MLR: Drivetrain Study Guide

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Introduction

All conventional automotive vehicles must have a **drivetrain**. The purpose of the drivetrain is to transfer the power developed in the engine to the driving wheels. The turning force (torque) from the engine's crankshaft is carried by the drivetrain and its **drive axles** to the drive wheels.

Many configurations have been used to accomplish this task, but some components are common to all vehicles in one form or another. **Front**-**engine**, **rear**-**wheel**-**drive** vehicles have a **transmission** to provide gear reduction, and a **drive shaft** to transmit power from the transmission to the other major component, the **rear axle assembly**. The rear axle assembly splits up the torque coming from the drive shaft to send power to both **rear axles**. The rear axles are at 90 degrees to the drive shaft. This is accomplished by using a **differential assembly**. The differential also provides additional gear reduction and a means for torque to be delivered to the rear wheels even when they are rotating at different speeds (such as when turning - the outside wheel must travel farther and therefore faster than the inner wheel).

Front-**engine**, **front**-**wheel**-**drive** vehicles incorporate the transmission and the differential assembly into a single case, and the unit is called a **transaxle**. **Drive axles** then deliver the power from the transaxle to drive wheels.

For simplicity's sake, in our discussions of clutches, transmissions, and differentials, we will use mostly rear-wheel-drive applications in our examples and animations. The principles are the same as for front-wheel-drive applications, which use a transaxle. Note that in some general contexts elsewhere, the term "drivetrain," "powertrain," or "running gear" may be intended to include the engine as well.

Automatic vs. Manual

The drivetrain must provide a means of connecting and disconnecting engine power from the transmission to permit the stopping and idling of the vehicle. It must also allow this coupling to be gradually engaged, for smoothly pulling away from the curb.

The job of disconnecting, connecting, and transitioning the power to the transmission (or transaxle) is accomplished in one of two ways, depending on the type of transmission used. Vehicles equipped with an **automatic transmission** achieve this through the use of a fluid coupling called a **torque converter** between the engine and transmission. No action is required by the driver to engage the drivetrain, other than to depress the accelerator pedal.

On vehicles equipped with a **manual transmission**, in which the driver manually selects the proper gear for the conditions, this connecting and disconnecting is achieved through the use of a driver-operated **clutch** between the engine and transmission. With manual transmission-equipped vehicles, engine power must also be temporarily disconnected to enable the driver to shift from one gear to another.

Drivetrain Layouts

You will need to be able to identify parts of the drivetrain depending on which type of drivetrain the vehicle has:
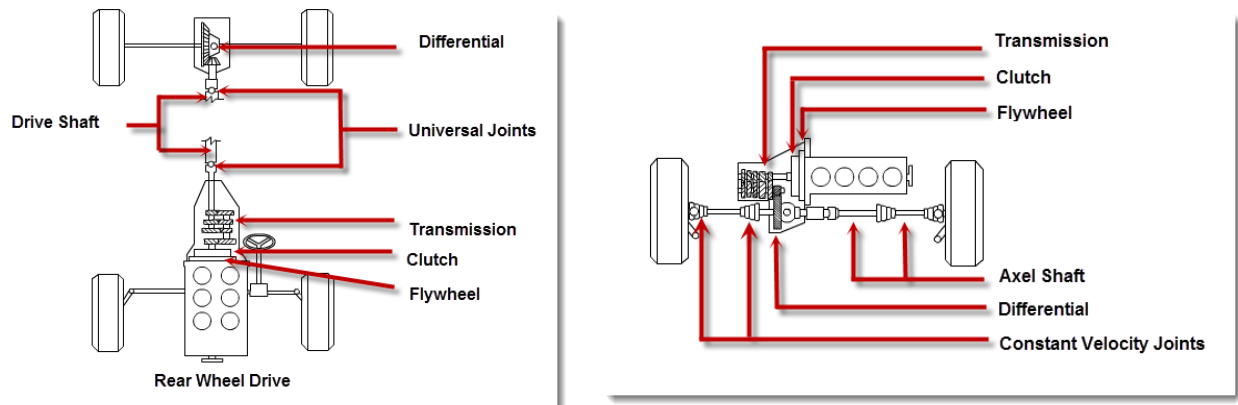
Chapter 2: Service Preparation and Lubricant

Review Vehicle and Service Information

An important step before working on a vehicle is to review service information. Identify all fluid types and capacities, note service precautions, and review Technical Service Bulletins (TSBs) related to the vehicle's drivetrain system. When completing the repair order, ask the owner for the vehicle's service history. This information is useful to safely perform diagnosis procedures and service the drivetrain components.

Checking Lubricant

Sometimes, problems such as noise and hard shifting are caused by insufficient or incorrect lubricant. If the customer is lucky, the problem might be corrected by repairing any leaks and refilling with approved lubricant before substantial damage has been done. Leaks can occur due to gasket failure, oil seal failure, loose or missing case bolts, or case damage. The lubricant level on most transmissions should reach the bottom of the fill hole when at operating temperature. You should be able to easily reach it with a finger. Make sure the piece you remove is indeed the fill plug and not transmission hardware before removing it.

The oils seals are normally lip seals found in the front bearing retainer and the rear of the extension housing. When these seals leak, you should check or replace the shaft bushing or bearing, too. A bad bushing or bearing allows too much lateral movement of the shaft, which is often what caused the seal to leak in the first place. The extension housing bushing and seal can usually be replaced without removing the transmission.

How to check and refill transmission/transaxle fluids

Most manual transmission/transaxles have an access port located in the side of the case that is at the correct height for the fluid level. To check the fluid level:

- The vehicle must be raised in the level position
- The technician must locate and identify the access port, remove the access port, and determine if the fluid level is at or near the access port opening
- If fluid level is low, the technician must first determine the correct fluid specified for refilling the transmission/transaxle
- Then, using a fluid pump, fluid is added through the access port until it reaches the bottom of the opening (do not overfill)
- Re-install the access port plug and clean away any remaining fluid residue from the outside of the transmission/transaxle

Diagnosing and Correcting for Fluid Loss

How to diagnose fluid loss and fluid condition concerns and determine necessary action to correct the condition

A visual inspection is used to identify the cause of manual transmission/transaxle fluid loss. The inspection should include fluid leaks at each seal and gasket area and at the clutch housing. Fluid leaking from the clutch housing could be caused by a fluid leak from the transmission input shaft seal (not visible without removing the transmission). If the input shaft seal fails, transmission/transaxle fluid can flow into the clutch housing where it leaks through the opening to the outside of the clutch housing.

Note: Fluid leaking from the clutch housing must be analyzed to determine the source. Engine oil and clutch release fluid as well as transmission/transaxle fluid are all possible sources of fluid leakage from the clutch housing. Check transmission/transaxle case and extension housing(s) for leaks that may be caused by cracks or damage to these components.

To check transmission/transaxle fluid condition:

- Remove a small amount of fluid and place in a clean container
- Inspect the fluid for water contamination
  - If the fluid is milky or foamy, water may have entered the transmission/transaxle
  - If the fluid appears to be burned, the transmission may have been driven with low fluid level or have been abused by the driver
- Inspect the fluid for metal particles
  - Fine brass colored particles are normally the result of synchronizer wear
  - Small silver metal particles can be caused by gear wear
  - Chunks of metal are signs of gear damage
- Based on the type and amount of material in the fluid, the technician must determine the necessary action to correct the condition

- Contaminated fluid must be drained and replaced, but if the transmission/transaxle has symptoms that indicate that damage has occurred, changing the fluid may not correct the condition
- A small amount of brass or silver particles in the fluid may be normal and if the vehicle has no symptoms of transmission/transaxle problems, draining and replacing the fluid is the only service required
- If metal chunks or a large amount of brass or metal particles are found in the fluid or if the vehicle has symptoms of transmission /transaxle problems, the transmission/transaxle will need to be removed and repaired or replaced

Draining and Refilling

How to drain and refill the manual transmission/transaxle and final drive
Review service information to determine the correct procedure and correct fluid type for vehicle being serviced.

Common procedures for draining and refilling the transmission/transaxle and final drive normally include:

- Remove the drain plug (not all units have drain plugs; use service information to determine how to remove the old fluid) and catch the old fluid as it drains
- When all of the fluid has drained out, reinstall the drain plug and tighten to correct specifications
- Remove the fill port, access plug and using a fluid pump, refill the transmission/transaxle to the correct level
- Reinstall the access port plug and tighten to correct specifications

Many transaxles have separate compartments for the transmission fluid and differential fluid. In these types it is necessary to:

- Drain the fluid from the differential (through a drain plug or removing a cover)
- Once all of the fluid has drained out, reinstall the drain plug or cove
- Use service information to identify the correct fluid type and the location of the differential fill access port plug
- Remove the fill plug and use a fluid pump to refill the differential to the correct level
- Reinstall the full plug and tighten to the correct specifications

# Unit 2: Clutch Diagnosis and Repair

Chapter 1: Clutch Components

Clutch Principles and Function
For our study of the drivetrain, it is logical to begin at the front of the drivetrain and work our way back from there. So, we will begin with the clutch, which of course is only found in manual transmissions.

As we noted in the introduction, the connecting, disconnecting, and gradual application of torque to a manual drivetrain is accomplished with the use of a clutch. Without a clutch, the engine would not be able to run while the vehicle was at rest, nor would you be able to change gears as needed for different speeds. To apply the engine power to the transmission gradually from a stop, the driver increases engine speed slightly, while gradually releasing the clutch pedal. The clutch is allowed to "slip" briefly. This enables the vehicle to develop enough momentum to permit complete connection of the engine to the transmission without stalling the engine. This is referred to as "engaging the clutch." It takes a little practice, and most people stall the engine the first time they try it.

Fundamentally, the clutch consists of friction surfaces. A friction surface is attached to the end of the crankshaft and another is attached to the input shaft of the transmission. When engaged, spring tension strongly holds the surfaces together, forming a mechanical coupling that transfers power through the clutch. When disengaged by depressing the clutch pedal, a small gap exists between the friction surfaces, so there is no contact and thus no power is transferred.
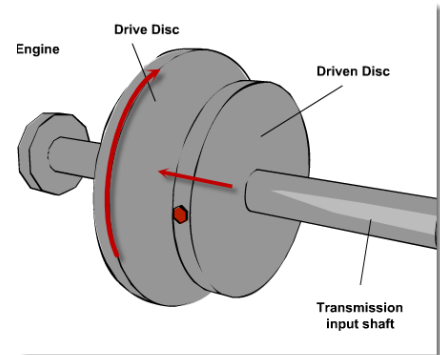
Clutch Components and Operation

The main components of a clutch are the flywheel, the pressure plate, the clutch disc, and the clutch release mechanism with its associated parts. There are also bearings that reduce shaft friction, center the drivetrain, and support its weight. Let's look at the parts of the automotive clutch and how they work together.
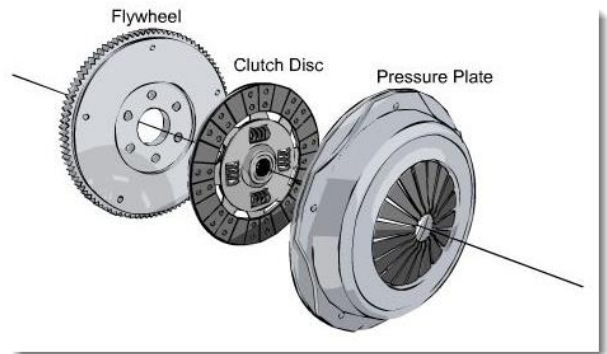
Flywheel

The flywheel serves several functions for the engine and drivetrain. The flywheel is a heavy, balanced disc that is bolted to the end of the crankshaft. It has a ring gear around its circumference with teeth to provide a means to start the engine. The pinion gear on the starting motor engages with these teeth when starting the engine.

The flywheel is usually made heavy to give it a lot of mass. The momentum of the spinning flywheel helps to even out power pulses from the engine and provide smoother running.

Since the back, or face, of the flywheel is a clutch friction surface, it is precision machined with a smooth, slightly textured surface. It functions much like a disc brake rotor. The friction surface (if not the whole flywheel) is usually made of iron because it's durable and dissipates heat well. Some flywheels are made of steel or aluminum.

Vehicles equipped with automatic transmissions have a similar disc bolted to the crankshaft, called a flex plate, but it is much lighter than a flywheel and its chief purpose is to provide a means to crank the engine. The other functions of the flywheel are provided by the torque converter.

Clutch Disc

The clutch disc is a round metal plate with **friction material** on both sides and a **splined hub** in the center. The splines in the hub mesh with splines on the **input shaft** of the transmission, locking them together. However, the clutch disc is free to move back and forth on the shaft. This allows it to contact the flywheel for clutch engagement, and to move away from the flywheel for disengagement.

The friction material lining the faces of the clutch disc are made of heat-resistant materials similar to brake linings. You may think of the flywheel and pressure plate faces as similar to a brake rotor, and the clutch disc as similar to brake pads or shoes. And here is a similar warning:

Caution: Clutch disc friction materials for many years were commonly made of asbestos compounds for their superior heat resistance. Breathing asbestos dust may cause serious bodily harm such as cancer. Avoid creating airborne dust or breathing dust when working with clutches.

Other, non-asbestos materials have been developed and used for many years; however, there are still vehicles on the road with asbestos clutch materials. Some vehicle applications and parts suppliers also may still employ asbestos clutch linings. For this reason, treat all friction material dust as if it contained asbestos. The friction linings are riveted to the clutch plate, and are cut with grooves for cooling and to aid in clutch disengagement.

The clutch disc has a couple of features designed to soften and smooth clutch engagement. Springs are used in two ways to do this. The first way is with the use of **torsion springs**. Most clutch discs have a number of torsion springs between the hub and the friction disc. Also called **damping springs**, they compress when the clutch is first engaged, reducing the shock. They also reduce the amount of engine vibration reaching the transmission while driving.

The second way a spring is used to smooth the clutch engagement is with a **cushioning spring**. The cushioning spring is a plate-like disc of spring steel in between the faces of the clutch disc. It's made in a wavy shape that allows some compression of the clutch disc, cushioning clutch engagement.

Pressure Plate

The pressure plate assembly, or **clutch cover assembly**, is the working member of the three friction components of the clutch. It enables the clutch to be disengaged and engaged. The springs that clamp the friction surfaces together when the clutch is engaged are contained in the pressure plate assembly. This assembly is bolted to the back of the flywheel, and the clutch disc is sandwiched in between the flywheel and the pressure plate. The assembly consists of the **pressure plate cover**, **face**, **springs**, and sometimes **release levers**. Since the pressure plate assembly is bolted to the flywheel, it rotates at all times. But the clutch disc only rotates when the clutch is engaged. Since the clutch disc is splined to the transmission input shaft, power is then delivered to the transmission.
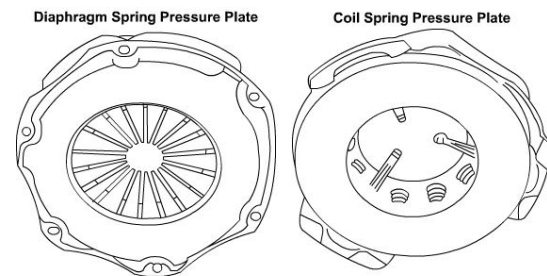
Pressure Plate Cover

The cover houses the components of the pressure plate assembly and holds them together. We have shown that it provides the means to bolt the assembly to the flywheel.

Pressure Plate Face

Like the flywheel, the pressure plate face is usually made of iron, and the friction surface is precision-machined. The pressure plate springs are seated or attached to the back of the face. The pressure plate face moves back and forth inside the cover as the clutch pedal is operated.

Pressure Plate Springs

There are two main types of pressure plate spring systems: **coil spring** and **diaphragm spring**.
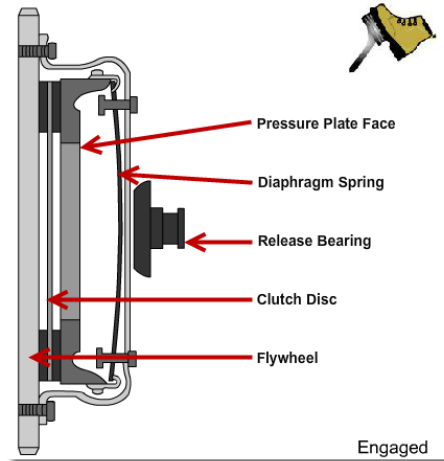
Diaphragm Spring Pressure Plate

All of the pressure plate images shown until now illustrate diaphragm spring pressure plates. The diaphragm spring is a round, dish-shaped spring with numerous segments radiating towards the center. The spring action is similar to that of an old-style oil can. A **release bearing**, actuated by the clutch pedal, acts directly on the inner ends of the spring, overcoming the spring tension that engages the clutch. This disengages the clutch.

Holes around the circumference of the spring at the base of the spring segments enhance the spring action and eliminate stress points that would cause cracks.

Diaphragm springs require less force from the release bearing to disengage the clutch, they use less space, and the assembly is lighter and more easily balanced than the other main type of pressure plate (coil spring).

Engaged

Coil Spring Pressure Plate

Operation of a coil spring pressure plate is similar to a diaphragm spring pressure plate, but it has a few additional parts. Instead of one large spring, this type has a number of smaller coil springs placed around the back of the pressure plate face. The release bearing does not act directly on the springs, but rather on **release levers** that pivot and push or pull the pressure plate face away from the clutch disc and flywheel.

Coil spring pressure plates are better suited than the diaphragm type for heavier-duty applications. The pressure plate can be "tuned" for different applications by using more or larger springs at the factory, or even in the aftermarket. This will make the clutch apply with more force, so it doesn't slip under heavy load. Stronger springs mean more pedal effort will be required to disengage the clutch. For such applications, engineers often design clutch disengagement mechanisms that make the most of mechanical leverage in linkages, or use hydraulics. One way in which mechanical leverage can be increased is with the use of **overcenter** springs. The overcenter spring principle will be discussed later in this section. A coil spring pressure plate can be made even stronger still with the use of weights that are angled towards the rear on the outer ends of the release levers. The weights use centrifugal force to make the pressure plate grip tighter at higher RPMs.

Engaged
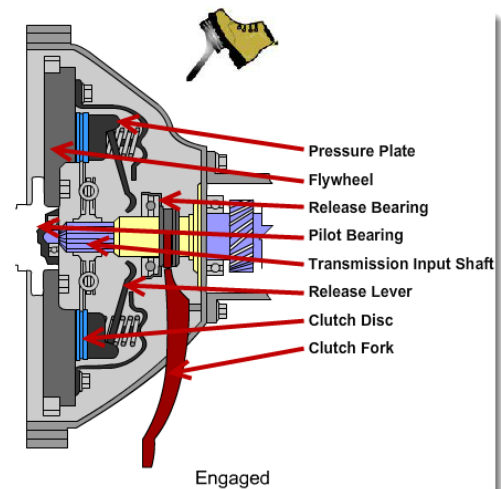
Release Mechanism

Clutch Release Methods

Movement of the clutch pedal can be transmitted to the clutch assembly in three ways: by **mechanical linkage**, a **cable**, or a **hydraulic circuit**. Return springs are used to help bring the release mechanism and clutch pedal home to their normal positions when the clutch is engaged.
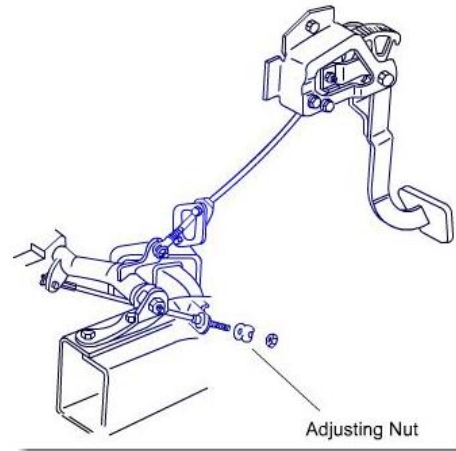
Mechanical Linkage - This method uses a system of levers and rods to disengage the clutch. Many different arrangements have been used. Typically, the clutch pedal acts upon a **bellcrank** that reverses the direction of travel and pushes on a **release rod**. The release rod then pushes on the clutch fork, disengaging the clutch. The release rod is often threaded at one end to provide a means of adjusting its length, and thus the clutch operation. Mechanical linkage is mainly found on some older vehicles.

In an earlier section, we mentioned the use of **overcenter springs** to aid leverage. Overcenter springs are designed to use springs and angles of motion to provide spring assistance when it is needed the most. This is a common principle used in many mechanical devices of various types. The way the hood springs and hood hinges on many cars work together is an example. Overcenter springs can be used on clutch linkages, and this principle is also found in the design of diaphragm spring pressure plates.
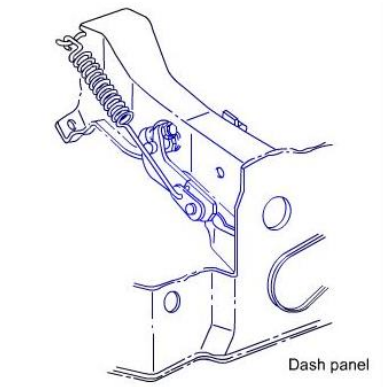
Clutch Cable - We introduced the clutch cable release in our discussion of the clutch fork. A steel cable attached to the clutch pedal moves back and forth inside a flexible housing as the clutch pedal is operated. The housing is mounted in a stationary position. It usually has a threaded sleeve on one end to allow the lengthening and shortening of the cable for clutch adjustment. Some cable release systems are self-adjusting, using a ratcheting mechanism on the clutch pedal to take up slack as the clutch disc wears.

To disengage the clutch, the cable system pulls the fork in the opposite direction (towards the front) than the other types. The cable release system is inexpensive and simple in design and operation, but it is more prone to wear and binding than other types.
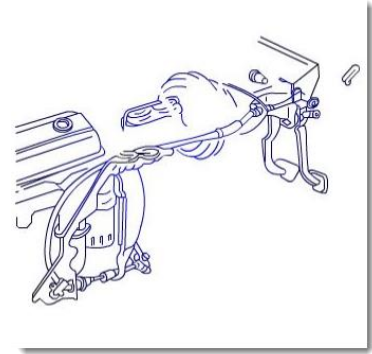
Hydraulic Circuit - Hydraulic clutches are very popular for several reasons, but they are by no means a new development. They are inexpensive to design, produce, and service, and hydraulics can multiply the force applied to the clutch pedal, reducing the amount of pedal effort required to disengage the clutch. Hydraulic lines require little space, and engineers can run them where convenient, so hydraulic clutches in a wide variety of different configurations can use similar components.

The hydraulic clutch release system uses a **clutch cylinder** (also called a **clutch master cylinder**), **a hydraulic line**, and a **slave cylinder** to transfer clutch pedal motion to the clutch fork. The hydraulic system is very much like a brake hydraulic system, and clutch systems commonly use brake fluid as well. The master cylinder is normally located on the firewall next to the brake master cylinder. A fluid reservoir may be built into the unit, or there may be a separate reservoir remotely mounted above the unit for easier access. The master cylinder is like a single-circuit brake master cylinder with no residual check valve. The hydraulic line consists of metal tubing and rubber hoses, just like a brake system. It runs from the clutch cylinder to the slave cylinder. The slave cylinder is mounted on the bell housing near the clutch fork. It is much like a wheel cylinder on a drum brake with one piston and actuating pin.
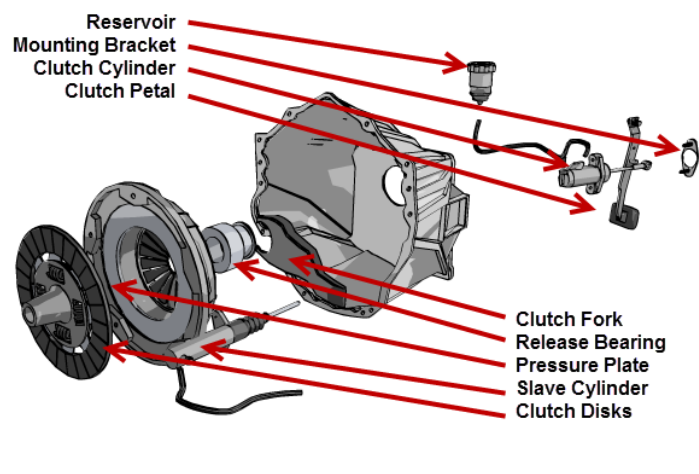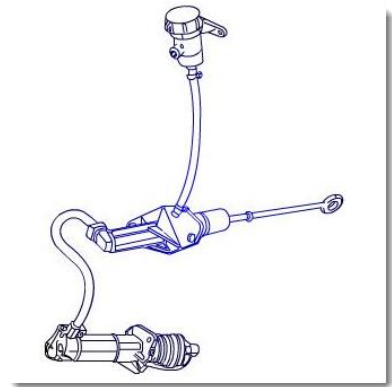
Clutch Fork

The clutch fork is part of the clutch **release mechanism**. Also called a **release arm**, **release fork**, or throwout lever, the clutch fork transmits movement from the external parts of the release mechanism to the release bearing. Many clutch forks pivot with a lever action on a **ball stud** close to the middle of the fork, although the fork on cable-operated release mechanisms pivots on the end opposite the cable. Since a cable can only pull, the cable-operated mechanism pulls the entire fork and release bearing towards the pressure plate to disengage the clutch.

The fork extends through a hole in the clutch housing to reach the external parts of the release mechanism. A protective rubber boot fits in the hole to prevent contaminants and debris from entering the clutch housing.

Another type of clutch fork uses a round shaft that rotates when the release mechanism is operated, swinging the fork and release bearing towards the pressure plate.

Release Bearing

The release bearing, commonly called a **throwout bearing**, allows the release mechanism to be activated against the rotating diaphragm spring or release levers. Most release bearings consist of ball bearings in a collar and hub assembly. Most modern release bearings are lubricated and sealed at the factory.

The release bearing slides back and forth on a sleeve that covers the transmission input shaft. This sleeve is usually part of the transmission **front bearing retainer**. Most release bearings have a groove in them to accept the **clutch fork**, which actuates the movement of the bearing along the sleeve. When the release mechanism is properly adjusted, there is a small clearance gap between the throwout bearing and the release levers or diaphragm spring, so the bearing only has to spin during clutch disengagement. This reduces wear on the bearing, and results in a small amount of **free travel**, or **free play** at the clutch pedal. The amount of free travel will be specified in the service information, usually about an inch. However, some vehicles with "self-adjusting" clutch engagement mechanisms use a special bearing that is designed to remain in contact with the pressure plate at all times.

Some older European cars use a release bearing with a solid graphite anti-friction material. When disengaging the clutch, it contacts a plate that covers the release levers.

Other Parts

Pilot Bearing or Bushing

The pilot bearing or bushing is a small but important part. It supports the input shaft of the transmission and keeps it from moving off center; this is especially important when engaging the clutch. The pilot bearing or bushing fits into the center of the crankshaft, usually with a light press fit. Pilot bearings may be of several types, using roller, ball, or needle bearings, and some are simply a sintered bronze bushing, impregnated with lubricant. Some front-wheel-drive vehicles with transaxles do not use a pilot bearing. These applications use a self-centering release bearing.
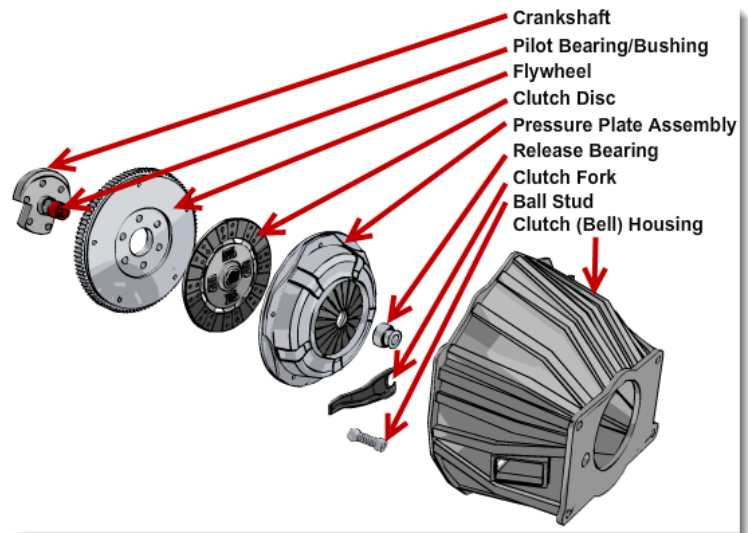
Clutch Housing

The clutch housing is also called the **bell housing**, and it encloses the clutch assembly. It bolts to the back of the engine, and the manual transmission is bolted to the back of it. On some vehicles, the clutch housing is part of the transmission case.

Clutch Assembly

Consists of the components listed in the image to the right.

Crankshaft
Pilot Bearing/Bushing
Flywheel
Clutch Disc
Pressure Plate Assembly
Release Bearing
Clutch Fork
Ball Stud
Clutch (Bell) Housing

Clutch Start Switch

Modern vehicles have a Clutch Start Switch that prevents cranking the engine with the transmission in gear unless the clutch pedal is depressed. This is a safety feature designed to prevent the vehicle from lurching or the engine from suddenly starting if the starter motor is operated while the clutch is engaged and the transmission is in gear. The switch is part of the ignition/starter circuit.

Chapter 2: Clutch Diagnosis

Replacing a clutch requires removal of the transmission or transaxle, a labor-intensive job, and so it is important to establish that the clutch is indeed faulty. You need to be sure that the symptom is not caused by improper adjustment or by some other component or system. You also need to determine why the clutch failed so the problem will not recur. If the failure was caused by oil leaking onto the friction surfaces, then you will need to repair the oil leak, for example. You will also need to be sure clutch adjustment and function is correct before releasing the vehicle to the customer.

Verify the problem with a test drive and a thorough inspection. Listen for noises and feel for vibrations or unusual behavior from the clutch. Test the clutch with procedures given here and in the service information for the vehicle to determine the problem.

Clutch Diagnosis

It is the fate of any automotive clutch to eventually require repair, if the vehicle remains in service long enough. Clutches are intended to provide a long service life, theoretically for the life of the engine. Most clutches will give service in excess of 100,000 miles, but for a variety of reasons, it is common for a clutch to need replacement at least once in the life of the vehicle. The friction material on the clutch disc wears with normal use, and when the material wears away, the result is poor clutch performance, accompanied or followed by slippage or breakage. Damage to clutch components is not uncommon. This is not surprising when you consider the tough job the clutch has to do. Several factors can take their toll on a clutch, and some may fail after as few as 50,000 miles. Some factors that can reduce the service life of the clutch are:

- Extensive **stop-and-go city driving**, especially in **hilly terrain**
- Frequent **severe duty**, such as towing or hauling
- **Contamination** (such as oil leaking from the engine or transmission)
- Driver **misuse** or **abuse**

Driver misuse or abuse can take several forms, with the most common being "riding the clutch." This refers mostly to the practice of driving with a foot on the clutch pedal at all times, which keeps the release bearing constantly spinning, causing premature bearing failure (conventional bearing) and possibly causing slippage, wearing the friction surfaces. "Riding the clutch" may also refer to excessive slippage of the clutch from a stop or between gears, especially at a high RPM, or using the clutch to hold the vehicle in place when stopped facing uphill. Sometimes, a bit of excessive slippage is unavoidable, such as when it is necessary to move at very slow speeds with a lot of control, as when backing up to a loading dock, for example.

In sporting exhibitions or competition, sometimes the engine is revved to a high RPM and the clutch pedal is released suddenly for a quick take-off. This is referred to as "dumping" or "dropping" the clutch. It should be obvious that this practice will not promote long clutch life (or the life of other drivetrain components!)

Clutch life is extended by slipping the clutch as little as possible when starting out or changing gears. The clutch should be smoothly slipped at a low RPM when starting from a stop, and engaged fully as soon as possible without lugging the engine (loading the engine too heavily for the RPM), which stresses drivetrain components.

Clutch Noises

Several noises can be associated with the clutch and can be useful in pinpointing problems.

- A bad release bearing will often produce a high-pitched squeal or grinding noise. With standard (not self-adjusting) release bearings, the noise will usually be most noticeable during the first part of pedal travel. This is the period after the bearing has begun to spin, but before it is loaded with clutch spring pressure.

- The pilot bearing/bushing can make a squealing noise or cause vibration. This noise will be most prominent with the clutch fully disengaged (pedal down) and the vehicle stopped in gear, because the transmission input shaft is stationary while the crankshaft is turning.

- A variety of noises can be produced in the release system, due to binding, interference, lack of lubrication, etc. With the engine off, operate the clutch pedal or have an assistant do so while you locate the source.

- Problems with the friction surfaces may produce noise when the clutch is first engaging. Rattling or other odd sounds may be caused by broken disc torsion springs or other cracked or broken parts.

- A noise that occurs when the vehicle is in neutral with the clutch engaged and disappears when the pedal is pushed down may be a transmission problem, such as a bad front bearing. Keep in mind that the input shaft is turning any time the clutch is engaged.

Slipping vs. Dragging

A slipping clutch and a dragging clutch are two problems on opposite ends of a spectrum. However, either of these two conditions can be caused by improper adjustment or faulty components. Either of them can cause excessive heat and can quickly damage the friction components (if they're not damaged already), and either of them cause driveability problems.

To easily understand these two conditions, let's look at the "life cycle" of a standard clutch. Suppose a vehicle has just been driven out of the dealer showroom in perfect condition by its new owner. The clutch fully engages at about midway through the pedal travel. Over many miles, as the clutch disc wears, the pedal free travel is gradually reduced, and the clutch engages closer and closer to the top of the pedal travel. As the condition worsens, the release bearing becomes in constant contact with the diaphragm spring. Eventually, not only is the release bearing spinning all the time, but it is also putting a slight pressure on the diaphragm spring. This relieves some of the spring tension that normally clamps the clutch assembly together when the clutch is engaged. Now, the clutch doesn't engage as strongly as it should. You hardly have to press the pedal down at all before the clutch is disengaged. When the driver attempts to slip the clutch to pull away from the curb, the clutch continues to slip for quite some time, even with his foot off the clutch pedal. The engine races to a high RPM and does not deliver the engine power to the wheels. This also happens after shifting gears, and when pulling a steep grade. The clutch is **slipping**.

The owner takes the vehicle to a shop to look into the problem, and he is advised that the clutch needs to be adjusted. However, suppose that due to a miscommunication, an apprentice technician adjusts the release mechanism with excessive free travel - three times the specification. Now, there is little movement of the pressure plate before the pedal reaches the floor. There is still contact between the friction surfaces, and so the clutch doesn't fully disengage. The technician test drives the vehicle, and notices that when trying to shift gears, the shifter is hard to move and the gears clash. When waiting at a traffic light with the transmission in gear, the vehicle creeps forward even though the clutch pedal is all the way to the floor. This is because the transmission input shaft is still turning, being driven by the disc. The clutch is **dragging**.

The technician re-adjusts the clutch properly, with the specified free travel, and the clutch no longer slips nor drags. Over the years, the owner has to have the clutch adjusted a couple more times, but now he takes the car in for adjustment when the clutch engagement starts occurring with the pedal too high.

But one day, the clutch begins to slip again. The owner is concerned, because the clutch is engaging at near its normal pedal height. He takes the vehicle in for service and the technician checks the adjustment and tests the clutch. He informs the owner that the clutch will need to be repaired. The reason the clutch is slipping this time is because the friction material is all worn off of the disc. This makes the disc thinner, relieving much of the spring pressure from the pressure plate, so the clutch does not engage as strongly. Even if it still had ample spring tension, without the gripping properties of the friction material, the clutch would engage poorly and slip under load.

Other Causes of Slipping or Dragging

A slipping or dragging clutch can also be caused by binding or sticking in the release mechanism, bent or broken parts, oil on the clutch disc (slippage), and warped or bent friction components (dragging). *Clutch discs are often damaged by improper installation. They are easily bent, and so the weight of the transmission (or transaxle or engine) should never be allowed to hang on the clutch disc.* This can also damage the pilot bearing, input shaft splines, and other components. Rusty or damaged input shaft splines can also cause a clutch to drag, by impeding disc movement along the shaft. Similarly, rust or damage to the transmission bearing retainer, clutch fork, or the release bearing can inhibit proper movement of these parts. A broken engine mount can cause clutch slippage, due to excessive movement of the engine during engagement.

Testing for Slipping or Dragging

To test a clutch for slipping, set the parking brake and start the engine. Place the transmission in high gear and slip the clutch as if you were driving away. The engine should stall (die) immediately. If the engine continues to run with the pedal released, even momentarily, the clutch is slipping.

Note: Never slip the clutch for more than a few seconds. Damage to friction surfaces can occur.

To test a clutch for dragging, run the engine up to operating temperature. With the engine idling and the transmission in neutral, depress and hold the clutch pedal to the floor. Wait 10 to 15 seconds to allow the clutch to fully stop rotating, and then shift the transmission into reverse gear. The transmission should shift smoothly into reverse with no gear clash. If there is clashing of gears, the clutch is dragging. Creeping in gear with the pedal depressed occurs only if the clutch is dragging severely.

Chattering or Grabbing

Clutch chatter or grabbing occurs when the clutch engages unevenly. When starting off, instead of a smooth power transition during clutch engagement, there is shuddering or jerking as the clutch is engaged. Severe chattering can cause extreme shaking and vibration through the vehicle, which may be very noisy and annoying. Chatter can be caused by broken or defective engine mounts or oil on friction surfaces. Uneven release bearing application to the pressure plate, due to a broken or bent clutch fork, broken or bent release levers, or the like can also cause chatter. Chatter can damage friction surfaces, which just makes the chattering worse.
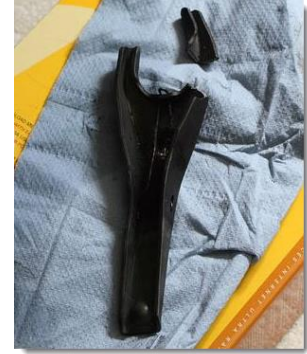
Clutch Pedal Problems

A clutch pedal that is stiff or hard to depress can have several causes. Binding or a lack of lubrication in the clutch linkage or cable, or a problem in the hydraulic system could be the cause. Occasionally, a malfunction in the pressure plate assembly or another component inside the clutch housing can be the cause.

Sometimes a pulsation of the clutch pedal, especially under light foot pressure, will be experienced. This is usually caused by runout or warpage in one of the rotating components of the clutch. The pressure plate attaching bolts might be loose. The pressure plate bolts are sometimes accessible through an inspection or dust cover. If the bolts are properly torqued, the clutch will normally have to be disassembled to correct the problem.

Heat, Damaged Friction Surfaces, and other Clutch Problems

Sometimes clutch problems can compound one another. A great deal of heat is produced when slipping the clutch, and the longer and harder the clutch is slipped, the more heat is produced. Misuse or driving with the clutch severely out of adjustment or malfunctioning can cause a damaging heat buildup very quickly. This heat can damage the friction surfaces, reducing their effectiveness. The flywheel and/or pressure plate can become warped, glazed, or cracked, and develop hardened "hot spots." These problems cause more slippage and uneven clutch engagement, generating more heat, and making matters worse. A severely chattering clutch can cause damage to friction components, and damaged friction components can in turn cause a severe chatter.

Clutch linings that are contaminated with oil will slip. The excessive slippage will generate heat that burns the disc and damages the flywheel and/or pressure plate. The disc and pressure plate must be replaced and the exposed surfaces of all other components must be thoroughly cleaned to remove any traces of oil. The leak must be repaired to prevent a recurrence of the clutch failure. Any extreme oil leak might cause this problem, but the common culprits are the valve cover or oil pan gaskets, rear main seal (crankshaft), and front transmission seal.

Because clutches often remain in service for a lengthy period after the clutch disc is worn out before being repaired, it is common for the flywheel and pressure plate to become heat-damaged, sometimes severely. For this reason, the flywheel is normally resurfaced and the pressure plate assembly replaced along with the friction disc during a clutch repair. The flywheel's condition must be carefully evaluated and its thickness and flatness measured against specifications to determine if it can be re-used. Pressure plates are not routinely reconditioned in the field.

This flywheel has heat marks but can be resurfaced.

This flywheel has hot spots and small cracks (checking). It can probably be resurfaced.

This flywheel has moderate to deep cracks. It is too thin to be resurfaced and will have to be replaced.

This flywheel has deep cracks and cannot be resurfaced.

These cracks were too deep to be machined out. The flywheel cannot be re-used.

Extreme abuse caused this pressure plate to shatter, damaging the bell housing and starter in the process.

Chapter 3: Clutch Service

Clutch services can range from adjustments and service of the release mechanism and other accessible components to replacement of the clutch assembly.

Clutch Adjustment

We have discussed the need for proper clutch adjustment. Some systems have partially or fully self-adjusting mechanisms and some of these have constant-contact release bearings. Others require periodic adjustment of the pedal free travel as routine maintenance. Refer to the service information for the vehicle for adjustment methods and specifications.

Mechanical Linkage - The adjustment for mechanical linkages is usually found on the pushrod that actuates the clutch fork. The rod will have a threaded portion with an adjustment nut to lengthen or shorten the working part of the rod. The rod is shortened to increase free travel. A **locknut (jam nut)** is tightened against the adjustment nut to retain the adjustment. Two wrenches are usually needed to loosen and tighten the nuts.

Adjusting Nut

Cable - The clutch cable is also usually adjusted with a nut. The nut lengthens or shortens the cable housing.
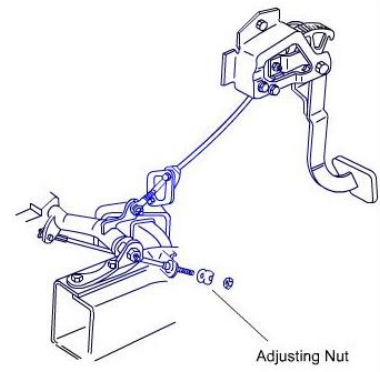
Hydraulic Systems - There is usually an adjusting nut on the fork pushrod, but sometimes it is located on the clutch master cylinder pushrod.
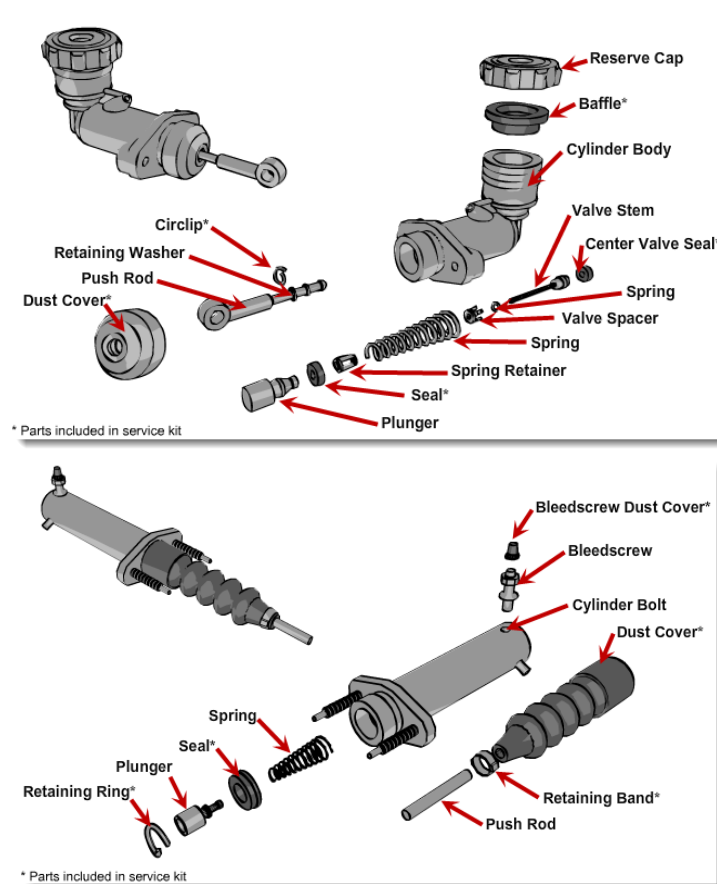
Servicing the Hydraulic System

As noted earlier, the hydraulic clutch release system is similar to a hydraulic brake system, and so failures and service are also similar. Leakage from the master cylinder or slave cylinder is a common problem. When the fluid in the system gets low, the pedal free travel is increased. This will eventually lead to clutch dragging or a complete loss of disengagement. Also, the master cylinder can develop an internal leak, which can cause the clutch to gradually engage itself while the vehicle is stopped in gear with the pedal depressed, an unnerving and frustrating experience for the driver.

If leakage is indicated, inspect the system carefully. Check for wetness under and behind the master cylinder and around the slave cylinder. Look at the hoses and lines, too.

Many clutch master cylinders and slave cylinders can be rebuilt. Check the vehicle service information to see if rebuilding is permissible, and check parts suppliers for the availability of kits. Some manufacturers allow honing the bore of master or slave cylinders during rebuilding; others specify replacement if there is any pitting, scoring, or roughness. Coat rubber parts with hydraulic fluid (normally brake fluid) during assembly.

Replacing the component is a good idea and sometimes as cost-effective when you consider the labor involved in rebuilding.

Bleeding the Hydraulic System

Just as with a brake system, any time the hydraulic system is opened, the system must be bled to remove air. *When filling the master cylinder reservoir, always use fresh hydraulic fluid from a sealed container*. Do not re-use fluid that has been bled from the system. *Keep in mind that brake fluid will damage painted surfaces and some plastics.*

There are several methods of bleeding the hydraulic system. Professional bleeder machines that use pressure or vacuum can be used. The master cylinder should be bench bled before installation. The system can also be manually bled using an assistant.

When manually bleeding the system, the fluid level in the master cylinder must be checked often. The assistant begins the procedure by depressing the clutch pedal to build up fluid pressure. The assistant then continues to hold a steady pressure on the pedal while the other technician opens the bleeder valve and observes as fluid and air bubbles are expelled. The pedal will go to the floor and the assistant will continue to hold steady pressure on the pedal until the other technician closes the bleeder valve. This process is repeated until all the air has been expelled.

Removing all of the air from some hydraulic clutch systems can be tricky. Gravity bleeding can be effective. Below is a procedure for gravity bleeding a system.

1. Clean dirt and grease from the cap to ensure no foreign substances enter the system.
2. Remove cap and diaphragm and fill reservoir to the top with approved fluid only.
3. Fully loosen bleeder screw in the slave cylinder body.
4. Fluid will now begin to move from the master cylinder down the tube to the slave cylinder. It is important for efficient gravity fill that the reservoir is kept full at all times.
5. Bubbles will appear at the bleeder screw outlet. This means that air is being expelled. When the slave cylinder is full, a steady stream of fluid will come from the slave cylinder bleeder. At this point, tighten bleeder screw.
6. Assemble diaphragm and cap to the reservoir.
7. The hydraulic system should now be fully bled and should release the clutch. Check vehicle by starting, pushing clutch pedal to the floor and selecting reverse gear. There should be no grating of gears; if there is, the hydraulic system still contains air. If this is the case, repeat bleed procedure.

For more information on hydraulics, hydraulic fluid, master cylinders, bleeding procedures, and other information, consult those sections in the Today's Class Brakes module.

Unit 3: Transmission/Transaxle Diagnosis and Repair

Chapter 1: Transmission Components and Power Flow

Manual Transmission Fundamentals
An automobile engine has a somewhat limited range of torque output and operational speed. In the Introduction, we noted that a transmission provides **gear reduction**. Gear reduction increases torque output and reduces speed output from the transmission at a given engine RPM. Gear reduction is required in motor vehicles because of the varying amounts of **torque** (turning force) needed to propel the vehicle at different road speeds and under different conditions.

Newton's First Law of Motion explains this. That law basically states that an object at rest tends to stay at rest, unless acted upon by a force, and an object in motion tends to stay in motion and at the same speed, unless acted upon by a force. This is sometimes called the law of inertia.

Gear Reduction

It takes a lot of torque at the wheels to get a vehicle going. Once the vehicle is moving, it takes less torque to keep it moving. When the vehicle reaches cruising speed, gear reduction is no longer needed and the transmission input shaft rotates at the same speed as the output shaft. This means that for one revolution of the input shaft, there is one revolution of the output shaft, for a ratio of one-to-one (expressed as 1:1). This is called **direct drive**, or "high gear" on older, conventional transmissions (we'll get to overdrive shortly).

Gear reduction uses leverage to provide increased torque. When a smaller gear drives a larger gear, the larger gear turns slower than the driving gear, and there is an increase in torque output at the driven gear. The greater the difference in size between the two gears, the greater the torque increase and the slower the speed of the larger, driven gear. A driving gear half the size of the driven gear results in twice the torque output.

In the gearset shown here, the drive gear has 10 teeth and the driven gear has 20 teeth. To determine the **gear ratio**, the number of teeth on the driven gear is divided by the number of teeth on the drive gear. In this case, 20/10 = 2, for a gear ratio of 2:1. The driven gear turns at half the speed of the drive gear, with double the torque.

In automotive transmissions, an additional gear is used to counter the reversal in direction.

Driving gear with 10 teeth makes one revolution.
Driven gear with 20 teeth makes 1/2 of a revolution.
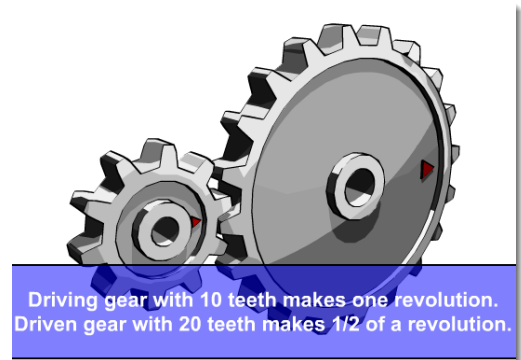
Typical Gear Strategies and Ratios

It was once common for manual transmissions in cars and light trucks to have three forward gears, or **speeds**, but modern vehicles may have four, five, or even six speeds (plus a reverse gear, of course). The highest gear in many vehicles today is an **overdrive** gear, which uses an additional gearset to allow the output shaft to actually turn faster than the input shaft. This provides lower engine speed for increased fuel economy on the highway, when less torque is needed. The next lower gear is normally direct drive.

Vehicles that must get the most out of available engine torque, such as compact cars with small engines, or trucks designed for serious hauling tend to have more speeds. Some commercial light and medium duty trucks have a very low first gear ratio, sometimes called a "granny gear." It may have a ratio of as much as 8:1, and is only used when starting out with a very heavy load. It's common to start out in second gear under non-loaded conditions in these trucks.

Gear ratios in automotive transmissions vary widely among manufacturers and applications. A typical 5-speed transmission might have a gear ratio of 3:1 in first, 2.5:1 in second, 1.5:1 in third, 1:1 in fourth, and 0.7:1 in fifth (overdrive).

Gear Types

There are many different types of gears used in all kinds of machinery, including the drivetrain and other components of an automobile. Several gear types are shown here.

Planetary gearsets are found in some overdrive units and all conventional automatic transmissions. By holding different members, this setup can provide gear reduction, direct drive, overdrive, and reverse. From the center out are the sun gear, planet pinions with carrier, and ring or internal gear.
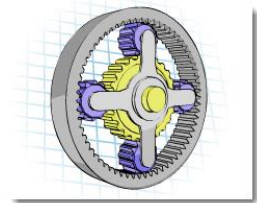
Two gear types are used to transmit power in a manual transmission: **spur gears** and **helical gears**.

Spur gears, or **straight-cut** gears, are no longer used on modern transmissions, except sometimes in the reverse gearset. Spur gears are a simple type in which only one tooth is in ideal contact with another tooth at a time. Spur gears slide into mesh easily, and for this reason they are found on transmissions where the reverse idler gear slides into mesh without a synchronizer (covered later).

Backlash causes spur gears to be noisy. Backlash is the small clearance between meshing gears necessary for lubrication and heat expansion. With spur gears, this backlash is taken up all at once as each tooth contacts its corresponding tooth on the other gear, causing a slight clicking noise. At higher speeds, the noise becomes a growl or whine.

The teeth on **helical** gears are cut at an angle to the center line of the gear shaft. This makes them quieter and stronger than spur gears, because backlash is kept to a minimum and contact is distributed over more area. Helical gears provide a continuous flow of power across the teeth, but they produce **end thrust** as the gears tend to push away from one another laterally. This thrust is accounted for in the design of the transmission. The speedometer drive gear found in older transmissions is a **worm gear**.
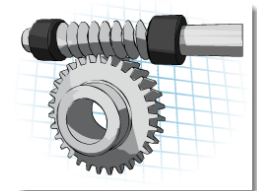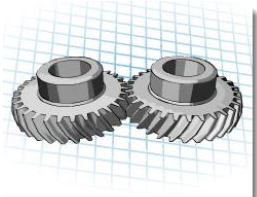
**Bevel** gears are used in differential assemblies.

Transmission Components and Operation

The internal parts of the transmission are housed in a **case** made of iron or aluminum. An **extension housing**, or **tail shaft housing**, bolts to the back of the case and encloses the output shaft. Oil seals are installed at the back of the extension housing and at the **front bearing retainer**. The mating surfaces of these components and the **cover plate** are sealed with **gaskets**. The case normally has a drain plug on the bottom and a fill plug on the side. The fill plug also serves as a means to check the lubricant level, which in most cases should reach the bottom of the hole when at operating temperature. The drain plug often has a magnet attached to it to capture metal fragments. A **vent** (**breather**) will be located somewhere at the top of the case assembly. Let's take a look at the case and begin looking at what's inside.
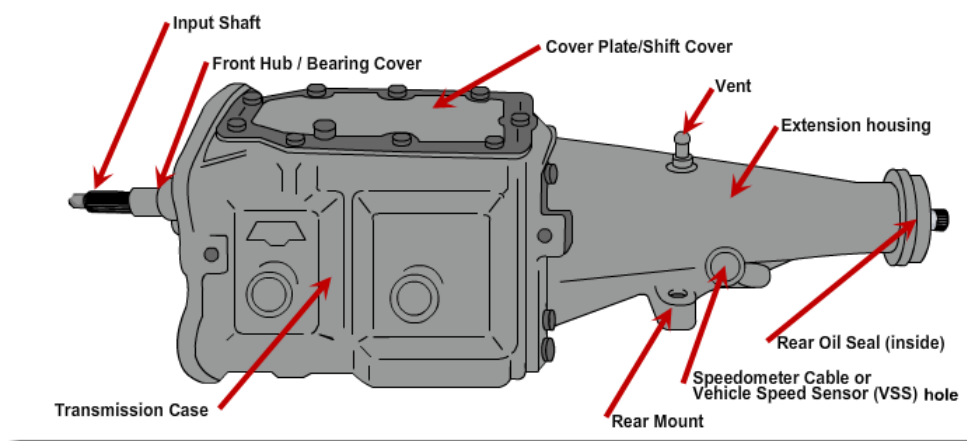
Note: In the cutaway image that the input shaft and gear are one piece and the output shaft is a different, separate piece. These two shafts fit together and can rotate independently of each other.
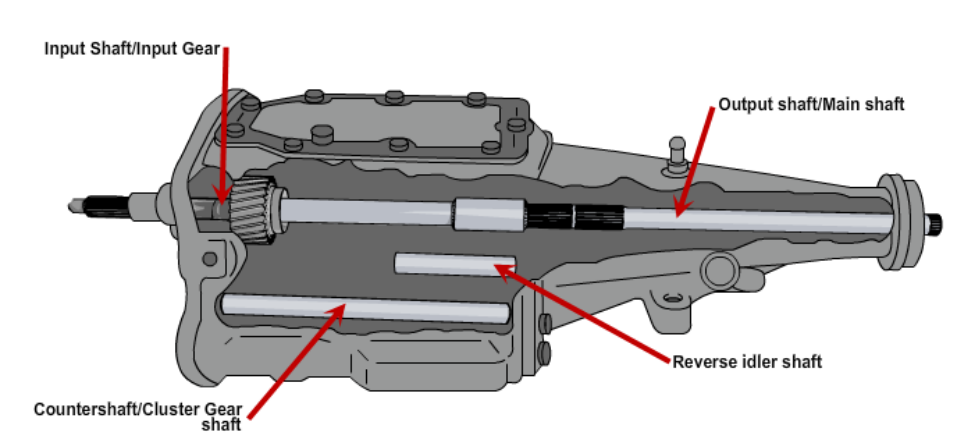
Shafts and Gears

In our opening discussion of transmission components and operation, we viewed the various shafts in the transmission case. The **input shaft**, or **clutch shaft**, rotates any time the clutch is engaged. The **input gear**, sometimes called the **input drive** gear or **clutch gear**, is machined as part of the input shaft, and thus also rotates when the clutch is engaged. It has a small spur gear behind the drive gear. The spur gear is used by a synchronizer.

The **countershaft**, or **cluster gear shaft**, is located below the input and main shafts. The countershaft itself does not normally turn; the ends are held fast in the case. The **countergear**, or **cluster gear**, rotates on this shaft, usually over rows of needle bearings. The countergear adds a third member to the gear train, countering the reversal of direction that results when one gear turns another. "Cluster gear" is a good descriptive name for this gear as well, because the countergear is normally one solid steel piece machined into several gears.

The countergear is in constant mesh with the input gear which drives it. It is also in constant mesh with all of the other forward gears. This is a good time to take note of a very important characteristic of modern manual transmissions:

The input gear, the countergear, and all of the forward output gears are always in mesh with each other. They are all rotating any time the clutch is engaged (with the exception of the overdrive gear when in neutral on some transmissions).

How can all of these gears of different ratios be in mesh with each other at the same time? The answer is that only the selected gear is locked to the output shaft - all the other output gears are simply freewheeling on the shaft. They are only along for the ride.

All of the output gears and synchronizers are mounted on the **output shaft**, or **main shaft**. The synchronizers are splined to this shaft and thus rotate with it, while the gears rotate freely on their bearings on the shaft. When an output gear is selected, a shift collar moves a synchronizer to engage it with the desired gear, locking the gear to the shaft.

The **reverse idler shaft** is commonly mounted between the output shaft and the countershaft, or sometimes below the countershaft if spur gears are used. The **reverse idler gear** rides on this shaft, and if spur gears are used, it may move to mesh with other gears. When spur gears are used in the reverse gearset, the transmissions will whine in reverse.

Major Components
- Input Shaft
- Front Bearing Retainer
- Case
- Counter Shaft
- Shift Cover
- Main Shaft and Gears
- Extension Housing
- Shift Mechanism
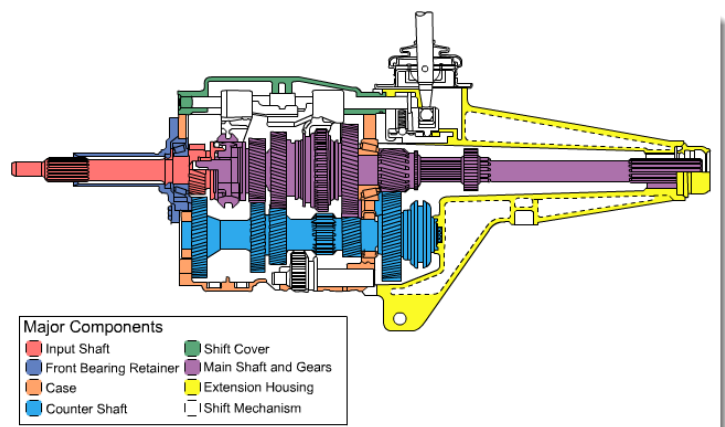
Lubrication

The internal transmission parts are lubricated with an oil bath as the gears rotate. The turning gears sling oil inside the case, creating **splash lubrication**. The main shaft is cut with a number of shallow grooves to distribute oil, and some transmissions may have funnels and other channels to aid lubrication. 80W or 90W gear oil, or gear lube, is used in many transmissions, while others specify motor oil or even automatic transmission fluid (ATF). If the unit is not labeled with the type of lubricant to use, check the service information. ***Be sure to use the proper lubricant***.
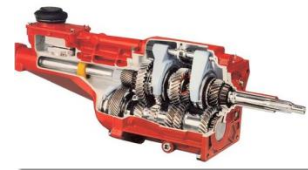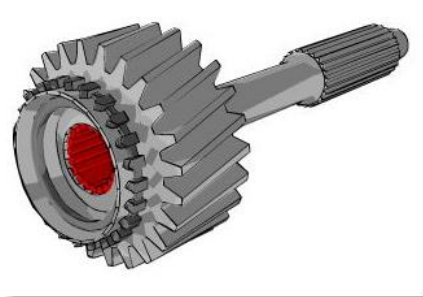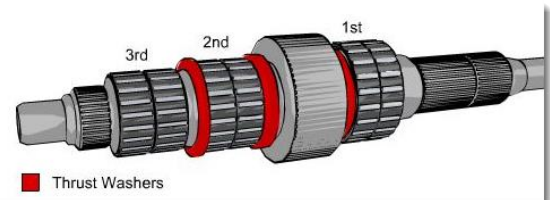
Bearings

A manual transmission contains many bearings to reduce friction of the many rotating parts. Ball bearings, roller bearings, and needle bearings are commonly used. Some bearings are held in cages or are housed inside their own hubs and races, while others are not. Thrust bearings and thrust washers are used to control thrust forces induced by the helical gears under load. Some transmissions use simple bushings for reverse gear parts.
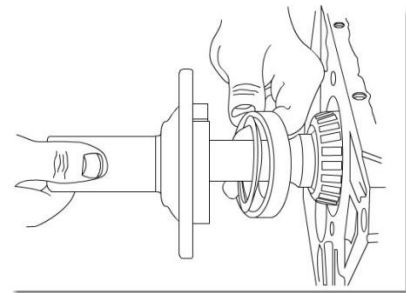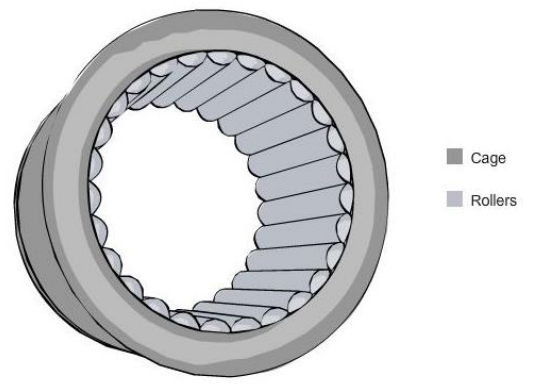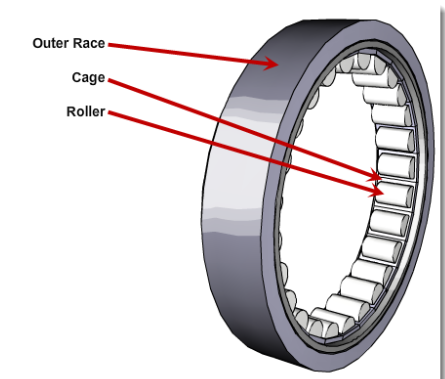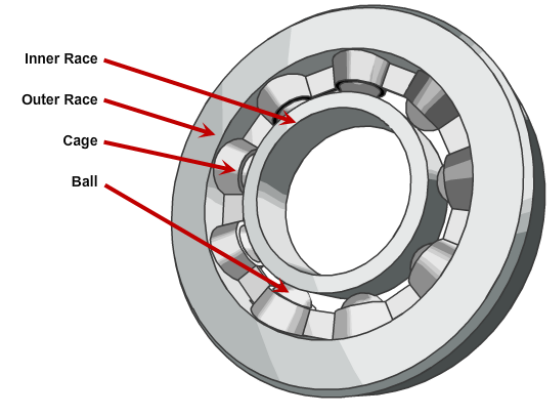
The front (input shaft) bearing for this transmission is a tapered roller bearing (right). The technician is installing the front bearing retainer or hub (left). In his other hand are shims and the bearing outer race. The shims are used to set shaft endplay.

Note the roller bearings in this input shaft. The end of the main shaft rides on these bearings.

This main shaft has caged needle bearings that the output gears ride on.

Synchronizer Assemblies

Some vehicles up until the mid-1960s had no first gear synchronizer and had to be brought to a complete stop before the vehicle could be shifted into first gear without clashing the gears. Fortunately, modern transmissions are synchronized in all forward gears.

The purpose of the synchronizer assembly is to match the rotating speed of the selected gear to the speed of the shaft it must interlock with. The synchronizers work by braking or accelerating parts that are rotating at different speeds to close to the same speed, thus permitting the desired gear to be engaged without gear clash.

The synchronizer assembly is a cluster of internally and externally cut gears that can be interlocked. When the synchronizer is not interlocked with an output gear, the individual output gears turn at different speeds. When the synchronizer is interlocked with one of the output gears, the assembly turns as a single unit.

Synchronizer **hubs** with internal splines are positioned on the main shaft between the gears. These hubs must turn with the main shaft. The synchronizer hubs also have external splines on which the synchronizer **sleeves** slide. Spring-loaded detent **keys** retain the sleeve in a forward, center, or rear position. In the center position, no gear is engaged with the synchronizer, and both adjacent gears freewheel. One synchronizer can work for two adjacent gears.

The gears have a set of external synchronizer teeth that can interlock with the internal splines of the synchronizer sleeves. A gear is selected by sliding the synchronizer sleeve either forward or backward and thereby engaging the gear to the main shaft.

The synchronizers have **brass synchronizer rings** (**blocker rings**) between the sliding synchronizer sleeves and gears. These rings grip a smooth cone surface on the gear just prior to engagement, causing the gear and sleeve to turn at the same speed, thus providing grind-free shifting.

Don't worry if synchronizer operation seems a bit complicated at this point. It's not, really. Taking the cover off of a training unit on the workbench and manually shifting it through the gears will aid in your understanding. Be careful not to pinch or nick your fingers; you might want to wear gloves.
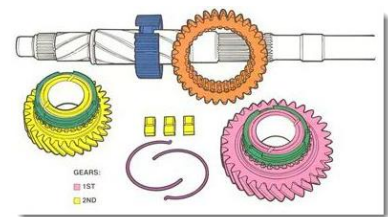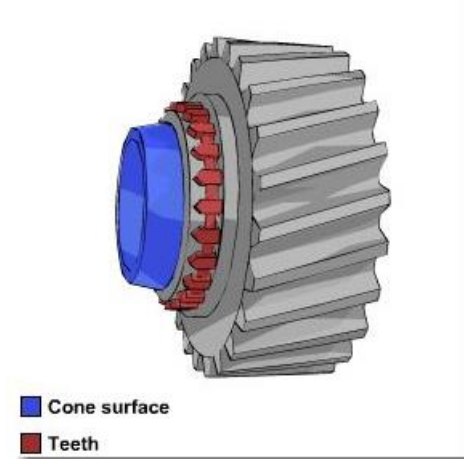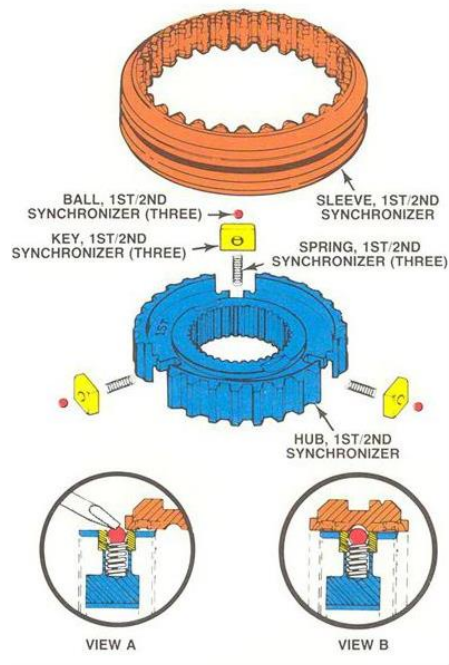
Gear Shift Mechanisms

Note that the synchronizer sleeves, or **shift collars**, have a large groove in them. **Shift forks** fit into these groves and slide the synchronizer assemblies forward or backward to shift gears. An **interlock** mechanism prevents two gears from being engaged at once, which would be catastrophic. Only one of the shift collars can be moved out of its center, neutral position at a time. Wear in the synchronizer shift collar parts can cause a transmission to fall out of gear.

A **detent** mechanism is used to keep the transmission in the selected gear. The detent mechanism consists of some type of spring-loaded ball or cylinder that snaps into a notch. This is the same principle as found in detent mechanisms used in all kinds of everyday devices, like the detent that holds a socket on the end of a ratchet wrench.

Shift linkage that operates from the top of the transmission is of the **internal shift rail** type. Those that are operated from the side are often the **external shift rod** type. **Cable** linkages are also used.

Different shift patterns have been used for the gear shift lever, but most use a variation on the typical "H" pattern. The location of reverse may vary, and you may have to push down on the gear shifter or push sideways against spring tension to locate the reverse gate.
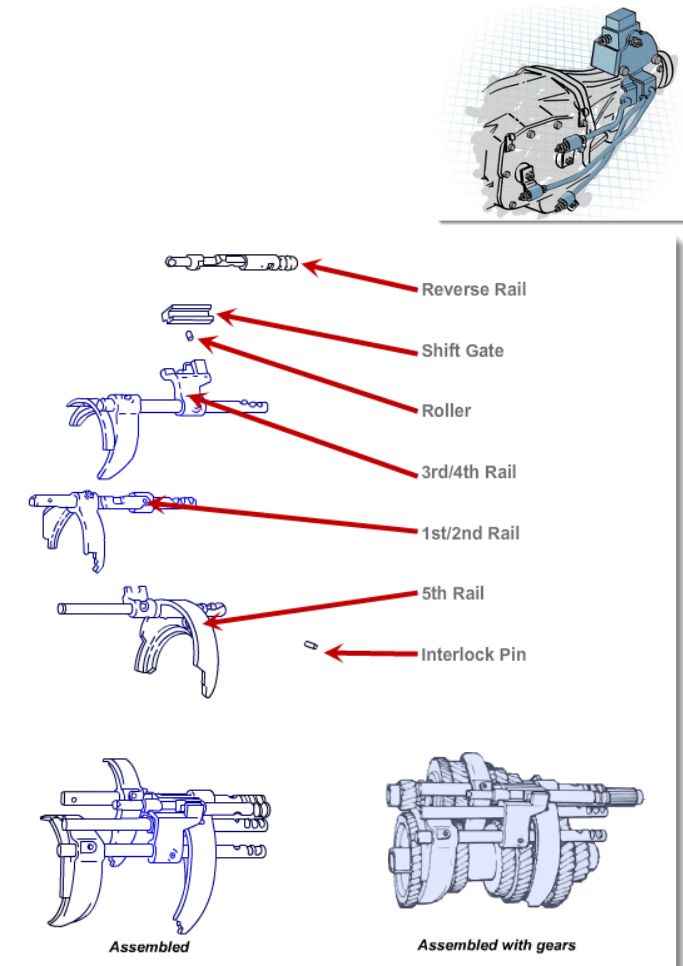

It was once common for the shifter to be mounted next to or in the steering column. The shift pattern on these old three-speed vehicles is the same as shown here.
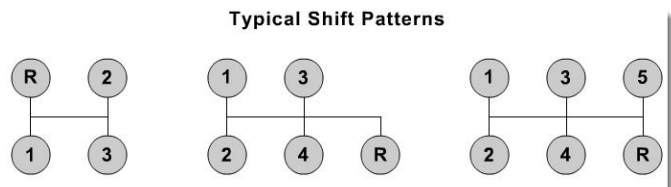
Transmission Power Flow

Now that you understand the main parts and operation of a manual transmission, we will examine the power flow through a simple three-speed unit. The principles are the same on transmissions with more speeds.
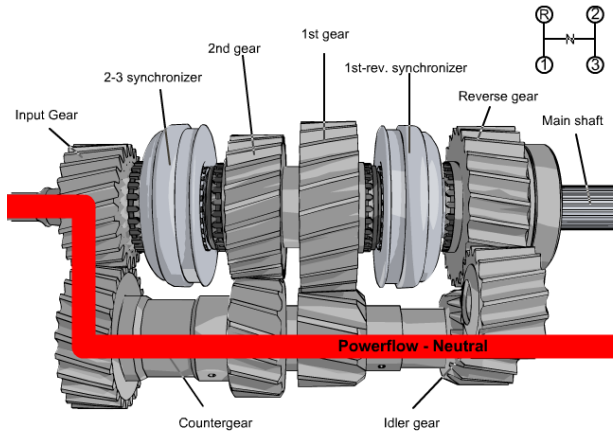
In neutral, both synchronizers are in their center positions. No output gears are locked to the main shaft, thus no power is transmitted. The input gear turns the countergear, but the output gears freewheel.
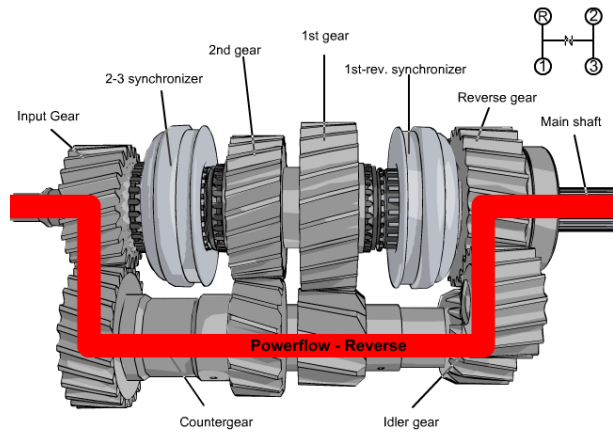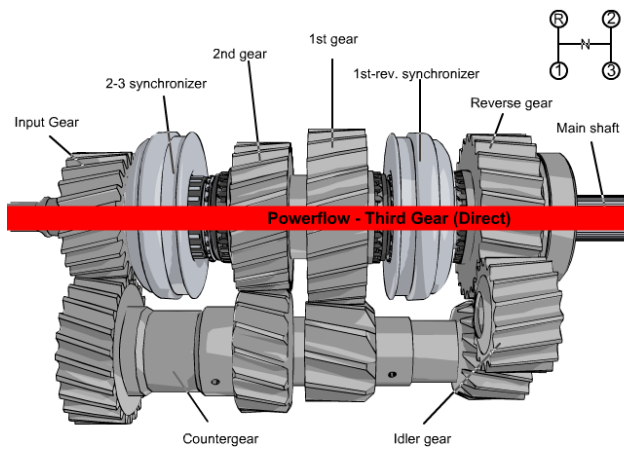
To shift into reverse, the second-third synchronizer must be in neutral. In this example, the first-reverse synchronizer moves into mesh with the reverse output gear, locking it to the output shaft. The countergear drives the reverse idler gear, and the idler gear drives the reverse gear backwards.
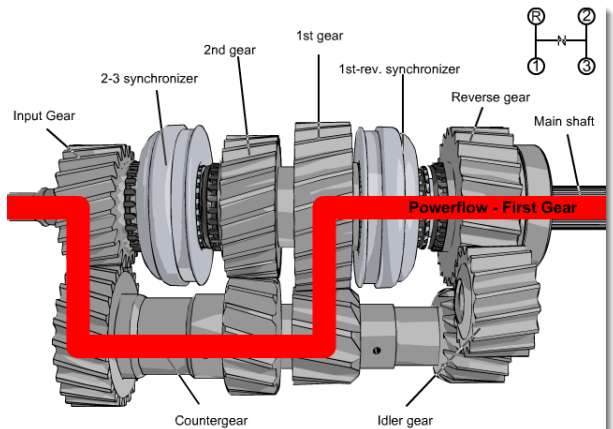
Shifting into first gear, the first-reverse synchronizer moves to engage with the first speed output gear. The other synchronizer remains in neutral. The first speed gear is locked to the output shaft and delivers high torque to the output shaft at low speed.
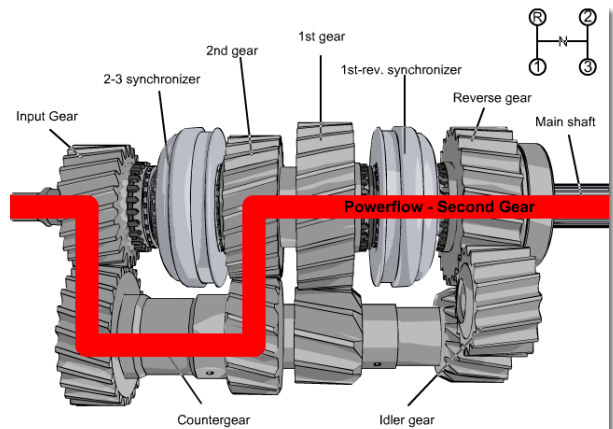
To shift into second gear, the first-reverse synchronizer moves into neutral, and then the second-third synchronizer moves to engage the second speed output gear. With the second speed gear now locked to the output shaft, a higher speed is attained, but with less torque increase than in first gear.

Shifting into third gear, or direct drive, the second-third synchronizer moves to disengage with the second speed output gear and then engages with the input shaft gear. This locks the input shaft directly to the output shaft, and power flows straight through at a 1:1 ratio. Note that there is no third speed output gear. The input gear still drives the countergear, but the output gears freewheel.

Electronically-Controlled Manual Transmissions

There are a number of ways that electronic controls have been adapted for use in manual transmission/transaxles. The three most common designs are outlined below.

- The most basic electronically controlled manual transmissions use the vehicle's computer system to limit the driver's shift options. This is done to improve performance and durability of the vehicle.
- In a more advanced design, the clutch is operated by the vehicle's computer system while the driver controls the timing of the shift by moving the gear shifter (the electronic control system operates the clutch and throttle to complete the shift). Most of these types of transmission/transaxles operate in sequential mode and only allow up-to-down shifts one gear at a time. This type of transmission/transaxle may use a dual clutch system.
- In most advanced designs, both the clutch operation and gear selection are controlled automatically (like an automatic transmission but use a clutch in place of the torque converter). The driver's ability to control shifts on these types of vehicles varies between makes and models.

Switches and Sensors

Various sensors and switches are used on modern manual transmissions. Some switches, like the backup light switch, have been in use for many years. Such switches may be part of an electronic control strategy now. Sensors and switches can communicate conditions to a vehicle's electronic control module, which may cause changes in engine management strategies. The ECM might allow more ignition timing advance in high gear, for example. Most modern transmissions use a Vehicle Speed Sensor (VSS) instead of a speedometer drive gear and cable system to determine vehicle speed.

Unit 4: Driveshafts and Halfshafts

Chapter 1: Driveshaft Design, Diagnosis, and Repair

Driveshaft Principles, Function, and Construction

As was noted in the introduction, **front-engine**, **rear-wheel-drive** vehicles use a **driveshaft** to transmit power and motion from the **transmission** to the **rear axle assembly**. The driveshaft has to be strong enough to handle the highest expected amount of torque load transferred to the rear axle, yet flexible enough to allow normal powertrain and suspension component movement.

In addition to being strong and flexible, the driveshaft must be absolutely straight and in balance so that it does not generate vibration at operating speed. The driveline components (which include the driveshaft, axle shafts, pinion shafts and transmission and/or transfer case output shafts) in most vehicles are dynamically system balanced at the factory. This process insures the smoothest possible running driveline.
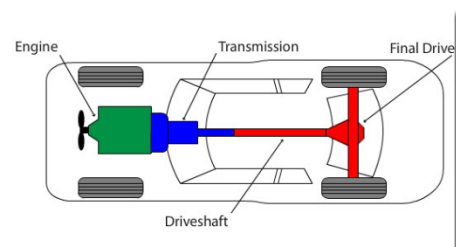
To show the necessity of precision balance, the following chart lists example driveshaft speeds in each gear of a five-speed manual transmission at 2000 engine RPM. Note in this example that both fourth and fifth gears are **overdrive** ratios. When a vehicle is equipped with an overdrive transmission, the driveshaft in that vehicle rotates faster than the engine does when overdrive is engaged.

| Gear	Gear Ratio	Driveshaft RPM (with engine at 2000 RPM)
1st	3.166:1	632
2nd	1.882:1	1063
3rd	1.296:1	1543
4th	0.972:1	2058
5th	0.738:1	2710

Driveshaft RPM in gears at 2000 engine RPM. Note also that higher or taller gears mean higher driveshaft speeds.

The driveshaft is generally a long, hollow steel tube. The use of a hollow tube rather than a solid shaft greatly reduces the driveshaft's weight. Some high-performance and racing driveshafts are made of aluminum or a high-strength composite material to further reduce weight.
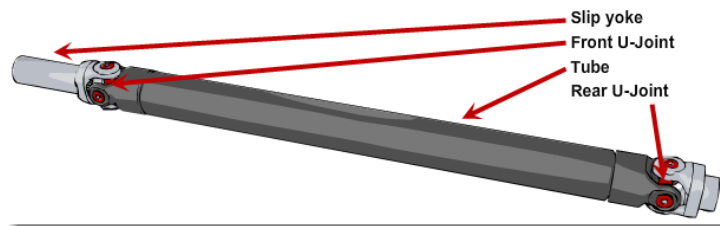
Yokes

Why can't driveshafts be solid or of a fixed length? When the vehicle is driven, the rear axle assembly moves up and down on the vehicle's suspension. This movement requires the drive shaft to have the ability to flex and change length as the axle moves. Also, vehicle bodies and frames flex and twist, and most engines and transmissions use cushioned mounts that isolate vibration and noise from the passengers. These design factors make a solid, inflexible driveshaft impossible.
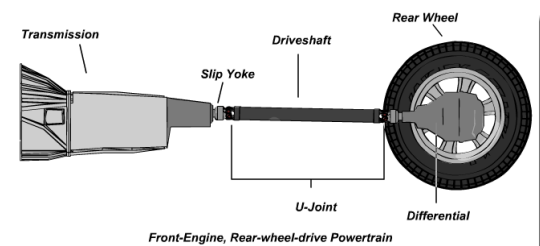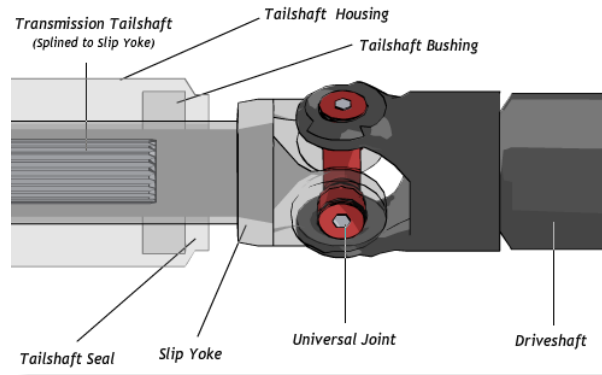

Slip Yokes

The **slip yoke** is designed to accommodate this required change in driveshaft length by sliding in and out of the transmission tailshaft housing. Typical slip travel is .75 to one inch (19 to 25.4 mm).

The entire forward end of the drive shaft is supported by the transmission **tailshaft bushing**, which is a press-fit into the **tailshaft housing**. This holds the output shaft centered and prevents runout (wobbling) and vibration.

The slip yoke and transmission tailshaft are coupled using **splines** which allow the slip yoke to slide while receiving power from the tailshaft.

A **tailshaft seal** prevents transmission lubricant leakage by sealing against the slip yoke's smooth outer surface. The slip yoke in most instances is coupled to the driveshaft via a **universal joint**.
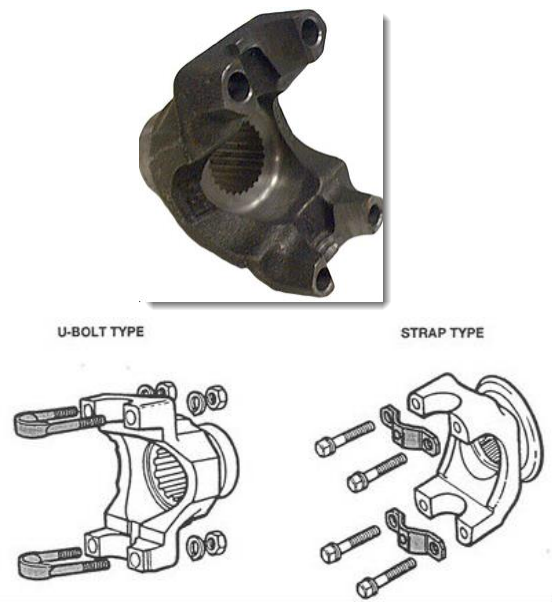

Pinion Flanges and Pinion Yokes

The rearward end of the driveshaft attaches to the rear axle via either a pinion flange or a pinion yoke, depending on the design.

A separate yoke pressed onto the U-Joint caps is bolted onto the pinion flange for retention.

Straps or U-Bolts along with bolts or nuts hold the rear U-Joint to the pinion yoke.


Universal Joints

In simple terms, universal joints (also called U-Joints) allow the transmission of power at an angle.

A typical U-Joint (sometimes called a **Cardan** or **Hooke** joint) is a pivoting coupling made up of a four way center **crosspiece** mounted between two yokes. This crosspiece (sometimes called a **spider**) is the heart of the U-Joint. There is a precision-machined journal called a **trunnion** at each of the crosspiece's four ends. A **bearing cup** assembly fits over each trunnion and contains a row of **needle bearings** that roll on the trunnion surface. Because the center cross can pivot and swivel on these bearings as the angle of the yokes change, a U-Joint allows the operating angle of the driveshaft to change.
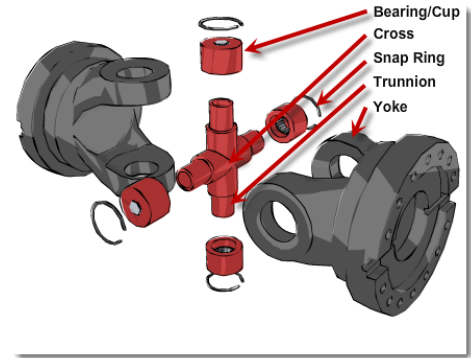
In the examples shown, the bearing cups are a precise fit inside the holes in the yokes. The cups are retained in the yokes by **snap rings**. These snap rings either fit in grooves machined inside the bearing cup holes or fit into grooves machined into the outside surfaces of the bearing cups themselves.

Some U-Joint bearing cups are retained in their yokes by **plastic injection**. When the driveshaft is assembled, molten plastic is injected into grooves in the bearing cups through small holes in each yoke. This plastic holds the bearing cups tightly in place once it cools and solidifies.
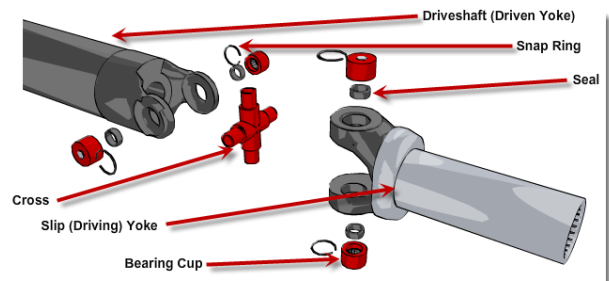
Some vehicles have driveshafts that are not designed to be field-serviceable. These have U-Joints that are staked or swaged in place. Some specialty machine shops or driveline shops can in fact replace worn or damaged U-Joints in these types of driveshafts.

Universal Joint Design Limitations

Universal joints are designed to handle the effects of various loads and rear axle windup conditions during acceleration and braking. Though the universal joint operates efficiently and safely within the designed angle variations, when the design angles are exceeded the operational life of the joint decreases.

As discussed, a universal joint is basically two Y-shaped yokes connected by a pivoting X-shaped crosspiece. This crosspiece allows the two yokes to operate at various angles to each other. One yoke will be the **driving yoke**, which in our previously pictured example will be the slip yoke that is connected to the transmission tailshaft. The other yoke will be the **driven yoke**, to which force is applied by the driving yoke via the crosspiece and bearing caps. The driven yoke is welded to the forward end of the driveshaft tube.
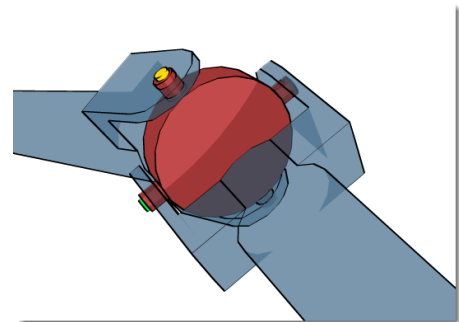
The main design limitation of Cardan-style U-Joints is that even when the driving yoke revolves at a steady, even speed, the driven yoke's rotational speed fluctuates. During driveshaft operation, the driving yoke stays at the same angle and as a result revolves at a constant velocity. The driven yoke changes angles as the rear axle assembly moves up and down on the vehicle's suspension. This angle change causes the driven yoke to speed up and slow down twice per driveshaft revolution.

The greater the angle between the two yokes, the greater the change in driven yoke speed. This fluctuation of driven yoke speed can result in significant drive train vibration. It also increases the strain on the U-Joint crosspiece.

In summary, as a Cardan-style U-Joint's angle is increased, its reliability and its torque and speed capacity decrease proportionally.
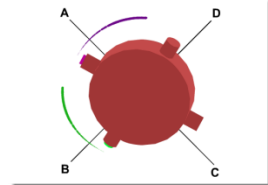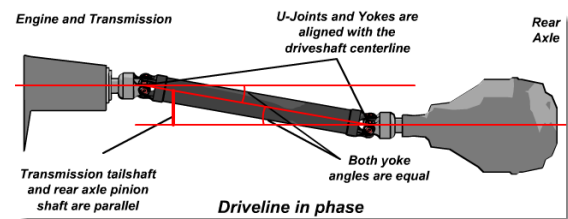
Reducing Rotational Speed Fluctuation

Phasing

A vehicle's driveline must be phased to minimize vibration. A one-piece driveshaft assembly is phased when the yokes at each end are welded exactly in line with each other. In addition, both the front and rear U-Joints should operate at approximately the same angle under most driving conditions.

A properly phased driveline causes the velocity-changing effect of one yoke and U-Joint assembly to cancel out the other.

For example, if the driveshaft angle causes the slip yoke to relay a fluctuating rotational speed to the front driveshaft yoke and tube, the similar operating angle at the rear of the driveshaft will, if the joints are in proper alignment, change the fluctuating rotation of the driveshaft tube and rear yoke into steady rotation, or **constant velocity** at the differential yoke. The only components that must change their turning velocity are the drive shaft tube and yokes.

The driveshaft is designed and built with the yoke lugs/ears in line with each other. Since the yokes on one-piece drive shaft assemblies are welded to the drive shaft tube, U-Joint timing or phasing can change only if the tube develops a torsional twist. All splined shaft slip yokes are keyed in order to ensure proper phasing.

Double Cardan Style U-Joint

One answer to the rotational speed fluctuation inherent in Cardan U-Joint design is the **Double Cardan style U-Joint**. This is essentially two Cardan U-Joints back-to-back.

The Double Cardan design is not as prone to vibration due to rotational speed fluctuation as the single Cardan U-Joint. Rotational speed fluctuation is almost completely cancelled out because the Double Cardan design puts the yokes close together and at equal input and output angles.
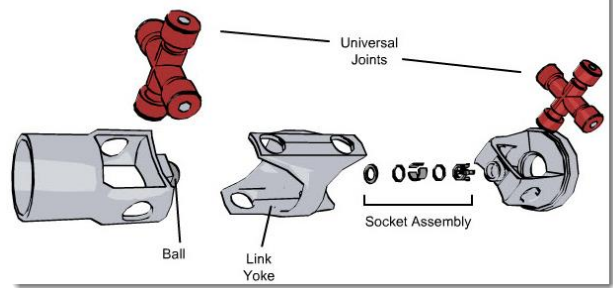
The center **link yoke** (which produces little vibration due to its light weight) becomes the only part that will still change rotational speed. Though better and smoother than a single U-Joint, the Double Cardan U-Joint only provides "near" constant velocity.

This design uses a spring loaded ball-and-socket centering device to stabilize the joint and prevent the link yoke from spinning with wobble or runout regardless of driveshaft angle.
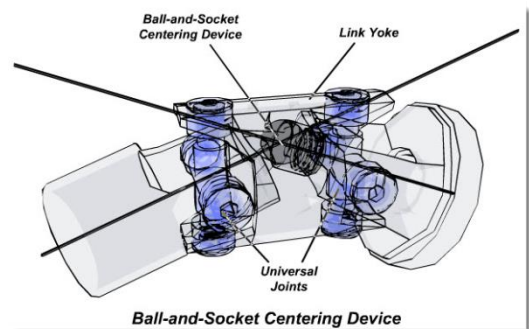
Two-Piece Driveshaft

A particular vehicle design may make it necessary to limit the length and/or diameter of the driveshaft, for a variety of reasons. Because of this, some vehicles use a two-piece driveshaft assembly that pivots in or near the center.

There are three universal joints used on the two piece driveshaft. A center support bearing assembly is used to support the propeller shaft connection point, and help isolate the vehicle from vibration.
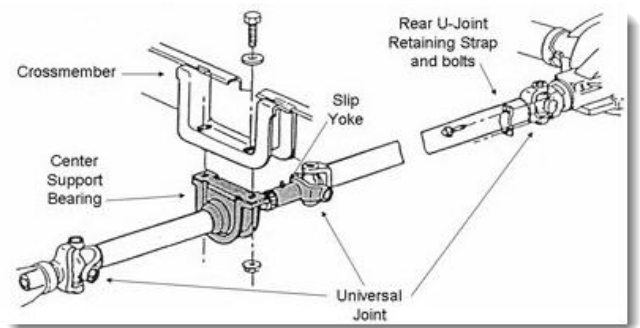
The two-piece driveshaft uses the same components as previously discussed, plus a center support bearing and slip yoke. Typically, the forward or transmission section of the two-piece shaft stays in position. The rear shaft accommodates all differential/suspension travel.

The caged and sealed center support bearing is pressed onto the machined end of the front drive shaft end. The outer bearing race is mounted in a large rubber bushing which in turn is held stationary by a bracket attached to the vehicle's frame. It allows small amounts of driveline vertical motion and helps isolate the vehicle from vibration.

Driveshaft Diagnosis and Service

To effectively diagnose the wide range of driveshaft and driveline-related problems requires more study than can be provided in this introductory course; however, some basic diagnostic information and testing methods will be provided to help you get started. Understanding some of the test methods included will also help in your understanding of how driveshafts and their components work, why they work, and what happens when they don't work properly. A logical, step-by-step approach should be developed and used in diagnosing all automotive systems. A systematic approach will save time and ensure that the proper repairs are made.

Verifying the Customer's Concern

Effective communication between the customer, service writer, and technician is essential for efficient and satisfactory repairs. To begin with, you must know the correct or normal operation of the system and verify that the customer concern is a deviation from normal operation. You need to know what, where, when, and the magnitude of the complaint. This may necessitate a road test. Try to have the vehicle owner/driver ride along during the road test. The owner/driver can assist in identifying the source of any problems. Remember that you will not always be able to verify or even identify each and every customer concern.

CAUTION:
- Always check engine oil and coolant levels prior to running the engine or road testing!
- Safety first when road testing - NEVER drive in an unsafe manner when attempting to identify a problem!

Information Gathering

In identifying and verifying the customer's concern, you are actually gathering information from both the customer and from the vehicle itself. This process of gathering information is an essential step in forming a diagnostic strategy that in turn will identify the cause of the customer concern. Once you've gathered information from the customer and the vehicle, the next step is to research service information related to the owner/driver's concern. Service manual information and manufacturer's technical service bulletins (TSBs) should be searched and read to familiarize yourself with the system. TSBs may also contain information on updated parts and service procedures related to your customer's concern.

Determine a Diagnostic Direction

Based on the information that you've gathered, you now should be able to determine what diagnostic procedures should be performed to locate the concern. Here's a real-world example of this process. A regular customer brings you a 2012 Cadillac Escalade. This customer states that a squawk noise is heard and felt when pulling away from a stop. Your shop has serviced this vehicle regularly, so you have the vehicle's service history. As a part of the information gathering process, you find GM TSB # 01-04-17-004B while researching manufacturer's technical service bulletins. This technical service bulletin identifies a slip/stick condition between the transfer case output shaft and the driveshaft slip yoke as being a potential cause for your customer's concern. The bulletin also describes how to verify the customer complaint and even gives a part number for an updated slip yoke that should be used in making the repair.

Keep in mind that your customer's vehicle still needs to be properly diagnosed. The TSB in this example tells you how to perform the diagnosis to either confirm or rule out a slip/stick condition as being the cause of the customer complaint.

Driveshaft Symptoms

Driveshaft symptoms can usually be classified into the following categories:

Leaks - these are generally the result of worn transmission tailshaft or differential pinion yoke/flange seals. Diagnosis should include careful inspection of the areas of the yoke/flange where the seal contacts for burrs and grooves. When in doubt, replace the yoke/flange in question.

Noises and Vibrations - driveshaft vibration can be caused by any issue that affects balance, runout (straightness) and U-Joint or driveshaft angle. Though it is possible to have noise without vibration or vibration without noise, in most cases these go hand-in-hand when a driveshaft or driveline-related customer complaint is involved.

Driveshaft Inspection

CAUTION:
- Always follow all general safety guidelines for servicing motor vehicles with regards to electrical connections, flammable or corrosive materials, adequate ventilation, jacking and supporting, working around hot or moving parts, proper use of parking brake, gear selector, wheel blocks, and disabling fuel or ignition systems. Refer to the equipment User's Manual and vehicle Service Manual for the operation you are performing.
- Never drive a vehicle with its doors open. Never attempt to listen to sounds coming from underneath a moving vehicle.
- Never attempt to engage the cruise control while the vehicle is on a hoist. Always have another technician operate the vehicle while it is on a hoist.
- The drive shaft angle will be different when the vehicle is supported by the frame. Support a rear-wheel-drive vehicle by the rear axle and a front-wheel-drive vehicle by the lower control arms to duplicate driving conditions.

This chart can be used to help diagnose possible causes for driveshaft-related noise or vibration. Remember that other components such as wheels, tires, rear axle and suspension can also produce similar conditions.

Basic Driveshaft Problems

| The Symptom	Likely Cause(s)	Correction
Shudder when accelerating from stop or at low speed	Loose U-Joint	Replace U-Joint
	Defective center bearing	Replace center bearing
Loud clunk in driveshaft when shifting gears	Worn U-Joint(s)	Replace U-Joint(s)
Roughness or vibration at any speed	Out-of-balance, bent or dented driveshaft	Balance or replace driveshaft
	Worn U-Joint(s)	Tighten U-Joint clamp bolts to specification
	U-Joint clamp bolts loose	Tighten U-Joint clamp bolts to specification
Squeaking noise at low speeds	Lack of U-Joint lubrication	Lubricate or replace U-Joint(s)

If a customer complains of noise or vibration, carefully inspect the driveshaft, center support bearing (where applicable) and U-Joints.

With the engine off, the transmission in neutral and the vehicle properly supported on lift equipment, grasp the driveshaft. Shake the shaft up and down at each end and rotate it back and forth while carefully observing the yokes and U-Joints.

The source of any movement should be easy to pinpoint. A small amount of play where the slip yoke goes into the transmission tailshaft is not abnormal or unusual. It should not be of concern unless there's enough play to cause significant seal leakage.

Other things to look for when pinpointing a noise or vibration complaint include:

- Excessive mud or undercoating on the driveshaft
- A lost balance weight
- A bent drive shaft (excessive runout - check using a dial indicator)
- Loose rear U-bolts
- Improperly seated or installed U-Joints
- U-Joints which are too loose or too tight (this may require driveshaft removal to verify)
- Excessive looseness at the slip yoke bushing (again, a small amount of play is acceptable)
- Imbalance, runout, or looseness of the pinion yoke/flange
- An out-of-phase and/or incorrect U-Joint angle condition caused by suspension damage or modification (lifting/lowering)
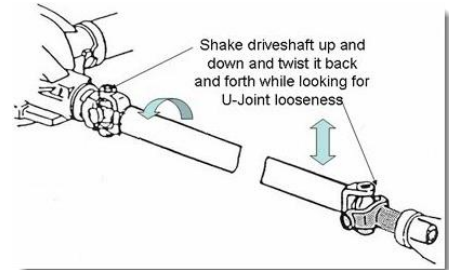
Roughness at 15 to 25 mph (24 to 40 kph) under light load may be caused by excessively tight U-bolts. Brief roughness upon heavy acceleration may be caused by a worn double cardan joint ball-and-socket centering device (on vehicles so equipped). Most shops will sublet driveshaft balancing and fabrication-related jobs out to a driveline specialty shop.

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Driveshaft Service

The following is a generic overview of driveshaft service procedures.

Note: Manufacturer's specific service procedures detailing driveshaft service, component and fastener removal sequence, component inspection, component replacement, and fastener torque should be followed to the letter.

Removal (one-piece):

- Mark the driveshaft and pinion flange/yoke so that they can be reassembled in their same relative positions.
- Remove the U-bolts or straps that hold the rear U-Joint to the pinion flange/yoke.
- **Note**: On some models, the rear yoke is separated from the pinion flange by threading a bolt into a specially threaded hole in the pinion flange. When tightened, the bolt runs into an area of the rear yoke mating surface that is not drilled and forces the rear yoke away from the pinion flange.
- Move the drive shaft forward to separate the rear U-Joint from the pinion flange/yoke.
- Wrap the rear U-Joint bearing cups with tape to keep them from falling off the rear U-Joint.
- Pull the slip yoke and driveshaft out of the transmission extension housing.
- Install a plug in place of the driveshaft yoke to prevent the loss of lubricant.
- Reverse this procedure to reinstall.

Removal (two-piece with center bearing):

- Mark the driveshaft(s) and pinion flange(s)/yoke(s) so that they can be reassembled in their same relative positions.
- Remove the U-bolts or straps that hold the rear U-Joint to the pinion flange/yoke.
- Move the drive shaft forward to separate the rear U-Joint from the pinion flange/yoke.
- Wrap the rear U-Joint bearing cups with tape to keep them from falling off the rear U-Joint.
- Pull the slip yoke and rear driveshaft off of the splined union at the center support bearing.
- Remove the center support bolts from the crossmember and slip the center support and front driveshaft assembly from the transmission.
- Reverse this procedure to reinstall.
- **Note**: Make sure the U-Joints are phased correctly and that the front face of the center support bearing is perpendicular or 90 degrees to the driveshaft centerline during reinstallation. Manufacturer's specific service procedures should be followed.

U-Joint Replacement (vise procedure):

- **Note**: Manufacturer's specific service procedures, which may specify a U-Joint press or other special tool, should be followed.
- Remove the internal or external snap rings that retain the bearing cups, if necessary.
- Mark the driveshaft(s) and pinion flange(s)/yoke(s) so that they can be reassembled in their same relative positions.
- **Note**: Some OE joints use an injected plastic to hold the cups in place. Replacement retainers are furnished with the replacement U-Joint.
- Select a suitable pressing arbor or socket. The arbor or socket must be smaller than the diameter of the bearing cup.
- Select a receiving socket into which the U-Joint cup can be pressed. The socket must have an inside diameter larger than the bearing cup, but small enough to make good contact with the yoke.
- Use a heavy-duty vise or a press to push the bearing cup through the yoke.

- Remove the U-Joint from the vise. Remove the outside bearing cup from the yoke.
- Return the joint to the vise. Using the arbors or sockets, press the cross in the opposite direction to push out the other bearing cup.
- Remove the joint from the vise. Remove the other bearing cups and cross.

Center Support Bearing Inspection Procedure:

- Clean the center support and bearing.
- Turn the bearing by hand and check for roughness, looseness, or binding.
- Inspect the rubber collar and bracket for damage. Replace them if they are defective.
- Replace the bearing if it is defective.
- **Note**: To replace the center support bearing, press the carrier bearing off the drive shaft and press on a new one.

Installing a New U-Joint:

- **Note**: Remove all traces of sheared plastic from the grooves in the yoke and drive shaft cups if the cups were held in place by injected plastic.
- Push one bearing cup into the yoke and install the cross.
- Insert the trunnion part of the way into the bearing cup.
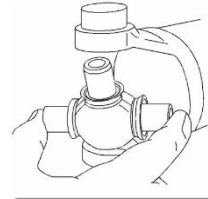
Note: If the new U-Joint has a grease fitting, orient the cross so that the grease fitting points towards the driveshaft.

- Install the other bearing cup and press the assembly together in a vise. Check cross movement for binding, which indicates misplacement of needle bearings. If binding occurs, remove the cups and crosspiece and repeat the procedure.
- Press the cups in until the snap rings can be installed. If the snap rings cannot be installed, a needle bearing may be turned sideways in the cup. Remove the U-Joint from the yoke and repeat the procedure.
- Make sure the final assembly can move freely. If the joint feels tight, center the U-Joint by resting the cups or slip yoke on the jaws of the vise with a protective cloth between the joint and the vise. Next, gently tap the ears of the yoke with a hammer to center the cross and push the bearing cups out against the snap rings.
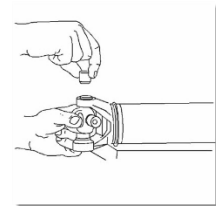
CAUTION: Never clamp the driveshaft tube in a vise or strike the yokes with a hammer while the tube is extending over the edge of a table. Either action may bend the driveshaft tube.

Note: Again, these procedures are generic. Manufacturer's specific published service procedures should be followed for the vehicle that you're working on.
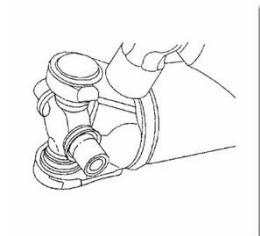
Chapter 2: Halfshaft Design, Diagnosis, and Repair

Halfshaft Principles, Function, and Construction

As was noted in the introduction, **front**-**engine**, **front-wheel-drive** vehicles use a pair of **halfshafts** to transmit power and motion from the **transaxle** to the **drive wheels**. The halfshafts must be strong enough to handle the highest expected amount of torque load applied by the transaxle, yet flexible enough to allow normal powertrain, suspension, and steering component movement.

Like the driveshaft in a rear-wheel-drive vehicle, the halfshafts must be straight and balanced for smooth operation. Unlike the driveshaft, halfshafts rotate at wheel speed rather than at transmission output shaft speed, and are shorter. These two design characteristics make them less likely to cause vibration issues when compared to a rear-wheel-drive driveshaft.
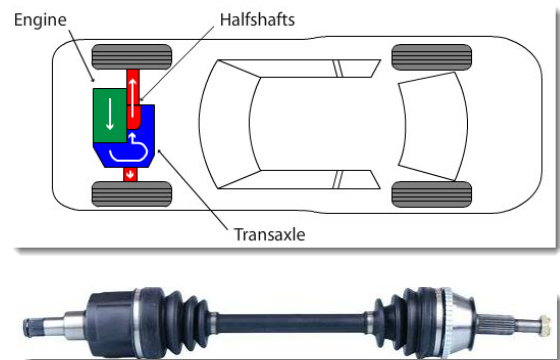
Halfshafts also must have greater flexibility than rear-wheel-drive driveshafts. Cardan-style U-Joints are restricted as a general rule to operation at angles of 15° or less. As a Cardan-style U-Joint's angle is increased, its reliability and its torque and speed capacity decrease proportionally. A different design is therefore needed when transmitting power and motion to a front wheel that may turn at a 30° or greater angle when steered.

CV (**Constant Velocity**) Joints are designed to allow the halfshaft to transmit power and motion through a variable angle at constant rotational speed. The most common outer CV joint design used is called a **Rzeppa-style joint**, and is named for the Ford engineer that invented it. Outer CV joints are not designed to plunge.
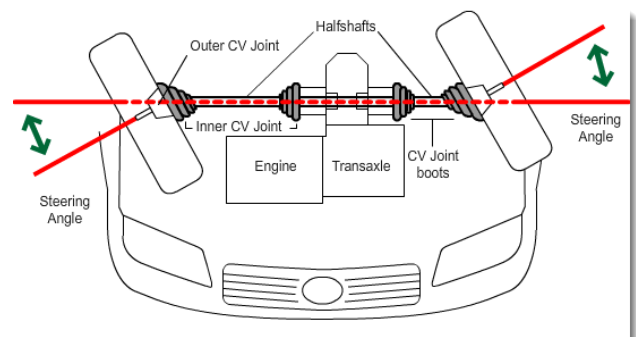
Note: Rzeppa is pronounced "shep-ah"

Consider also the changes in halfshaft angle and length as the suspension moves up and down. These changes require a different design than the Cardan-style U-Joint and slip yoke used on most rear-wheel-drive driveshafts. Inner CV Joints are not subject to the same extreme steering angles that outer CV Joints are, but they must be designed to accommodate plunge or halfshaft length change.
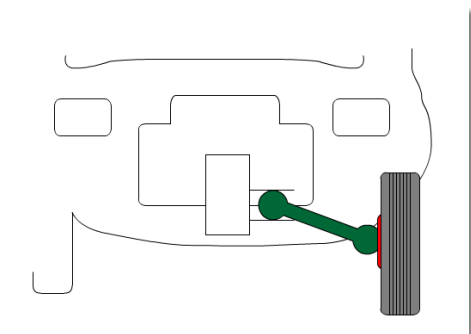
The most common inner **plunge-style** CV joint design used is called a **Tripod-style joint**. Plunge-style joints can also use either **crossgroove** or **double-offset** designs, which are variations of the Rzeppa-style joint design. All three of these allow greater halfshaft angle and length changes than their previously discussed driveshaft counterparts.
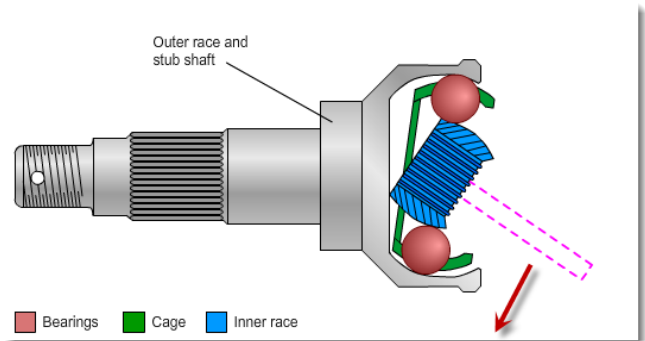
Rzeppa-Style Joint Design

The Rzeppa joint consists of a spherical **inner and outer races** connected by six steel **bearings** that run in longitudinal grooves cut into both races.

The grooves and bearings are precision-machined to extremely close tolerances and hardened for long life. Molybdenum Disulfide grease is commonly used as a lubricant.
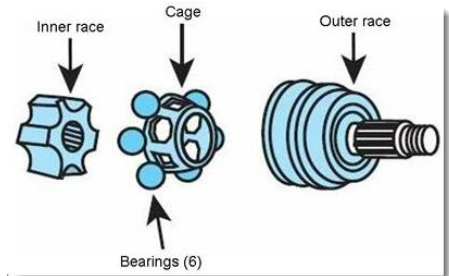
The **axle shaft** is splined to the inner race, which is retained by an external or internal snap ring. The outer race has a **stub shaft** made onto its outside end which is splined to the **wheel hub**. A **cage** fitted between the inner and outer race retains the bearings. The bearings connect and transmit power and motion between the inner and outer races.

The cage and bearings will always self-position to evenly split the angle between the inner and outer race. Dividing this operating angle eliminates the cyclic variations in speed that a Cardan-style U-Joint experiences when its operating angles change. In summary, unlike a Cardan-style U-Joint, a Rzeppa-style CV Joint's reliability and its torque and speed capacity do not appreciably decrease as its operating angle is increased.

Tripod-Style Joint Design

The tripod joint consists of a three-legged **inner race** or cross with **rollers** on the end of each leg. This inner race is splined to the axle shaft, and is retained by an external or internal snap ring. The rollers run on **needle bearings** and roll in precision-machined grooves or channels in an **outer** "**tulip**" **race**. The rollers connect and transmit power and motion between the inner and outer races. This type of joint is designed to plunge in and out with suspension movement and corresponding halfshaft length change.

As with the outer CV Joint, the grooves, rollers and needle bearings are precision-machined to extremely close tolerances and hardened for long life. Molybdenum Disulfide grease is commonly used as a lubricant.
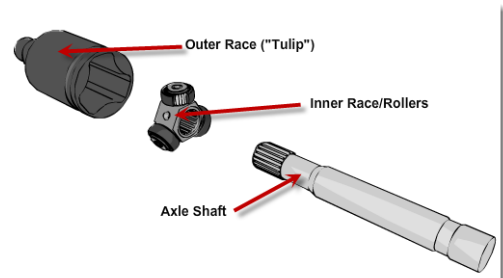
The **axle shaft** is splined to the inner race, which is retained by an external or internal snap ring. The outer race or tulip can have a **stub shaft** or **flange** made onto its outside end for attachment to the output shaft of the transaxle depending upon the specific vehicle's design.
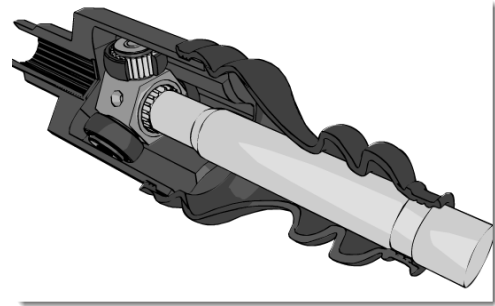
As mentioned earlier, there are also Plunge-style joints that use the **double-offset** and **crossgroove** designs, which are variations of the Rzeppa-style joint design that allow halfshaft length changes.

Many European vehicles use the crossgroove design, which is very compact. Double-offset CV Joints are more expensive to manufacture, but they make for a smoother driveline and can accommodate greater halfshaft angles than tripod joints.
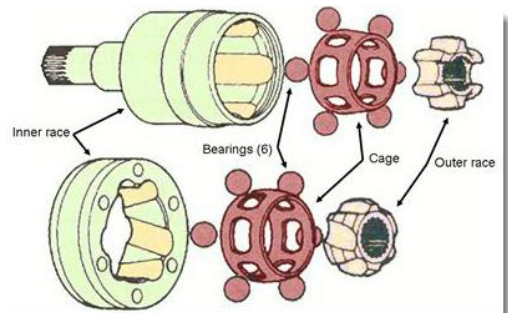
Boots and Clamps

All CV Joints are enclosed by a neoprene or plastic boot to keep lubricant in and contaminants out. The boot is **convoluted** to allow it to flex as halfshaft angles change.

The boot is clamped firmly at both ends using metal strap-style clamps or retaining rings.

Halfshaft Symptoms

Halfshaft symptoms can usually be classified into the following categories:

Leaks - these are generally the result of punctures, tears, or splits to the CV Joint boot. A ripped or split boot in most cases is the root cause of many halfshaft and CV Joint problems. Since the halfshaft rotates at drive wheel speed, any holes or splits in the boot will cause the lubricating grease to be quickly thrown out. Insufficient lubrication causes internal CV Joint components to wear rapidly.

Another issue with ripped or split boots is contamination. Once the boot is open to the elements, water and dirt contaminate whatever grease was not flung out. This causes rapid CV Joint component wear as well.

Other leaks can come from worn stubshaft (transaxle to halfshaft or wheel bearing) seals. Diagnosis should include careful inspection of the areas of the CV Joint outer races where the seal contacts for burrs and grooves. When in doubt, replace the CV Joint or halfshaft in question.

Separation - Worn or misaligned steering, suspension and/or engine and transaxle mount parts can cause CV-joint and/or halfshaft separation. As little as two or three degrees of misalignment can cause the engine and transaxle to be more than 1/2 inch (13mm) out of position. CV Joints can be pulled apart and halfshafts can be pulled out of the transaxle as a result. These issues should be the first things checked before a replacement CV Joint or halfshaft is installed if separation caused the original failure.

Noises - As discussed earlier, CV Joint internal parts are precision-machined to very close tolerances. This means that excessive wear usually makes itself known via clicking sounds audible when stopping, starting, or turning tight circles.

Vibration - A worn CV Joint can sometimes cause vibration or shudder, particularly when power is applied while turning the vehicle.

Remember that other components such as wheels, tires, engine mounts and suspension components can also produce similar noise and vibration conditions.

Halfshaft Inspection
CAUTION:
- Always follow all general safety guidelines for servicing motor vehicles with regards to electrical connections, flammable or corrosive materials, adequate ventilation, jacking and supporting, working around hot or moving parts, proper use of parking brake, gear selector, wheel blocks, and disabling fuel or ignition systems. Refer to the equipment User's Manual and vehicle Service Manual for the operation you are performing.
- Never drive a vehicle with its doors open. Never attempt to listen to sounds coming from underneath a moving vehicle.
- Never attempt to engage the cruise control while the vehicle is on a hoist. Always have another technician operate the vehicle while it is on a hoist.
- The halfshaft angle will be different when the vehicle is supported by the frame. Support a vehicle by the lower control arms to duplicate driving conditions and prevent potential halfshaft damage when investigating halfshaft vibration or noise.

This chart can be used to help diagnose possible causes for driveshaft-related noise or vibration. Remember that other components such as wheels, tires, bearings, engine / transaxle mounts and suspension components can also produce similar conditions.

Basic Halfshaft Problems		
The Symptom	**Likely Cause(s)**	**Correction**
Noise / vibration while turning	Worn or contaminated outer CV Joint	Replace CV Joint or halfshaft
	Worn wheel bearing	Replace wheel bearing
Vibration when accelerating	Worn or contaminated outer or inner CV Joint	Replace CV Joint or halfshaft
	Damaged / misaligned steering / suspension / engine / transaxle mounts	Align / replace as needed
Roughness or vibration at cruising speed	Outer CV Joint misassembled/not seated	Assemble correctly or replace halfshaft
	Worn wheel bearing	Replace wheel bearing
	Tire imbalance / out-of-round	Balance or replace tire
Thump when applying torque	Damaged / misaligned steering / suspension / engine / transaxle mounts	Align / replace as needed
	Worn or contaminated outer CV Joint	Replace CV Joint or halfshaft
Axle shaft / inner CV Joint pullout	Damaged / misaligned steering / suspension / engine / transaxle mounts	Align / replace as needed
	Bad / improperly seated snap rings	Replace / reseat

With the engine off, the transmission in neutral and the vehicle properly supported on lift equipment, visually inspect the halfshafts. If the boots are intact, grasp each axle shaft. Shake the shaft up and down at each end and rotate it back and forth while listening and feeling for looseness in each CV Joint. A torn boot, contaminated grease or play in the shaft indicates a problem.

If no play is found and the boots are intact, remove the halfshaft from the vehicle and rotate each CV Joint by rotating it in a circular motion. This action should be smooth and even. If any binding and/or roughness is felt the CV Joint should be replaced.

CV Joints can be cleaned and repacked, and CV Joint boots can be replaced. Given the cost of labor and the potential warranty liability involved, you may find that in many cases replacing the entire halfshaft with a new or reconditioned unit makes the most economic sense for the vehicle owner.

Unit 5: Differential Assemblies and Drive Axle Assemblies

Chapter 1: Differential Assemblies

Differential Principles, Operation, and Diagnosis

In the Introduction, we noted that on front-engine, rear-wheel-drive vehicles, a drive shaft transmits power from the transmission to the final major component, the rear axle assembly. The rear axle assembly splits up the torque coming from the drive shaft to send power to both rear axles. The rear axles are at 90 degrees to the drive shaft. This is accomplished by using a differential assembly.

The differential also provides additional gear reduction and a means for torque to be delivered to the rear wheels, even when they are rotating at different speeds (such as when turning, when the outside wheel must travel farther and therefore faster than the inner wheel). Typical gear reduction might be from 2.5:1 to a very low ratio of 4:1 in applications where a great deal of torque is required.

Front-engine, front-wheel-drive vehicles incorporate the transmission and the differential assembly into a single case, and the unit is called a transaxle. Drive axles then deliver the power from the transaxle to drive wheels.

This section will provide a brief overview of differential principles, components, operation, and diagnosis, using rear-wheel-drive applications in our examples for simplicity.
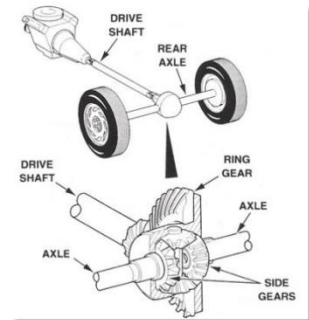
### *Major Components of a Rear Axle*

There are three major parts to a rear axle:

- The ring and pinion gearset
- The differential gearset
- The carrier housing

Both the ring and pinion gearset and the differential gearset are contained within the carrier housing.

Ring and Pinion Gearset

The ring and pinion gearset has two components, the ring gear and the pinion gear. The pinion gear is connected to the drive shaft by the companion flange. The pinion gear is supported in the carrier housing by two bearings. The ring gear is connected to the differential case (part of the differential gearset). The ring and pinion gearset provide the 90-degree change in rotation required for torque transfer from the drive shaft to the wheels.
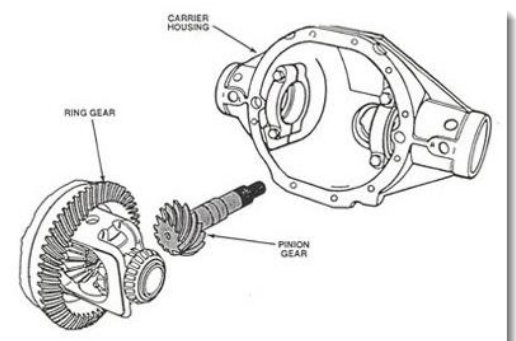
Inspecting and Replacing Fluid in the Differential Housing

Inspect differential housing, check for leaks, and inspect housing vent

Inspect differential housing for signs of damage that may be the result of collision, abuse or corrosion. Look for fluid leakage from the housing that might indicate a crack in the housing. Inspect the housing vent for blockage and check the condition of the vent hose (if used); the hose should be flexible and tight at the connects.

Drain and refill differential housing

Note: Before performing service, the first step is to review service information to determine the correct fluid type and the procedure for draining and refilling the differential. Many differential housings have a cover that can be removed to drain the fluid and inspect the internal components.

- Place a drain pan under the differential
- Remove the cover bolts and slowly remove the cover; allow the fluid to drain completely before reinstalling the cover
- **Note**: If the housing does not have a cover, service information will detail the procedure to drain the fluid
- Most differential housings have an access port located at the correct height for the fluid level; use service information to locate and remove the access port plug
- Identify the correct fluid type and use a fluid pump to refill the differential housing
- Replace the access port plug and tighten to specifications

Chapter 2: Drive Axle Assemblies

Rear Axle Bearing Assemblies

Rear axle bearing assemblies are designed to support rotating components while allowing them to rotate independently of the support component (the rear axle carrier housing). Rear axle bearing assemblies have the following components:

- Inner bearing race
- Outer bearing race
- Bearings
- Bearing cage
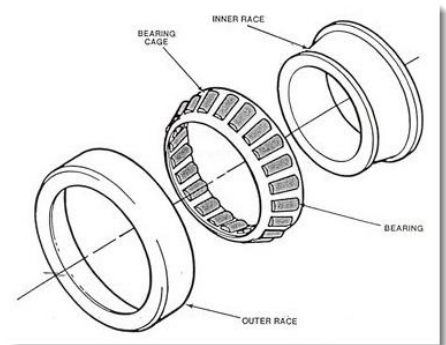
Rear axle bearings can be either ball bearings, straight roller bearings, or tapered roller bearings. Rear axles typically use tapered roller bearings to support the pinion gear and the differential case. Ball bearing or tapered roller bearings are used to support the axle shafts.

Axle Shaft Assemblies

The axle shafts are used to connect the rear axle gearsets to the wheels of the vehicle. One end of the axle shaft has splines for meshing with the differential side gears. There are two types of axle shaft assemblies:

- Semi-Floating
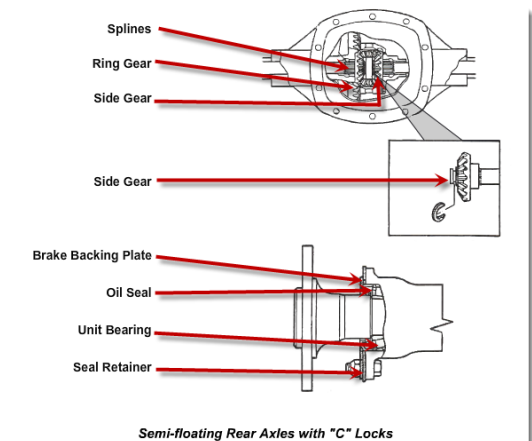- Full Floating

Semi-Floating Axle Shafts

The semi-floating axle shafts support the vehicle weight and are typically used in light duty trucks and cars. The semi-floating axle shafts have flanges for mounting the brake drums/discs and wheels. Wheel bearings are used to support the axle shaft in the axle tubes.

Currently there are two methods used to retain semi-floating axle shafts in the carrier housing:

- "C" locks
- Seal retainer plates

The "C" lock method is the most widely used. The axle shafts used with this method have recesses at the inner end of the shaft for the "C" locks. The "C" locks keep the axle shafts splined to the differential side gears. In this method, the wheel bearings are pressed into the axle tubes.

The second method uses wheel bearings that are pressed onto the axle shafts. A seal retainer plate is positioned between the bearing and the axle flange. The seal retainer bolts to the axle tube and positions the outer race of the wheel bearing inside the axle tube. The press fit of the bearing on the axle shaft prevents the axle shafts from coming out of the axle tubes.

Semi-floating Rear Axles with "C" Locks

Full Floating Axle Shafts

The full floating axle shafts do not support the vehicle weight and are typically used in medium and heavy duty truck applications. Full floating axle shafts are also used in some 3/4- and one-ton light duty trucks (based on Gross Vehicle Weight, GVW). Like semi-floating axle shafts, the full floating shafts are splined to the differential side gears. The other end of the axle shaft is bolted to the wheel hub.

The vehicle weight is supported by bearings between the wheel hubs and the axle tubes. Bearings are not used to support full floating axle shafts.
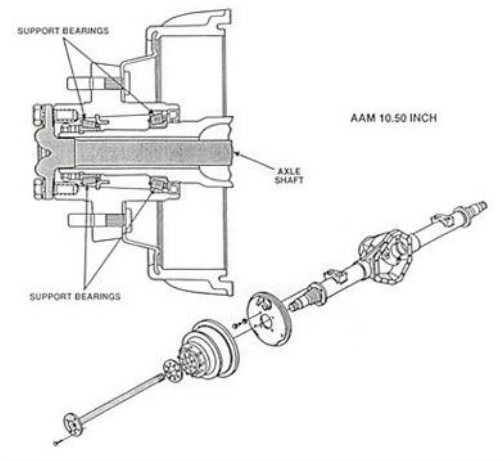
Axle Wheel Studs

Wheel studs can have damaged threads as a result of overtightening of the lug nuts or corrosion; they can break when the wheel is being removed. Often the stud can be replaced without removing the hub/axle. A hammer and punch can be used to drive out the damaged stud and a C-clamp-type press is commonly used to press the new stud into place. Some vehicle designs do not allow space to install the wheel studs without removing the hub/axle from the vehicle. Use service information to locate a procedure to remove the hub/axle. Following the procedure:

- Remove the hub/axle assembly
- With the hub/axle off the car, use a hammer and punch or press to remove the damaged stud
- Press the new stud in place and reinstall the hub/axle assembly
- Install the tire and wheel assembly and tighten lug nuts to specifications

Unit 6: Four-Wheel Drive/All-Wheel Drive Diagnosis and Repair

Chapter 1: Drive Axle Assemblies

Four-Wheel Drive

A vehicle with four-wheel drive (4WD) has a drive train that can send power to all four wheels. This provides maximum traction for off-road driving. It also provides maximum traction when the road surface is slippery, or covered with ice or snow. Some vehicles have a four-wheel-drive system that engages automatically or remains engaged all the time. Other vehicles have a selective arrangement that permits the driver to shift from two-wheel to four-wheel drive, and back, according to driving conditions. The instrument panel or console may include an indicator light or display to show when the vehicle is in four-wheel drive.

Many four-wheel-drive vehicles have rear-wheel drive with auxiliary front-wheel drive. A two-speed gearbox, or transfer case engages and disengages the front axle while providing high and low speed ranges. Other vehicles use the front axle as the main drive axle. To get four-wheel drive, the transfer case engages the rear axle, which then serves as the auxiliary-drive axle. Four-wheel-drive vehicles usually have high ground clearance, oil-pan and underbody protection, and tire treads suitable for off-road use.
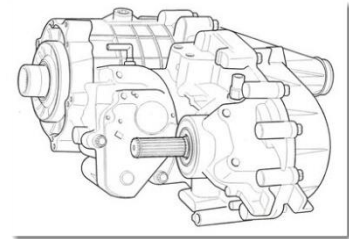
Inspection of Front-Wheel Bearings and Locking Hubs

Not many four-wheel-drive vehicles still use locking hub to disengage the front axles, but locking hubs are common on older trucks. Locking hubs can be manually operated which require the driver to get out of the vehicle and twist a dial on each hub to engage and disengage the drive axles. Locking hubs sometimes become contaminated with dirt and water which can prevent their operation.

To inspect lockout hub operation:
* Jack up the vehicle so that the front wheels can be turned by hand
* Turn the dial to the lock position on one side of the vehicle, rotate the wheel and tire assembly, and watch the axle; it should be rotating with the tire and wheel assembly
* Move the dial to the unlock position and rotate the wheel and tire assembly. Watch the axle; it should not rotate with the tire and wheel assembly
* Repeat the procedure on the other side of the vehicle

Some four-wheel-drive vehicles use an axle disconnect system in place of locking hubs. These systems use vacuum or electrical to move a shift fork that connects and disconnects the front axle on one side of the vehicle only. The system is designed to reduce wear on the ring and pinion and improve fuel mileage.

To test the operation:

Raise both front wheels and with the engine running, place the four-wheel-drive selector in the four-wheel-drive position

- Rotate one front wheel; the wheel on the other side should rotate in the opposite direction
- Move the four-wheel-drive selector to the 2-wheel-drive position
- Rotate one front tire and wheel; the wheel on the other side of the vehicle should not rotate
- To inspect the front wheel bearing:

Raise the vehicle

- With the tires off the ground, rotate the wheel and tire assembly and note any rough or varying resistance
- Place one hand at the top of the wheel and tire assembly and the other at the bottom. Using your hands, try to move the top and bottom of the tire and wheel assembly in and out; there should be no movement
- If movement is found, remove the tire and wheel assembly, the brake caliper, and pads. Use your hands to try to move the rotor assembly in and out at the top and bottom
- If movement is found, the rotor/hub assembly must be removed and the wheel bearing inspected or replaced

Check Drive Assembly Seals and Vents; Check Lube Level

Perform a visual inspection of the drive assembly seals for leakage. If leakage is present, the seals will have to be replaced.

Inspect the drive assembly vent for blockage and check the condition of the vent hose (if used); the hose should be flexible and tight at the connectors.

To check the lube level:

- Review service information to determine the correct type of fluid and the location of the access port plug
- Remove the plug and check fluid level
- If the level is low, use fluid pump to add fluid to the correct level
- Install the access port plug and tighten to the correct specifications

Unit 7: Automatic Transmissions/Transaxles

## Chapter 1: Automatic Transmission/Transaxle Components and Operation

Reviewing Service Information and Fluid Levels

An important step before working on a vehicle is to review service information. Identify all fluid types and capacities, note service precautions, and review TSBs related the vehicle's drive train system. When completing the repair order ask the owner for the vehicle's service history. The information is useful to safely perform diagnosis procedures and servicing the drive train components.

One of the most important things to review is the drivetrain of the vehicle, as this will affect the layout of the vehicle's transmission.

Rear-Wheel-Drive

The automatic transmission of a rear-wheel-drive vehicle is fastened to the rear of the engine by bolts located around the transmission housing. Power from the engine is transferred through the engine flywheel and into the torque converter for distribution to the planetary gearsets. From the planetary gearsets, power is transferred through the differential to the rear wheels. In addition to transferring power, the torque converter and transmission convert the relatively high revolutions per minute of the engine into levels of torque that are required to move the vehicle.
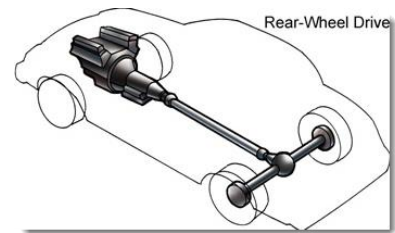
When the vehicle is standing still, the engine cannot develop enough torque to get the vehicle moving. The transmission converts the relatively high revolutions per minute of the engine into torque that is high enough to move the vehicle. Once the vehicle begins moving, the engine continues to maintain high revolutions per minute while the transmission provides various degrees of torque to the driveline and rear wheels.

Front-Wheel-Drive

In front-wheel-drive vehicles, a **transaxle** serves the same purpose as the transmission and differential in rear-wheel-drive vehicles. The transaxle transfers engine torque to the drive wheels. The engine and transaxle are transversely mounted to reduce the overall length of the drive train.
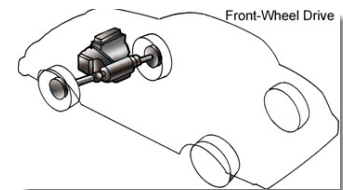
The differential gears are housed in the transaxle as an integral part of the drive assembly. The differential gears are connected to the front wheels by the front-drive axles.

The front-drive axles transfer the final drive torque to the front wheels. Because the front wheels also steer the vehicle and are independently suspended, the drive axles must also pivot, swing, and change length. Special joints called **constant velocity joints** (CV-joints) are used to achieve this flexibility.

Four-Wheel-Drive and All-Wheel-Drive

In four-wheel-drive and all-wheel-drive vehicles, all four wheels are driven. **Four-wheel-drive vehicles** use gearing in the transfer case to send power to both the front and rear axle assemblies.

All-wheel-drive vehicles use a viscous fluid coupling center differential instead of a transfer case to route drive torque to all four wheels.

Checking Fluid Levels on Vehicles Equipped with a Dip Stick

Most vehicles equipped with dip sticks for measuring the transmission/transaxle fluid level require that the engine is running and the transmission/transaxle be parked on a level surface and the gear selector placed in the park or neutral position (check service information for the vehicle being serviced). Most dip sticks have a cold and warm level marks for accurate readings. If the fluid level is below the dip stick mark, fluid will need to be added. To add fluid to transmission/transaxle with a dip stick, a funnel is used and the fluid poured through the dip stick tube. It is important to not overfill the transmission/transaxle.

Check Fluid Levels on Vehicles Not Equipped with a Dip Stick

Vehicles with automatic transmission/transaxle that do not have dip sticks fluid is checked and added through access ports and plugs similar to manual transmission/transaxles. First review service information to identify the location of the access port and the procedure to measure fluid level. If the fluid level is low determine the procedure for adding fluid.

Note: In some automatic transmission/transaxles, it is not possible to check the fluid level or add fluid with the unit in the vehicle.

Check Fluid Condition

When checking the fluid level, the condition of the fluid should also be inspected. Dark fluid or fluid that smells burned may indicate transmission/transaxle overheating. A check of the transmission cooling lines and cooler should be performed. If the fluid is pinkish or foamy, it may be contaminated with water. The source of the water contamination must be identified and corrected followed by a complete transmission flush and new fluid and filter installed. Brass, metal or clutch material in the fluid is an indication of internal transmission/transaxle damage; in most cases, the transmission pan should be removed to make a more accurate determination of the transmission/transaxle condition.

Torque Converter Components and Operation

The **torque converter** consists of three sets of blades - the **pump impeller** (referred to as the pump), the **turbine runner** (referred to as the turbine), and the **stator**. The pump blades are connected to the engine flywheel through the converter housing. The pump blades are driven directly by the engine. As the engine rotates, the blades of the pump throw fluid outward at a high velocity.
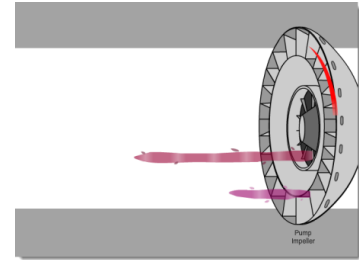
This fluid strikes the blades of the turbine, causing the turbine to turn.

As the blades are struck by the fluid, the turbine blades begin to move at a slower velocity but at a higher torque than the fluid. The fluid's high velocity is converted into torque. The turbine is connected to the transmission input shaft, the end of which is connected to the planetary gearset. When the turbine turns, planetary gearsets also turn.
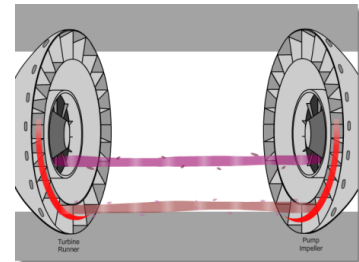
Note: The blades on the turbine are curved to direct the fluid into its center. Because the fluid strikes the turbine blades at an angle, not all of the fluid velocity is converted into torque. Even after striking the blades, the fluid still is moving fairly fast and can do more work.
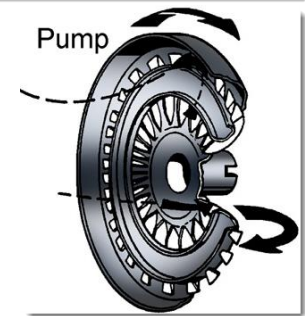
Note: As the vehicle begins to move, pump speed is greater than turbine speed. However, turbine speed will eventually reach pump speed. This means that transmission/transaxle speed will reach engine speed, and speed is no longer being converted in torque.

The **stator** is located in the center of the torque converter and is mounted on a one-way clutch. After the transmission fluid leaves the pump blades, it strikes the turbine. The fluid is then routed back to the pump by the stator. The angled blades of the stator are able to redirect the flow of the fluid according to the rate at which the stator spins.

By routing the fluid back to the pump, the velocity maintained by the fluid is added to the velocity of the fluid leaving the pump; therefore, the force exerted on the turbine is increased. The stator allows for the multiplication of torque within the torque converter as long as the pump and turbine are turning at different speeds.
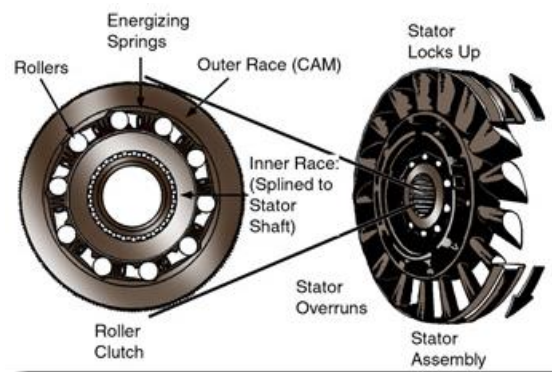
When the pump and turbine are turning at the same speed, the one-way clutch allows the stator to freewheel in the direction of the pump and turbine rotation. If the difference between the pump and turbine velocity is sufficient, the clutch will lock up the stator.

When accelerating from a stop, the pump turns rapidly because of increased engine revolutions per minute; the turbine, on the other hand, is just beginning to turn. Fluid exits the turbine at high speed, strikes the face of the stator blades, and locks up the one-way clutch. When the clutch is locked up, the fluid is redirected to the pump.

If the turbine blades are moving at the same velocity as the pump blades, the fluid will leave the turbine on the back side of the stator blades and rotate the stator in the same direction as the pump and turbine. Less fluid redirection occurs. The one-way clutch allows the stator to help the torque converter produce high torque at low vehicle speeds (high engine load) and low torque at high vehicle speed (low engine load).

Torque Converter Operation at Various Stages of Engine Operation

As the engine idles, some fluid is forced out of the torque converter pump and into the turbine. The fluid is moving slowly and cannot strike the turbine blades hard enough to move the vehicle. In a sense, the engine is disconnected from the vehicle drive train in the same way a manual transmission is separated from the drive train by the disengagement of the clutch.

As the driver accelerates the engine, the pump spins faster and increases the fluid velocity. The fluid strikes the turbine blades with enough velocity to cause the blades to turn. The fluid leaves the turbine, enters the locked-up stator, and is redirected back into the pump, where it strikes the back of the blades and increases the rotational speed of the pump.

As the engine approaches its maximum torque, the pump spins at or near the same speed as the turbine. Less fluid needs to be redirected to the pump; a locked stator would actually block fluid return and absorb fluid velocity. The fluid leaving the turbine is moving at almost the same speed as when it entered; as it leaves, the fluid strikes the stator blades from behind. This causes the stator to unlock and rotate with the turbine.

Driving up a steep hill or accelerating rapidly will increase engine speed. The increase in engine speed increases the pump speed. The pump speed is now greater than turbine speed, and the fluid strikes the turbine blades with great force. The stator locks up, and fluid is redirected until the turbine comes up to pump speed or until the engine revolutions per minute is lowered.

Under proper conditions, the friction clutch inside the torque converter is locked to the converter housing, causing a solid connection between the engine crankshaft and the transmission input shaft. Modern transmissions use an onboard computer to control converter clutch application.

Planetary Gearset Components and Operation (Powerflow Principles)

Automatic transmissions use an assembly called a **planetary gearset** to change output speed and torque. Changes in output speed and torque must be made as the vehicle accelerates from a standstill to cruising speeds.

A simple planetary gearset includes the following components: a **sun gear**, a set of **planet gears**, a **planet carrier**, and an internal or **ring gear**. By varying the drive and driven relationship between the planetary gearset components, reductions or increases in input-to-output revolutions per minute/torque can be achieved.

The sun gear is located in the center of the gearset. The sun gear functions in one of the three ways described below.

- The sun gear may function as the driving gear by transferring engine torque to the gearset.
- The sun gear may function as a driven gear.
- The sun gear may be locked in position, thus forcing the pinion gears to rotate about it.

The planet (pinion) gears rotate around the sun gear. Small shafts extending from the carrier base support the planet gears. Like the sun gear, the planet gears may drive the gearset, be driven by another member of the gearset, or be locked (or held). When the planet gears are locked, the other gearset components are forced into a reverse rotation.
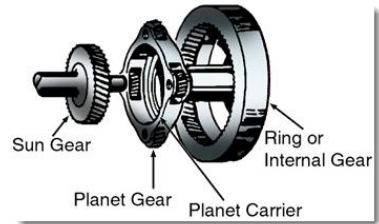
The internal (ring) gear is the outermost gear in the planetary set. The teeth of the internal gear mesh with the planet gears. The internal gear can serve as a driver, driven, or stationary gear.

The planetary gearset can provide eight different speed, torque, or direction combinations. Planetary gearset arrangements vary, depending on the vehicle model. Some typical arrangements are listed below.

When the sun gear is held, either the ring gear or planet carrier can drive. When the ring gear drives and the sun gear is held, the ring gear walks the planet gear around the sun gear. This arrangement produces a forward increase in torque and a reduction in speed through the planet carrier.
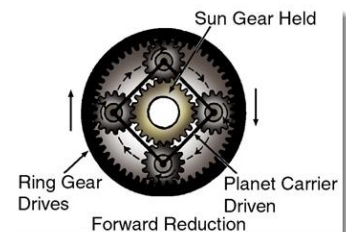
Note: When one gearset component increases the speed of another, torque is reduced. When one gearset component reduces the speed of another, torque is increased.
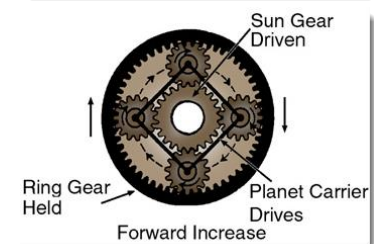
When the planet carrier drives and the sun gear is held, the planet carrier drives the ring gear. This arrangement produces a decrease in torque and an increase in speed through the ring gear.
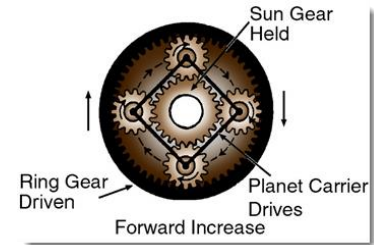
When the ring gear is held, either the sun gear or the planet carrier can drive. When the sun gear drives and the ring gear is held, the sun gear drives the planet carrier around the internal gear. This arrangement produces an increase in torque and a decrease in speed through the planet carrier.
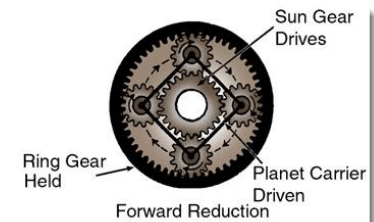
When the planet carrier drives and the ring gear is held, the planet carrier drives the sun gear. This arrangement produces a decrease in torque and an increase in speed through the planet carrier.

When the planet carrier is held, either the sun gear or internal gear can drive. With the planet carrier locked, however, a reverse movement occurs.

If any two members of the planetary set are held, a locked gearset (direct drive) results. When the two members are held, there is no reduction, increase, or direction change; torque is simply passed through.

If all members are released (free to turn), the transmission is in neutral.

Two or more simple planetary sets can be combined into one assembly called a compound planetary gearset. This combination of gearsets allows for a larger range of torque and revolutions per minute inputs and outputs in a relatively small, lightweight unit. The compound planetary gearset operates on the same principle as a simple planetary set; however, the compound set offers more options for distribution of power to the wheels.

In an automatic transmission, gear ratios are achieved by holding some members of the planetary gearset and allowing different members to drive (i.e., connecting different members to the input or output shaft). In most automatic transmissions, members of the planetary gearset are held and engaged or disengaged from the input or output shaft through the use of multiple disc clutches, bands, and one-way clutches.
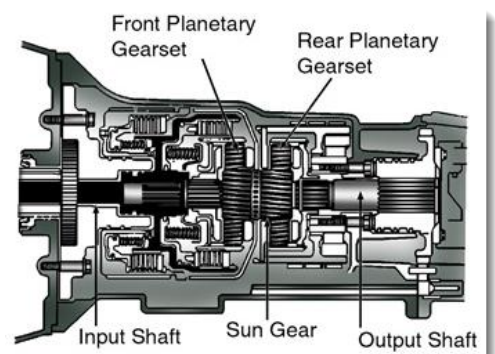
Powerflow Example

The three-speed transmission shown in this example is fictitious and meant only to cover the interrelationships between common components contained by many types of modern transmissions. The drive shaft is separated into three pieces: the input shaft, the intermediate shaft and the output shaft. The intermediate and output shafts are driven by a series of planetary gear sets. Controlled by clutches and bands, these planetary gear sets affect the output rotation of the transmission.

Drive First Gear - 2.45 : 1.00 ratio

Output shaft rotation is much slower than input shaft rotation.

The overrunning clutch is engaged, causing the second planetary set to turn the sun gear in the opposite direction from the input shaft. This creates a slower rotation for the first planetary carrier, slowing the output to a great extent.

Drive Second Gear - 1.45 : 1.00 ratio

Output shaft rotation is faster than that of first gear, but still slower than input shaft rotation.

The sun gear is held in place due to the application of the front band. This band holds the sun shell, which is attached to the sun gear. This causes the first planetary carrier to rotate faster than it did in first gear, supplying a higher (but still diminished) output speed.

Drive Third Gear - 1.00 : 1.00 ratio

Output shaft rotation is the same as input shaft rotation.

The first and second clutches are both engaged, causing the sun gear to rotate in the same direction as the input shaft. As a result, the first planetary carrier is locked and rotates at the same speed as the input shaft.

Reverse - 2.20 : 1.00 ratio

The output shaft rotates in the opposite direction of the input shaft.

The first clutch and the intermediate band are both engaged. The intermediate band holds the second planetary carrier and planetary gears in place. The second planetary gear set is driven by the sun gear, causing the ring gear to rotate in the opposite direction of the input shaft.

Overdrive - 1.00 : 1.35 ratio

Overdrive causes the output shaft to turn at a faster rate than the input shaft.

The overdrive sun gear is held in place by a clutch. The rear band is applied and the third clutch is disengaged so that the third carrier drives the rear planetary gear set, applying a faster rotation to the output shaft through the third ring gear.

Clutch Pack Components and Operation

Depending on the design, the multiple disc clutch either holds planetary members or connects them to the input or output shaft. A multiple disc clutch is made up of a clutch housing, a clutch piston, a return spring or springs (either a single spring, multiple coil spring, or a belleville spring), a piston seal, a set of friction discs, and a set of steel discs.

The multiple disc clutch housing can be either integral with the case or mounted on the input or output shaft. This allows for a sealing area for the piston seals. The clutch also includes a set of splines that mesh with the clutch disc and a system or sometimes a set of return springs for piston return.

The clutch piston applies pressure to the return springs; this locks the friction discs and steel discs together. The clutch piston itself is activated by hydraulic pressure. The piston seals are usually made of neoprene but are occasionally made of cast iron. The piston receives hydraulic pressure from the pump through drilled passages in the transmission case or through rifled shafts.

The automatic transmission clutch uses multiple friction discs. This allows for a variety of friction surfaces in a small area. The friction discs require no external adjustment and reduce the chance of parts failure due to stress. Materials used on the faces of the discs include cork, cotton, and paper. They provide good contact with the steel disc without significant loss of friction material.

The automatic transmission clutch also uses steel discs, which are stacked alternatively with the friction discs. As the piston compresses the clutch pack, the friction discs contact and bind to the steel discs and lock the two units together. To reduce wear, grooves in the friction disc reduce heat during application. Some units use a wavy steel plate to absorb shocks within the clutch pack.
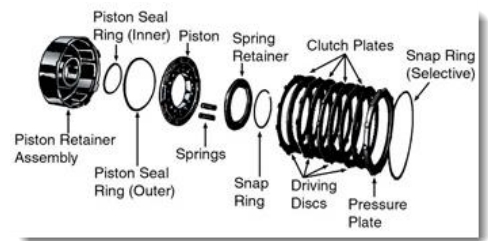
Some clutches use a single coil spring to return the piston to the rest position after the removal of hydraulic pressure. The single coil spring system includes a large coiled spring that rests on the piston face and spring retainer. The spring retainer is a part of the housing.

Note: The rate of piston return is determined by the spring size and piston leak-down rate. Do not use springs from one assembly on another one.

Some automatic transmissions use multiple coil springs. One of the coil ends rests on extrusions or hollows molded in the piston; the other end rests against the retainer.

Note: The number, location, and size of the springs determine the rate of piston return. Do not mix springs with other units or place them in the wrong order during assembly.
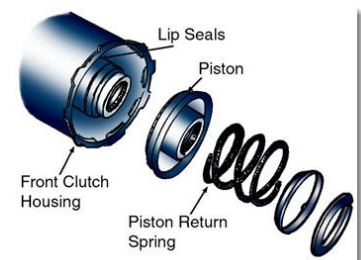
Some automatic transmissions use a **belleville** or **disc spring**, which is a disc that is cupped in one direction. When the piston is applied, it flattens the cup. When hydraulic pressure on the piston is released, the disc returns to its original cup shape and forces the piston to return to its rest position.

Note: During assembly, be sure to place the belleville spring in the proper direction.
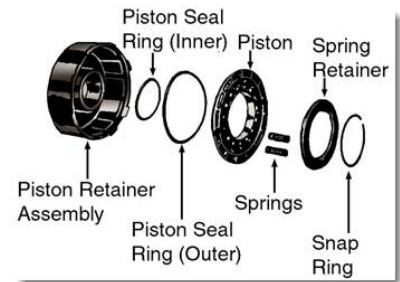
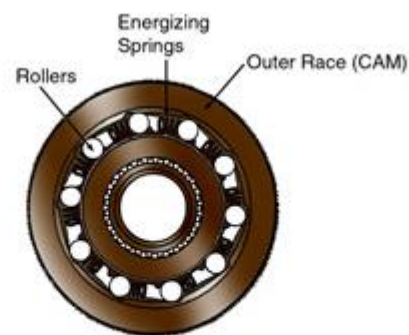## Band/Servo Components and Operation

The **band and servo assembly** consists of a **friction band**, a piston, a stem, and a return spring. Hydraulic pressure is routed to the servo piston that compresses the band around the drum. The band cannot rotate because one end is anchored. When the fluid pressure is released, the piston return spring relaxes the band. Most band and servo assemblies have an adjustable anchor to compensate for wear.
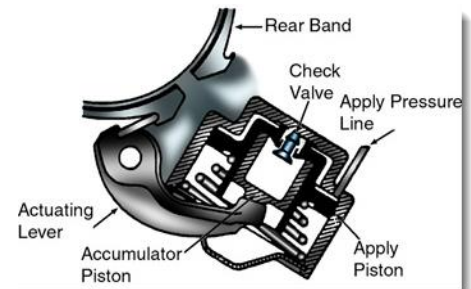
One-Way Clutch Components and Operation

The **one-way clutch** holds a planetary member when it begins to rotate in one direction and allows it to rotate freely in the opposite direction. The one-way clutch will be either a roller or sprag type.

The **roller clutch** consists of an inner and outer race, a set of rollers, and a set of roller springs. When the inner race turns clockwise, the rollers are pushed up into the grooves cut in the outer race. This collapses the springs and allows freewheeling. When the inner race rotates counterclockwise, spring tension and the rotation of the race push the rollers into the narrow part of the outer race and lock the races together.

The **sprag clutch** uses sprags, which are specially shaped pieces of steel with a wide end and a narrow end. As the inner race rotates in the proper direction, the sprags roll to their narrow ends and allow the race to freewheel. If the race is rotated in the opposite (or improper) direction, the wide ends of the sprags roll into contact with the outer race and lock the races together.
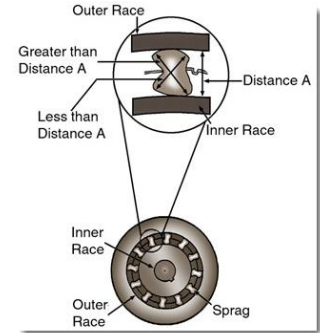

Transmission Cooling Systems

Cooling systems are required for automatic transmissions. The transmission fluid can become very hot. A cooling system must be provided to maintain fluid temperature between 150°F and 250°F. Two common devices used are the **radiator heat exchanger** and the **auxiliary cooler**.

Most manufacturers use the radiator heat exchanger to cool the transmission fluid. Fluid is pumped at a reduced rate from the transmission into a heat exchanger located in the engine radiator.

When automatic transmissions are used in extremely adverse conditions (such as hot climates) or placed under a heavy load, an auxiliary cooler can be used to increase the cooling capacity of the cooling system. Auxiliary coolers are mounted in front of the vehicle radiator and are placed in series with the original equipment cooler. Hydraulic fluid passes through both the original cooler and the auxiliary cooler before returning to the transmission.
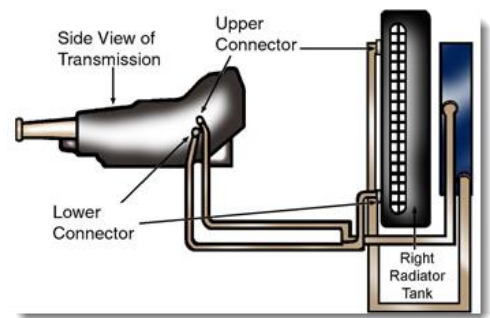
Types of Automatic Transmission Pumps and How They Operate

Automatic transmissions use a variety of rotary pumps to provide mainline pressure. The pumps are usually driven by a hub on the torque converter. On some older models, the output shaft drives a second auxiliary pump.

As pump components rotate, they create clearances that change in shape and size, depending on their position relative to each other. Fluid is pulled into the pump when a void is created by the rotating pump gears. Fluid is expelled from the pump by shrinking chambers that squeeze the fluid out of the outlet port. The construction of the pump chambers allows very little leakage, so the pump exhausts a predictable volume of fluid with each rotation. These pumps are called **positive displacement pumps**.

Gear pump

The **gear pump** has a center (internal) drive gear, which is connected to the torque converter by lugs or drive flats. Gear pumps also have an external (outer) driven gear, which is meshed to the internal gear. A crescent-shaped divider separates the two gears. Oil is trapped between the divider and the teeth of both gears. The space between the meshed teeth becomes larger and smaller as the gears rotate, thus drawing fluid in through an inlet and discharging it through an outlet.
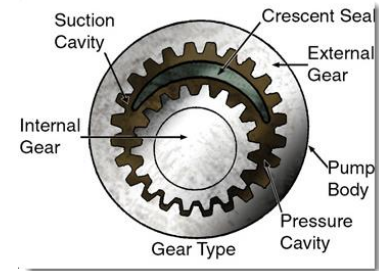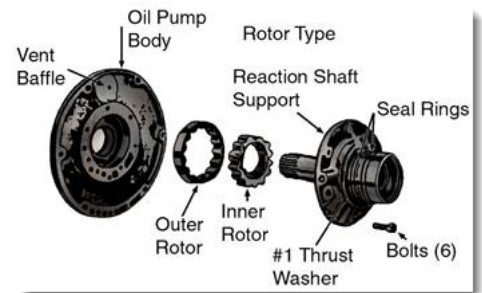
Rotor pump

The **rotor pump** is similar to the gear pump in appearance and operation. The gear teeth of the rotor pump, however, are rounded and larger in size. The rotor pump does not use a dividing crescent, but instead relies on the changing volume of the chambers made by the rotor to draw oil into the pump and force it out.

Vane pump

The **vane pump** uses a set of vanes that are rotated by a driving rotor. As the vanes rotate, they slide in and out of an eccentrically shaped chamber. The subsequent change in size of the chambers between the vanes produces the suction and discharge of the pump. There are some vane pumps that use a sliding eccentric that can vary the pump's output; these pumps are called variable vane pumps. By varying the output of the pump, less torque is needed to drive the pump when demand on the system is low.

Electronic Control System Components and Operation

Conventional Automatic Transmissions and Transaxles

Conventional automatic transmissions and transaxles are hydraulically controlled. Hydraulically controlled transmissions and transaxles use signals from a governor and throttle pressure device to force gear shifts. They also use pressure differential at the sides of the shift valve to hold or change gears.

Hydraulically controlled transmissions and transaxles can waste a large amount of torque. Gear shifts are dependent on the movement of automatic transmission fluid. This can cause upshifts and downshifts to be sluggish at times and produce a jarring ride for the driver and passengers as the vehicle changes gears.

Electronically-Controlled Automatic Transmissions and Transaxles

In today's vehicles, automatic transmissions and transaxles are usually controlled electronically to allow for automatic gear changes when certain operating conditions are met. Electronically controlled transmissions and transaxles have better shift timing and quality. Better shift timing and quality provides improved fuel mileage, lower exhaust emission levels, and improved comfort for the driver and passengers.

Electronically controlled automatic transmissions and transaxles function in the same basic way as hydraulically controlled models. The difference is that shift points, torque converter lockup, and other functions are controlled by the powertrain control module (PCM), body control module (BCM), or transmission control module (TCM). For consistency, PCM is used throughout this module.

Sensors and Their Operation

Sensors monitor a condition and modify an electrical signal in response to changes in the condition.

Input regarding changing conditions is sent from the sensors to the PCM. In response, the PCM sends signals to output control devices to control transmission and transaxle functions.

The **throttle position (TP) sensor** monitors how far and how fast the throttle is opening. This information is a good indication of engine speed and load. Engine speed and load are important in determining shift patterns and torque converter clutch applications.
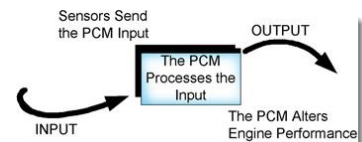
The **crankshaft position (CKP) sensor** is a permanent magnet signal generator that monitors crankshaft speed, which is important in determining shift patterns and torque converter clutch applications.

The **vehicle speed sensor** (VSS) is a permanent magnet signal generator that monitors vehicle speed, which is used in determining shift patterns and torque converter clutch applications.
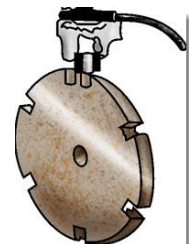
The **engine coolant temperature (ECT) sensor** monitors engine coolant temperature, which is used in determining torque converter clutch applications.
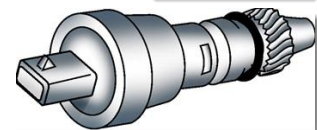
The **transmission fluid temperature (TFT) sensor** tells the PCM the temperature of the transmission fluid, which is important in determining torque converter clutch applications.

The **manifold absolute pressure (MAP) sensor** monitors the absolute pressure in the intake manifold and indicates engine load. In response to engine load, the PCM may delay upshifts or cause a downshift to provide extra engine power to the driving wheels.

Chapter 2: Automatic Transmission/Transaxle Maintenance and Adjustment

Adjusting the Manual and Throttle Valve Linkage or Cable

Adjusting a manual valve linkage or cable involves indexing the gear shift lever position to that of the manual valve. Inside the transmission is a detent pawl device that positions the manual valve according to a set of shift gates. The shift gates are slotted positions that coincide with the required manual valve position. The shift lever us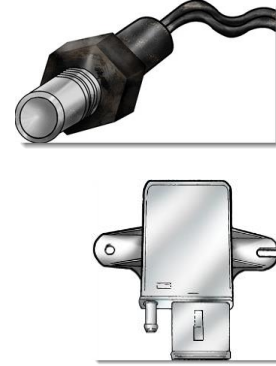ually has a position indicator; the shift lever may also have its own detent in park. An adjustment device is provided between the two systems. The adjustment device may be a slip joint or snap lock cable or other kind of adjustable link. Because the manual valve and shift gate position is not adjustable, all other linkage adjustments are referenced to the manual valve position. Sometimes a separate neutral safety switch is also needed. Use service information to locate the procedure required for each.

Note: The following are general procedures. Consult the appropriate service information for the procedure that applies to the specific vehicle.

Inspecting and adjusting the manual shift linkage
The procedure for inspecting and adjusting the manual shift linkage is outlined below.

- Move the shift selector through the gears and observe how the transmission clicks into each gear. If detents cannot be felt at each gear, the linkage needs to be adjusted.
- Use proper lifting equipment to raise the vehicle.
- **CAUTION**: When lifting a vehicle, always use proper lifting equipment and observe all safety precautions.
- Inspect the linkage for wear. Replace the linkage if it is damaged or broken.
- Loosen the nut on the shift linkage.
- Put the shift selector and the transmission lever in the same gear. Consult service information for the correct gear.
- Tighten the nut and check the shift linkage.
- Lower the vehicle.
- Check the gear position indicator in the vehicle. If needed, adjust the pointer so that it indicates the correct gear.

Replacing the shift linkage

Replace the shift linkage, if needed.

- Use proper lifting equipment to raise the vehicle.
- **CAUTION**: When lifting a vehicle, always use proper lifting equipment and observe all safety precautions.
- Disconnect the linkage and any clips or retainers holding it in place.
- Remove the linkage.
- Reverse the removal procedures to install the linkage.
- Adjust the linkage.
- Lower the vehicle.
- Check the gear position indicator.

The transmission may use either a downshift throttle valve or a shift modifying and downshift throttle valve.
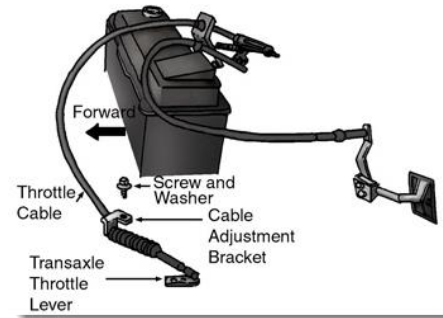
A shift modifying and downshift throttle valve has a continuous effect on the shift signal generated by the governor. By monitoring the throttle opening, the throttle valve can tailor the shift sequence to the driver's desires while allowing the governor to shape the time of shifts according to engine load. If the throttle valve travels its maximum distance, it will force a downshift to the next lower gear (passing gear). The valve opening is adjusted according to throttle opening like the manual valve. A variety of adjustment devices, such as sliding joints and cable snap locks, are used. Consult the service information for the specific adjustment procedure.

On a transmission with a vacuum modulator, the throttle valve linkage is sometimes not a throttle valve at all but is used only to force a downshift. The relationship of forced downshift to wide open throttle position can be adjusted. Adjustment is about the same as in the shift modifying type. Sometimes an electrical detent (forced downshift) solenoid is used. An electrical detent switch is contacted by the wide open throttle, energizing a detent solenoid valve and forcing a downshift.

Switches and Sensors

Some automatic transmissions contain electrical sensors. These sensors are used to control components and functions external to the transmission, such as the starter circuit, backup lights, control of output shaft speed, and overdrive engagement. The sensors fall into two basic categories: switches and speed sensors.

There are three types of switches used in transmissions: **grounding switches**, **line switches**, and **multiple contact switches**.

- Grounding switches, when activated, complete the circuit by providing a current path to ground. Grounding switches establish ground through a single wire. Some grounding switches are adjustable and must be positioned in relation to the device that activates them.

- A line switch (sometimes called a single throw, single pole switch) opens and closes a circuit. A line switch has two wires, one coming from the source and the other going to the load. Line switches require adjustment in some vehicles.
- A multiple contact switch may have multiple in and out contacts and a variety of off and on positions. A multiple contact switch may incorporate several different control possibilities.

Speed sensors monitor the rotational speed of internal components, such as the output shaft revolutions per minute. There are two basic types of speed sensors: magnetic pickup and Hall-effect.

In a **magnetic pickup speed sensor**, a magnet is rotated past a fixed coil. As the magnet comes near the coil, a magnetic field is broken across the coil, thus inducing a current in the coil. The number of weak currents induced in the coil is counted by computerized circuitry, which produces a signal indicating the speed of rotation (revolutions per minute).

The **Hall-effect sensor** uses a stationary Hall effect switch and a rotating component that is slotted or grooved. As the slots pass by the Hall-effect switch, a signal is generated in relation to the passing of the slots or grooves. Computer circuitry counts the signals and produces another signal indicating output revolutions per minute.
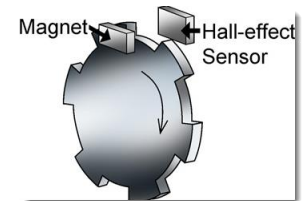
Adjusting the Neutral Safety Switch and Transmission Range Switch

The **neutral safety switch (NSS)** and **transmission range (TR) switch** are multicontact and multiterminal switches that perform similar functions. The neutral safety switch sends a signal to the PCM and allows engine cranking only when the transmission is in neutral or park. The transmission range switch sends a signal to the PCM to indicate the gear range the driver has selected. In some vehicles, the functions of the NSS and TR switch are combined. The procedures for servicing the NSS and TR switch are similar. The procedures for servicing the neutral safety switch are outlined below.

Note: The following are general procedures. Consult the appropriate service information for the procedure that applies to the specific vehicle.

Checking the neutral safety switch

Check the neutral safety switch.

- With the key turned to the start position, move the transmission gear shift lever into different positions.
- If the neutral safety switch closes and lets the starter operate in positions other than park and neutral, it needs adjustment.

Note: Some neutral safety switches cannot be adjusted. If a nonadjustable neutral safety switch is not functioning correctly and the gear selector linkage is properly adjusted, replace the switch. Consult the manufacturer's service information for the proper procedure.

<u>Testing the neutral safety switch</u>

Test the neutral safety switch using a 12-volt test light.

Touch a 12-volt test light to the neutral safety switch input terminal (battery voltage from the ignition switch). The test light should glow when the ignition switch is in the start position.

With the transmission gear shift lever in park or neutral and the ignition switch in the start position, touch the test light to the output terminal. The test light should glow.

If the test light fails to glow in park or neutral, move the gear shift to different positions while the test light is connected. If the test light glows in positions other than park and neutral, the neutral safety switch needs to be adjusted. Failure of the test light to glow in any position indicates a defective (open) switch.

<u>Adjusting the neutral safety switch</u>

Adjust the neutral safety switch.

- Connect the exhaust ventilation equipment.
- **CAUTION**: Be sure to use approved exhaust ventilation equipment when operating the vehicle in an enclosed area.
- Loosen the switch bolts.
- Put the shift selector in park.
- Turn the ignition key to start and slide the switch toward park.
- When the engine begins to turn over, turn off the ignition and tighten the switch bolts.
- Check the adjustment by starting the engine in park and neutral.
- Shut off the engine and disconnect the exhaust ventilation equipment.

<u>Replacing the neutral safety switch</u>

Replace the neutral safety switch, if needed.

- Put the shift selector in park.
- Loosen the switch bolts.
- Remove the defective switch.
- Reverse the removal procedures to install the switch.

Inspecting and Replacing External Seals and Gaskets

On most automatic transmissions, two basic types of external seals are used: the lip type and compression type. For inspection procedures for these types of seals, refer to "Hydraulic Control System Components and Operation."

Note: The following are general procedures. Consult service information for the procedure specific to the vehicle.

Use the procedure outlined below to replace a lip-type seal.

- Using a pry bar, lift the lip of the outer ring.
- Remove the seal by using one of the following procedures: pry downward to lift the seal from the bore; use a seal driver to push the seal from the back of the bore; remove the seal with a seal puller.
- Use a seal driver to install the new seal.
- Check for leaks.

Use the procedure outlined below to replace a compression-type seal.

- Remove the seal retainer and the seal.
- Clean the seal area.
- Install a new seal.
- Replace the seal retainer.
- Check for leaks.

On most automatic transmissions, three types of gaskets are used: paper, cork, and composition. Installation procedures are the same for all three types of gaskets. During the installation of any gasket, make sure that all surfaces are clean, positioning is correct, and proper torque is used.

Note: Refer to "Maintenance and Adjustment of Transmissions and Transaxles" for procedures for removing pan flange dimpling.

Use the procedure outlined below to replace a gasket.
- Remove the old gasket.
- Clean the gasket area with an appropriate solvent.
- Remove dimples from metal flanges.
- Use petroleum jelly to hold the new gasket in place.
- Reinstall the cover.
- Check for leaks.

Replacing the Extension Housing Bushing and Seal

The procedure for replacing the extension housing bushing and seal (on rear-wheel-drive vehicles) differs from manufacturer to manufacturer. Use the manufacturer's recommended procedure to ensure that the governor and speedometer parts are not damaged.

CAUTION: The case can be broken by extreme pry-bar pressure. Remove the seal by prying firmly on the inside edge of the seal.

To remove a bushing, the bushing must be split with a chisel or pulled out with a bushing remover.

Note: The following replacement procedure applies to all large diameter bushings in the transmission.

A bushing chisel is driven parallel to the bushing bore. (A bushing chisel is a specially designed chisel that peels a narrow piece of metal from the length of the bushing in order to split the bushing.) Do not angle the chisel into the bore wall.

If the bushing can be accessed from both sides, use a bushing driver to force out the bushing. A hydraulic press or a hammer can be used to apply force to the driver. The bushing driver has a centering extension, a driver shoulder, and an impact end. By locating the bushing on the centering extension, the driving shoulder can be used to force the old bushing out and the new one in.

CAUTION: Some bushings can only be removed and installed in one direction. Retaining ridges are used to keep the bushings from "walking." If the bushing is forced through this ridge, the ridge may be damaged or broken out, requiring replacement of the housing.

Note: Some repair procedures require filing notches in the front pump housing to hold a replacement bushing in place. Consult the appropriate service information and technical service bulletins for the vehicle being serviced.

Blind bushings may be pulled out by using either a slide hammer puller or a screw tap.

The slide hammer puller consists of an expandable set of fingers that lock on the edge of the bushing. A slide hammer is screwed to the puller and the force of the hammer pulls the bushing free. A driver is used to replace the bushing.

A screw tap and a ball bearing can be used to pull a blind bushing that is small in diameter. A tap slightly larger than the minor diameter of the bushing is threaded into the hole. A ball bearing is dropped into the bottom of the hole to act as a thrust point for the tap. When the tap bumps the bearing, the bushing will be pushed out by the tap threads.

Inspecting and Servicing Powertrain Mounts

Engines and transmissions are suspended on rubber isolating mounts that absorb vibration and powertrain noise.

Inspecting and Measuring Alignment of Rear-Wheel-Drive Transmission Mounts

Most vehicles have three different mounts: two engine mounts and one transmission mount. The engine mounts can be tested by brake torquing the engine forward and backward. If a mount is broken, the engine will lift and visibly separate from the mount. To test the transmission mount, use proper lifting equipment to raise the vehicle and attempt to lift the extension housing. If the mount is separated, the extension housing will lift from the mount.

CAUTION: When lifting a vehicle, always use proper lifting equipment and observe all safety precautions.

Some drivelines have adjustable mounts to compensate for variations in drivelines. An angle gauge can be used to measure the angle of the drive shaft. Consult proper service information for the correct procedure.

Inspecting and Measuring the Alignment of Front-Wheel-Drive Mounts
Front-wheel-drive mounts not only suspend the engine and transaxle but also locate the assembly left to right and absorb the torque wrap-up of the engine from front to back.

The suspension mounts are located on the left and right of the engine and transaxle. They have slotted mounting holes, which allow for minor adjustments in position. The ability to adjust position allows for equal distribution of half the shaft length from side to side. If adjusted improperly, the CV-joints will undergo undue compression or extension, which will cause them to fail prematurely.

The front-to-back engine mount is sometimes called a torque strut because it absorbs the forward and backward movement of the engine and transaxle during acceleration and deceleration. This forward and backward movement of the engine is called torque wrap-up.

Front-wheel-drive transaxle and engine mounts can be inspected in much the same way as rear-wheel-drive transmission mounts. When the weight of the assembly is lifted from the mount, look for looseness or separation of the rubber from the metal. If the rubber bushing is loose on the mount bolt of the torque strut, the strut is defective.

An additional check can be made by brake torquing the engine forward and backward. This will force the engine back and forth against the strut. If the bushing is bad, there will be a noticeable cling or thumping in the mount.

Procedures for centering front-wheel-drive mounts vary, depending on the manufacturer. On some vehicles, the drive shaft hub nuts must be loosened and the CV-joints bottomed. Then the amount of shaft thread that extends from the hub is measured, and the mounts are adjusted until they are equal. Other vehicles require different centering procedures. All centering procedures are designed to achieve sufficient length clearance to allow for changes in suspension geometry. Consult proper service information for the correct procedure.

Continuously Variable Transmissions

A **continuously variable transmission** (CVT) is a transmission that can change through an infinite number of effective gear ratios between maximum and minimum values. This contrasts with other mechanical transmissions that only allow a few different distinct gear ratios to be selected. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient rpm for a range of vehicle speeds. Alternatively, it can be used to maximize the performance of a vehicle by allowing the engine to turn at the RPM at which it produces peak power. This is typically higher than the RPM that achieves peak efficiency.

In the most common CVT system, there are two V-belt pulleys that are split perpendicular to their axes of rotation, with a V-belt running between them. The gear ratio is changed by moving the two sections of one pulley closer together and the two sections of the other pulley farther apart. Due to the V-shaped cross section of the belt, this causes the belt to ride higher on one pulley and lower on the other. Doing this changes the effective diameters of the pulleys; this in turn changes the overall gear ratio. The distance between the pulleys does not change, and neither does the length of the belt. So changing the gear ratio means both pulleys must be adjusted (one bigger, the other smaller) simultaneously in order to maintain the proper amount of tension on the belt.

The V-belt needs to be very stiff in the pulley's axial direction in order to make only short radial movements while sliding in and out of the pulleys. This can only be achieved by a chain and not by homogeneous rubber. A film of lubricant is applied to the pulleys. It needs to be thick enough so that the pulley and the belt never touch and it must be thin in order not to waste power when each element dives into the lubrication film.

Continuously variable automatic transaxles (CVTs) use a steel belt running in a pair of variable width pulleys to provide varying gear ratios. The pulley ratios change with vehicle speed and engine load, allowing the engine to run at a more constant speed and close to its maximum operating efficiency. Most CVTs use an electronically controlled hydraulic control system to vary the pulley ratio.

For forward motion, the forward clutch locks the sun gear and the planet carrier together.

For reverse, the reverse clutch locks the ring gear to the case, causing the planet pinions to turn the sun gear and output shaft backward. Position of the belt and pulley width varies the gear ratio.

A low gear ratio is obtained when the belt is running close to the center of the input pulley and near the outside of the output pulley.
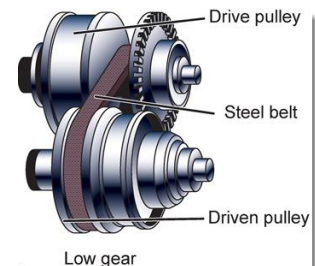
A high gear ratio is obtained when the belt turns near the outside of the input pulley and near the center of the output pulley.
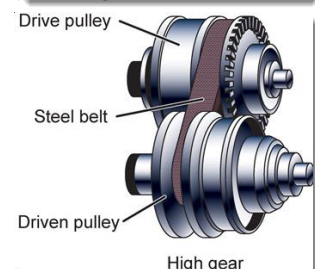
When each pulley is in the same position, the transmission ratio is 1 to 1.

Changing the width of the pulley groove determines the position of the belt. A cone-shaped side of one pulley moves in while one side of the other pulley moves out. This changes the width of the pulleys and the resulting gear ratio.

While CVTs are still being installed in new vehicles, they have not proved to be always popular with buyers. CVTs have not delivered the expected improvement in fuel mileage, and many people find the CVT disconcerting because of the way vehicles with CVTs sound. When stepping on the accelerator, the engine races as it would with a slipping clutch or a failing automatic transmission. This is normal as the CVT is adjusting the engine speed to provide optimal power for acceleration. This has lead manufacturers to switch to 6-speed manual transmission or dual clutch automatic transmission with six or more gear ratios.

Hybrid Vehicle Drivetrains

Hybrid vehicles are vehicles with more than one source of propulsion. Today's hybrid vehicles combine a conventional gasoline engine propulsion system with an electric propulsion system. The purpose of the electric powertrain is intended to achieve either better fuel economy than a conventional vehicle or better performance.

Most hybrid vehicles use other efficiency-improving technologies such as regenerative braking, which converts the vehicle's kinetic energy into battery-replenishing electric energy rather than wasting it as heat energy as conventional brakes do.

Some varieties of hybrids use their internal combustion engine to generate electricity by spinning an electrical generator to either recharge their batteries or to directly power the electric drive motors.

Many hybrids reduce idle emissions by shutting down the engine at idle and restarting it when needed; this is known as idle stop system. A hybrid-electric may produce less vehicle emissions from its internal combustion engine than a comparably-sized gasoline car by using a gasoline engine that is smaller than a pure fossil-fuel vehicle, and if not used to directly drive the car, can be geared to run at maximum efficiency, further improving fuel economy.

Not all hybrids are designed only to save fuel; several manufacturers are building high performance vehicles that use powerful electric motors, which produce high torque to produce rapid acceleration.

A recent development in hybrid technology is the "plug-in hybrid." These vehicles are gasoline/electric hybrids with the addition of the ability to recharge the vehicle's storage battery by plugging into the electrical grid when the vehicle is not being driven, which greatly reduces the use of the gasoline engine.

Totally electric vehicles are also being produced. This type of vehicle relies only on battery power and must be recharged by connecting to the electrical grid. Totally electric vehicles are not hybrids because they have only one source for propulsion.

Servicing HEVs can be potentially dangerous. Careless service can result in potentially fatal electrical shock, arcing temperatures up to 3,500°F, or explosion of molten metal. It is imperative to know and adhere to service precautions.

During service, the technician must wear high-voltage safety gloves similar to an electrical lineman's gloves when removing the service plug. The technician should also shield the face.

At the time of this writing, most high-voltage cables are bright orange (some are very light orange and can appear yellow). Also, caution labels are used to identify the high-voltage battery pack and other high-voltage components.

CAUTION: Be sure to identify the high-voltage cables before beginning service.

High-voltage cables can be located near vehicle lift locations. Be sure lift pads are placed properly.

Some components contain strong magnets that must be handled with special care. People with pacemakers or other magnetically sensitive medical devices should not work on or near these components. Remove all metal items from pockets or clothing before beginning service.

The high-voltage system should be disconnected before beginning service. Disconnecting the auxiliary battery shuts down the high-voltage circuit. For additional protection, the service plug can be removed.

Wait at least 5 minutes after removing the service plug to allow the capacitors inside the inverter to fully discharge.

Some HEVs automatically turn the engine on and off when the ready light, located on the instrument panel, is on. Remove the key from the ignition before beginning service.