Steering and Suspension Systems Study Guide

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Introduction

A vehicle chassis is made up of several systems that all work in unison to provide a safe and comfortable ride. The chassis includes the frame (or unibody), brake system, steering and suspension systems, and wheel assemblies.

Steering Systems

The steering system works with the suspension system to provide directional control with a comfortable amount of steering effort. It must do this while allowing for the necessary movement in the vehicle's suspension system. Some parts serve both systems. The steering system consists of a steering gear, steering linkage, a steering column and a steering wheel. Two types of steering systems are widely used in today's vehicles: **rack-and-pinion** steering and "**conventional**" steering.

Rack-and-pinion Steering

Rack-and-pinion steering transmits circular motion from the steering wheel to a pinion that meshes with teeth on a flat rack. The pinion moves the rack in a linear direction, steering the wheels. Rack-and-pinion steering can be found on cars, mini-vans and small SUVs. It is simpler and less expensive to produce than conventional steering systems.

Conventional Steering

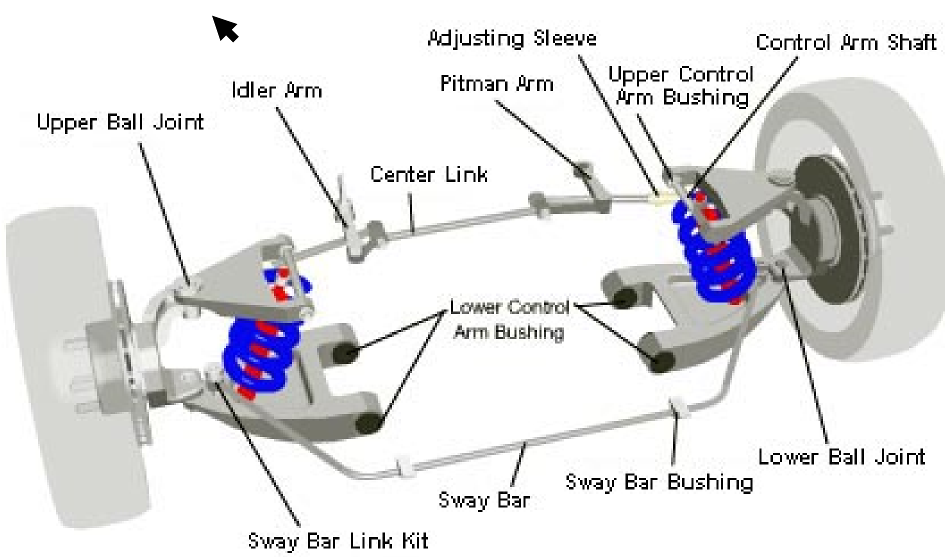
Conventional steering transmits the circular motion from the steering wheel through a gear that moves an arm through a back-and-forth arc, acting on a set of linkages to steer the wheels. It is also referred to as "recirculating ball" or "worm gear" steering, for the type of gear it uses, or "parallelogram," "trapezium," or simply "linkage" steering, for the shape formed by the linkage set. This type of system can be found on most rear wheel drive cars, light trucks and full size vans.

Suspension Systems

The suspension system supports the vehicle, allowing the wheels to move up and down over irregularities in the road. It cushions the ride for the frame, engine, transmission, and passengers, while keeping the tires in firm contact with the road under all conditions. Suspension system parts include springs, dampening devices (shocks), ball joints, steering knuckles, and spindles or axles. Two types of front suspension systems are widely used in today's vehicles: the **MacPherson strut** suspension and the **short/long arm (SLA)** suspension. Early automobiles and some medium- and heavy-duty trucks and four-wheel drive vehicles have a **straight axle** (I-beam) front suspension, and up until recently some light trucks were built with a variation called a twin I-beam suspension. Many rear suspensions still use a straight axle.

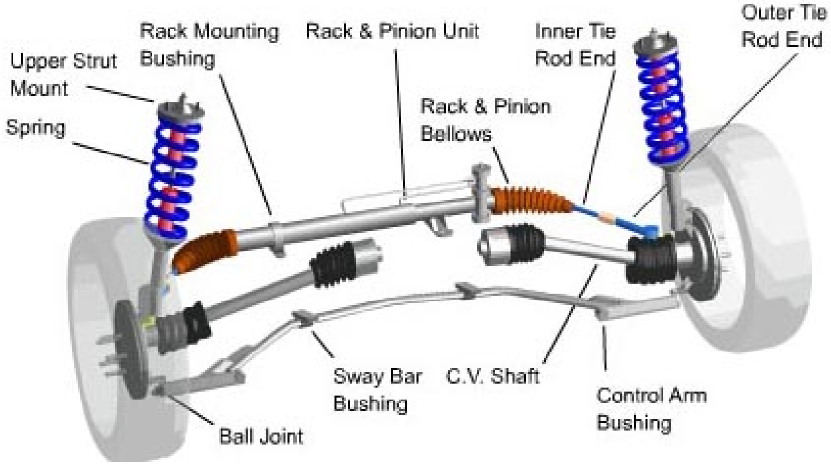
Short/Long Arm (SLA) Suspension

Each side of the SLA suspension consists of two control arms attached to the frame at one end and the steering knuckle at the other. The arms pivot on ball joints at the steering knuckle, and on rubber bushings at the frame. A variety of spring arrangements may be used; a coil spring placed between the two arms is the most common, but the spring may be mounted over the upper control arm, or it may be a torsion bar attached to the lower control arm. Using a shorter upper arm allows the track width to remain constant at the road surface during spring compression, eliminating the tire slide or scrub that would occur if the arms were of the same length. A conventional steering system is commonly used with this suspension, which may also be referred to as a conventional suspension.



Conventional, SLA Suspension with Conventional Steering

MacPherson Strut Suspension
The MacPherson strut suspension combines a coil spring and a shock absorber into a single unit on each side. The strut is attached to the body at the top and to a lower control arm through a ball joint at the bottom. The other end of the control arm attaches to the frame and pivots on rubber bushings. The steering knuckle is rigidly mounted to the strut. This suspension is lighter and smaller than the SLA design, and can be found on smaller vehicles with rack-and-pinion steering. It is commonly used on front-wheel drive cars.



MacPherson Strut Suspension with Rack-and-pinion Steering

This course will cover these steering and suspension systems in depth, and their service, as well as other aspects of steering and suspension service. Subjects covered will include:

- Steering system design
- Diagnosing steering system problems
- Inspecting and replacing steering linkage components
- Steering column inspection and repair
- Front suspension system designs
- SLA suspension system diagnosis and service
- MacPherson strut system diagnosis and service
- Design and operating principles of rear suspensions
- Wheel alignment / steering and suspension diagnosis

Course Objectives
Upon completion of this course, technicians should understand and be able to apply their knowledge of:

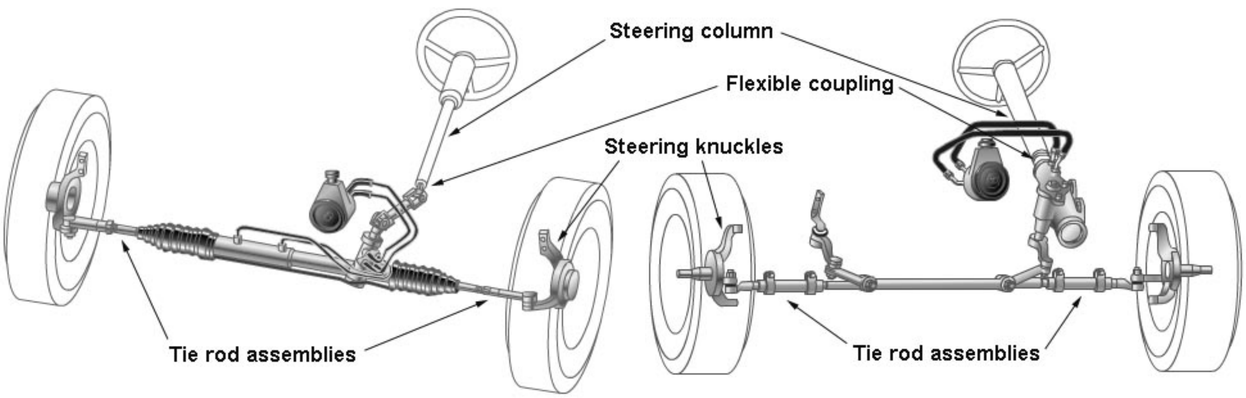
- Identifying the components and operating principles of different types of steering systems
- Diagnosing steering systems and determining needed repairs
- Identifying and replacing worn steering linkage components
- Diagnosing and repairing steering columns
- Identifying the components and operating principles of various types of front suspension systems
- Determining the condition of suspension system components
- Replacing worn suspension system components
- Identifying and replacing worn MacPherson strut suspension components
- Identifying the components and operating principles of various types of rear suspension systems; diagnosing and replacement
- Wheel alignment angles and correction, diagnosing wheel alignment problems

Using the Job Sheets
As you proceed through the online module, on some pages you will find links that will open a window with a printable procedure or job sheet containing hands-on lab activities based on the NATEF standards related to the content you are studying. When you come upon a procedure or job sheet link, you can click on it to access the material and print the job sheet for completion in the shop. See your instructor for guidance in completing the job sheets. Some jobs sheets will require supplemental materials such as a vehicle service manual, equipment manual, or other references. Your instructor may prefer you to print the entire set of job sheets and assign them when appropriate, or your instructor may provide you with the printed job sheets to complete. You can view and print any or the entire set of job sheets for this from the online course.

Steering Systems

Components Common to both Conventional and Rack-and-pinion Systems

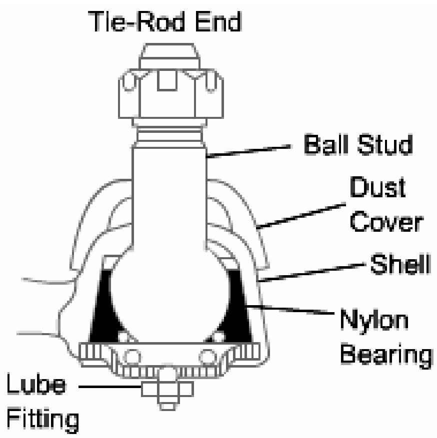
- Tie rod assemblies
- Tie rod ends
- Steering knuckles
- Steering shaft
- Steering column
- Flexible coupling
- Universal joint (if needed)
- Lower ball joints
- Backup fasteners (cotter pins or lock nuts)

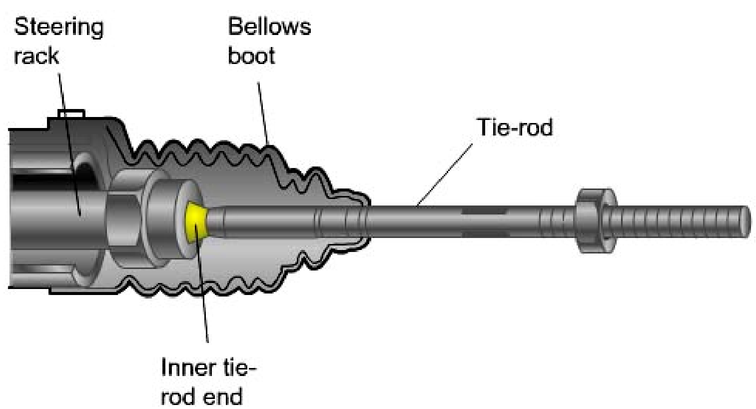


Rack-and-pinion System ***Conventional System***

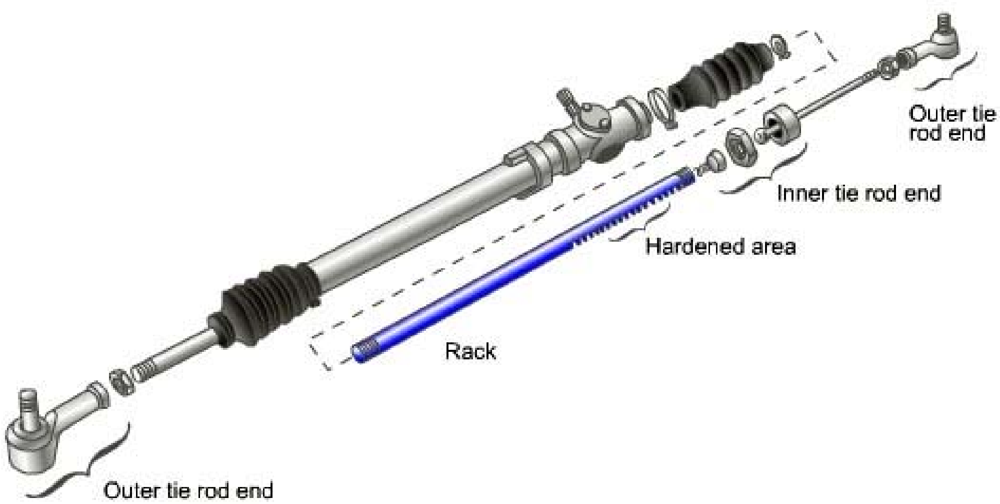
Tie Rod Ends

- Ball-and-socket joint
- Tapered ball stud fits into a tapered hole
- Inner tie rod ends on rack-and-pinion units thread onto the end of the rack
- May be sealed at factory, or may have a grease fitting
- Rubber dust cover or boot protects the socket
- Threads on tie rods and sleeve or adjuster are used to adjust the length of the tie rod assembly to set wheel alignment (toe)

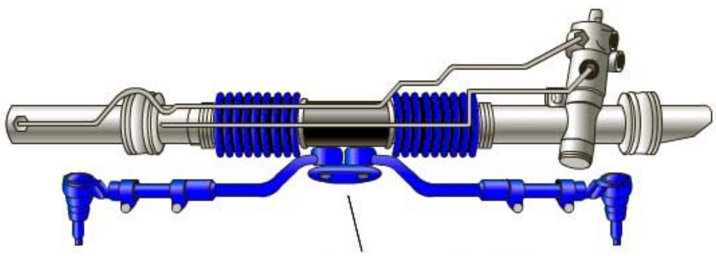




Inner tie rod end on a rack-and-pinion unit



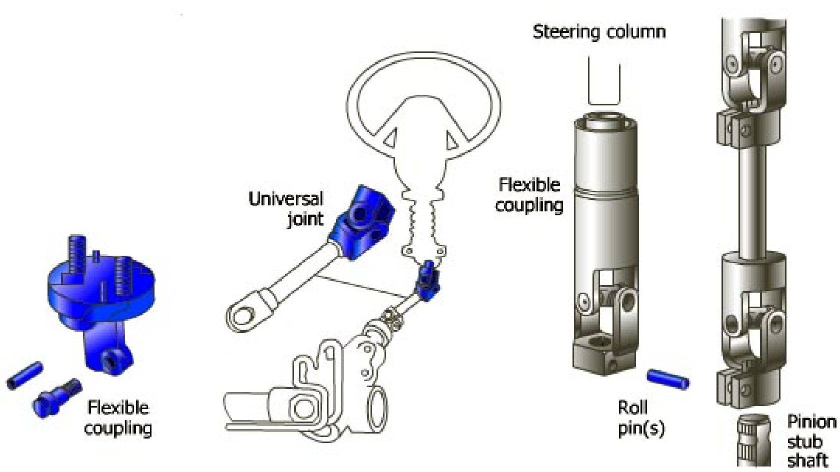
Note the inner and outer tie rod ends on this rack-and-pinion unit.



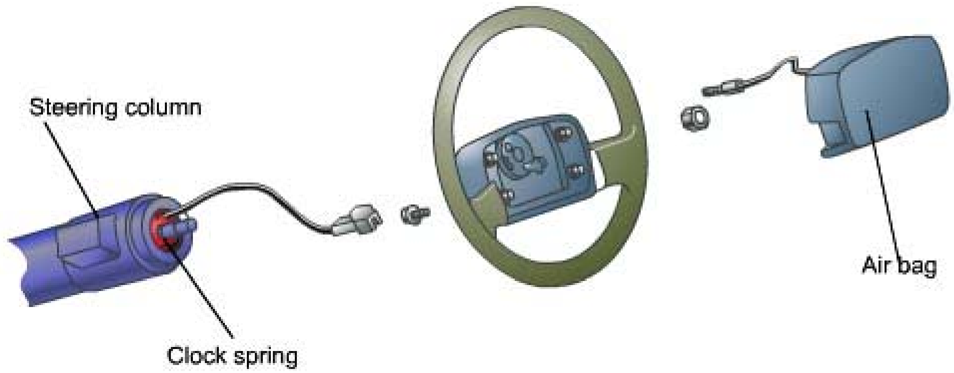
The inner tie rod ends on this design attach at the center of the rack.

Steering Column Assembly Components

- Steering wheel
- Steering column
- Steering shaft
- Ignition key mechanism and switch
- Flexible coupling and universal joint
- Turn signal mechanisms, horn controls, tilt mechanism, anti-theft steering lock mechanism, headlight and dimmer switch controls, windshield wiper and washer controls, cruise control, transmission gear selector, and other components
- Collapsible components crumple or slide together ("telescope") during impact
- Air bag (Supplemental Inflatable Restraint, or **SIR**) in steering wheel is part of the Supplemental Restraint System (**SRS**). The SRS must be disabled to prevent accidental deployment of the air bag.
- ***Caution: accidental air bag deployment can cause serious injury or death***
- A steering wheel puller is used to remove the steering wheel.



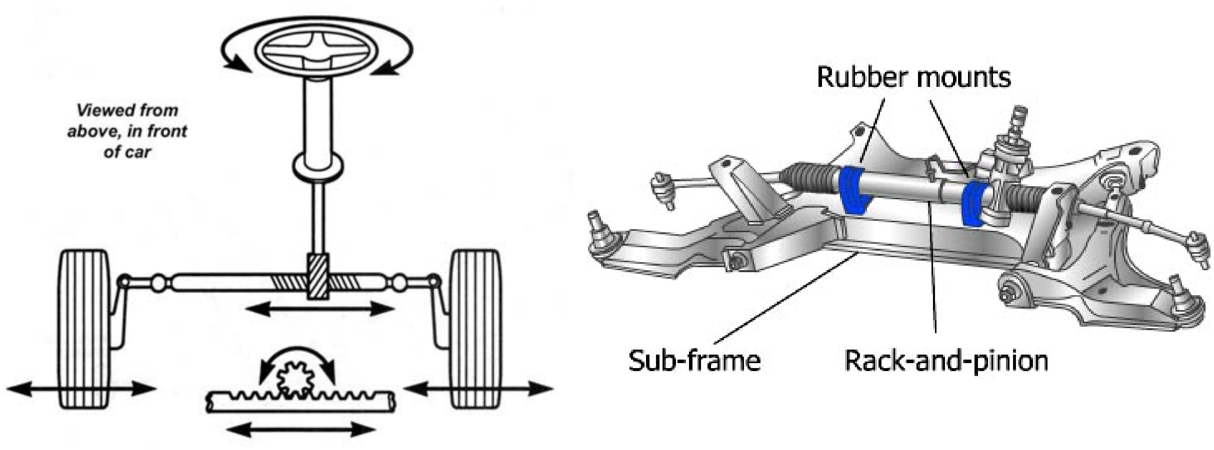
Steering Shaft Couplers



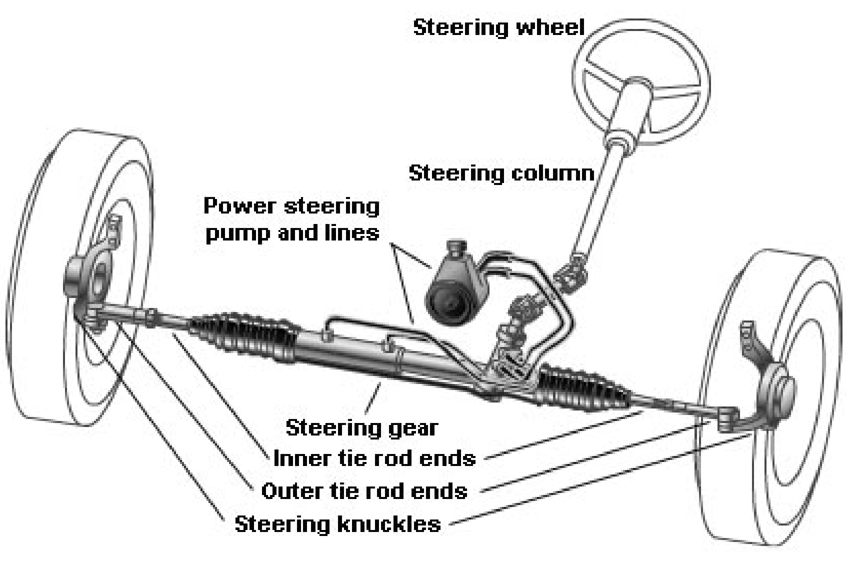
Air bag in steering wheel

Rack-and-pinion Steering

- **Steering gear**: pinion transmits rotary motion to the rack, which converts this movement into linear, side-to-side motion
- Rack is mounted to the sub-frame (or frame) with rubber bushings. Inner and outer tie rod assemblies connect the rack to the steering knuckles.
- Can be either manual or power assisted

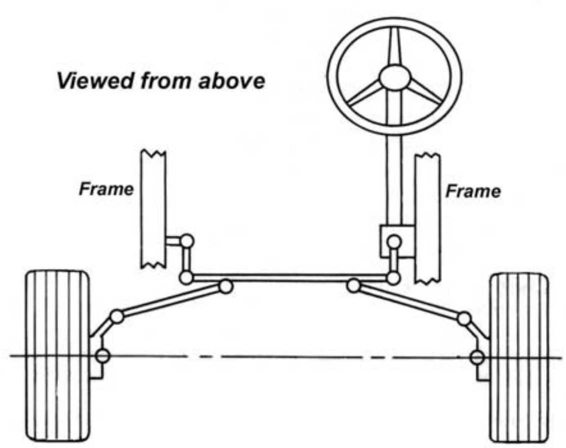


Rack-and-pinion System Components

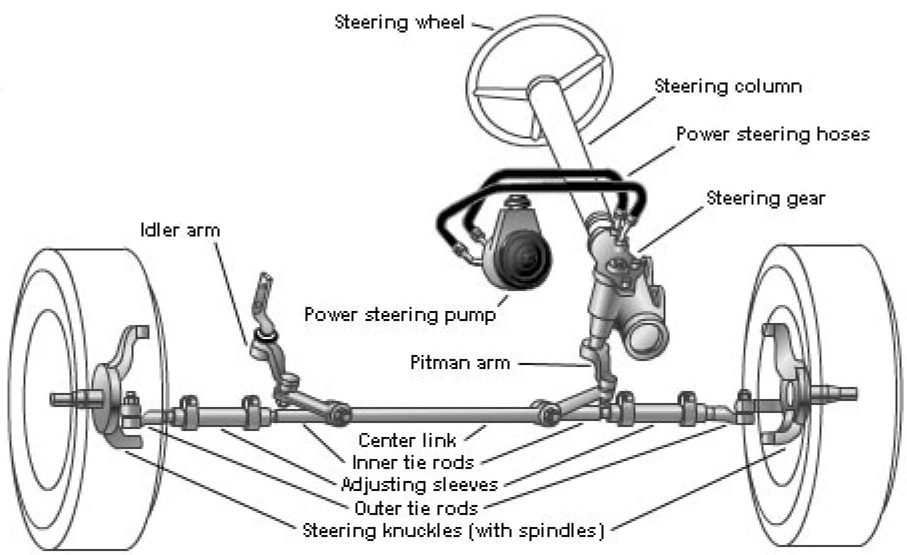


Conventional Steering Systems

- Also called “parallelogram” or “trapezium” systems
- They use a **recirculating ball steering gear** to transmit rotary motion from the steering wheel into linear motion at the steering arm (**pitman arm**).
- Steering gear and **idler arm** are bolted to the frame
- Pitman and idler arms are connected to the rest of the steering linkage through a **center link**.
- Can be either manual or power assisted
- Power steering control components are normally within the steering gear housing as part of an **integral unit**.

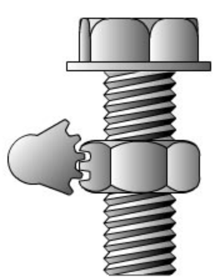


Conventional Steering System Components



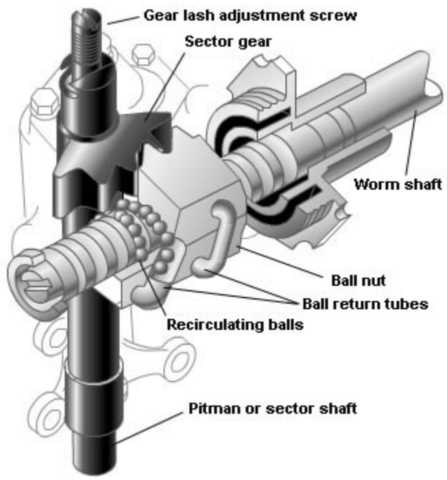
Recirculating Ball Steering Gear

- Input shaft is called a **worm shaft** because at its end is a **worm gear**
- Worm gear provides gear reduction to reduce steering effort
- Worm gear meshes with and acts upon a **ball nut**
- Ball nut meshes with and acts upon teeth on the **sector gear** (output)
- Sector gear transmits movement through the **sector shaft** (or **pitman shaft**) to the pitman arm



***When the bolt head rotates, if the nut is prevented from also rotating,
then it must move up or down on the shaft, acting upon the gear (sector gear).
The threads act as a worm gear.***

- Rather than resembling a threaded shaft, like a common worm gear, the steering worm gear has channels that house recirculating steel balls. The ball nut has corresponding channels for the balls to ride in. When the worm shaft is turned, the balls act upon the channels in the ball nut, causing the ball nut to screw up or down on the worm shaft as a rolling thread. The balls rotate and recirculate in their channels, returning through ball return tubes or guides.
- Using recirculating balls creates less friction and provides smoother and easier steering with less wear than would be possible with a common, threaded worm gear arrangement.
- The gearbox is lubricated with power steering fluid, if so equipped, and gear oil is normally used on manual units.

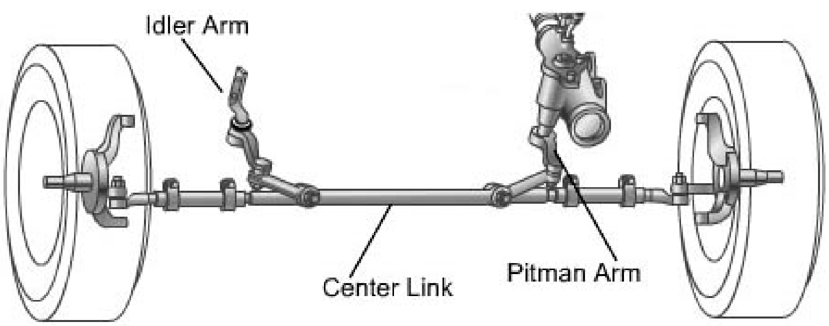


Recirculating Ball Steering Gear Components (manual unit)

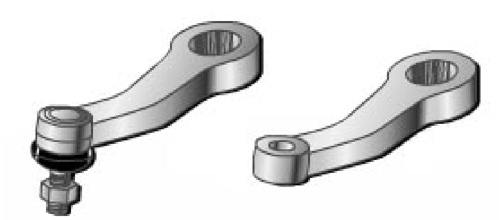
Conventional Linkage Components

In addition to tie rod ends, the conventional system also has the following linkage components:

- **Pitman arm –** Usually splined to the sector (output) shaft with a press fit. Most sector shafts and pitman arms have a master or “blind” spline that permits installation in the correct position only. The pitman arm is connected to the center link with a ball socket or pivoting bushing. The ball socket or bushing may be either a part of the pitman arm or part of the center link. When the ball socket or bushing is part of the center link, the pitman arm is a non-wearing item and would only need to be replaced if bent or damaged. This is the more common arrangement.

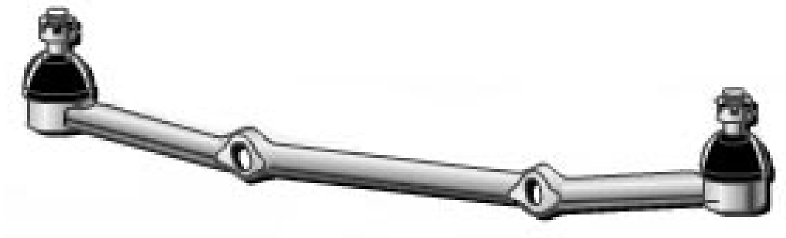


Additional Conventional Linkage Components



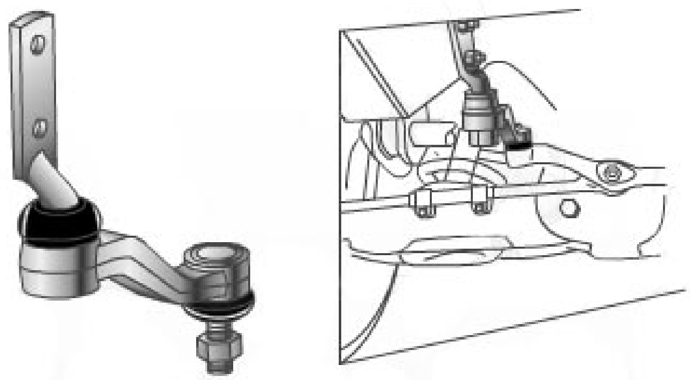
Pitman arm with ball socket ***Non-wearing type pitman arm***

- **Center link –** Variations on this component may be called a **drag link**. The center link is attached to the pitman arm, idler arm, and inner tie rods, and connects the right and left sides of the steering linkage together. As with a pitman arm, the ball socket or bushing arrangement varies depending upon the design. Some center links have two ball sockets or bushings – one for the pitman arm and one for the idler arm, and some have none and are little more than a rod with tapered holes.



This center link includes bushings for the pitman arm and idler arm.

- **Idler arm –** The idler arm bolts to the frame or subframe and attaches to the center link to support the linkage. It corresponds to the pitman arm to complete a strong and symmetrical linkage set. There are many different designs of idler arms, and again, if the center link does not have a pivot socket or bushing at the connection, the idler arm will.

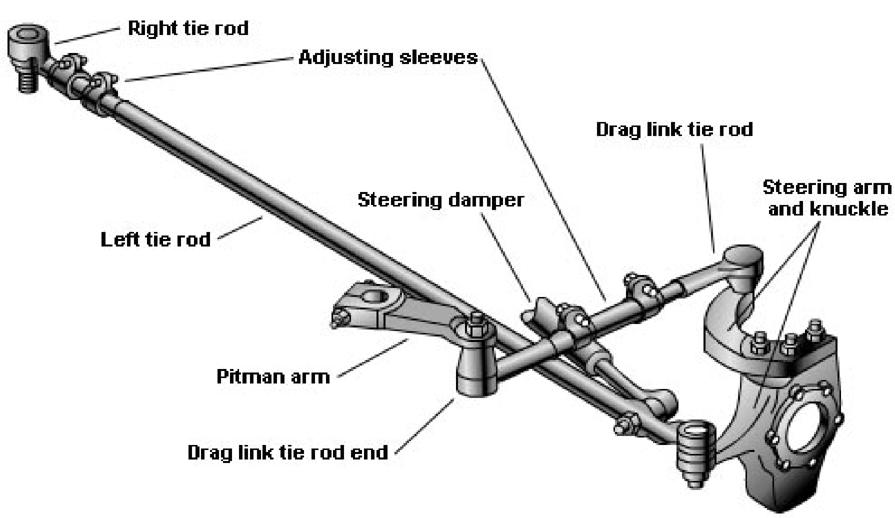


The idler arm on the left contains a pivot for the center link.

Cross Steer and Haltenberger Linkage Systems
Other types of linkage systems have been used. Straight axle trucks and some four-wheel-drive steering linkage designs use one long tie rod assembly that connects to both of the steering knuckles, or variations on this arrangement. **Cross steer linkage** and **Haltenberger linkage** systems may be found on light and medium duty trucks.

Cross Steer Linkage

- Has two tie rods and an adjusting sleeve connecting the wheels
- The left steering arm is connected to the steering gear with another tie rod assembly, sometimes called a drag link. The adjustment sleeve on this assembly is used to center the steering wheel during a wheel alignment.
- Note that the pitman arm attaches to the steering gear with a pinch bolt in this application.



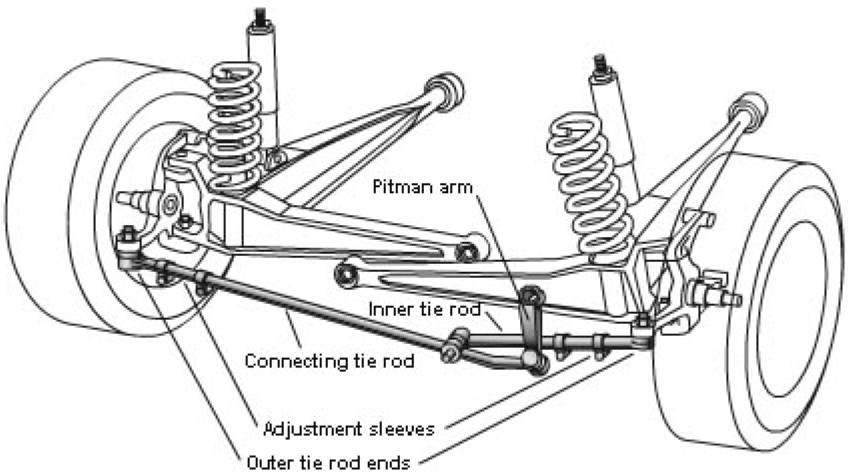
Cross Steer Linkage

- Many light truck and four-wheel-drive applications use another part shown above, a **steering damper**. A steering damper is a steering stabilizer that looks and functions like a shock absorber. The purpose of a steering damper is to absorb shimmy (rapid back-and-forth oscillation of the front wheels) or wheel kick. One end of the damper is mounted to the steering linkage, and the other mounts to the vehicle frame. As the wheels turn, a hydraulic piston is forced through an oil-filled cylinder. Small, calibrated holes allow the oil to flow in and out of the piston chambers at a controlled rate, preventing the steering linkage from moving back and forth too rapidly. Steering dampers may be original equipment or add-ons, and are most common on off-road or severe duty applications.

Steering Damper

Haltenberger Linkage

- Used on twin axle four-wheel-drive suspensions and twin I beam suspensions like the one shown below.
- No idler arm is used; instead, a long right connecting rod is attached to the pitman arm, and the left inner tie rod end is attached to the connecting rod.



Haltenberger Linkage

Power Steering Systems

- Most steering systems used today are power assisted, though there are still some manual units produced. For easier steering on manual units, the gear ratio is usually about 24 to 1, so you would have to turn the steering wheel 12 times to turn the sector shaft through one half a rotation. Power assisted units normally have a ratio of about 15 to 1, providing a quicker turning response. Turning the steering wheel only 7 times will move the sector shaft through nearly a half a rotation.
- Nearly all power steering systems use a belt-driven pump to provide hydraulic steering assistance, although a few electric power assisted rack-and-pinion units are beginning to appear. These units use an electric motor to assist in moving the rack.
- Vehicles with hydraulic power steering must use an approved power steering fluid. Automatic transmission fluid has been widely used, but may not be approved for later models.

Power Steering Pump

- Four main types of power steering pumps have been used. They are the **roller**, **vane**, **slipper**, and **gear** types. The pump must provide sufficient pressure for steering assist at all engine speeds to meet the various steering demands.
- A fluid reservoir is often mounted on the pump housing, or it may be a separate component.
- The need for assist is greatest during periods of low-speed maneuvering, which may occur at idle or low engine speeds, and less when cruising at high speed.
- When the pump is turning fast and steering demands are low, most of the fluid is diverted back to the inlet side of the pump through a pressure relief valve. The two-stage pressure relief and control valve provides the correct amount of steering assist at different rpms, and opens a bypass port to the pump intake when pressure gets too high.
- Some power steering pumps are capable of producing up to 1,500 psi.
- A power steering pump can require a significant amount of horsepower. Some vehicles' control module will sense the increased engine load caused by power steering demands at idle and increase the idle to prevent stalling or stumbling. The control module may also turn off the A/C compressor or the alternator at such times.

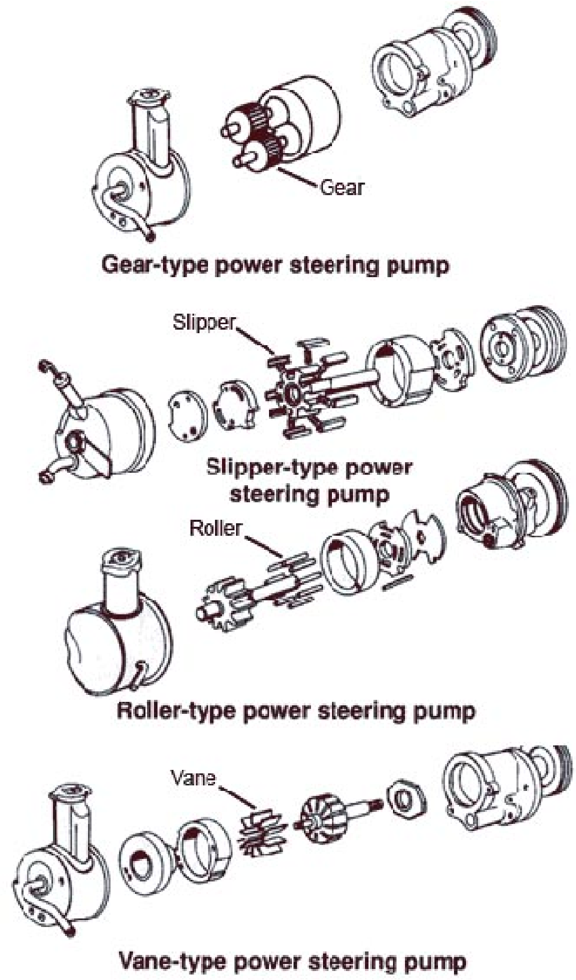
Two Main Types of Power Steering

- Power rack-and-pinion steering
- Integral power steering gearbox – Conventional recirculating ball steering gear with a hydraulic control system built in

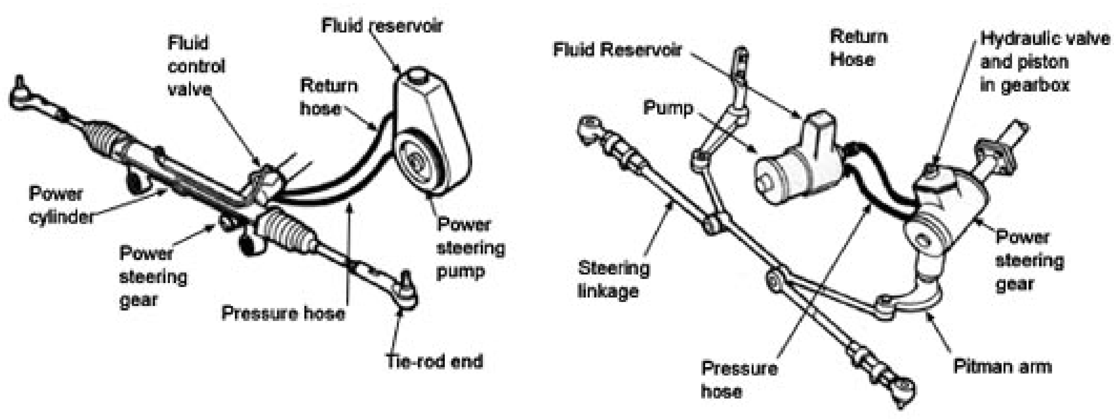
Power rack-and-pinion steering systems include the following:

- Power cylinder – a hydraulic cylinder inside the rack or gear housing
- Power piston – a double-acting, hydraulic piston in the power cylinder that acts upon the rack
- Control valve mechanism – located in the steering gear; senses and controls power assist
- Hydraulic lines – steel tubing from the control valve to the power cylinder that carries the power steering fluid
- Most power rack-and-pinion units have a small tube that runs along the housing and connects to each bellows boot. This tube allows the air pressure in the bellows boots to equalize from one side to the other during turns.

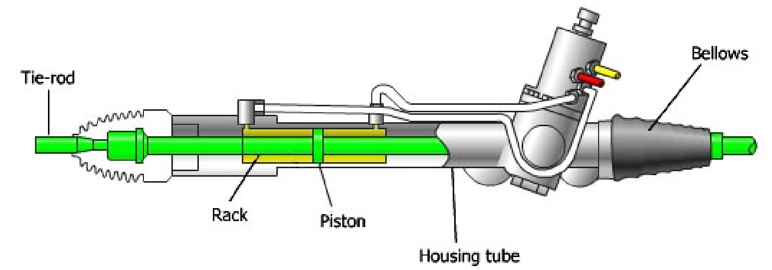
The power cylinder and piston are precisely machined and sealed with rubber O-rings. In operation, fluid is directed to a chamber of the power cylinder on either side of the rack. This fluid creates pressure to move the piston and thus the rack to the left or right. To sense and control assist, two types of control valves are used: either rotary control valves, or a spool control valve. Rotary control valves use a torsion bar attached to the input shaft to make the control valve move, aligning oil passages to the proper chamber. On spool valve units, the spool valve detects the thrust action of the input shaft caused by attempting to turn the steering wheel, and directs fluid to the proper chamber of the power cylinder.



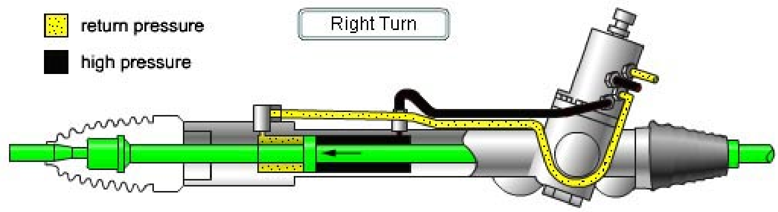
Types of Power Steering Pumps



Power Rack-and-pinion System, left; Integral Power Steering Gearbox System, right

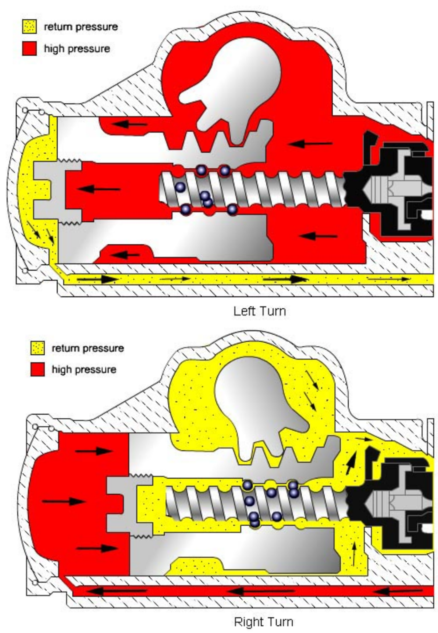


Power Rack-and-pinion



Integral power steering systems

- Commonly used with linkage-type steering
- Steering gearbox contains a conventional worm-and-sector gear. The hydraulic power piston and directional control valve are mounted inside the gearbox housing.
- As with power rack-and-pinion units, the valve may be a spool valve or a rotary valve with a torsion bar.
- When the steering wheel is in the straight-ahead position, the valve maintains equal pressure on both sides of the power piston. Oil flows back to the pump reservoir. During a turn, the control valve routes oil to one side of the power piston, which pushes it in the desired direction to provide assist. The oil on the non-pressurized side of the piston is forced back through the control valve and to the pump reservoir.



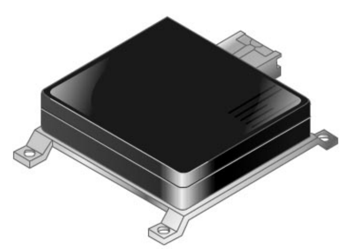
Integral Power Steering Gearbox

Steering System Advancements, Innovations, and Variations

As electronic controls on vehicles continue to become more sophisticated, some manufacturers have applied this technology and other innovations in the steering systems of some models. These advancements can conserve horsepower, space, and weight, and can also improve maneuverability. In addition, efforts to improve handling and turning radius have resulted in four-wheel steering systems of several types.

Variable Assist (Speed Sensitive) Power Steering

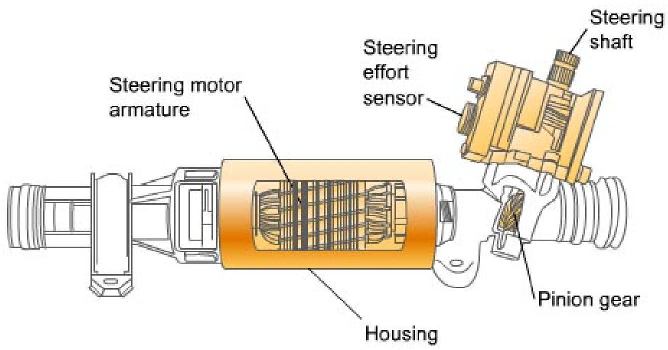
- Efforts to improve fuel economy by conserving horsepower have led to the development of computer-controlled hydraulic and/or electric steering systems. Varying the amount of assist according to vehicle speed helps conserve power while improving road feel at high speed, where less assist is desirable.
- With some hydraulic systems, fluid output from the pump is controlled; others control the fluid pressure at the steering gear. Variable assist systems use signals pertaining to vehicle speed, engine RPM, and other parameters from the Vehicle Control Module and/or other modules to determine and control the correct fluid pressure, and thus the amount of power assist provided.



This variable assist control module is located under the footwell kick panel on the driver's side.

Electric Power Steering

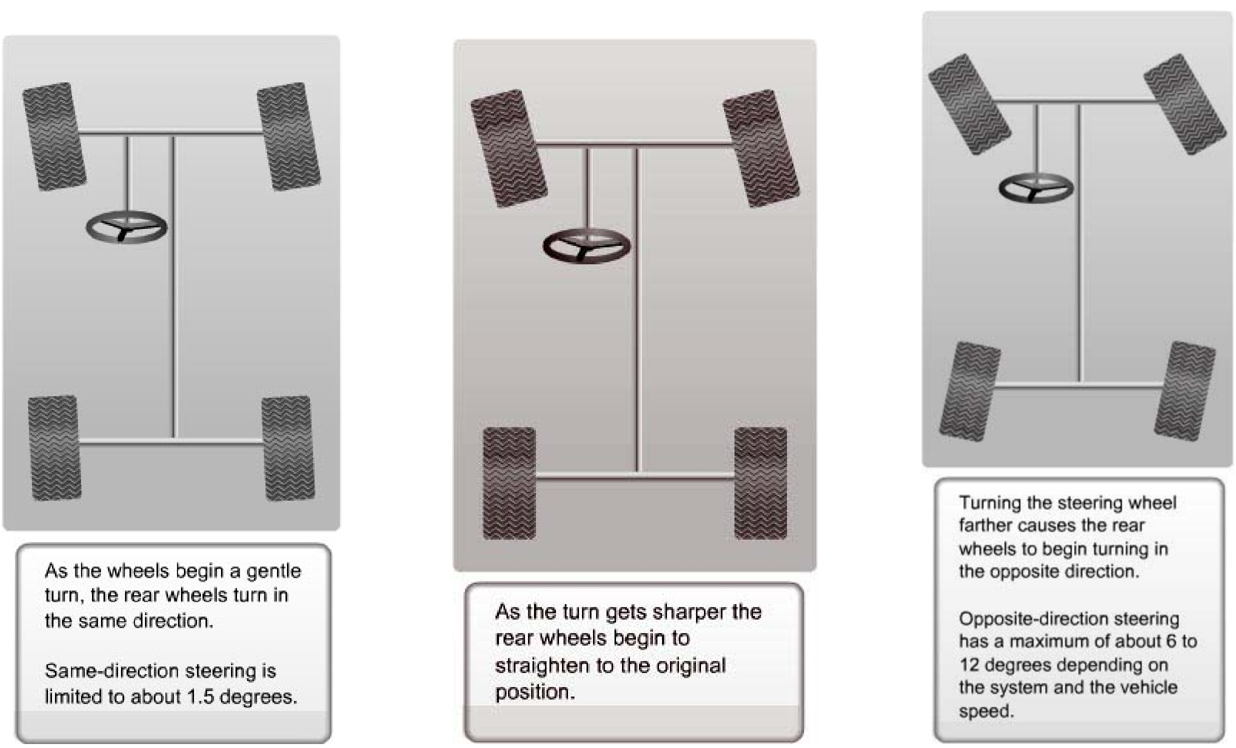
- Computer-controlled electric power rack steering systems are used on some vehicles. These systems use a small electric motor within the housing to assist in moving the rack. Some include a recirculating ball steering gear.
- Computer-controlled electric systems typically use inputs from the antilock brake wheel speed sensors, steering angle and steering effort sensors, and other inputs to provide the proper amount of steering assist.



Computer-controlled Electric Assist Rack-and-pinion

Four-Wheel Steering

- Systems have been in production for several years on a variety of models
- Several different types of four-wheel steering systems are used. Generally, at low speeds, the rear wheels turn in the opposite direction from the front wheels, reducing the turning radius for tighter turning and easier parking.
- At high speeds, the rear wheels turn in the same direction as the front wheels, providing for improved handling and stability.
- Simple hydraulic systems permit four-wheel steer only at high speeds (over 30 mph) and in the same direction, while electronic four-wheel steering systems can provide sophisticated rear steering using a computer to determine rear steering angles. These systems permit same-direction steering during a gentle turn, and then as the steering wheel is turned more sharply, the rear wheels straighten and then begin to turn in the opposite direction from the front. A steering control module uses inputs from several sensors to determine the correct steering angles.
- Early, mechanical four-wheel steering systems function similarly, but use a shaft connected from the front gearbox to a rear gearbox through a planetary gearset to achieve the proper rear steering mode.
- Rear steering is subtle: same-direction steering is limited to about 1.5° and opposite-direction steering has a maximum of about 6° to 12° depending on the system and vehicle speed. Same-direction rear steering begins to diminish after the steering wheel is turned through 120° and at 240°, the rear wheels are straight. Turning the steering wheel farther causes the rear wheels to begin turning in the opposite direction.



Steering System Service

This section covers service of the steering system components related to power steering, steering gears, and other parts of the system. Linkage and ball-and-socket components are covered in the suspension section.

- All steering and suspension system parts must be checked for looseness and wear, not only to ensure safety and proper handling, but also to confirm that the vehicle is capable of holding wheel alignment settings within specifications.
- This check is commonly performed on a drive-on alignment rack, where the vehicle can easily be raised and properly lifted to unload the suspension with a hoist-mounted jack.

Common Steering System Problems

The steering system components from the steering wheel to the output of the steering gear are generally reliable, with a few exceptions. Flex couplings to the steering shaft can fail (causing excessive free play) and power steering fluid circuits in some rack-and-pinion units are failure-prone (causing intermittent or uneven assist). Some common overall steering and suspension system problems include:

- Hard steering
- Noise
- Abnormal tire wear or vehicle handling
- Leaks (power steering)
- Excessive free play in the steering wheel for a variety of reasons

Hard Steering

A number of conditions can cause hard steering. Some simple causes of hard steering are:

- Low tire pressure
- Low power steering fluid level
- Loose power steering belt
- Incorrect wheel alignment, binding of the steering linkage or MacPherson strut upper mounts, or steering gear problems also can cause hard steering. Listen for noise while confirming a hard steering complaint, and begin with a check of the simple causes. Check the belt condition and fluid level. If the fluid level is low, inspect the system for leaks. If the problem persists, perform a complete steering and suspension inspection.

Noise

There are several types of noises associated with steering system problems.

- Loose parts or dry ball sockets can cause a clunk or a pop when turning or going over bumps.
- Noises may also be produced in the power steering system. Low fluid level may cause the pump to whine or “groan” when the wheel is turned, especially when turned all the way to the end of its travel against a stop. However, some noise is normal when the wheel is turned to a stop in this manner, as the excess fluid pressure is bypassed. This normal noise may be described as a hissing or whirring sound.
- A loose or worn out power steering belt can cause a loud squealing noise, especially when turning hard or against a stop. This may be accompanied by a jerky feel in the steering wheel. The belt condition and tension should be checked and adjusted if needed, to prevent glazing of the belt or damage to the pulley.
- Other noises in steering system related parts may be caused by bad or dry wheel bearings. Front wheel bearings on rear-wheel drive vehicles may squeak or roar (bad rear wheel bearings on these vehicles may growl). On front-wheel drive cars, **constant velocity joints** (CV joints) on CV shafts or “half-shafts” may clunk or shudder. A bad CV joint will often make a telltale, rapid clicking sound when backing in reverse with the wheels turned sharply. Look for damaged or torn rubber CV boots on the CV joints, and grease leakage in the area. Many CV joints can be replaced; however, it may be more practical to replace the CV shaft. The replacement shaft will come assembled with two new joints and boots, ready to install. Compare the costs for the application – when you consider the labor to rebuild a CV joint, it may make more sense to replace the shaft.

Abnormal Tire Wear or Vehicle Handling

Steering and suspension problems can cause rapid, abnormal tire wear and/or handling problems. Tires may wear unevenly or have a scalloped wear pattern. A wheel alignment may correct the problem. How to read wear patterns is covered in the section on wheel alignment.

Excessive Free Play

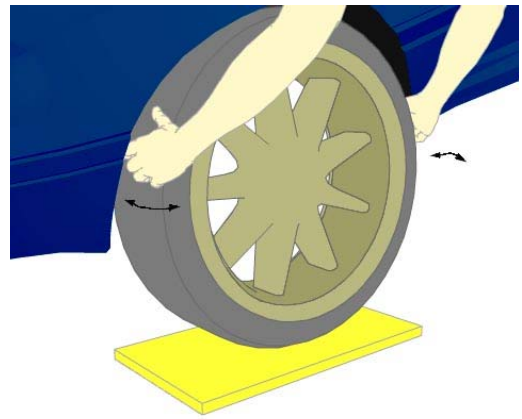
Too much free travel in the steering wheel can have several causes. Common causes of free play include:

- Worn ball joints
- Center link
- Idler arm
- Tie rod ends
- Steering column flexible couplings
- A worn or misadjusted steering gear also may cause excessive free play. These parts are checked during a complete suspension and steering inspection before a wheel alignment, but some of them can be effectively checked in a “**dry park check**” with the weight of the vehicle on the wheels.

Dry Park Check

The dry park check will reveal obvious movement in the steering linkage and associated parts, but will not usually show movement in ball joints, control arm bushings, and other suspension parts. These parts must be checked with the suspension properly unloaded.

- A variation on this check is the most effective way to discover excessive movement in the inner tie rod ends on rack-and-pinion systems.
- Best performed on an alignment rack, but it is possible do it on the ground.
- To perform the check, have an assistant turn the steering wheel a small amount from side to side while you inspect the junction and pivot points of each steering and suspension component. Look closely for any independent movement. For inner and outer tie rod ends and center links, there should be no perceptible movement. Idler arms and ball joints are covered later. For power steering-equipped vehicles, the engine must be running.
- A similar check can be performed with the vehicle lifted and the wheels hanging free. Have an assistant work the steering back and forth a small amount while you inspect the parts.
- Inner tie rod ends on rack-and-pinion systems can be checked on an alignment rack before jacking the vehicle to unload the suspension. With the full weight of the vehicle on the wheels, remove the locking pins from the turn plates on the alignment rack. With the steering unlocked, grasp the front and rear of the tire and try to move it back and forth, as if it were being steered. Looseness in the inner tie rod end will be easy to feel before the rack begins to move. It takes much more effort to move the rack. You will be able to see the change in toe that the looseness causes. You can have an assistant confirm that the other wheel is not moving and that the movement is not in the outer tie rod end or wheel bearing.



Checking an inner tie rod end for movement

Power Steering Fluid Leaks

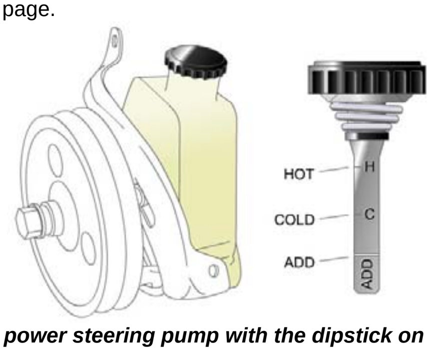
Leaks in the power steering system are a common problem. The system operates under high pressures, and rubber hoses can deteriorate, fittings may leak, and seals can fail.

- Refer to the procedures and diagnostic charts for checking leaks, named "PD3 Diagnosing Power Steering Fluid Leaks" in the online course. The link to the printable file appears at the end of the section named "Steering System Service" on the "Procedures and Job Sheets" page.

Common Steering System Services

Fluid Level

- Some power steering systems have a see-through reservoir with markings for the proper levels. Others may have a dipstick, often made as part of the reservoir cap.
- Levels are usually given for hot and cold, as the level will rise when hot. Be careful not to overfill the reservoir.
- Refer to the procedures for lubricant and fluid levels, named "PD1&2. Manual and Power Steering Fluid Levels" in the online course. The link to the printable file appears at the end of the section named "Steering System Service" on the "Procedures and Job Sheets" page.



A power steering pump with the dipstick on the cap.
Note that the slide bracket for belt tension adjustment is behind the pulley on this model.

Lubrication

One of the most basic steering and suspension services is lubrication of the ball-and-socket joints and steering linkage, if these parts are not of the permanently sealed type. Often performed as part of a complete chassis lube, this important service should receive the attention it is due.

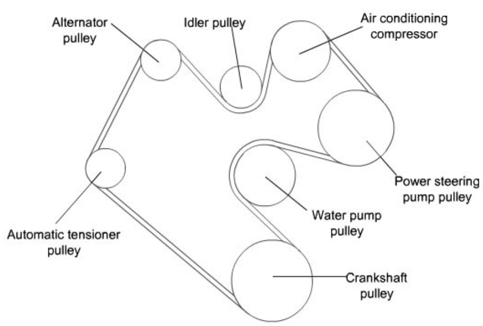
- Extremely important to **wipe all grease and road grime away from the grease fittings** (zerks) prior to attaching the grease gun, and to wipe the tip of the grease gun. This prevents grit from being injected into the joint or damaging the one-way valve in the grease fitting.
- Some joints have a grease relief port designed into the base of the protective rubber dust boot. Grease will begin to escape from the relief port when the joint is full. Many others do not have such a port. On these joints, the rubber boot

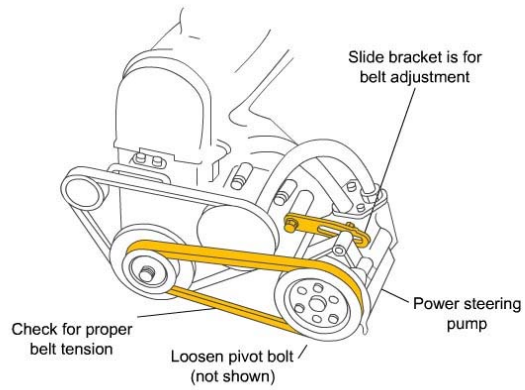
will swell slightly when sufficiently greased. **Do not over-grease these joints, as this will rupture the boot and cause premature part failure**.

- When lubricating the suspension, a film of grease should be applied to the steering stops on the steering knuckles and control arms.
- Chassis lubrication during maintenance also includes lubrication of other wear points. Check the vehicle service information to locate all of the lubrication points and proper lubricants.

Belt Tension Adjustment

- Check power steering belt for glazing (hard, shiny inner surface), cracking, fraying, and proper alignment.
- Check tension with a belt tension gauge and compare to specifications.
- Many serpentine belts use an automatic belt tensioner and do not require adjustment.
- V-belts and applications that do require adjustment may use either a screw-type adjustment or prying to set the proper tension.
- Excessive tension can damage the pump bearings.
- On applications with a screw-type adjustment, make sure you have loosened all the required pivot and bracket fasteners to avoid stripping or bending the adjuster mechanism. If the tension is set by prying, loosen the fasteners, pry to the proper tension, and then tighten the slide bracket bolt. Use care when prying; do not pry against the reservoir or the side of the pump. Look for a 3/8ths or 1/2 inch square hole on the housing or a bracket. This hole is designed for a pull handle to be inserted for safe and easier prying.



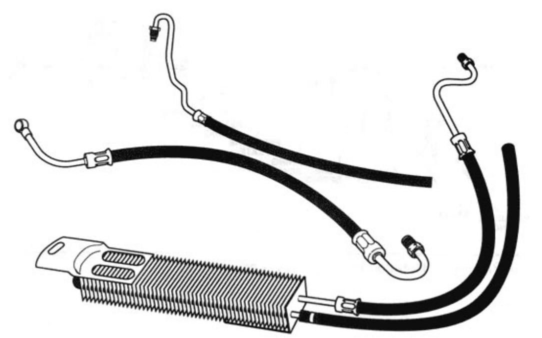


Left: Serpentine Belt Routing Diagram – note the location of the automatic belt tensioner.
Right: This V-belt application requires prying to adjust belt tension.

Power Steering Hoses

Standard power steering systems have two hoses: a pressure hose and a return hose. The hoses are designed to be tough, since they are exposed to high pressure and temperature, but they may leak or fail.

- Check for leakage at the connections and the joints where the metal pipes are crimped to the rubber hoses. Look for swelling, abrasions, cracks, and feel for soft or spongy places that indicate internal deterioration.
- When replacing hoses, also replace any O-rings, and torque the hose fittings to factory specs. Flush, refill, and bleed the system.



Power Steering Hoses – note the oil cooler on the lower assembly.

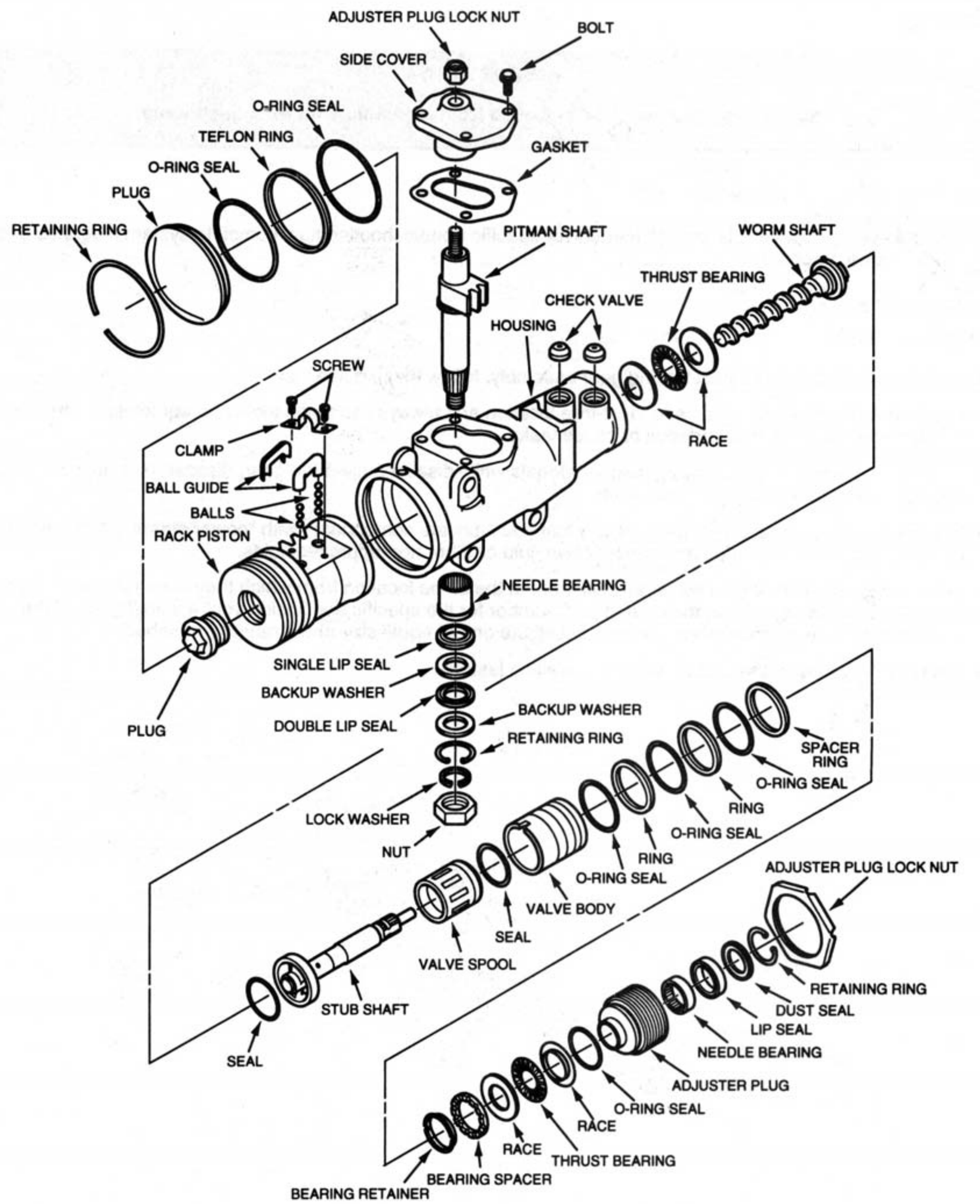
Power Steering Pressure Test

In some cases, it may be necessary to perform a power steering pressure test. This test checks the operation of the power steering pump, pressure relief valve, control valve, power piston, and hoses. A pressure gauge and shutoff valve is installed in line with the pressure hose for testing. Refer to the vehicle service manual for the procedure and specifications.

Steering Gear Service

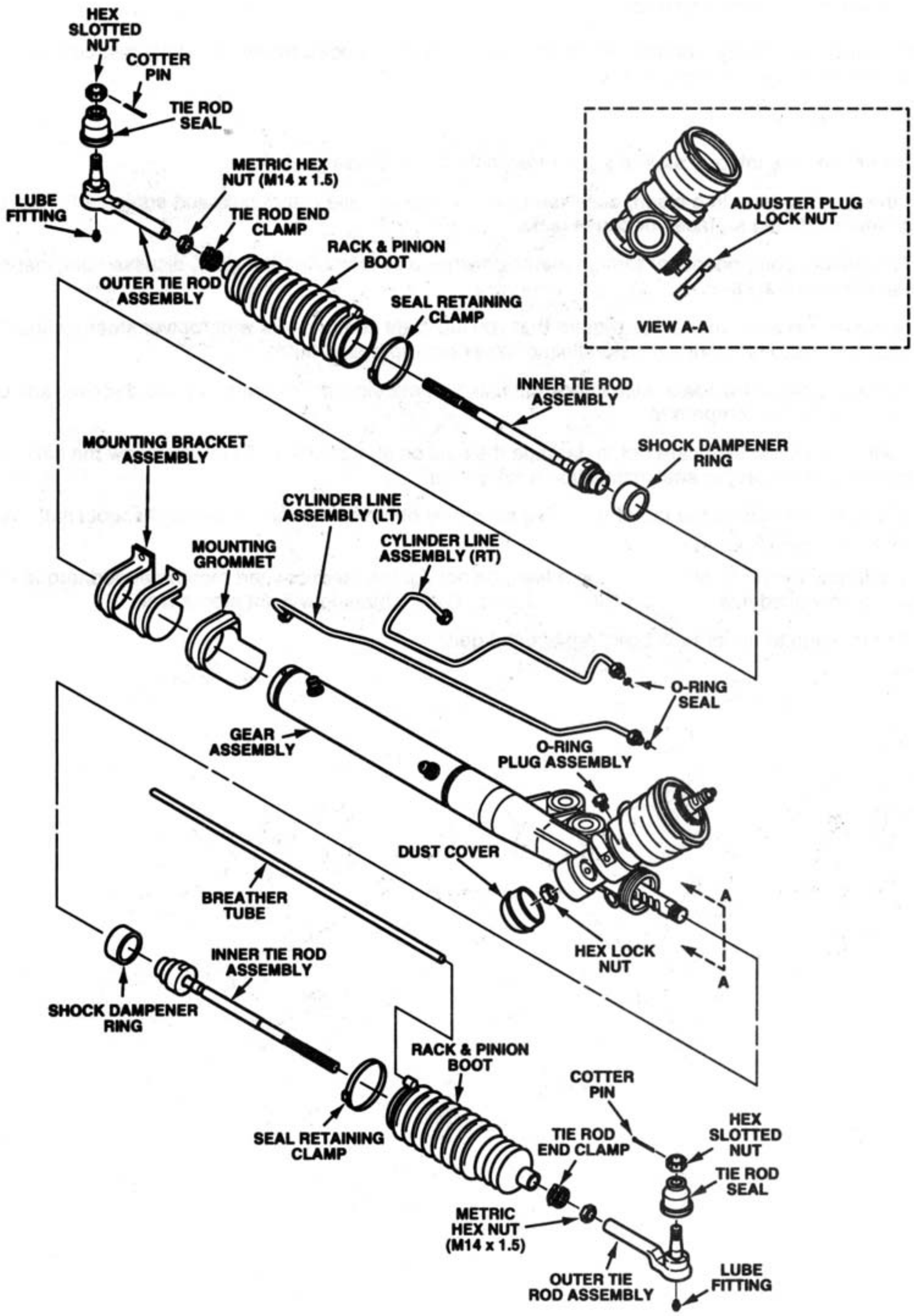
Most steering gears, whether conventional or rack-and-pinion, provide an adjustment for gear lash or pinion tension. Adjustment is not normally required during the life of the vehicle**. These adjustments must be made with caution to avoid damage to the steering gear.** Refer to the vehicle service manual for specs and adjustment procedures if adjustment is needed.

- **Conventional steering gears** will normally last the life of the vehicle. It is possible to rebuild both manual and power steering conventional gears; however, it may not be cost-effective. Refer to the vehicle service information for available kits and parts (seals, bushings, bearings, power valves, etc.), and the setup procedures and adjustments, and compare the cost of the parts and labor to that of a new or used unit.



Exploded view of a typical integral steering gear

- **Rack-and-pinion steering gears** are often replaced with new or rebuilt units. Rebuilt rack units are typically available with inner tie rod ends installed. Although many rack-and-pinion units can be rebuilt in the shop, this is another area where it may be more practical to replace the unit. Again, refer to the vehicle service information for available kits, parts, and the setup procedures and adjustments, and compare the cost of the parts and labor to that of a new or rebuilt unit.
- A common failure of power rack-and-pinion units occurs when grooves wear in the control valve housing, causing poor assist. The symptom usually happens on cold start-ups and disappears after several turns, and has been called "**morning sickness**." Rebuilt units for models that are prone to this problem normally have a hardened sleeve pressed into the aluminum housing to prevent a recurrence of the problem.
- When replacing a rack-and-pinion unit, refer to the vehicle service materials for the removal and replacement procedures and any special tools or materials needed.



Exploded view of a typical rack-and-pinion system

Suspension Systems

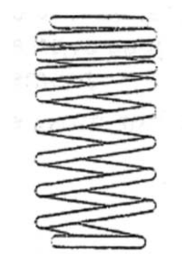
Main Components
In the introduction, we briefly discussed the most common types of suspension systems used on cars and light trucks. In the sections on steering, we discussed ball-and-socket joints and steering linkage components. Now, we'll discuss the rest of the components to complete our picture of steering and suspension systems, and examine the different types of suspensions in greater detail.

Springs
All suspension systems have some type of springs to support the weight of the car and absorb the up and down (jounce and rebound) motion of the wheels, rather than allowing this motion to be transmitted to the frame and body.

- Three types of steel springs found on automobiles: **coil springs**, **leaf springs**, and **torsion bars**. Springs can also be made of composite materials.
- Some vehicles use **air springs**, which consist of a rubber cylinder pressurized by an electric compressor. Air springs can be effectively used for automatic leveling systems.
- **Spring rate** refers to the stiffness, or tension, of a spring, and is based on the amount of weight required to bend it. Spring rate can vary among applications. For example, a vehicle with a towing package may have springs with a higher spring rate than a similar model with standard equipment.
- **Sprung weight** is the weight of the vehicle components that are supported by the springs, such as the frame, body, and engine. **Unsprung weight** is the weight of the parts that are not supported by the springs, such as the tires, wheels, wheel bearings, steering knuckles, and axle housing. Vehicle engineers and designers try to minimize unsprung weight to improve ride and handling.

Coil Springs

- Very common on suspension systems
- A rod of spring steel (specially hardened steel) rolled into a coil
- Can be made to have a **variable rate** by either tapering the width of the rod, or by varying the spacing of the coils. The coils that are of narrower width or closer together are the first to be compressed; the other coils come into play as more load is placed on the spring.
- Fatigued (weak) coil springs must be replaced with new units.



Variable Rate Coil Spring

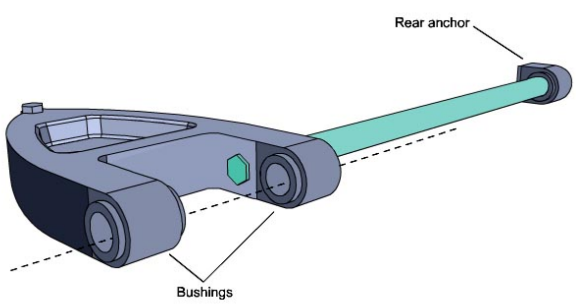
Leaf Springs

- Have been used on suspension systems since the horse-and-buggy days
- A long flat strip of spring steel forged into an arch
- Attached to the frame through a shackle assembly that permits changes in the effective length of the spring as it is compressed
- To carry heavier loads, additional leaves can be stacked below the master leaf. This also provides a variable spring rate.
- Some suspensions use transverse leaf springs that are mounted perpendicular to the frame. One spring supports both sides of the suspension.
- When leaf springs become fatigued, they can be re-arched in a frame shop.

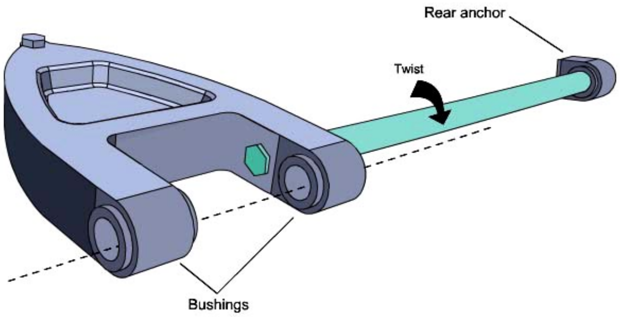
Leaf Spring

Torsion Bars

- A long straight rod of spring steel
- One end of the bar is attached to the frame, and the other end is attached to the inboard side of the lower control arm.
- During jounce, the bar twists to absorb the movement of the control arm. During rebound, the bar returns to its normal loaded shape. Often used because of space considerations
- Found mostly on light trucks and some SUVs
- Tension of the torsion bar can be adjusted by turning a bolt or nut near the end of the bar, which allows the vehicle height to be restored without replacing the springs. Adjustments to torsion bars will affect alignment angles.



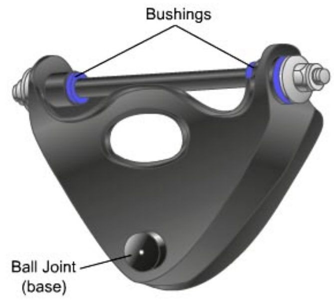
Torsion Bar Suspension



Torsion Bar

Control Arms

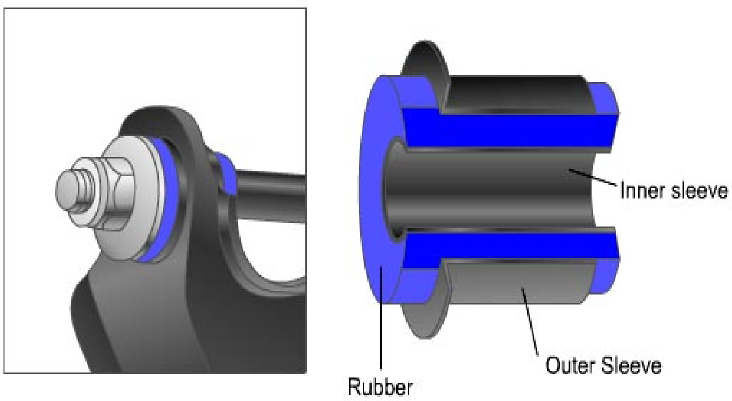
- Provide up-and-down pivot points for the suspension
- The outer end of a control arm contains a ball joint that attaches to the steering knuckle; the inboard end contains a rubber bushing or bushings.
- A bolt or shaft through the eye of the bushing connects the arm to the frame.



An upper control arm. Upper control arm shaft and bushings are visible at top.

Bushings

- Rubber bushings are used to separate parts while permitting the movement necessary for the suspension to function. Rubber cushions the parts and reduces vibration and noise to the body.
- Control arm bushings have a metal inner and outer sleeve with rubber in between. The bushing is usually pressed into a hole in the control arm. The outer sleeve moves with the control arm, while the inner sleeve remains stationary with the frame. The rubber twists to allow the arm to move up and down.
- Bushings can also be found on strut rods, sway bars, shock absorbers, MacPherson strut upper mounts, leaf spring eyes and shackles, and other components.

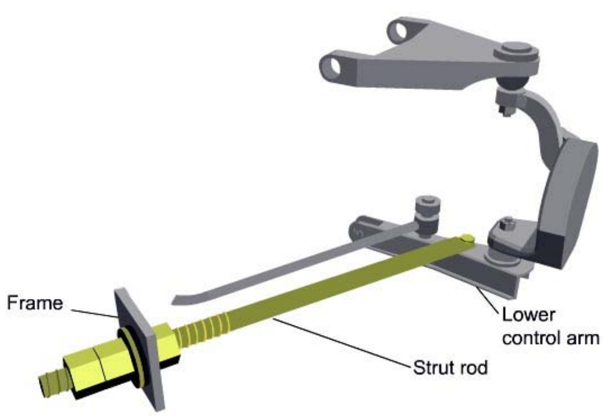


Cutaway of a control arm bushing

Strut Rods

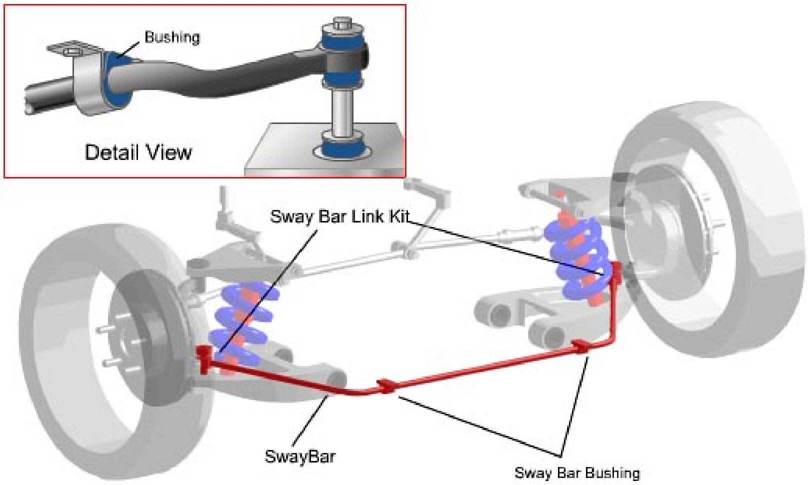
On suspension systems that use a lightweight lower control arm with a single anchor point at the frame, a strut rod is used to provide stability. The strut rod prevents the control arm from moving fore and aft.

- Rod is rigidly bolted to the outer end of the control arm, and attached to the front of the frame through a bushing or a pair of bushings
- A nut or nuts threaded onto the rod holds the rod in place.
- Some are adjustable for wheel alignment and others are not.



Sway Bar (Stabilizer Bar)

- A spring steel sway bar, or anti-roll bar, can be found on the front or rear of many suspension systems.
- Front sway bar connects to both of the lower control arms, usually through **sway bar links,** each link having a set of four bushings. It is secured to the frame with brackets and one-piece bushings.
- The bar prevents excessive body lean, or roll, by resisting the centrifugal forces that tend to make the inside of the body rise and the outside of the body drop during cornering. The resistance is provided through a twisting action of the bar.

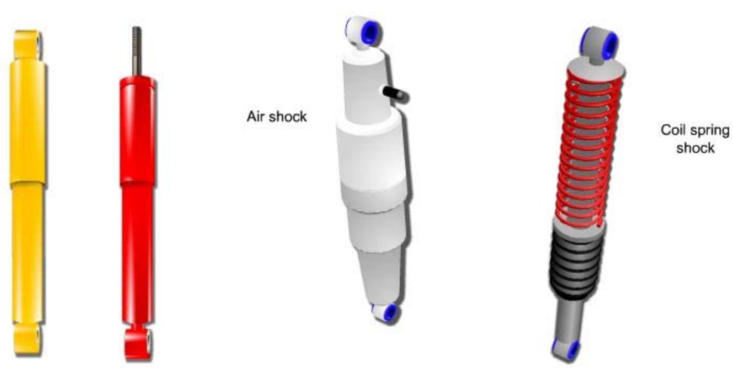


The sway bar reduces body roll in turns.

Shock Absorbers

- Dampen spring oscillations (repetitive compression and extension cycles). Without shock absorbers, a vehicle would continue to bounce up and down long after striking an irregularity in the road
- Help maintain proper contact between the tires and the road, reduce body roll when cornering, and dipping of the front end when braking
- One end of the shock absorber is attached to the suspension and the other end is attached to the frame or body.
- A shock absorber is a hydraulic device which consists of oil-filled chambers in a cylinder with a piston attached to a rod. The piston has calibrated orifices with valves to control the rate of oil flow from one chamber to another, and thus the rate of piston movement within the cylinder. The shock absorber uses resistance to the movement of the oil to dampen spring action. Though the principle is simple, modern shocks have an extensive system of valving and oil control strategies, and there are many different designs and types of shock absorbers.
- A shock absorber's resistance is sensitive to piston velocity. The faster the piston is forced through the oil, the greater the resistance to its movement. While shocks control both up and down movement, the resistance during compression is designed to be generally much lower than the resistance during rebound.
- Many shock absorbers are **gas charged**. These oil filled shocks also contain a pressurized gas to prevent aeration of the oil on rough roads. If air bubbles form around the piston, the shock's performance is reduced. Placing the oil under pressure keeps the air that is naturally bound up in the oil in solution. Shocks that are not gas charged may suffer from foaming under severe conditions.

- There are aftermarket devices that use the shock absorbers as a means to increase load carrying capacity or adjust the height of a vehicle. **Air shocks** use a rubber bladder in the shock to distribute some of the vehicle load to the shock mounts. The shocks are charged with air from a compressor. **Coil spring shocks** have a small coil spring mounted around a conventional shock. A disadvantage of these systems is that the shock mounts are not designed to carry the vehicle's weight. Putting too much stress on the shock mounts may cause them to break.



Shock Absorbers

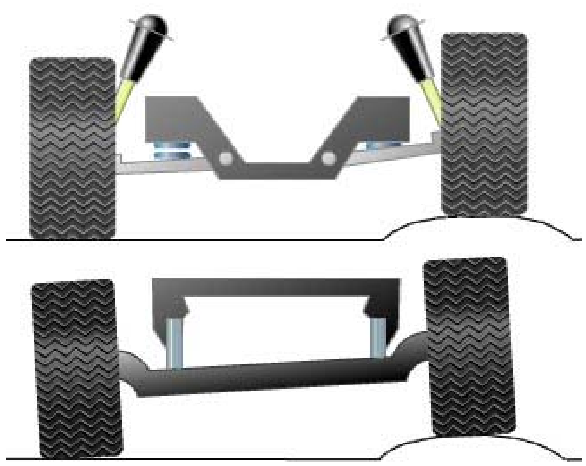
Load Carrier and Follower Ball Joints
Depending on the suspension design, a ball joint can function in one of two ways: either as a **load carrier**, or as a **follower ball joint**.

- On suspensions with two control arms (SLA), the ball joint in the control arm that has the spring mounted on it is the load carrier. This is most often the lower ball joint.
- On MacPherson strut suspensions, the ball joint is a follower. The load is carried by the body through a bearing at the upper strut mount. Follower ball joints provide the necessary pivot points and keep parts in their proper position.
- Whether a ball joint is a load carrier or a follower is an important distinction, because it will determine where to jack the suspension properly for inspection. In addition, the testing methods and specs can be quite different.

Ball Joint Cutaway

Independent and Non-independent Suspensions

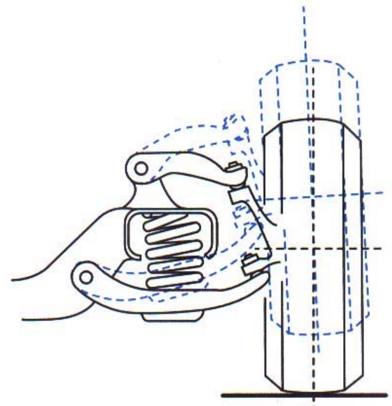
- On an independent suspension, one wheel can move up and down with minimal effect on the other wheels. On non-independent suspensions, the deflection of the suspension at one wheel affects the other wheel. This can reduce handling and ride quality. Independent suspension is desirable and widely used on modern vehicles, though some still use a non-independent rear suspension.
- MacPherson strut and SLA suspensions are independent.
- A non-independent suspension has a **solid** or **straight axle**. Straight axles are strong and can carry heavy loads. For this reason, they are used on the rear of many light trucks and SUVs.
- Some four-wheel-drive vehicles have a solid front axle housing, and some medium-duty trucks have a straight front axle called an **I-beam**. I-beams are often connected to the steering knuckles using steel pins similar to a hinge, called **king pins**.



Independent (top) and non-independent suspensions going over a bump

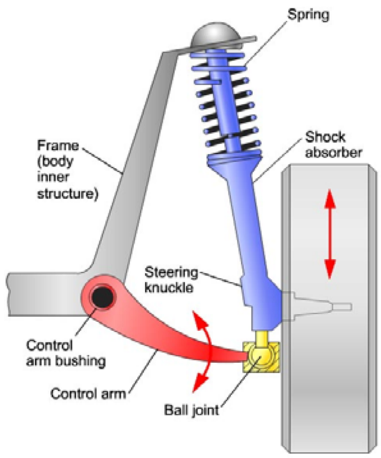
Short/Long Arm (SLA) Suspension Design

- Early independent front suspensions used two control arms of equal length. This caused the bottom of the wheel to move in and out as the suspension jounced and rebounded, resulting in tire scuffing and wear.
- The SLA design reduced this problem and provided better ride quality and improved directional stability. The shorter upper arm allows the track width to remain nearly constant at the road surface.

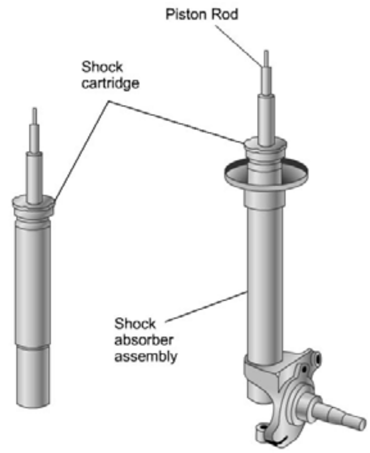


SLA Suspension

MacPherson Strut Suspension
We have noted that the MacPherson strut suspension combines a coil spring and a shock absorber into a single unit. The shock absorber can often be replaced with a new cartridge when it wears out. This is the most common front suspension on passenger cars.



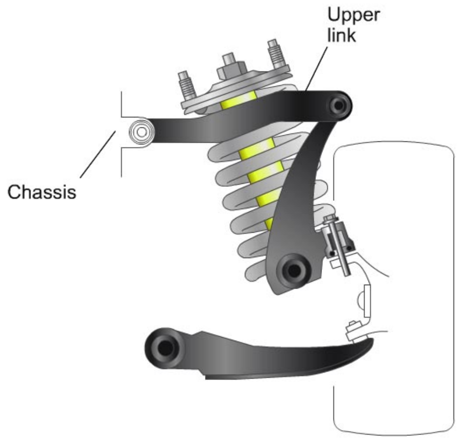
MacPherson Strut Suspension

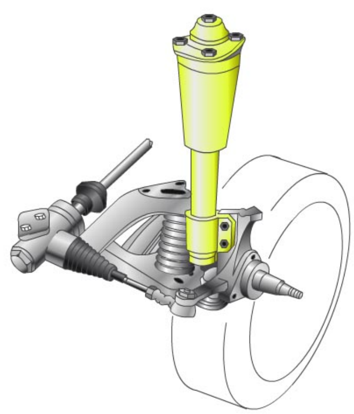


Replaceable Shock Cartridge

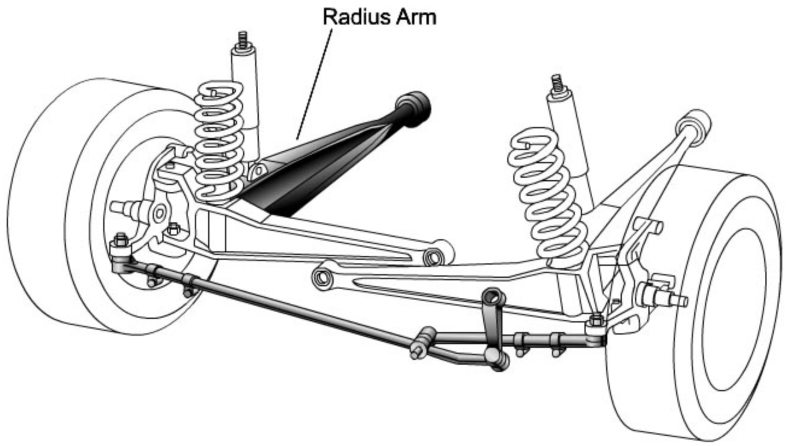
Other Suspension Types

- **Multi-link** suspensions are a variation on the MacPherson strut type, and are popular on both front and rear of smaller, performance-oriented cars. This design uses a small upper arm, or link, attached to the chassis to add stability.
- Another MacPherson strut variation is the **modified MacPherson strut**, which has the coil spring mounted on the lower control arm. This arrangement has been used on front and rear independent suspensions.



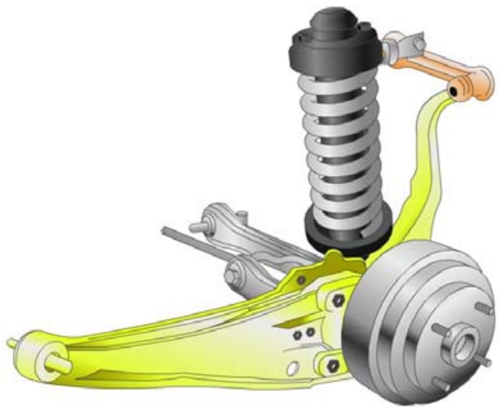
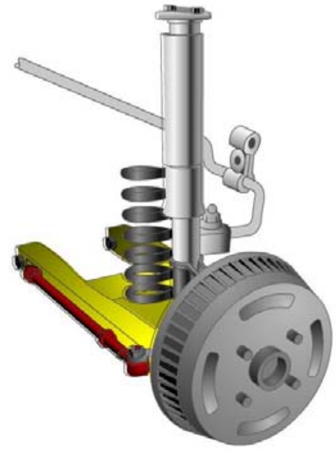

Multi-link (left) and modified MacPherson strut suspensions

- A twin axle, or **twin I-beam** front suspension was very popular on some lines of light trucks from 1965 until 1996, and many are still in service. This suspension is still used on some commercial and medium duty lines. On this suspension, each I-beam is attached to the frame on the opposite side from the wheel. A **radius arm**, similar to a strut rod, is attached to the outer end of each I-beam and extends rearward where it is attached to the frame through bushings.

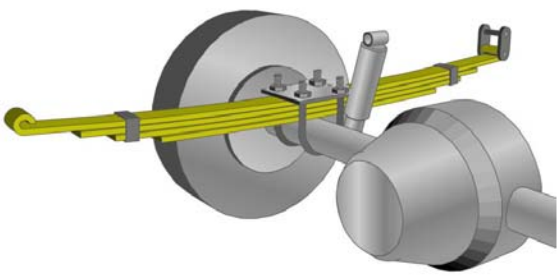
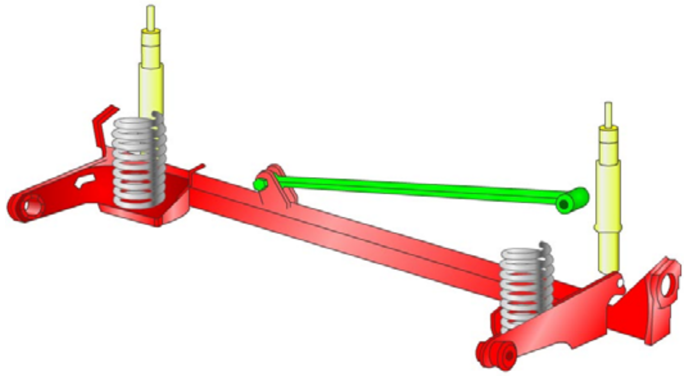


Twin I-beam Suspension

Rear Suspensions
There are numerous rear suspension designs, many of which are variations on the SLA, MacPherson strut, multi-link, or modified strut designs. On light trucks, a solid axle with leaf springs is common. Some front-wheel-drive rear suspensions use a **track bar** or **track rod** to prevent lateral or side-to-side movement of the rear axle.

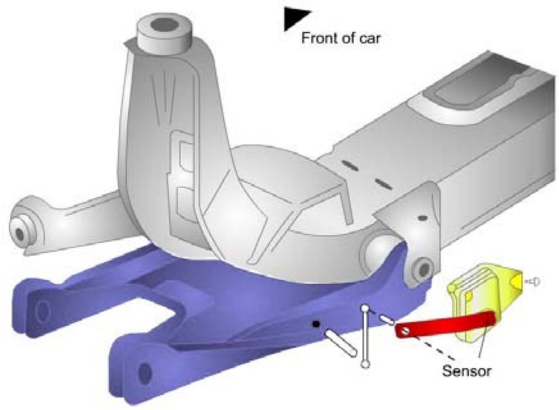
Left: Multi-link rear suspension. This design has two lower control arms. Right: Modified MacPherson strut rear suspension. Note the tie rod end bolted to the control arm, used to adjust rear toe.

Left: Solid axle rear suspension with leaf springs. Right: Solid axle "trailing arm" rear suspension for a front-wheel-drive model. Note the track bar directly above the axle.

Suspension Leveling Systems
Some vehicles have the capability to adjust their suspensions to maintain the proper attitude (ride height) of the vehicle regardless of how they are loaded. They use air shocks or air springs and an onboard compressor to adjust the suspension's height and rate.

Early leveling systems were operated with a manual switch. Later systems are automatic and rely on height sensors to determine the vehicle's attitude. The compressor is switched on, or air is bled out accordingly. System designs and operations vary.



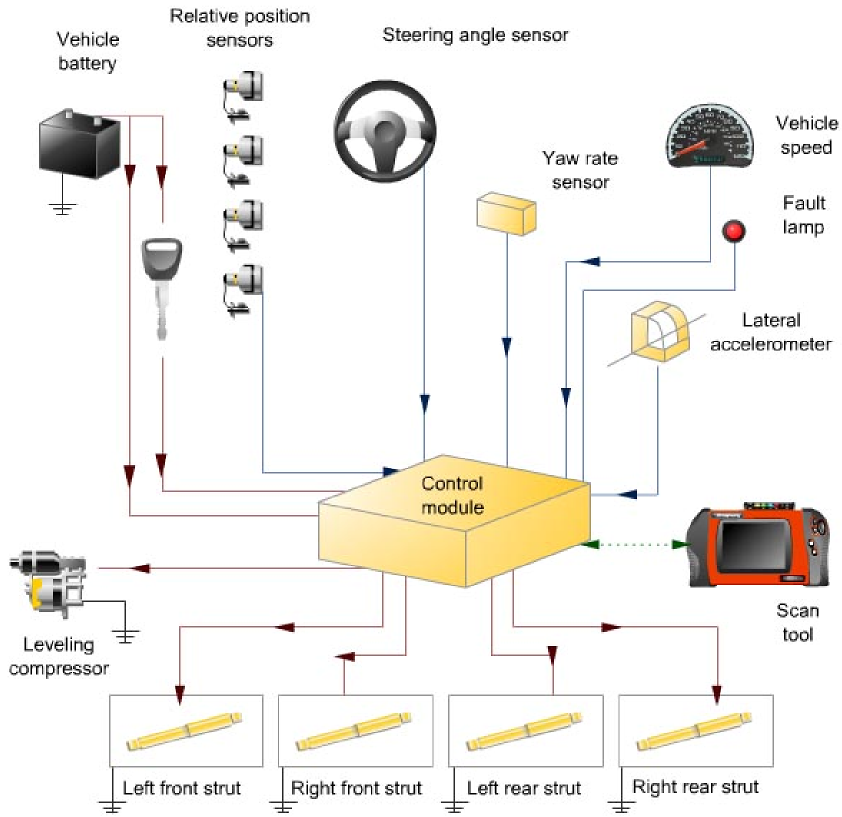
A height sensor mounted on the frame. The actuating arm moves up or down with the suspension, varying a voltage signal at the electrical connection.

Electronically Controlled Suspension Systems
Suspensions are being produced that can change vehicle loading and ride characteristics very quickly, either automatically or on demand. These systems vary a great deal among manufacturers and model lines.

Some luxury or high performance models have electronically controlled shock absorbers. These systems vary the shock valving according to vehicle conditions, as determined by a control module with inputs from a variety of sensors. The control module activates motors or solenoids that change the size of the valve orifices. The module may use inputs from numerous sensors, including:

- Height sensors located on the frame near the wheels
- Vehicle speed sensor
- Steering sensor – detects steering wheel rotational angle and speed
- Brake and door sensors
- Throttle position sensor

One type of electronically controlled shock absorber system uses a magneto-rheological fluid (MR) in the shocks, instead of changing the valving. This fluid is a synthetic oil that contains suspended iron particles. The shocks or struts contain a winding that, when energized, acts upon the particles, giving the fluid a thicker consistency for more damping action. The damping characteristics can be changed variably and instantaneously.



Electronically Controlled MR System

Active Suspension Systems
A few luxury and performance vehicles have active suspension systems. The height and ride characteristics are actively computer controlled.

- Uses hydraulic cylinders (rams) in place of conventional springs and shock absorbers. Sensors on each ram send signals to the computer, which can extend or retract the rams by varying the fluid pressure. Other sensor inputs may also be used.
- Pressure is provided by a hydraulic pump driven by the engine.
- The system can react within milliseconds to changes in driving conditions, such as hard braking or cornering, bumps and dips.
- When a wheel encounters a bump, sensors signal the computer, which immediately releases pressure from a control valve. It can release pressure instantly or more slowly, depending on the road surface. When the bump is passed, the computer increases the pressure in the ram, so the tire follows the surface of the road.

Suspension System Service

Suspension systems are designed to stand up to the abuse they receive under various driving conditions, but the tremendous "beating" they take can result in the need for minor and major repairs over time. Springs can fatigue and sag; ball joints, steering linkages, bushings, and shock absorbers can wear out and fail. The elements don't help – water, salt, and other contaminants promote rust and corrosion that can also take a toll on these components.

Common Suspension System Problems

Looseness is the enemy of steering and suspension parts. When wear causes looseness, the loose parts tend to hammer against each other, causing further wear and looseness. In extreme cases, parts can become bad enough to separate and cause a catastrophic failure, possibly resulting in an accident.

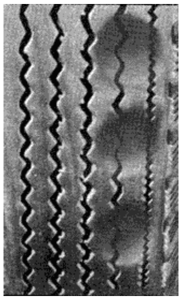
In the section on steering system service, we noted some common overall steering and suspension problems, including **noise**, **abnormal tire wear or vehicle handling**, and **excessive free play** in the steering wheel. In this section, we will examine these and other problems in detail.

- Worn ball joints
- Bad control arm bushings
- Worn steering components
- Sagging or broken springs
- Loose or missing sway bar link kits
- Bad sway bar bushings
- Loose or bad rack mount bushings
- Torn rack-and-pinion bellows boots
- Bad upper strut mounts or bearings
- Worn or broken shocks or strut cartridges

Shock Absorbers and MacPherson Strut Cartridges

Worn shock absorbers or MacPherson strut shocks will cause a vehicle to ride and handle poorly, especially on bad roads. The vehicle will have excessive body motion. Some shocks can still be effective after over 50,000 miles, while others might not make it to 20,000.

- Shocks can develop internal or external oil leaks that reduce their damping effectiveness, or they can even break.
- Conventional shock absorbers' rubber **grommets** or mounting bushings are prone to fail, and shocks also can come loose from a mount.
- Shocks are replaced in pairs (front or rear).
- Sometimes shocks that are broken or non-functioning cause a **scalloped** wear pattern on tires. The tread will have cupped or dished areas.



Scalloped Tire Wear

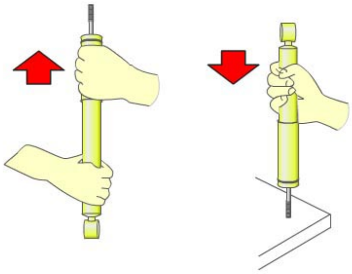
Most original equipment shocks and struts are designed to give a comfortable ride with a tight, new suspension. After 20 or 30 thousand miles, the suspension has settled considerably, and some people choose to replace the shocks to firm up the ride and handling.

Checking Shocks and Struts

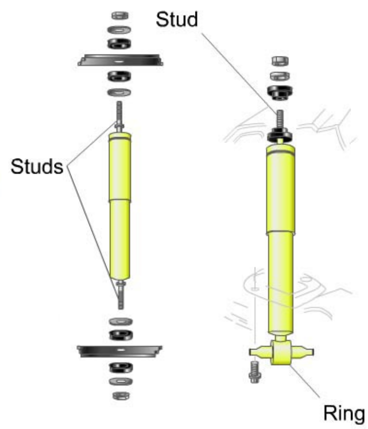
- One quick way to tell if shocks or struts are badly worn or broken is with a "bounce test." Push down hard several times on a corner of the body and then release it. The body should bounce about twice and then stop. If the body continues to bounce several times, the shock is bad. Repeat this on each corner. This is not the best way to evaluate shocks that might be marginal.
- Shocks can be visually inspected for external leakage. An oily residue running down the shock indicates a seal leak, and the shocks will need to be replaced. A slight wetness at the seal is normal. Also inspect the mounts and rubber bushings, and look for physical damage to the shock.
- The best way to evaluate shocks and struts is to drive the vehicle over a variety of roads, especially a bad two-lane highway if possible. Excessive body sway, dip, wander, or "float" will be evident with poorly functioning shocks.

Replacing Conventional Shock Absorbers

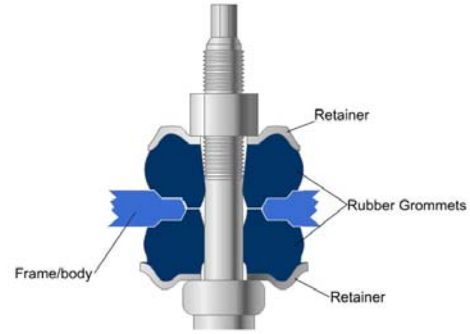
- An air impact wrench greatly eases removal of most shock absorbers. An aerosol can of penetrating oil also comes in very handy for spraying rusty threads.
- A wheel alignment is not required after replacing conventional shock absorbers (although it is required after servicing MacPherson struts).
- Shock absorbers that have been stored horizontally should be purged of air before installation. Holding the shock vertically and extend the piston all the way out, then turning the shock over and collapse it. Repeat this process until the shock extends and collapses smoothly, with no "skips."
- Gas shocks are shipped with a strap that keeps them compressed. When the strap is removed, the shock should fully extend on its own.



Purging air



Shock mounts



Upper mount with grommets

Front Shocks - The upper mount for many front shocks is a single threaded stud that attaches to the frame through two grommets with retaining washers and a nut. The stud is part of the piston rod. The bottom of the shock is usually connected to the lower control arm with bolts. The upper nut is usually removed with the vehicle on the ground. Rusty upper nuts and studs may require you to hold the top of the stud with a special wrench or vice grips while you back the nut off manually with an end wrench. Spray the stud liberally with penetrating oil and give it some time to soak. Some especially stubborn nuts may have to be cut off with an air chisel or other power tool. Once the nut is removed, you may lift the vehicle to access and remove the bottom mount. Reverse the procedure with the new shock. Shock absorbers that use this grommet arrangement are often over-torqued. The upper nut should be tightened only until the grommet bulges to the same diameter as the retaining washers.

Caution – Some vehicles must be raised on a hoist to access the upper shock mounts. Many shocks limit spring travel. An additional jack stand or lifting device must be used to support the suspension before the shock can be removed, in order to prevent sudden forceful movement of the axle or control arm, which could cause personal injury.

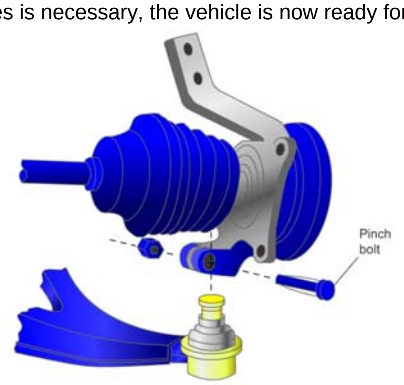
Rear Shocks – Other than the above caution, rear shock replacement is straightforward. Consult the vehicle and product service information for replacing shock absorbers.

Air Shocks – When installing air shocks, be sure to run the air lines clear of any possible pinch, heat, or rub points on the chassis. Air shocks are prone to leakage if overloaded to compensate for weak springs. Air shocks can be checked for leaks with a soapy water solution applied to lines and fittings.

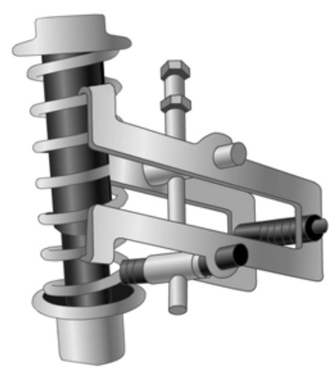
Replacing MacPherson Strut Shocks

To replace the shock absorber in a MacPherson strut, the entire strut assembly must first be removed from the vehicle. On some models, you must separate the ball joint from the steering knuckle in order to get enough clearance to remove the strut assembly. Removing the brake line from the caliper is required on some applications, which necessitates bleeding the brakes after the struts are serviced.

After the strut is removed, the housing is placed in a vice for disassembly and service. A **spring compressor** must be used to compress the coil spring before the upper nut can be removed. Once the spring is compressed, the nut can be safely removed. A large nut that seals the strut's shock is then removed, and after removing the piston and disposing of the old oil, a sealed replacement cartridge unit can be installed in the housing. The strut is then reassembled and installed on the vehicle. Unless bleeding the brakes is necessary, the vehicle is now ready for a wheel alignment.



This ball joint is attached to the steering knuckle with a pinch bolt.



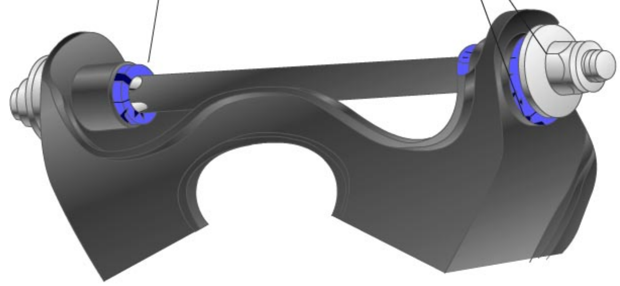
MacPherson Strut Spring Compressor

- Refer to the procedures and diagnostic charts for checking leaks, named "PD46 MacPherson Strut Suspension Service" in the online course.

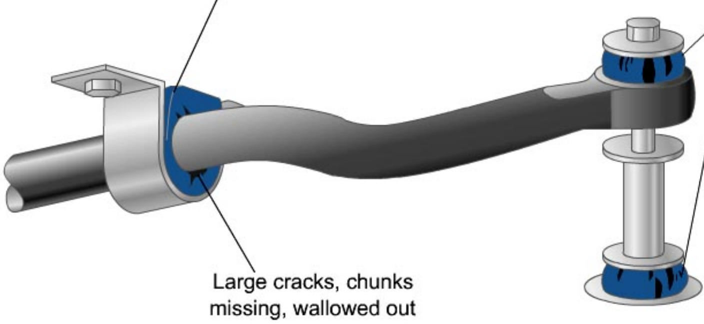
Bushing Inspection and Service
Failure of rubber bushings is a common noise-maker, as well as a cause of abnormal tire wear or vehicle handling, because of their affect on wheel alignment settings. While modern synthetic rubbers are very good, they have limitations. Oils, fluids, and road contaminants can attack the rubber. Excessive heat can deteriorate bushings near exhaust components. The rubber can deteriorate to the point where much or most of it falls out, allowing components to shift and cause problems.

- **Upper control arm bushing** failure can have a serious effect on tire wear and steering. It can cause a profound shimmy of what feels like "the whole front end" under certain conditions, as well as noise.
- **Strut rod bushing** failure can cause a loud clunk or knocking sound, as well as steering problems such as a sensation of shifting weight during stopping, starting, or cornering. It can also cause a pull to one side.
- **Sway bar link or frame bushing** failures only affect sway bar effectiveness, but they can also produce annoying rattling or popping noises.

Bushing Inspection
Bushings should be inspected for deterioration and splits in the rubber. Some surface cracking is acceptable, but the rubber should be in tact all the way around the bushing. With control arm bushings, look for missing chunks of rubber between the sleeves and for polished areas on shafts. With the vehicle properly lifted, rock the wheel in and out and feel for movement. Confirm visually.



Bad Upper Control Arm Bushings



Sway bar bushing and link kit inspection

Bushing Replacement
Some control arm bushings can be replaced with the arm still on the vehicle; others require removal of the arm. On a few applications, control arm bushings are threaded into the control arm, but most are press fitted.

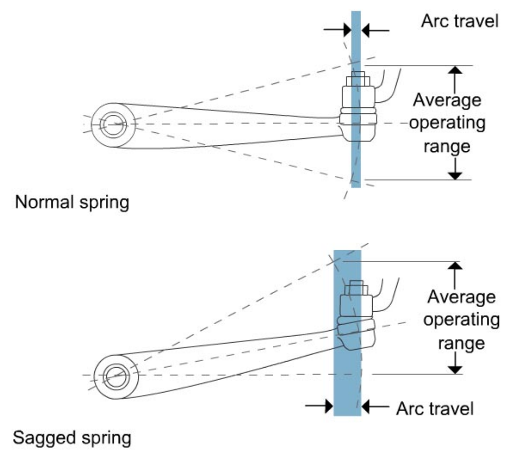
- Press fitted bushings can be removed and installed with a bushing driver. Some may be removed with an air chisel, and some may be pressed into the arm with the retaining nut. This method can require periodic vibration of the control arm to coax the bushing into place.
- Care must be used in bushing replacement to avoid damage to the control arm. To properly position the bushing, the weight of the vehicle must be on the suspension before tightening the nut on most designs. Check the service information for the vehicle for the proper procedure.
- Replacement of other types of suspension bushings is generally straightforward. Consult the service information.

Vehicle Ride Height and Spring Service
A vehicle's suspension is designed to operate at a specified ride height, or curb height. Over time, springs can fatigue, causing the suspension to sag below the proper ride height.

- Can cause the vehicle to bottom out excessively
- Adversely affects the wheel alignment geometry and vehicle handling characteristics. On SLA suspensions in particular, this causes rapid tire wear. The control arms move outside their normal operating range during jounce and rebound, which increases tire scrub (lateral movement).

Inspection and Measurement

- An air impact wrench greatly eases removal of most shock absorbers. An aerosol can of penetrating oil also comes in very handy for spraying rusty threads.
- Broken or missing rubber **jounce bumpers** (strike-out bumpers) on the control arms, and corresponding shiny areas on the frame are good indicators that the springs are fatigued. Check the springs for misshapen or broken coils.
- The vehicle ride height must be checked prior to a wheel alignment. Service information will provide the measurement points and specifications for the vehicle. Wheels and tires must be of the proper size and inflated to the recommended pressure, and a full fuel tank (or equivalent weight) is usually specified. The vehicle interior and trunk or bed should be cleared of excess weight.



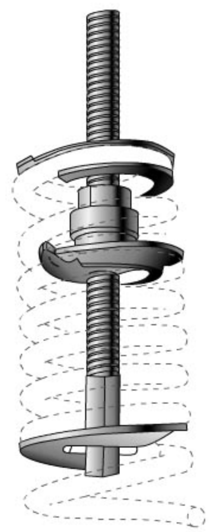
Increased tire scrub from weak springs

Coil Spring Replacement

Rear coil spring replacement is often a simple matter, but front coil spring replacement can be more involved. Procedures vary with different manufacturers and models, and some call for special tools. Refer to service information for the vehicle.

An internal spring compressor may be needed when removing and replacing front coil springs. The springs are under compression, even when the vehicle is lifted by the frame. After removing the shock, the replacement procedure may involve breaking ball joint tapers (lower, upper, or both), removing a ball joint, and removing other components such as sway bar links. The lower control arm can then be pried downward, and the spring pried out from its place.

Caution – Compressed springs have tremendous stored energy. To avoid injury, make sure a spring compressor or other spring control device is in place, or the control arm is supported, before disconnecting any spring-loaded components. Handle compressed springs with care.



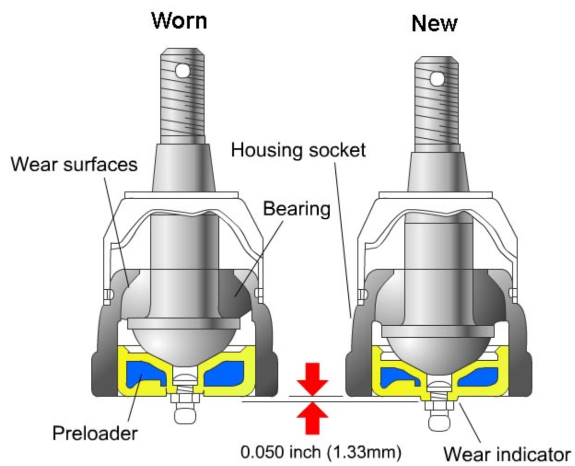
Coil Spring Compressor

Ball Joint Wear, Inspection, and Service

Ball joints normally have a long service life, but they can fail due to a loss of lubricant, or from contamination if the seal (boot) fails. A worn ball joint allows looseness in the suspension between a control arm and the steering knuckle. This looseness causes poor handling and misalignment, and it doesn't take much looseness to cause problems.

Inspecting Ball Joints

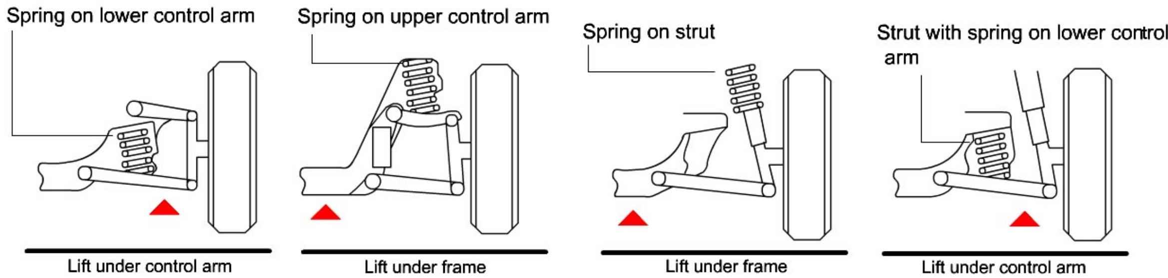
Some manufacturers make ball joint inspection easy by providing **wear indicators** on their ball joints. These are checked with the full vehicle weight on the suspension. On the most common type, the grease fitting is threaded into a round boss that protrudes from the base of the ball joint. As the joint wears, the boss recedes into the joint. When the shoulder of the boss is flush with the base of the ball joint, the joint should be replaced. A small screwdriver may be used to scrape away any debris and help determine the position of the boss. The service information will identify wear indicator ball joints and how to read them.



Wear Indicator Ball Joints

- Manufacturers provide specifications for allowable movement in ball joints. The vertical (up-and-down) spec is listed as **axial movement**, and the horizontal (side-to-side spec), if provided, is listed as **radial movement**. Typically, load-carrying ball joints have an axial movement limit specification of around 0.060 of an inch, though some may allow up to 0.200 of an inch. The spec for many follower ball joints is "no perceptible movement."

- To check for ball joint and other component movement, the suspension must be unloaded by jacking it at the proper lift points. Recall that if the spring is mounted on the lower ball joint, then the joint is a load carrier, and that on a standard MacPherson strut suspension, the ball joint is a follower. If the lower ball joint is a load carrier, lift under the lower control, as near as possible to the ball joint. Below the spring seat is usually a good place. If the lower ball joint is a follower, lift by the frame. Study the diagram of lift points.

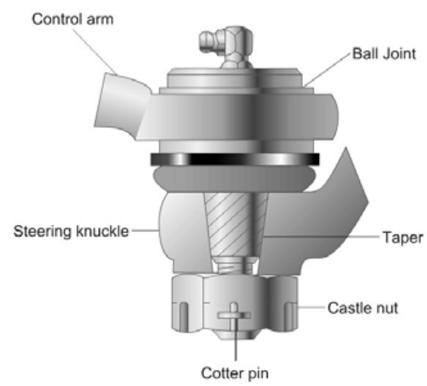


Lifting points for unloading different types of suspensions

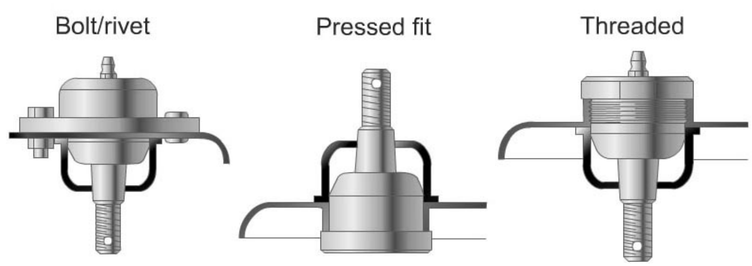
- With the suspension properly lifted, a long steel pry bar is used to wiggle the tire up and down and side to side, while observing the amount of movement in the upper and lower ball joints. Compare the amount of movement to the specs. A **dial indicator** mounted to the control arm with the plunger placed on the steering knuckle can be used to measure small amounts of movement.

Replacing Ball Joints

- Replaced in pairs (both upper or both lower)
- Attached to the control arm using a press fit, rivets, bolts, or threads
- Similar to tie rod end tapers, a tapered ball stud fits into a mating tapered hole in the steering knuckle, and a castellated nut or locknut draws the stud into a tight fit. A special tool or a large hammer can be used to "break" the taper. To break the taper with a hammer, remove the cotter pin and back the nut off several turns. Position the vehicle so that the ball joint is loaded by the spring. Then use the hammer to sharply strike the steering knuckle on the outside of the taper. The taper will pop loose and the knuckle will rest against the nut. The suspension can then be unloaded so that the nut and ball joint can be removed.



Ball Joint Taper



Ball Joint Retention Methods

- If the ball joints are pressed into the control arm, a **ball joint press** is used to press in the new joint. Care must be used to align the ball joint in the hole properly to avoid damage to the control arm.
- If the ball joints are held in with rivets, the rivets are removed and replaced with hardened nuts and bolts.
- Threaded ball joints are simply threaded in place and torqued to specs.
- Use the supplied lock nut or a **new cotter pin** to secure the nut.

Using a ball joint press

Steering Linkage Wear, Inspection, and Service
With the suspension unloaded for a complete steering and suspension inspection, all steering linkage parts should be checked for looseness.

- Looseness in any of these parts can cause steering wheel play, poor handling, and tire wear.
- The vehicle will not hold a wheel alignment.
- The linkage check is similar to the dry park check, but more thorough.
- Loose parts must be replaced and then a wheel alignment must be performed.

Idler Arm Inspection

- Common wear item
- To check it for looseness, grasp the center link as near to the idler arm as possible and try to move it up and down. Note the amount of movement at the end of the arm. Compare the amount of movement with the specifications. A typical spec might be a limit of 1/4 of an inch.
- This type of movement will cause a toe change.
- Note that the spec might pertain to safety limits rather than tire wear concerns.
- Recall that some idler arms have a pivot point at the center link. Check this point for movement as described under "Center Link Inspection" below.

Center Link Inspection

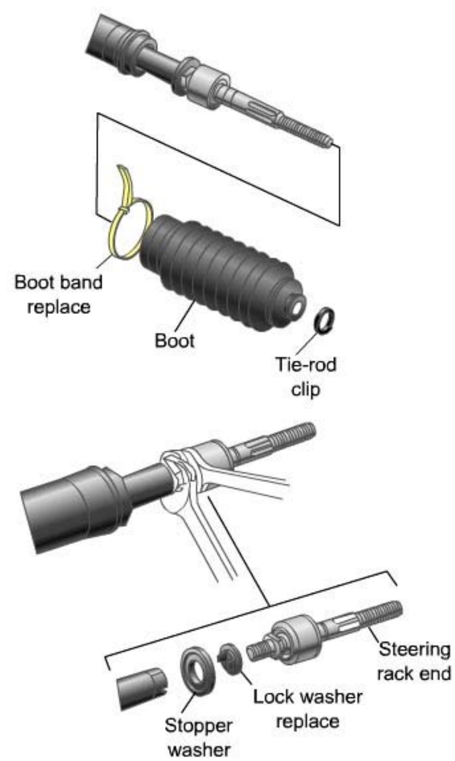
- The most common wear point for most center links is at the pitman arm.
- Place your hands, palms out, against the inside of each front tire. Alternate between pushing one tire outward and then the other, creating a rocking motion, while looking for movement at the pitman arm. Compare to the specs.
- In general, there should be no perceptible independent movement.
- Recall that on some designs, the wear points are in the pitman arm and idler arm, so check this type accordingly.

Tie Rod End Inspection

- Conventional tie rod ends can be checked by grasping them near the ball socket and squeezing the tie rod into the connecting part, or attempting to push the tie rod towards and then away from the connecting part.
- Tie rod ends with looseness should be replaced.
- Some designs are spring loaded, and it is possible to overcome the spring tension, but the spring should provide firm resistance. Don't confuse the spring movement for looseness in the ball and socket.
- Inner tie rod ends on rack-and-pinions may be checked by grasping them and attempting to move them in and out. An effective method for checking them was covered in the section on steering service under "**Excessive Free Play**."

Steering Linkage Service
As with tie rod ends and ball joints, many idler arms have a **taper** connection, which must be broken to remove the idler arm. The tapers on steering linkage components are easier to break than those on ball joints. The tapers can be broken with the suspension unloaded. Either a hammer method similar to that described under "**Replacing Ball Joints**," or a taper breaking tool can be used.

- A **taper breaking tool** can destroy the part, so the hammer method should be used when breaking the taper to replace a different part (if the part is to be reused). Leave the nut on the stud to help protect against a glancing hammer blow that could damage the threads.
- **Measure or mark** the tie rod length before disassembly. This will allow you to obtain an approximate toe setting for reassembly, making alignment much easier.
- Inner tie rod ends on rack-and-pinions are usually threaded onto the rack. Various methods are used to lock the tie rod end. Consult the vehicle service information.



Two wrenches are needed to loosen this inner tie rod end from the rack.

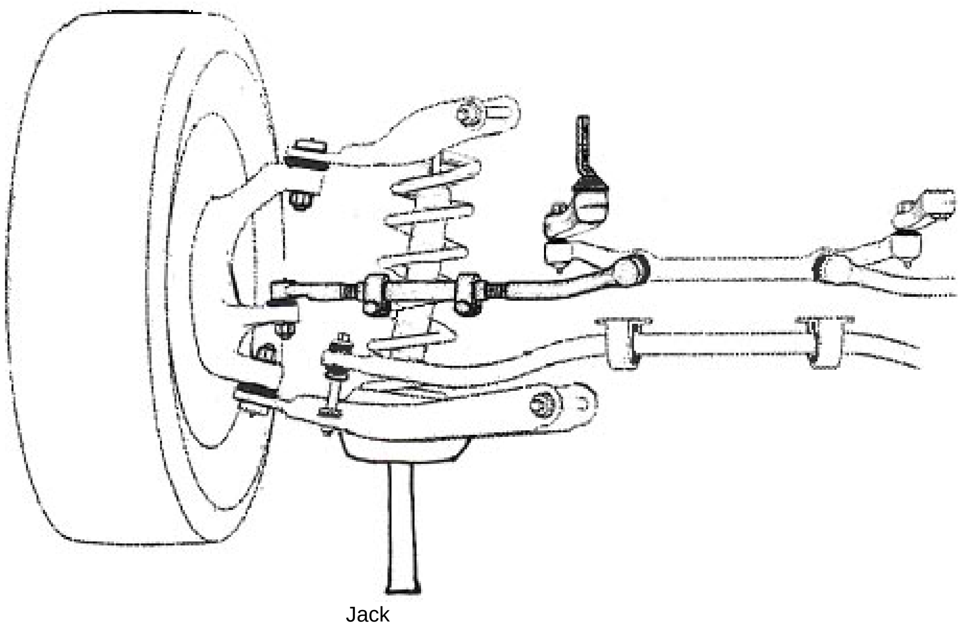
The Complete Steering and Suspension Inspection

We have noted that all of the steering and suspension components must be checked prior to a wheel alignment. This is when most steering and suspension problems will come to light. The customer may not realize that they have steering or suspension problems, or they may expect that a wheel alignment will “cure” their steering or suspension concerns.

A complete steering and suspension inspection should begin with a test drive, if possible. Anything unusual about the steering and suspension systems should be noted, such as any noises or handling problems. The vehicle should then be placed on an alignment rack, the parking brake set, and the hood raised for the inspection. At this time, you should check:

- Tires and wheels for proper size, tires for inflation and uniform construction (same type)
- Vehicle ride height
- Under the hood – upper control arm bushings, if applicable; upper strut mounts for binding or other problems, flexible steering links, shocks and mounts, power steering hoses, etc.

Next, turn the ignition key to unlock the steering, and then raise the vehicle. If the ball joints have wear indicators, check them now. Then, use the hoist-mounted jack to unload the suspension. You can then check all of the steering and suspension components as previously described. Once you have identified and corrected any steering and suspension problems, you may proceed to perform a wheel alignment.



Preparing to perform the undercar portion of the complete steering and suspension inspection

Wheel Alignment Principles

The purpose of wheel alignment is to allow the vehicle's wheels to roll straight down the highway with little steering effort, and to minimize scuffing, slipping, or dragging of the tires under all operating conditions. Correct wheel alignment is essential for safety, proper steering response and vehicle handling, and long tire life. For a vehicle's steering and suspension systems to operate as designed, the wheel alignment settings must be within their specified range and the vehicle must be capable of retaining the settings.

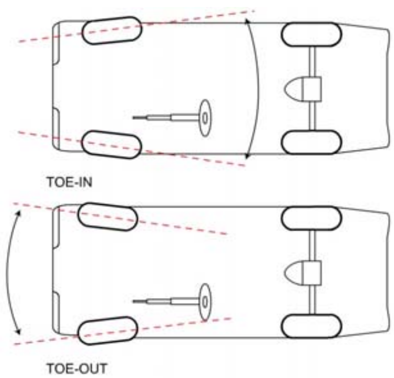
While the methods of vehicle adjustment and the equipment used to check wheel alignment may change, the basic geometry and dynamic forces involved do not change.

There are six essential wheel alignment angles:

- Toe
- Camber
- Caster
- Tracking (thrust angle)
- Steering axis inclination (SAI)
- Turning radius (toe-out on turns)

Toe

- The difference in distance between the front and rear of the tires. When the tires are closer together at the front than at the rear, the wheels are said to be **toed in**, and if they are farther apart at the front, they are **toed out**. Toe-in is also called **positive** and toe-out **negative**.
- The **most critical** tire wearing angle, because if toe is outside of specs, excessive tire wear will quickly result, due to scuffing, as the tire tends to be dragged sideways on the road while it rolls.
- Measured in fractions or decimals of an inch, in millimeters, or degrees

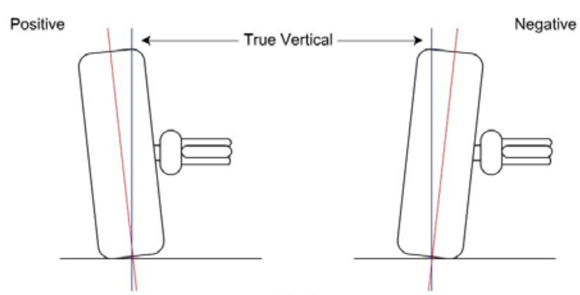


Toe

- Changes in the toe angle occur during normal wear and settling of steering and suspension parts. Incorrect toe can also occur due to an improper adjustment or collision damage.
- Front toe is adjustable on all vehicles, and rear toe is also adjustable on most front-wheel-drive vehicles. A few rear-wheel-drive models have an adjustment for rear toe.
- Toe will change under different driving conditions, and the **preferred setting** given in the specifications is a "best average."
- When rear-wheel-drive vehicles are driven, the front wheels tend to toe out, as the rolling resistance of the tires acts upon the steering and suspension systems. Higher speeds produce more toe-out action. For this reason, they are usually set to have a small amount of toe-in on the alignment rack to compensate. A typical setting might be 1/16 to 1/8 of an inch (0.06" to 0.13" or 1.6mm to 3.2mm).
- On front-wheel-drive vehicles, engine torque tends to cause toe-in at road speed, and toe may change depending on whether the vehicle is accelerating or decelerating. They are commonly set to have a small amount of toe-out, or zero toe on the alignment rack.

Camber

- The inward or outward lean of the top of the wheel. If the top of the wheel tilts outward from true vertical, it has **positive camber**, and if it tilts inward at the top, it has **negative camber**.
- Tire wearing angle – wear occurs on the side to which the wheel leans (on the outer or the inner area of the tread). The proper camber setting will correctly load the suspension and minimize tire wear.
- Measured in degrees of a circle, with zero degrees at true vertical



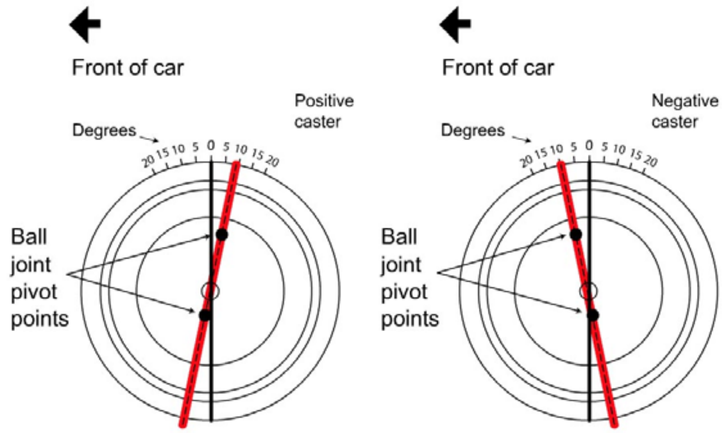
Camber

- Camber changes can occur during normal wear and settling of suspension parts. On many suspensions, negative camber develops as the frame and suspension settle.
- To properly load the larger inner wheel bearing and spindle assembly, SLA suspensions are usually set with a small amount of positive camber, typically about ¼ to ½ degree (0.25° to 0.5°). Some MacPherson strut front suspensions call for a small amount of positive camber, but many have a preferred setting of zero degrees.
- Vehicle loading affects camber. You can lean on a vehicle during an alignment to observe the effect.

- Camber is adjustable on most suspensions, but not all Macpherson strut designs include an adjustment for camber.
- Camber is also a **directional control angle**. A wheel will tend to roll in the direction of the lean. For example, a vehicle with negative camber on the left front wheel (driver's side) and/or positive camber on the right front wheel may drift or pull to the right.

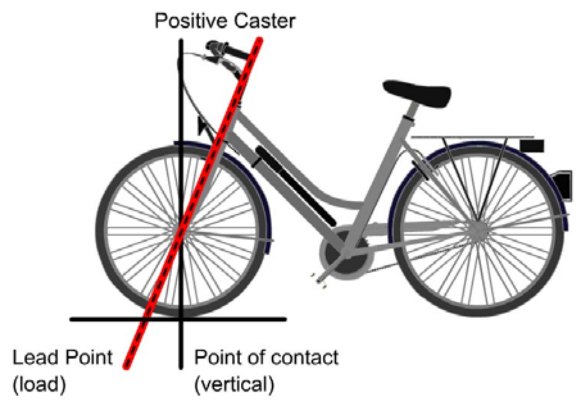
Caster

- Forward or rearward tilt of the steering knuckle away from true vertical. Viewed from the side, a line drawn through the upper and lower ball joints (SLA) describes the caster angle. On a MacPherson strut system, the caster is a line through the upper strut mount and lower ball joint. If such a line tilts rearward at the top, the caster is **positive**, and if the line tilts forward at the top, the caster is **negative**.
- Many MacPherson strut systems do not provide an adjustment for caster.
- Not a tire wearing angle; caster is a directional control and stability angle.
- Measured in degrees



Caster

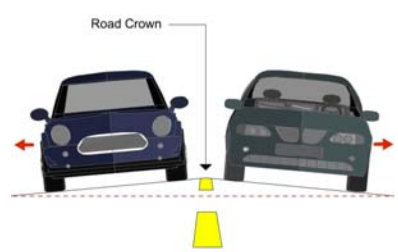
- Most vehicles call for a small amount of positive caster. Positive caster places the **lead point**, or the point of load, in front of the tire contact point (true vertical). This makes the wheels tend to continue in a straight ahead position on the road, and aids in returning to the straight ahead position after a turn. Consider a front bicycle fork. The fork has a lot of positive caster, which helps keep it going straight. You can even take your hands off the handlebars and say, "Look, Ma! No hands!"



Positive caster on a front bicycle fork

- Too much positive caster can cause excessive steering effort, or a feeling of **understeer**. Too much positive caster can also increase road shock. (**Understeer** is when a vehicle responds poorly to turning the steering wheel and "wants" to keep moving in the same direction. With severe understeer, the front tires slide forward instead of rolling into the turn. **Oversteer** is the opposite condition. The front wheels "dive" into the turn, and severe oversteer can cause the rear wheels to slide laterally, possibly resulting in a spinout.)
- Negative caster or insufficient positive caster eases steering, but may cause wander and require constant steering wheel corrections by the driver on the highway.
- Vehicles with manual steering are generally set with less caster (more towards the negative) than are vehicles with power steering. Caster that is far out-of-specs can cause a wheel shimmy.
- Too much difference in the caster settings between the wheels (**spread**) will cause the vehicle to drift or pull to one side. Spread may also be referred to as "**cross caster**." The vehicle will pull towards the side with the ***least*** amount of positive caster.

- **Road Crown**
  Most roads are built with a crown in the center to promote water drainage. The crown is a slope downwards from the center. The slope tends to lead a vehicle towards the edge of the road. Caster and/or camber can be used to offset this effect. Slightly less positive caster or more positive camber on the left wheel (or more positive caster and less positive camber on the right) compensates for road crown. Note that these settings may cause a normal drift to the left when cruising in the left lane on a four-lane highway.

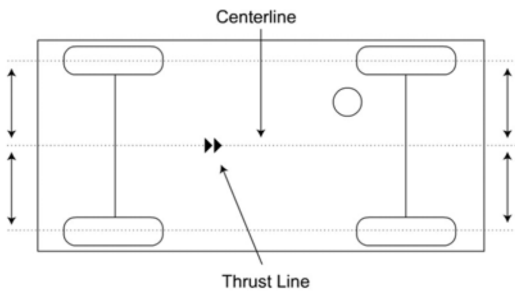


Road Crown

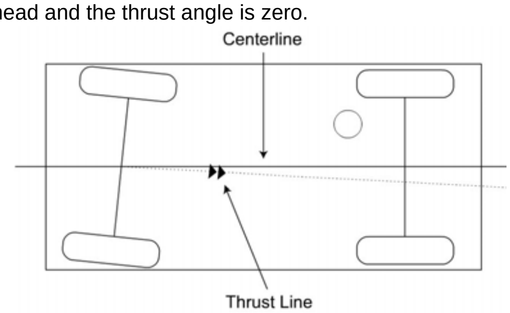
Tracking (Thrust Angle)

Tracking is the relationship of the rear wheels to the front wheels. In a properly aligned vehicle, the rear wheels follow directly behind the front wheels. On rear-wheel drive vehicles, the rear wheels will be parallel with an imaginary line drawn through the **centerline** of the vehicle. On front-wheel drive vehicles, the rear wheels will be parallel or nearly parallel with the centerline, with equal individual toe. When the front wheels are also placed nearly parallel to the centerline (splitting the total toe equally), the steering wheel points straight ahead.

- The **thrust line** is a line that is projected forward, perpendicular to the axle line of the rear wheels (whether or not there is actually a straight axle). On front-wheel-drive vehicles, the thrust line is an average determined by measuring the individual rear toe. The difference between the centerline and the thrust line is the **thrust angle**. On a properly aligned vehicle, the centerline and the thrust line are both straight ahead and the thrust angle is zero.



Properly aligned: center line and thrust line are the same

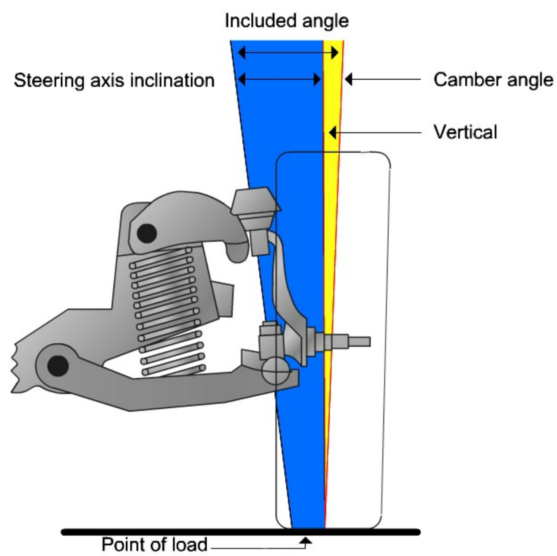


Improper tracking: thrust line deviates from the center line

- When the tracking is off, the rear of the vehicle shifts sideways when driving straight down the road. Called **dog tracking**, this condition adversely affects handling and tire wear, and causes an off-center steering wheel. The steering wheel spokes will appear crooked, as the driver steers to compensate for the thrust angle.
- The thrust angle on most rear-wheel-drive vehicles is not adjustable and incorrect thrust is less common. Also called **axle skew**, it is usually caused by collision damage, broken leaf spring tie bolts, or other problems that allow the rear axle to shift. On most front-wheel-drive vehicles, the thrust angle is set by adjusting the rear toe.

Steering Axis Inclination (SAI)

- The angle, away from true vertical, formed by a line drawn through the ball joints (or the lower ball joint and the upper strut mount on MacPherson strut systems)
- The SAI is always an inward tilt.
- SAI is neither a tire wearing angle nor adjustable. It is designed into the suspension system.
- The combination of the SAI and camber is called the **included angle**.
- Incorrect SAI can prevent proper camber adjustment, and can be caused by bent components. Checking these angle can be useful in determining if collision damage has occurred.
- The function of SAI is similar to caster, only more so. SAI helps return the steering to straight ahead after a turn and keeps the vehicle going straight with little steering wheel correction needed. As the wheel is turned, the geometry created by the SAI causes the outer spindle to attempt to swing in a downward arc. This forces the weight of the vehicle to be lifted. The weight of the vehicle tends to return the wheels to the straight ahead position and keep them there.

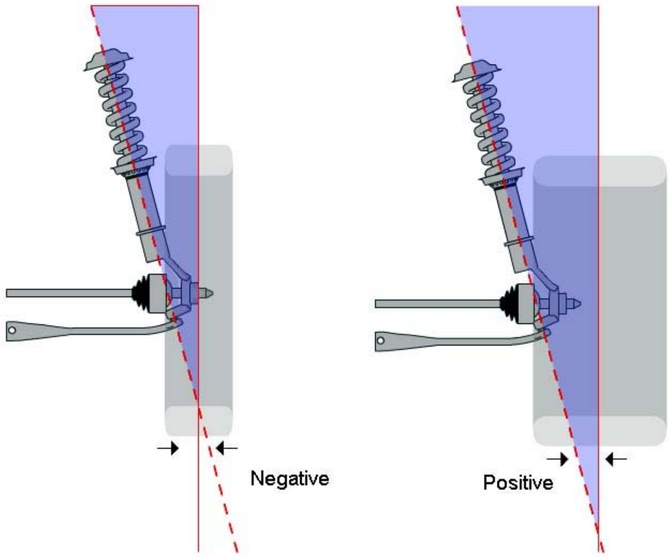


The SAI helps the vehicle steer straight ahead.

Scrub Radius

- The distance between where the SAI line meets the road and the centerline of the tire. It is the turning pivot area for the tire's contact patch on the road. If the scrub area is inboard of the centerline, it is said to be a positive scrub radius, and if it is outside of the centerline, it is said to be a negative scrub radius.
- Steering and suspension systems can benefit from either a positive or a negative scrub radius, depending on the design. A few have been designed with a scrub radius of zero, but stability and handling are generally better and more consistent when a scrub radius is somewhat positive or negative, and better tire wear also results.
- SLA systems normally have a positive scrub radius, and MacPherson strut systems are usually designed with a negative scrub radius.
- Too much positive scrub radius increases steering effort and too much positive or negative scrub radius can adversely affect vehicle handling, stability and braking.
- The proper amount of scrub radius is designed into the suspension, wheels, and tires by the manufacturer.

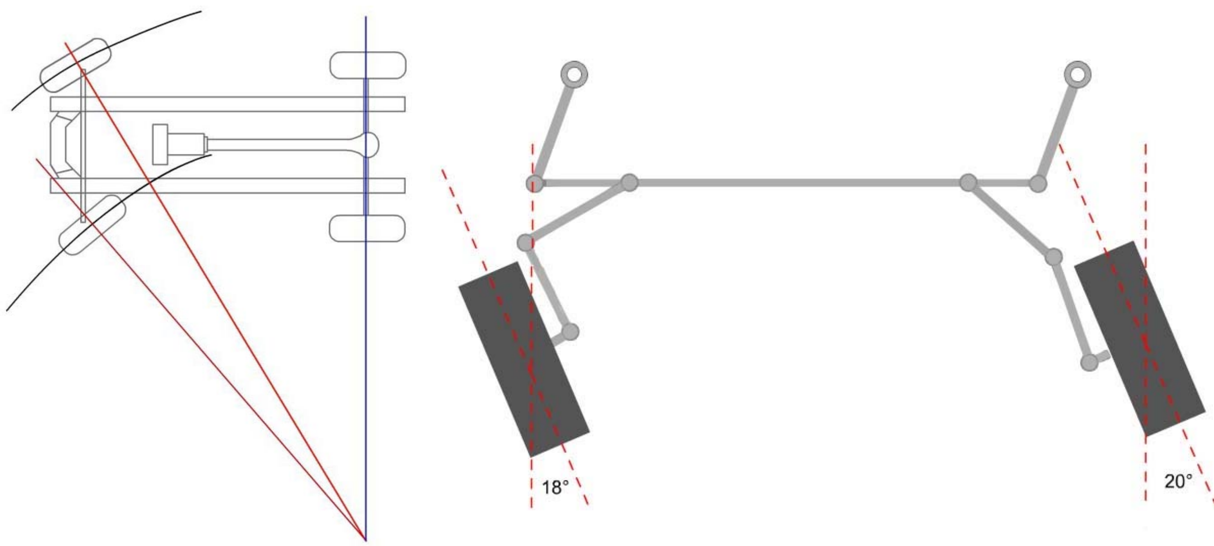
- Tire and wheel size affects the scrub radius. Installing lower profile tires and wide, offset wheels will increase the scrub radius. Tires and wheels that are too tall decrease the scrub radius. **Alignment cannot correct or compensate for a change in scrub radius.** Modifications to the suspension must be made.



Original design with negative scrub radius (left), offset wheel with positive scrub radius (right)

Turning Radius (Toe-out on Turns)
When turning a corner, the outer wheel must travel a greater distance than the inner wheel, so it follows a wider arc. The inner wheel must turn more sharply, and so a toed out condition is necessary to eliminate tire scrubbing and squealing. Toe-out on turns provides better traction and reduces tire wear when cornering.

The turning radius, or toe-out on turns, is the amount the front wheels toe out when turning. Also called the **Ackerman angle**, the different turning radius angles are built into the inward angle of the steering knuckle arms and are not adjustable.



The outer wheel travels a wider arc to cover the greater distance (left). The inner wheel must turn more sharply (right).

Wheel Alignment Service

Aside from vehicle handling and steering concerns, long tire life with even wear is one of the primary goals and reasons for routinely checking and correcting wheel alignment.

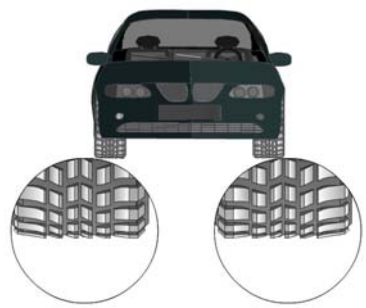
Reading Tire Wear

Examining the tires closely will provide an indication of the vehicle's wheel alignment condition and prepare you for what problems to expect. If the tires provided long life and are worn evenly across the tread, chances are good that the alignment requires little or no correction. On the other hand, misalignment or other problems can produce characteristic wear patterns on the tires, and recognizing them will help you identify the problem. Examining the tires in this manner is called **reading the tires**.

- **Wear on the Inside or the Outside** – More wear on the inside or outside of the tread can be an indication of incorrect camber or toe, or both. Negative camber will wear the inside tread on wheels that are out-of-spec. Toe-out will also wear the inside tread, but the wear will be similar on ***both*** front wheels. Excessive positive camber or toe-in will show up as wear on the outer tread in the same manner. In general, camber wear tends to be located more on the edge of the tread, or the shoulder of the tire, but this is not always the case; other combinations or conditions can appear similar.

Camber Wear

- **Feathered Edges** – Type of wear pattern caused by excessive front toe-in or toe-out. With feathered edge wear, one side of each tread rib is raised and "sharp," while the other side of the rib is lower and rounded. You can feel these edges by running your hand across the tread from one side to the other. Your hand will catch on the raised edges, but slide smoothly going the other way. If your hand catches while moving out and slides smoothly as you move it in, toe-in is indicated. Check also for accompanying uneven inside or outside wear on both front tires. A feathered wear pattern usually indicates toe that is far beyond specs.



These feathered edges indicate excessive toe-in. This condition will wear the outer tread on both wheels.

- **Wear on Both Edges** – Wear to both the inner and the outer edges of a tire can indicate underinflation. ***Underinflation is the most common cause of rapid tire wear***. An underinflated tire flexes too much at the sidewalls and has poor road contact at the center of the tread. This can also cause overheating, tread cracking, and sudden tire failure. Wear on both edges can also be caused by hard cornering.

Underinflation or hard cornering

- **Wear to the Center Ribs** – Can indicate overinflation. This pattern became less common when radial tires largely replaced bias ply tires, but with today's wider wheels and lower profile tires, it is making a comeback.

Overinflation

- **Diagonal Wear Pattern** – Occasionally, a diagonal wear pattern appears on the rear tires of front-wheel-drive vehicles. This is an indication that the toe is out-of-specs. Because of all of the turning the front wheels do, front toe wear is distributed evenly around the circumference of the tire. Since the rear wheels carry less weight and do not turn, excessive toe makes the tire tend to drag and then roll, setting up this pattern, which causes noise and vibration.

Rear Toe Wear

- **Erratic Wear –** Can have several causes, though seldom caused by alignment settings. Broken or non-functioning shocks can cause a scalloped wear pattern on tires. Failed suspension parts can cause this type of wear also. Other irregularities such as bald spots can be caused by an unbalanced wheel, or a wheel or tire defect.

Scalloped or cupped

Tire defect (belt separation)

Relationship of Angles and Adjustment Sequence
The alignment angles are interrelated, and changes to one angle may cause change to another. For this reason, a specific sequence is followed when setting the alignment, so that once an angle has been properly set, it does not usually have to be set a second time. However, if the changes are large, resetting a previous angle may be required, so always check the other angles after making changes to one.

The sequence may vary among some equipment or vehicle manufacturers, but the standard sequence is this:

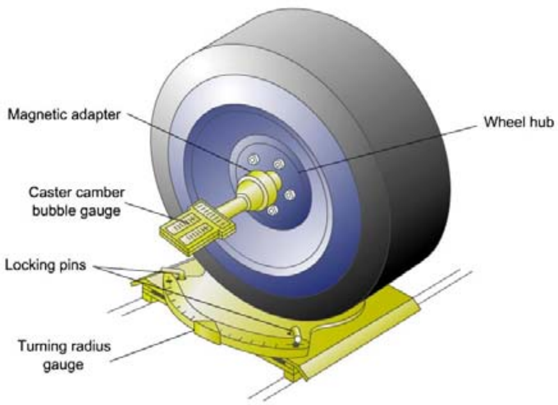
1. Rear camber
2. Rear toe
3. Front caster
4. Front camber
5. Front toe

Note: On many designs, caster and front camber must be adjusted together.

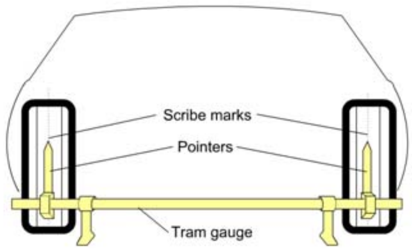
In most cases, the SAI, included angle, and turning radius are checked if the other angles cannot be brought into specs, bent parts are suspected, or when troubleshooting a specific problem.

Wheel Alignment Equipment
The design and complexity of wheel alignment equipment varies greatly, ranging from simple gauges to complex computerized machines.

- A level surface must be used in any case.
- The simplest equipment consists of small mechanical **bubble gauges** that are attached to the wheels or hubs to measure caster and camber. A **turn plate**, or **radius gauge**, is placed under each wheel to be aligned. Resting on ball bearings, the turn plate is marked in degrees and used in measuring the caster and turning radius angles. The turn plates allow the suspension to remain in a relaxed position with easy turning of the wheels.
- A **tram gauge** can be used for toe measurements. The tram gauge is a shaft with two pointers. The pointers slide on a gauge marked in inches or millimeters. The distance between the fronts of the tires is measured and compared to the distance between the rears of the tires.
- A satisfactory alignment can be performed with simple equipment; however, modern, sophisticated equipment is more accurate, easier to use, and much faster. It will make some measurements automatically, and can measure angles such as SAI and the IA (included angle) that some simple equipment cannot.



Bubble gauge and turn plate

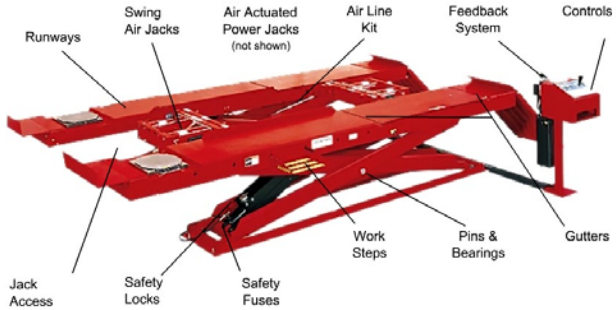


Tram Gauge

A professional alignment system consists of:

- A drive-on rack with turn plates for the front wheels and slip plates for the rear wheels
- Alignment **heads** (or targets in some cases) that mount to the wheels
- Some type of console with a display. The console usually consists of a dedicated computer, a monitor, a keyboard, and a printer. The computer software can contain a great deal of information, such as instructions for using the equipment, vehicle specs, adjustment methods, diagrams, photos, and other helpful reference materials. The software is often stored on CD-ROMs. These materials can be displayed on the monitor or printed. The monitor also displays screen prompts during the alignment process, and displays current "live" measured values.
- For measuring the angles, modern equipment may use infrared light beams, laser beams, video cameras, attitude and proximity sensors, or other means.

This computerized alignment system uses four digital video cameras. Two are mounted on each side of the vertical beam. (Image courtesy of Hunter Engineering)



Alignment racks are designed to provide a level surface with convenient lifting capabilities. A popular type of rack is shown here. (Courtesy of Hunter Engineering)

Alignment Heads
Alignment sensors, or heads, do the measuring on most modern equipment.

- Mounted to the wheels with adapter clamps
- After the heads are mounted and the safety cable is connected to the wheel's valve stem, each head must be set to compensate for **lateral runout**. This step compensates for differences in wheels and bracket placements. The simple procedure may be a mechanical adjustment or a mathematical calculation performed by the computer. Follow equipment instructions for the procedure. Some heads are magnetic and mount to the wheel hub. The wheel hub is a machined surface and lateral runout is assumed to be negligible.

Alignment sensor and clamp adapter (Courtesy of Hunter Engineering)

Three Types of Alignments: Centerline, Thrust, and Four-wheel Alignment

Centerline Alignment

- Two-wheel or "front end" alignment
- Heads are mounted only on the front wheels
- References the vehicle centerline for straightening the front wheels and centering the steering wheel when adjusting front toe. Measurements to the frame or body are used to determine the centerline.
- Can be performed on rear-wheel-drive vehicles, and was standard for many years
- If the thrust angle is off, the result can be a crooked steering wheel after the alignment.

Thrust Alignment

- Similar to a four-wheel alignment, because heads are mounted on all four wheels
- Instead of referencing the vehicle centerline, this type of alignment references the rear wheels to the front wheels and measures the thrust angle. This information is used for straightening the front wheels and centering the steering wheel.
- The only difference between a thrust alignment and a four-wheel alignment is that a thrust alignment is performed on vehicles that have no method of correcting the rear wheels.
- Referencing the rear wheels takes the guesswork out of straightening the front wheels and centering the steering wheel.

Four-Wheel Alignment

- Performed on vehicles with adjustments for all four wheels
- All wheels are measured and corrected, resulting in a thrust angle at or near zero and a centered steering wheel.
- Two-wheel alignment equipment can be used to perform a four-wheel alignment by backing the vehicle onto the rack first and referencing and setting the rear wheels to the vehicle centerline. The vehicle is then turned around and the front wheels are referenced and corrected to the vehicle centerline.

Alignment Preparations and Setup (Four-Wheel and Thrust Alignments)

Due to the wide variety of alignment equipment available and the differences in their operation, you must refer to the operating instructions for your equipment. However, there are some general similarities in the setup and usage of most wheel alignment equipment.

- Before driving a vehicle onto the alignment rack, be sure the locking pins are in place in the turn plates and slip plates. After you position the vehicle on the rack, set the brake and block the rear wheels. Turn the ignition key to the "unlocked" position.
- Perform a complete steering and suspension inspection as outlined in the Suspension Service section. Raise the vehicle and then jack the front suspension for inspection, then jack and inspect the rear.
- After the vehicle passes inspection, extend the leveling legs on the rack and lower the vehicle onto them (if equipped), or lower the rack into position for mounting the heads and engage the leveling locks.
- Start the alignment program on the console. Most computerized machines will prompt you as to the type of alignment to be performed, vehicle make, model, year, (or Vehicle Identification Number) and sometimes other vehicle information. The computer will retrieve the vehicle data, offer various display options, and prompt you to mount and compensate the sensors (heads).
- Place the transmission in neutral, release the parking brake, mount the heads, and then compensate them. If rotating the wheel is part of the compensation process, be sure the heads that are mounted on drive wheels are free to rotate (not locked to the wheel brackets), because rotating one drive wheel can cause the other wheel to rotate as well. After compensating the heads, place the transmission in park or gear and reset the parking brake.
- Remove the locking pins from the turn plates and slip plates, and then lower the rear wheels. Next, lower the front wheels onto their plates. With the rear wheels blocked, place the transmission in neutral and release the parking brake. Jounce the rear and front suspensions several times to settle them. Place the transmission in park and reset the parking brake. **Note: You may have to use wheel blocks on the front or rear and set and release the parking brake several times during the course of an alignment. Be sure the vehicle is never free to roll while on the alignment rack.**
- Level the heads. You are now ready to begin taking measurements.

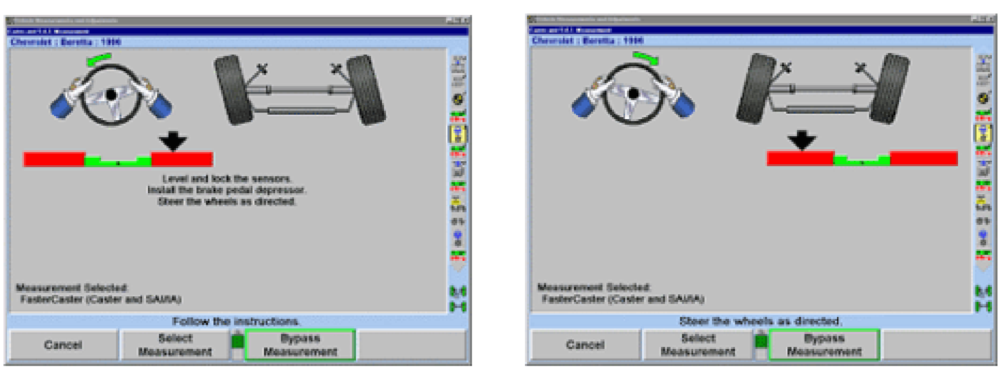
Measuring Wheel Alignment

Despite differences in the equipment used to check wheel alignment, the basic principles and geometry of wheel alignment remain the same. With your equipment's operating instructions and an understanding of how alignment measurements are made, you will be able to perform a precision alignment regardless of the type of equipment being used.

Measuring Caster

To measure caster, each front wheel must be turned through an arc to take the readings. This is known as a "**caster sweep**." The caster angle is actually determined by measuring the difference in camber from one position to the other. A brake pedal depressor tool is used to prevent the wheels from rotating.

- To measure caster with bubble gauges, turn one of the wheels in or out 20 degrees on the radius gauge. Turn the adjustment knob on the caster gauge to center the bubble on zero. Then, turn the wheel the other direction through a 40-degree arc, stopping at the other 20-degree mark. The degree mark next to the bubble on the caster scale indicates the caster for that wheel. Repeat the process for the other wheel.
- To measure caster with computerized equipment, the sweep for both wheels is done at the same time, often by turning the steering wheel. The monitor prompts the user to turn in one direction and then the other. The display shows a graphic of the wheel positions so the user can see where to stop and hold the wheels while the computer takes the reading. The screen then prompts the user to return the wheels to the straight ahead position, and then the measurements for caster (as well as the other angles) will be displayed. The caster measurement is usually not a "live" reading (continuous in real time); if the caster or camber is adjusted, another caster sweep will have to be made.



Caster Sweep (Courtesy of Hunter Engineering)

Measuring Camber

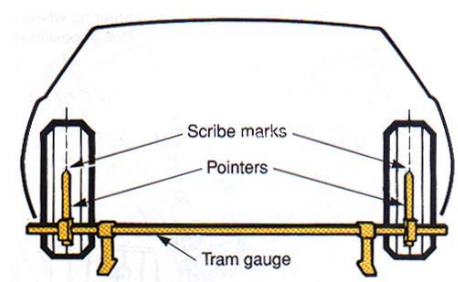
- Obtaining the camber measurement is simple. The camber reading is taken with the wheels pointing straight ahead.
- With a bubble gauge, read the camber value where the bubble appears on the camber scale at each wheel.
- With computerized equipment, the camber value is displayed live on the screen.

Camber and other angles are displayed on the screen. (Courtesy of Hunter Engineering)

Measuring Toe

- To measure toe with a tram gauge, the tires must first be marked for reference (after the vehicle passes inspection is a good time). With the wheels off the ground, apply a chalk line around the center rib of each tire. Then, while spinning each tire, use a scribing tool to mark a fine line within the chalk line. This will give you a precise reference point for measuring. With the wheels on the turn plates, use the tram gauge to measure the distance between the scribe marks at the fronts of the tires and at the rears of the tires at spindle height. The difference in distance is twice the actual toe. **Note:** When adjusting rear toe using a tram gauge, extra steps must be taken to ensure that the vehicle centerline (thrust) is correct.

- Electronic equipment can use a variety of methods to measure toe. Optical devices, such as lasers or infrared projectors are common. The heads project towards each other: rear to front, front to rear, and front to front. With computerized equipment, the heads communicate to the computer the relative positions of each wheel. The computer takes the information from the heads and calculates the individual toe for each wheel, total toe per axle, thrust angle, and other parameters. The measurements are displayed on the monitor.

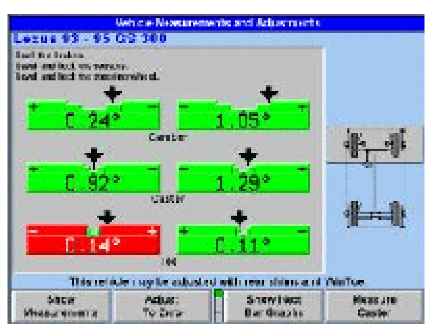


Measuring toe with a tram gauge

The component on the left of this sensor projects a toe signal across to the sensor on the opposite wheel. It receives a similar signal in return, and the left rear sensor projects a signal forward to this sensor. (Courtesy of Hunter Engineering)

Monitor Display

- The format for the monitor display will vary among manufacturers, and some offer a variety of graphic displays that can be selected according to user preferences.
- Typically, the values displayed for the angles are color coded, with those that are within specs displayed in green and those that are outside specs in red.
- The graphic may show the amount and direction of adjustment required, and the live readings will indicate when the adjustment is within specs and at the preferred setting.

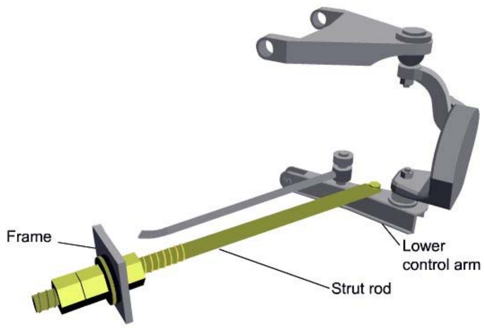


Color-coded display. The reading on the lower left is out-of-spec. (Courtesy of Hunter Engineering)

Adjustment Methods
Many methods of adjusting alignment angles are used. We will discuss some of the most popular ones here. Other methods may be used. Always consult the service information if you are unsure of the method of adjustment.

Adjusting Caster

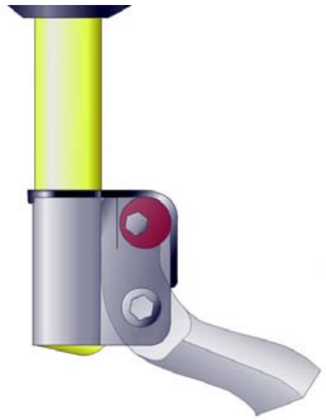
- One popular method for adjusting caster on MacPherson strut systems and on SLA suspensions with the spring on the upper control arm is by lengthening or shortening the strut rod. This moves the lower control arm fore or aft. Caster is increased by shortening the rod and decreased by lengthening it. A jam nut is tightened against the retaining nut to secure the setting.
- On many vehicles, caster and front camber must be adjusted **together**.



Caster adjusted with strut rod

Adjusting Camber

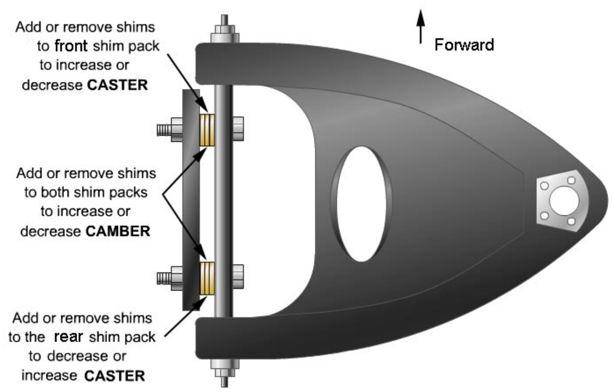
- Some MacPherson strut systems use an **eccentric cam** at the lower attaching bolts on the strut to adjust camber. On each strut, one strut mounting hole is slotted. The eccentric cam lobe acts against bosses on the strut housing, moving the spindle assembly in or out when the bolt head is turned.
- Other vehicles use a similar method to set camber, but do not have the eccentric cam. On these models, the wheels must be jacked to unload the suspension, and the wheel held in the proper position while the lower strut mounts are tightened.
- On other MacPherson strut designs, camber can be adjusted by loosening the upper strut mounting nuts and sliding the strut in or out. This type may or may not also include a caster adjustment at this location.



Camber adjusted with eccentric cam

Adjusting Caster and Camber Together

- Many SLA suspensions use **shims** between the upper control arm shaft and the frame. Others use eccentrics to position the front and rear of the control arm shaft. Slots in the frame have also been used for adjusting caster and camber.
- On vehicles that use shims, the shims are added or removed to affect changes in caster and camber.
- If the control arm shaft is on the inboard side of the frame, removing shims will increase camber, and if the shaft is on the outboard side of the frame (as with many light trucks) removing shims will decrease camber.
- With shims, changes can be made to either the caster or camber with little affect on the other angle. To change camber, shims are added or removed equally from the front and rear shim packs. To change caster, shims are moved from the front shim pack to the rear or from the rear to the front. Shims of various thicknesses can be used to make fine adjustments.

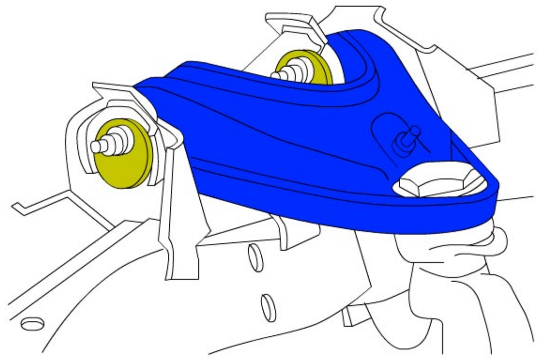


Caster and camber adjusted with shims

Shim

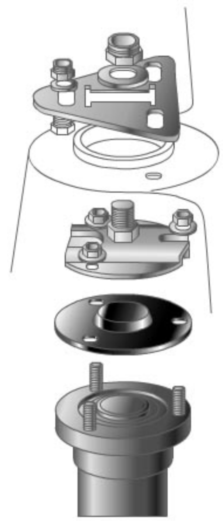
- Suppose you are aligning a light truck, and you want to increase both the caster and the camber on the left front wheel by 0.5 degrees. Adding a 1/16 inch shim to the front shim pack might give you the desired changes. Suppose on the other wheel the camber is good, but you want to reduce the caster by 0.5 degrees. Moving a 1/32 inch shim from the front to the rear might give you the desired change. Actual changes will vary by make and model.

- A similar strategy is used with vehicles that have eccentrics at the upper control arms, but the movement is obtained by rotating the cam.
- With practice, you can loosen the nuts enough to permit the desired movement of the cams without allowing them to move too far, or in the wrong direction under the weight of the vehicle.
- In some cases, you may have to unload the suspension to make the desired adjustments.



Upper Control Arm Eccentrics

- Some vehicles use an eccentric or an offset bushing at the ball joint to change caster, camber, or both.
- Some MacPherson strut systems permit changes to caster and camber at the upper strut mount. In addition to the method of loosening the upper mounting nuts and sliding the strut inward, outward, forward or back, on some strut systems the upper nuts are removed to drop the strut down. The upper mount is then rotated into another position and reinstalled. This type is an "either/or" adjustment with a limited range of settings.

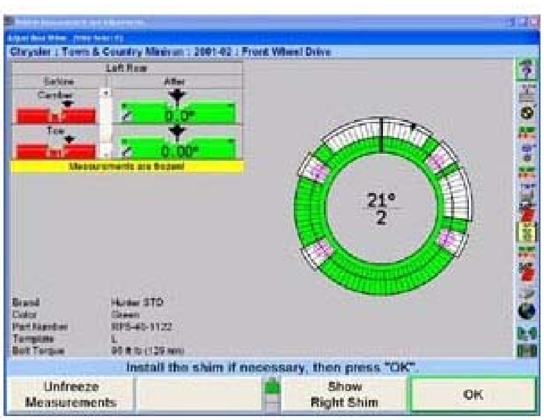


Upper strut mount with slots for adjusting caster and camber

Adjusting Rear Toe

There are several methods used to adjust rear toe on front-wheel-drive vehicles, including tie rods, eccentrics, and shims.

- On vehicles that use shims, one shim placed between the back of the spindle and the axle is used to correct both camber and toe.
- Most vehicle manufacturers whose products may require rear shims specify the use of full contact shims, rather than "half" shims.
- Calculating which shim thickness and the correct orientation for the shim is simplified by using the computer alignment software, some of which will display templates and directions.



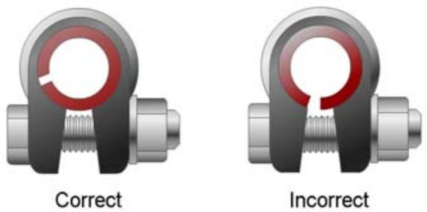
Selecting a rear shim

Installing a rear shim

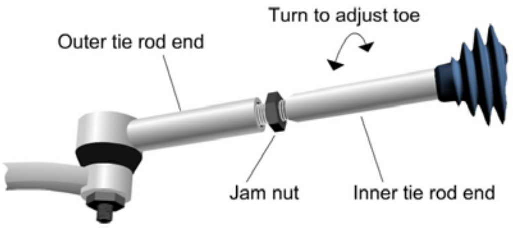
Adjusting Front Toe
Front toe is adjusted by lengthening or shortening the tie rod assemblies.

- A steering wheel holder is used to lock the steering wheel in place during adjustments.
- With conventional linkage systems, it is possible to tighten the tie rod sleeves in such a way as to bind the tie rod ends.
- The tie rod assembly is designed to pivot to allow for movement of the suspension. Before tightening a tie rod sleeve, ensure that both ball studs are either centered or pointing in the same direction in their sockets. When properly aligned, the assembly can rock forward and backward.
- On turnbuckle type sleeves, do not allow the gap in the sleeve clamp to align with the gap in the sleeve.
- The tie rod adjustment on most rack-and-pinion systems is secured with a jam nut.

Tightening the tie rod assembly in this position will bind the tie rod ends.



Tie Rod Sleeve Gap



Rack-and-pinion Tie Rod Assembly

- Special tools are available for turning rusty or stubborn tie rod sleeves. The tool grips the edge of the sleeve's gap without squeezing the sleeve.
- Rack-and-pinion tie rods are solid and sometimes machined with flats for easier turning. A pipe wrench can be used to turn stubborn round tie rods.

Tie Rod Adjusting Tool

Centering the Steering Wheel
When a vehicle is properly aligned, the steering wheel is centered while driving straight ahead. If the steering wheel is not centered, it can be corrected by adjusting the front toe.

- Use the alignment equipment to ensure that the thrust angle is correct and the front toe is evenly split, and then look at the steering wheel. It should point straight ahead. If it does not, straighten it and lock it in place with the steering wheel holder.
- Now, the equipment will indicate a great deal of toe-in on one front wheel and toe-out on the other. Adjust the tie rods for each side to bring them to the preferred setting for each wheel, and the steering wheel should now be centered when driving straight.
- On vehicles with power steering, start the engine and move the steering wheel back and forth a few times to center the steering before installing the steering wheel holder. Some manufacturers specify that the engine should be running while adjusting the toe.

- If a centerline alignment shows a centered steering wheel on the rack, but produces a crooked steering wheel when driving straight, the thrust angle is off. To compensate for this and center the steering wheel, note the steering wheel position when driving straight and then set up the alignment equipment again. Turn the steering wheel an equal amount off center in the opposite direction, and install the steering wheel holder. The equipment will show a great deal of toe-in on one front wheel and toe-out on the other. Adjust the tie rods for each side to bring them to the preferred setting for each wheel, and the steering wheel should now be centered when driving straight.

Alignment Tips and Strategies:

If the Vehicle Pulls to One Side
Caster or camber that is out-of-spec, or too much spread in these angles can cause a pull. Several other conditions can also cause a pull.

- **Tires** – One of the most common causes of a pull to one side is actually the tires. Radial tires can set up a wear pattern in which the belts shift, squirm, or separate, causing a pull. Rotating the front tires from one side to the other and test driving the car can confirm if the tires are the cause. If the pull subsides or the vehicle pulls the other way, the tires are causing the pull. Low air pressure in one front tire, or tires of different sizes can also cause a pull.
- **Brakes** – If the pull worsens or occurs only during braking, the cause may be a sticking brake caliper or a restricted line.
- **Power steering** – Occasionally, a sticking or misadjusted spool valve or a restricted line can cause a pull. A pressure test may be necessary to confirm this.
- **Torque steer** – This condition can occur on front wheel drive vehicles with transverse engines and CV shafts of different lengths. It is characterized by a pull to one side when accelerating, and sometimes a pull in the other direction when decelerating. This condition can also be caused by front drive axles being at different heights, due to a loose or damaged sub-frame or other problem.
- **Bump steer** – If tie rods are at unequal heights, a vehicle may momentarily pull to one side when going over bumps. This may be caused by a bad or improperly installed idler arm.
- Some drivers may confuse an off-center steering wheel with a pull. Confirm the complaint with a test drive.

Vibration

- Chassis vibrations, especially at road speeds, are usually caused by out-of-balance wheel assemblies, or tire defects such as out-of-round.
- High frequency vibrations of this type can also be caused by driveline faults, such as a bent or out-of-balance drive shaft, or CV or universal joints that are worn or damaged.
- Brake rotors and drums that have thrown a balance weight can also cause a vibration.
- One thing that **does not** normally cause this type of vibration is wheel alignment settings.
- In addition to the causes of shimmy previously discussed (such as bad or missing control arm bushings), a low-speed shimmy or “wiggle” can be caused by a tire with broken or separated belts.

Preferred Specs
Vehicle manufacturers provide a range of settings that are acceptable for each of the wheel alignment angles on their products. The preferred setting is in the middle of this range, or it may be specified, such as, “Front toe: 0.0 inch plus/minus 0.06 (1/16th).” We have noted that the preferred setting is a “best average” that assumes various operating conditions. The preferred specification may not always be the best setting on a particular vehicle. For example, a rear-wheel-drive vehicle that is seldom driven on the highway may get better tire wear with the front toe set at less than the preferred spec. An especially heavy driver may need less camber on the left front than called for. It’s up to the alignment technician to read the tires and consider any other factors to determine the operating conditions of the vehicle and set the alignment angles accordingly.

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