the opposite direction, thus actuating the work unit accordingly.

2.3.2 Vane Type

A typical vane-type air motor is illustrated in *Figure 10-14*. This particular motor provides rotation in only one direction. The rotating element is a slotted rotor mounted on a drive shaft. Each slot of the rotor is fitted with a freely sliding rectangular vane. The rotor and vane are enclosed in the housing-the inner surface of which is offset with the drive shaft axis. When the rotor is in motion, the vanes tend to slide outward because of centrifugal force. The distance the vanes slide is limited by the shape of the rotor housing.

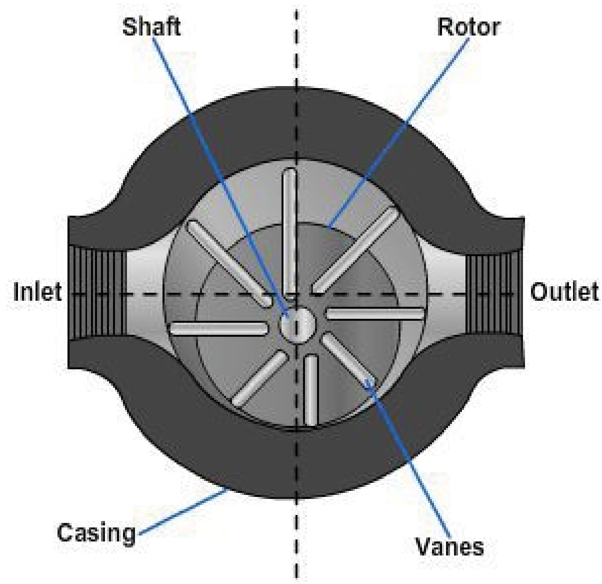

Figure 10-14 – Vane-driven hydraulic pump.

This motor operates on the principle of differential areas. When compressed air is directed into the inlet port, its pressure is exerted equally in all directions. Since area A is greater than area B, the rotor will turn counterclockwise. Each vane, in turn, assumes the No. 1 and No. 2 position and the rotor turns continuously. The potential energy of the compressed air is thus converted into kinetic energy in the form of rotary motion and force. The air at reduced pressure is exhausted to the atmosphere. The shaft of the motor is connected to the unit to be actuated.

Many vane-type motors are capable of providing rotation in either direction. The principle of operation is the same as that of the vane type of motor previously described. The two ports may be alternately used as inlet and outlet, thus providing rotation in either direction. Note the springs in the slots of the rotors. Their purpose is to hold the vanes against the housing during the initial starting of the motor, since no centrifugal force exists until the rotor begins to rotate. Springs are not required in vane-type pumps because the drive shaft provides the initial centrifugal force.

2.3.3 Piston Type

Like piston (reciprocating) type pumps, the most common design of the piston type of motor is the axial. This type of motor is the most commonly used in hydraulic systems.

Although some piston-type motors are controlled by directional control valves, they are often used in combination with variable displacement pumps. This pump-motor combination (hydraulic transmission) is used to provide a transfer of power between a driving element (for example, an electric motor or gasoline engine) and a driven element. Some of the applications for which hydraulic transmissions may be used are speed reducer, variable speed drive, constant speed or constant torque drive, and torque converter. Some advantages of hydraulic transmission over mechanical transmission of power are as follows:

- Quick easy speed adjustment over a wide range while the power source is operating at constant (most efficient) speed. Rapid, smooth acceleration or deceleration.
- Control over maximum torque and power.
- Cushioning effect to reduce shock loads.
- Smoother reversal of motion.

While you are studying the description of the piston type of motor in the paragraphs below, it may be necessary to refer back to the piston type of pump for a review of the operation and particularly the parts nomenclature.

The operation of the axial-piston motor (*Figure 10-15*) is similar to that of a radial piston motor. Fluid from the system flows through one of the ports in the valve plate and enters the bores of the cylinder block that are open to the inlet port. (For example, in a nine piston motor, four cylinder bores are receiving fluid while four are discharging.) The fluid acting on the pistons in those bores forces the pistons to move away from the valve plate. Since the pistons are held by connecting rods at a fixed distance from the output shaft flange, they can move away from the valve plate only by moving in a rotary direction. The pistons move in this direction to a point around the shaft axis, which is the greatest distance from the valve plate. Therefore, driving the pistons axially causes them to rotate the drive shaft and cylinder block. While some of the pistons are being driven by liquid flow from the system, others are discharging flow from the outlet port.

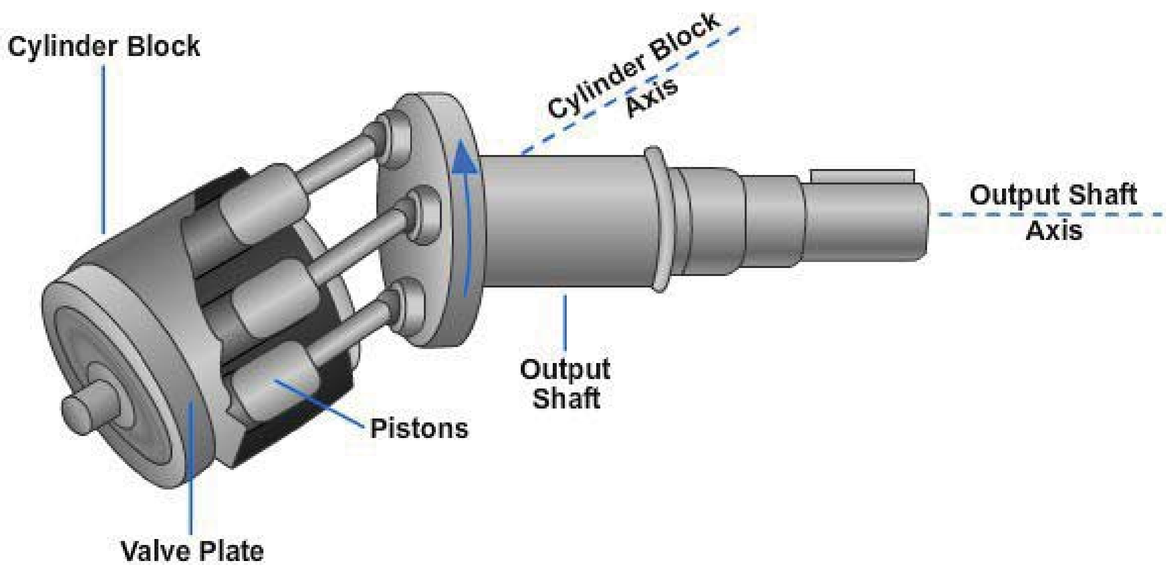

Figure 10-15 - Piston type hydraulic motor.

This type of motor may be operated in either direction of rotation. The direction of rotation is controlled by the direction of flow to the valve plate. The direction of flow may be instantly reversed without damage to the motor. This design is found mainly on construction equipment as an auxiliary drive motor.

The speed of the rotation of the motor is controlled by the length of the piston stroke in the pump. When the pump is set to allow a full stroke of each piston, each piston of the motor must move an equal distance. In this condition, the speed of the motor will equal that of the pump. If the tilting plate of the pump (normally called a swash plate or hanger assembly) is changed so that the piston stroke of the pump is only one half as long as the stroke of the motor, it will require the discharge piston one full stroke; therefore, in this position of the plate, the motor will revolve just one half as fast as the pump. If there is no angle on the tilting plate of the pump, the pumping pistons will not move axially, and liquid will not be delivered to the motor; therefore, the motor will deliver no power.

If the angle of the tilting plate is reversed, the direction of flow is reversed. Liquid enters the motor through the port by which it was formally discharged. This reverses the direction of rotation of the motor.

An additional benefit to this axial-piston pump/axial-piston motor configuration is the dynamic braking effect created when the motor, in a coasting situation, in effect becomes a pump itself and attempts to reverse-rotate the hydraulic pump. In this situation the pump now becomes a motor and attempts to reverse-rotate the prime mover. The degree of reverse angle on the tilting plate in the pump determines the effectiveness of the dynamic braking.

2.4.0 Valves

Once the pump has begun to move the fluid in a hydraulic system, valves are usually required to control, monitor, and regulate the operation of the system. While the pump is recognized as the heart of the system, the valves are the most important devices for providing flexibility in today's complex hydraulic systems.

Valves are included in a hydraulic system to control primarily (1) the direction of fluid flow, (2) the volume of fluid going to various parts of the system, and (3) the pressure of the fluid at different points in the system.

It is beyond the scope of this training manual to cover all of the many different valves in use today; however, since most of these valves are almost always combinations and elaborations of basic types, an understanding of their operation can be obtained by a review of the basic types.

The basic valves are those designed to do one of the primary functions mentioned above, that is, control direction of flow, control volume, and regulate fluid pressure.

Valves, like pumps, are precision made. Usually, no packing is used between the valve element and the valve seat since leakage is reduced to a minimum by machined clearances. (Packing is required around valve stems, between lands of spool valves, etc.) Here again is an important reason for preventing system contamination. Even the most minute particle of dirt, dust, and lint can do considerable damage to hydraulic valves.

2.4.1 Relief Valves

A relief valve is a simple pressure-limiting device. It is incorporated in most hydraulic systems and acts as a safety valve used to prevent damage to the system in case of overpressurization.

A simple two-port relief valve is shown in *Figure 10-16*. An adjustment is provided so that the valve may be regulated to any given pressure; therefore, it can be used on a variety of systems. Before the system pressure can become high enough to rupture the tubing or damage the system units, it exceeds the pressure required to overcome the relief valve spring setting. This pushes the ball off its seat and bypasses excess fluid to the reservoir. If the system pressure decreases, the spring setting reseats the ball; the ball then remains seated until the pressure again reaches the predetermined maximum.

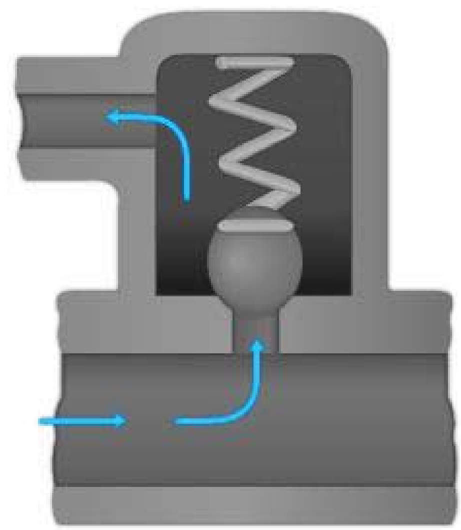

Figure 10-16 – Relief valve.

2.4.2 Pressure Regulator Valve

As the name implies, the pressure regulator valve is designed to regulate system pressure between a maximum operating pressure and a minimum operating pressure. This valve is often referred to as an unloading valve. It is designed to remove the system load from the pump once system pressure has been reached.

The functions performed by the regulator valve are accomplished by its two operational phases-cut-in and cut-out. The regulator is said to be cut-in when it is directing fluid under pressure into the system. The regulator is cutout when fluid is bypassed into the return line and back to the reservoir. *Figure 10-17, View A* shows a typical pressure regulator in the cut-in position. *Figure 10-17, View B* shows the regulator in the cutout position. Notice the check valve in these figures. The check valve can be an integral part of the regulator or a separate unit, but it is necessary that a check valve be used, as shown in the figures.

Referring back to *Figure 10-17, View A*, you can see that the pump supplies a pressure to the top and bottom of the regulator valve. By finding the pressure areas of the ball and piston, plus the 600-pound spring tension, you can find the balanced state of the valve--in this case, 800 psi. This means that any pressure in excess of 800 psi unseats the regulator ball and provides the pump with an unrestricted fluid flow back to the reservoir.

In *Figure 10-17, View B* the regulator ball is unseated. When this happens, pressure drops immediately. Now the importance of the check valve can be seen. With the sudden reduction in pressure, the check valve snaps shut, and the fluid trapped in the system line continues to hold the regulator piston in the raised position. This trapped fluid also maintains pressure on the system until the mechanism actuates or is relieved by leakage, either of which can cause the regulator to cut in.

Hydraulic systems using a constant volume pump require a pressure regulator valve; those using a variable volume pump do not.

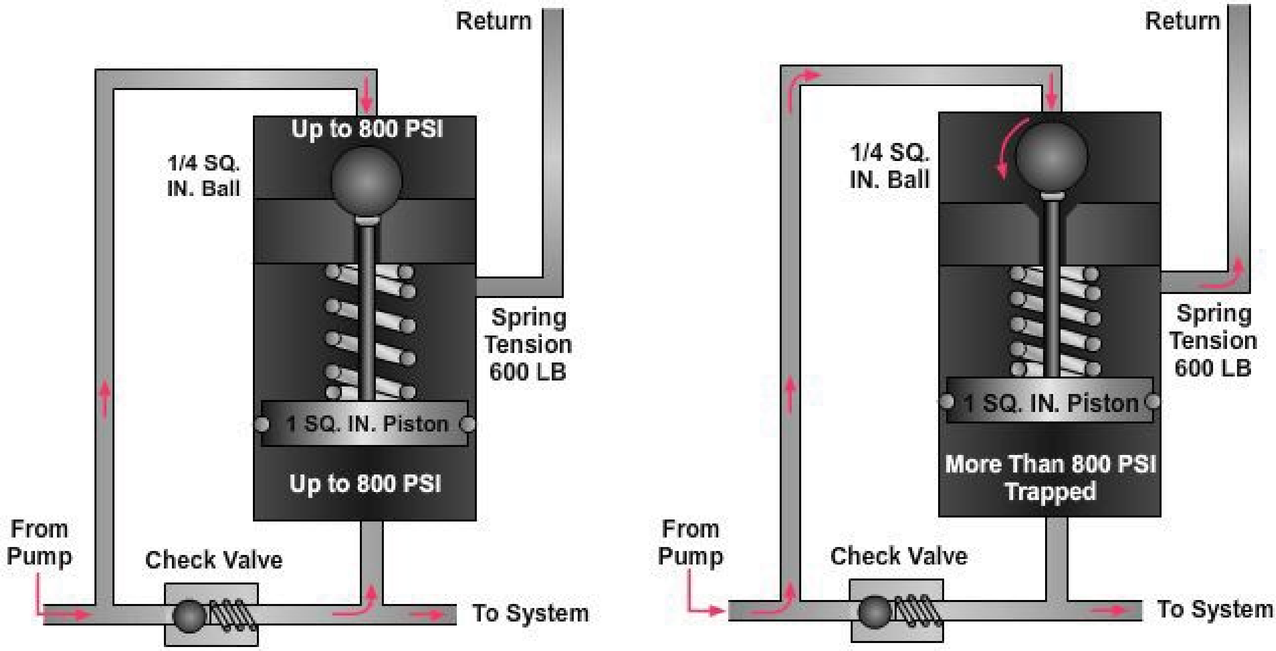

Figure 10-17 - Pressure regulating valve.

2.4.3 Selector Valves

The purpose of a selector valve is to control the direction of fluid flow; this in turn controls the operation or direction of the mechanism. Although all selector valves share the common purpose of controlling the direction of fluid flow, they vary considerably in physical characteristics and operation.

The valving element of these units may be one of three types: the poppet type, in which a piston or ball moves on and off a seat; the rotary spool type, in which the spool rotates about its axis; or the sliding spool type, in which the spool slides axially in a bore. Selector valves may be actuated mechanically, manually, electrically, hydraulically, or pneumatically.

2.4.3.1 3.1 Poppet Valve

The poppet valve consists primarily of a movable poppet that closes against a valve seat (*Figure 10-18*). In the closed position, fluid pressure on the inlet side tends to hold the valve tightly closed. A small amount of movement from a force applied to the top of the poppet stem opens the poppet and allows fluid to flow through the valve.

The poppet, usually made of steel, fits into the center bore of the seat. The seating surfaces of the poppet and the seat are lapped or closely machined so the center bore will be sealed when the poppet is seated. The action of the poppet is similar to the valves of an automobile engine. An O-ring seal is usually

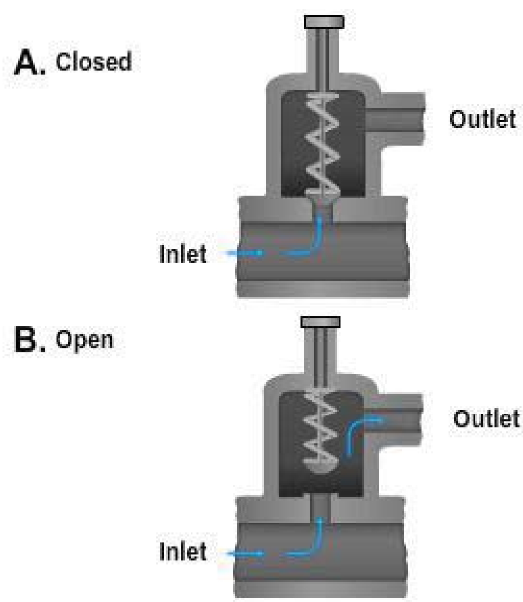

Figure 10-18 - Poppet control valve.

installed on the stem of the poppet to prevent leakage past this portion of the housing. In most valves the poppet is held in the seated position by a spring. The number of poppets in a particular valve depends upon the design and purpose of the valve.

2.4.3.2 3.2 Rotary Spool Valve

The rotary spool type of directional control valve has a round core with one or more passages or recesses in it (*Figure 10-19*). The core is mounted within a stationary sleeve. As the core is rotated (generally by a hand lever or a knob) within the stationary sleeve, the passages or recesses connect or block the ports in the sleeve. The ports in the sleeve are connected to the appropriate pressure, working, and return lines of the fluid power system.

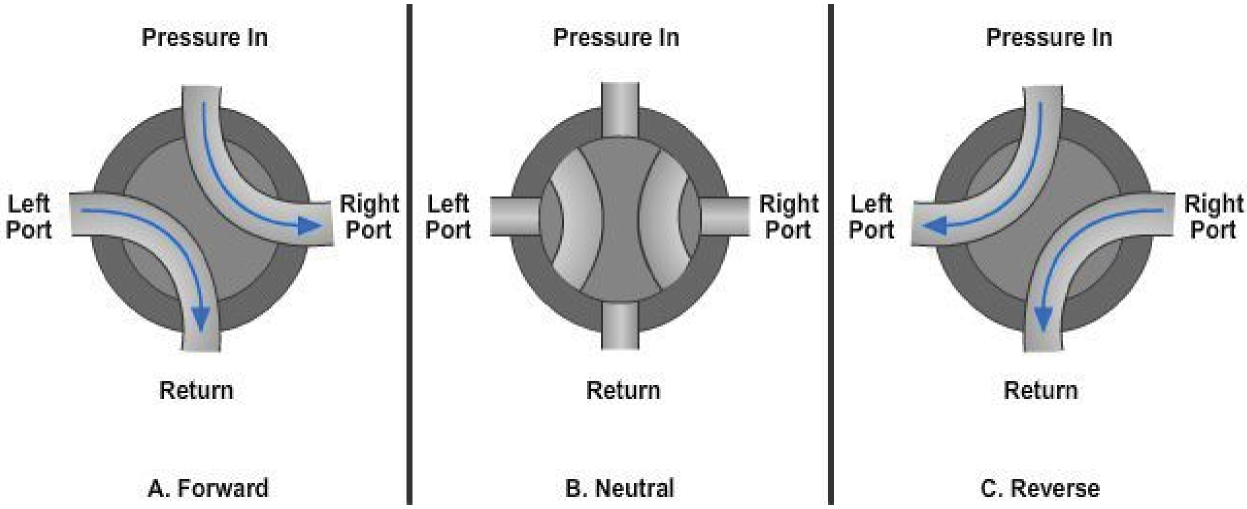

Figure 10-19 - Rotary spool control valve.

2.4.3.3 Sliding Spool Valve

The sliding spool valve is probably the most common type of valving element used in directional control valves (*Figure 10-20*). The valve is so named because the shape of the valving element resembles that of a spool and because the valving element slides back and forth to block and uncover ports in the housing.

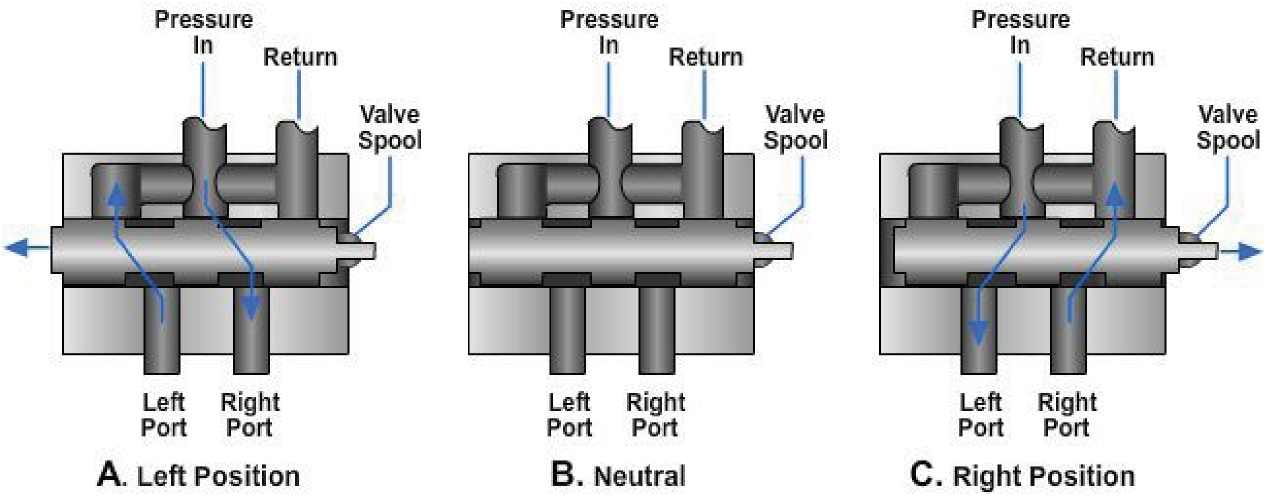

Figure 10-20 - Sliding spool control valve.

The valve is shown in neutral position (no fluid flow), but by moving the spool valve to the left position, fluid flows from the pressure line out through the right port; fluid returns back through the left port to the return line. Movement of the spool to the right position gives similar results; the left port becomes a pressure port and the right port becomes the return port.

Like all classes of directional control valves, various methods are used for positioning the sliding spool valve. Some of the most common methods are by hand levers, cam angle plates, directional control arms, and self-regulating poppet valve linkage.

2.5.0 Reservoirs

As stated previously, an adequate supply of the recommended fluid is an important requirement for the efficient operation of a fluid power system. The reservoir (*Figure 10-21*), which provides a storage space for fluid in hydraulic systems, differs to a great extent from the receivers used for this purpose in pneumatic systems. For this reason, the two components are covered separately in the paragraphs below.

The reservoir is the fluid storehouse for the hydraulic system. It contains enough fluid to supply the normal operating needs of the system and an additional supply to replace fluid lost through minor leakage. Although the function of a reservoir is to supply an adequate amount of fluid to the entire hydraulic system, it is more than just a vessel containing fluid. It is here that the fluid has the greatest potential danger of becoming contaminated. In the reservoir any air entering the fluid system has the opportunity of escaping; dirt, water, and other matter settle to the bottom. Reservoirs are designed in a way that permits just clean hydraulic fluid to come to the top.

These reservoirs have a space above the fluid, even when they are full. This space allows the fluid to foam, and thus purge itself of air bubbles that normally occur as the fluid makes its way from the reservoir, through the system, and back to the reservoir.

An air vent allows the air to be drawn in and pushed out of the reservoir by the ever-changing fluid level. An air filter is attached to the air vent to prevent drawing atmospheric dust into the system by the ever-changing fluid level. A securely fastened filling strainer of fine mesh wire is always placed below the system filler cap.

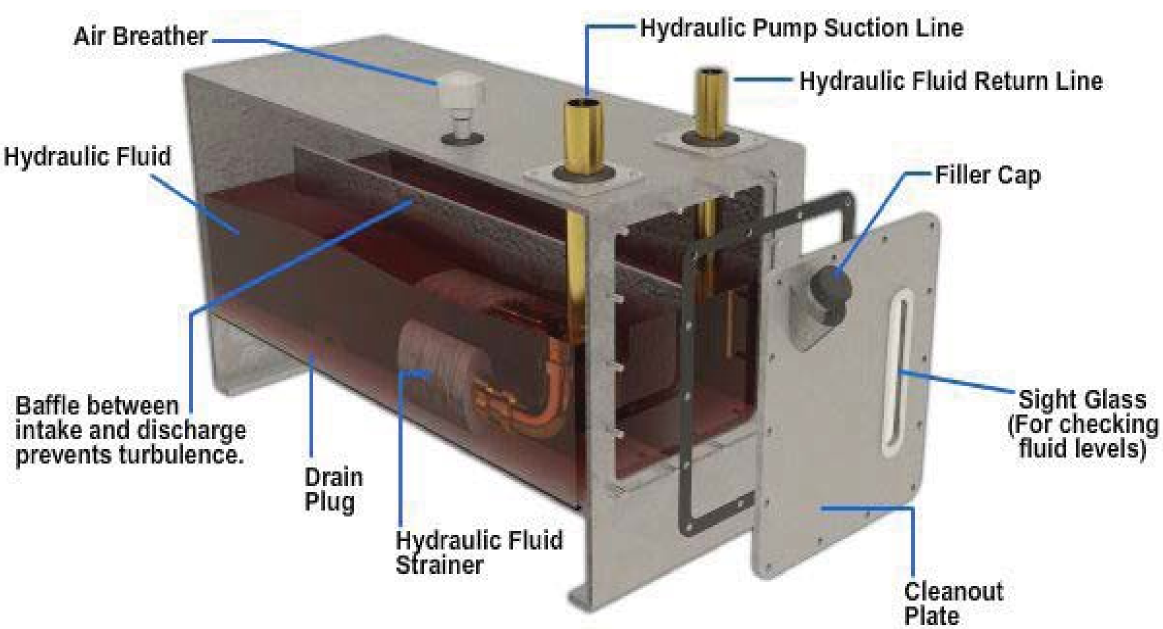

Figure 10-21 - Typical hydraulic reservoir.

The sight gauge is provided so the normal fluid level can always be seen, as it is essential that the fluid in the reservoir be at the correct level. The baffle plate segregates the outlet fluid from the inlet fluid. Although not a total segregation, it does allow time to dissipate the air bubbles, lessen the fluid turbulence (contaminants settle out of nonturbulent fluid), and cool the return fluid somewhat before it is picked up by the pump.

Reservoirs used on CESE may vary considerably from that shown in *Figure 10-21*; however, manufacturers retain as many of the noted features as possible, depending on design limits and use.

2.6.0 Accumulators

Hydraulic accumulators are incorporated in some hydraulic systems to store a volume of liquid under pressure for subsequent conversion into useful work or to absorb rapid fluid pulsations when valves are operated repeatedly. Two types of accumulators are the spring-operated and the gas-operated.

2.6.1 -Operated Accumulators

In the spring-operated accumulator, the compression resulting from the maximum installed length of the spring or springs should provide the minimum pressure required of the liquid in the cylinder assembly (*Figure 10-22*). As liquid is forced into the cylinder, the piston is forced upward and the spring or springs are further compressed, thus providing a reservoir of potential energy for later use.

2.6.2 as-Charged Accumulators

The gas-operated accumulator is often referred to as a pneumatic or hydropneumatic accumulator. This type of accumulator uses compressed gas (usually air or nitrogen) to apply force to the stored liquid. Air-operated accumulators are classified as either nonseparator or separator types.

2.6.2.1 Nonseparator Type of Accumulator

In the nonseparator type of accumulator, no means are provided for separating the gas from the liquid (*Figure 10-23*). It consists of a fully closed cylinder mounted in a vertical position, containing a liquid port on the bottom and a pneumatic charging port (Schrader valve) at the top.

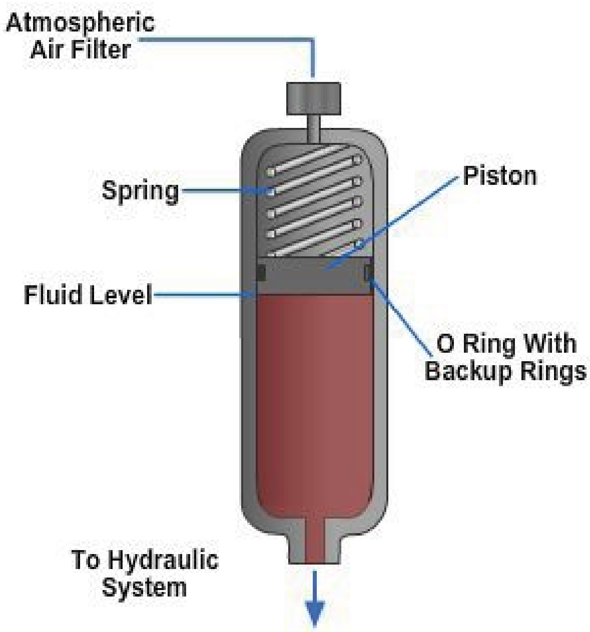

Figure 10-22 - Spring-loaded accumulator.

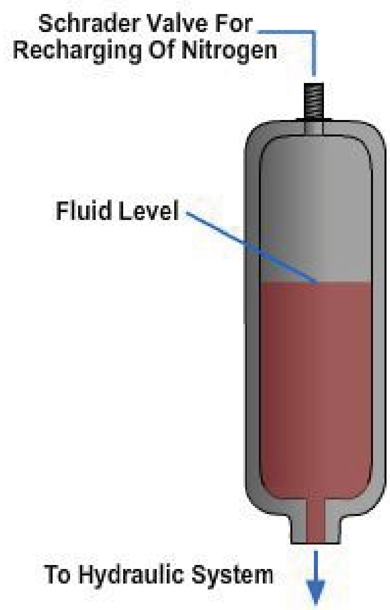

Figure 10-23 - Gas-charged accumulator.

2.6.2.2 Separator Type of Accumulator

In the separator type of air-operated accumulator, a means is provided to separate the gas from the liquid. The three styles of separators are bladder (bag), diaphragm, and piston (cylinder).

One version of an air-operated accumulator is the bladder style (*Figure 10-24*). This accumulator derives its name from the shape of the synthetic rubber bladder or bag that separates the liquid and gas within the accumulator.

Although there are several different modifications of the diaphragm style accumulator, it is usually spherical in shape. *Figure 10-25* illustrates an example of this type. The shell is constructed of two metal hemispheres that are either screwed or bolted together. The fluid and gas chambers are separated by a synthetic rubber diaphragm.

A cylinder style accumulator is illustrated in *Figure 10-26*. This accumulator contains a free-floating piston that separates the gas and liquid chambers. The cylindrical accumulator consists of a barrel assembly, a piston assembly, and two end cap assemblies. The barrel assembly houses the piston and incorporates provisions for securing the end caps.

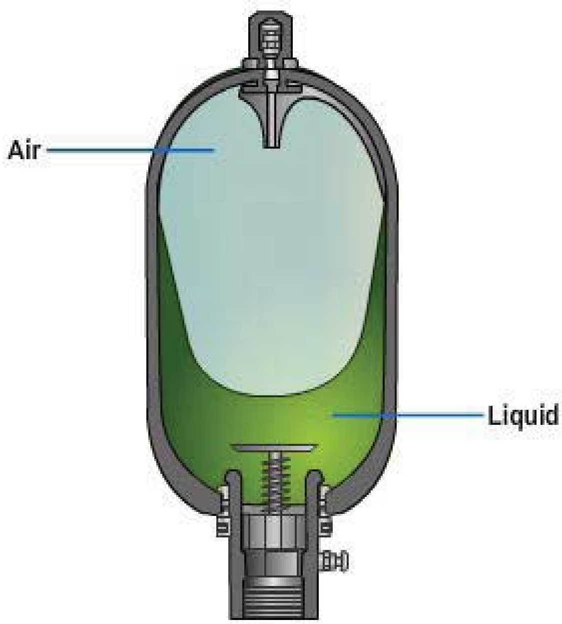

Figure 10-24 - Bladder-type accumulator.

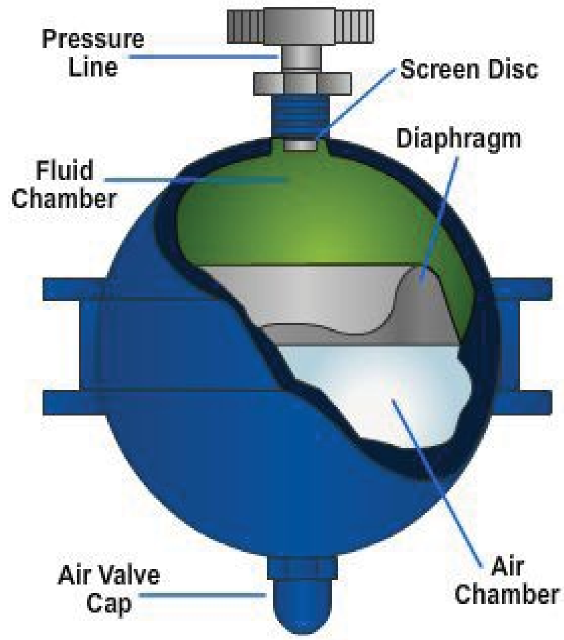

Figure 10-25 - Diaphragm-type accumulator.

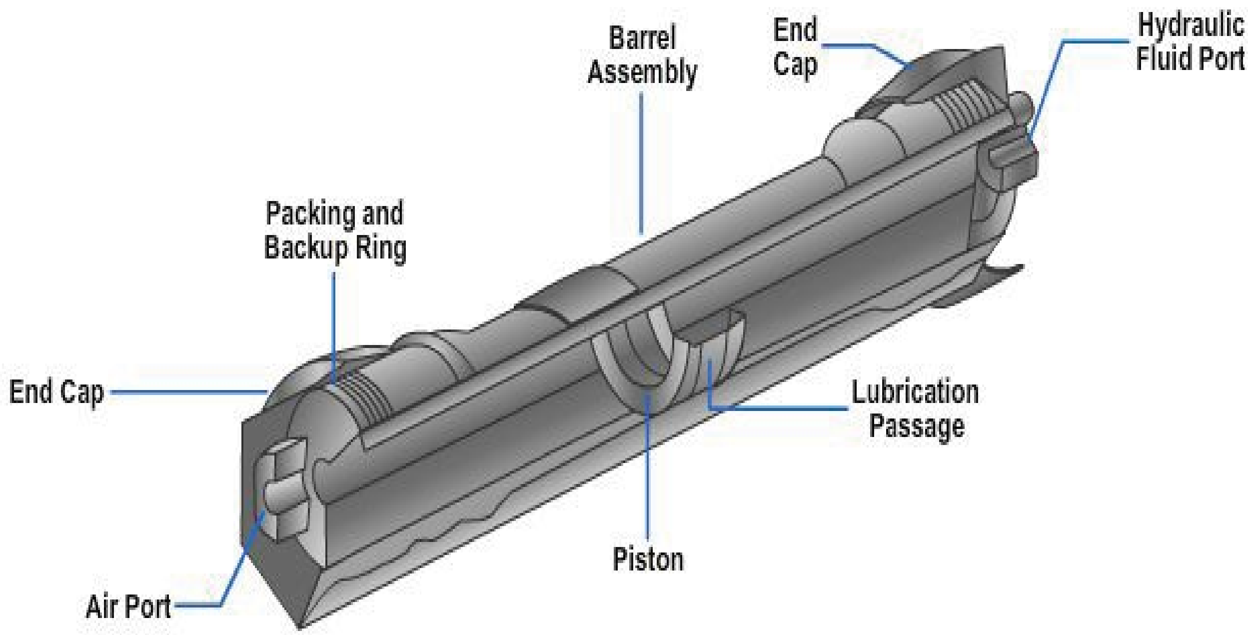

Figure 10-26 - Cylinder style accumulator.

2.6.3 Application

Much of today's CESE is equipped with one or more hydraulic accumulators that serve several purposes in the hydraulic system, as described in the paragraphs below. Some of the hydraulic systems illustrated and described later in this chapter show the applications of accumulators and their relationship to other components in the system.

2.7.0 Filters

When small bits of metal, rubber, paper, dust, and dirt enter into a system, they contaminate the fluid. The fluid may be contaminated in many different ways. The contaminants may enter the system during the manufacturing of the components or during servicing and maintenance of the system; they can be created in the system by internal wear of the components, or because of deterioration of seals, hoses, and gaskets. These impurities can become suspended in the fluid and circulate throughout the system. Because of the close tolerance of the system components, the contamination in a system must be kept at an acceptable level; otherwise, the components are damaged, destroyed, or become clogged and inoperative. For these reasons, filters are essential in hydraulic and pneumatic systems.

A filter in a hydraulic system is a screening or straining device used to remove impurities from the hydraulic fluid. Filters may be located within the reservoir, in the pressure line, in the return line, or in other locations where they are needed to safeguard the hydraulic system against impurities. There are several different types and arrangements of filters. Their position in equipment and design requirements determine their shape and size.

2.7.1 Filter Elements

The filter element is the part or parts (single or dual element) of the filter that removes the impurities from the hydraulic fluid as the fluid passes through the filter. Filter elements are usually classified by either their material and/or their design and construction. The most common filter elements used in CESE equipment are wire mesh, micronic, and porous metal.

2.7.1.1 Wire Mesh Filter

A wire mesh filter element is made of a fine wire mesh (screen) and is usually used where the fluid enters and/or leaves a container or component (*Figure 10-27, View A*). The size of wire mesh openings varies with the particular filter element, but normally a wire mesh filter element removes only the larger particles of contamination from the fluid.

A wire mesh filter element can be reused. It should be removed, cleaned, and reinstalled at scheduled intervals or when it becomes dirty. Replace it when it cannot be properly cleaned or is damaged.

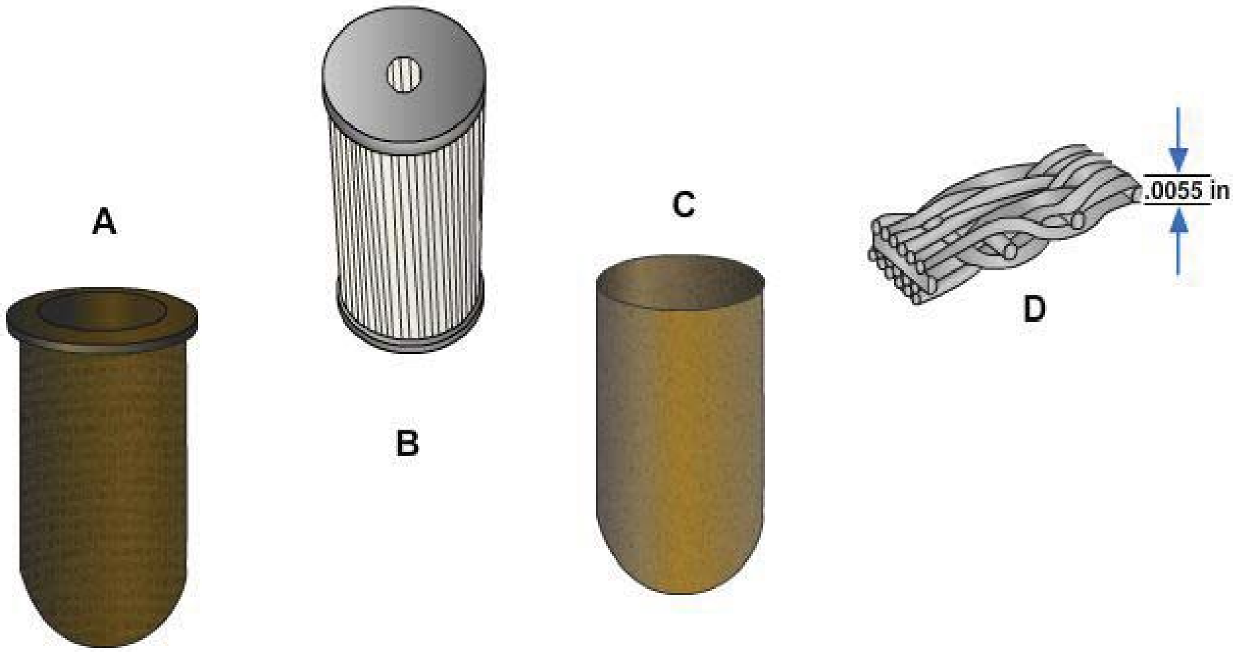

Figure 10-27 - Hydraulic filter elements.

2.7.1.2 Micronic Filter

Micronic, a term derived from the word micron, can be used to describe any filter element. Through usage, however, micronic has become associated with a specific filter with a filtering element made of a specially treated cellulose paper. The paper is formed in vertical convolutions (wrinkles) and is made in a cylindrical pattern. A spring in the hollow core of the element holds the element in shape (*Figure 10-27, View B*).

Micron is a unit of measurement used to express the degree of filtration. A micron equals one millionth of a meter or 0.0000394 inch. For comparison value, consider that the normal lower level of visibility to the naked eye is about 40 microns. (A grain of table salt measures about 100 microns, the thickness of a human hair is about 70 microns, and a grain of talcum powder is about 10 microns.)

When it is used in CESE hydraulic systems, the micronic element normally prevents the passage of solids of 10 microns or greater in size. The micronic filter element is disposable.

2.7.1.3 Porous Metal Filter

Use porous metal filter elements in hydraulic systems in which high pressures exist and/or a high degree of filtration is required. The two porous metal elements discussed-sintered bronze and stainless steel-are capable of filtering out solid particles and 5 and 15 microns, respectively.

Porous metal filter elements are reusable. When the filter element becomes contaminated, it is removed from the system, cleaned, tested, and reinstalled for further use. The number of times a filter element can be cleaned and reused depends on the particular type of element and the system in which it is used. Likewise, if the filter element is damaged in any way or does not meet test requirements, it must be discarded.

- The sintered bronze element consists of minute bronze balls joined together as one solid piece while still remaining porous (*Figure 10-27, View C*).
- Stainless steel filter elements are used in many of the Navy's most modern hydraulic systems. This element is similar in construction to the sintered bronze element described previously. The design is usually a corrugated, sintered, stainless steel mesh, such as the magnified cross section shown in *Figure 10-27, View D*. One manufacturer calls the design a "Dutch Twill" pattern. The curved passages of the filter element (through which the fluid passes) limit the length of the particles that pass through the element. Most filters that use the stainless steel are equipped with a contamination indicator, described later in this chapter.

2.7.2 Filter Classification

The hydraulic systems of CESE use several different types of filters. There are a number of factors to be considered in determining the full classification of a particular type of filter. When hydraulic filters are being classified, you must consider the following factors: flow characteristics, filtering medium, bypass characteristics, and contamination indicators.

- **FLOW CHARACTERISTICS.** In the full-flow filter, all the fluid that enters the unit passes through the filter element, while in a proportional flow, only a portion of the fluid passes through the element. Practically all filters used in the hydraulic systems of CESE are full-flow.
- **FILTERING MEDIUM.** The different filter elements-wire mesh, micronic, and porous-were discussed earlier. Normally, only one element is used in each filter; however, some equipment uses two or more elements in order to obtain the desired degree of filtration.

  A full-flow micronic bypass filter is shown in *Figure 10-28*. This filter provides a positive filtering action; however, it offers resistance to flow,

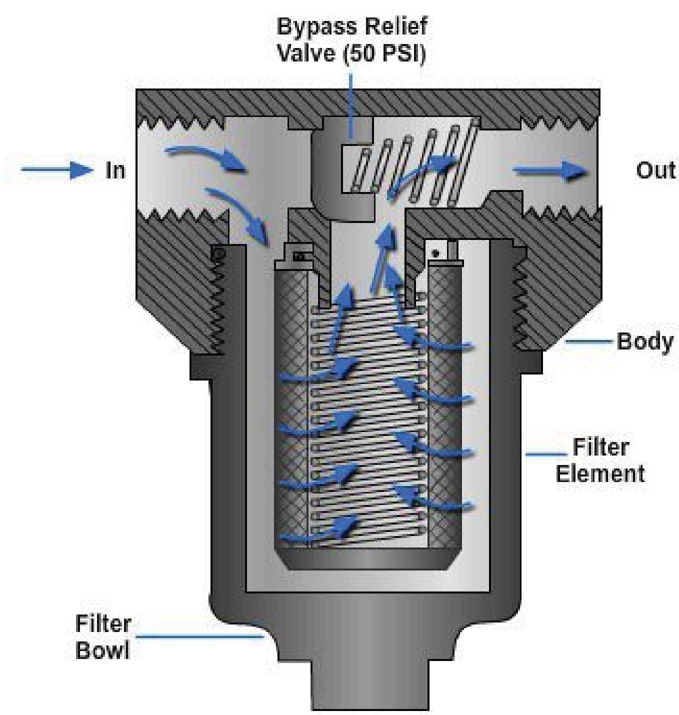

Figure 10-28 – Full-flow type of hydraulic filter.

particularly when the element becomes dirty. For this reason, a full-flow filter usually contains a bypass valve which automatically opens to allow the fluid to bypass the element when the flow of fluid is restricted because of contamination buildup on the element.

Hydraulic fluid enters the filter assembly through the inlet port in the body and flows around the filter element inside the filter bowl. Filtering takes place as the fluid passes through the filter element and into the hollow core, leaving dirt and impurities deposited on the outside of the filter medium. The filtered fluid then flows from the hollow core through the outlet port, and continues on through the system.

- **BYPASS CHARACTERISTICS.** TMS bypass relief valve in the body allows the fluid to bypass the filter element and pass directly into the outlet port if the filter element becomes clogged. In many micronic filters, the relief valve is set to open when the differential in pressure exceeds 50 psi; for example, if the pressure at the filter inlet port is 90 psi and the pressure at the outlet drops below 40 psi, the bypass valve opens and allows the liquid to bypass the element.

NOTE

Oil that bypasses the hydraulic oil filter is unfiltered oil. This is a clear indication of a hydraulic system in need of serious maintenance, repair, or both.

- **CONTAMINATION INDICATORS.** Contamination indicators are often used on bypass filters. The full-flow, porous metal bypass electrical-indicating hydraulic filter is used in some hydraulic systems. This filter uses one or a combination of the contamination indicators previously described.

Under normal conditions the fluid enters the inlet of the filter (*Figure 10-29, View A*), passes through the filter element, and leaves the filter through the outlet. As the fluid passes through the filter element, impurities are deposited on the outside of the element. As the deposits accumulate, they cause a differential

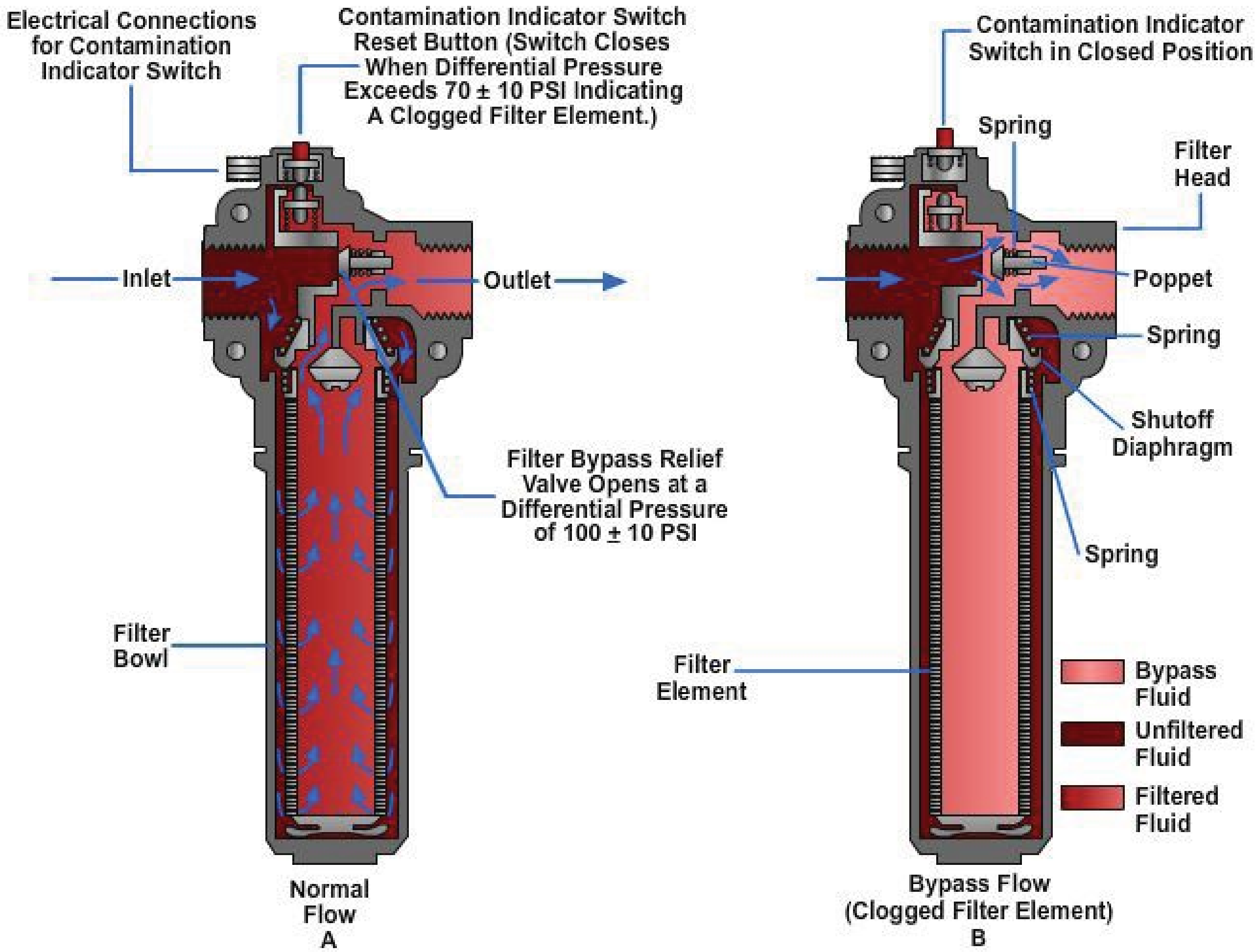

Figure 10-29 - Full-flow, porous metal bypass hydraulic filter.

pressure to build up between the inlet and outlet of the filter. The pressure is sensed across the contamination indicator switch; on this particular filter, the switch closes at 70 + 10 psi, actuating a warning device (light, horns, etc.). The equipment should be stopped and the filter serviced, cleaned, or replaced. An important fact for you to remember is that cold hydraulic fluid can produce a false pressure indication. To prevent needless changing of filters, fluid should be at operating temperature for a true indication of a contaminated filter. Some filters have a button to reset the switch after the filter has been serviced; however, on other filters the switch resets automatically when the differential pressure is relieved.

If the filter is not properly serviced following the contamination indication and the equipment is kept in operation, the differential pressure continues to build. At 100 + 10 psi, the bypass valve will open and allow the fluid to flow straight through, bypassing the filter element (*Figure 10-29, View B*). But on this filter the contamination indicator is to warn the operator that the filter element is clogged. The equipment can then be stopped before the bypass valve opens, thus preventing contaminated fluid from being passed through the hydraulic system.

Test your Knowledge (Select the Correct Response)

2. Porous metal filter elements are .

   A. reusable
   B. disposable
   C. recyclable
   D. one time use only

3.0.0 HYDRAULIC SYSTEMS

In spite of the great variety of support equipment, all hydraulic systems-from the simplest to the most complex--operate according to the basic principles and make use of the components discussed thus far in this chapter.

As a CM you are responsible for analyzing the malfunctions of hydraulic equipment, ranging from the simple jack to large earth-moving equipment. Thus, the development, piece by piece, of a representative system should assist you in analyzing any hydraulic system.

3.1.0 Representative Hydraulic System

Basically, any system must contain the following units: PUMP, ACTUATOR, RESERVOIR, CONTROL VALVE, and TUBING. *Figure 10-30* shows a simple system that uses only these essentials.

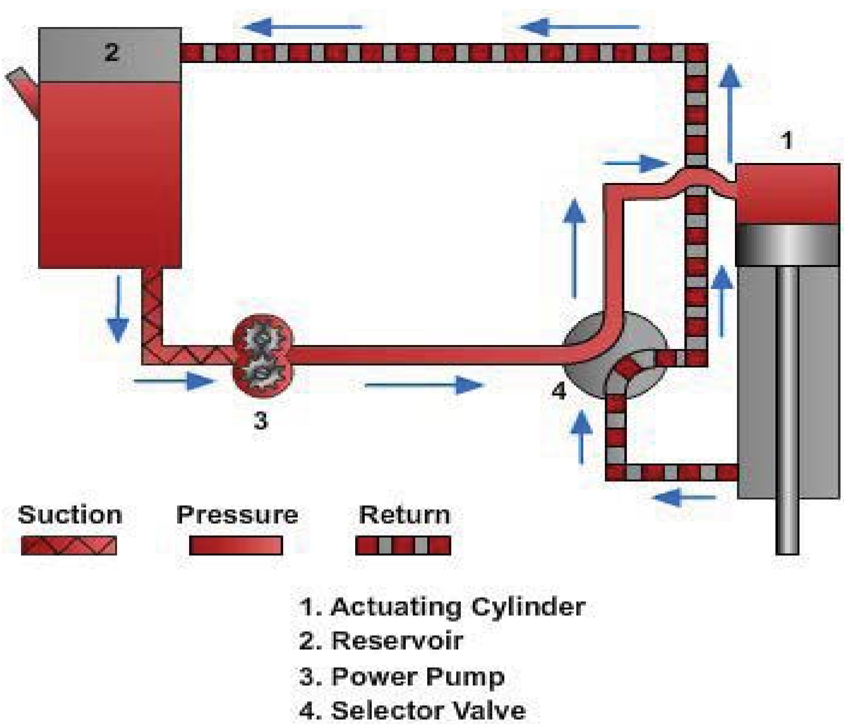

Figure 10-30 - A simple hydraulic system.

The flow of hydraulic fluid can be easily traced from the reservoir through the pump to the selector valve. With the selector valve in the position indicated by the solid lines, the flow of fluid created by the pump flows through the valve to the upper end of an actuating cylinder. Fluid pressure then forces the piston down, and at the same time forces out the fluid on the lower side of the piston, up through the selector valve, and back to the reservoir.

When the selector valve is rotated 90 degrees, the fluid from the pump then flows to the lower side of the actuating cylinder, thus reversing the process. The movement of the piston can be stopped at any time simply by moving the selector valve to the neutral position (45-degree movement either way). In this position, all four ports are closed and pressure is trapped in both working lines.

The hydraulic system just described would be practical if it were operated by a hand pump, such as a system common to the engine installation/removal stands and bomb trucks. However, since the illustrated pump is a power-driven, constant delivery gear pump, pressure builds up immediately to such proportions that either the pump fails or a line bursts. Therefore, a pressure relief valve is incorporated in the system to protect it, as shown in *Figure 10-31*. This valve is set to relieve system pressure before it becomes sufficient enough to rupture the system or damage the pump. The relief valve ball is unseated at a predetermined pressure, and excess fluid is bypassed to the reservoir.

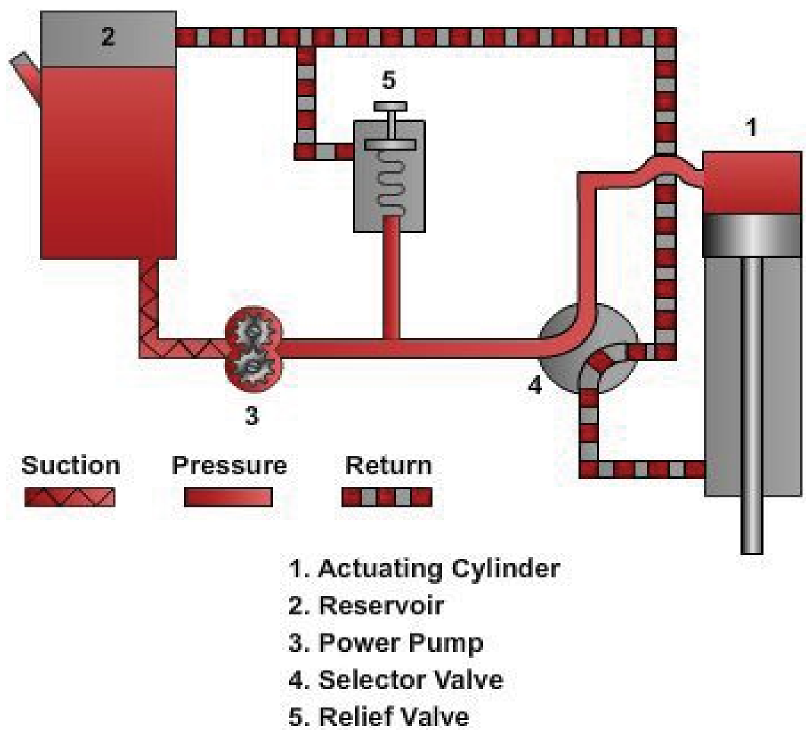

Figure 10-31 - A simple hydraulic system with a relief valve incorporated.

At this point, *Figure 10-31* illustrates a workable system, but it is still impractical. After a few hours, an ordinary pump would probably fail because it has to maintain a constant load. (The pump is keeping the relief valve unseated except when the cylinder is being moved.) With the addition of a check valve and pressure regulator (*Figure 10-32*), the work load on the pump is relieved and the system is more efficient, safer, and more durable. (A variable volume pump with its own built-in pressure control serves the same purpose in a system as the pressure regulator valve in this system.) The pressure regulator maintains system pressure between two predetermined pressure limits and relieves the pump when no mechanisms are moving, bypassing the pump flow unrestricted back to the reservoir. When you are adding the regulator valve to the system, the relief valve becomes a safety valve, used to prevent system damage in case of regulator or variable volume pump control failure.

The hydraulic system (*Figure 10-32*) is a practical, workable system; however, today's more complex equipment normally incorporates more components for the purpose of increasing efficiency, safety, and emergency or standby operation.

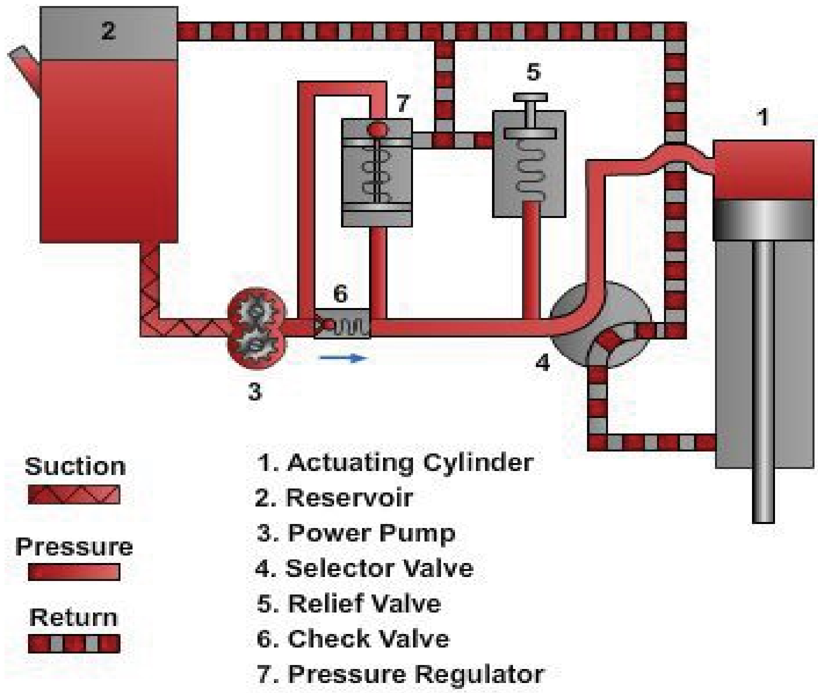

Figure 10-32 – A hydraulic system with a relief valve and regulator incorporated.

A complete hydraulic system is shown in *Figure 10-33*. In addition to the components already mentioned, this system includes more check valves, pressure gauge, filters, and a hand pump. The hand pump is added as art auxiliary system, normally used as an emergency power source in case of main power pump failure.

The complete hydraulic system discussed above may be further expanded by including a pressure manifold, more selector control valves, actuating mechanisms, and more power-driven pumps connected in parallel.

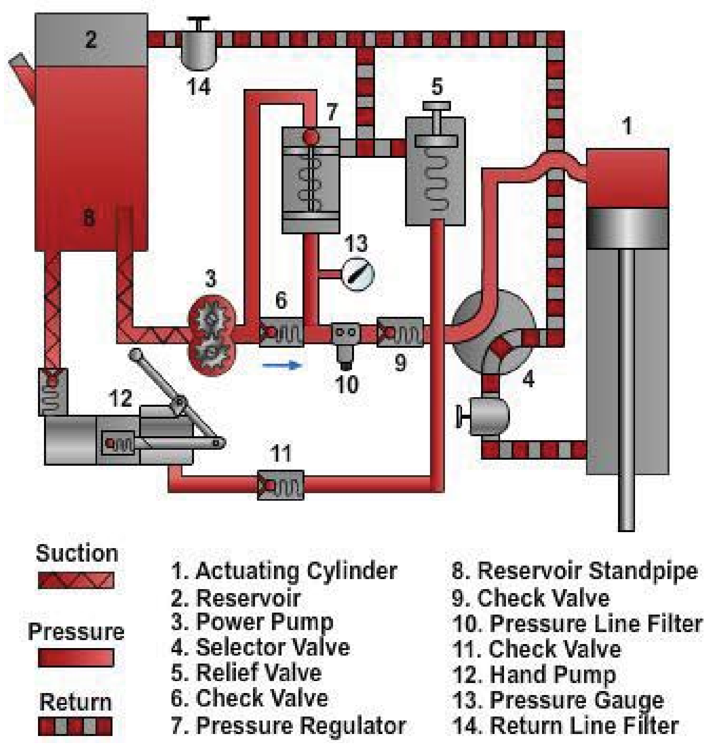

Figure 10-33 - A complete hydraulic system.

3.2.0 Types of Hydraulic Systems

There are two types of hydraulic systems used in support equipment. A system may be either an open center or a closed center, or in some cases, both.

3.2.1 Open Center

An open-center system is one having fluid flow, but no pressure in the system whenever the actuating mechanisms are idle (*Figure 10-34*). Fluid circulates from the reservoir, through the pump, through the selector valves, and back to the reservoir. Pressure developed in the system of an open-center system is controlled by open-center selector valves and is limited by a system relief valve. Note the position of the selector valves and the fact that the valves are connected in series. In this type of system, there is no pressure in the system until one of the subsystems is actuated by the positioning of the selector valve. When in the neutral position (*Figure 10-34, View A*), the open-center selector valve directs the fluid to the return line. When the selector valve is positioned out of neutral, pressure builds up in the actuating section and operates the selected mechanism (*Figure 10-34, View B*). When an open-center system is not being used (no actuating mechanisms), the pump is said to be idling because there is no pressure buildup in the system; therefore, there is no load on the pump. Constant-volume pumps are used in open-center systems and normally do not require a pressure regulator.

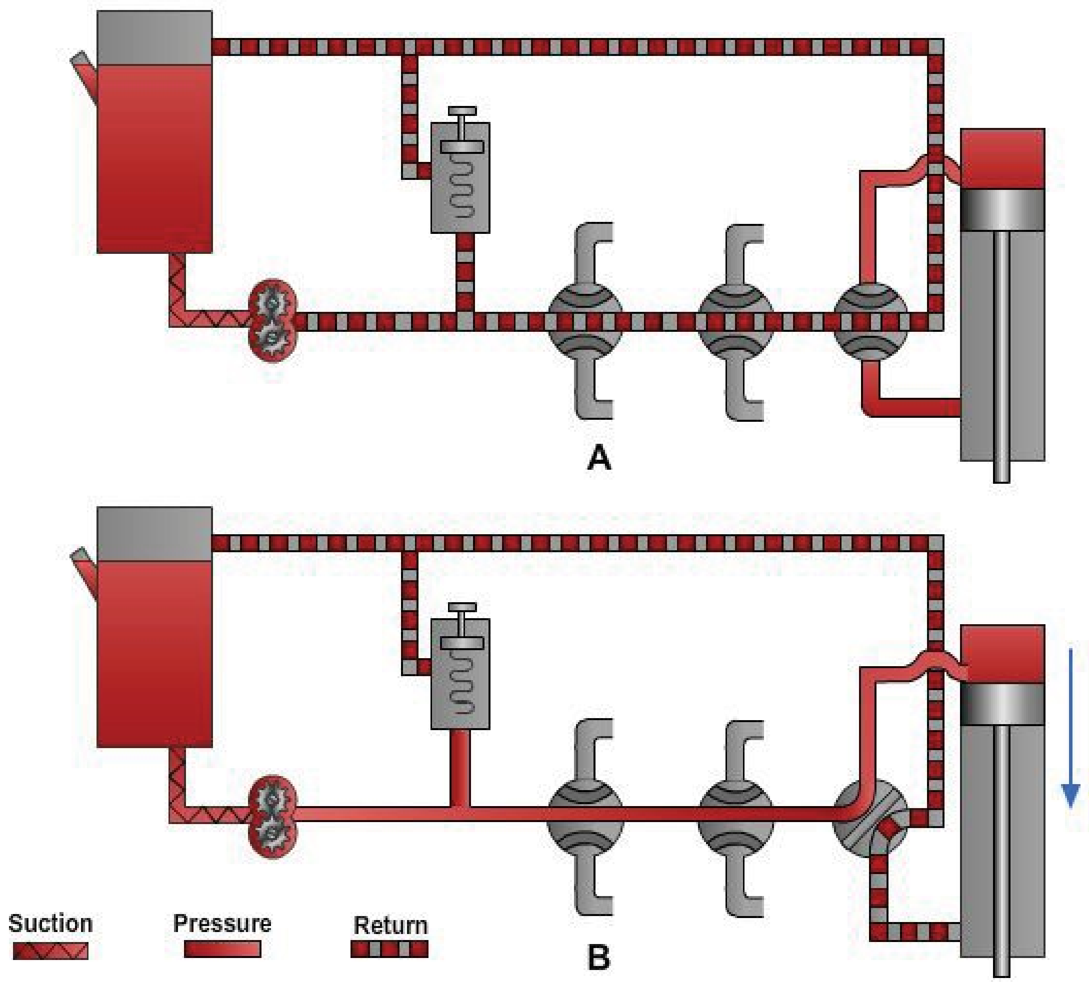

Figure 10-34 - Basic open-center hydraulic system.

3.2.2 Closed Center

The closed-center system always has fluid stored under pressure whenever the pump is operating; however, when pressure is built up to predetermined value, the load is automatically removed from the pump by a pressure regulator or the integral control valve of the variable volume pump.

The representative hydraulic system discussed earlier is a closed-center system, but all closed-center systems are basically the same. Any number of subsystems may be incorporated into the closed-center system. This system differs from the open-center system in that the selector valves are arranged in parallel rather than in series.

3.3.0 Hydraulic System Troubleshooting and Maintenance

Every hydraulic system has two major parts or sections: the power section and the actuating section. A power section develops, limits, and directs the fluid pressures that actuate various mechanisms on the equipment. The actuating section is the section containing the various operating mechanisms and their units, such as brakes, steering, lift cylinders, extend cylinders, and hydraulic motors.

Since an actuating mechanism is dependent on the power system, some of the troubles exhibited by the actuating system may be caused by difficulties in the power system. By the same token, a trouble symptom indicated by a unit of the power system may be caused by leakage from one of the units of an actuating system. When any part of the hydraulic system becomes inoperative, refer to the schematic diagrams located in the applicable technical manual (in conjunction with tests performed on the equipment) to assist in tracing the malfunction to its source.

NOTE

No unit should be removed and replaced (or adjusted) unless there is sound reason to believe it is faulty.

3.3.1 ng

Most hydraulic troubles can be included in one or more of the following categories: lack of fluid supply, external leaks, internal leaks, physically defective units, or related troubles caused by mechanical control linkages and electrical control circuits.

Insufficient fluid in the system results in no pump delivery or at best a sluggish or erratic operation. The reservoir must always contain sufficient fluid to fill the system completely without letting the pump run dry. The proper fluid must always be used to replenish a low system. Do not mix hydraulic fluids or reuse old fluid. Make sure all replenishment fluid is properly filtered before it is dispensed into the reservoir. Remove and repair or replace defective units when there is an indication of external leakage of the unit.

If foreign particles are found when you remove and disassemble a unit, identify and trace them to the source; for example, a common source of foreign particles is found in flexible hose. Generally, the cause is improper installation or internal deterioration; either can release slivers of the lining into the system, causing units to leak or become inoperative.

To analyze malfunctions in hydraulic systems, like all other systems, you need to have a complete understanding of the system and its operating components. Also, you need to know the interrelationship of one component to another; for instance, a complete understanding of a pressure regulator lends itself to troubleshooting the entire system as well as the regulator itself.

Pressure regulators, like all hydraulic components, are normally reliable pieces of equipment; nevertheless, they can malfunction. Keep in mind, though, that instead of being a source of trouble, the regulator can be a fairly reliable watchdog on the other units in the system. The particular behavior of the regulator may be the only indication of leakage in places where no other indication is available. It should be kept in mind that troubleshooting the regulator is done only after the obvious steps have been taken, such as checking the system fluid level to check for external fluid loss and opening shutoff valves.

Troubleshooting the pressure regulator is done by timing the cycle of operation--from the cut-in position to the cutout and back to the cut-in position. A standard regulator operating in a normal system completes this cycle in a certain period of time. This time can be obtained from the equipment manual or closely estimated by maintenance personnel.

Since you normally use the pressure regulator only with a constant volume pump, it should take a certain definite time to build up system pressure; for example, suppose a pump has a volume output of 6 gallons per minute, and the system requires 1 gallon of fluid to become completely filled (pressurized). As the system takes only one-sixth of the pump output to build up pressure, it should require only one-sixth of a minute (10 seconds) to pressurize the system. This is true if the system is in good operating condition. But what if the system contains an internal leak? In the 10 seconds usually required to build up pressure, the pump is still delivering 1 gallon, but some of the fluid is being lost. Thus, at the end of 10 seconds the system cannot be pressurized; therefore, the regulator cannot be cut out. The cut-in and cutout pressure of the regulator can be seen on the system pressure gauge. Once the regulator is cut out, the system should hold fluid under pressure for a reasonable length of time; however, if the system leaks, pressure drops fast and the regulator cuts in faster than normal. These indications may mean that the regulator is faulty or the other components in the system are faulty; however, by isolation techniques, such as subsystem operation, and checking shutoff valves, the problem can be located.

If the fault is the regulator, it is probably leaking at the regulator check valve or at the regulator bypass valve.

A leaking regulator check valve is one of the most common and easily recognized troubles. Again the regulator cycle is affected. With the regulator cut in, the check valve is open, and fluid is flowing into the system.

When the system pressurizes, the check valve closes, and the regulator is cut out; therefore, a leaking check valve does not affect the cutout time of the regulator, but it does affect the cut-in time.

The purpose of the check valve is to trap fluid under pressure in the system during the regulator cutout operation; however, it cannot do this if there is leakage around the seat. Even a slight leak around the valve seat causes the regulator to cut in faster than it should, but a bad leak causes the regulator to cycle rapidly (chatter). This rapid cycling, as indicated on the system pressure gauge, is usually caused only by a leaking valve. Thus, a leaking check valve gives normal regulator cutout and faster than normal cut-in operation.

The regulator bypass valve may also leak, causing an indication that affects the cycle of the regulator. If the bypass leaks, part of the fluid from the pump, which should be going into the system, bypasses and returns to the reservoir. This bypass causes the regulator to take longer than usual to cut out. Once the regulator has cut out, the bypass opens; therefore, it does not affect the regulator cut-in cycle.

3.3.2 Maintenance

Hydraulic systems maintenance includes servicing, preoperational inspections, periodical (scheduled) inspections, repair, and test/check following repair. The key to hydraulic system dependability is the attention given to the cleanliness of the repair facilities. Externally introduced contaminants are credited for more component failure than any of the self-induced contaminations during normal operating conditions. Hydraulic contamination is discussed in great length later in this chapter. The various repair procedures for the more common hydraulic system components are addressed in the paragraphs below.

3.3.2.1 Hydraulic Pumps

All hydraulic pumps have one thing in common-precision construction. In general, damaged or worn pump parts should be replaced, as they do not lend themselves readily to repair; however, some manufacturers do allow restoration of sealing surfaces to their original flat plane if it can be done by lapping. Also, very minor scratches, scoring, and corrosion can be removed with a crocus cloth.

Generally, the maintenance of hydraulic pumps consists of disassembly, inspection, repair (including replacement of parts and reassembly), and testing. After disassembly, thoroughly clean and critically inspect all parts for nicks, cracks, scratches, corrosion, or other damage that might cause pump malfunction. Inspect all threaded parts and surfaces for damage; inspect pistons, piston shafts and springs for distortion, and all check valves for proper seating. Replace all defective parts, and before reassembly, lubricate all internal parts with the specified type of clean hydraulic fluid.

Because of the many different versions of pumps and the complexity of most piston pumps, refer to the applicable technical manual for repair limits, procedures, and testing information.

The test after repair of hydraulic pumps is a must. This should be done by activities that have proper test machines. Hydraulic shops usually have the correct testing machines and trained personnel to test these pumps, along with other accessories such as relief valves, selector valves, and actuating cylinders.

3.3.2.2 Actuators

Maintenance of cylinders in general is relatively simple--the most common trouble is leakage. As with all other hydraulic units discussed in this chapter, consult the technical manual for the specific cylinder for all maintenance information.

Maintenance of hydraulic motors is generally the same as that discussed earlier for hydraulic pumps.

3.3.2.3 Hydraulic Valves

Hydraulic valves, like most other hydraulic units, normally require little maintenance if the fluid is kept clean; however, they do occasionally fail. Internal leakage and control adjustments are the most common valve problems.

Generally, the maintenance of hydraulic valves consists of disassembly, inspection, repair, and testing. The amount of maintenance that can be performed is primarily determined by the type of valve and the available facilities. Some valves are not repairable; in this case, return them to supply or scrap the valve and install a new one.

Replace all defective parts that are not repairable, including all kitted parts and cure-dated parts at each disassembly. Before reassembly, lubricate all internal parts with the specified type of clean hydraulic fluid. After you reassemble a valve, test it on a test machine. The tests normally include flow control, pressure settings (for relief valves and regulators), and internal leakage. Consult the applicable technical manual for maintenance, testing, and repair information.

3.3.2.4 Reserviors

Reservoirs are fairly simple tanks that require periodic flushing and cleaning. Since the reservoir collects a large quantity of foreign material contaminants in the bottom, the drain valve in the bottom of the tank should be opened to allow any sediment to be purged. Additionally, most reservoirs are designed with cleanout covers to assist in inspection and maintenance.

3.3.2.5 Accumulators

Accumulators, being designed like cylinder actuators, are similarly repaired using the same techniques. Exercise caution, however, to ensure that the pneumatic pressure has been relieved before disassembly of an air-operated accumulator.

3.3.2.6 Filters

Maintenance of filters is relatively simple since it mainly involves cleaning the filter housing and replacing or cleaning the filter elements. Replace the element on filters using the micronic (paper) element, and clean the elements on filters using the porous metal elements according to the applicable technical manuals.

Completely test the filters that have been cleaned and repaired before reinstalling them in the system. This test includes pressure setting of the relief valve, operation of the contamination indicators, leakage tests, and proof pressure test. Consult the technical manual for the equipment or the filter design for the test information.

3.4.0 Hydraulic System Contamination

Contamination is the direct or indirect cause of more hydraulic system failures than any other single source; therefore, contamination prevention is a major concern for all who operate, service, and maintain hydraulic systems.

A small mistake involving injection of contaminants can result in damage to equipment that cannot have a money value placed upon it; for example, a hydraulic in a line tester that contains contaminated fluid is used to service construction equipment. This can result in damage to expensive equipment, loss of CESE costing thousands of dollars, or injury and loss of life to personnel on the jobsite.

3.4.1 Classes of Contamination

The two general contamination classes are as follows:

- Abrasives. This includes such particles as dust, dirt, core sand weld spatter, machining chips, and rust.
- Nonabrasives. This includes things that result from oil oxidation and soft particles worn or shredded from seals and other organic components.

The mechanics of the destructive action by abrasive contaminants are clear. When the size of the particles circulating in the hydraulic system is greater than the clearance between moving parts, the clearance openings act as filters and retain such particles. Hydraulic pressure then embeds these particles into the softer materials; the reciprocating or rotating motion of component parts develops scratches on finely finished surfaces. Such scratches result in increased tolerances and decreased efficiency.

Oil-oxidation products, usually called sludge, have no abrasive properties; nevertheless, sludge may prevent proper functioning of a hydraulic system by clogging valves, orifices, and filters. Frequent changing of hydraulic system liquid is not a satisfactory solution to the contamination problem. Abrasive particles contained in the system are not usually flushed out, and new particles are continually created as friction products; furthermore, every minute remnant of sludge acts as an effective catalyst to speed up oxidation of the fresh fluid. (A catalyst is a substance that, when added to another substance, speeds up or slows down chemical reaction, but is itself unchanged at the end of the reaction.)

3.4.2 of Cantamination

The origin of contaminants in hydraulic systems can be traced to the following areas:

- PARTICLES ORIGINALLY CONTAINED IN THE SYSTEM. These particles originate during fabrication of welded system components, especially in reservoirs and pipe assemblies. The presence is minimized by proper design; for example, seam-welded overlapping joints are preferred, while arc welding of open sections is usually avoided. Hidden passages in valve bodies, inaccessible to sandblasting, are the main source of core sand entering the system. Even the most carefully designed and cleaned casting occasionally frees some sand particles under the action of hydraulic pressure. Rubber hose assemblies always contain some loose particles, most of which can be removed by flushing; others withstand cleaning and are freed later by the action of hydraulic pressure and heat.

  Rust or corrosion initially present in a hydraulic system can usually be traced to improper storage of replacement materials and component parts. Particles can range in size from large flakes to abrasives of microscopic dimensions (remember the discussion earlier on the size of a single micron). Proper preservation of stored parts is helpful in eliminating corrosion.

- PARTICLES OF LINT FROM CLEANING MATERIAL. These can cause abrasive damage in hydraulic systems, especially to closely fitted moving parts. In addition, lint in a hydraulic system packs easily into clearances between packings and contacting surfaces, leading to component leakage and decreased efficiency. Also, lint contributes to prematurely clogged filters.
- PARTICLES INTRODUCED FROM OUTSIDE FORCES. Particles can be introduced into hydraulic systems at points where either the liquid or certain working parts of the system (e.g., piston rods) are at least in temporary contact with the atmosphere. The most common danger areas are at the refill and breather openings and at cylinder rod packings. Contamination arising from carelessness during servicing operations is minimized by the use of an approved dispensing cart using proper filters and filler strainers in the filling adapters of hydraulic reservoirs. Hydraulic cylinder piston rods incorporate wiper rings and dust seals to prevent the dust that settles on the piston rod during its outward stroke from being drawn into the system when the piston rod retracts. Similarly, single-acting actuating cylinders incorporate an air filter in the vent to prevent ingestion of airborne contamination during the return stroke.
- PARTICLES CREATED WITHIN THE SYSTEM DURING OPERATION. Contaminants created during system operation are of two general types:

mechanical and chemical. Particles of a mechanical nature are formed by wearing of parts in frictional contact, such as pumps, cylinders, and packing gland components. Additionally, over-aged hydraulic hose assemblies tend to break down inside and contaminate the system. These particles can vary from large chunks of packings and hose material down to steel shavings of microscopic dimensions that are beyond the retention potential of system filters.

The chief source of chemical contaminants in hydraulic liquid is oxidation. These contaminants are formed under high pressure and temperatures, and are promoted by the catalytic action of water and air and of metals, like copper or iron oxides. Oil-oxidation products appear initially as organic acids, sludge, gums, and varnishes--sometimes combined with dust particles as sludge. Liquid soluble oxidation products tend to increase liquid viscosity, while insoluble types form sediments and precipitates, especially on colder elements, such as heat exchanger coils.

Liquids containing antioxidant have little tendency to form gums under normal operating conditions; however, as the temperature increases, resistance to oxidation diminishes. Hydraulic liquids that have been subjected to excessively high temperatures (above 250°F) break down in substance, leaving minute particles of asphalting suspended in the liquids. The liquid changes to brown in color and is referred to a decomposed liquid. This explains the importance of keeping the hydraulic liquid temperature below specified levels.

The second contaminant producing chemical action in hydraulic liquids is one that permits these liquids to establish a tendency to react with certain types of rubber. This causes structural changes in the rubber, turning it brittle, and finally causing its complete disintegration. For this reason, the compatibility of system liquid with seals and hose material is an important factor.

- PARTICLES INTRODUCED BY FOREIGN LIQUIDS. One of the most common foreign-fluid contaminants is water, especially in hydraulic systems that require petroleum-based oils. Water, which enters even the most carefully designed systems by condensation of atmospheric moisture, normally settles to the reservoir bottom. Oil movement in the reservoir disperses the water into fine droplets; agitation of the liquid in the pump and in high-speed passages forms an oil-water-air emulsion. Such an emulsion normally separates out during the rest period in the system reservoir, but when fine dust and corrosion particles are present, the emulsion is catalyzed by high pressures into sludge. The damaging action of sludge explains the need for water-separating qualities in hydraulic liquids.

3.4.3 3.4.3 Control of Contamination

Filters provide adequate control of the contamination problem during all normal hydraulic system operations. Control of the size and amount of contamination entering the system from any other source must be the responsibility of the personnel who service and maintain the equipment; therefore, precaution must be taken to ensure that contamination is held to a minimum during service and maintenance. Should the system become excessively contaminated, the filter element should be removed and cleaned or replaced.

As an aid to exercising contamination control, adhere to the following maintenance and servicing procedures at all times:

- Maintain all tools and the work area (workbenches and test equipment) in a clean, dirt-free condition.
- Always provide a suitable container to receive the hydraulic fluid which is spilled during component removal or disassembly procedures.

NOTE

The reuse of hydraulic fluid is not recommended; however, in some large-capacity systems, the reuse of fluid is permitted. When liquid is drained from the latter systems, it must be stored in a clean and suitable container. This liquid must be strained and/or filtered as it is returned to the system reservoir.

- Before disconnecting hydraulic lines or fittings, clean the affected area with an approved dry-cleaning solvent.
- Cap or plug all hydraulic lines and fittings immediately after disconnecting.
- Before assembly of any hydraulic components, wash all parts with an approved dry-cleaning solvent.
- After cleaning parts in dry-cleaning solvent, dry the parts thoroughly and lubricate them with the recommended preservative or hydraulic liquid before assembly.

NOTE

Use only clean, lint-free cloths to wipe or dry component parts.

- Replace all packings and gaskets during the assembly procedures.
- Connect all parts with care to avoid stripping metal slivers from threaded areas. Install and torque all fittings and lines according to applicable technical instructions.
- Keep all hydraulic servicing equipment clean and in good operating condition.

3.4.4 Checks for Contamination

Whenever you suspect that a hydraulic system has become excessively contaminated or the system has been operated at temperatures in excess of the specified maximum, make a check of the system. The filters in most hydraulic systems are designed to remove most foreign particles that are visible to the naked eye; however, hydraulic liquid which appears clean to the naked eye may be contaminated to the point that it is unfit for use.

Thus, visual inspection of the hydraulic liquid does not determine the total amount of contamination in the system. Large particles of impurities in the hydraulic system are indications that one or more components in the system are being subjected to excessive wear. Isolating the defective component requires a systematic process of elimination. Liquid returned to the reservoir may contain impurities from any part of the system. In order to determine which component is defective, take liquid samples from the reservoir and various other locations in the system.

3.4.4.1 Fluid Sampling

Take liquid samples according to the instructions provided in applicable technical publications for the particular system and the contamination test kit. Some hydraulic systems are provided with permanently installed bleed valves for taking liquid samples, while on other systems lines must be disconnected to provide a place to take a sample. In either case, while the liquid is being taken, a small amount of pressure should be applied to the system. This ensures that the liquid will flow out of the sampling point and thus prevent dirt and other foreign matter from entering the hydraulic system. Hypodermic syringes are provided with some contamination test kits for the purpose of taking samples.

3.4.4.2 4.2 Contamination Testing

Various procedures are recommended to determine the contaminant level in hydraulic liquids. The filter patch test provides a reasonable idea of the condition of the fluid. This test consists basically of filtration of a sample of hydraulic system liquid through a special filter paper. This filter paper darkens in degree in relation to the amount of contamination present in the sample and is compared to a series of standardized filter disks which, by degree of darkening, indicates the various contamination levels.

To check liquid for decomposition, pour new hydraulic liquid into a sample bottle of the same size and color as the bottle containing the liquid to be checked. Visually compare the color of the two liquids. Liquid which is decomposed will be darker in color.

At the same time the contamination check is made, it may be necessary to make a chemical analysis of the liquid. This analysis consists of a viscosity check, a moisture check, and a flash point check; however, since special equipment is required for these checks, the liquid samples must be sent to a laboratory where a technician will perform the test.

3.4.4.3 Flushing the System

Whenever a contamination check indicates impurities in the system or indicates decomposition of the hydraulic liquid, the hydraulic system must be flushed.

NOTE

The presence of foreign particles in the hydraulic system indicates a possible component malfunction that you should correct before flushing the system.

A hydraulic system in which the liquid is contaminated should be flushed according to current applicable technical instructions. Flushing procedures are normally recommended by the manufacturer. The procedure varies with different hydraulic systems. One method is as follows:

Drain out as much of the contaminated liquid as possible. Drain valves are provided in some systems for this purpose, while on other systems lines and fittings must be disconnected at the low points of the system to remove any trapped fluid in the lines and components. Close all the connections and fill the system with the applicable flushing medium. Any of the hydraulic liquids approved for use in power-transmission systems may be used for flushing purposes.

CAUTION

Diesel fuel oil must not be used for flushing hydraulic systems in active service because of its poor lubricating qualities and its contaminating effect on the subsequent fill of hydraulic liquid.

While being flushed with an approved hydraulic liquid, power-transmission systems can be operated at full load to raise the temperature of the liquid. Immediately following the warming operation, the system should be drained by opening all drain outlets and disconnecting the hydraulic lines to remove as much of the flushing medium as possible. All filter elements, screens, and chambers should be cleaned with new fluid before filling the system with the required service liquid.

CAUTION

The system should not be operated while or after draining the liquid.

Power-transmission systems and their interconnected hydraulic controls whose inner surfaces have been inactivated and treated with a corrosion prevention or preservation compound must be flushed to remove the compound. The latest current instructions for flushing and other operations required to reactivate a particular system must be strictly followed to prevent damage.

Some hydraulic systems are flushed by forcing new liquid into the system under pressure, forcing out the contaminated or decomposed liquid.

Hydraulic liquid which has been contaminated by continuous use in hydraulic equipment or has been expanded as a flushing medium must not be used again but should be discarded according to the prevailing instructions.

CAUTION

Never permit high-pressure air to be in direct contact with petroleum-based liquids in a closed system because of the danger of ignition. If gas pressure is needed in a closed system, nitrogen or some other inert gas should be used.

Summary

In this chapter, you added to your knowledge of the hydraulic systems used in the NCF. You also learned how to troubleshoot some problems with the different components in a hydraulic system. In addition, you learned preventive maintenance on hydraulic systems and the importance of clean fluid. Mastering the knowledge of hydraulics will enable you to be a better construction mechanic.

Review Questions (Select the Correct Response)

1. What term is used to describe the amount of force distributed over each unit on the area of an object?

    A. Hydraulics
    B. Pneumatics
    C. Pressure
    D. Force

2. Practically all pumps fall within what category?

    A. Rotary
    B. Reciprocating
    C. Centrifugal
    D. All of the above

3. Rotary pumps operate on which displacement principle?

    A. Positive
    B. Negative
    C. Fixed
    D. Variable

4. Which pump will deliver a constant volume of fluid at any given rpm?

    A. Vane
    B. Gear
    C. Lobe
    D. Reciprocating

5. The inlet port of a vane pump is located in that part of the pump where the chambers are ________ in size.

    A. expanding
    B. diminishing
    C. constant
    D. narrowing

6. Which type of pump is used for applications requiring high pressures and accurate control of the discharge volume?

    A. Vane
    B. Gear
    C. Lobe
    D. Reciprocating

7. The volume output of the constant volume piston pump is determined by the angle between the drive shaft and what other component?

   A. Cylinder block
   B. Gear
   C. Lobe
   D. Piston

8. One advantage of the variable volume pump is that it eliminates the need for a system ____________.

   A. surge reducer
   B. pressure regulator
   C. bypass regulator
   D. pressure reducer

9. How many different designs of hand pumps are there?

   A. 1
   B. 2
   C. 3
   D. 4

10. Since linear motion is a back-and-forth motion along a straight line, the cylinder-type actuator is also referred to as a ______.

   A. pressure motor
   B. pressure regulator
   C. linear motor
   D. radial motion

11. The single-acting ram applies force in how many directions?

   A. 1
   B. 2
   C. 3
   D. 4

12. What type of directional control valve is used to control the single-acting piston-type cylinder?

   A. One-way
   B. Two-way
   C. Three-way
   D. None of the above

13. The speed of the rotation of the pump is controlled by what device?

    A. Rotation of the crankshaft
    B. Length of the crankshaft
    C. Length of the piston
    D. Rotation of the piston

14. What is another name for the tilting plate of the piston-type hydraulic motor?

    A. Hold
    B. Two-way
    C. Hang-up
    D. Swash

15. Valves are included in a hydraulic system to control which point?

    A. Direction
    B. Volume
    C. Pressure
    D. All of the above

16. What type of valve is probably the most common type of valving element used in directional control valves?

    A. Rotary spool
    B. Poppet
    C. Selector
    D. Sliding spool

17. What type of gas is commonly used in gas-charged accumulators?

    A. Air
    B. Nitrogen
    C. Helium
    D. Both A and B

18. What type of hydraulic system has fluid flow but no pressure in the system?

    A. Open-center
    B. Closed-center
    C. Neutral
    D. Differential

19. What type of hydraulic system has fluid stored under pressure whenever the pump is operating?

    A. Open-center
    B. Closed-center
    C. Neutral
    D. Differential

20. Before you reassemble a hydraulic pump, you must lubricate all internal parts with what material?

A. Oil
B. Petrolium jelly
C. Gear lube
D. Hydraulic fluid

21. Rust or corrosion initially present in a hydraulic system can usually be traced to what improperly handled action?

A. Storage of replacement parts
B. Installation of replacement parts
C. Removal of broken parts
D. Order procedures of broken parts

22. What is the chief source of chemical contaminants in hydraulic liquid?

A. Chlorination
B. Oxidation
C. Condensation
D. Algae

23. What color will decomposing hydraulic fluid turn?

A. Darker
B. Lighter
C. Reddish
D. Bluish

24. You should never allow high-pressure air to be in direct contact with petroleum-based liquids because of what hazard?

A. Contamination
B. Separation
C. Ignition
D. Corrosion

Trade Terms Introduced In This Chapter

Force	The push or pull on an object.
Pressure	The amount of force distributed over each unit on the area of an object.
Incompressible	Unable to be compressed, cannot be squeezed into a smaller space.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Heavy Duty Truck Systems 4th Edition, Sean Bennet, Delmar Cengage Learning, 2006. (ISBN-13:978-1-4018-7064-5)

Modern Automotive Technology 7th Edition, James Duffy, The Goodheart-Wilcox Company, Inc., 2009. (ISBN: 978-1-59070-956-6)

Automatic Transmissions and Transaxles, James Duffy, The Goodheart-Wilcox Company, Inc., 2005. (ISBN: 1-59070-426-6)

Manual Drive Trains and Axles, Chris Johanson, James Duffy, The Goodheart-Wilcox Company, Inc., 2004. (ISBN: 1-59070-320-0)

Power trains, Fundamentals of Service, Deere and Company, John Deere Inc., 2005. (ISBN: 0-86691-325-4)

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Chapter 11

Inspecting and Troubleshooting Brake Systems

Topics

To hear audio, click on the box.

Overview

As a CM, you will be responsible for the maintenance, repair, and troubleshooting of braking systems. Braking systems are usually inspected yearly or every 12,000 miles to ensure safe operation, to comply with state and local regulations, and to keep personnel and equipment safe. To avoid personal injury or loss of equipment, CESE should not leave the shop if the brake system is not operating properly. Many accidents caused by defective brakes might have been avoided by frequent and thorough brake inspections. These brake inspections must be done more frequently when vehicles are used in sand, mud, or constant fording.

This chapter will discuss the basic principles associated with inspecting and troubleshooting brake systems. The purpose of this information is to give you an analytical understanding of the interrelationships of principles and components of an operating system. When you understand the operation of a system, it is much easier to analyze a malfunction and make the proper repairs.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand how to inspect and troubleshoot hydraulic brake systems.
2. Understand how to troubleshoot vacuum-assisted hydraulic brakes (power) systems.
3. Understand the principles of anti-lock brakes and methods of repairing them.

Prerequisites

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air Conditioning Systems	↑	C
Air Compressor Overhaul		M
Inspecting and Troubleshooting Brake Systems		
Hydraulic Systems		A
Wheel and Track Alignment		D
Troubleshooting Transmissions, Transfer Cases and Differentials		V
Clutches and Automatic Transmissions		A
Troubleshooting Electrical Systems		N
Fuel System Overhaul		C
Engine Troubleshooting and Overhaul		E
The Shop Inspectors		D
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 INSPECTING and TROUBLESHOOTING HYDRAULIC BRAKE SYSTEMS

The stopping distances for all vehicles depend on the distance the driver can see and think before pressing the brake pedal. *Figure 11-1* shows some stopping distances from different speeds with good brakes. These stopping distances came from actual tests.

Hydraulic brakes should be inspected for the external condition of the hoses and tubing, especially for leakage or seepage at the couplings. Hose or tubing worn or weakened by rubbing against other parts of the vehicle must be replaced.

CAUTION

Under no circumstances should steel brake tubing be replaced with copper tubing.

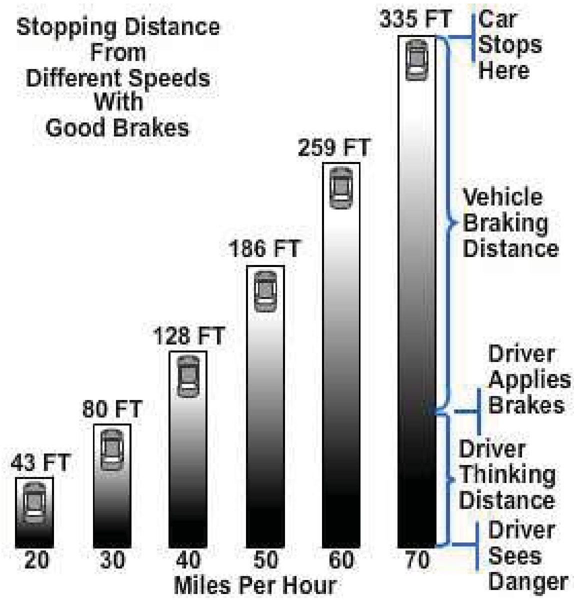

Figure 11-1 – Total vehicle stopping distance of an average vehicle.

Test for leakage by holding the brake pedal depressed for at least 1 minute. If the pedal does not hold, there is a leak in the system. If you find a leak, repair it, even if you have to pull all the wheels to examine the wheel cylinders. Then fill the master cylinder with fluid and bleed the brakes.

NOTE

NFELC Maintenance Bulletin No. 75 directs the Naval Construction Force to use silicone brake fluid. Silicone brake fluid will not mix with glycol brake fluid and no adverse effects will occur to brake parts if it is combined accidently in small quantities. Some of the advantages of silicone brake fluid are that it will not damage painted surfaces, it has excellent dielectric properties, it will not deteriorate during long periods of system storage or climatic exposure, and it will not absorb or retain moisture.

To comply with requirements for testing brakes, you must see that at least one of the wheels is removed to check the brake lining and drum/rotor. Some manufacturers recommend pulling two wheels--one on each side. Look for loose or broken brake shoe retracting springs, worn clevis and cotter pins in the brake operating mechanisms, and grease or oil leaks at the wheel bearing grease retainer. Check for any signs of brake fluid leakage around the wheel cylinders or caliper operating pistons.

Brake linings that pass inspection for wear must be securely fastened to the brake shins and free from grease and oil. Small grease or oil spots can be removed from the lining with a non-oil based solvent. Linings saturated with grease or oil should be replaced only after the source of contamination has been repaired.

Badly worn or scored brake drums/rotors should be machined smooth and true on a lathe or replaced (*Figure 11-2, View A*). Cracked brake drums or brake drums that have been machined beyond their maximum allowable diameter should be discarded (*Figure 11-2, View B)*. Brake drums and discs have the maximum or discard diameters cast into their outer surfaces (*Figure 11-2, View C*).

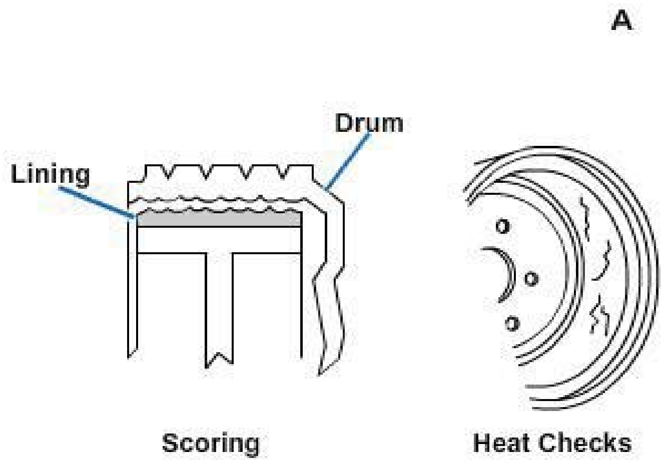

Figure 11-2 – Checking and inspecting brake drims.

Brake shoe and drum trouble that is detected during road tests but is not immediately evident when the wheels are pulled may be caused by the wrong kind of lining, ill-fitting brake shoes, or brake drums slightly out of round. The clue to these troubles may be ***chattering***, ***spongy***, or ***grabbing brakes***.

CAUTION

Before troubleshooting brake systems by road testing, be sure that the vehicle is mechanically sound. Different size tires, low tire pressures, faulty shock absorbers, loose wheel bearings, and worn front-end parts may each indicate brake problems where there are none.

Navy vehicles seldom have the wrong kind of brake lining. However, an inexperienced mechanic may reverse the primary and secondary shoe on one of the wheels or interchange them between wheels so that the shoes are not exactly mated with the drums against which they expand. If you replace shoes or machine the drum/rotor on one side, do the same to the opposite side to prevent pull or loss of control.

The preceding paragraphs apply to most braking systems but do not list all of the problems you will have. For other probable causes of trouble and their remedies in standard hydraulic brake systems, refer to *Table 11-1*.

Table 11-1 - Troubleshooting Chart for Hydraulic Brakes (Standard).

MALFUNCTION	PROBABLE CAUSE	POSSIBLE REMEDY
Low pedal, pedal goes to floor board.	1. Excessive clearance between linings and drum.	1. Adjust brakes.
	2. Automatic adjusters not working.	2. Make forward and reverse stops. If pedal stay low, repair faulty adjusters.
	3. Weak brake hose.	3. Replace hose.
	4. Leaking brake pipe.	4. Repair or replace faulty parts
	5. Leaking wheel cylinder.	5. Clean and rebuild.
	6. Leaking master cylinder.	6. Clean and rebuild.
	7. Leaking master cylinder check valve.	7. Replace valve.
	8. Leaking stop light switch.	8. Replace switch.
	9. Air in system.	9. Bleed system.
	10. Plugged master cylinder filler cap.	10. Clean filler cap vent holes; bleed system.
	11. Improper brake fluid.	11. Flush system and replace with correct fluid.
	12. Low fluid level.	12. Fill reservoir; bleed system.
Springy, spongy pedal.	1. Air trapped in hydraulic system.	1. Remove air by bleeding.
	2. Improper brake fluid.	2. Flush and bleed system.
	3. Anchor pin adjustment incorrect.	3. Adjust anchor pin.
	4. Improper lining thickness or location.	4. Install specified lining or replace shoe lining.
	5. Drums worn too thin.	5. Replace drums.
	6. Master cylinder filler vent clogged.	6. Clean vent or replace cap; bleed brakes.
	7. Weak hose.	7. Replace hose.
Excessive pedal pressure required to stop car.	1. Brake adjustment not correct.	1. Adjust brakes or repair self adjuster.
	2. Incorrect lining.	2. Install specified lining.
	3. Grease or fluid soaked lining.	3. Repair grease seal, or wheel cylinder. Install new linings.
	4. Improper fluid.	4. Flush out system; fill with correct type fluid.
	5. Frozen master or wheel cylinder pistons.	5. Rebuild or replace.
	6. Brake pedal binding on shaft.	6. Lubricate or replace.
	7. Linings installed on wrong shoes.	7. Install primary and secondary linings correctly.
	8. Glazed linings.	8. Sand surface of linings.

Table 11-1 - Troubleshooting Chart for Hydraulic Brakes (Standard) con't.

MALFUNCTION	PROBABLE CAUSE	POSSIBLE REMEDY
Light pedal pressure. Brakes too severe.	1. Brake adjustment not correct.	1. Adjust the brakes or repair self adjusters.
	2. Loose backing plate on front axle.	2. Tighten plates.
	3. Small amount of grease or fluid on linings.	3. Replace the linings.
	4. Glazed linings.	4. Sand the surface of the linings.
	5. Incorrect lining.	5. Install factory specified linings.
	6. Wheel bearings loose.	6. Adjust wheel bearings.
	7. Lining loose on shoe.	7. Replace lining or shoe and lining.
	8. Excessive dust and dirt in drums.	8. Clean and sand drums and linings.
	9. Bad drum.	9. Turn drums in pairs or replace.
Brake pedal travel decreasing.	1. Master cylinder compensating port plugged.	1. Open with compressed air or replace.
	2. Swollen cap in master cylinder.	2. Replace rubber parts; flush system.
	3. Master cylinder piston not returning.	3. Rebuild master cylinder.
	4. Weak shoe retracting springs.	4. Replace springs.
	5. Wheel cylinder pistons sticking.	5. Clean cylinder bores and parts. Replace bad parts.
Pulsating brake pedal.	1. Drums out of round.	1. Refinish drums to specifications.
	2. Loose brake drum on hub.	2. Tighten.
	3. Worn or loose wheel bearings.	3. Replace or adjust.
	4. Bent rear axle.	4. Replace axle.
Brake fade.	1. Incorrect lining.	1. Replace lining with lining recommended by factory.
	2. Thin Drum.	2. Replace drums.
	3. Dragging brakes.	3. Adjust or correct cause.
All brakes drag when adjustment is known to be correct.	1. Pedal does not return to stop.	1. Lubricate the pedal.
	2. Improper fluid.	2. Replace rubber parts and refill.
	3. Compensating or bypass part of master cylinder closed.	3. Open with compressed air.
One wheel drags	1. Weak or broken shoe retracting springs.	1. Replace the defective brake shoe springs and lubricate the brake shoe ledges.
	2. Brake shoe-to-drum clearance too small or the brake hoe eccentric is not adjusted properly.	2. Adjust.
	3. Loose wheel bearings.	3. Adjust wheel bearings.
	4. Wheel cylinder piston cups swollen and distorted or the piston stuck.	4. Rebuild cylinders.
	5. Pistons sticking in wheel cylinder.	5. Clean or replace pistons; clean cylinder bore.

Table 11-1 - Troubleshooting Chart for Hydraulic Brakes (Standard) con't.

MALFUNCTION	PROBABLE CAUSE	POSSIBLE REMEDY
	6. Drum out of round.	6. Grind or turn front or rear drums.
	7. Obstruction in line.	7. Clean out or replace.
	8. Loose anchor pin.	8. Adjust and tighten lock-nut.
	9. Distorted shoe.	9. Replace.
	10. Defective lining.	10. Replace with specified lining.
	11. Parking Brake cable frozen.	11. Lubricate.
Rear brakes drag.	1. Maladjustment.	1. Adjust brake shoes and parking brake mechanism.
	2. Parking brake cables frozen.	2. Lubricate.
Vehicle pulls to one side.	1. Grease or fluid soaked lining.	1. Replace with new linings.
	2. Anchor pin adjustment not correct.	2. Major brake adjustment.
	3. Loose wheel bearings; loose backing plate on rear axle or front axle or loose spring bolts.	3. Adjust the wheel bearing; tighten the backing plate on the rear axles and tighten spring bolts.
	4. Linings not of specified kind or primary and secondary shoes reversed.	4. Install specified linings.
	5. Tires not properly inflated or unequal wear of tread. Different tread nonskid design.	5. Inflate the tires to recommended pressures. Rearrange the tires so that a pair of nonskid tread surfaces of similar design and equal wear will be installed on the front wheels and another pair with the tread will be installed on the rear wheels.
	6. Linings glazed.	6. Sand the surfaces of the linings.
	7. Water, mud, etc., in brakes.	7. Remove any foreign materials from all of the brake parts and the inside of the drums. Lubricate the shoe ledges and the rear brake cable ramps.
	8. Wheel cylinder sticking.	8. Repair or replace wheel cylinder.
	9. Weak or broken retracting springs.	9. Check springs. Replace bent, open-coiled or cracked springs.
	10. Out-of-round drums.	10. Re-surface or replace drums in left and right hand pairs (both front and back).
	11. Brake Dragging.	11. Check for loose lining. Adjust.
	12. Weak chassis springs, loose U-bolts, loose steering gear, etc.	12. Replace spring, tighten U-bolts, adjust steering gear, etc.
	13. Loose steering	13. Repair and adjust.
	14. Unequal camber.	14. Adjust to spec.
	15. Bad drum.	15. Refinish drums in pairs.

Table 11-1 - Troubleshooting Chart for Hydraulic Brakes (Standard) con't.

MALFUNCTION	PROBABLE CAUSE	POSSIBLE REMEDY
One wheel locks.	1. Gummy lining.	1. Reline.
	2. Tire tread slick.	2. Match up tire tread side to side.
	3. Faulty anchor adjustment.	3. Adjust.
Wet weather, brakes grab or won't hold.	1. Linings sensitive to water.	1. Reline.
	2. Dirty brakes.	2. Clean out.
	3. Bent backing plate-opening.	3. Straighten or replace.
	4. Scored drums.	4. Grind or turn in pairs.
Brakes squeak.	1. Backing plate bent or shoes twisted.	1. Straighten or replace damaged parts.
	2. Metallic particles or dust embedded in lining.	2. Sand linings and drums. Remove all particles of metal in surface of linings.
	3. Lining rivets loose or lining not held tightly against the shoe at the ends.	3. Replace rivets and/or tighten lining by reriveting.
	4. Drums not square or distorted.	4. Turn or grind or replace drums.
	5. Incorrect lining.	5. Replace lining per factory specs.
	6. Shoes scraping on backing plate ledges.	6. Lube ledges. Replace with new shoe and linings, if distorted.
	7. Weak or broken hold down springs.	7. Replace defective parts.
	8. Loose wheel bearings.	8. Tighten to proper setting.
	9. Loose backing plate, anchor, or drum wheel cylinder.	9. Tighten.
	10. Loose shoe links.	10. Tighten.
	11. Linings located wrong on shoes.	11. Install linings correctly.
Brakes chatter.	1. Incorrect lining-to-drum clearance.	1. Readjust to recommended clearances.
	2. Loose backing plate.	2. Tighten securely.
	3. Grease, fluid, road dust on lining.	3. Clean or reline.
	4. Weak or broken retractor spring.	4. Replace.
	5. Loose wheel bearing.	5. Readjust.
	6. Drums out of round.	6. Grind or turn drums in pairs.
	7. Distorted shoes.	7. Replace shoes.
Grinding noise.	1. Shoe hits drum.	1. Switch drums or grind drums.
	2. Foreign material in lining.	2. Remove or replace lining.
	3. Rivets or shoe rubbing drum.	3. Reline. Refinish drums.
	4. Rough drum surface.	4. Refinish drums.

1.1.0 Pedal Goes to the Floor

Pedal reserve is the distance from the brake pedal to the floorboard with the brakes applied (*Figure 11-3*). Low or no pedal reserve indicates brake problems. When there is no pedal reserve or an unlikely occurrence with a dual master cylinder, it could mean anything from a lack of brake fluid, to worn brake linings, a faulty master cylinder, or only the need for a simple brake adjustment. Each of these conditions demands that you closely inspect the brake system.

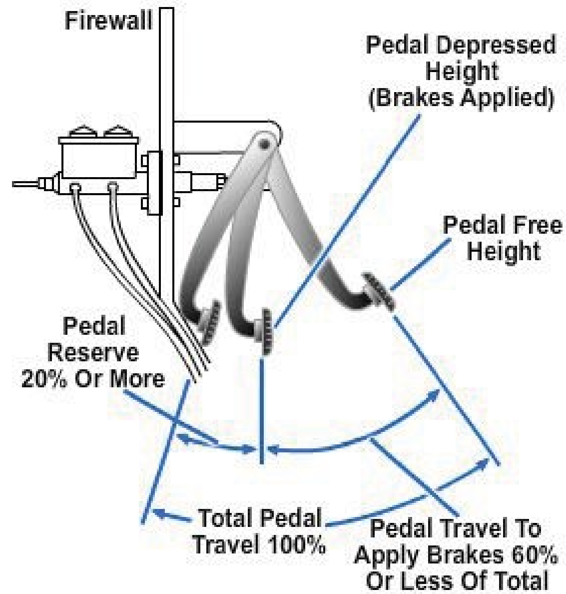

Figure 11-3 – Brake pedal reserve.

1.2.0 Brake Drag

Dragging brakes are caused by the following: one or more sets of shoes being adjusted too tightly, broken or weak return springs, a wheel cylinder piston that is stuck, drums that are out of round, defective lining material, loose anchor pins, or clogged lines or hoses. When both rear wheels drag, the cause may be the parking cable linkage being adjusted too tightly or a frozen parking brake cable. All wheels dragging can be the result of a stuck master cylinder pedal linkage or a defective power booster.

1.3.0 Car Pulls to One Side

Be sure all other parts related to the front end are in good working order before placing blame on the brakes. Loose anchor pins or backing plates, improper lining, wrong adjustment, broken return springs, drums out of round, defective wheel cylinder, a binding disc caliper piston, or a clogged or crimped hydraulic line can all cause a vehicle to pull to one side during braking.

1.4.0 Soft Pedal

The most common cause for a soft or spongy brake pedal will be air trapped in the hydraulic lines. This problem may also be caused by a brake drum being cut too thin when it is being resurfaced, and by weak or old flexible brake lines.

1.5.0 Brakes Too Hard to Apply

This problem may be the result of grease or brake fluid on the lining, pedal linkage binding, a faulty master cylinder, or glazed brake linings.

1.6.0 Brakes Too Sensitive

Incorrect brake adjustment, or brake lines or brake lining fouled with grease or brake fluid maybe the cause of sensitive brakes.

1.7.0 Brake Noise

Before you determine a noise to be coming from the brakes, eliminate all other possible sources, such as body noise, loose front-end parts, loose lug nuts, and so forth. Brake noise may be coming from shoes scraping the backing plate; in addition, loose brake lining (riveted), loose anchor pins, loose or weak return springs, and loose backing plates can all cause some sort of brake noise.

1.8.0 Brake Fluid Loss

Brake fluid loss is a serious problem caused by loose fittings, or leaking wheel cylinders, master cylinder, brake lines, and hydraulic hoses.

1.9.0 Brakes Do Not Self-Adjust

The brake drum must be removed to check the self-adjust mechanism (*Figure 11-4*). Worn or frozen star wheels, broken or dislodged adjusting cable, or broken hold-down clips will all cause the self-adjuster to malfunction.

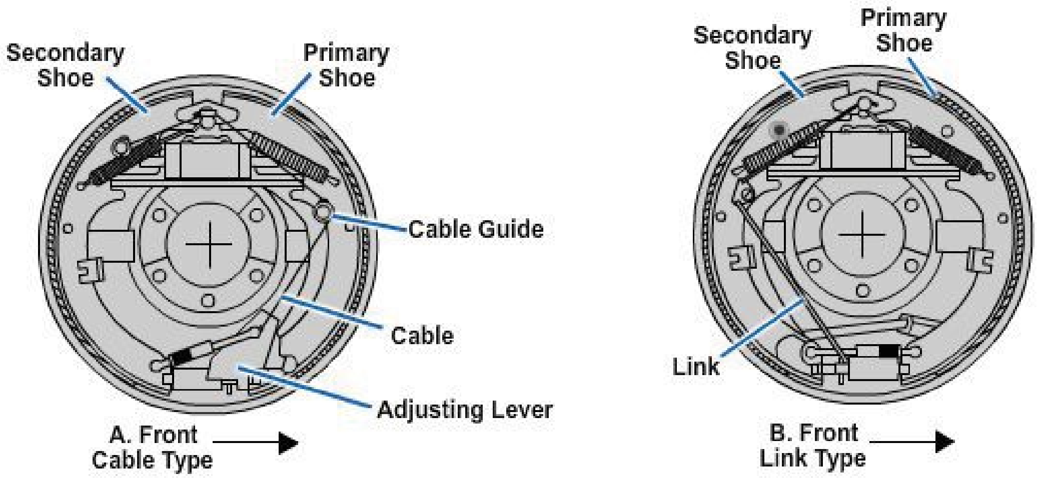

Figure 11-4 - Self-adjusting brake mechanisms.

1.10.0 Brake Warning Lamp Will Not Go Out

If the brake failure warning lamp comes on, it is a signal that one of the two hydraulic circuits has malfunctioned. Check the entire system and after you make any repairs, reset the brake failure warning lamp switch (*Figure 11-5*). See *Table 11-1* for a complete listing of possible brake problems and repairs.

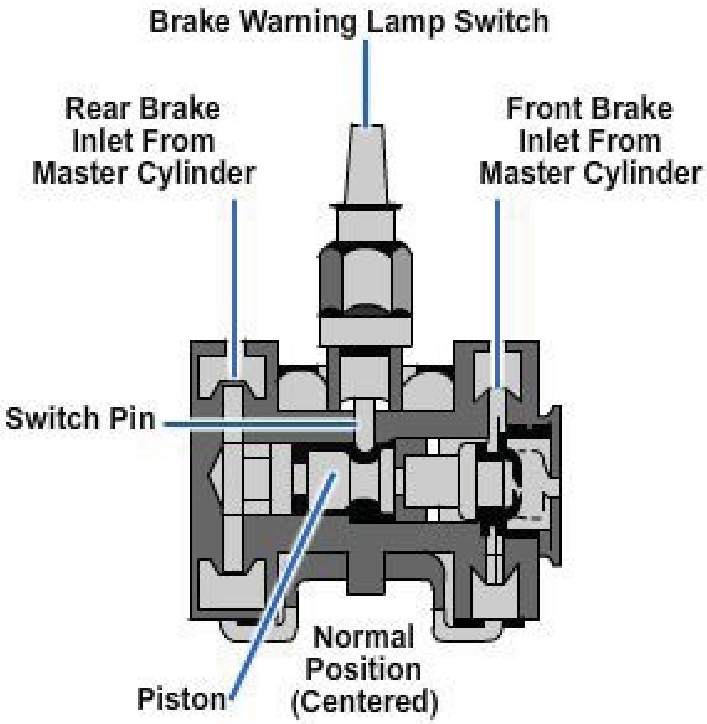

Figure 11-5 - Pressure differential valve with brake lamp warning switch.

Test your Knowledge (Select the Correct Response)

1. Braking systems are usually inspected yearly after what maximum number of miles?

   A. 6,000
   B. 8,000
   C. 12,000
   D. 15,000

2.0.0 TROUBLESHOOTING VACUUM-ASSISTED HYDRAULIC BRAKES (POWER) SYSTEMS

Aside from the vacuum booster, the same basic inspection procedures given in the hydraulic brake section apply to the vacuum-assisted hydraulic brake system. When you check this system for a source of trouble, refer to the chart for the standard hydraulic brake system (*Table11-1*). After you isolate possible causes by consulting this chart, check for causes in the troubleshooting chart of *Table 11-2*.

NOTE

Conduct the following test BEFORE you check the cause of a hard pedal. With the engine stopped, depress the brake pedal several times to eliminate all vacuum from the system. Apply the brakes, and while holding the foot pressure on the brake pedal, start the engine. If the unit is operating correctly, the brake pedal will move forward when the engine vacuum power is added to the pedal pressure. If this test shows the power unit is not operating, check the probable causes of vacuum failure in *Table 11-2*.

Table 11-2 - Troubleshooting Chart for Vacuum-Assisted Hydraulic Brakes (Power).

MALFUNCTION	PROBABLE CAUSE	POSSIBLE REMEDY
*Hard pedal.	1. Broken or damaged hydraulic brake lines.	1. Inspect and replace as necessary.
	2. Vacuum failure.	2. Check for: a. Faulty vacuum check valve or grommet--replace. b. Collapsed or damaged vacuum hose--replace. c. Plugged or loose vacuum fitting--repair. d. Faulty air valve seal or support place seal--replace. e. Damaged floating control valve--replace. f. Bad stud welds on front or rear housing of power head--replace unless easily repaired.
	3. Defective diaphragm.	3. Replace.
	4. Restricted air filter element.	4. Replace.
	5. Worn or badly distorted reaction disc. (tandem diaphragm).	5. Replace reaction disc.
	6. Cracked or broken power pistons or retainer.	6. Replace power pistons and piston rod retainer.
	7. Incorrect selective reaction piston (tandem diaphragm only).	7. Gauge reaction piston and replace with correct piston.
Grabby brakes, (apparent off-and-on condition).	1. Broken or damaged hydraulic brake lines.	1. Inspect and replace as necessary.
	2. Insufficient fluid in master cylinder.	2. Fill reservoirs with approved brake fluid and check for leaks.
	3. Defective master cylinder seals.	3. Repair or replace as necessary.
	4. Cracking master cylinder casting.	4. Replace.
	5. Air in hydraulic system.	5. Bleed system.
Brakes fail to release.	1. Blocked passage in power piston.	1. Inspect and replace as necessary.
	2. Air valve sticking shut.	2. Check for proper lubrication of air valve O ring.
	3. Broken piston return spring.	3. Replace.
	4. Broken air valve spring.	4. Replace.
	5. Tight pedal linkage.	5. Repair or replace as necessary.
*Hard pedal is excessive pedal pressure required to apply the brakes.		

2.1.0 Hard Pedal

A "hard pedal" means the booster is inoperative, and you should suspect and check the following as the cause: collapsed vacuum hoses, faulty vacuum check valves, internal damage to the power booster, or a broken plunger stem.

2.2.0 Grabby Brakes

Uncontrolled stopping is a problem that may be caused by grabbing or oversensitive brakes. This symptom may result from a faulty power booster, a damaged vacuum check valve, leaky or incorrectly connected vacuum lines, or a broken plunger stem.

2.3.0 Brakes Fail to Release

When you apply the brakes and they fail to release, the following could be the problem- a broken power booster return spring, a sticking valve plunger in the booster, or a jammed power piston.

2.4.0 Loss of Fluid

Loss of brake fluid may occur through the rear seal of the master cylinder past the piston stop plate and into the power booster. The leak is not visible on the backing plates, the wheels, or the frame because the fluid collects in the power booster. Some of the fluid may be drawn through the vacuum lines and burned in the engine. The end result is that you do not see the leak. For a more complete listing of vacuum booster hydraulic brake problems and remedies, see *Table 11-2*. Always consult the specific manufacturer's manual whenever you replace or repair any vacuum power booster.

2.5.0 Hydroboost Power Brake Systems

Diesel engines do not create enough usable vacuum to actuate the vacuum power brake booster. The alternative is a hydraulic-assisted power brake booster or hydroboost. The hydroboost uses hydraulic pressure developed by the power steering pump rather than vacuum from the engine (*Figure 11-6*). The booster unit contains a spool valve that has an open center that controls the pump pressure as braking occurs. A lever assembly has control over the valve position and the boost piston provides the necessary force that operates the master cylinder. See *Figure 11-7* for a parts breakdown of the booster assembly.

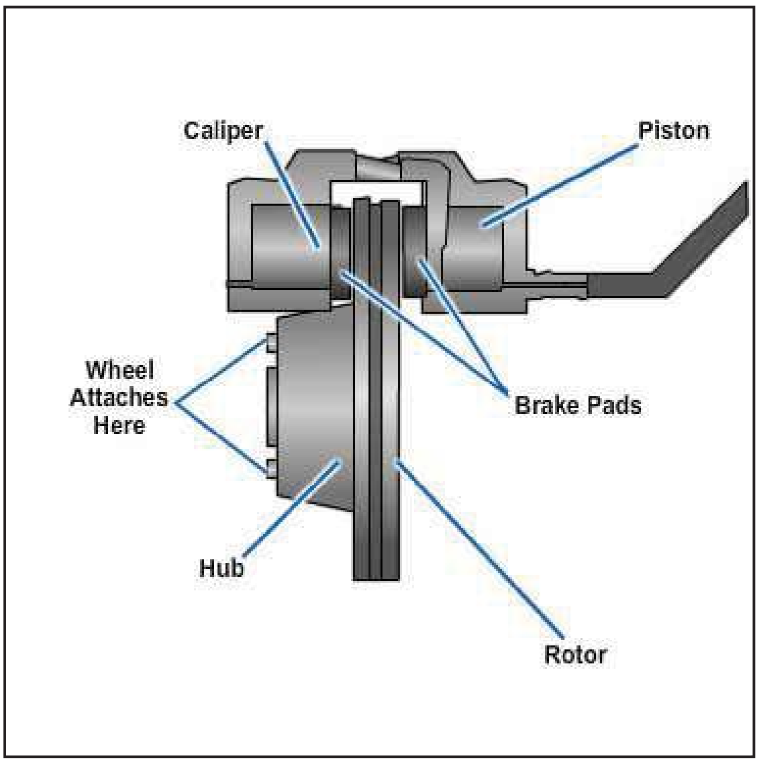

Figure 11-6 - Hydraulic power booster system.

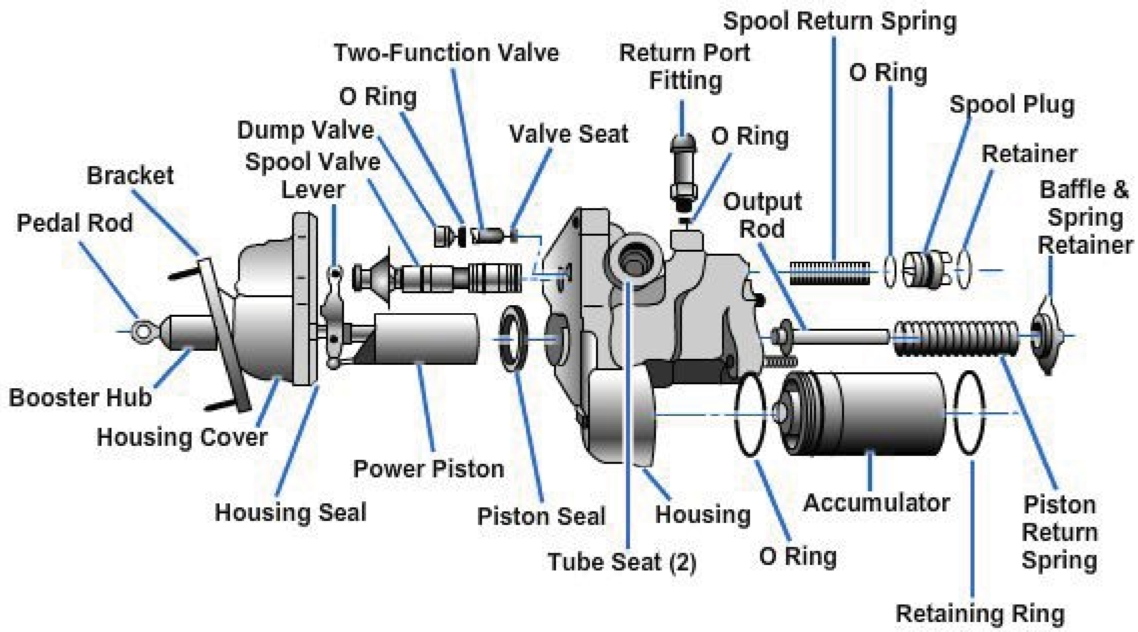

Figure 11-7 - Hydraulic power booster assembly.

In the event of hydraulic pressure loss, a springloaded accumulator is provided on the unit. This will provide for at least two power brake applications. The brakes will operate without the power assist unit, but the pedal pressure will be noticeably higher. AVOID DRIVING IN THIS CONDITION.

2.5.1 ng

2.5.1.1 Hard Pedal (at an Idle)

This problem may be caused by fluid contamination, pedal linkage binding, or a bad hydroboost unit.

2.5.1.2 High Pedal and Steering Effort

A loose or broken power steering belt, low pump fluid level, low engine idle, a restriction in one or more hydraulic lines, or a defective power steering pump will cause these symptoms.

2.5.1.3 Slow Pedal Return

Slow pedal return can be caused by pedal linkage binding, a restricted booster hydraulic line, or an internal problem with the hydroboost unit.

2.5.1.4 Pedal Pulsation

Pedal chatter/pulsation is caused by a loose or slipping drive belt, low power steering fluid level, a defective power steering pump, or a defective hydroboost unit.

2.5.1.5 Brakes Too Sensitive

Pedal linkage binding or a defective hydroboost unit will cause this to happen.

2.5.1.6 Excessive Noise

Excessive noise originating in the hydroboost unit is an indication of the following problems: low power steering fluid, air in the power steering fluid, a loose power steering belt, or a restriction in the hydraulic hoses.

WARNING

The interchanging of parts between hydroboost units of different makes of CESE is not recommended. Tolerances of parts and pressure differentials may be different, causing a jerry-rigged hydroboost unit to exceed the normal 1,400 psi accumulator pressure. INJURY TO PERSONNEL AND DAMAGE TO THE VEHICLE COULD BE THE RESULT. PROTECT YOURSELF. USE THE MANUFACTURER' S SPECIFICATIONS WHEN YOU WORK ON THESE UNITS.

The manufacturer recommends that this unit not be rebuilt or overhauled. If the problem is in the booster, replace the booster.

2.6.1 Troubleshooting Air Brake Systems

The purpose of air braking systems is to enable the operator to apply sufficient braking action to the wheels of larger and heavier trucks and construction equipment (*Figure 11-8*). Considerable force is available for braking since the operating pressure is as high as 110 pounds per square inch. More often, stopping distances will be much greater than those shown in *Figure 11-1*, primarily because of the increased weight of the equipment and load.

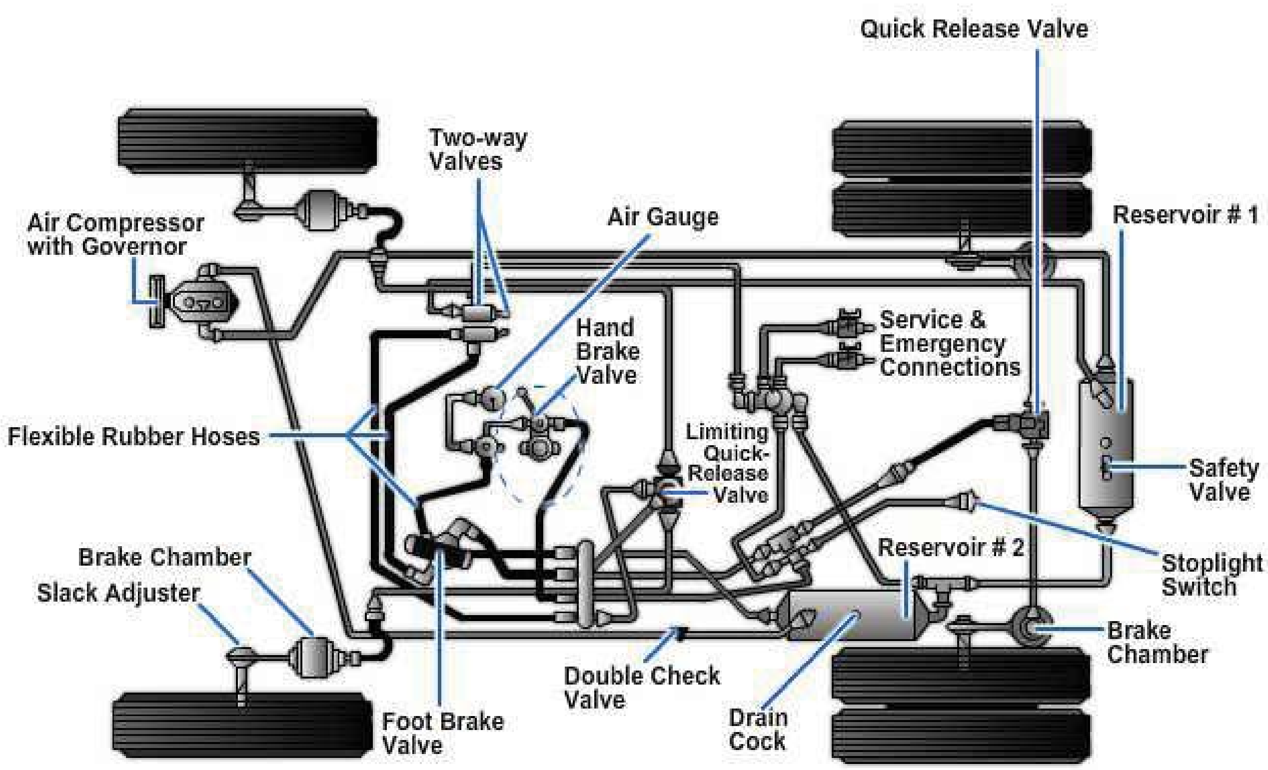

Figure 11-8 – Typical air brake system.

When you are troubleshooting, first make a visual inspection and check all the obvious things--open air drain cocks, off-track compressor belt, broken air lines, and so forth. Next, perform an air buildup test and an air leakage test.

Perform the air buildup test in the following sequence:

1. Before starting the engine, open the air drain cocks and release the air pressure from the system.
2. Close the air reservoir air drain cocks (*Figure 11-9*).
3. Start the engine and watch the air pressure gauge to see how long it takes to build up to safe operating pressure. If it takes longer than 10 minutes to bring the air pressure from 0 to 60 psi, check the system for leaks, and check the air compressor and relief valves.

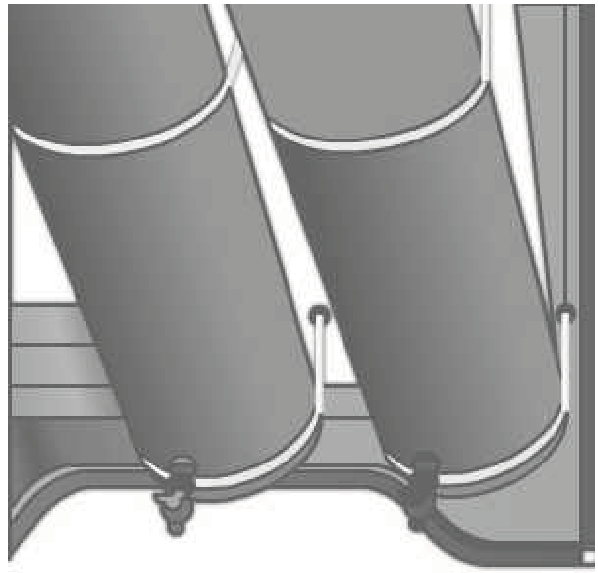

Figure 11-9 – Air reservoir with an air drain valve.

Conduct the air leakage test with the air brake system at normal operating pressure and the engine turned off. Hold the air brakes in the maximum applied position and watch the air pressure gauge on the dashboard of the vehicle. The air pressure should not drop more than 3 pounds in 1 minute after the brakes are applied and 2 pounds in 1 minute with the brakes released. If the indicated air pressure drops more rapidly than the times specified here, there is an air leak in the system. Trace the air lines to determine the exact source of the leak. Since air leaks normally make a distinct hissing sound, when you find the source of the noise, you have found the leak. Smaller leaks are not as audible and are harder to detect; however, you can detect these leaks by brushing the hose or tubing connections of the air brake system with a solution of soapy water. Air bubbles indicate a leak.

Air brakes on trailers get an external brake inspection as part of the inspetion required on a truck-trailer combination. They are also tested for holding as if the trailer were suddenly disconnected from the tractor. To conduct this test, first make sure the air lines between the tractor and trailer are coupled properly. Then, after you start the engine so both tractor and trailer air reservoirs are charged, quickly and simultaneously disconnect both air line couplings. The trailer or semitrailer brakes should be automatically applied. Trailer brakes are designed to stop the trailer when it is accidentally disconnected from the towing vehicle. All states require automatic application of trailer brakes in an emergency. Some states go even further for trailers having a chassis and body weight of 1,000 pounds or over; such trailers must be equipped with adequate brakes that will also hold the vehicle for at least 15 minutes after application.

If these inspections and tests do not disclose the fault, consult the troubleshooting chart of *Table 11-3*.

Table 11-3 - Air Brake System Troubleshooting Chart.

IMPROPER AIR PRESSURE	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Air pressure in system is above normal.	Check governor settings. Adjust air compressor unloading valves. Replace governor if necessary.
Air reservoir damaged.	Inspect air reservoir and replace if necessary.
CARRIER HAND BRAKE DOES NOT HOLD WHEN APPLIED	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Hand brake linkage out of adjustment.	Adjust linkage.
CARRIER HAS NO BRAKE ACTION, INSUFFICIENT ACTION, OR BRAKES APPLY SLOWLY	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Improper brake shoe adjustment.	Adjust brake shoes.
Blocked, bent, or broken tubing or hose.	Remove obstruction in line or replace faulty tubing.
Brake valve delivery pressure below normal.	If brake valve is defective, replace unit.
No air pressure.	Replace or repair air compressor.
BRAKES RELEASE TOO SLOWLY WITH PEDAL RELEASED	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Insufficient brake shoe clearance.	Adjust brake shoes if clearance is insufficient.
Weak or broken valve diaphragm return spring.	Replace brake valve.
Defective quick-release valve.	Replace quick-release valve.
ONE BRAKE DRAGS WTH PEDAL RELEASED	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Insufficient brake shoe clearance.	Adjust brake shoe clearance.
Blocked or defective quick-release valve.	Clean or replace faulty unit.
Weak or broken brake shoe return spring.	Replace faulty spring.
Brake shoe binds on anchor pin.	Remove shoe; clean and lubricate anchor pins.
BRAKES GRAB WHEN PEDAL IS DEPRESSED	
PROBABLE CAUSE	**POSSIBLE REMEDY**
Brake shoe clearance too great.	Adjust clearance.
Grease or oil on linings.	Clean linings or replace brake shoes or linings.
Drums out of round.	Replace drum.
Defective brake valve.	Replace faulty unit.
Brakes need relining.	Replace brake shoes.
Brake chamber diaphragm leaks.	Tighten all fittings. If caused by broken or faulty unit, replace brake chamber.

2.7.0 Air-over-Hydraulic

On vehicles equipped with air-over-hydraulic brakes (*Figure 11-10*), do a good visual inspection of the air compressor, the air reservoir, the air lines, the brake pedal and linkage, the wheel brakes, the master cylinder, and the hydraulic line from the master cylinder to the air-hydraulic power cylinder and from the air-hydraulic power cylinder to the wheel brakes.

Operating troubles resulting from malfunction of the air-over-hydraulic power cylinder are hard pedal (excessive pedal pressure required to apply the brakes) and dragging brakes (power cylinder fails to return to released position when the brake pedal is released).

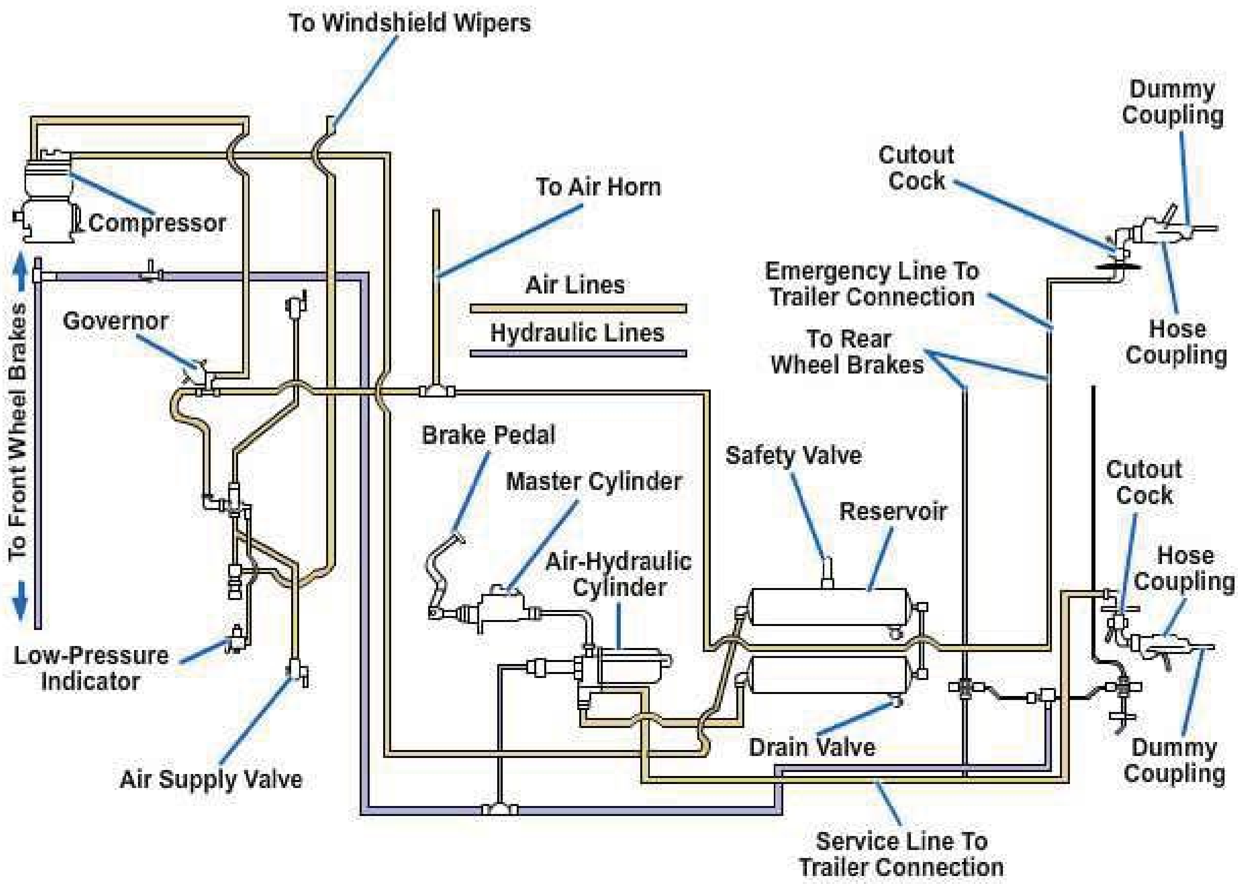

Figure 11-10 - Air-over-hydraulic brake system.

To test a sluggish or inoperative power cylinder, first install an air pressure gauge in the control valve housing and a hydraulic gauge at both the hydraulic fluid inlet line and the hydraulic brake line output port. Then slowly depress the brake pedal and observe the gauges. When the air control pressure gauge shows between 1 and 5 psi, the hydraulic pressure at the hydraulic inlet should not exceed 40 psi. Excessive hydraulic pressure indicates a sticking relay piston (caused by swollen or damaged piston scaling cups or a corroded or damaged relay piston sleeve) or sticking control valve poppets (caused by corrosion of the poppets, poppet seats, or damaged poppets).

With the brake pedal completely depressed in the fully applied position, the air control pressure gauge should show 90 psi and the hydraulic output pressure gauge should show full power (runout) pressure of 1,400 to 1,600 psi. Low pressure or no pressure on the air pressure gauge indicates air leakage or an inoperative control valve. Low hydraulic output pressure indicates hydraulic fluid leakage, a sticking hydraulic piston, or an inoperative check valve (in the hydraulic piston), or a residual line check valve.

To test for internal and external air leakage or hydraulic leakage, fast depress the brake pedal and apply soapsuds at the air control line and its connections, the double check valve (if so equipped), and the cylinder body and end plate. Bubbles appearing at any of these points indicate external air leaks. While the pedal is depressed, check for hydraulic fluid leakage at the outlet fitting cap and around the jam nut on the slave cylinder housing. Internal air leakage is indicated by a pressure drop in excess of 2 psi in 15 seconds. The trouble is a worn or damaged piston packing, a scored cylinder body, or leakage at the poppets in the control valve. Internal hydraulic pressure leakage can also be indicated by hydraulic pressure drop at both hydraulic pressure gauges while the brake pedal is depressed.

Dragging brakes can be tested by releasing the brake pedal and observing the air pressure gauge and the two hydraulic pressure gauges. All gauges should register zero without lagging. When pressure is noted at the air pressure gauge, a sticking relay piston, damaged or corroded control valve poppet, or a ruptured control valve diaphragm exists. Pressure at the hydraulic pressure gauges indicates a sticking hydraulic piston, a sticking power piston, or a weak or broken piston return spring. If the hydraulic pressure gauges show a slow pressure drop, it indicates a defective check valve (in the hydraulic piston) or a defective residual line check valve.

If the tests indicate external air leakage, tighten the control line connections, and/or replace a damaged control line or control line gasket, or double check the valve. For internal air leakage you must remove the unit to replace worn or damaged power piston packing or end plate gasket, and repair or replace the cylinder body or end plate.

If the tests indicate hydraulic fluid leakage, an inoperative control valve, sticking power piston, relay piston, or hydraulic piston, remove the unit for disassembly and repair or replace the worn or damaged parts.

2.8.0 Parking/Emergency Brakes

Serviceable parking/emergency brakes are essential to the safe operation of any piece of automotive or construction equipment. Several types of these brakes are manufactured, such as the external contraction, drum, and disk types (*Figure 11-11*). These are drive line brakes common to heavy construction equipment, and are usually mounted on the output shaft of the transmission or transfer case directly in the drive line. Theoretically, this type of system is preferred for heavy equipment because the braking force is multiplied through the drive line by the final drive ratio, and the braking action is equalized perfectly through the differential. Drawbacks are that severe

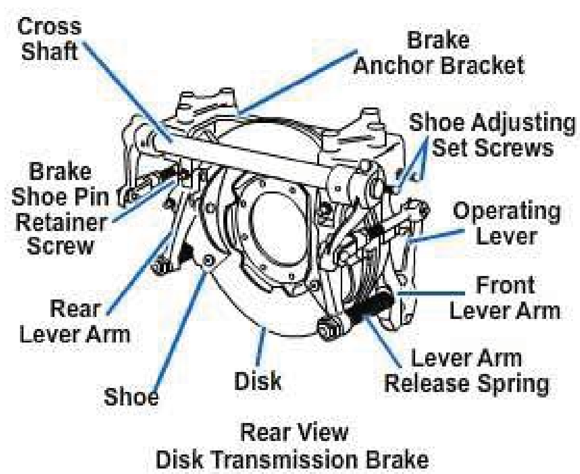

Figure 11-11 - Transmission mounted emergency/parking brake.

strain is placed on the power transmission system, and also that the vehicle may move while it is being lifted since the differential is not locked out.

Parking brakes interconnected with service brakes are usually found on automotive types of equipment (*Figure 11-12*). This type of emergency/parking brake is actuated by a foot pedal or a dash mounted handle assembly, and is connected through linkage to an equalizer lever (*Figure 11-13*), rod assembly, and cables connected to the emergency/parking brake mechanism within the drums/discs at the rear wheels.

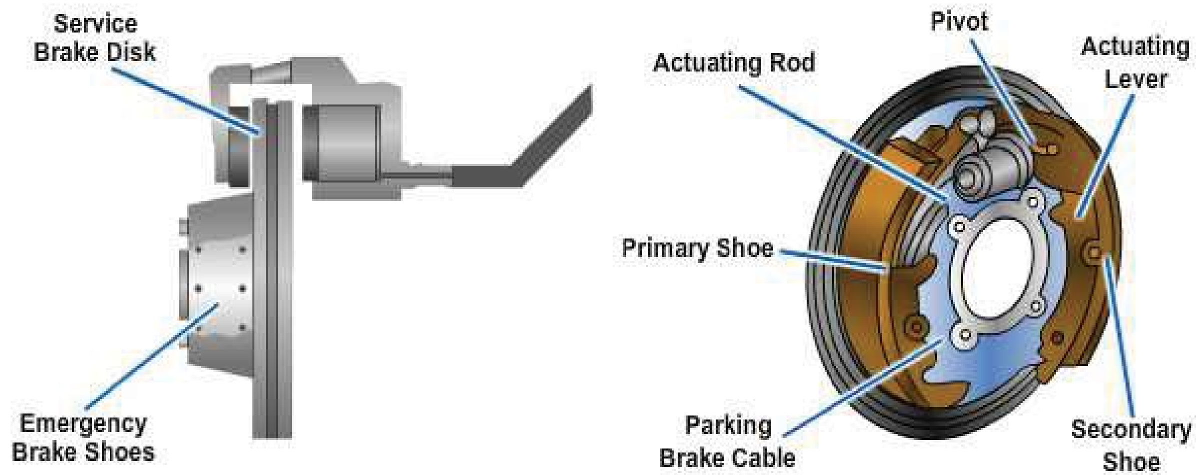

Figure 11-12 - Automotive parking/emergency brake.

When you test parking brakes, stop the vehicle on a road graded at about 30 percent. Set the parking brake and release the service brakes. The vehicle should maintain its position and not roll or inch backwards. Repeat the test in the opposite direction. Again, the vehicle should hold its position. If there is no hill close by, you may test parking brakes by setting the brake, placing the vehicle in first gear (low), and slowly releasing the clutch with the engine idling (do not rev the engine while doing this exercise). This action should stall the engine of the vehicle you are testing. In the case of an automatic transmission, the vehicle should not move in any gear. In either of these tests, if the vehicle does move, it is an indication that there is a parking brake malfunction.

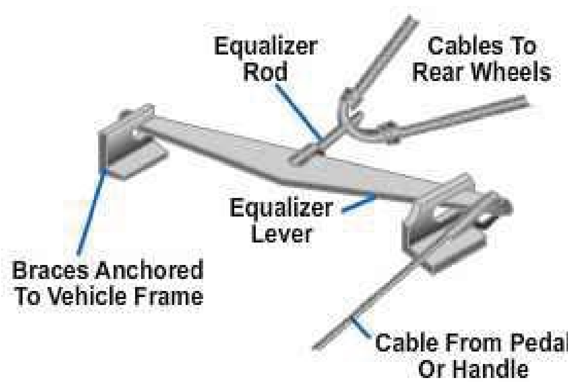

Figure 11-13 - Equalizer linkage.

Once you determine there is a problem, proceed as follows. First, inspect the condition of the emergency brake linings and contact surfaces just as you would for service brakes and just as carefully. Pay attention to the ratchet and pawl or any other automatic locking device that holds the brake in the applied position to make sure it is operating properly. In addition, when inspecting the drive line type brake, examine the universal joints and splines for loose bolts and grease leaks. Loose bolts are not uncommon for vehicles having brakes mounted in the drive line.

The emergency brake must hold the vehicle on any grade. This requirement covers both passenger and commercial motor vehicles equipped with either the enclosed type of emergency brake at each rear wheel or a single emergency brake mounted on the drive line. The Federal Motor Carrier Safety Regulations Pocketbook lists emergency brake requirements.

2.8.1 lti Wheeled Vehicle (HMMWV)

The HMMWV has one of two types of parking brakes. It is equipped with either a single parking brake assembly or a left and right parking/service brake. They need to be inspected semi-annually, and you must replace the pads when they are 1/8 inch in thickness or less.

On versions equipped with the single parking brake assembly, the system works much like the ones discussed earlier that are located on the transmission shaft. There is a separate parking brake located between the rear driveshaft and the rear differential. The pads are squeezed against the rotor when the hand brake is applied.

On versions that have a service/parking brake in one system, the parking brake is applied through a mechanical linkage when the parking brake lever is set.

CAUTION

Use MIL-B-46176 Silicone Brake Fluid (BFS) for filling master brake cylinder. Failure to use BFS will cause damage to brake cylinder.

2.8.2 Maxi Brakes Systems Dual Chamber

Vehicles that operate air brake systems have a different type of parking brake. The dual chamber air brake system also uses a spring inside the chamber. This spring is held off with air pressure. When air pressure is applied, the diaphragm pushes the spring back and releases the brakes. When there is a decrease of air pressure, the spring takes over and pushes against the brakes locking the wheel.

Test your Knowledge (Select the Correct Response)

2. A standard power booster will not work with a diesel engine for which reason?

   A. Not enough usable vacuum is created.
   B. Too high a vacuum is created.
   C. Low volume vacuum is created.
   D. Vacuum pressure created exceeds safe operating values.

3.1.1 ANTI-LOCK BRAKES

The first anti-lock brake systems (ABSs) were developed and used in aircraft in the early 1950s. Certain automobiles had the systems in the experimental stages in the mid 1950s and in the production stages in the early 1970s. The ABSs are common today in many production cars and trucks.

Why we use ABS is simple, CONTROL. A high percentage of vehicle accidents on the highway are caused by skidding. Since braking is most effective and steering is not lost when the wheels are still rotating, the anti-lock brake system prevents skidding by allowing the wheels to continue turning during maximum braking effort. On wet pavement, hydroplaning of the tires is cut to a minimum. One final benefit is that of extended tire wear by the elimination of flat spots caused by brake lockup during panic stops.

All ABS (either two wheel or four wheel) operate on the same principle, that is, the system is monitored by an electronic control module for the rate of reduction of vehicle wheel speed during brake system operation. If the system feels that lockup is about to occur at one or more wheels, modulated hydraulic pressure is fed to that brake caliper by a hydraulic control unit or an electro-hydraulic valve. In this way, even if hydraulic pressure is not the same at each wheel, maximum tire adhesion to the road surface is maintained. Once again, the way the modulated hydraulic pressure is maintained is different with each manufacturer. Before going any further, get a copy of the manufacturer's maintenance and repair manual of the vehicle that you are working on.

While these systems are not yet common in the Naval Construction Force, the first equipment you are most likely to see the system used on is automotive type CESE. Very little should malfunction on the system. If the ABS is in need of repair, you should take the following precautions before working on it:

1. Repressurize the system before attempting to make repairs.
2. Do not work on an anti-lock brake system with the ignition turned on. (Damage to the system computer can result.)
3. Do not substitute parts. Use parts that are approved for the system you are working on.
4. Keep the correct size tires on your vehicle. Mismatched tire sizes will give the computer false readings.
5. Check the speed sensors for cleanliness. A dirty speed sensor will give the computer a false or zero reading.
6. Wheel lugs must be torqued to the correct foot pounds and in proper sequence. Your failure to do so may distort the wheel and sensor, thus sending incorrect readings to the anti-lock brake system computer.
7. An incorrect air gap on the wheel sensors will lead to false input to the anti-lock brake system computer.
8. DO NOT USE SILICONE BRAKE FLUID in a vehicle equipped with an anti-lock brake system.
9. If electric arc welding must be done to the vehicle you are working on, disconnect the anti-lock brake system computer first.
10. A low battery caused by a faulty charging system will cause the anti-lock brake system to malfunction.
11. Antennas for transmitting-type radios should not be located near the computer of anti-lock brake system.

CAUTION

Using an improper test method on these systems can lead to damage to the system or personal injury to yourself or to the personnel working for you.

CAUTION

All anti-lock brake systems have special system bleeding instructions. Your failure to follow these instructions will lead to an inoperative or a faulty system.

For further reading concerning anti-lock braking systems, consult the manufacturer's service and repair manual of the vehicle you are working on.

Summary

In this chapter you learned how to inspect hydraulic, power, and air brake systems. In addition, you learned troubleshooting techniques for those systems as well as some safety protocols. The ability to stop a vehicle that is heavy or moving at great speeds is one of the most important responsibilities of a construction mechanic. After all, there is no known way to measure how many lives you can save by possessing this unique ability. When you have mastered the knowledge of these systems, you will become a better CM.

Review Questions (Select the Correct Response)

1. Under what circumstances would copper tubing be used in a brake system?

   A. Under no circumstance
   B. For use on augment equipment only
   C. For use on construction equipment only
   D. For use on equipment power brakes

2. When testing for leakage in a hydraulic brake system, you must depress and hold the brake pedal for at least how many minutes?

   A. 1
   B. 2
   C. 4
   D. 5

3. NFELC maintenance bulletin #75 directs the Naval Construction Force to use which fluid or materials?

   A. Glycol brake fluid
   B. Silicone brake fluid
   C. Non-asbestos brake pads
   D. Metalic brake pads

4. **(True or False)** Brake drums that have been worn or machined past their discard diameter or thickness must not be used.

   A. True
   B. False

5. Which condition could indicate brake problems where none, in fact, exist?

   A. Loose wheel bearings
   B. Worn front end parts
   C. Low tire pressure
   D. All of the above

6. Which statement provides a good description of pedal reserve?

   A. Full travel of the brake pedal
   B. 1/4 travel of the brake pedal
   C. 1/2 travel of the brake pedal
   D. Distance from the pedal to the floorboard with the brakes applied

7. Both rear brakes may drag as a result of which problem?

   A. Frozen emergency brake cable
   B. Over-full master cylinder
   C. Jammed wheel cylinder
   D. Broken emergency brake cable

8. A brake drum that is cut too thin will cause which problem?

   A. No brakes
   B. Soft brake pedal
   C. Pulsating brake pedal
   D. Hard brake pedal

9. After completing repairs to a brake system, you should take which action first?

   A. Close out the ERO.
   B. Road test the vehicle.
   C. Reset the brake failure warning light.
   D. Fill the system with approved brake fluid

10. On a power brake system with a vacuum booster, if the air valve sticks, what will happen?

   A. Brakes will fail to release.
   B. Slow braking application will occur.
   C. Brakes will not function at all.
   D. Nothing

11. In a brake system that uses a vacuum booster, a hard pedal could indicate which situation?

   A. Normal brakes
   B. Internal damage to the vacuum booster
   C. Worn brake linings
   D. Worn brake rotors

12. In a brake system using a vacuum booster, a hydraulic leak may not be seen for which reason?

   A. Brake fluid evaporates.
   B. Fluid is drawn into the intake manifold and burned in the engine.
   C. Brake fluid collects in the power booster.
   D. Both B and C

13. On a vehicle using a hydroboost power brake system, hydraulic pressure is created by which means?

   A. Separate hydraulic pump
   B. Power steering pump
   C. Power boost cylinder
   D. Power boost pump

14. In the event of a hydroboost power brake system failure, the spring-loaded accumulator will provide for a total of how many power brake applications?

    A. 2
    B. 3
    C. 4
    D. 5

15. When the power steering belt breaks in a hydroboost power brake system, which situation will occur?

    A. There will be no braking action.
    B. A high pedal effort will be felt.
    C. A soft pedal effort will be felt.
    D. The pedal will travel to the floor.

16. Excessive noise in a hydroboost power brake system could be caused by which problem?

    A. Air in the system
    B. Loose fan belt
    C. Loose power steering belt
    D. Wrong fluid in the system

17. What is the normal accumulator pressure of a hydroboost power brake system, in psi?

    A. 600
    B. 1,000
    C. 1,400
    D. 1,800

18. The stopping distance of construction equipment and heavy trucks is greater due to which factor?

    A. Increased weight of the equipment
    B. Increased payload weight
    C. Increased length of the equipment
    D. Both A and B

19. An air brake system should build up to safe operating pressure in what maximum number of minutes?

    A. 5
    B. 7
    C. 10
    D. 12

20. You should check for inaudible air leaks by which means?

    A. Your hand
    B. Soapy water and a brush while watching for bubbles
    C. Light oil and a brush while watching for bubbles
    D. Leak detector

21. The automatic application trailer brakes must hold a vehicle for how many minutes?

    A. 5
    B. 10
    C. 15
    D. 20

22. In an air-over-hydraulic power braking cylinder, excessive hydraulic pressure would likely be caused by which part?

    A. Damaged relay piston sleeve
    B. Swollen piston sealing cups
    C. Sticking relay piston
    D. Worn brake components

23. In an air-over-hydraulic power braking cylinder, internal air leakage is considered excessive if there is a pressure drop of 2 psi in what number of seconds?

    A. 10
    B. 15
    C. 20
    D. 25

24. On construction equipment, the drive line brakes are usually mounted in which location?

    A. Parking pawl located inside the transmission case
    B. Directly on the drive line
    C. On the wheel
    D. None of the above

25. When compared to an emergency braking system that is interconnected with the rear service brakes, a drive line emergency braking system has greater holding power for what reason?

    A. Larger brake shoes
    B. Multiplication of the braking force through the final drive system
    C. Use of a disc brake system
    D. Combination of A and C

26. A parking brake that is interconnected with the service brake is usually found on what type of equipment?

A. Construction
B. Automotive
C. MHE
D. Augment

Trade Terms Introduced In This Chapter

Chattering brakes	A metallic sound made when pressure is exerted upon the braking mechanism.
Spongy brakes	The feeling of the brake pedal when a force is applied to the brake pedal resulting in a soft feeling felt in the operator's foot.
Grabbing brakes	When force is applied to the brake pedal, the brake shoes/pads will lock up or try to lock the wheel for a short period of time.
Pedal reserve	The distance between the brake pedal and the floor board when the brakes are applied.
Dragging brakes	When the wheel is prevented from turning without resistance due to the brakes engaging with the drum or rotor.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Heavy Duty Truck Systems 4th Edition, Sean Bennet, Delmar Cengage Learning, 2006. (ISBN-13:978-1-4018-7064-5)

Modern Automotive Technology 7th Edition, James Duffy, The Goodheart-Wilcox Company, Inc., 2009. (ISBN: 978-1-59070-956-6)

Automatic Transmissions and Transaxles, James Duffy, The Goodheart-Wilcox Company, Inc., 2005. (ISBN: 1-59070-426-6)

Manual Drive Trains and Axles, Chris Johanson, James Duffy, The Goodheart-Wilcox Company, Inc., 2004. (ISBN: 1-59070-320-0)

Power trains, Fundamentals of Service, Deere and Company, John Deere Inc., 2005. (ISBN: 0-86691-325-4)

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Chapter 12

Air Compressor Overhaul

Topics

1.0.0 Types of Air Compressors

2.0.0 Components of Compressors

3.0.0 Air Compressor Troubleshooting

4.0.0 Air Compressor Overhaul

To hear audio, click on the box.

Overview

Part of your job as a Construction Mechanic is to maintain and repair air compressors. Air compressors range from small reciprocating brake units to systems that are so large they require their own trailer. You will need to understand how air compressors function before you can become a competent troubleshooter. This chapter gives you the foundation to recognize problems and repair them. Your knowledge in this area is essential to the successful completion of a job or unit mission.

This chapter introduces you to the fundamental operating principles, parts, and maintenance of air compressors, and operating problems that you may experience.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify types of air compressors.
2. Identify components on compressors.
3. Understand how to troubleshoot air compressors.
4. Understand how to overhaul air compressors.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air Conditioning Systems		CM ADVANCED
Air Compressor Overhaul		
Inspecting and Troubleshooting Brake Systems		
Hydraulic Systems		
Wheel and Track Alignment		
Troubleshooting Transmissions, Transfer Cases and Differentials		
Clutches and Automatic Transmissions		
Troubleshooting Electrical Systems		
Fuel System Overhaul		
Engine Troubleshooting and Overhaul		
The Shop Inspectors		
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

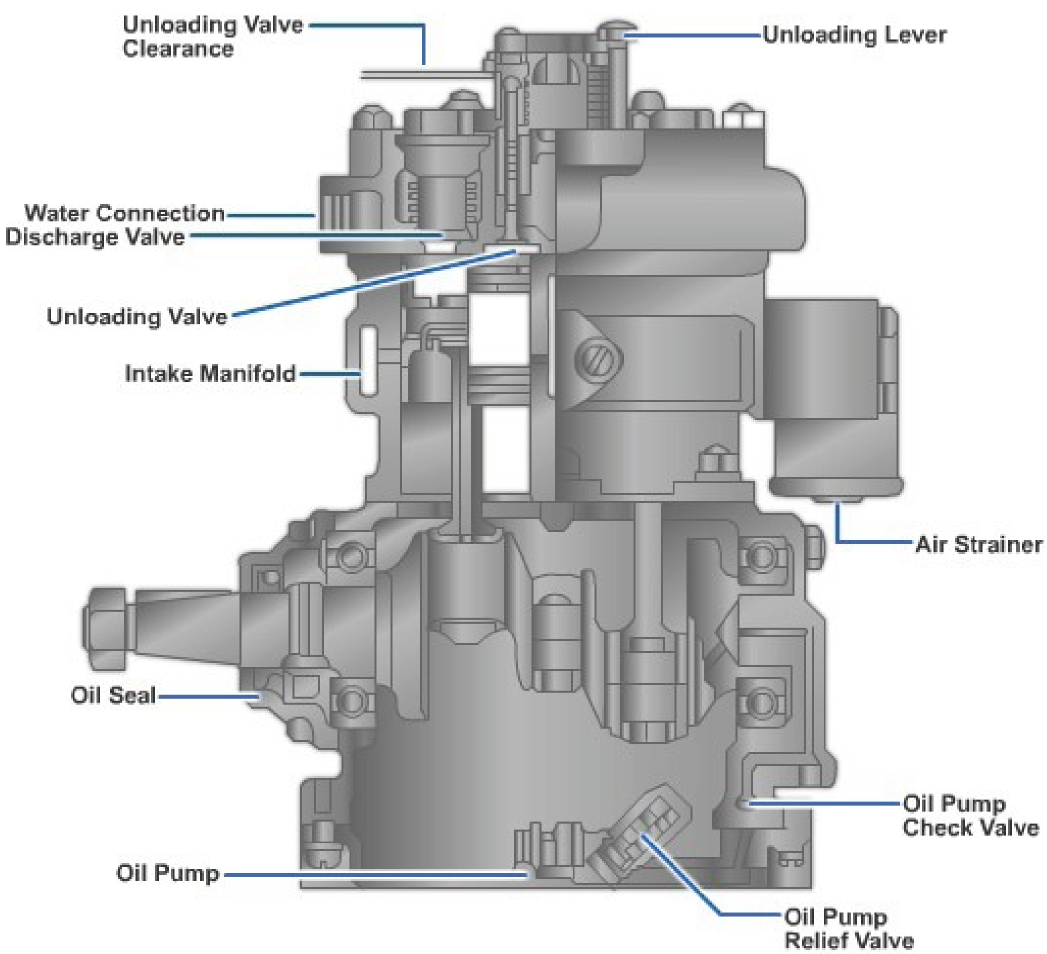
- Figure and table numbers in the text are italicized. The Figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the

information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 TYPES of AIR COMPRESSORS

Positive displacement air compressors are used throughout the Naval Construction Force (NCF). They supply compressed air for numerous pneumatic tools, rock drilling, well drilling, diving, cleaning operations, and air-brake systems (*Figure 12-1*). In air brake systems the compressor may be smaller than others described in this chapter, but the operating principles are the same.

There are two basic types of positive displacement compressors. In one, air is compressed as the volume of the enclosed space is reduced. In the other, a definite quantity of air is trapped and transferred from the suction intake to the discharge port without reducing its volume. Pressure increase is caused by backflow into the casing when the discharge port is uncovered. Examples of the first type are reciprocating compressors, rotary sliding vane compressors, and rotary liquid piston compressors. An example of the second type is the rotary twin-lobe compressor. In this chapter, we will discuss troubleshooting and overhaul of air compressors and their related controls.

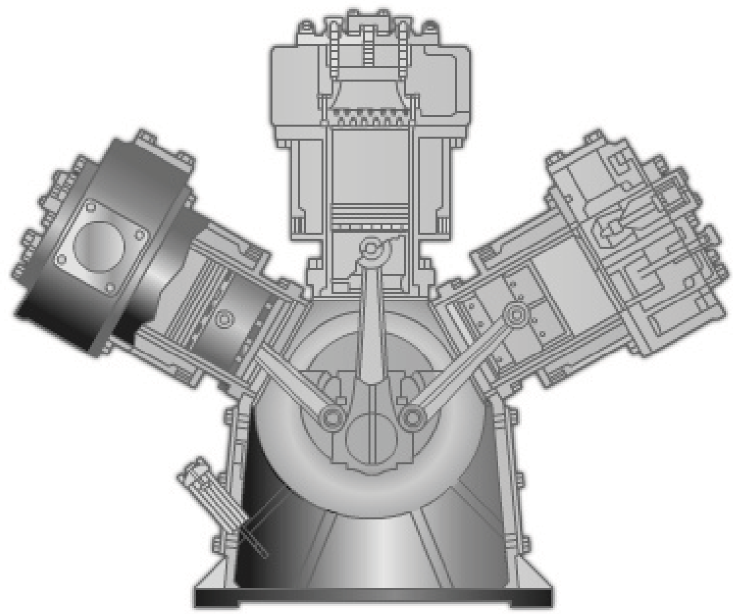


Figureure 12-1 - Air brake compressor.

Of the two different types of positive displacement compressors, we will focus our attention on the type that reduces the enclosed air space. There are three main types: reciprocating, sliding vane, and screw design. The driving unit provides power to operate the air compressor and is usually a diesel engine but can also be electric. Air compressors may be air or liquid-cooled. The compressors used by the NCF are almost identical to those used in private industry. The difference is not in the compressor, but in the trailer. For example, a Sullair 750 cfm 250 psi unit is carried on a specially modified trailer. This allows the unit to be loaded on an aircraft for detachment exercises and other contingency purposes.

1.1.0 Reciprocating Compressor

Reciprocating air compressors are manufactured in a variety of shapes, sizes, and capacities. Single-stage machines draw air from the atmosphere and discharge it into the receiver or storage tank. Two-stage compressors bring the air up to intermediate pressure in one cylinder and to final pressure in a second cylinder. Where two or more stages are used, the unit is defined as a multistage air compressor (*Figure 12-2*). Multistage compressors produce higher discharge pressures. Stationary air compressors are usually water-cooled, with the exception of small units that are air-cooled. Portable units are also usually air-cooled. Air-cooled compressors utilize finned cylinders to increase the heat exchange area. Compressor drives include electric motors, or internal combustion engines. Drives may be direct connected, connected through reduction gears, or belt connected.

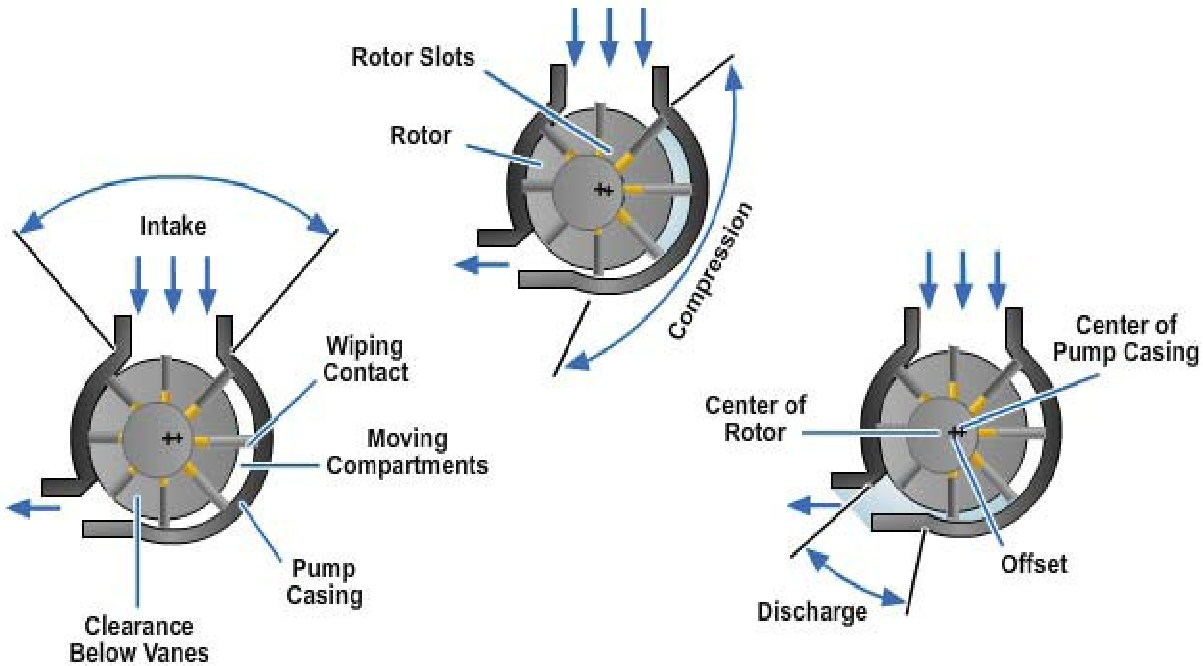


Figureure 12-2 - Multi stage compressor.

At the top of the air compressor's cylinder, you will find a valve head that holds the inlet and discharge valves. Both are simple, thin metal flaps, one mounted underneath and one mounted on top of the valve plate. As the piston moves down, a vacuum is created above it. This allows outside air at atmospheric pressure to push open the inlet valve and fill the area above the piston. As the piston moves up, the air above it compresses, holds the inlet valve shut, and pushes the discharge valve open. The air moves from the discharge port to the tank. With each stroke, more air enters the tank and the pressure rises. The reciprocating compressor is most likely to be found at public works stations, in a shop supplying air for industrial use, or under the hood of CESE with air actuated brakes.

1.2.0 Sliding Vane (Rotary) Compressor

Rotary sliding vane compressors such as reciprocating and rotary screw compressors are positive displacement compressors. The compressor pump consists primarily of a rotor, stator, and multiple blades. The slotted rotor is eccentrically arranged within the stator providing a crescent-shaped, swept area between the intake and exhaust ports. As the rotor turns a single revolution, compression is achieved as the volume goes from a maximum at the intake ports to a minimum at the exhaust port. The vanes slide outward from the rotor slots, and are held against the stator wall by rotational acceleration (*Figure 12-3*). Oil is injected into the air intake and along the stator walls to cool the air, lubricate the bearings and vanes, and provide a seal between the vanes and the stator wall. After the compression cycle, the oil and air must be separated before the air can be transferred to the air system.



Figureure 12-3 - Rotation of sliding vanes.

1.3.0 Screw Type of Compressor

Screw type air compressors are positive displacement compressors. They come in single or multiples stage configurations with and without oil. The most common screw air compressor is the single-stage helical or spiral lobe oil flooded screw air compressor. These compressors consist of two rotors within a casing where the rotors compress the air internally (*Figure 12-4*). As the screws rotate, air is trapped between the male and female lobes and compressed, as the air is forced into a smaller area and finally discharged at the end tof the screw (*Figure 12-5*). There are no valves. These units are oil cooled (with air or water-cooled oil coolers) where the oil seals the internal clearances. Since the cooling takes place right inside the compressor, the working parts never experience extreme operating temperatures. The rotary compressor, therefore, is a continuous duty, air-cooled or water-cooled compressor. Because of the simple design and few wearing parts, rotary screw air compressors are easy to maintain and operate, and provide great installation flexibility.

Figure 12-4 - Screw type compressor.

The two-stage oil flooded rotary screw air compressor uses pairs of rotors in a combined air end assembly. Compression is shared between the first and second stages, flowing in series. This increases the overall compression efficiency up to fifteen percent of the total full-load kilowatt consumption. The two-stage rotary air compressor combines the simplicity and flexibility of a rotary screw compressor with the energy efficiency of a two-stage, double-acting reciprocating air compressor. Two-stage rotary

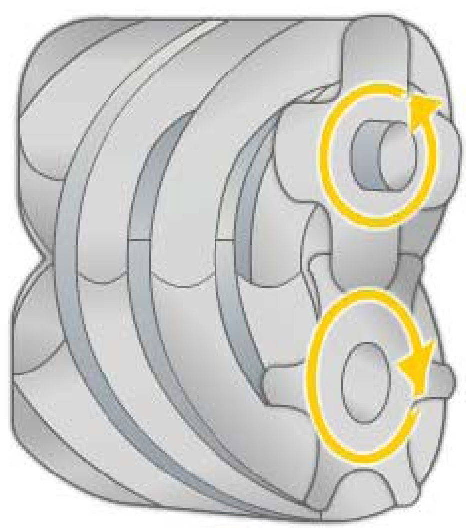


Figure 12-5 - Compression cycle.

screw air compressors are either air-cooled or water-cooled.

There is a wide range of availability in configuration and in pressure and capacity. Compressor oil is injected into the twin-bore cylinder and picked up by the mating rotors. The oil serves to seal the rotor surfaces and to cool the air in its compression stages. The oil that mixes with the air during compression is passed into a receiver separator, where it is removed and returned to the oil sump.

The oil-free rotary screw air compressor utilizes specially designed air ends to compress air without oil in the compression chamber, yielding true oil-free air. Oil-free rotary screw air compressors are available either air cooled or water cooled and provide the same flexibility as oil-flooded rotaries when oil-free air is required.

2.0.0 COMPONENTS of COMPRESSORS

Air compressors consist of basic systems and components such as the air filter, the air control system, the compressing element, and the air receiver and lubrication systems. Other components are safety devices, cooling systems, and air/oil separators. These systems and components allow the air compressor to perform its designed function efficiently and safely. The following sections detail the purpose of these different components and systems, and their relationship to efficient air compression.

2.1.0 Safety Devices of Compressors

Air compressors have automatic safety control devices that shut the unit down in the event of a mechanical malfunction.

CAUTION

Safety devices on air compression systems are not to be bypassed for any reason.

Engine overspeeding, overheating, low oil pressure, and low or high fuel pressure are all reasons for the prime mover to be shut down. These safety devices are placed on the power source to protect it. On the compressor, a pressure release (safety relief) valve (*Figure 12-6*) releases excess air pressure to protect personnel, the compressor, air receivers, and piping from damage if the air pressure exceeds the design limits. The safety valve is mounted in plain view on the air receiver and is normally set at 125 psi (special-duty air compressors may have different psi settings). The pressure settings may be stamped on tags and wired to the valve.

Figure 12-6 – Pressure valve.

CAUTION

Do not remove the pressure setting tags.

Air discharge temperatures of 220°F to 250°F (temperature ratings vary by manufacturer) will cause the engine to shut down automatically. Restart should not be attempted until the oil has cooled and a thorough inspection has been done to determine the cause of the shutdown. This switch is located on the intercooler (two-stage units) or on the aftercooler (single-stage and two-stage units). Your repair manual will show the exact locations.

Check safety controls periodically to be sure they are functioning properly. Check them according to the manufacturer's specifications.

2.2.0 Pressure Control System

A pressure control device governs air compressors. In a reciprocating compressor, the pressure control system causes the suction valves to remain open and the engine to idle when the air pressure reaches a set maximum. The discharge valve then acts as a check valve and air is trapped in the receiver at maximum required pressure. With the suction valve held open by receiver air pressure, the compressor cannot function (if it did, it would raise the receiver pressure above the design pressure and blow the safety valve). At the same time, receiver air pressure is fed to a speed control unit that returns the power source to idle (if the power source is an electric motor, the motor is shut off). As the air pressure in the receiver drops below the set minimum, the pressure control unit causes the engine to increase speed, the suction valves to close, and the compression cycle to resume.

The rotary type of air compressors control pressure by using a pneumatic, mechanical system (*Figure 12-7*) to select proper engine speed and air intake to suit demand. The air intake control is modulated by receiver air pressure, depending on the need for air. When the engine slows to idle as a result of low demand, the air intake valve closes to lessen the amount of free air entering the compressor, first by slowing, then by stopping the compression cycle. As the air pressure in the air receiver drops, it causes the control system to open the air intake valve and to apply the throttle at the same time, but only enough to return the receiver air pressure to its maximum limit.

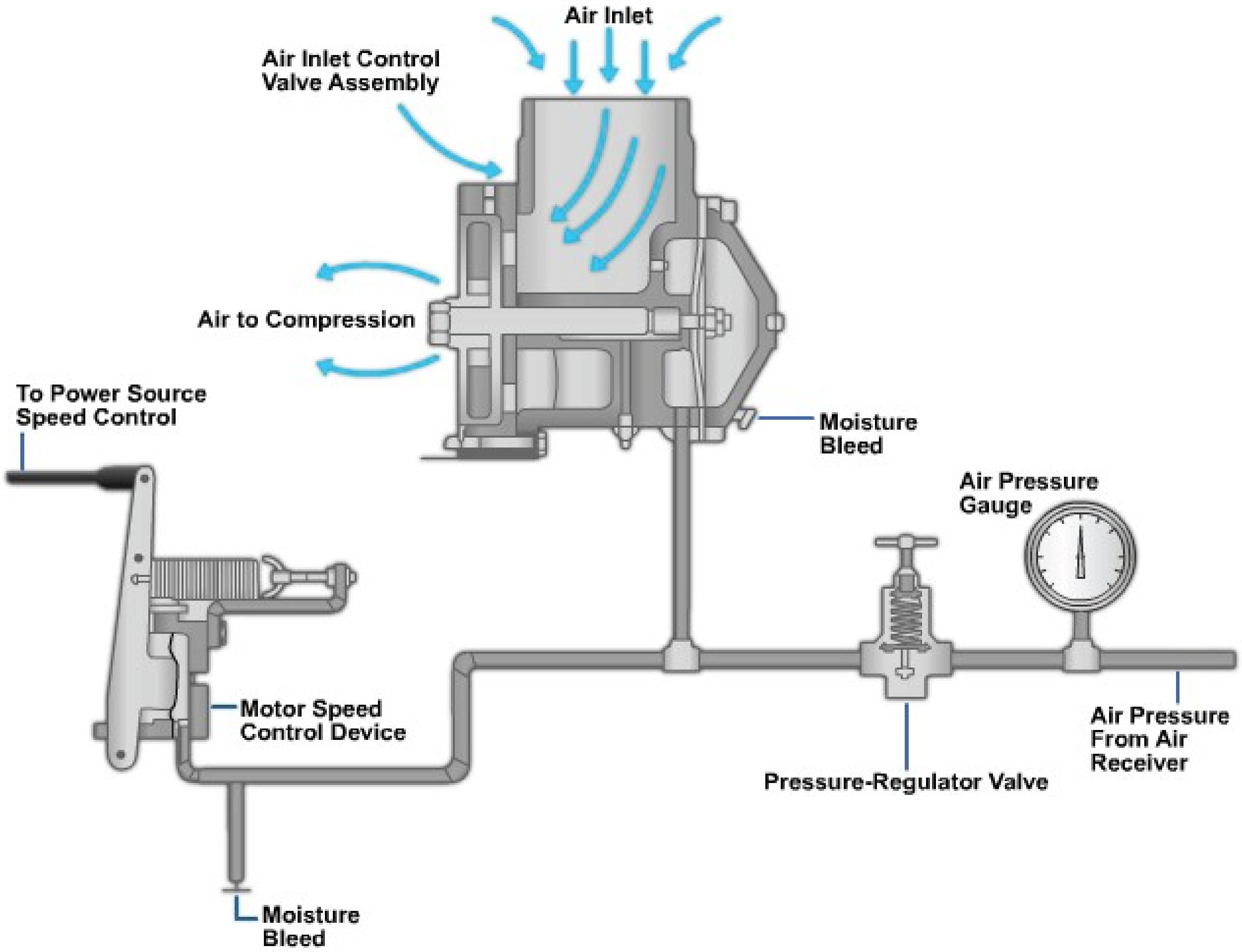


Figure 12-7 - Rotary vane pressure control system.

The screw type of compressor uses a pressure control system similar to that of the rotary compressor as it varies engine speed and air intake opening to meet the demand for compressed air.

Because of the great variety of throttle control and pressure-regulating devices used with compressors, detailed instructions on their adjustment and maintenance should be obtained from the manufacturer's maintenance and repair manual. When a control valve fails to work properly, disassembly and a thorough cleaning are necessary. Some control valves are fitted with filters filled with sponge or woolen yarn to prevent dust and grit from entering into the valve chamber and to remove gummy deposits that come from the oil used in the compressor cylinders. Replace the filter with the specified material each time a valve is serviced.

2.3.0 Air Intake System

Air cleaners protect air compressors against ingestion of dust and foreign particles. These may be oil bath or dry-filter type. The filtration system maybe a single filter serving both the power source and the air compressor, or each unit may have an individual filter. Larger air compressors working in dirty conditions may use a two-stage system (*Figure. 12-8*). In most cases, the filters are the same as those used on automotive and construction equipment engines, just larger.

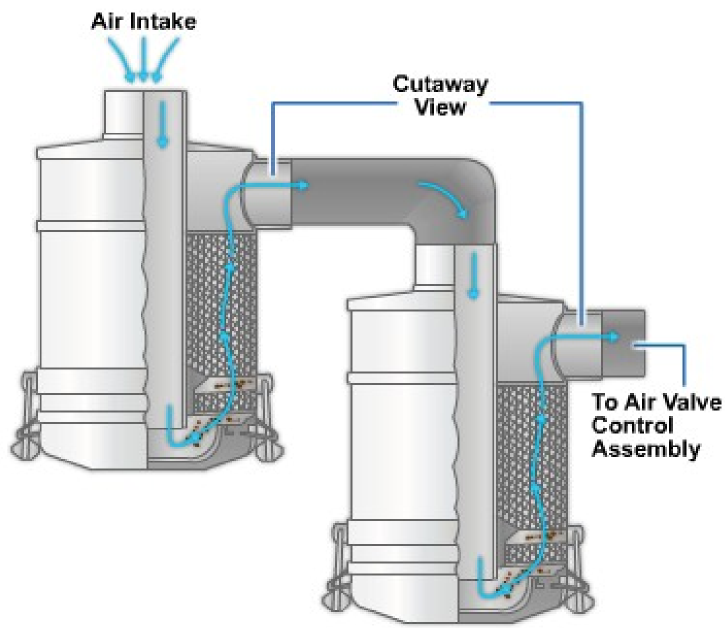


Figure 12-8 – Two stage air filtration.

The effect of intake air on compressor performance should not be underestimated. Intake air that is contaminated or hot can impair compressor performance and result in excess energy and maintenance costs. If moisture, dust, or other contaminants are present in the intake air, such contaminants can build up on the internal components of the compressor, such as valves, impellers, rotors, and vanes. Such build-up can cause premature wear and reduce compressor capacity.

Replace or clean air filters in accordance with the manufacture's recommendations. Oil bath air filter cleaning instructions are in the applicable maintenance and repair manual. Oil bath air filters are no longer common. The dry-type filter also requires servicing. Before cleaning, check the filter for damage that would require replacement, such as broken gaskets or dents that prevent sealing. One way to clean the filter is to use low-pressure air, to blow the debris trapped in the filter against the direction of airflow from the inside to the outside (*Figure. 12-9*). Never exceed pressures of 30 psi when using this method of cleaning, and never use this method of cleaning more than six times on the same filter. Another way you may clean the filter is to wash it with water and a mild detergent (*Figure. 12-10*). This is useful if compressed air is unavailable or if the filter is clogged with grease or oily dirt. When you are using water, do not exceed water pressures of 40 psi.

WARNING

Only use the manufacturers' recommended cleaning solutions to clean the filter.

Dry the filter and hold a bright light on the inside of it. Remember, concentrated light shining through the filter element indicates holes that require replacement of the filter. Following service to the air cleaning system, check and reset the air restriction indicator if required.

Figure 12-9 – Low pressure air filter cleaning.

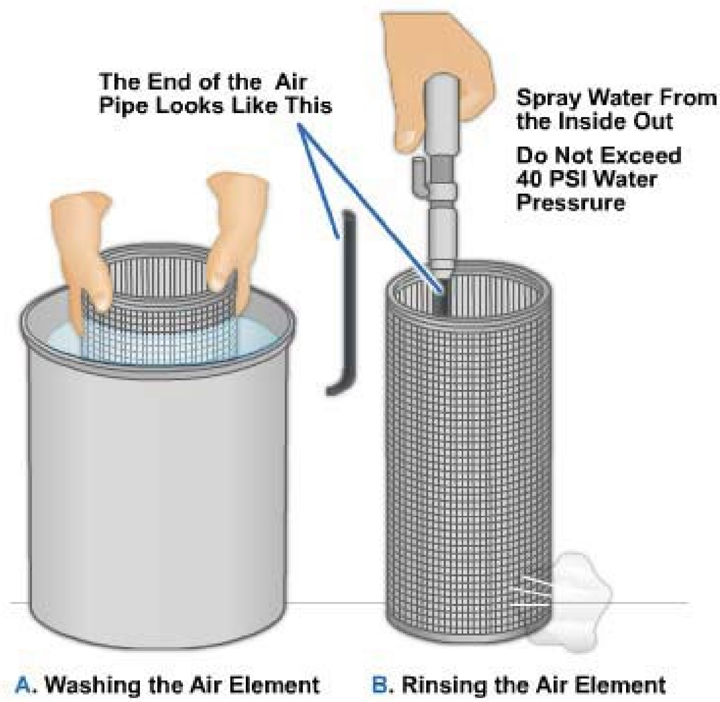


Figure 12-10 – Soap and water air filter cleaning.

2.4.0 The Air Receiver

The air receiver is a welded steel tank installed on the discharge side of the compressor. The air receiver dampens pulsations that enter the discharge line from the compressor; serves as a reservoir for sudden or unusually heavy demands in excess of compressor capacity; prevents frequent loading and unloading (short cycling) of the compressor; and separates moisture and oil vapor, allowing the moisture carried over from the aftercoolers to precipitate. The oil separator element is in the tank, and on top are the safety valve, automatic blow-down valve, and at least one outlet for a service valve. *Figure 12-11* is an example of a typical air receiver-oil separator.

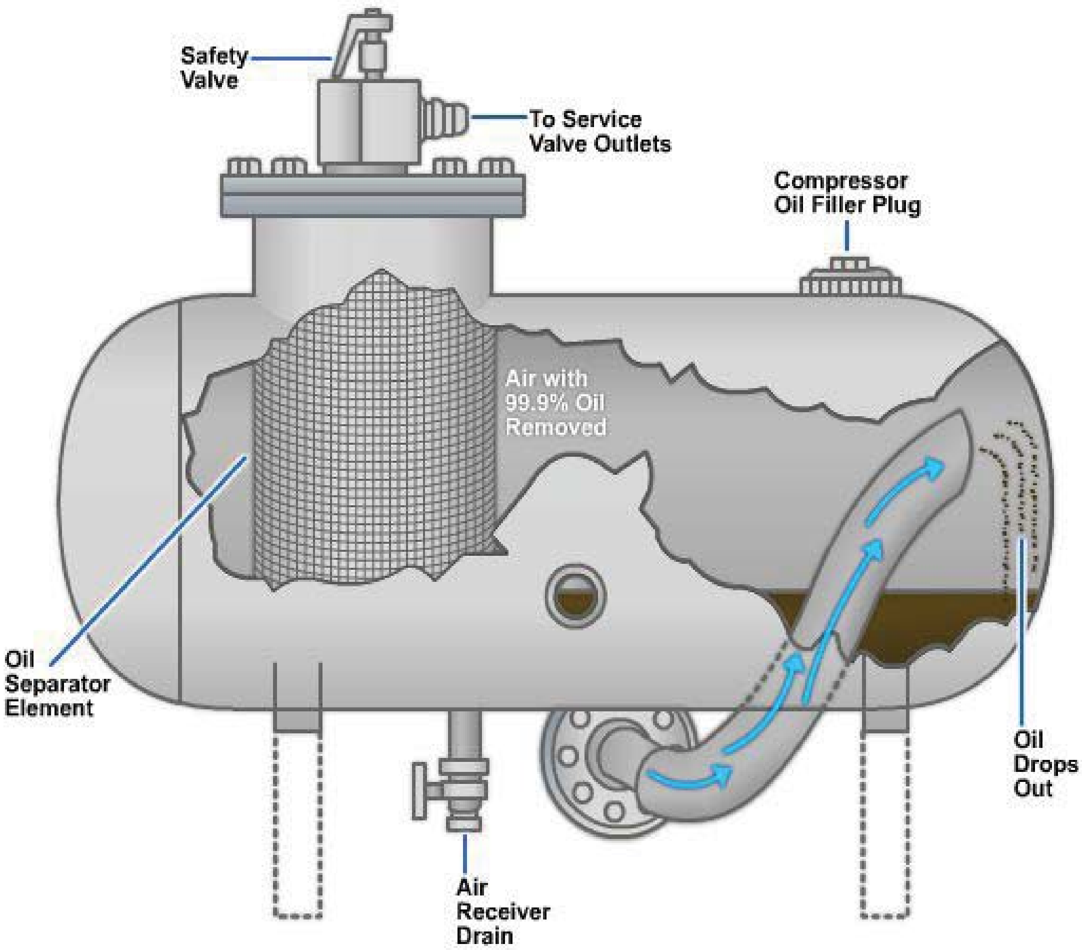


Figure 12-11 - Typical air receiver-oil separator.

NOTE

Reciprocating air compressors do not require oil separators because oil is not circulated through the air system. NAVSEA-approved reciprocating air compressors are the only systems used to compress air for diving operations.

Maintenance for the air receiver is not complicated and is limited to visual inspection of flanges and threaded fittings. The demister (*Figure. 12-12*), or oil separator, should be removed and replaced according to the manufacturer's recommendations for the unit on which you are working.

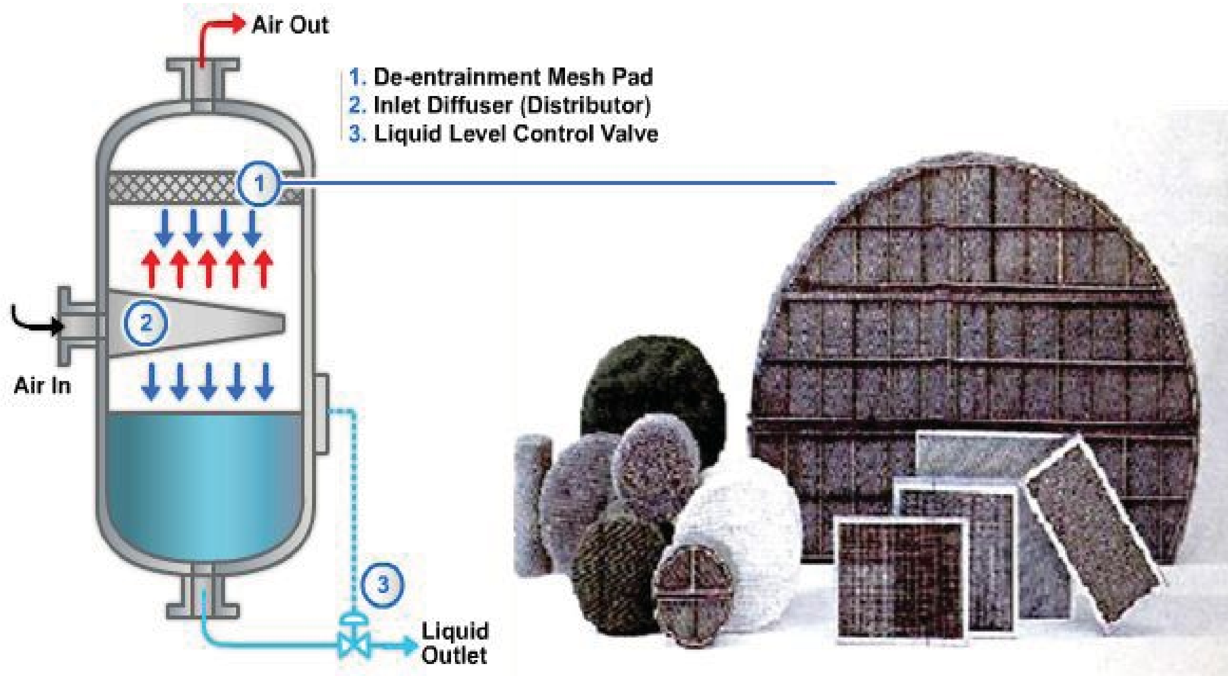


Figure 12-12 – Demister.

2.5.0 Intercoolers

As the air compressor compresses air, heat is generated which causes the air to expand, requiring an increase of horsepower for further air compression. If you remove the heat, the total horsepower required for additional air compression is reduced up to 15 percent. In multistage reciprocating compressors, heat is removed by the use of intercoolers (*Figure. 12-13*) or heat exchangers placed between each stage of compression.

NOTE

In the rotary and screw types of air compressors, oil is injected into the compressor at the first stage cooling the air which eliminates the need for an intercooler.

Some intercoolers have a condensation drain that should be serviced daily (at a minimum), and some have a safety relief. If the safety relief valve is opening due to overpressure, it is an indication of possible leakage in the high-pressure suction valves. You should keep the intercooler free of dirt and dust, and ensure that the airflow around the intercooler is not blocked or restricted.

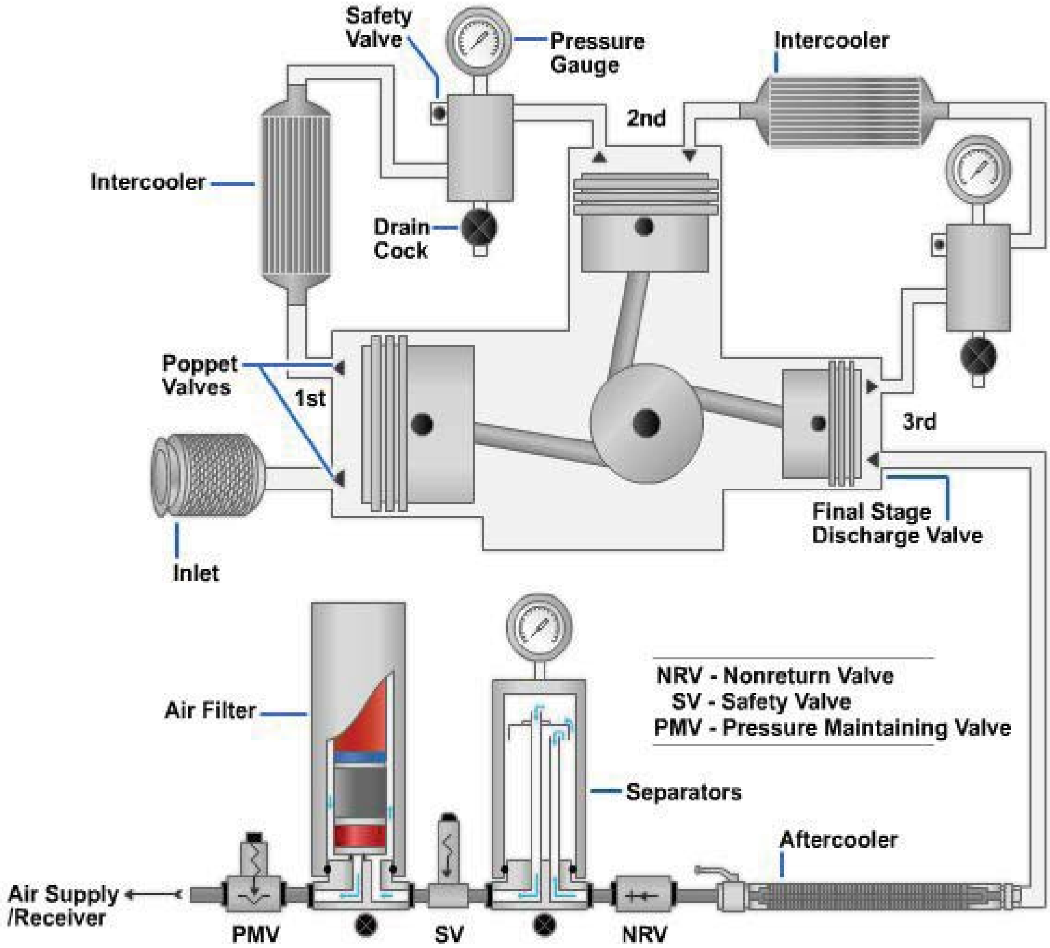


Figure 12-13 – Air cooling system.

2.6.0 Aftercoolers

Water or moisture is not desirable in the transmission lines of an air compression system. Water carried through the lines washes away lubricating oil from the tools the compressed air is running. This causes the tools to operate sluggishly and increases the need for maintenance. The effect is compounded in high-speed tools, where the wearing surfaces are limited in size and excessive wear reduces efficiency by creating air leakage. Further problems result from the decrease of temperature caused by the sudden expansion of air at the ted. This low temperature creates condensation that freezes around ports and valves and impairs efficiency. These conditions can be minimized by removing the moisture from the air directly after compression, before the air enters the distribution systems. With an aftercooler or air radiator, heat is transferred from the compressed air to the atmosphere reducing the temperature to a point where most of the moisture is removed. This eliminates the difficulties that moisture causes throughout the system and at the point where the air is used. Aftercoolers are normally found only on reciprocating units and are placed between the discharge valve and the air receiver (*Figure 12-13*).

2.7.0 Lubrication System

The lubrication system in the reciprocating compressor is similar to that of an automobile engine-a pressurized system that force-feeds oil to lubrication points (*Figure 12-14*). Oil assists the piston rings in forming a tight seal in the cylinders and performs a certain amount of cooling. Typical small compressors use a splash type of lubrication system.

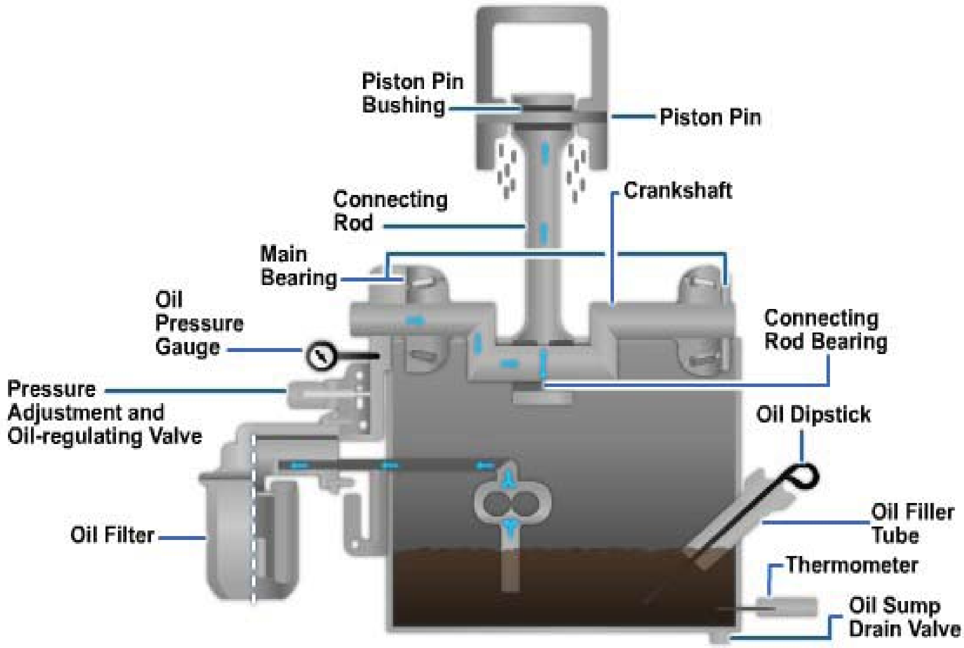


Figure 12-14 - Recipricating lubrication system.

As we have seen, vane and screw-type air compressors depend on oil for more than just lubrication. The oil lubricates the rotor bearings and internal working parts and adds to the efficiency of the compressor by forming a tight seal between each air compartment of the vanes or screws. Circulating oil also acts as a cooling medium absorbing the heat generated by the air as it is being compressed. The lubricating oil is force fed to the required lubricating points by a means called a pressure differential system. *Figure 12-15* shows the operation of this lubrication system. Trace it as you follow the text.

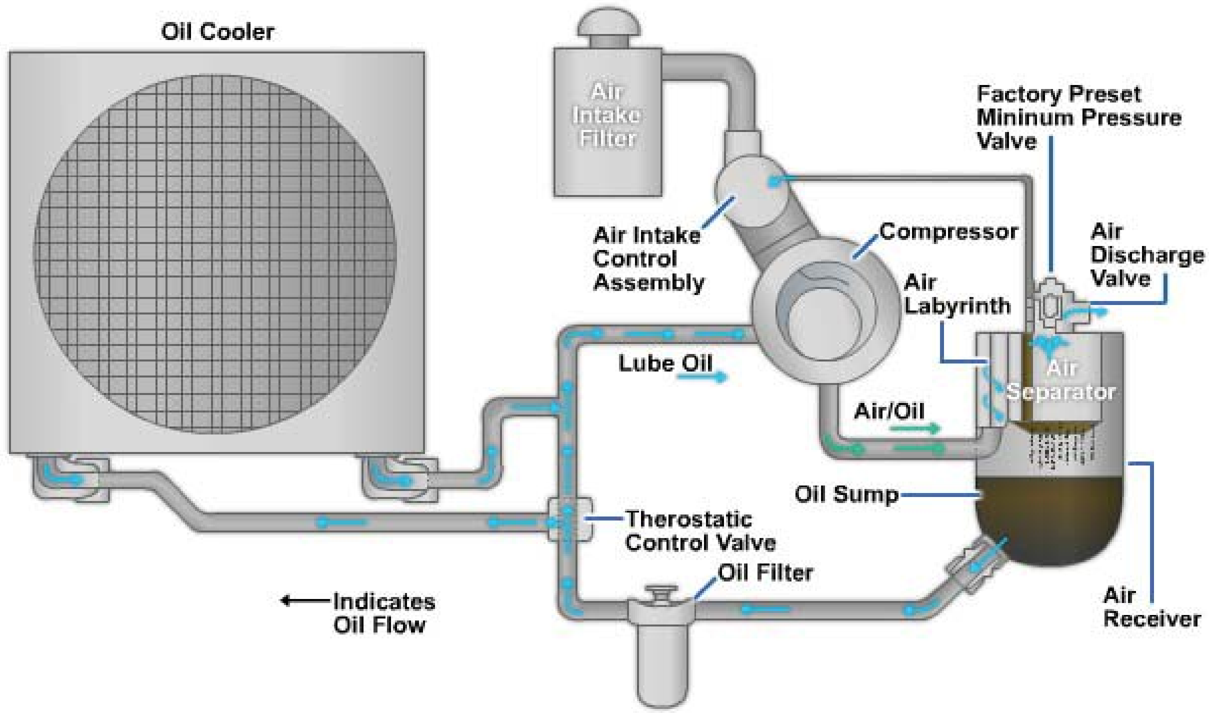


Figure 12-15 - Rotary vane lubrication system.

As the unit is started, air begins the compression cycle leaving the compressor and entering the air receiver. A factory-set minimum pressure valve, located on the air receiver, remains closed to allow rapid buildup of air pressure. The high-pressure air in the air receiver is the force that moves the oil through the oil lines to the working parts of the compressor. An oil filter is placed in the system to remove impurities. After leaving the filter, a thermostatic control valve directs heated oil through an oil cooler to keep the temperature between 130°F and 180°F. Oil already cool bypasses this step. The oil is then directed to the intake side of the compressor, where it is injected into the cylinder (vane type) or dual-bore cylinders (screw type) for sealing purposes and to cool the air as it is being compressed. Oil is also directed into the air intake control assembly, all bearings, and other moving parts at the same time. The air-oil mix exits the compressor at the discharge end and re-enters the air receiver. The oil is removed from the air by means of an air-oil-labyrinth-separator that returns it to the sump, where it starts the cycle again.

Some vane and screw types of air compressors use a mechanical type of oil pump in the lubrication system. You should check the level of the compressor oil daily, before operation. Refer to the manufacturer's maintenance manual for the correct type of oil and the proper procedure for checking and topping off.

CAUTION

Because the system is under high pressure, the vane and screw types of air compressors must be shut down and unloaded before oil is added to the system.

Preventive maintenance procedures for all three types of air compressors are outlined in current manuals for the unit you are working on or operating. Oil should be changed according to these manuals, in most cases, at 500-hour intervals. The compressor oil filter and air separator should not be overlooked. The air filter, taking into account operating conditions, should be inspected daily. Do not leave the unit unattended while it is running.

WARNING

Reciprocating air compressors used to produce breathable air for diving operations use special lubricating oil. Failure to observe these specific precautions set by NAVSEA maintenance instructions could lead to injury or death of the diver.

3.0.0 AIR COMPRESSOR TROUBLESHOOTING

Troubleshooting techniques are developed through experience, and all of us do it a little different however, there are basic steps that we all should take. The best way is to talk to the operator first and ask the following questions: Did it start at all? How did it shut down? What noises did it make? Was there any smoke or unusual smell? If you are not able to speak with the operator then the following strategies will provide you with a simple checklist of questions to ask yourself in order to start isolating the problem.

As tips, these troubleshooting suggestions are not comprehensive procedures: they serve as starting points only for the troubleshooting process. An essential part of expedient troubleshooting is probability assessment, and these tips help you determine which possible points of failure are more or less likely than others. Final isolation of the system failure is usually determined through techniques that are more specific.

A visual inspection for obvious problems should always be conducted.

Prior occurrence. If this compressor has been historically known to fail in a certain particular way, and the conditions leading to this common failure have not changed, check for this "way" first. A corollary to this troubleshooting tip is the directive to keep detailed records of failure. Ideally, a computer-based failure log is optimal, so that failures may be referenced by and correlated to a number of factors such as time, date, and environmental conditions.

Example: *The compressor is constantly running. The last two times this happened, the cause was a leaky regulator.*

What to do: Check the regulator first. Of course, past history by no means guarantees the present symptoms are caused by the same problem, but since this is more likely, it makes sense to check this first.

If, however, the cause of routine failure in a system has been corrected (i.e. the leak causing the constant running in the past has been repaired), then this may not be a probable cause of trouble this time.

Recent alterations. If a system has been having problems immediately after some kind of maintenance or other change, the problems might be linked to those changes.

Example: *The prime mover was recently overhauled and now the system will not fully pressurize.*

What to do: Check for something that may have been left loose after the motor was been repaired.

Function vs. non-function. If a system is not producing the desired result, look for what it *is* doing correctly; in other words, identify where the problem is *not*, and focus your efforts elsewhere. Whatever components or subsystems necessary for the properly working parts to function are probably okay. The degree of fault can often tell you what part of it is to blame.

Example: *The prime mover works fine but the air pressure being produced by the pump varies by over 20 psi.*

What to do: Eliminate from the list of possible causes. Being able to eliminate sections of the system as possible failures reduces the scope of the problem and makes the rest of the troubleshooting procedure more efficient.

Hypothesize. Based on your knowledge of how a system works, think of various kinds of failures that would cause this problem to occur, and check for those failures (starting with the most likely based on circumstances, history, or knowledge of component weaknesses).

Example: *The compressor is overheating.*

What to do: Consider possible causes for overheating, based on what you know of compressor operation. Either the engine is generating too much heat, or not getting rid of the heat well enough (most likely the latter). Brainstorm some possible causes: a loose fan belt, clogged filter or intercooler, etc. Investigate each one of those possibilities before investigating alternatives.

See *Table 12-1* for a more detailed listing of troubleshooting the vane and screw types of air compressors.

CAUTION

For exact information on the equipment on which you are working, go to the manufacturer's maintenance and repair manual.

Table 12-1 - Troubleshooting

Troubleshooting Compressed Air Systems		
Problem	**Probable Cause**	**Remedial Action**
Low pressure at point of use	Leaks in distribution piping	Check lines, connections and valves for leaks
	Clogged filter elements	Clean or replace filter elements
	Fouled dryer heat exchanger	Clean heat exchanger
Low pressure at compressor discharge	For systems with modulating load controls, improper adjustment of air capacity system	Follow manufacturer's recommendation for adjustment of air capacity system
	Worn or broken valves	Check valves and repair or replace as required
	Improper air pressure switch setting	Follow manufacturer's recommendations for setting air pressure switch
Water in lines	Failed condensate traps	Clean, repair, or replace the trap
	Failed or undersized compressed air dryer	Repair or replace dryer
Liquid oil in air lines	Faulty air/oil separation	Check air/oil separation system; change separator element
	Compressor oil level too high	Follow manufacturer's recommendation for proper oil level
Dirt, rust or scale in air lines	In the absence of liquid water, normal aging of the air lines	Install filters at point of use
Excessive service to load/hour ratio	System idling too much	For multiple compressor system: consider sequencing controls to minimize compressor idle time
		Adjust idle time according to manufacturer's recommendations
	Improper pressure switch setting	Readjust according to manufacturer's recommendations
Elevated compressor temperature	Restricted air flow	Clean cooler exterior and check inlet filter mats
	Restricted water flow	Check water flow pressure and quality; clean heat exchanger as needed
	Low oil level	Check compressor oil level add oil as required
	Restricted oil flow	Remove restriction, replace parts as required
	Excessive ambient temperature	Improper ventilation to compressor; check with manufacturer to determine maximum operating temperature

4.0.0 AIR COMPRESSOR OVERHAUL

Because of the durability of the vane and screw types of air compressors, major overhaul is seldom required. A properly maintained unit will perform reliably for 10,000 hours or more. When a major overhaul is required, the following preparations apply to air compressors, have a clean work area; obtain all special tools; get the manufacturer's repair manual; and preclean the unit. Always be aware of safety issues. Use a hoist for the heavy parts. You are now ready to start your overhaul.

The primary wear point on the rotary type of air compressor is the rotor vanes. For this reason, the unit has been designed to allow for simplified inspection of the vanes by the removal of the rear cover of the compressor (*Figure. 12-16*).

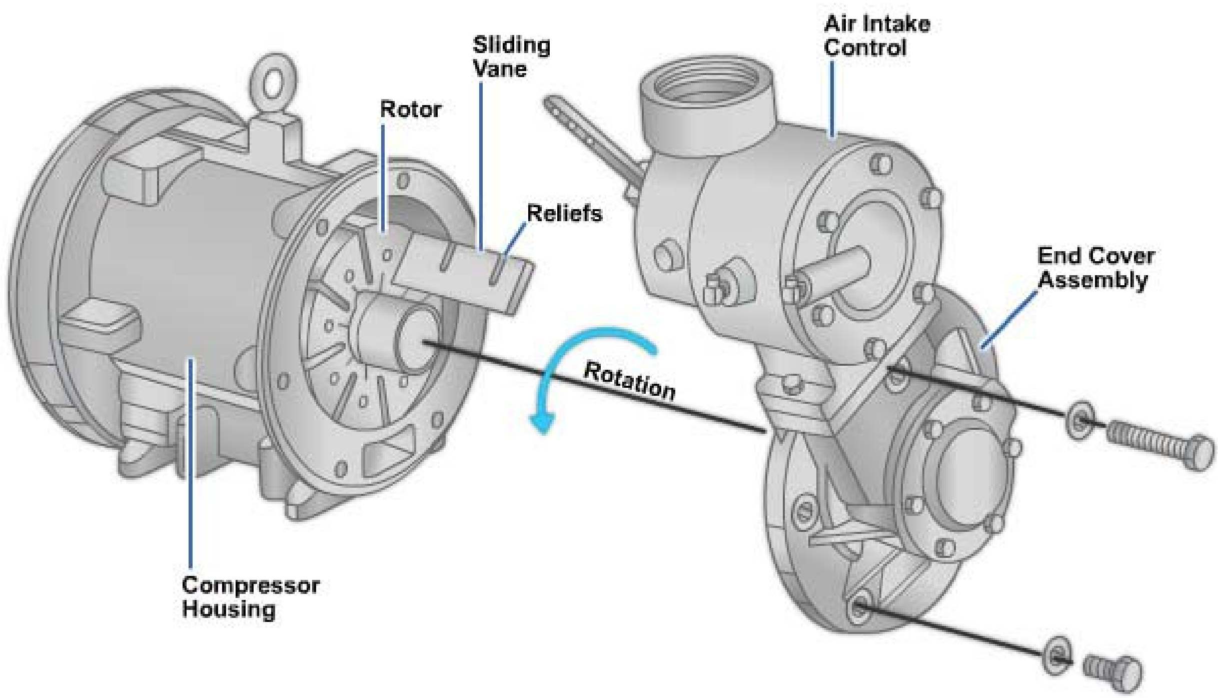


Figure 12-16 – Inspection of vanes.

CAUTION

Before the rotor vanes can be removed from most rotary compressors, the rotor must be positioned correctly (*Figure. 12-17*).

The rotor vanes should slide out easily offering little or no resistance. Rotor vanes that resist removal indicate problems. Once you remove the rotor vanes, shine a light inside the rotor compartment and slots. Inspect the condition of the rotor slots. The slots should be clean and have straight edges. A worn-rotor slot will most likely have a slight saw-toothed effect on the trailing edge-a condition that can cause rapid rotor vane wear. Next, inspect the inside of the rotor compartment for irregularities, such as scoring, heat cracks, or gouging. Damage to the rotor compartment usually means the replacement of this part is necessary.

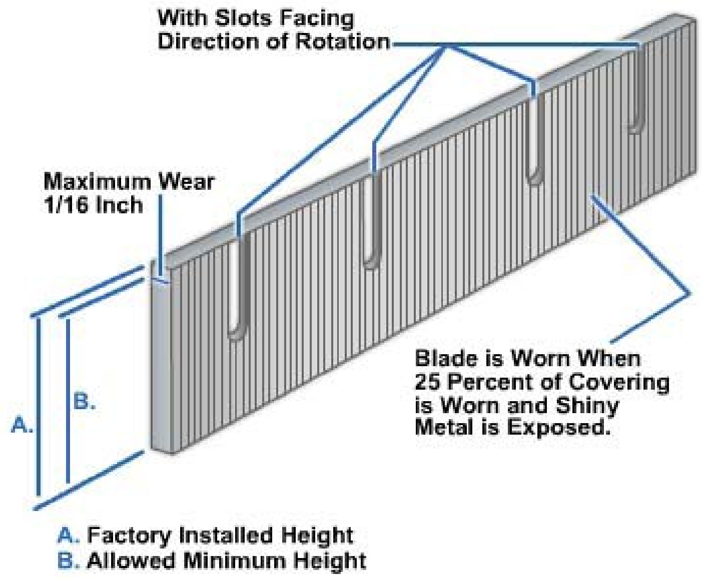


Figure 12-17 - Rotor vane inspection.

Inspect the individual rotor vanes; look for excessive wear, chipping, cracking, or breakage. Rotor vanes worn beyond specifications set by individual manufacturers should be replaced (*Figure. 12-17*). If the rotor vanes have broken in the compressor, it is of extreme importance that all pieces be removed. Chips and other foreign matter left in the compressor will be ingested into the lubrication system, causing further damage to the air control system and the compressor. Following rotor vane breakage, flush the cylinder and rotor with steam or high-pressure water. The oil tank or air receiver must be drained and flushed. Air and oil lines should be purged and entirely free of rotor vane chips.

Dry all parts with compressed air and lubricate them with compressor oil.

If you must change the rotor bearings and races, you should do so with suitable pullers and installers. In extreme circumstances, some manufacturers recommend heating the inner races to ease removal. Discard bearing races that have been heated in this type of removal process.

Some rotary and screw types of air compressors have an oil pump in the lubrication system. Disassemble, inspect, and overhaul the oil pump according to the manufacturer's specifications.

Before you reassemble the air compressor, make sure all the air and oil passages are clean. All parts should be lightly oiled and ready for use. The reassembly process of air compressors is not complicated; however, always use the instructions in the manufacturer's repair and maintenance manual.

The manufacturers of the screw type of air compressors do not recommend that overhaul be done in the field.

Always carry out preventive maintenance as required. The importance of timely oil, oil filter, and air filter changes cannot be overstressed.

Summary

In this chapter, we discussed the different types of air compressors. We specifically discussed reciprocating, sliding vane and screw compressors. We briefly talked about the different components of a compressor system from the safety devices to the lubrication systems. We concluded the chapter with general guidelines in regards to troubleshooting and compressor overhaul, which were by no means comprehensive. You should always refer to the maintenance manual for the specific type of equipment on which you are working, and remember, always keep safety in the forefront of any maintenance action you will be conducting.

Review Questions (Select the Correct Response)

1. Which type of air compressor does not reduce the air volume from the intake to discharge port?

   A. Reciprocating
   B. Rotary sliding vane
   C. Rotary liquid piston
   D. Rotary twin lobe

2. What is the difference between military and civilian compressors?

   A. Miliary compressors are armored
   B. Military compressors are made of stronger materials
   C. Military compressors use modified trailors
   D. Military compressors do not use oil lubrication

3. What cylinder design is used on air cooled compressors?

   A. Cast iron
   B. Multiport
   C. Finned
   D. Aluminum

4. Where are reciprocating compressors most likely being used in the NCF?

   A. In CESE
   B. On a remote jobsite
   C. At an underwater welding site
   D. On a well-drilling rig

5. What is the most common screw type of air compressor used in the NCF?

   A. Single stage, dry screw
   B. Single stage, oil flooded
   C. Double stage, dry screw
   D. Double stage, oil flooded

6. Where is the safety shutoff switch located to protect a compressor engine from overheating?

   A. Power source
   B. Fuel cutoff
   C. Output shaft
   D. Intake valves

7. What pounds per square inch is the safety valve on an air receiver normally set?

   A. 60
   B. 90
   C. 115
   D. 125

8. How is the air intake control modulated on a rotary type of air compressor?

   A. Input valve spring pressure
   B. Receiver air pressure
   C. Output regulator pressure
   D. Safety valve pressure

9. What is the maximum pounds per square inch recommended to clean a dry type air filter?

   A. 5
   B. 10
   C. 20
   D. 30

10. Reducing the temperature between stages of air compression can reduce the needed horsepower to compress the air by what percentage?

   A. 5
   B. 10
   C. 15
   D. 20

11. What type of air compressors use aftercoolers?

   A. Screw
   B. Rotary
   C. Reciprocating
   D. Twin lobe

12. What type of lubrication systems do small reciprocating compressors use?

   A. Pressurized
   B. Splash
   C. Injected
   D. Bath

13. What type of lubrication system is used with vane and screw type compressors?

   A. Pressure differential
   B. Osmosis
   C. Splash
   D. Bath

14. A rotary vane compressor passes oil through a thermostatic control valve to an oil cooler to maintain what temperature range in Fahrenheit?

    A. 90 - 110°
    B. 115 - 125°
    C. 130 - 180°
    D. 190 - 225°

15. What is the primary wear point of a rotary vane air compressor?

    A. The rotor
    B. The drive shaft
    C. The intake valve
    D. The vanes

Additional Resourses and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Maintenance and Operation of Air Compressor Plants NAVFAC MO-206, Naval Facilities Engineering Command, Alexandria Virginia, 1989

Maintenance of Steam, Hot Water, And Compressed Air Distribution Systems NAVFAC MO-209, Naval Facilities Engineering Command, Alexandria Virginia, 1989

Mechnical Science, DOE-HDBK-1018/2-93, U.S. Department of Energy FSC-6910, Washington, D.C. 20585, January 1993

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Chapter 13

Air-Conditioning Systems

Topics

To hear audio, click on the box.

Overview

Part of your job as a Construction Mechanic is to maintain and repair air-conditioning systems. You will need to understand how air-conditioning systems function before you can become a competent troubleshooter. This chapter gives you the foundation to recognize problems and repair them. Your knowledge in this area is essential to the successful completion of a job or unit mission.

This chapter introduces you to the fundamental operating principles, parts, and maintenance of air-conditioning systems, and operating problems that you may experience.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the principles of refrigeration.
2. Identify components of air-conditioning systems.
3. Identify malfunction of components in the air-condition systems.
4. Understand how to inspect air-conditioning systems for leaks.
5. Understand how to evacuate and recharge air-conditioning systems.
6. Understand how to add refrigerant to air-condition systems.
7. Understand how to perform functional testing on air-conditioning systems.

Prerequisites

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air-Conditioning Systems	↑	C M
Air Compressor Overhaul		
Inspecting and Troubleshooting Brake Systems		A
Hydraulic Systems		D
Wheel and Track Alignment		V
Troubleshooting Transmissions, Transfer Cases and Differentials		A
Clutches and Automatic Transmissions		N
Troubleshooting Electrical Systems		C
Fuel System Overhaul		E
Engine Troubleshooting and Overhaul		D
The Shop Inspectors		
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the

information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PRINCIPLES of REFRIGERATION

Refrigeration is the process of producing low temperatures. It is usually associated with refrigerators or freezers rather than with vehicles. An understanding of heat transfer, basic refrigeration, pressure temperature relationship, and the qualities of refrigerants is essential for a working knowledge of the air-conditioning system.

1.1.0 Heat Transfer

It may seem odd to cover heat transfer in connection with air conditioning. Keep in mind, however, that heat, like light, is a form of energy. As you remove light, a room grows darker. Likewise, when you remove heat, an area becomes colder. The process of transferring heat is the basis for air conditioning. Generally, when two objects of different temperatures are close to each other, heat energy will leave the warmer object and travel to the cooler. This is quite clearly illustrated in North America each fall and winter. As the rays of the sun become less direct and consequently give off less heat, we experience a drop in temperature. Cooler weather (refrigeration) results from this removal of heat.

Refrigeration applies a physical principle that is known to most of us through our everyday experiences. We have experienced the application of rubbing alcohol and its cooling effect. This example illustrates that an evaporating liquid absorbs heat. The evaporating moisture in the air on a hot day soaks up heat like a sponge. This removal of heat is exactly the same process used in automotive air conditioning. Heat is removed from the vehicle by an evaporating refrigerant and transferred into the atmosphere.

1.2.0 Pressure Temperature Relationship

Different liquids have different boiling evaporating points; however, the boiling point of any liquid increases when pressure is increased. When pressure is decreased, the boiling point is then decreased. This process of removing the pressure and allowing the coolant to boil is a vital part of any refrigeration system.

1.3.0 Refrigerant (134A)

With the exception of changes in state, gases used in refrigeration are recycled much like engine coolant. Different pressures and temperatures cause the gas to change state from liquid to gas and back to a liquid again. The boiling point of the refrigerant changes with system pressure. High pressure raises the boiling point and low pressure reduces it. These gases also provide good heat transfer qualities and do not deteriorate system components. A few years ago, vehicles were cooled with refrigerant-12 (R-12). It had a boiling point of 22^{0}F and vaporized at room temperature. Because R-12 has been found to be hazardous to the environment, it has been fased out. The replacement refrigerant is R-134a.

1.4.0 Handling Refrigerant

R- 34a is a relatively safe refrigerant; however, you must observe certain precautions when using and handling it:

- Refrigerant can cause frostbite if it makes contact with exposed skin.
- Always wear safety glasses. If refrigerant gets into your eyes, it can blind you.
- Keep refrigerant away from excessive heat.

- Keep refrigerant away from an open flame. When refrigerant is burned, it gives off phosgene gas.
- Use hot water (*Figure 13-1*) or rags saturated with water at temperatures not to exceed 125^0F when refrigerant containers must be warmed for system charges.
- Always reclaim refrigerant. It is dangerous to the environment and if released in a closed room, it can replace the oxygen and cause suffocation.

Some systems may still have R-12 in them. Here are some differences in the systems to help you identify them and the precautions involved:

- The refrigerant storage tank for R-12 is white; whereas the tank for R-134a is blue.
- Tool fittings on the R-12 system are standard thread; fittings on the R-134a are metric.
- R-134a service fittings are male. R-12 service fittings are female.
- R-12 systems use screw-on fittings on charging valves. R-134a uses a quick-disconnect.
- Never mix R-12 and R-134a. This will separate the oil and cause severe compressor damage, damage to O-rings, and seals to leak.
- Never mix organic and synthetic oils. This will separate the oil and cause severe compressor damage, damage to O-rings, and seals to leak.
- Only use O-rings designed for the type of refrigerant you are using. R-134a will dissolve seals designed for R-12 systems.

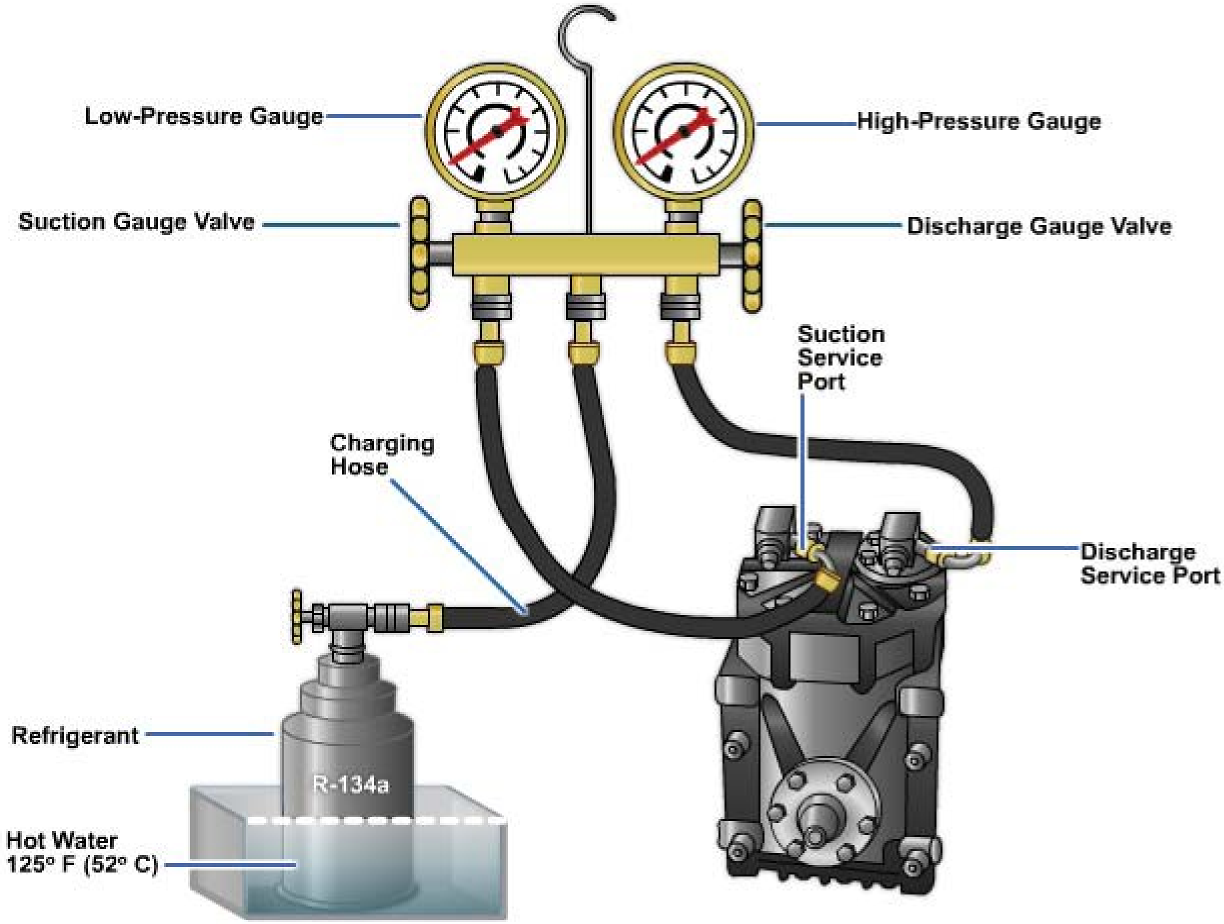

Figure 13-1 - Warming the refrigerant with warm water.

1.5.1 Refrigeration Cycle

The refrigeration cycle is a continuous closed-loop system. The refrigerant is pumped constantly through the components in the system. By changing the refrigerant pressure and by removing and adding heat, the refrigeration cycle is completed. The refrigeration cycle operates as follows:

1. The receiver/drier collects high-pressure refrigerant in a liquid form. Also, moisture and impurities are removed at this point.
2. The refrigerant is routed to the expansion valve through high-pressure lines and hoses.
3. The expansion valve reduces refrigerant pressure to the evaporator by allowing a controlled amount of liquid refrigerant to enter it.
4. A stream of air is passed over the coils in the evaporator as refrigerant enters.
5. As the low-pressure refrigerant moves through the coils in the evaporator, it absorbs heat from the airstream, which produces a cooling effect.
6. As the refrigerant nears the end of the coils in the evaporator, greater amounts of heat are absorbed. This causes the low-pressure liquid refrigerant to boil and change to a gas as it exits the evaporator.

7. As the refrigerant enters the compressor, the pumping action increases refrigerant pressure, which also causes a rise in temperature.
8. The high-pressure, high-temperature gas enters the condenser, where heat is removed by an outside ambient airstream moving over the coils. This causes the gas to condense and return to a liquid form again.
9. The high-pressure liquid refrigerant now enters the receiver again to begin another cycle. This continuous cycle, along with the dehumidifying and filtering effect, produces a comfortable atmosphere on hot days.

Test your Knowledge (Select the Correct Response)

1. The boiling point of any liquid is increased in what way?

   A. By raising the evaporation point
   B. By decreasing the pressure on the liquid
   C. By increasing the pressure on the liquid
   D. By lowering the evaporation point

2.0.0 COMPONENTS of the AIR CONDITIONING SYSTEM

Each air-conditioning system (*Figure 13-2*) must have a receiver/drier, an expansion valve or metering device, an evaporator, a compressor, and a condenser. Without these components, an air-conditioning system will not function. Additionally, the system must have some means of control. The following information briefly covers each air-conditioning component and the controls involved.

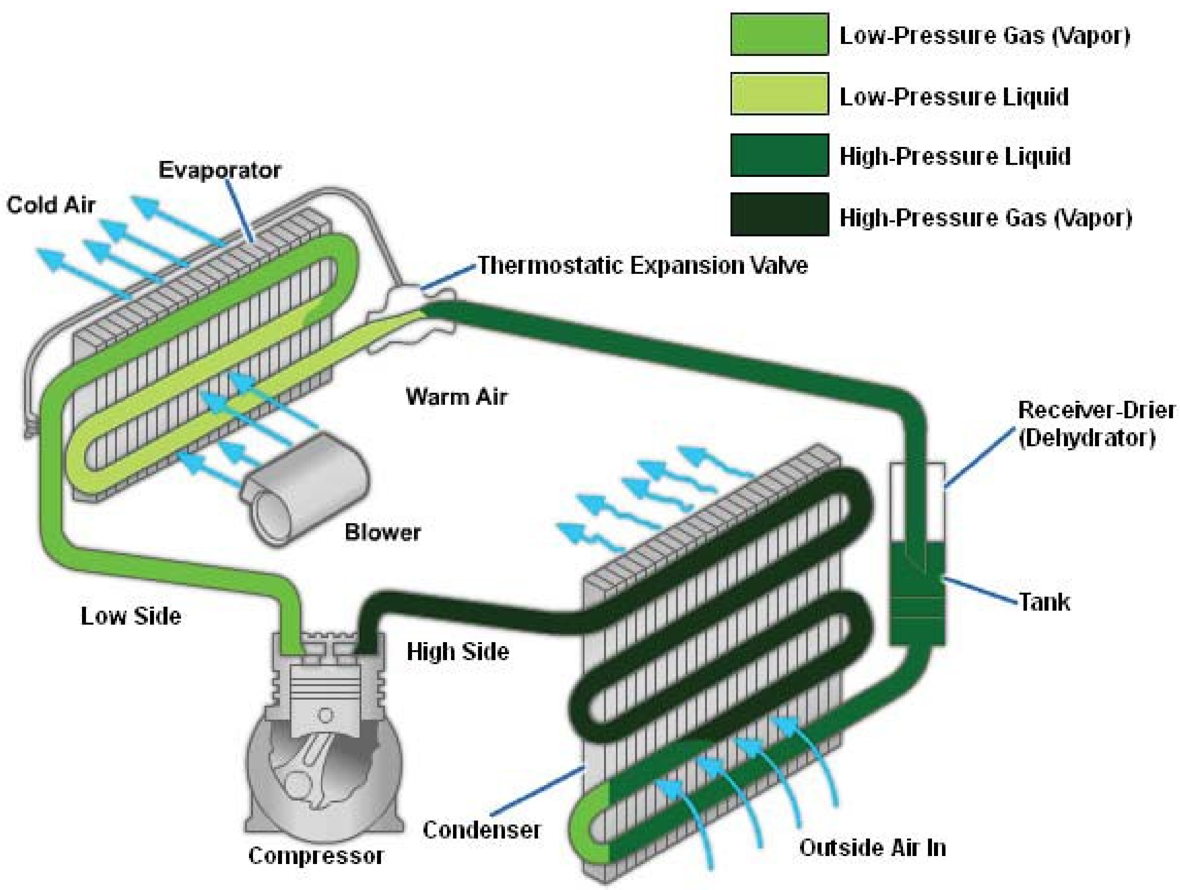

 Figure 13-2 - Air-conditioning system.

2.1.1 The Receiver/Drier

The receiver (*Figure 13-3*), otherwise known as a filter-drier or accumulator-drier, is a cylindrical-shaped metal tank that has two purposes; separate liquid from gas and to remove moisture and filter out dirt. The tank is hollow with an inlet to the top of the hollow cylinder. The outlet port has a tube attached to it that extends to the bottom of the receiver. This tube assures that only liquid refrigerant will exit the receiver because any gas entering will tend to float above the liquid.

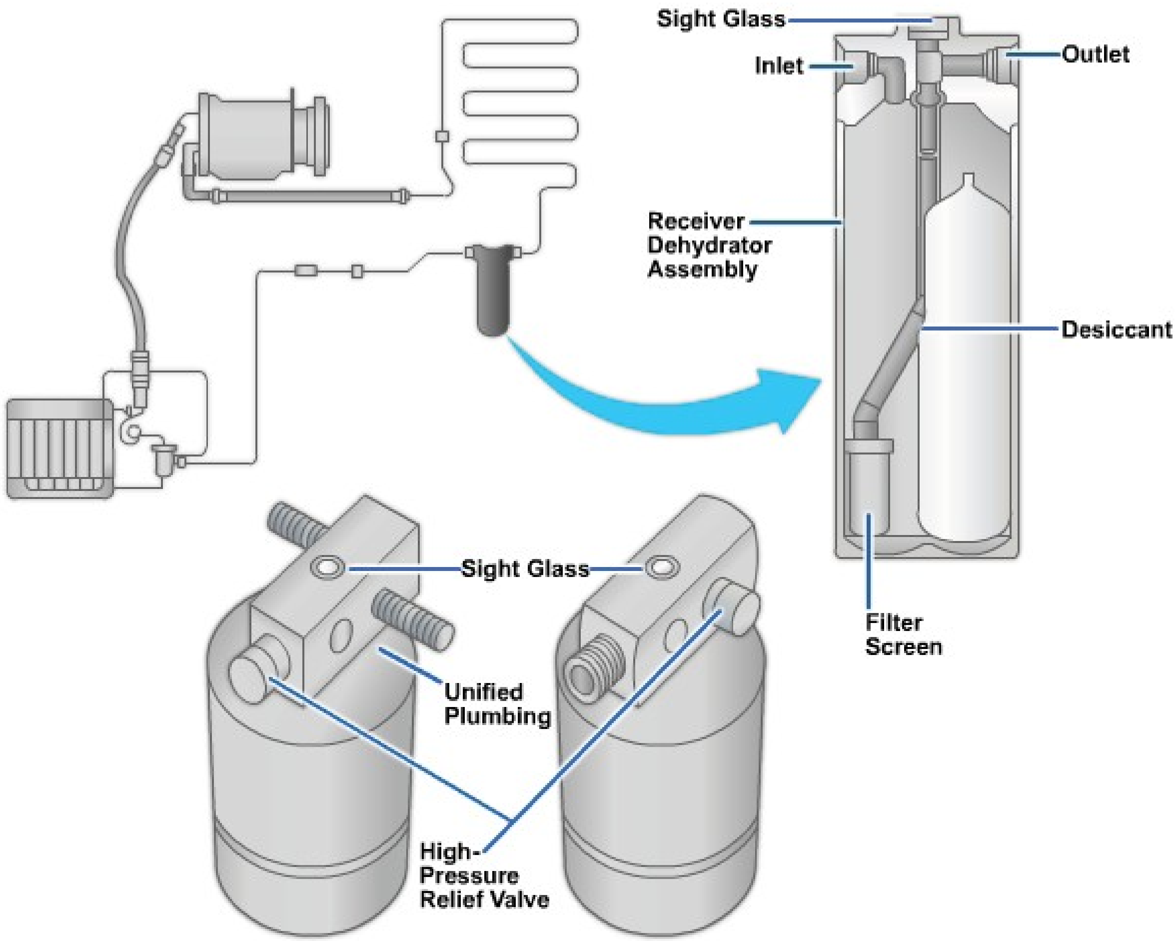

Figure 13-3 - Receiver and components.

Some other components of the receiver/drier are:

- Filter-The filter is mounted inside the receiver on the end of the outlet pipe. This filter removes any impurities from the refrigerant by straining it.
- Desiccant-A special desiccant or drying agent is also located inside the receiver. This agent removes any moisture from the system.
- Relief Valve-Some systems use a relief valve mounted near the top of the receiver. This valve is designed to open when system pressure exceeds approximately 450 to 500 psi. As the relief valve opens, it vents refrigerant into the atmosphere. As soon as excess pressure is released, the valve closes again so the system will not be evacuated completely.

- Sight Glass-A sight glass (*Figure 13-4*) is a small, round, glass-covered hole that is sometimes mounted on the outlet side of the receiver near the top. This observation hole is a visual aid you use in determining the condition and amount of refrigerant in the system. If bubbles or foam is observed in the sight glass while the system is operating (above 70°F [21°C]), it may indicate that the system is low on refrigerant. Some systems have a moisture-sensitive element built into the sight glass. If excessive moisture is present, the element turns pink. If the system moisture content is within limits, the element remains blue. In many later automotive air-conditioning systems, the sight glass has been eliminated. In such applications, you must depend on the system pressures.

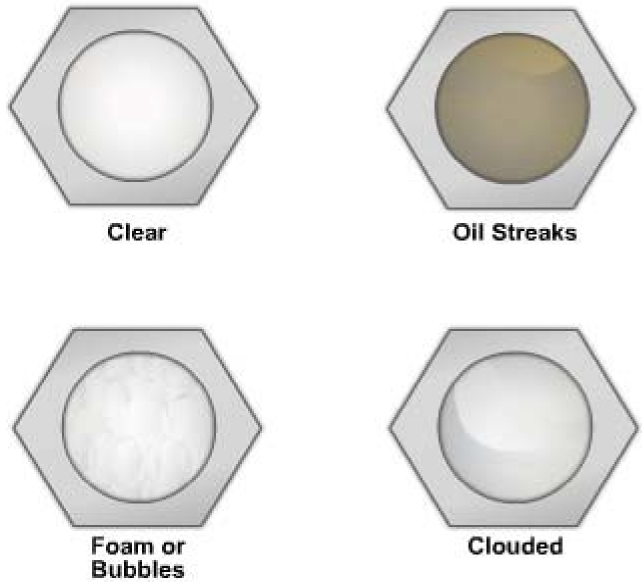

Figure 13-4 – Possible sight glass conditions.

2.2.0 The Expansion

The refrigerant expansion system is designed to regulate the amount of refrigerant entering the evaporator and to reduce its pressure.

2.2.1 Expansion Valve

One type of expansion system used on modem vehicles is the expansion valve (*Figure 13-5, View A*). The valve action is controlled by the valve spring, suction manifold, and pressure exerted on the diaphragm from the thermal bulb. Operation of the valve is as follows:

1. High-pressure liquid refrigerant flows into the valve and is stopped at the needle seat.
2. If the evaporator is warm, pressure is developed in the thermal bulb and transferred to the diaphragm through the capillary tube.
3. The diaphragm overcomes the pressure developed in the equalizer tube and valve spring pressure, causing it to move downward.
4. This movement forces the valve-actuating pin downward to open the valve.

As the refrigerant flows, it cools the evaporator and therefore reduces pressure in the thermal bulb. This allows the valve to close and stop refrigerant from flowing into the evaporator. By carefully metering the amount of refrigerant with the expansion valve, the evaporator cooling efficiency is increased greatly.

2.2.2 Expansion Tube

The expansion tube (*Figure 13-5, View B*) provides the same functions as the expansion valve. A calibrated orifice is built into the expansion tube. The tube retards the refrigerant flow through the orifice to provide the metered amount of refrigerant to the evaporator. The tube also has a fine screen built in for additional filtration.

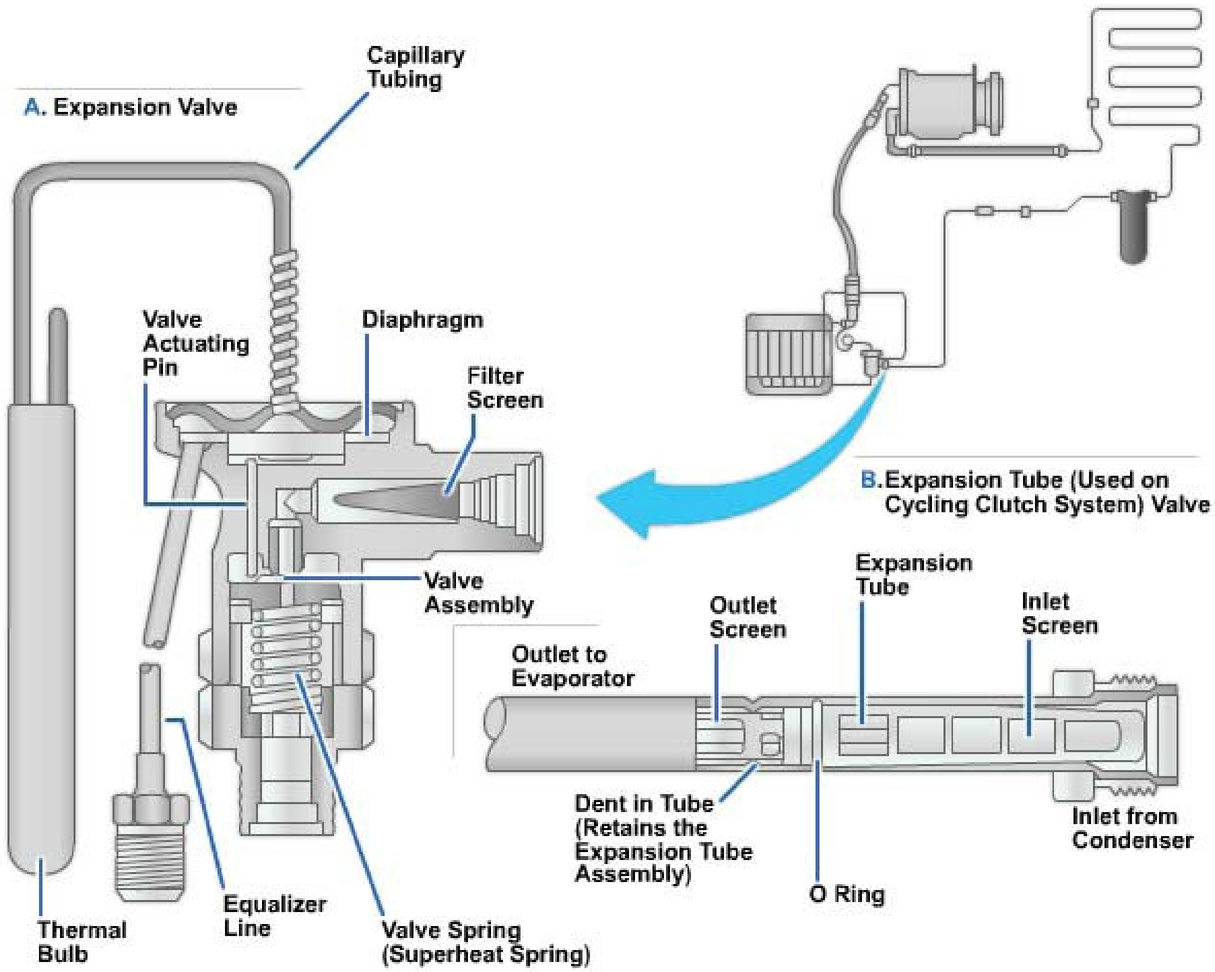

Figure 13-5 - Expansion valve and tube.

2.3.0 The Evaporator

The evaporator is designed to absorb heat from the airstream directed into the driver's compartment. It is a continuous tube looped back and forth through many cooling fins firmly attached to the tube. The evaporator dehumidifies the air by passing an airstream over the cooling fins. As this happens, the moisture condenses on the fins and drips down to collect and exit under the vehicle. Also, dust and dirt are collected on the moist fins and are drained with the moisture. The temperature of the evaporator must be kept above 32°F. Should the temperature fall below 32°F, moisture condensing on the evaporator will freeze and prevent air from passing through the fins. A typical evaporator is shown in *Figure 13-6*. There are basically three methods of regulating evaporator temperature; each is examined below.

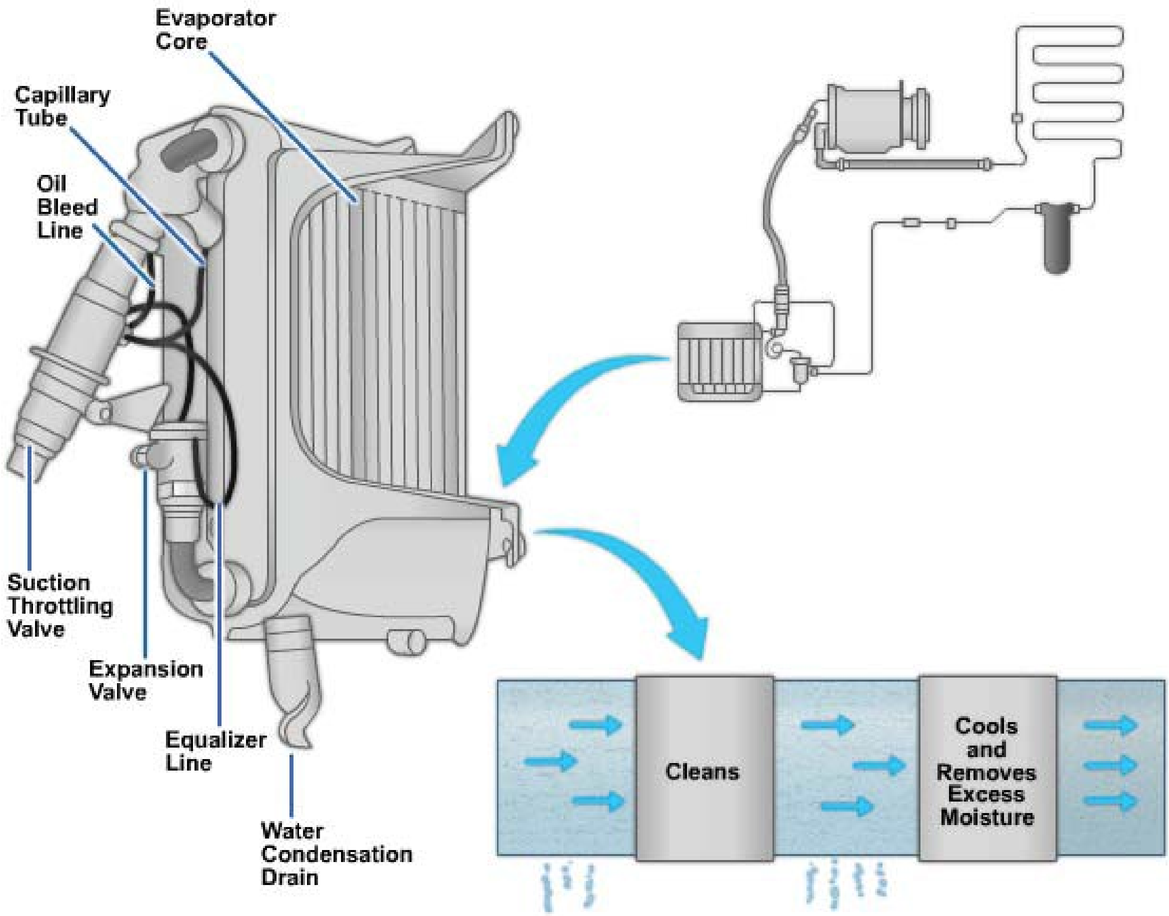

Figure 13-6 - Typical evaporator.

2.3.1 Thermostatic Switch

This system uses an electrically operated thermostatic switch (*Figure 13-7*) to engage and disengage the compressor. The switch is operated by a sensing bulb placed in the airstream after the evaporator. As the evaporator temperature falls, the thermostatic switch opens to disengage the magnetic clutch in the compressor. When the coil temperature reaches the proper level, the switch again closes to engage the clutch and drive the compressor.

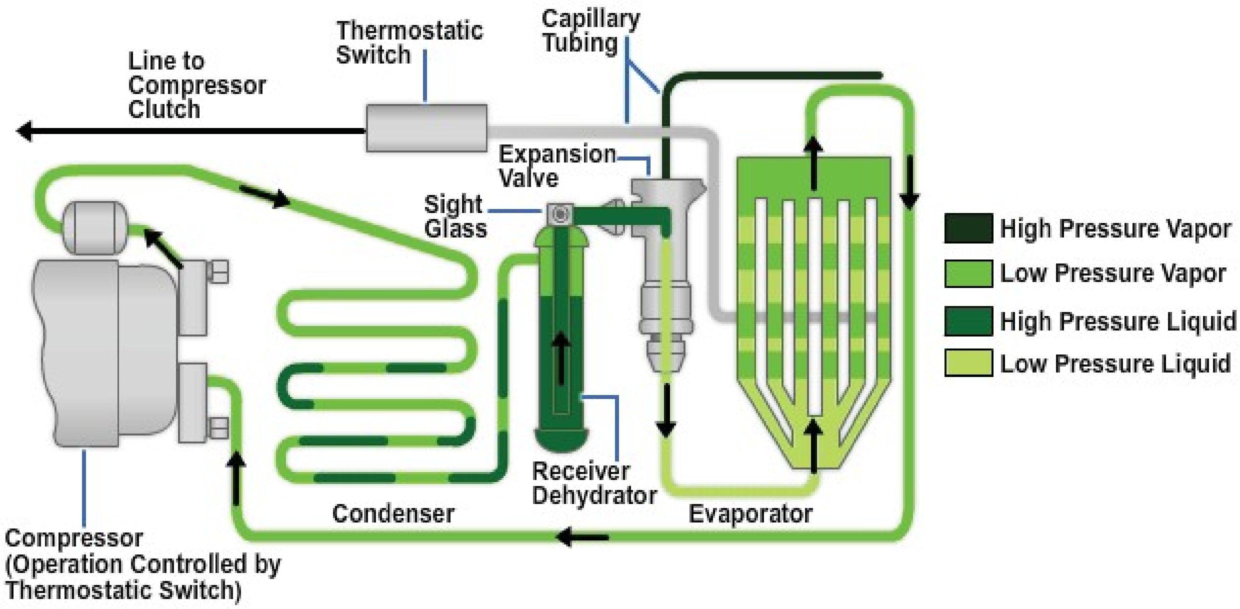

Figure 13-7 - Thermostatic switch.

2.3.2 Hot Gas Bypass Valve

The hot gas bypass valve (*Figure 13-8*) was used on some older models to control evaporator icing. The valve is mounted on the outlet side of the evaporator. The high-pressure gas from the compressor joins with the low-pressure gas exiting the evaporator. These two gases mix, causing a pressure increase. Also, the boiling point increases, which results in a loss of cooling efficiency. This, in turn, causes the evaporator temperature to increase, thus eliminating freeze-up. The compressor is designed to run constantly (when it is activated) in the hot gas bypass valve system.

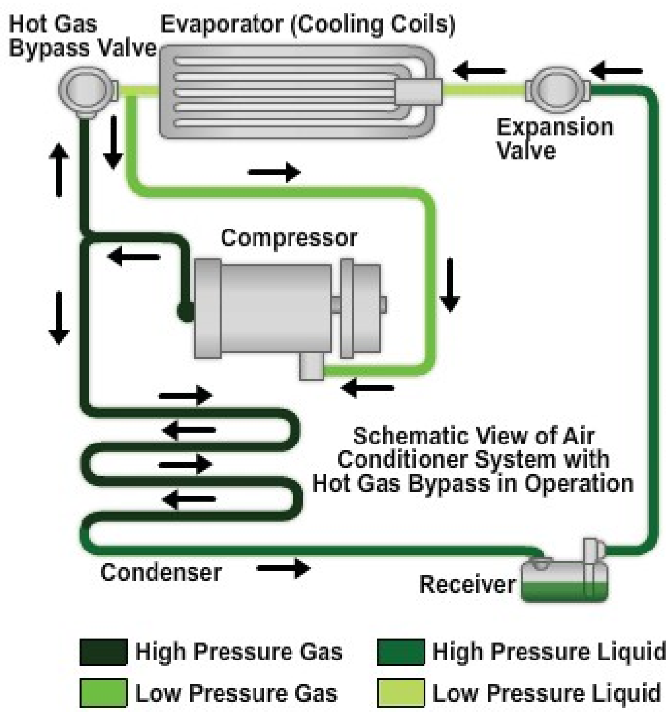

Figure 13-8 – Hot gas bypass valve operation.

2.3.3 ing Valve

The suction throttling valve (*Figure 13-9*) is now used in place of the hot gas bypass valve system. It is placed in line with the outlet of the evaporator. This system is designed to limit the amount of low-pressure vapor entering the compressor. The suction throttling valve operates as follows:

1. The outlet pressure enters the valve on the bottom.

2. The gas pressure passes through a fine screen and small bleeder holes to act on a diaphragm.
3. The valve spring and atmospheric pressure oppose the gas pressure on the opposite side of the diaphragm.
4. As the outlet pressure of the evaporator overcomes the opposing forces, the diaphragm and piston move upward, allowing low-pressure gas to flow through the valve and flow to the inlet of the compressor.

As pressure again drops on the inlet side of the valve, atmospheric pressure and valve spring pressure close the valve again. A vacuum power unit is mounted to the top of the valve to help reduce valve spring pressure and prevent icing at high elevations.

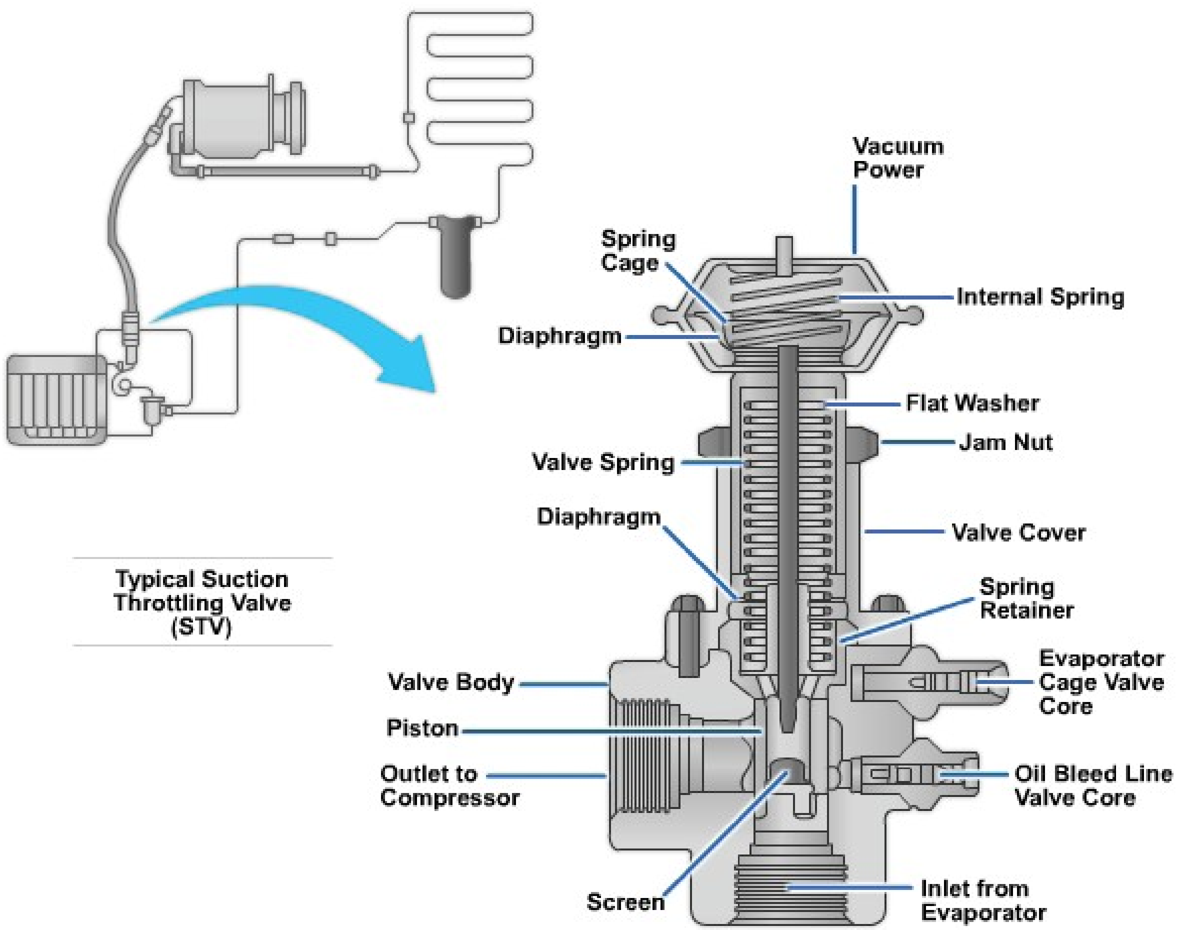

Figure 13-9 - Suction throttling valve.

2.3.4 ilot-Operated Absolute Suction Throttling Valve

The pilot-operated absolute (POA) suction throttling valve (*Figure 13-10*) maintains the proper minimum evaporator pressure regardless of compressor speed, evaporator temperature, and changes in altitude. The POA suction throttling valve is operated by a bellows containing an almost perfect vacuum. The expanding and contracting action of the bellows operates a needle valve, regulating its surrounding pressure. As inlet and outlet pressure are equalized, spring pressure closes the valve. The pressure differential across the valve then forces the piston toward the lower pressure, therefore opening the valve to allow refrigerant to flow.

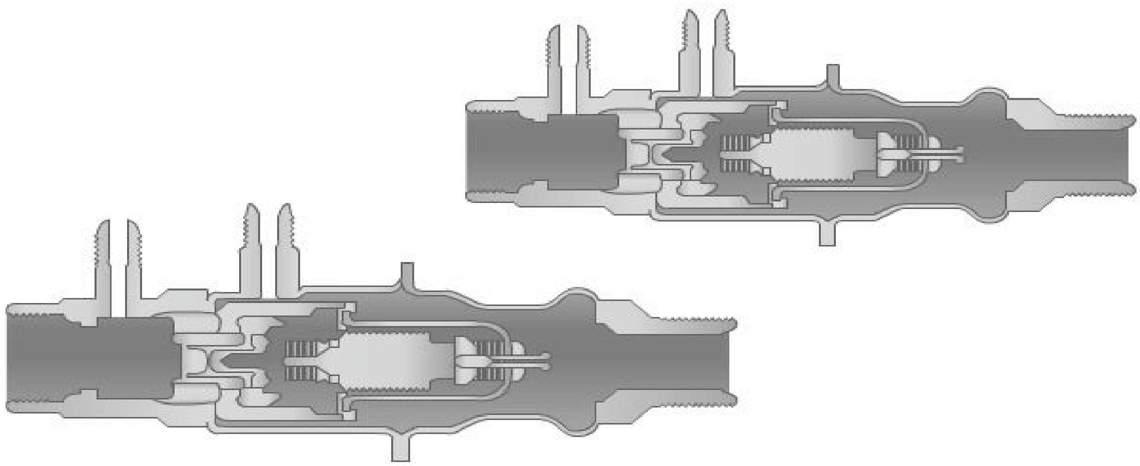

Figure 13-10 - Pilot-operated absolute suction throttling valve.

2.4.0 The Compressor

The compressor increases the pressure of vaporized refrigerant exiting the evaporator. When the system is activated, a coil produces a magnetic field that engages the drive pulley to operate the compressor (*Figure 13-11*). Some compressors are protected from overheating by a superheat switch located inside the compressor. Should the compressor develop an excess amount of heat due to a loss of refrigerant or oil, the superheat switch disengages the compressor by completing a circuit and opening a thermal fuse. Sometimes a compressor discharge pressure switch is used to protect against a low refrigerant condition. This switch disengages the compressor drive to protect the system when discharge pressure drops below approximately 35 psi (241 kPa). Often a muffler is used on the outlet side of the compressor. The muffler helps reduce compressor pumping noise and line vibrations.

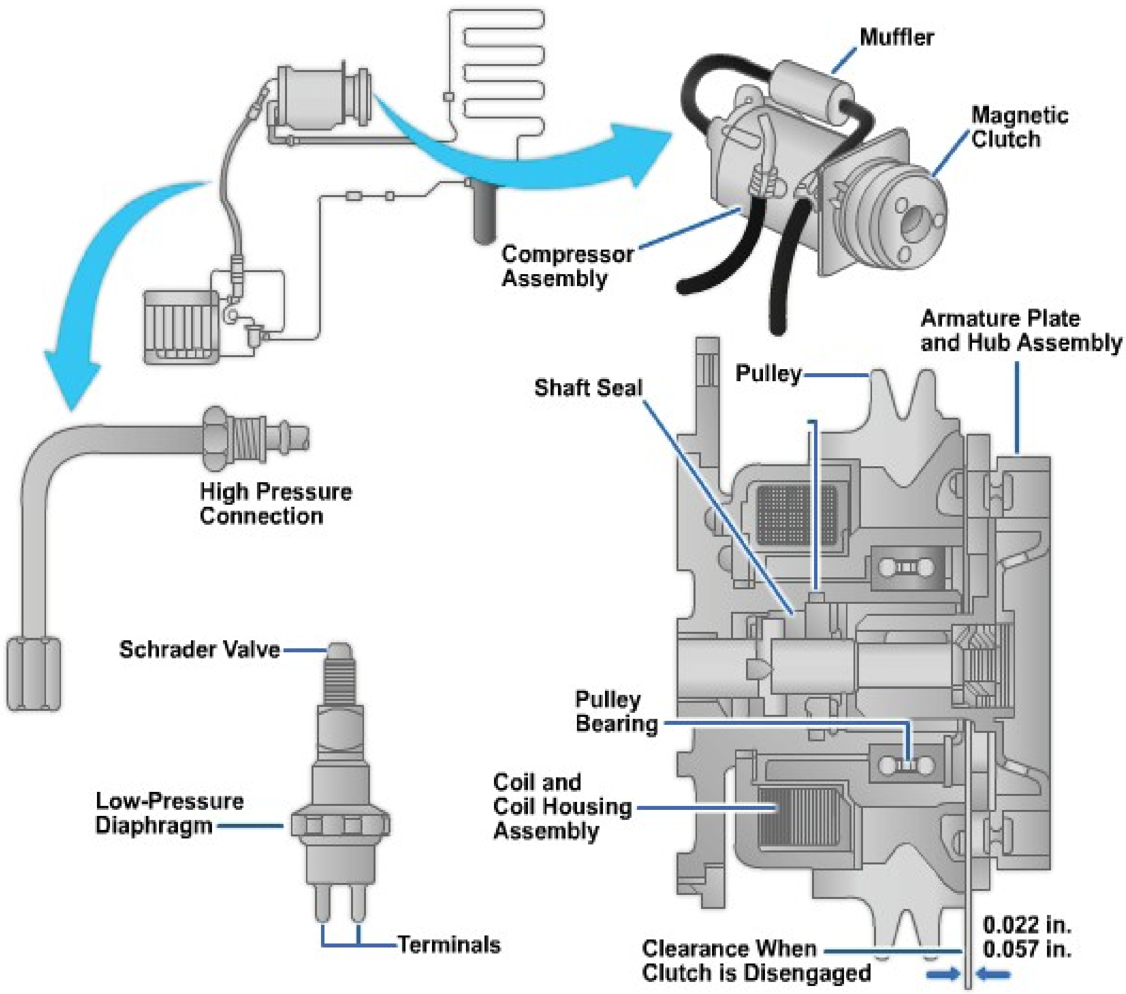

Figure 13-11 - The compressor and its components.

2.5.0 The Condenser

The condenser (*Figure 13-12*) is designed to remove heat from the compressed refrigerant, returning it to a liquid state. Generally, condensers are made from a continuous tube looped back and forth through rigidly mounted cooling fins. They are made of aluminum and can encounter pressures of approximately 150 to 300 psig and temperatures ranging from 120°F to 200°F (48°C to 93°C). Usually, the condenser is mounted in front of the radiator and is subjected to a steady stream of cooling air.

Refrigeration oil provides lubrication for the compressor. Each system has a certain amount of refrigeration oil (usually approximately 6 to 10 ounces (177 to 296 Ml)) added to the system initially. If the system stays sealed, the oil will not break down or need to be changed. Refrigeration oil is highly refined, must be free of moisture, and is designed for use in automotive air-conditioning systems.

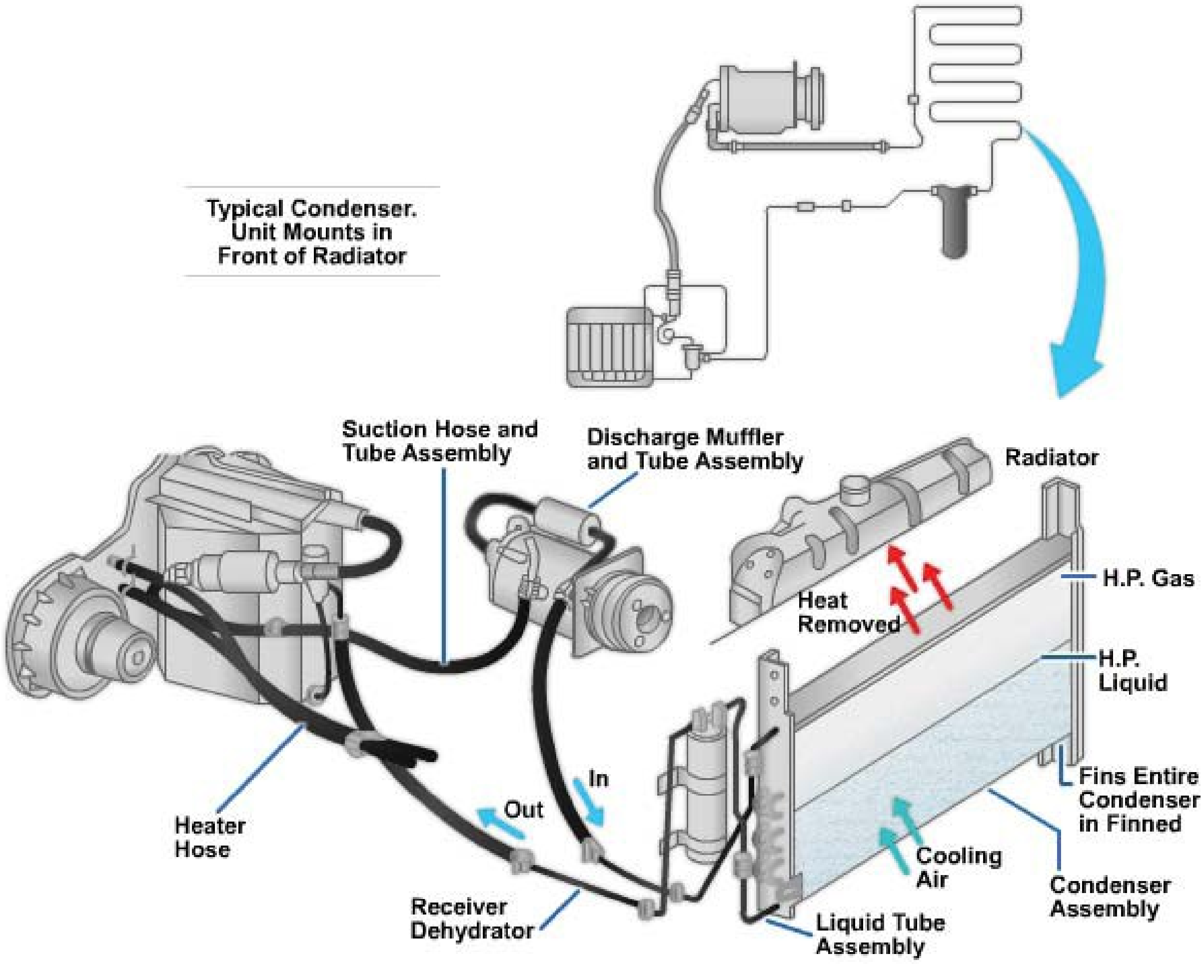

Figure 13-12 - The condenser.

Test your Knowledge (Select the Correct Response)

2. In an air-conditioning system, what is the purpose of the receiver/drier?

   A. It collects high-pressure refrigerant.
   B. It lowers the pressure of the refrigerant.
   C. It raises the pressure of the refrigerant.
   D. It seperates the liquid refrigerant to a gas.

3.0.0 MALFUNCTIONS of COMPONENTS in the AIR-CONDITIONING SYSTEM

Problems in automotive air-conditioning systems are not uncommon. An ordinary industrial system does not have to contend with the vibration that a mobile unit does. What follows is a list of common problems and possible causes associated with each air-conditioning component. This is by no means a complete list, so you should have the manufacturer's vehicle repair manual handy.

3.1.0 The Compressor

A thumping noise in the compressor or a cool and sweating compressor suction line accompanied by no cooling is usually caused by too much refrigerant in the system. If there is no moisture in the system, the excess refrigerant should be removed and stored for proper disposal. If moisture is present, you must discharge, evacuate, and recharge the system.

3.2.0 The Condenser

The condenser unit could have clogged fins that limit the cooling ability of the unit. This could be caused by bugs, leaves, or other debris caught in the tins. This can be corrected by using air pressure to blow out the coils, Check for any icy or frosty spots on the condenser. An abnormally cold spot usually indicates partial restriction inside the condenser coils at that point. Restrictions are normally caused by foreign matter. Correct this condition by discharging and purging the system.

3.3.0 The Evaporator

The evaporator is normally maintenance free for the life of a vehicle. If the evaporator does develop a leak, it will be necessary to remove the assembly for repair. An evaporator is repaired in the same manner as a radiator. If the evaporator does not get the right amount of refrigerant, the expansion valve is most likely at fault.

3.4.0 The Expansion Valve

The most common malfunction in the expansion valve is icing caused by moisture in the air-conditioning system. The system must be discharged and evacuated to remove all moisture. On occasion, the expansion valve may stick open or closed; in this case, you must replace the valve.

3.5.0 The Receiver/Drier

The receiver/drier may become saturated with moisture, or the filter may become restricted. If the receiver/drier is saturated or restricted, replace it. For any of these repairs, comply with the appropriate maintenance manual.

4.0.0 INSPECTING the AIR CONDITIONING SYSTEM for LEAKS

Approximately 80 percent of all air-conditioning service work consists of your inspecting for and repairing leaks. Many leaks will be located at points of connection and are caused by vehicle vibration. They may only require the retightening of a flare connection or a clamp. Occasionally, a hose will rub on a structural part to create a leak, or a hose may deteriorate and require replacement. The compressor shaft seal may also require occasional replacement. Anytime the system requires more than one-half pound of refrigerant after operating during one season, a serious leak is indicated that you must locate and repair. The following information covers a few of the various means of detecting leaks.

CAUTION

When any tests or repairs are being made on a charged air-conditioning system, always wear adequate eye protection.

4.1.0 Internally Charged Detector

This detector is a specially colored leak detector available in a pressurized can and mixed with R-134a. It can be introduced into the air-conditioning system with regular charging equipment. When a leak occurs in the system, a bright red-orange spot appears at the point of leakage and remains until it is wiped off. The internal leak detector remains in the system and will spot future leaks in the same manner. A sticker is usually placed under the vehicle hood to indicate that the system is charged with a leak detector.

4.2.0 Bubble Detector

The bubble detector is a solution applied externally at suspected leak points. Leaking refrigerant will cause the detector to form bubbles and foam.

4.3.0 Electronic Detector

This instrument indicates leaks electronically by flashing a light or sounding an alarm. There are several different types of electronic detectors. Directions for using the instruments are furnished by the manufacturer. This type of electronic leak detector is the one most widely used today (*Figure 13-13*).

Figure 13-13 - Electronic leak detector.

5.0.0 PURGING THE AIR-CONDITIONING SYSTEM

Anytime an air-conditioning system is discharged and opened before it is returned to service, it must be evacuated and recharged. To perform this operation, you need certain tools, such as a vacuum pump (*Figure 13-14, View A*), a gauge manifold set (*Figure 13-14, View B*), and a leak detector. Using the vacuum pump, draw the system down to at least 29 inches of mercury at sea level and hold it there for at least 30 to 45 minutes. This will remove all moisture from the system.

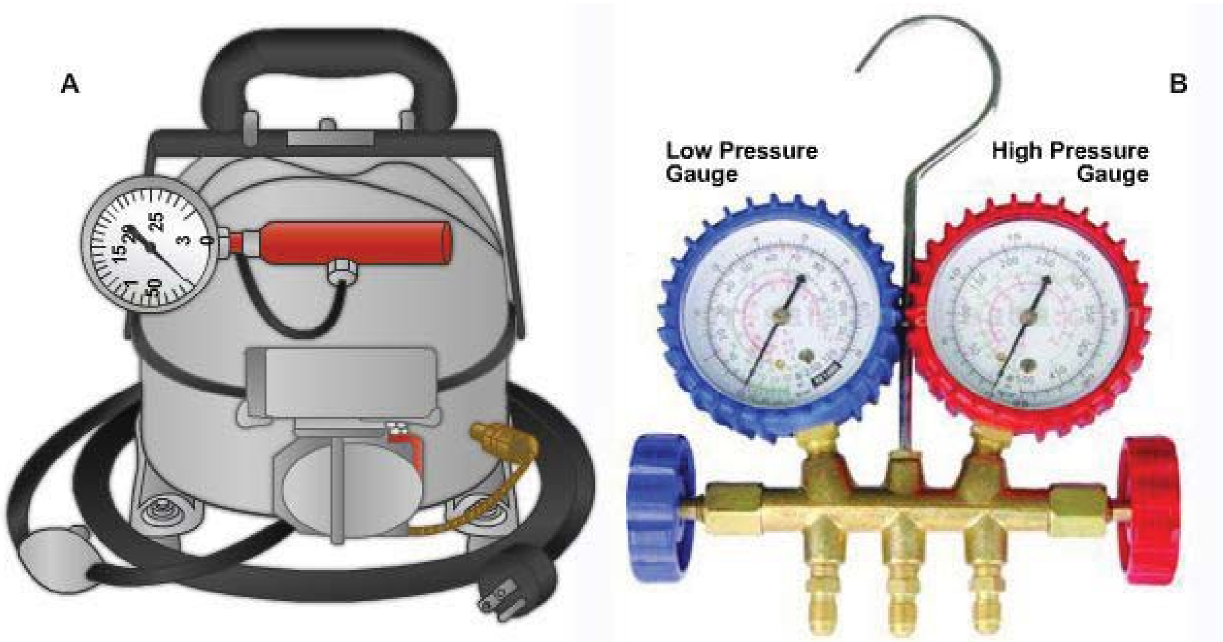

Figure 13-14 - Vacuum pump and gauge manifold set.

As the system is being pumped down, the vacuum should drop to the required inches of mercury. If it does not drop, this is an indication of a leak; in which case you must recharge the system to detect the leak. After you detect the leak, repair the damage and re-evacuate the system.

Once the system is totally evacuated, again close both valves on the gauge manifold set, disconnect the vacuum pump, and connect the refrigerant source.

NOTE

Any oil lost during the discharge of refrigerant must be replaced or damage to the compressor will result.

NOTE

During discharge of an automotive air-conditioning system, the vehicle engine must NOT be running.

In the past, when a system was discharged before disassembly, the standard practice was to vent the refrigerant into the atmosphere. For environmental and legal reasons, this is no longer permissible. The proper procedure is to use a refrigerant recovery/recycling device (*Figure 13-15*) and reuse the refrigerant. You are to turn in excess used refrigerant to the Defense Recycling and Management Office (DRMO) for proper disposal.

NOTE

Disposal instructions for refrigerants may not be the same at different naval stations. Before you take any action concerning R-134a or any refrigerant, contact your supply department for proper disposal instructions.

Figure 13-15 – Refrigerant recovery/recycling device.

6.1.1 ADDING REFRIGERANT to the AIR-CONDITIONING SYSTEM

Now that the system is pumped down, leave the gauge manifold set attached and attach your refrigerant source, as shown in *Figure 13-16*. You are to take the following actions:

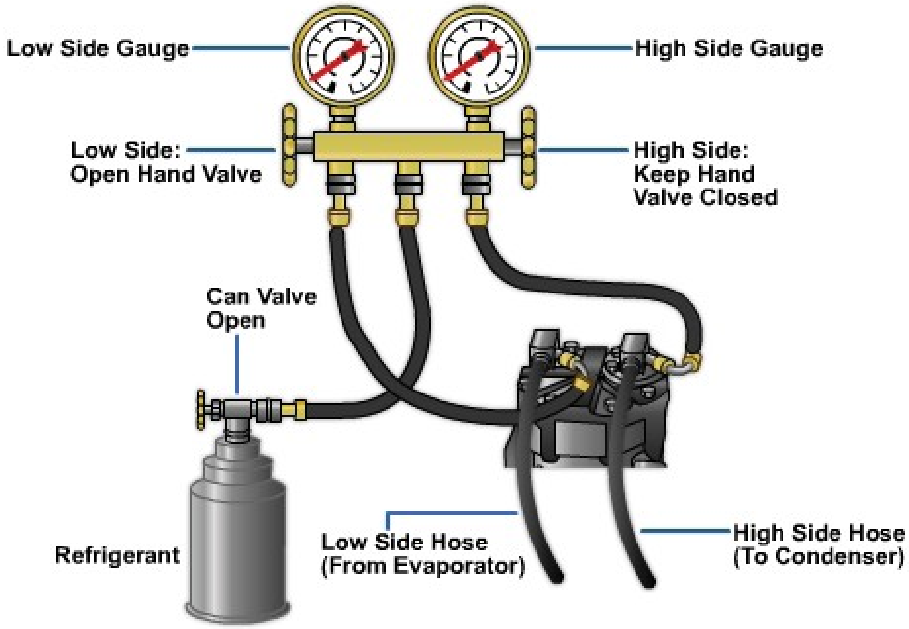

Figure 13-16 - Adding refrigerant to the air conditioning system.

1. Loosen the center hose connection at the gauge manifold set.
2. Open the can valve for several seconds to purge air from the center hose.
3. Tighten the hose connection and close the can valve.
4. Start the vehicle engine and operate the air conditioner.
5. With the system operating, slowly open the low-side manifold hand valve to allow refrigerant to enter the system.

NOTE

The low side of the system is the suction side, and the compressor will pull the refrigerant from the can into the system.

6. With the container in an upright (vapor) position, add the refrigerant until the sight glass clears or the test set gauge readings are normal.
7. Rock the refrigerant can from side to side to increase the flow of refrigerant into the system.

CAUTION

Never turn a can into a position where liquid refrigerant will flow into the system.

8. Close the low-side manifold valve and the refrigerant can valve.
9. Continue to stabilize the system and check for normal refrigerant charge.

7.0.0 FUNCTIONAL TESTING of the AIR-CONDITIONING SYSTEM

Functional testing is required to establish the condition of all components in the system. The engine must be running and the air-conditioning system operating when performing this test. After the initial charge of refrigerant is installed into the system, watch the manifold gauge set. Correct pressure should be 15 to 30 psi for the low side and 175 to 195 psi for the high side. Evaluate the reading you receive against the standard chart in *Table 13-1*. If the vehicle you are working on is equipped with a sight glass (*Figure 13-4*), the bubbles should disappear at the correct pressures. Close the low side gauge manifold set hand valve. Check the temperature of the air exiting the cooling duct. It should be close to 40°F with the blower running on low speed. Stop the engine and disconnect the gauge manifold set.

Table 13-1 - Temperature Pressure Relationship.

Readings-Low Side		Readings-High Side	
Evap Temp (^{0}F)	Low Side Gage	Ambient Temp (^{0}F)	High Side Gage
10	2	60	95-115
12	6	65	105-125
14	10	70	115-135
16	14	75	130-150
18	18	80	150-170
20	20	85	165-185
22	22	90	175-195
24	24	95	185-205
26	27	100	210-230
28	29	105	230-250
30	32	110	250-270
35	36	115	265-285
40	42	120	280-310
45	48		
50	53		
55	58		
60	62		
65	66		
70	70		

Summary

In this chapter, you learned how to inspect, fill, and troubleshoot air-conditioning systems found in late model vehicles. Keeping the operators comfortable is an important aspect of being a Construction Mechanic. It is also important to know that you cannot let the refrigerant loose into the environment, and you now know some of the other hazards associated with refrigerant. Types of refrigerant and the oils the systems use can be ever changing with the environmental hazards associated with them, so stay up to date on what is required of you and your air-conditioning system. When you have mastered the knowledge of these systems, you will become a better CM.

Review Questions (Select the Correct Response)

1. If two objects have different temperatures and are close to one another, heat energy travels in what direction, if any?

   A. From the cooler object to the warmer object
   B. From the warmer object to the cooler object
   C. None; heat energy travels only when the objects actually touch one another

2. A sizeable amount of refrigerant-134 in the atmosphere may cause what result?

   A. Fire
   B. Explosion
   C. Suffocation
   D. Halucination

3. When warming a container of refrigerant-12, you should not exceed what temperature?

   A. 90°F
   B. 100°F
   C. 110°F
   D. 125°F

4. What is the purpose of the desiccant located inside the receiver?

   A. It relieves pressure in the system.
   B. It acts as a filter.
   C. It acts as a bypass for the refrigerant.
   D. It removes moisture from the system.

5. The relief valve opens between approximately what pressure ranges?

   A. 200 to 300 psi
   B. 300 to 400 psi
   C. 400 to 450 psi
   D. 450 to 500 psi

6. When you observe bubbles in the site glass of an air-conditioning system, what does it indicate?

   A. That no refrigerant is in the system
   B. That the system is overcharged
   C. That the system is undercharged
   D. That too much oil is in the system

7. The expansion tube retards refrigerant flow and performs what other function?

   A. It acts as a filter.
   B. It raises refrigerant pressure.
   C. It regulates refrigerant entering the condenser.
   D. It opens the valve to allow the refrigerant to flow.

8. The evaporator should be kept above what temperature in degrees?

   A. 30°F
   B. 32°F
   C. 40°F
   D. 45°F

9. Where is the thermostatic switch-sensing bulb located in an air-conditioning system?

   A. In the airstream after the evaporator
   B. In the airstream before the evaporator
   C. On the compressor clutch
   D. In the airstream after the condenser

10. In an air-conditioning system, what does the suction throttling valve limit?

   A. Condenser operation
   B. Evaporator operation
   C. The amount of high-pressure vapor entering the compressor
   D. The amount of low-pressure vapor entering the compressor

11. In an air-conditioning system that uses a pilot-operated absolute suction throttling valve, by what means does the valve close as the inlet and outlet pressures equalize?

   A. Spring pressure
   B. Outlet pressure
   C. Inlet pressure
   D. Oil pressure

12. A compressor discharge pressure switch is used to protect against what air-conditioning system problem?

   A. Overcharging
   B. Overspeeding
   C. Low refrigerant
   D. High-discharge pressure

13. The air-conditioning system compressor muffler reduces noise along with what other problem?

A. High-discharge pressure
B. Low-discharge pressure
C. Line vibrations
D. To aid in sealing

14. In an air-conditioning system, where is the condenser usually mounted?

A. Within the engine compartment
B. In front of the radiator
C. In back of the radiator
D. In the driver's compartment

15. Approximately how much refrigeration oil is contained within each system?

A. 1 pint
B. 2 to 4 ounces
C. 4 to 6 ounces
D. 6 to 10 ounces

16. In an air-conditioning system, when the compressor produces a thumping noise and no cooling, it is an indication of what condition?

A. A clogged condenser
B. A faulty evaporator
C. Low oil level
D. Too much refrigerant

17. An abnormally cold spot on a condenser could indicate what condition?

A. A faulty compressor
B. A partially clogged condenser
C. A faulty evaporator
D. Too much refrigerant

18. What action must you take if the receiver/drier is saturated?

A. Remove it and replace the desiccant.
B. Evacuate the system and recharge it.
C. Replace the receiver/drier.
D. Over-pressurize the system to blow it out.

19. Which of the following is the most widely used refrigerant leak detector in use today?

A. Flame
B. Bubble
C. Electronic
D. Internal charge

20. The air-conditioning system that is being evacuated must be drawn down to 29 inches and held for how many minutes?

A. 10 to 15
B. 15 to 30
C. 30 to 45
D. 45 to 60

21. What is normally done with excess used refrigerant?

A. It is pumped into containers and turned into DRMO.
B. It is turned into the local public works department.
C. It is held in the shop for reuse.
D. It is released into the building's ventilation filters.

22. What is another name for the low side of the compressor?

A. High-pressure side
B. Low-pressure side
C. Fluid side
D. Suction side

23. During the functional testing of an air-conditioning system, what should be the temperature of the air exiting the cooling duct?

A. 32°F
B. 35°F
C. 40°F
D. 45°F

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Heavy Duty Truck Systems 4th Edition, Sean Bennet, Delmar Cengage Learning, 2006. (ISBN-13:978-1-4018-7064-5)

Modern Automotive Technology 7th Edition, James Duffy, The Goodheart-Wilcox Company, Inc., 2009. (ISBN: 978-1-59070-956-6)

Automatic Transmissions and Transaxles, James Duffy, The Goodheart-Wilcox Company, Inc., 2005. (ISBN: 1-59070-426-6)

Manual Drive Trains and Axles, Chris Johanson, James Duffy, The Goodheart-Wilcox Company, Inc., 2004. (ISBN: 1-59070-320-0)

Power trains, Fundamentals of Service, Deere and Company, John Deere Inc., 2005. (ISBN: 0-86691-325-4)

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