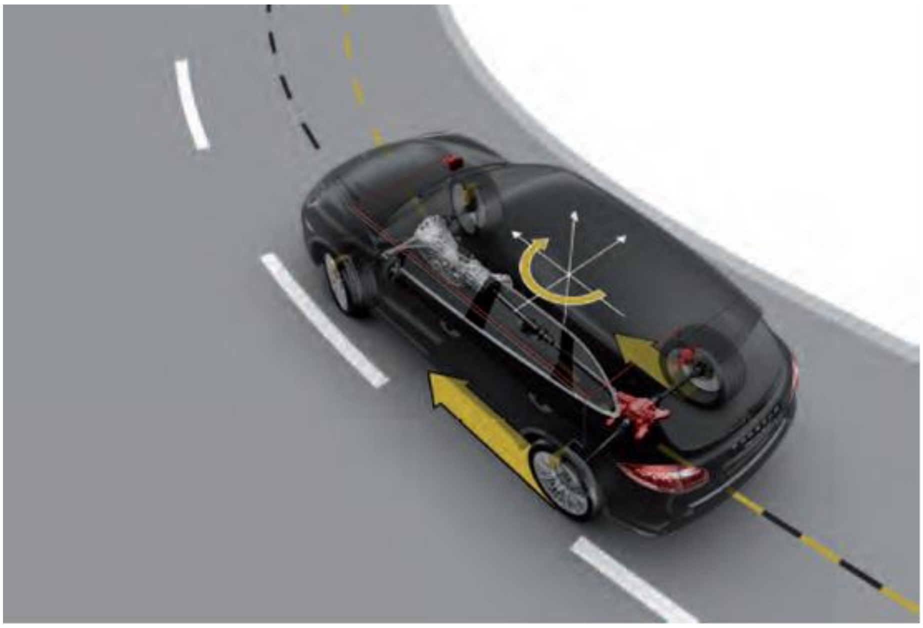
Steering systems

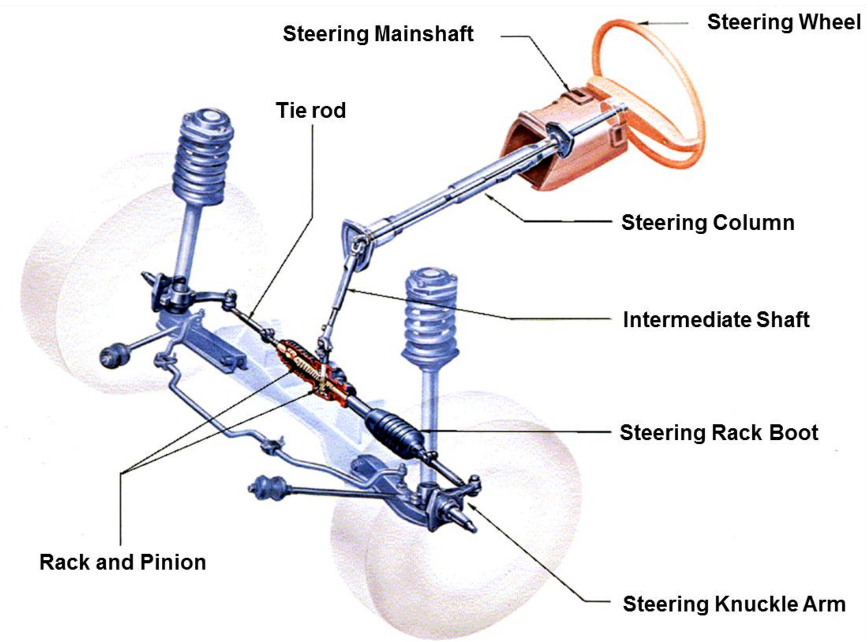
The steering system enables the driver to control the direction in which the vehicle is travelling by changing the angle of the front wheels. This is achieved regardless of vehicle speed.

The primary function of the steering system is to enable the driver to control the direction in which the vehicle is travelling, but it also needs to be able to reduce the effort needed by the driver to turn the wheels. This is achieved through the steering gears and on modern systems through the use of power assisted systems. Wheel alignment aids smooth recovery of the steering wheel, which also reduces the effort needed by the driver to control the vehicle.

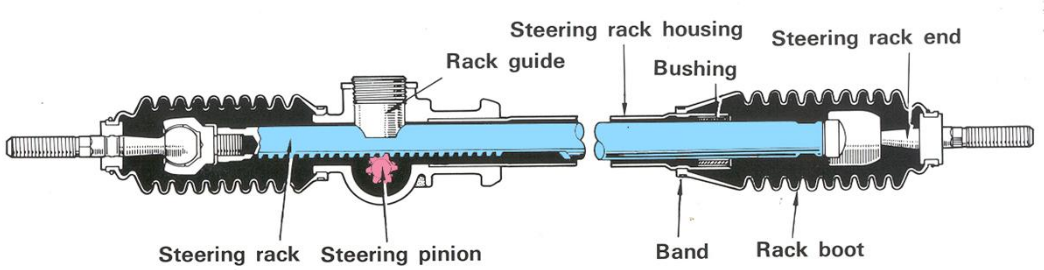
The driver is able to change the angle of the front wheel through the use of various components that are all connected together. The driver's physical contact is with the steering wheel that in turn is connected to the steering column. The steering column is then connected to the steering gears, which are then connected to the steering linkage; the steering linkage is connected to the front road wheels. The configuration of the steering gears and linkages are dependant on vehicle design and within this phase we will look at three different types. The most common types used are the Rack-and-Pinion system and the Recirculating-Ball system, although on older vehicles the Worm-and-Roller system was used.

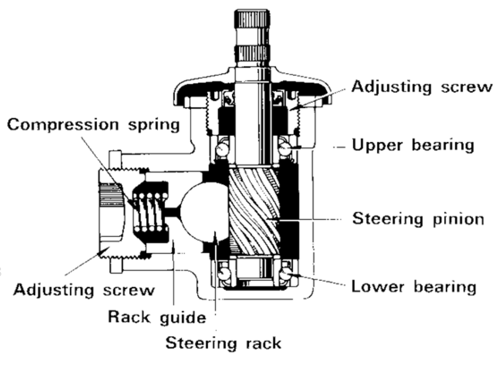


Rack-and-pinion steering system



The rack-and-pinion type steering system is commonly used on modern motor vehicles, especially vehicles fitted with independent suspension. The steering column connects to the rack pinion through a universal joint and this allows for angular changes between the column and rack pinion. The rack pinion is constantly meshed with the steering rack, and as the driver turns the steering wheel this rotational force is transmitted to the steering rack. This rotational force enables the driver to turn the steering rack to either the right or left, and as the steering rack is connected to the wheels through the steering rack ends directional change is achieved.

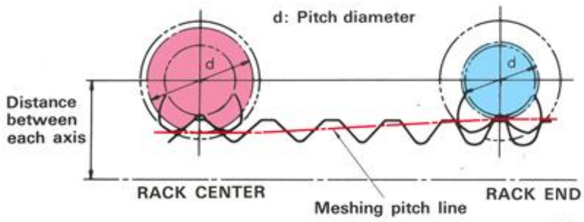


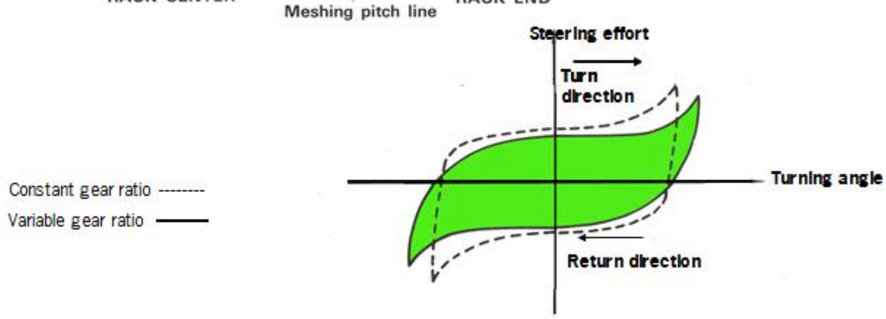


The rack-and-pinion steering system is widely used as it has the following advantages:

- the need for relay rods is removed, this makes the rack light weight and compact
- there is no maintenance needed just visual checks of items like the rack boots, for cracks or wear
- the rack pinion is directly meshed to the rack itself, and this improves steering response
- the amount of resistance generated by this system is very small, which reduces the amount of effort needed by the driver.

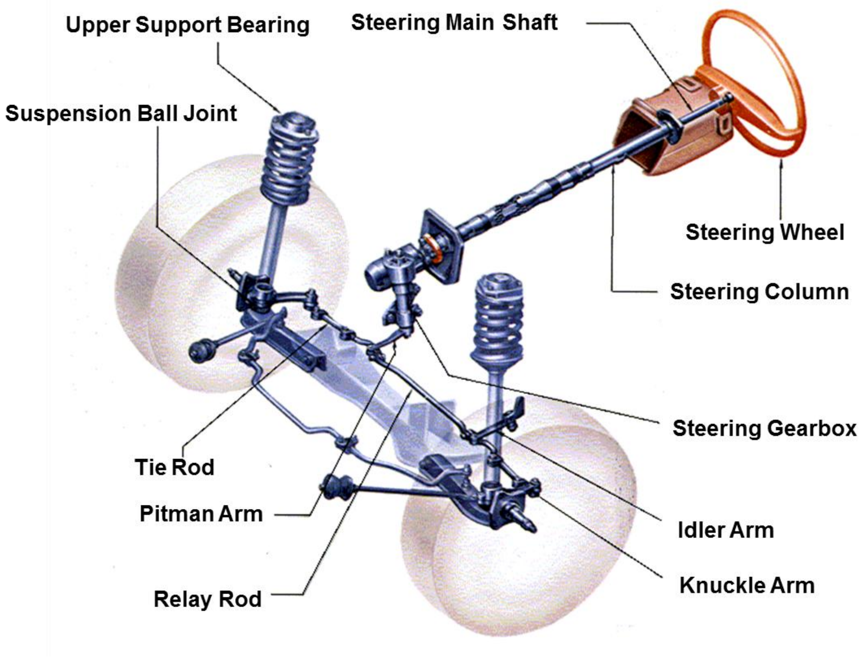
The steering rack needs to achieve more than just allowing the vehicle to change direction. It also needs to assist the drive to reduce the amount of steering effort needed. This is achieved by a gear ratio reduction between the pinion gear and the rack; this reduction is normally between 18 and 20:1. The gear ratio is a compromise between assisting the driver to turn the steering wheel and the amount he needs to turn the steering wheel to get the desired result. If a higher ratio is used then the assistance will be greater, but the driver will have to turn the steering wheel more times. A lower ratio will have the opposite effect causing the steering to be harder but reducing the amount of distance the steering wheel will need to travel.



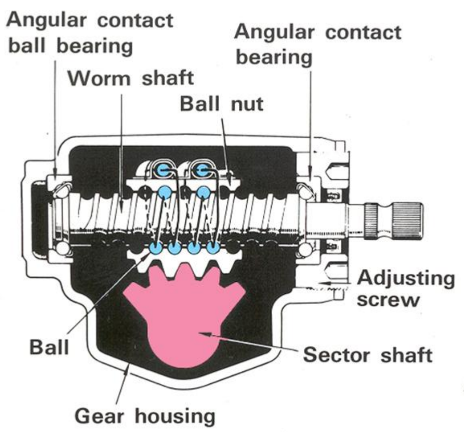


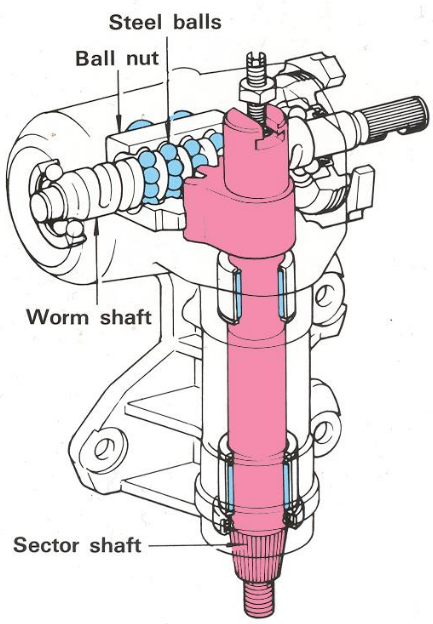
To assist this compromise variable ratio steering racks are now used on non-power assisted steering systems. The further the wheels are turned away from the straight ahead position the harder the steering becomes, so to compensate for this higher ratio are used towards each end of the steering rack. To achieve this higher ratio the pitch between the teeth at each end of rack is decreased. This results in more steering wheel movement with less turning of the wheels, thus reducing the amount of effort needed by the driver.

Recirculating-Ball steering system



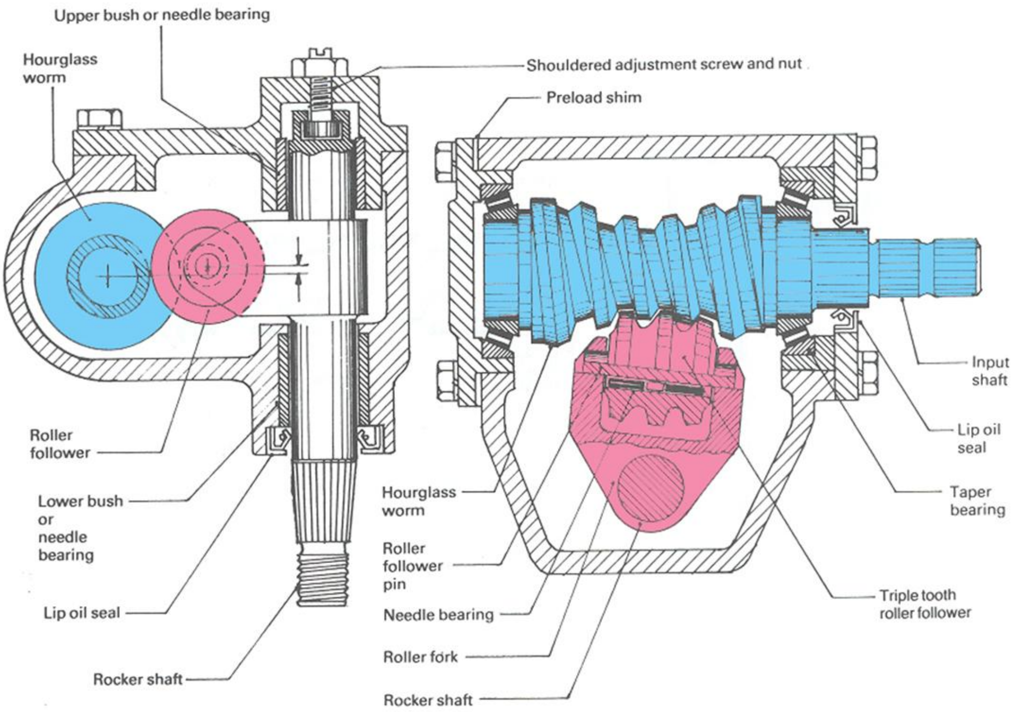
The recirculating-ball steering system is also commonly used on modern motor vehicles. Its operating principles are the same as the older screw and nut steering system, but by introducing steel balls in between the male and female threads steering efficiency is improved.





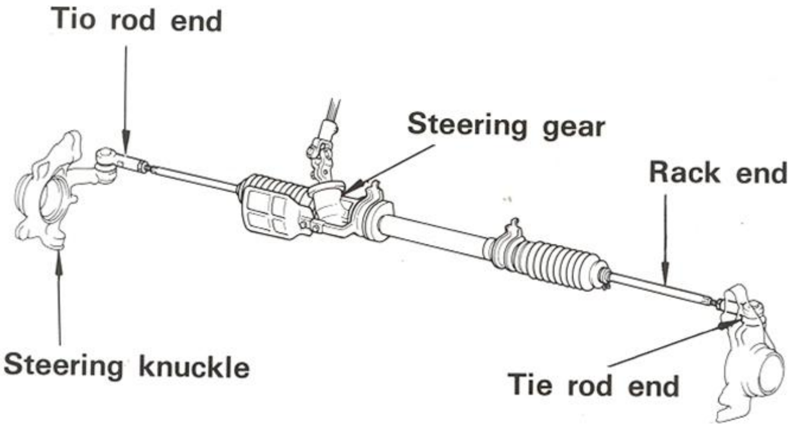
To allow the steel balls to move, the threads in both the ball nut and worm shaft have now been replaced with spiral groves. The worm shaft is connected to the steering column; the selector shaft is connected to the pitman arm and then through the steering linkages to the wheels. The recirculating-ball steering system is constructed so as to give a preload to the selector shaft for approximately 5˚ either side of the centre point. This will give the driver the correct steering resistance in the straight-ahead position thus aiding vehicle stability.

Worm and roller steering system

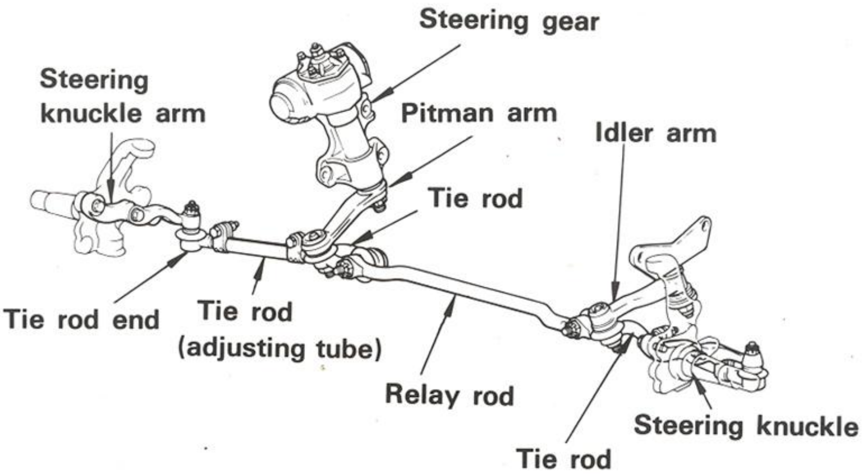


This steering system consists of an hourglass shaped worm mounted between opposing taper roller bearings. This worm then engages with a roller follower, which usually has either two or three teeth. The roller follower has a small offset with relation to the worm, and this allows an adjusting screw to be fitted. The adjusting screw is there to control backlash and end float of the rocker shaft.

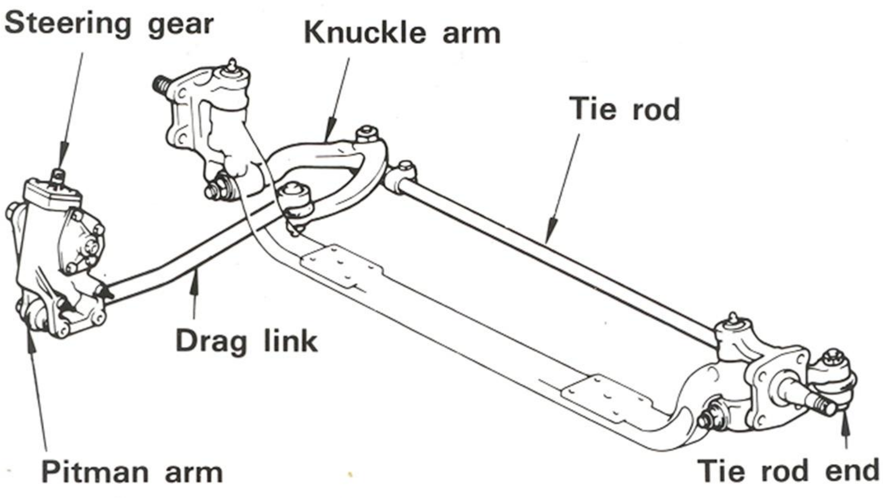
Steering linkage



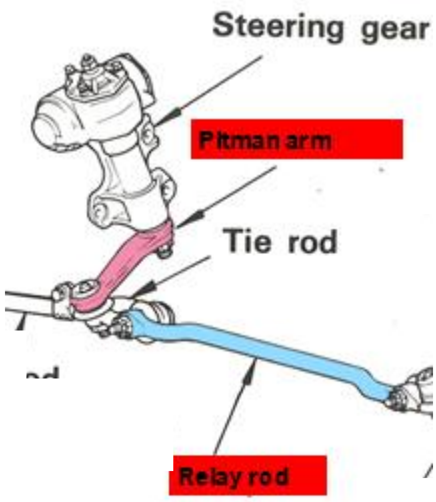
The steering linkage comprises of various rods and arms that transmit movement of either the steering rack or box to the wheels. These rods and arms must do this accurately regardless of the changing wheel position with relation to the steering rack or box. As the vehicle is travelling road conditions will cause constant deflection of the suspension causing this change in wheel position. The type of steering system used governs the complexity of the steering linkage arrangement. The rack-and-pinion steering system uses the least amount of linkages, but is still able to transmit this movement accurately.



The steering linkage needed for a steering box system, like recirculating-ball, is more complex. The types of linkage used will also be dependant on whether independent or rigid suspension is used. Independent front suspension when used in conjunction with a steering box has a complex relay rod and arm arrangement. As the wheels are able to move up and down independently the use of a single tie relay rod is inappropriate. With the wheels moving independently a single rod would cause wheel alignment problems with relation to toe-in. To compensate for this two tie rods are fitted, with an adjusting tube fitted to one side, allowing for toe-in adjustment. When a rack-and-pinion steering system is used the rack takes the place of the relay rod.

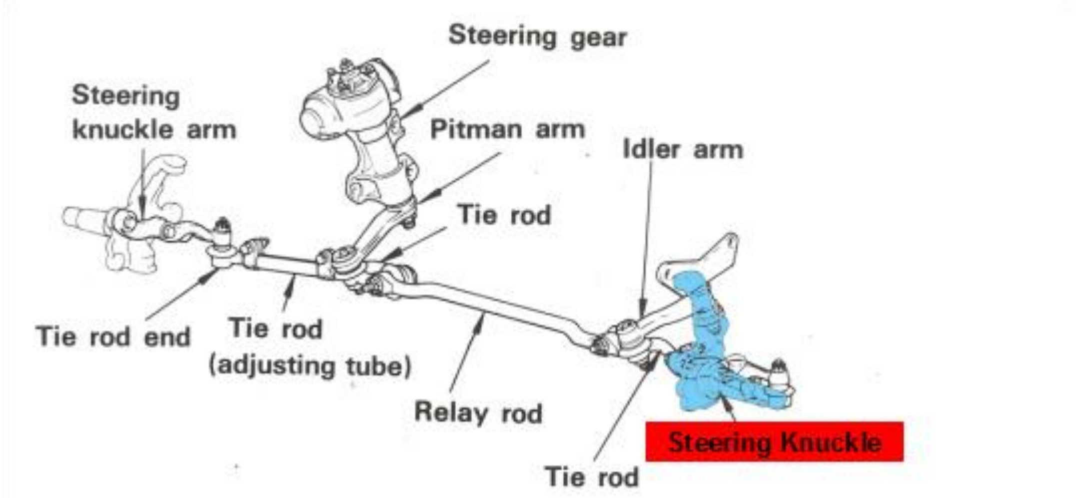


With rigid front suspension the complexity of the steering arrangement is reduced. As both front wheels are now connected together via an axle the steering knuckles will now move together, this means there will be no variation in the tread distance, and this enables them to be connected via a single tie rod. Even though there is no variation between the steering knuckles, there is varying height differences between the steering box and the knuckle arm, this is caused by the steering box being bolted to the chassis and the steering knuckles being part of the suspension. To compensate for this problem Ball joints are connected to each end of the drag link.



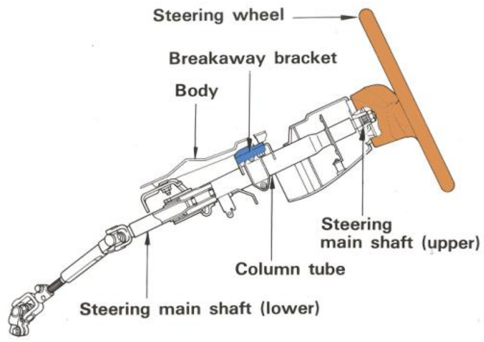
The pitman arm makes the physical connection between the steering gear and the relay rod or drag link. It is connected to the steering gear by a tapered-spline and is secured in place by a nut. The other end of Pitman arm is connected to the relay rod or drag link via a ball joint, which as described earlier allows for height variations between the steering box and steering knuckles. The relay rod in turn is connected to the tie rod, transmitting the movement of the pitman arm to the wheels. An idler arm is fitted at the opposite end of the relay rod to the pitman arm to support the steering linkage.

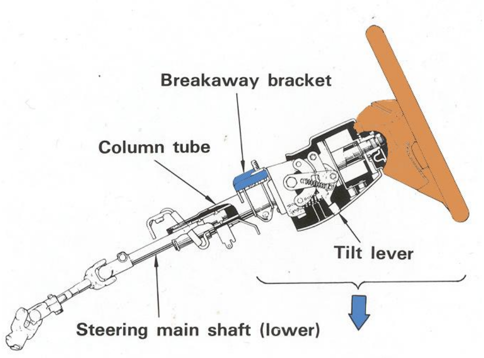
The steering knuckle is the final component of the steering linkage. It is connected to the tie rod end and is secured in place by both upper and lower ball joints or via a kingpin. The knuckle pivots around these joints allowing steering to take place. The steering knuckle also supports the load applied to the front wheels while allowing them to rotate freely.

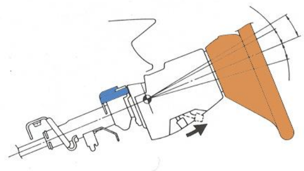


Steering column

In the past the steering column has been overlooked as a complex system within the motor vehicle. Modern steering columns incorporate systems including; Telescopic and tilt functions to enable the driver to find the ideal driving position, Impact-absorbing systems to stop injury of the driver in the event of a crash and other systems like the steering lock.

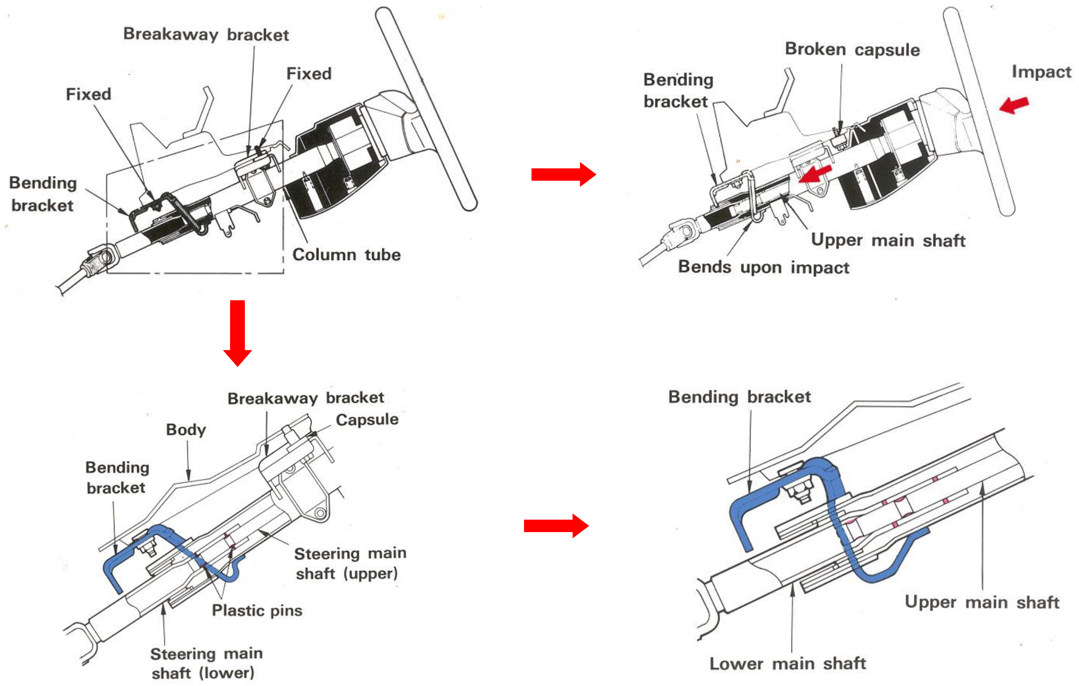






The steering column consists of a steering wheel that is connected to the main shaft via a tapered shaft, which is secured in place by a nut. The main shaft is housed in the column tube that is secured to the vehicle body. The top securing point is now made to be detachable in the event of a crash and forms the component called the breakaway bracket. The lower securing bracket takes the form of a bending bracket on some systems, to work in conjunction with the breakaway bracket to allow the steering column to move down and forward in the event of a crash. The lower part of the main shaft is then connected to the steering box or rack. This connection is made through a universal joint that allows for angular changes between the main shaft and steering box or rack, it also helps to reduce the amount of road shocks that are transmitted through the steering wheel to the driver.

There are various types of collapsible and energy absorbing steering columns available from different manufacturers and within the presentation two are explained. As part of the workbook we will look at one type called the bending bracket type. Regardless of the type of system used the end result is the same, which is to reduce the amount of shock that is transmitted to the drive in the event of an accident. This is achieved by allowing the steering column to detach from the vehicle body and move forward towards the engine. It is a natural instinct that in the event of an accident the driver will lock their arms transmitting their whole body weight through their arms to the steering wheel. This is demonstrated in many safety videos that show the steering wheel being physically bent by the driver in the event of an accident.

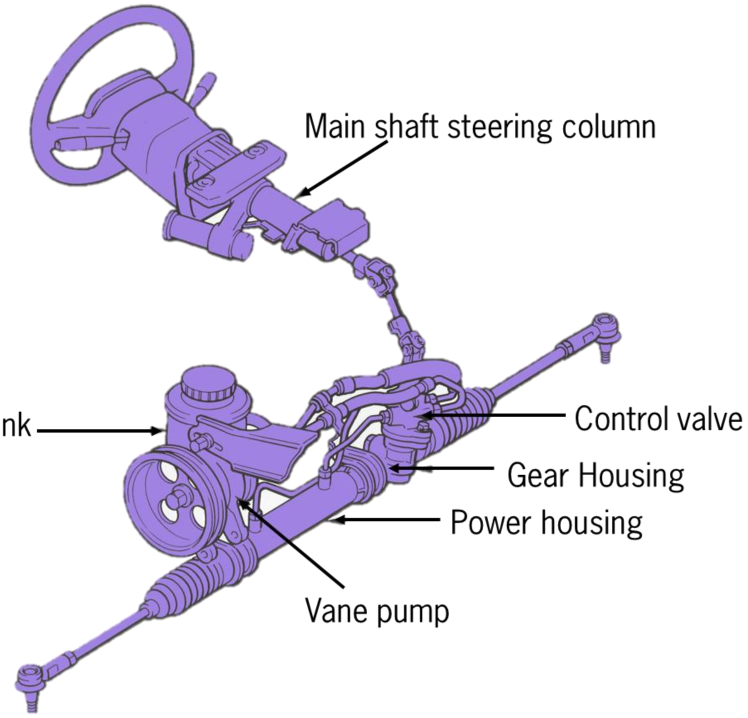


The bending bracket type steering columns operation is very simple. As force is applied to the lower main shaft from the steering box or rack in the event of an accident, it is initially allowed to travel up inside the upper main shaft, this helps to reduce primary shock as the steering wheel does not actually move. The driver's body will then begin to move forward as his body will not be slowing as quickly as the vehicle. This force will be transmitted through his arm to the steering wheel causing the breakaway bracket to detach from the vehicle body. The breakaway bracket is able to detach quickly as it is attached to the body via two capsules that are secured by plastic pins. When the breakaway bracket detaches from the body the bending bracket deforms allowing the column to move forward. These two actions help to absorb most of the force generated in the event of an accident.

Question

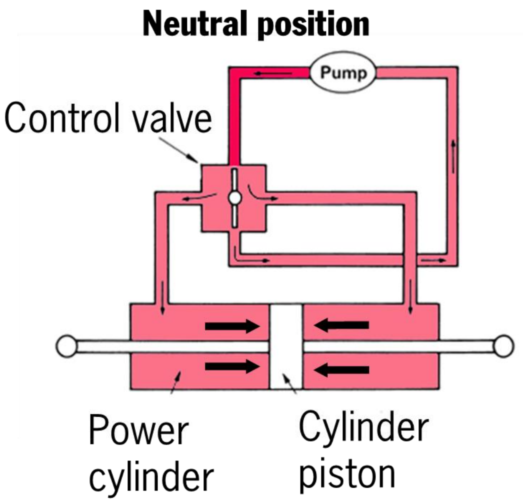
What precaution must be taken when removing a steering column fitted with an energy absorbing steering column?

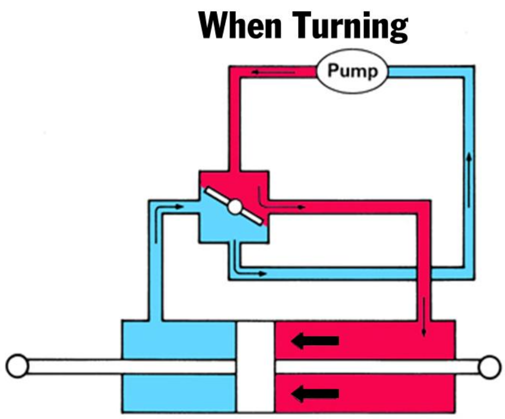
Power assisted steering systems



As motor vehicles continue to develop new systems need to be introduced. Modern vehicles are now fitted with wider and lower profile tyres, to improve the handling of the vehicle. The negative consequence of this is the increase in effort needed to turn the steering wheel, due to the extra friction generated between the tyres and the road. Assistance can be given to the driver as described in phase one, by changing the steering ratio within the steering box. This has the disadvantage that it also increases the amount of turns needed by the driver, to turn the steering from lock to lock. The introduction of power assisted steering has helped to solve this problem, by assisting the driver to turn the steering wheel without increasing the amount of steering wheel rotation needed. Power assisted steering can be used on various steering system configurations, although in this booklet the rack and pinion steering system will be used, to explain the principles.

Operating principles of power assisted steering



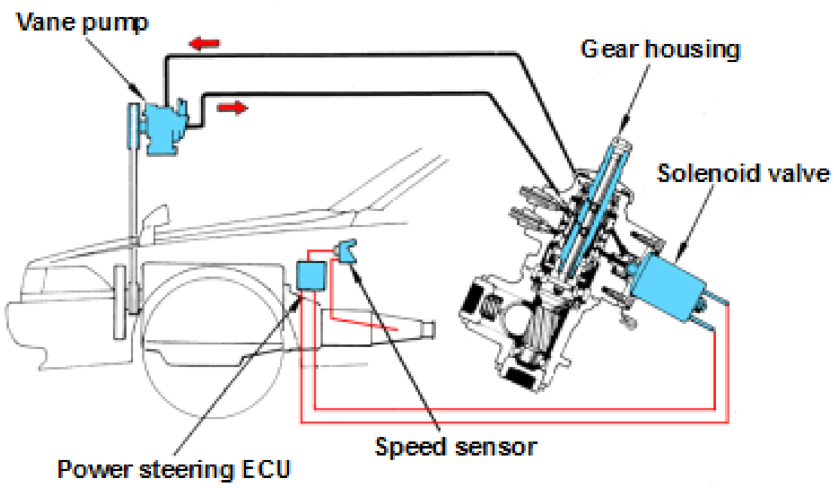


Power assisted steering utilises hydraulic pressure to assist the driver to turn the steering wheel. Either an engine driven pump or an electrically driven pump generates the hydraulic pressure needed to assist the driver. The pressure generated by the pump act on either left or right hand side of the power piston, and is directed there by the control valve.

When the steering wheel is in the straight-ahead position, the control valve is in the neutral position (see above). This means that the pressure generated by the pump is allowed to travel directly down the relief port, so very little pressure is sent to either side of the power piston. The pressure that is sent to the power piston acts equally on both sides, so no steering is achieved.
When the steering wheel is turned to either the left or right, the control valve is also moved. This is because the steering wheel is connected to the control valve via a torsion bar. As the control valve moves it opens one port and closes the other. This allows hydraulic pressure generated by the pump to be directed to either one side of the power piston or the other. The side of the power piston that does not have hydraulic pressure applied has its fluid directed to the intake side of the pump through the relief port. This causes a pressure difference between one side and the other, and thus aids the driver to turn the steering wheel.
As described earlier power steering is required to aid the driver to turn the steering wheel due to increased friction generated between the tyre and the road. The amount of assistance needed by the driver is dependant on vehicle speed. When the vehicle is stationary or travelling very slowly (when the vehicle is being parked) the driver needs maximum assistance, but as the vehicle speeds up the amount of assistance needed reduces.

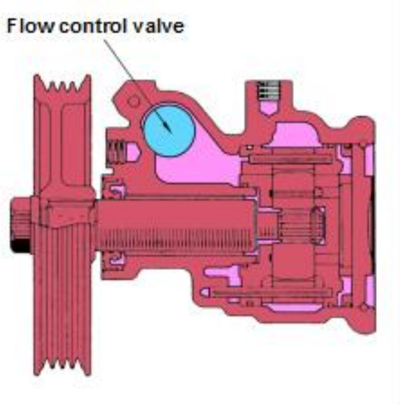
When the vehicle is travelling at high speeds very little or no assistance is needed, this is due to a reduction in the friction between the tyre and the road. If maximum assistance is given to the driver at high speeds, then the driver will tent to over steer due the little effort needed to turn the steering wheel. To compensate for this different devices are fitted to the steering system. These enable the steering system to increase or decrease the amount of assistance given to the driver under different driving conditions. Two types of system are explained below, but will be explained in full later in the booklet. These two systems are often used together to gain the desired result.

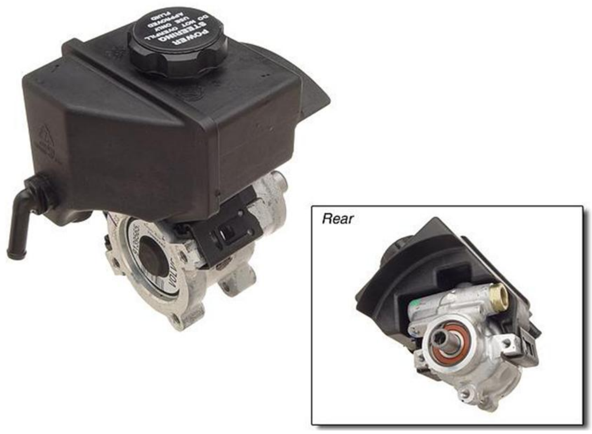
Vehicle speed sensing type



The vehicle speed sensing type detects the speed of the vehicle via a speed sensor normally fitted at the rear of the instrument cluster. From this signal the power steering ECU is able to determine the speed of the vehicle, and adjust the amount of assistance given to the driver.

Engine RPM sensing type

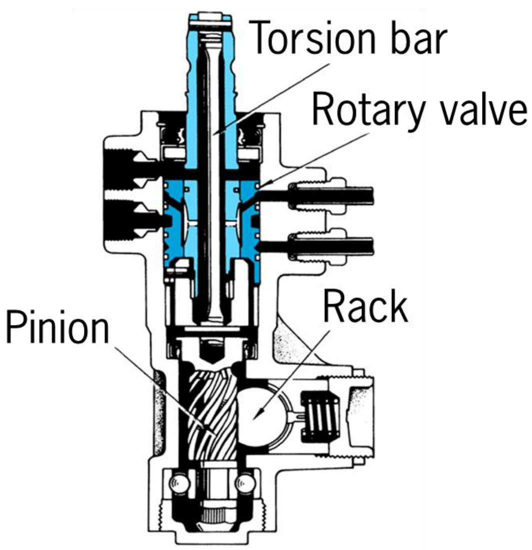




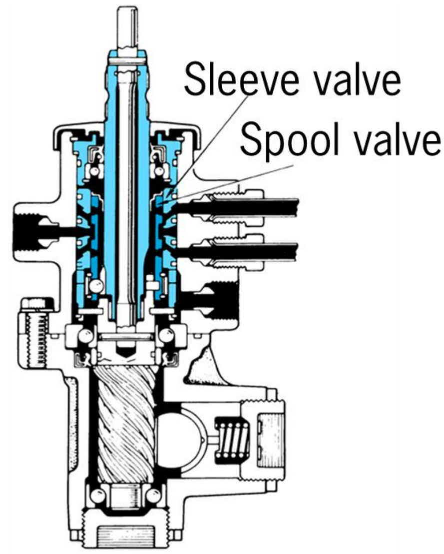
Most power steering systems are designed to send the same amount of fluid flow to the control valve regardless of engine RPM. With the engine RPM sensing type, as the speed of the engine increases and reaches a given point, the fluid sent to the control valve is reduced. This in turn reduces the pressure applied to the power piston.

Power steering components

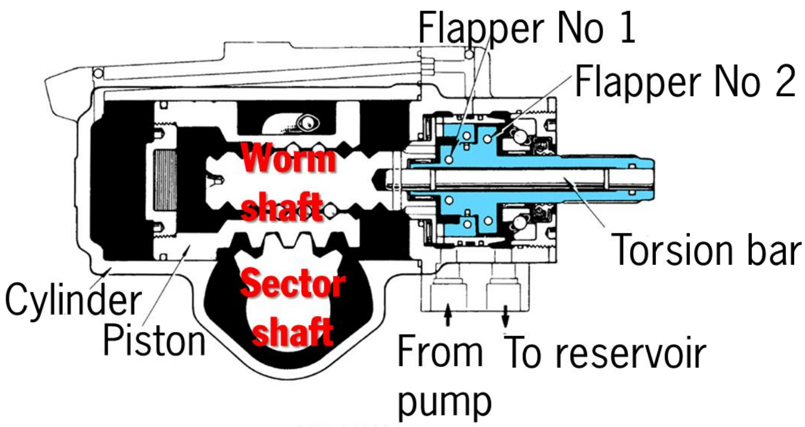
Most modern motor vehicles are fitted with either rack and pinion or recirculating ball type power steering. The three main components of any power steering system are the pump, power cylinder and the control valve. There are three types of control valves used on the two types of power steering systems. They are the rotary type, spool type and the flapper type.



Rotary valve type



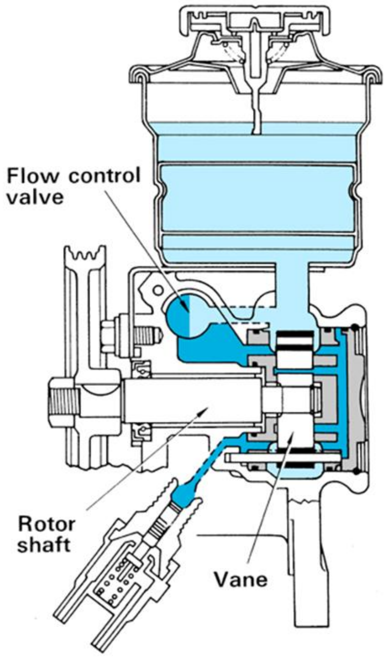
Spool valve type



Flapper Valve Type

The rotary type and the spool type control valves are used with the rack and pinion type steering system, and the flapper type is used with the recirculating ball

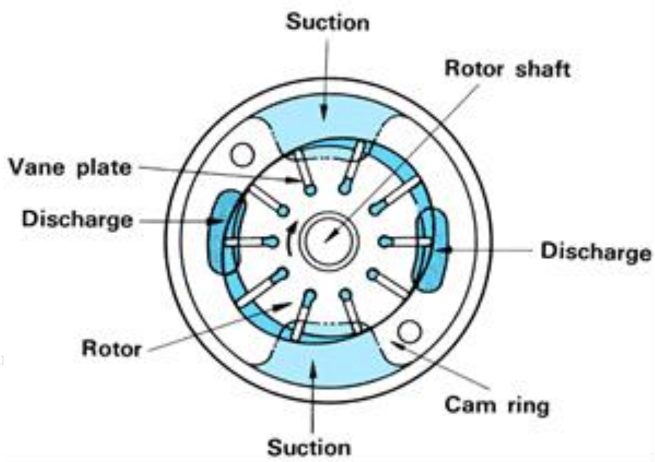
The power steering pump



The power steering system uses a vane type pump to generate the pressure needed to operate the power piston. The complete pump unit consists of the pump body, the reservoir tank and the flow control valve as well as the vane pump itself,

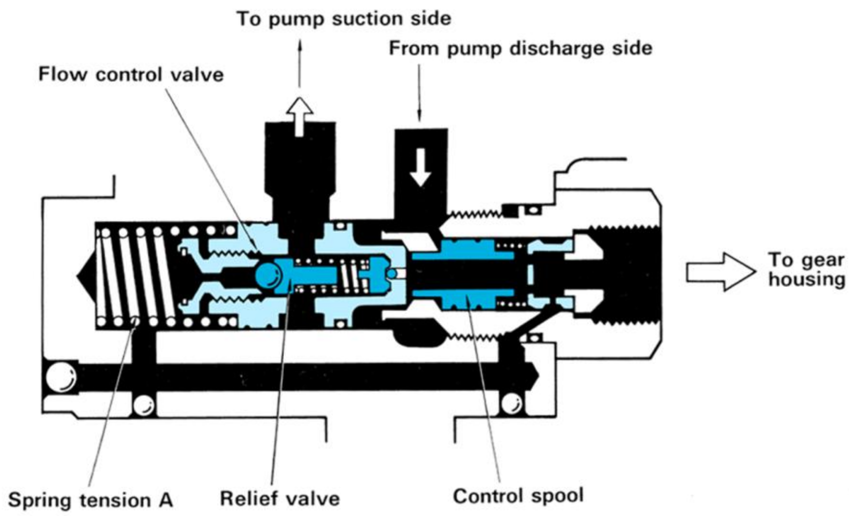
The reservoir tank supplies the fluid to the vane pump, and can be connected either directly to the top of the pump, or fitted to the vehicle body separately (under the bonnet). If the reservoir is fitted to the vehicle body then rubber hoses will be used to connect the reservoir to the pump. Both removing the cap and visually inspecting the dipstick will enable the fluid level to be checked. If a transparent reservoir is used, then visually looking at the reservoir and checking the fluid level, against the level marks on the reservoir will enable the oil level to be checked. When visually checking a transparent reservoir, identify which marks relate to the oil level when the oil is cold, and which marks relate to the oil level when the oil is hot. The reservoir should only be topped up with the oil recommended by the manufacturer.

The pump body houses the vane pump, the control valve and in some cases an anchor point for the reservoir. Either the engine, through the use of a belt and pulley arrangement, or an electric motor, drives the vane pump. The pressured fluid generated by the pump then travels through the flow control valve to the control valve housed in the steering gear housing.

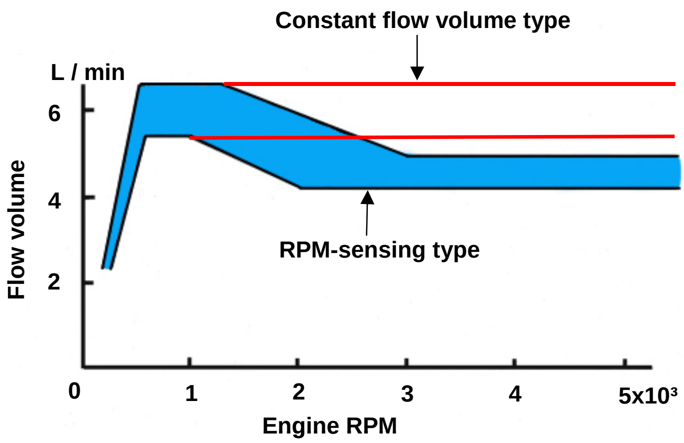


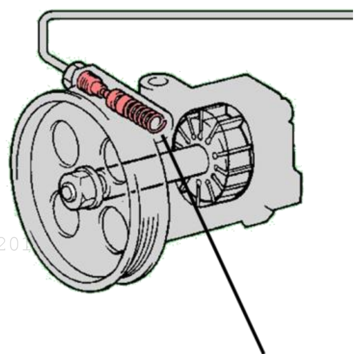
The vane pump itself is quite simple in construction, and consists of a rotor, cam ring and vane plates. As the vane rotor rotates the vanes are thrown out against the cam ring due to inertia, they are then held there by both the force of inertia and the pressure of the oil acting against the back of the vane plate. The cam ring is oval in construction so the discharge chamber is smaller than the suction chamber thus raising pressure as the pump is rotated. On most vane type pumps there are two suction and two discharge ports, so fluid is sucked in and discharged twice for each one revolution of the pump.

Flow control valve and control spool

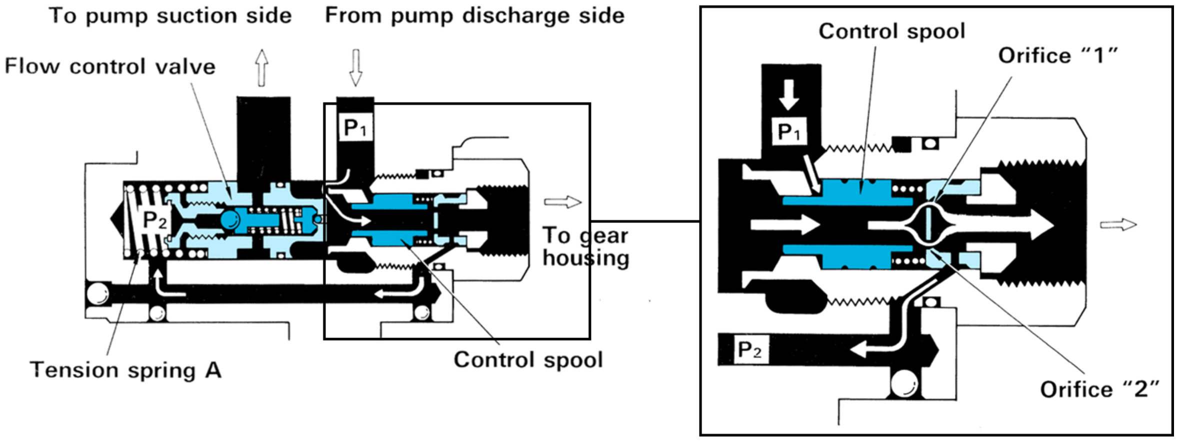


As with most types of pump the volume of fluid produced by the pump is relative to the speed at which the pump is turning. The faster the pump turns the higher the fluid volume that is produced. This means that greater assistance would be given at high engine RPM and less assistance would be given at low RPM. Problems may occur if this was allowed to happen, as steering stability would be affected. On most modern vehicles the steering assistance is reduced when the vehicle is travelling at high speed, as the there is less friction between the tyres and the road. To aid this process a RPM sensing flow control valve is fitted. This means that although the flow volume produced by the pump increases as engine RPM increases, the flow to the gear housing is actually reduced.



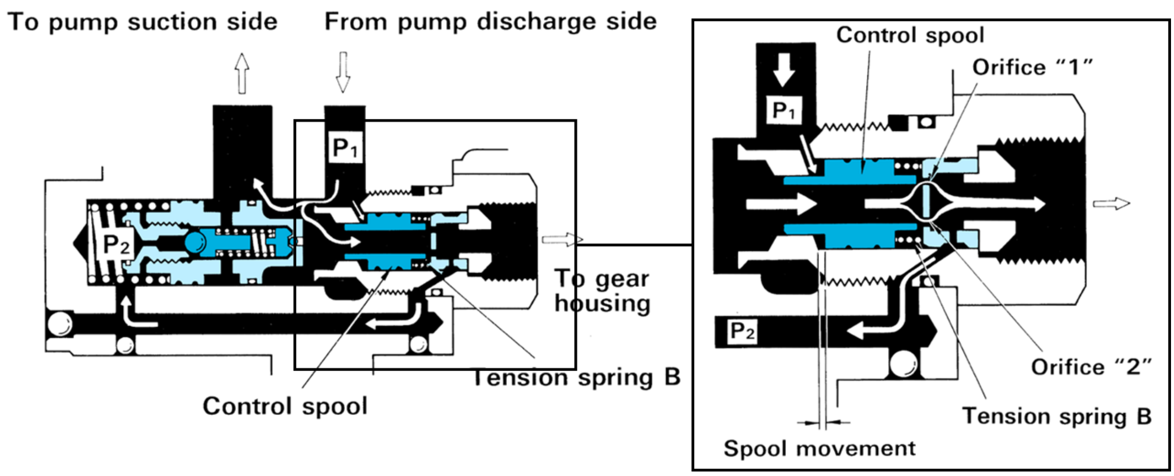


At low speeds (pump speed: 650-1250 rpm)



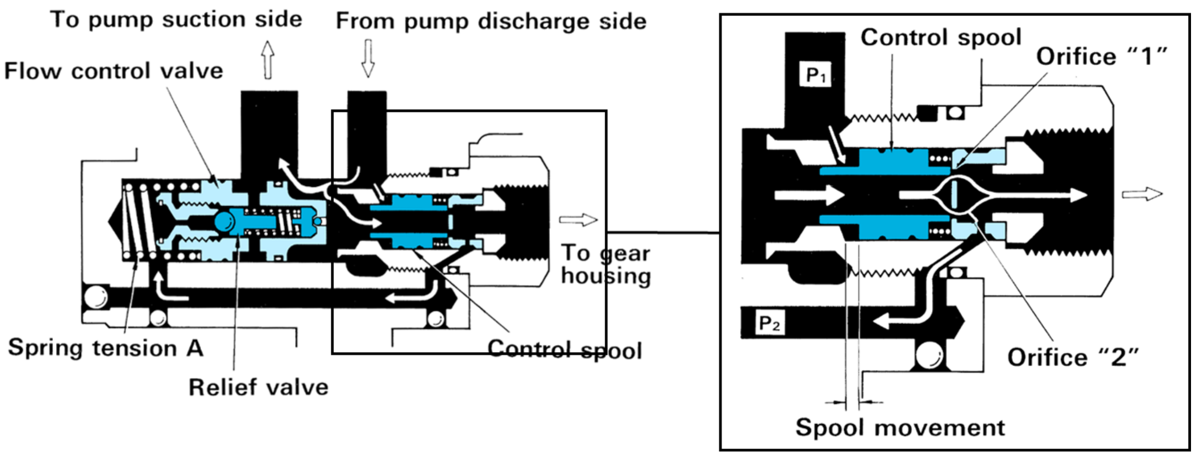
At low speed the fluid will be travelling through the control spool at a rate of approx. 6.6 litres per min. the pressure at P1 will be enough to overcome the spring pressure allowing max fluid travel through orifice 1 and 2. (Max assistance)

At medium speeds (pump speed: 1250-2500 rpm)



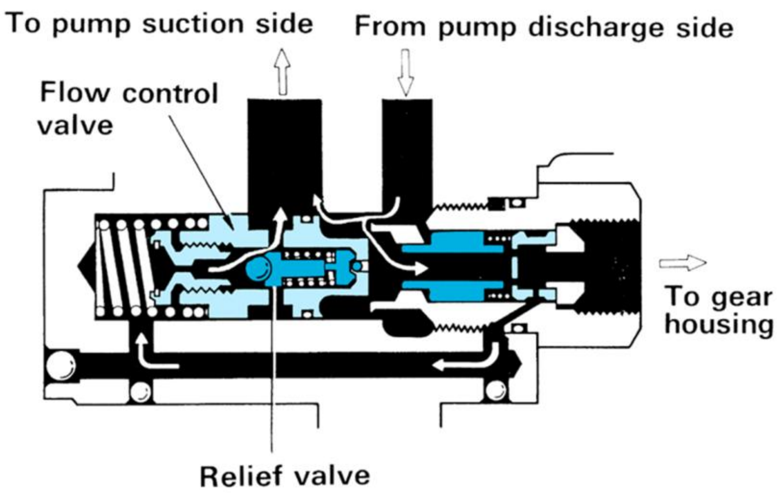
As the pump speed rises above 1250rpm the 6.6 litre per min has been reached the rise beyond that has caused tension spring b to become compressed and the control spool starts to cover orifice 1 and 2 this causes a flow reduction and the pressure difference at p2 reduces causing the suction side to opened up.

At high speeds (pump speed: over 2500 rpm)



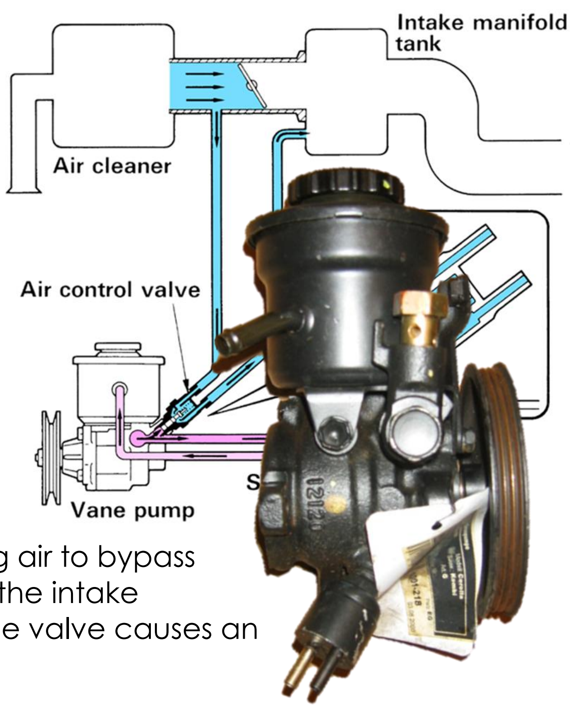
As the speed rises over 2500 rpm 3.3 litres per min is constant because the rise in pressure now moves the control spool all the way right which increases the cover area of orifices 1 and 2 reducing fluid travel output.

Relief valve



If the pressure rises above 80 bar the relief valve placed in the piston is now forced off its seat allowing the fluid to circulate back to the suction side of the pump thus reducing the pressure.

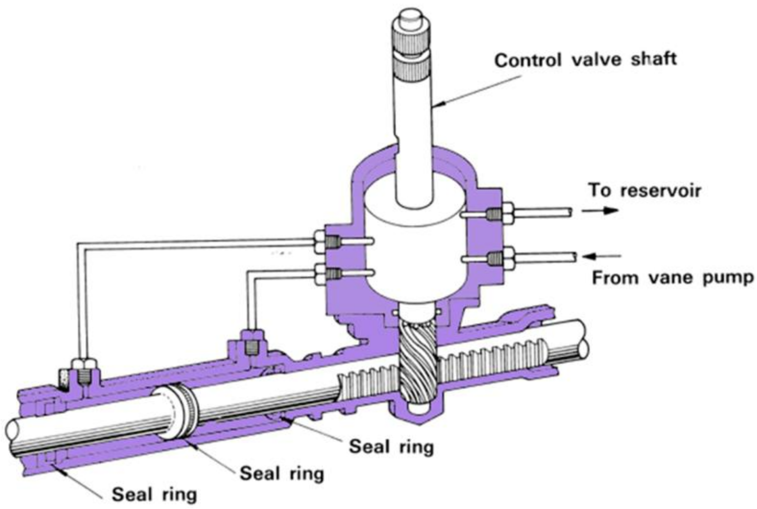
Maximum load idle up



When the steering wheel is turned fully to either the left or right, the power steering pump generates maximum fluid pressure. This increase in pressure generated within the pump causes a lowering of the engine RPM, and for this reason an idle up device is fitted. The idle up device raises the engine RPM whenever a high load is placed on the power steering pump. The idle up device fitted to electronic fuel injection engines is controlled via an air control valve. This valve in turn is operated via fluid pressure generated by the pump. As fluid pressure act on the air valve, the air valve opens allowing air to bypass the throttle valve and travel directly into the intake manifold. The air that bypasses the throttle valve causes an increase in engine rpm.

Air control valve

Control valves

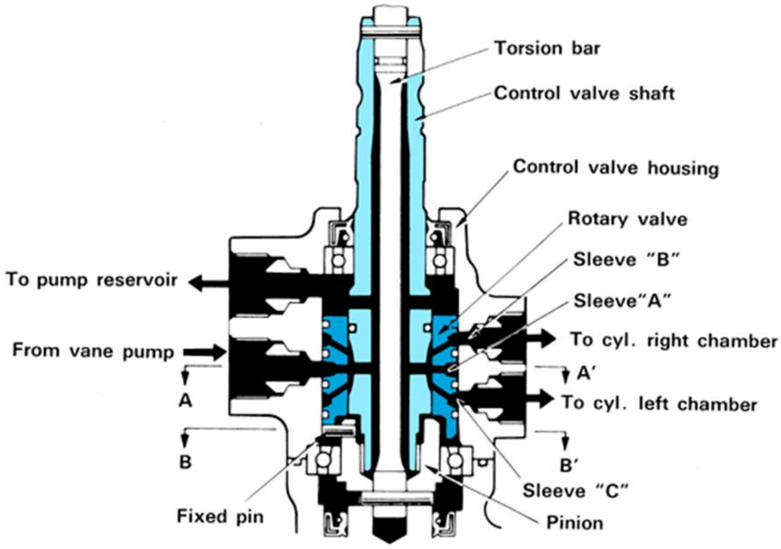


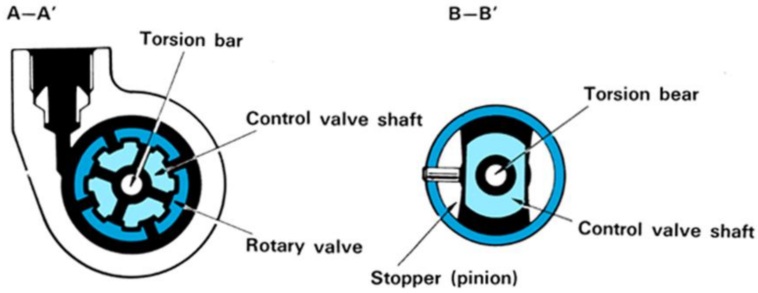
The three control valves, spool valve, rotary valve and flapper valve, are used to direct the pressured oil sent from the power steering pump to the power piston. The power piston uses sealing rings as shown above to prevent any fluid leakage from the power piston itself. When the steering wheel is in the straight-ahead position, the control valve is in the neutral position. The high-pressure fluid generated by the power steering pump is directed back to the reservoir, thus keeping the pressure even on each side of the power piston. When the steering wheel is turned to either the right or left, this movement is transferred to the control valve via the torsion bar, which connects the two together. As the torsion bar is twisted the control valves redirect the fluid flow causing power assistance. The amount of assistance given is proportional to the amount of twisting force exerted on the torsion bar. In the event of power steering pump failure, the direct connection between the steering wheel and the pinion gear via the torsion bar enables the driver to steer the vehicle. Although the drive is able to turn the wheels, the steering will feel very heavy as no assistance is being given.

Control valve operation

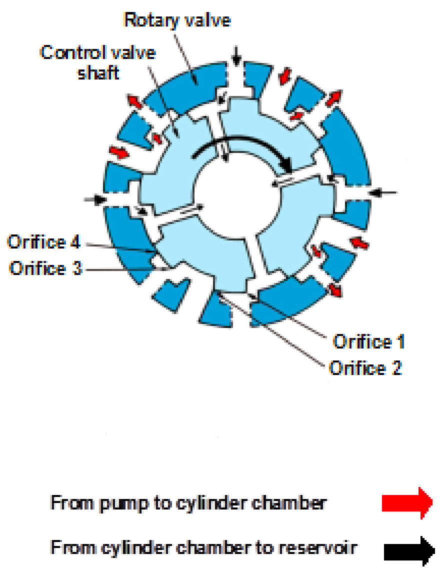
Rotary valve

The steering wheel movement is transmitted to the control valve through the torsion bar. The torsion bar is connected to the pinion and the rotary valve through a pin, and this allows the rotary valve to rotate integrally.



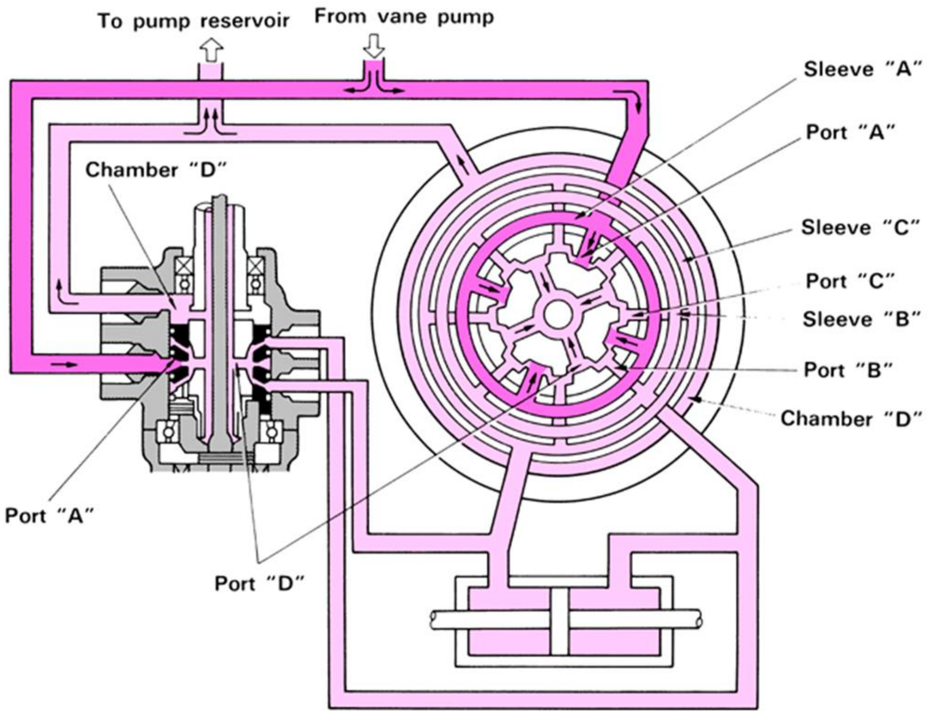


Operation



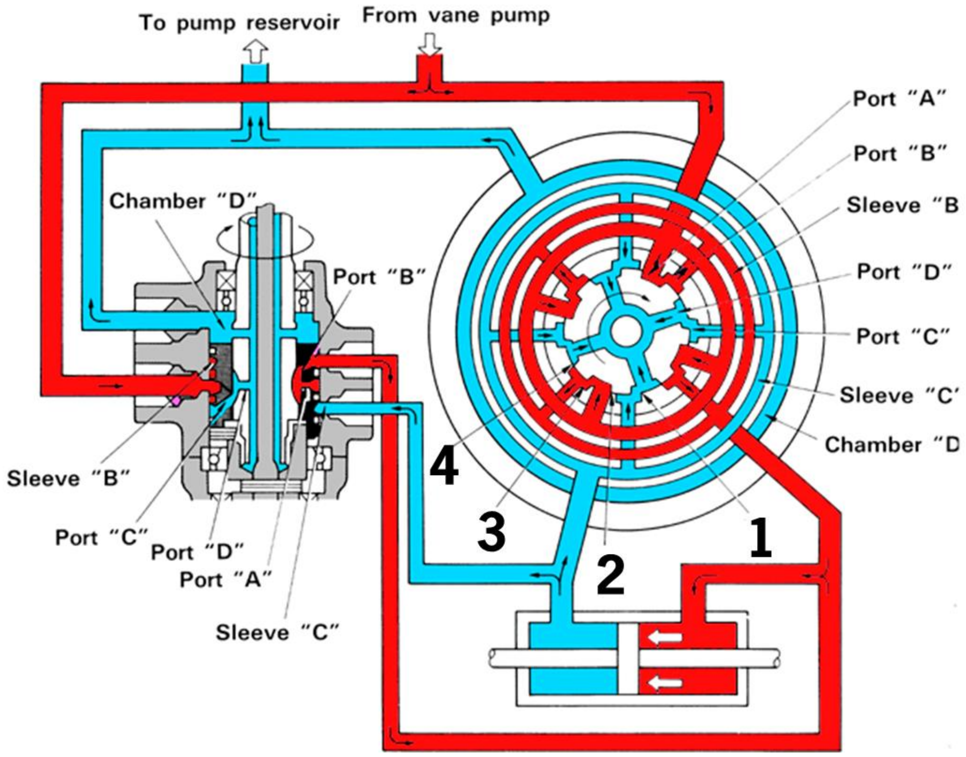
The control valve shaft is rotated by the twisting action of the torsion bar. This causes a restriction in orifices 2 and 4 when the steering wheel is turned to the right, and orifices 1 and 3 when the steering wheel is turned to the left. In contrast to the control valve shaft, which is operated by the twisting action of the torsion bar, the pinion gear turns as the torsion bar turns. The twisting action of the torsion bar is proportional to the force exerted by the road surface. As the control valve shaft is turned by the twist of the torsion bar orifices 1-4 are opened or closed in the correct order, directing the pressured oil to the correct side of the power piston, to give assistance to the driver. The fluid that is directed to the power piston enters via the outer circumference of the rotary valve, and is returned to the reservoir tank by passing between the control valve shaft and the torsion bar.

Neutral position

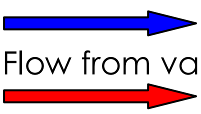


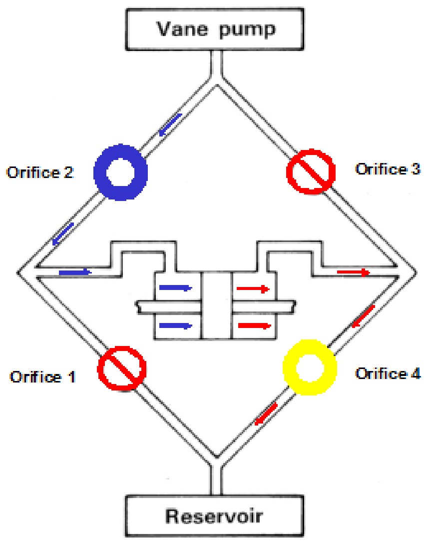
When in the neutral position there is no twisting force acting on the control valve shaft, so it is kept in the neutral position with relation to the rotary valve. The pressured fluid supplied by the power steering pump is returned to the reservoir tank through port **D.** A small amount of pressured fluid is able to enter the power piston, but as the pressure is even on both sides no assistance is given to the driver.

Turning right

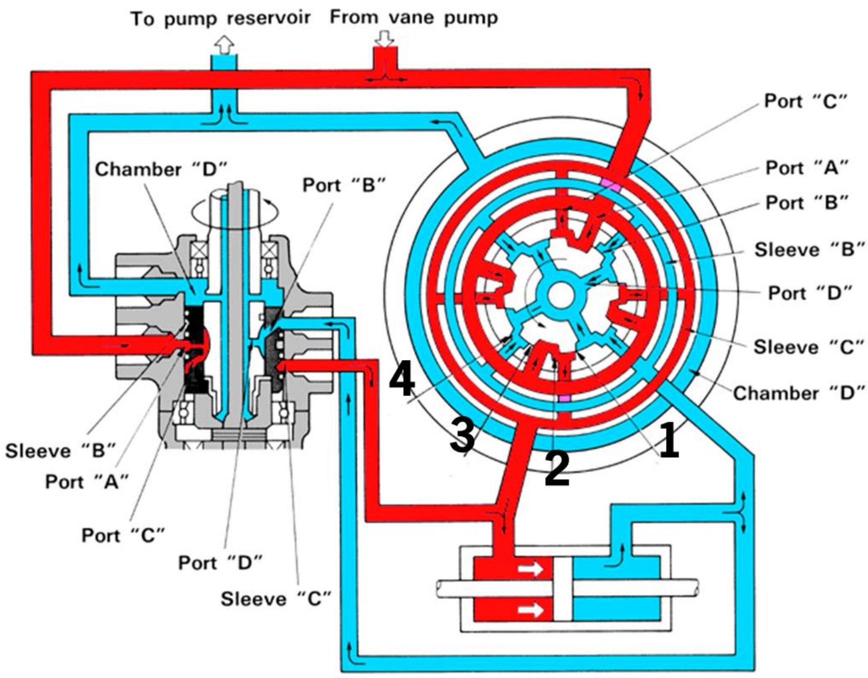


When the driver turns the steering wheel to the right, the twisting of the torsion bar causes the control shaft to rotate to the right. This action blocks orifices 2 and 4, which stops the flow of fluid to ports **C** and **D.** The pressured fluid is now directed through port **B** into sleeve **B** and onto the right hand cylinder of the power piston. Assistance is now given to move the steering rack to the left. The fluid from the left hand side of the power piston is returned to the reservoir through sleeve **C** into port **C,** Then into port **D** and finally into chamber **D**.





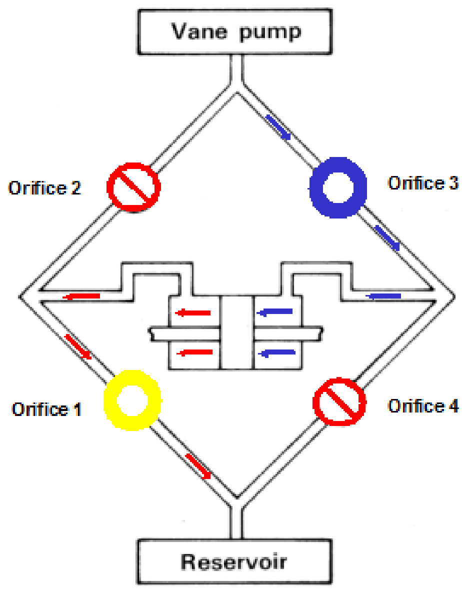
Turning left



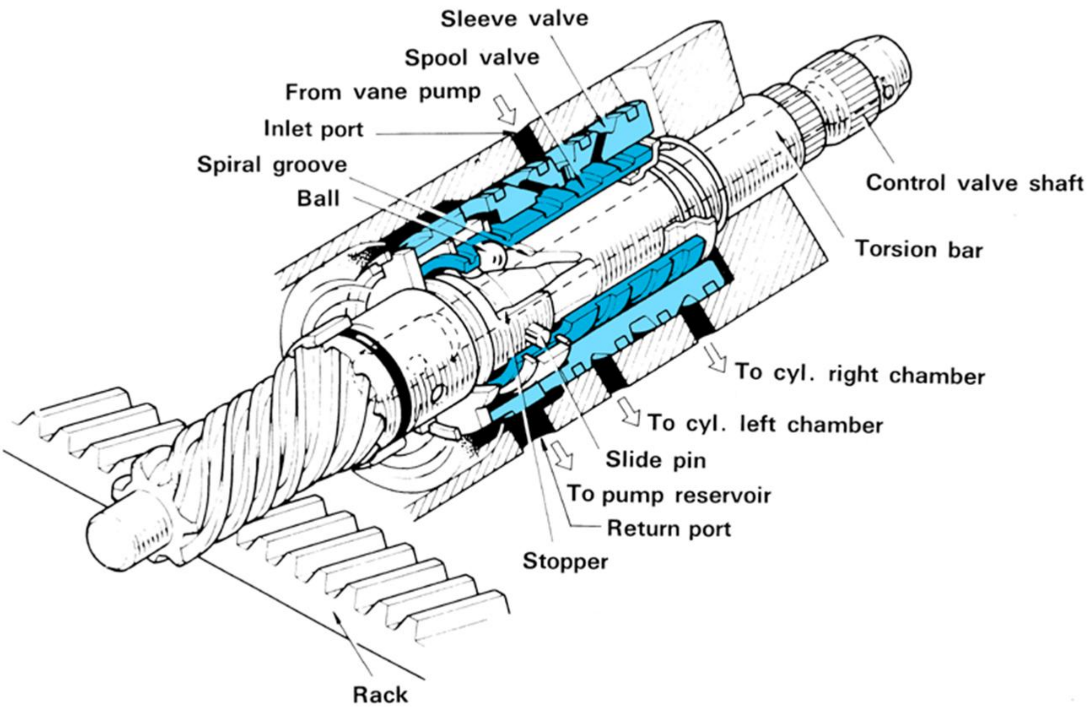
As with the previous explanation, when the vehicle is turning to the left, the torsion bar twists thus turning the control shaft to the left. In this case the opposite is true to a right hand turn, in that orifices 1 and 3 are blocked stopping flow to ports **B** and **D.** Fluid now travels through port **C** to sleeve **C** directing the pressurised oil to the left hand side of the power piston. This causes the rack to move to the right giving assistance to the driver. The fluid from the right hand side of the power piston is able to return to the reservoir via, sleeve **B** to port B and then from port **D** to chamber **D**.

Flow from the vane pump

Return to reservoir



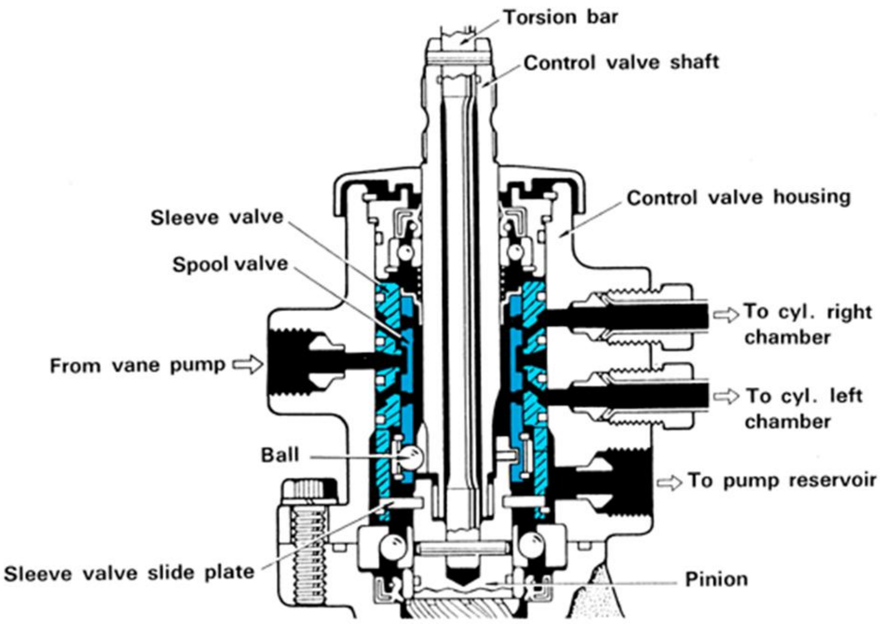
Spool valve



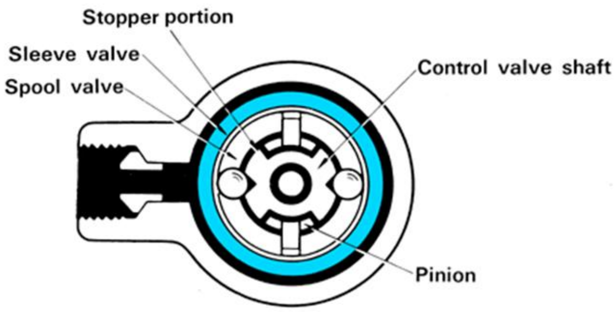
The spool valve type control valve carries out the same operation as the rotary valve type. It redirects the pressured oil from the power steering pump to the correct side of the power piston. The main difference is that the spool valve moves up and down rather than rotating like the rotary valve. The control valve shaft and the pinion are connected via a torsion bar, so if the power steering pump was to fail steering can still be achieved.

The spool valve is fitted inside the valve sleeve and the two are connected together via two steel balls. The whole unit is connected to the pinion gear via two sliding pins. As the pinion rotates the spool valve rotates in the same direction but also moves up and down by approximate 1mm. The sleeve valve is secured to the pinion gear via a slide plate and snap ring; this stops the sleeve valve from moving up or down.

Operation



The pressurised oil generated by the power steering pump is directed to the power piston by blocking orifices 2 and 4 when turning to the right, and orifices 1 and 3 when turning to the left.

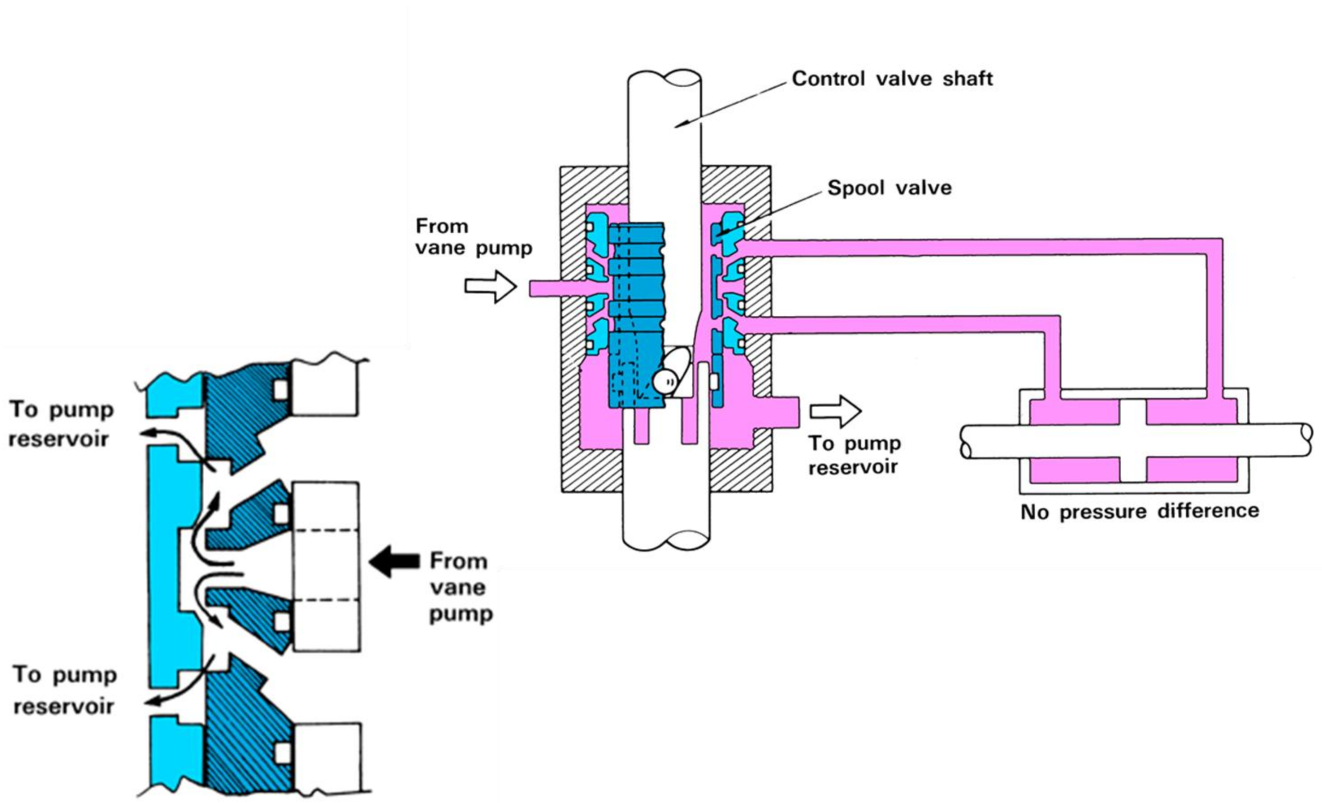


As the driver turns the steering wheel, this turning force is transmitted through the control valve shaft to the pinion gear via the torsion bar. As force is applied to the torsion bar due to the friction between the tyres and the road, the torsion bar begins to twist. The control valve shaft moves in proportion to the amount of twist of the torsion bar, thus raising or lowering the spool valve by the screwing action of the balls.
The amount that the torsion bar twists, controls the amount of upward or down ward movement of the spool valve, this is in relation to the sleeve valve.

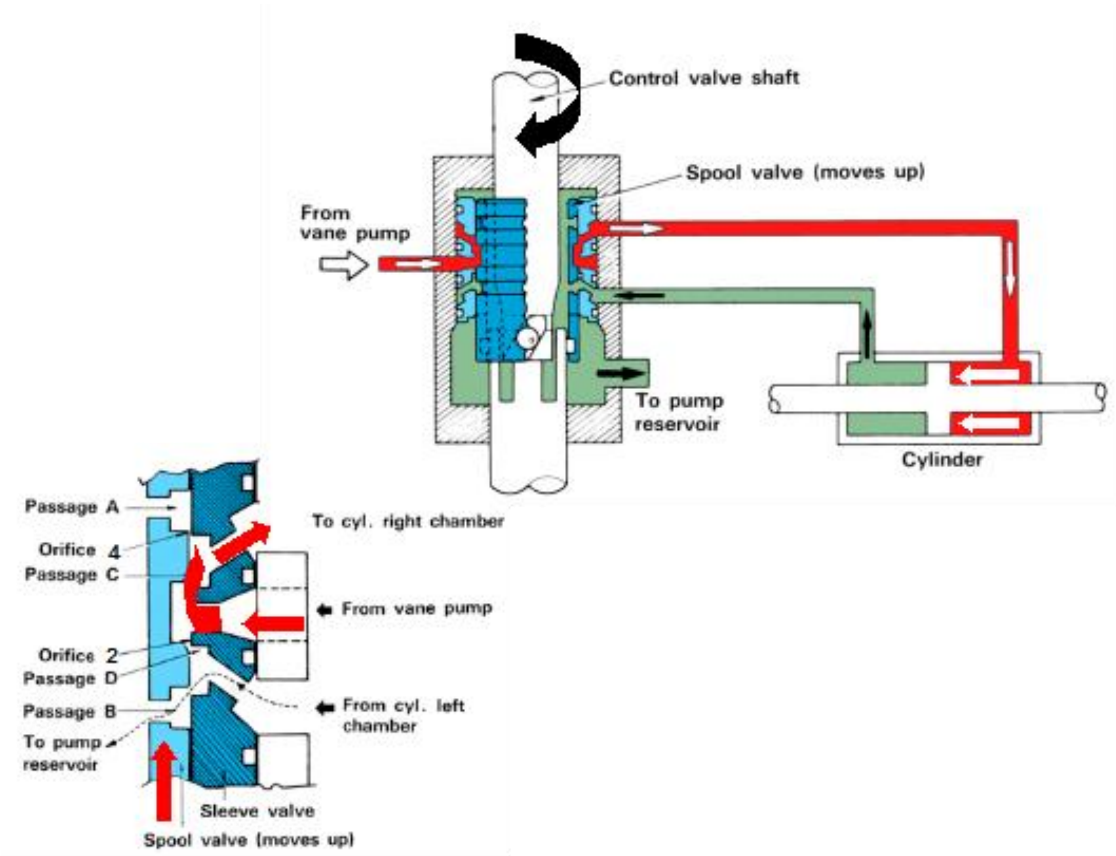
When the steering wheel is turned to the right the spool valve moves upward, and when the steering wheel is turned to the left it moves downward. This movement sends pressured fluid to either one side of the power piston or the other.

Neutral position

When the driver places the steering wheel in the straight-ahead position, the spool valve is in the neutral position. As the spool valve does not move up or down, there is no difference in pressure between the left and right hand sides of the power piston. The fluid returns to the reservoir through the control valve.

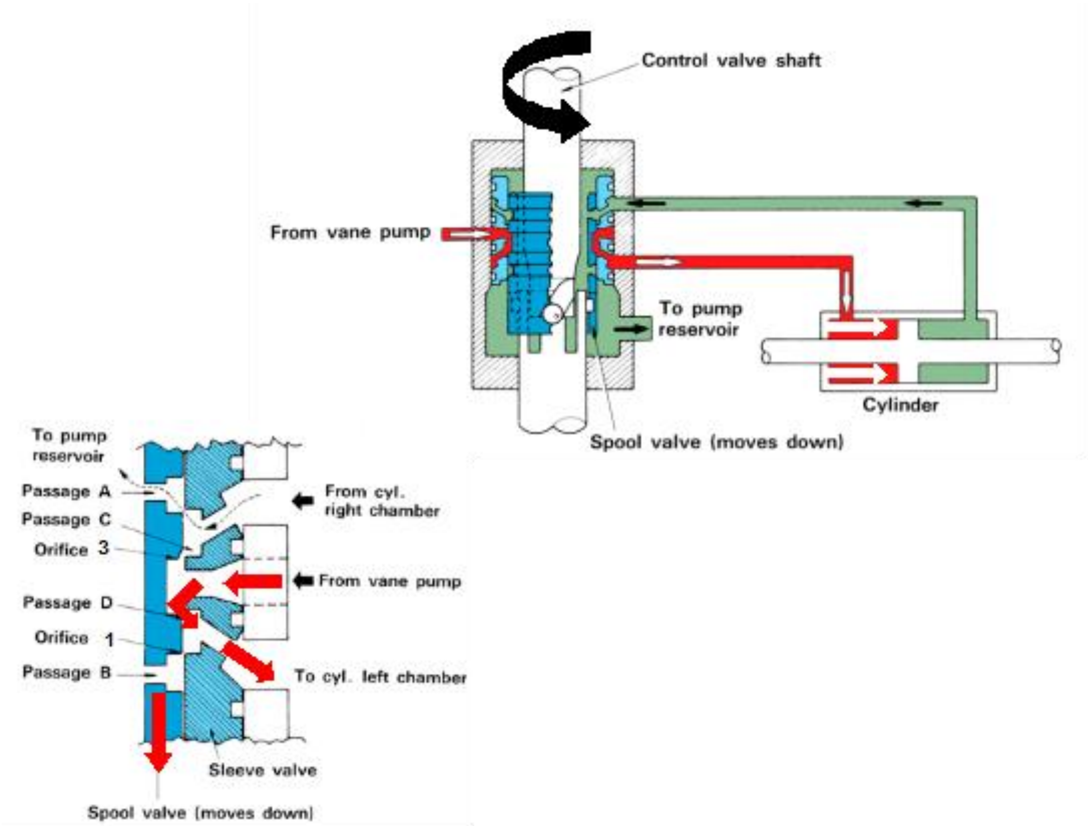


Turning right



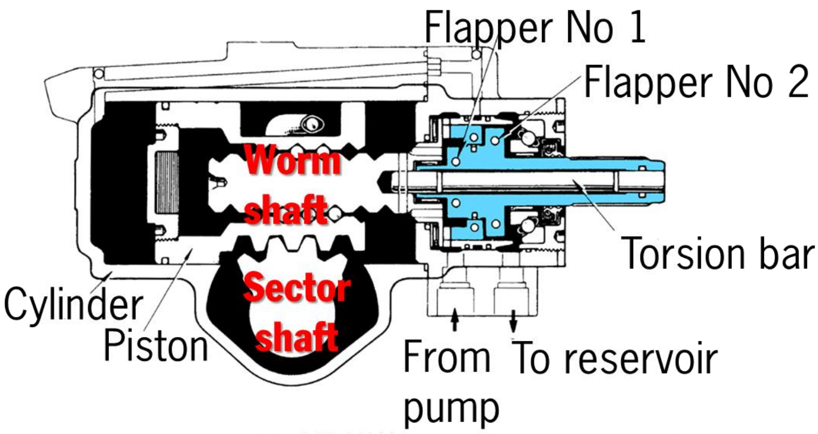
When the steering wheel is turned to the right, the control valve shaft also turns to the right causing the spool valve to move up. This upward movement is caused by the action of the spiral groove and the balls. As the spool valve move upward orifice 4 is blocked off, pressurised fluid is then diverted to the right hand side of the power piston. If the driver continues to turn the steering wheel, then the spool valve will continue to move upwards, blocking orifice 2. This will cause the fluid pressure to rise and give maximum assistance. The upward movement will cause the pressurised fluid to travel through passage **C,** due to the closure of passages **A** and **D.** The pressurised fluids will then travel to the right hand side of the power piston. The fluid in the left hand chamber will return to the reservoir through passage **B**.

Turning left

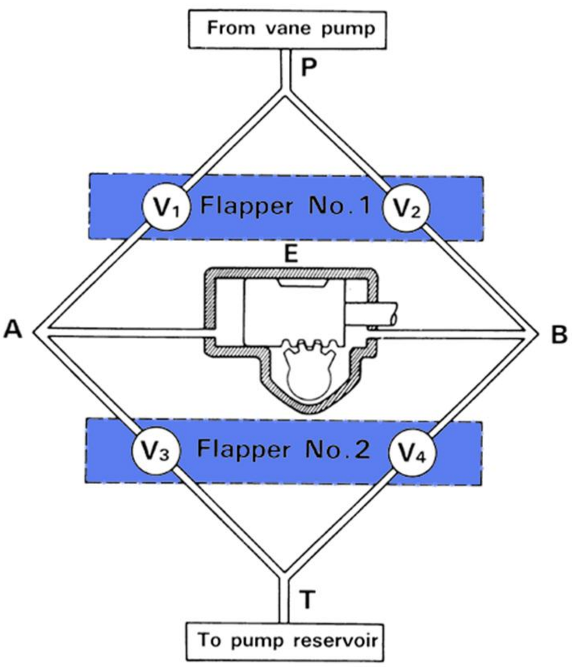


When the steering wheel is turned to the left, the control valve shaft also turns to the left, causing the spool valve to move downwards. This downward movement of the spool valve blocks off orifice 1, which diverts the pressurised fluid to the left hand side of the power piston. As the driver continues to move the steering wheel, the spool valve continues to move down blocking off orifice 3; this causes maximum pressure to be delivered to the left hand side of the power piston. At this time maximum assistance is given to the driver. Due to the closure of orifices 1 and 3, which relate to passages **B** and **C**, the fluid will flow through passage **D** to the left hand side of the power piston. The returning oil from the right hand side of the power piston will travel through passage **A** back to the reservoir.

Flapper valve



The flapper type control valve is used with the recirculating ball type steering system and is integral with the torsion bar. The high-pressure oil generated by the power steering pump is first directed through valves V1 and V2. These valves control the direction in which the fluid flows. Fluid is allowed to flow from P to A to T or from P to B to T depending on which direction the driver turns the steering wheel. These first two valves form flapper number one.



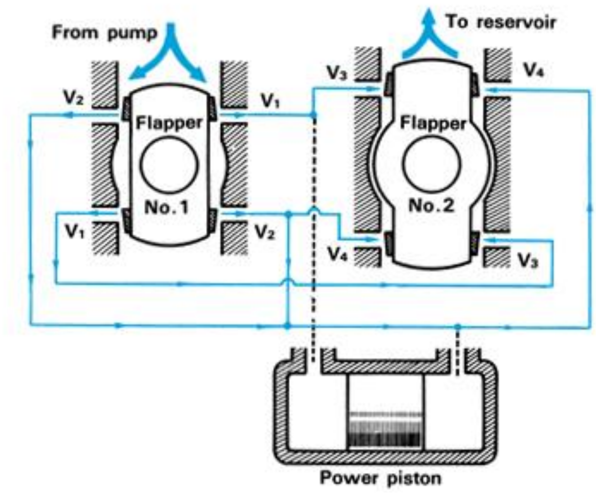
The second two valves act as pressure control valves, controlling the pressure at points A and B, depending on the amount of force generated by the drive turning the steering wheel. These two valves form flapper number two.

If the steering wheel is in the straight-ahead position so the control valve is in neutral, all four of these valves are open, so there is no pressure difference at points A and B.

If the driver now turns the steering wheel to the left, V1 off flapper number one is opened and V2 is closed. Flapper number two will also be operating at this point, Partially opening valve V3 and fully opening V4. By opening and closing these valves, pressure will rise at point a forcing the piston to the right thus giving assistance to the driver.

Neutral position

When the steering wheel is in the straight-ahead position, the control valve is in the neutral position. Neither flapper number one or flapper number two is moved so all four valves are open. This allow fluid to travel from the power steering pump directly back to the reservoir through all the passages. As all the valves are open, there will be no pressure difference between left and right hand sides of the cylinder so no assistance is given.



V_1 Open

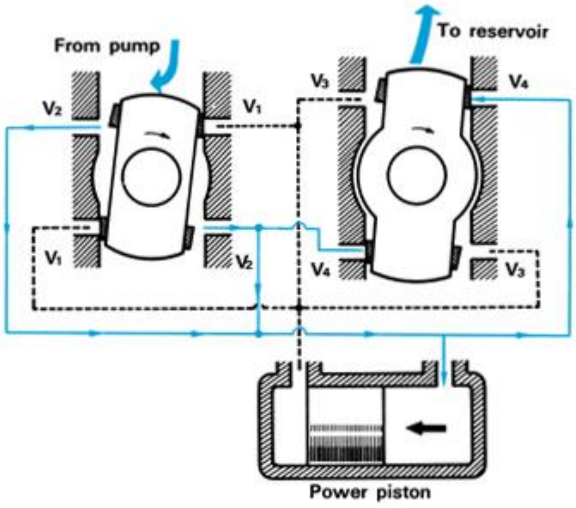
V_2 Open

V_3 Open

V_4 Open

Turning right

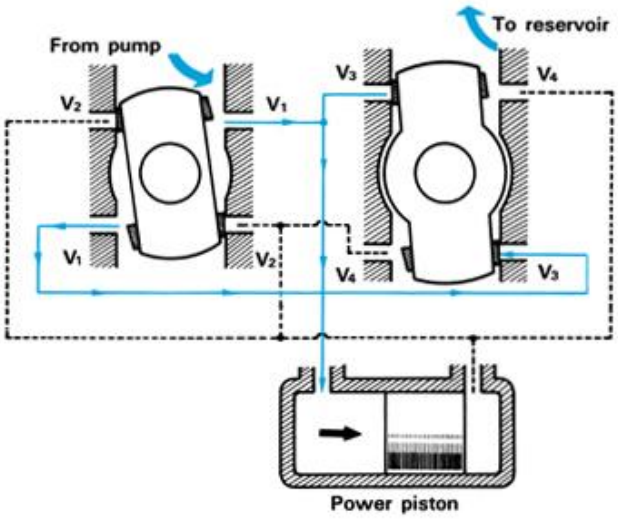
As the driver turns the steering wheel to the right, pressurised fluid will travel through valve V2 to the right hand side of the power piston. If the driver continues to turn the steering wheel then the pressure acting on valve V4 caused by the increased force generated by the driver, will close V4 tightly. This will cause the fluid pressure to raise giving maximum assistance to the driver. As the amount of turning force exerted by the driver is reduced, so is the amount of twisting of the torsion bar. This causes valve V4 to open slightly thus reducing the amount of assistance given.



V_1	Closed
V_2	Open
V_3	Open
V_4	Partially Open

Turning left

When the driver turns the steering wheel to the left, the flapper valves move in the opposite direction to when the driver is turning to the right. The operating principles are identically the same as when carrying out a right hand turn, except the pressurised fluid is directed to the left hand side of the power piston.



V_1	Open
V_2	Closed
V_3	Partially open
V_4	Open

Progress check

1. Why is power steering required?

___

___

2. What is the purpose of the flow control valve?

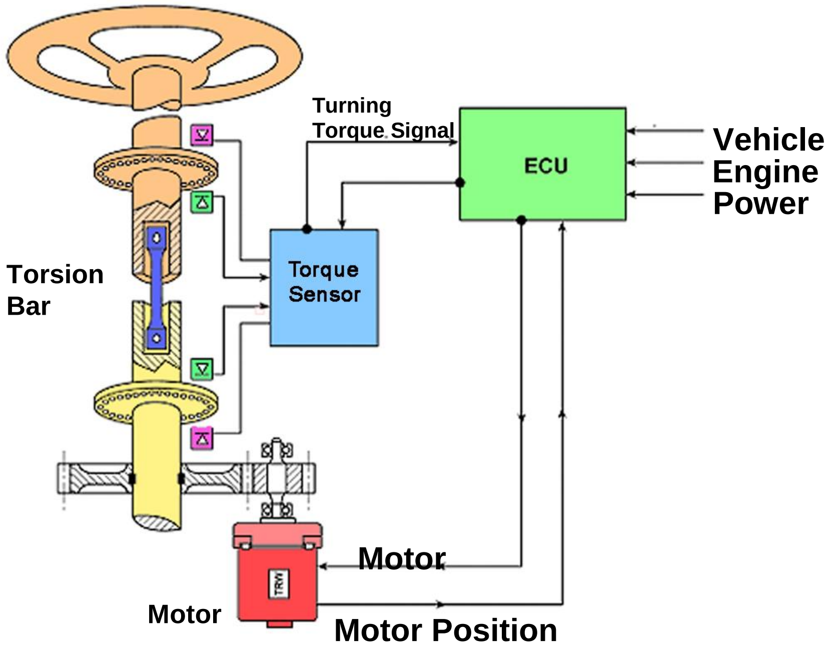
3. Name three types of control valve

4. Why are idle up devices fitted?

Electronic Power Steering (EPS)

EPS systems have become increasing popular with manufactures. They are more compact and can be easily adapted to many different vehicles by adapting the control software.

Review of Construction



The EPS system uses an electric motor acting on the steering column. The steering column is in two halves linked with a torsion bar. The torque sensor measures the relative position of the two sections of steering column. The example shown uses optical type sensors. An LED and phototransistor are arranged either side of a shadow plate fixed to the steering column. The outputs from the phototransistors are processed by the sensor circuit to produce a turning torque signal. The ECU calculates the required assistance level and controls the motor. It also provides a diagnostic system.

Principle of operation

The EPS system provides the following control functions:

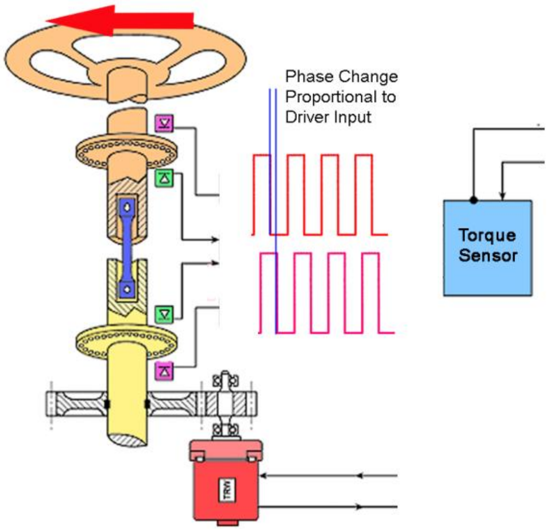
- road Speed sensitive power assistance
- assisted Steering Return.

Both of these functions are the result of the motor voltage control by the ECU. The ECU determines the voltage supply to the motor based on the following data:

- force applied to the steering wheel by the driver
- vehicle speed

- steering angle position
- speed of steering angle change.

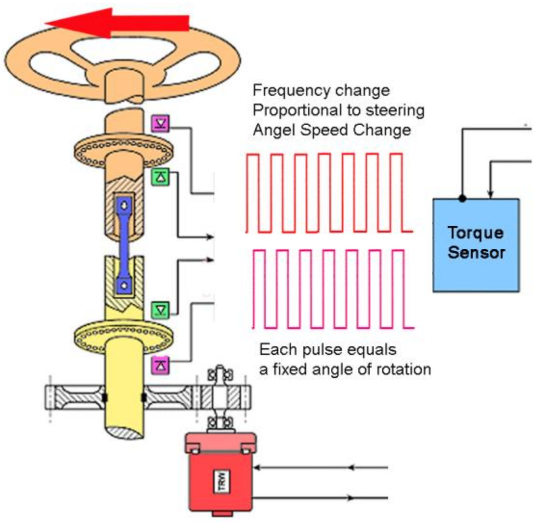
Torque sensor measures the input force applied by the driver. When the driver turns the steering wheel the torsion bar between the two halves of the steering column will twist. The amount of twist is proportional to the force applied. The output signal of the two phototransistors, will move out of phase. The size of the phase change will be proportional to the twist in the torsion bar and therefore to the force applied by the driver.



The torque sensor will also measure the steering angle position and the speed of angle change. The steering angle position is calculated by counting the number of pulses from the phototransistor. The speed of steering angle change is proportional to the frequency of the signal from the phototransistor.

The torque sensor circuit measures these three parameters and then outputs a digital signal to the EPS ECU.

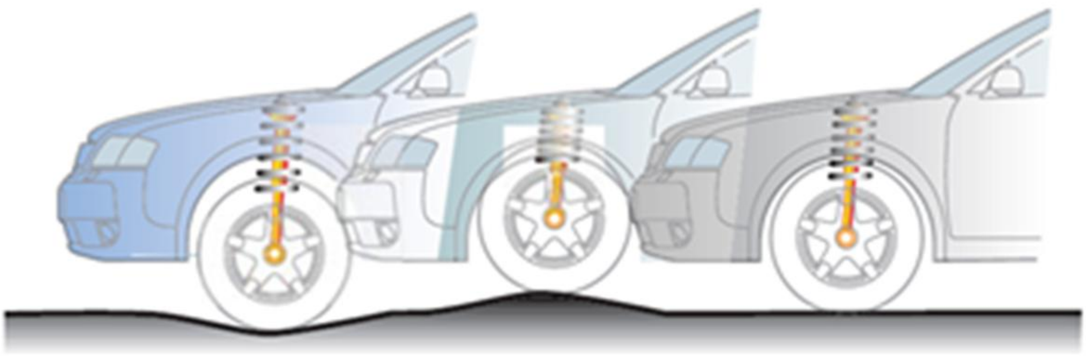
The EPS ECU combines this data with the road speed to calculate the direction and speed of the motor.



Advantages of power steering

- Reduced driver effort
- Increased driver comfort
- Reduced driver fatigue
- Increase manoeuvrability
- Reduces the number of turns from lock to lock
- Reduces transmission of shock from the road surface
- Safer steering control

The operating principles of suspension systems



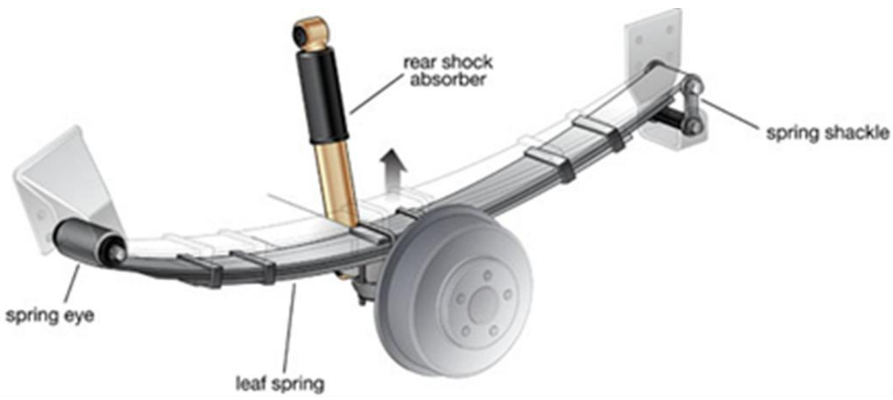
The purpose of the suspension system is to isolate the vehicle and it's occupants from most of the vertical movement of the road wheels as they pass over bumps in the road surface. This ensures that the driver and passengers have a comfortable ride and the vehicle body is not subjected to excessive shocks, which could cause damage. The spring absorbs road shocks and allows the wheels to follow the undulations of the road surface. This last point is important to ensure that the driver has control of the vehicle. If the road wheels leave the ground control of the vehicle is lost.

Types of metal springs

There are three types of metal vehicle springs in common use.

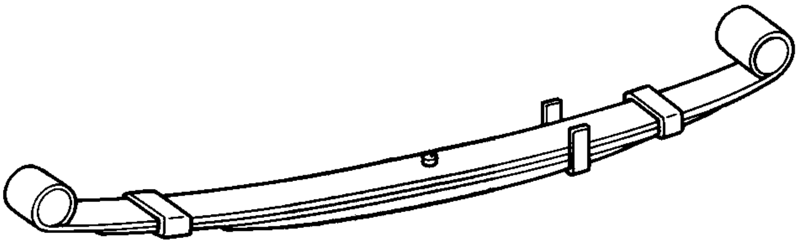
- The leaf spring,
- the coil spring (or helical spring)
- torsion bar.

Leaf springs



Leaf springs perform a dual role. They act as spring and also hold the axle in place. Unfortunately, when used alone, they tend to be too stiff as a spring and too flexible as an axle-locating device

The front end of the spring is fixed to the chassis by means of a pin through a bracket. This called the fixed shackle. A similar arrangement holds the spring in position at the rear; this is called a swinging shackle and is to allow for the changing length of the spring as it moves up and down.



The diagram above shows a multi-leaf spring again. Number the following on the diagram.

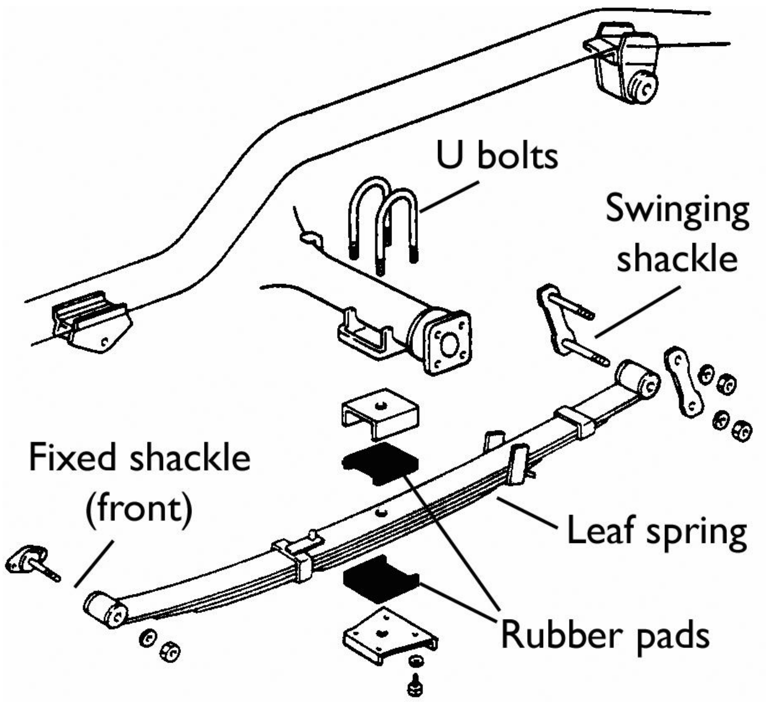
1. spring eyes,
2. centre bolt
3. rebound clips

The spring eyes are used to fix spring to chassis via shackle pins.

The centre bolt keeps leaves in position and locates spring to axle.

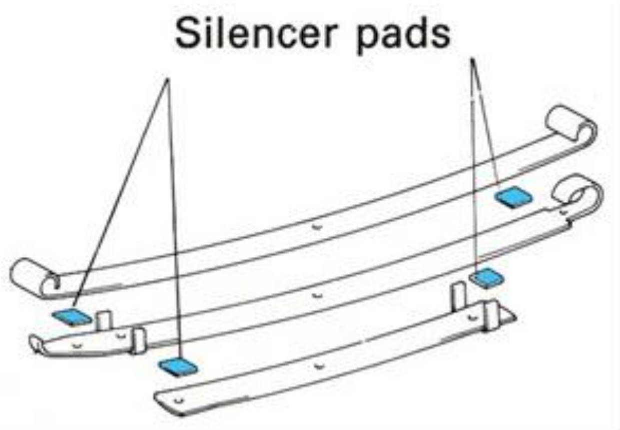
The rebound clips prevent overloading of the main leaf during rebound by holding all the leaves together.

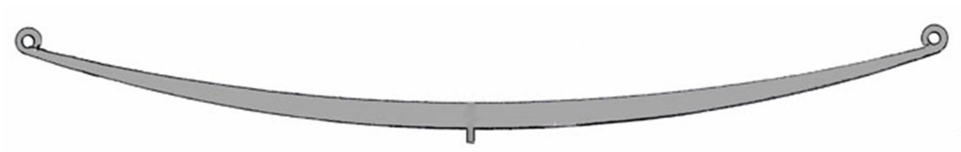
The diagram on the right shows all the components used to mount a leaf spring to an axle. In this example it is a driven rear axle.
The centre bolt in the spring can be seen. This passes through the hole in the upper rubber pad, and its plate, into a hole in the mounting, which is welded to the axle tube. The U bolts clamp the assembly to the axle via the rubber pads and their plates. The front fixed shackle pin passes through the holes in the chassis mounted bracket and a



rubber bush in the spring eye. The swinging rear shackle is mounted in a similar fashion by way of rubber bushes in the spring eye and shackle bracket. The use of rubber reduces the transmission of road noise and vibration.

The diagram below illustrates a simple three leaf spring with rubber or nylon silencer pads. These pads are used to reduce noise and inter-leaf friction.



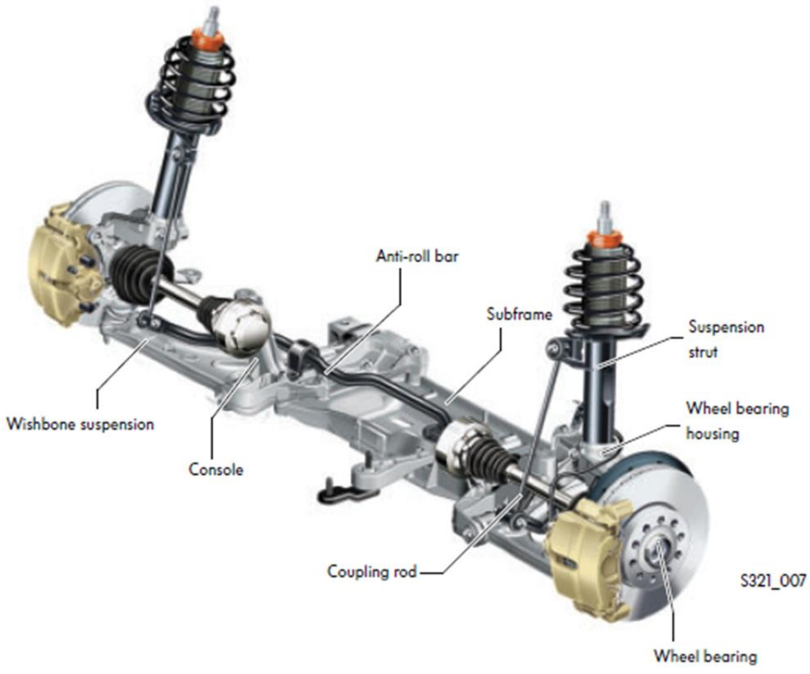


A single taper leaf spring is shown above. It has a parabolic shape. This type of spring is now used on pick- ups and light vans. The shape of the spring ensures that the stress is equally distributed throughout the spring.

Coil springs

The diagram on the right shows a typical coil or helical spring. As shown, the spring is formed from a single length of spring steel formed into a coil.

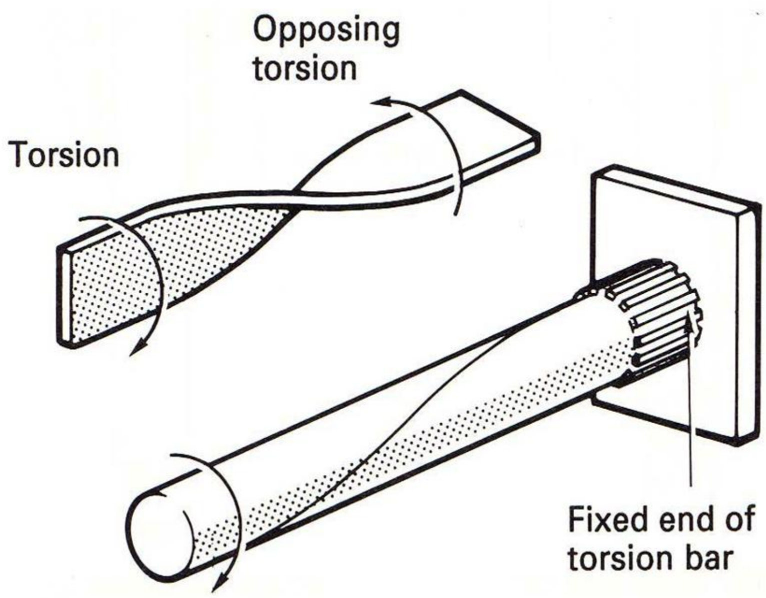
The majority of cars and light vans use coil springs for both front and rear suspension systems for the following reasons. It is a simple compact design, which is easy to manufacture in its many forms. The diagram shows a simple constant rate spring. Variable rate springs may be tapered or have the coils closer together at one end.



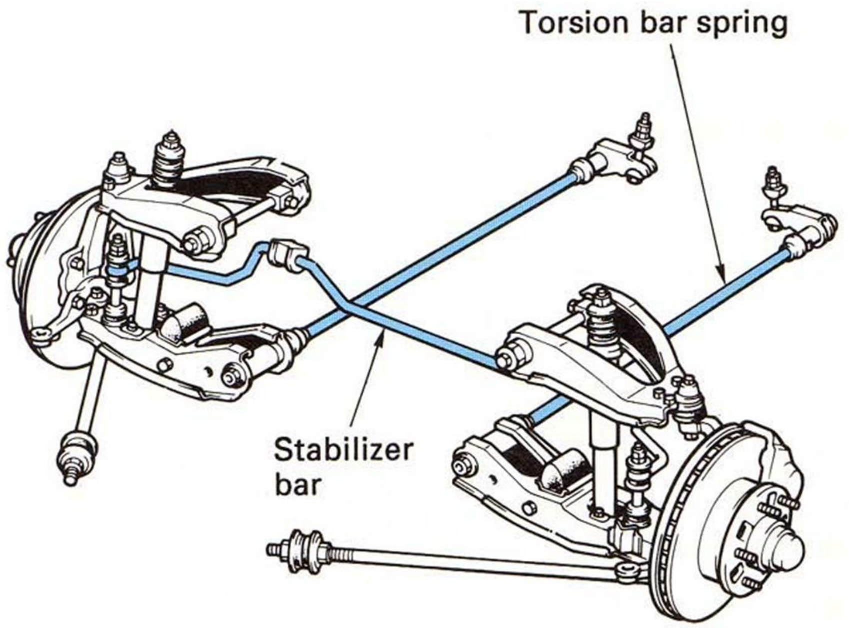
An example of the use of coils springs is shown in this front suspension system. This is very typical of the type of suspension used on the modern front wheel drive car.

Torsion bar spring

The torsion bar spring is the last metallic spring to be covered. It is rarely used on cars today but has uses where limited space or suspension/transmission design prevents the use of coil springs. It is a very simple design and it easy to adjust the ground clearance of the vehicle. This diagram shows the principle of the torsion bar spring. The rate, or stiffness, of the torsion bar depends on its length and diameter. Increasing its diameter or reducing its length will make the spring stiffer and vice versa.



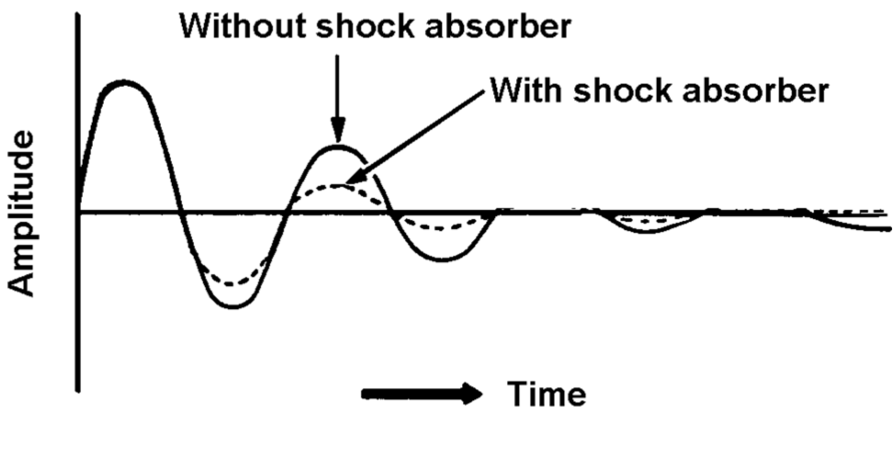
The same principle applies to a coil spring since this is in effect a helical torsion bar.



The diagram above shows a front suspension system using torsion bars and wishbones top and bottom. (We will cover the use of wishbones later). The fronts of the torsion bars are splined into the bottom wishbones and as the road wheel moves upwards the torsion bar is twisted. The fixed end of the spring is splined into chassis mounted brackets. The adjusting bolts on these brackets are to set the ride height or ground clearance of the vehicle.

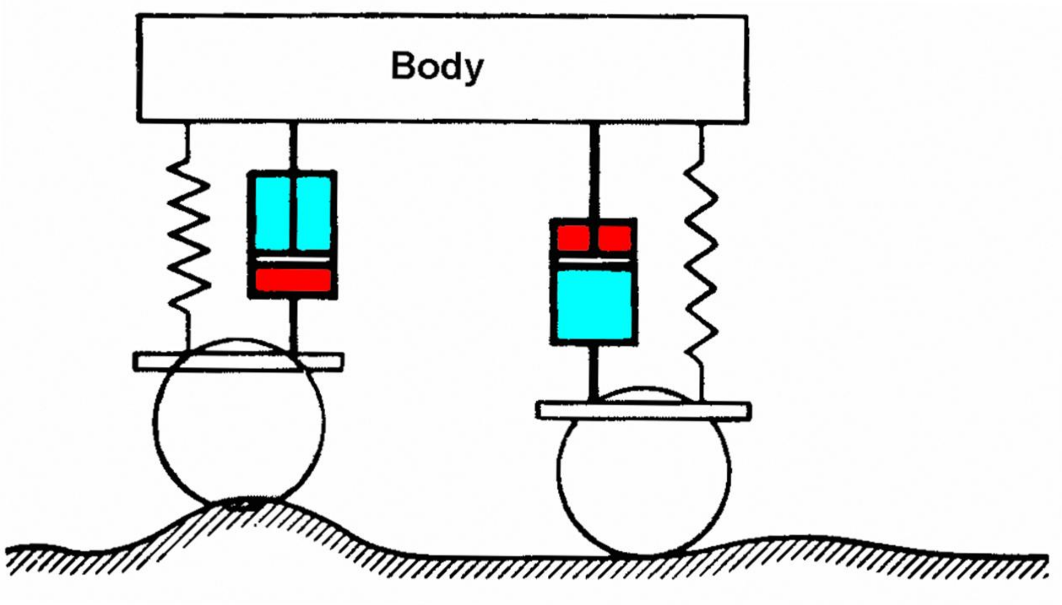
Spring dampers

These are used to absorb some of the energy stored in the spring. This reduces the likelihood of the vehicle body bouncing as it passes over bumps in the road surface.
Almost all dampers or shock absorbers as they are sometimes called, are hydraulic telescopic.

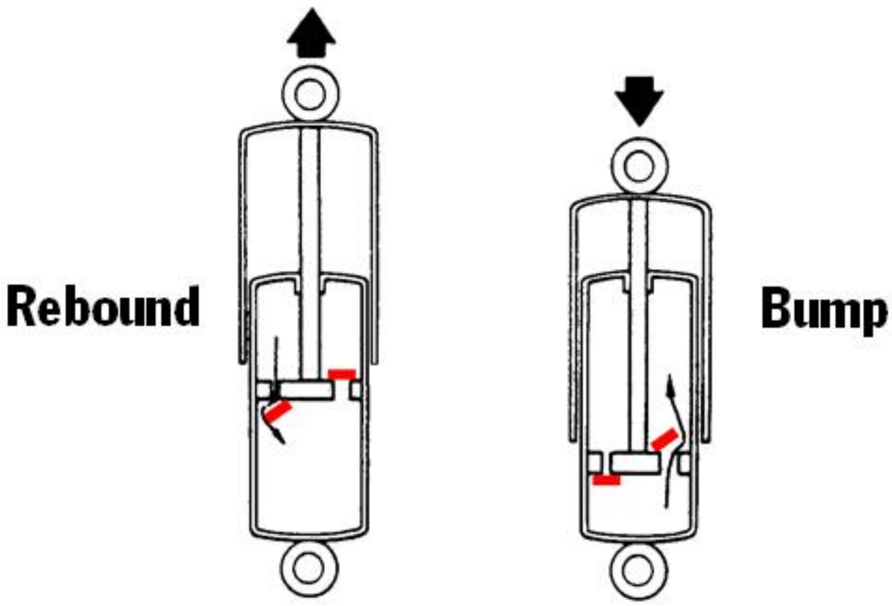


The graph above shows the oscillation of the spring and suspension with and without a damper. The rising line on the graph is bump and the falling line is rebound.

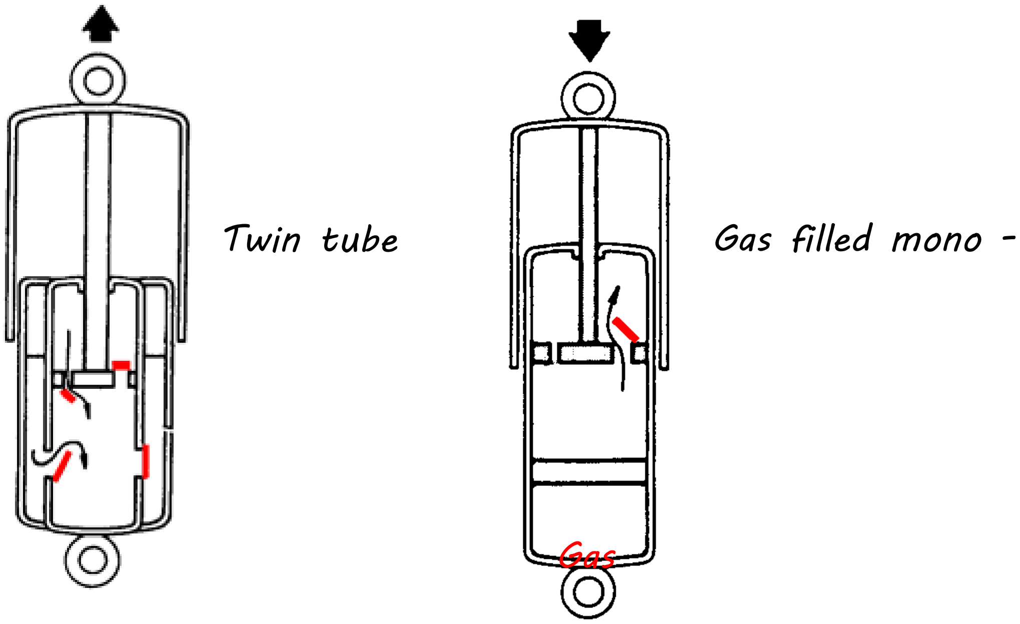
Principles of suspension



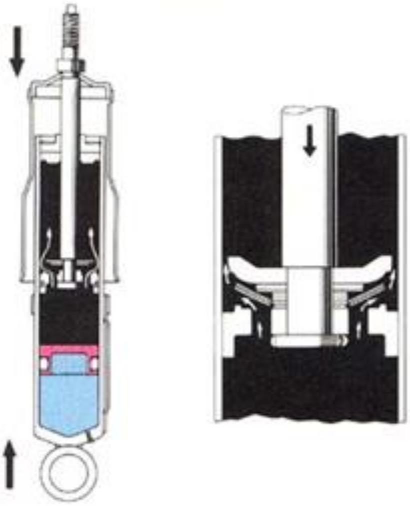
The drawing above shows the basic principle of the telescopic damped coil spring suspension system.

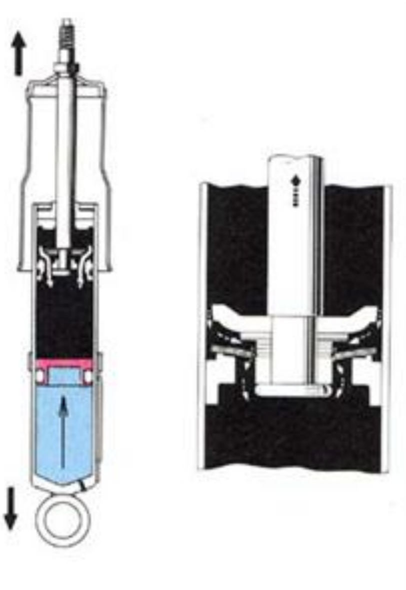


The principle of the hydraulic damper is shown above. Oil is forced through the valve holes in the piston as the damper is compressed on the bump stroke (RH) and extended on the rebound stroke (LH).

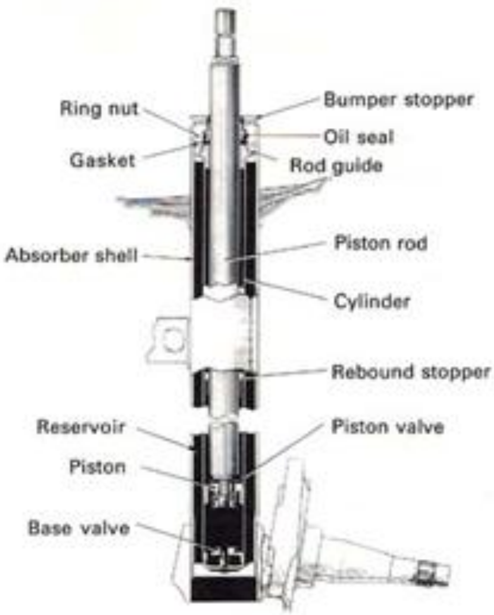


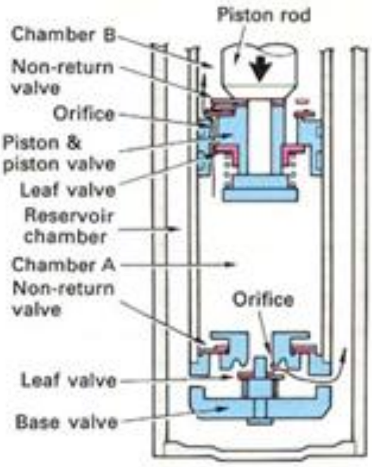
The diagrams above show a twin tube damper and a modern gas filled mono-tube damper. These designs of dampers are used because there is a basic flaw in the design of the simple damper shown previously. When the damper is on the bump stroke oil flows from the lower chamber to the upper chamber as the piston moves down, but the piston rod takes up some of the volume in the upper chamber. Means must therefore be taken for the oil that is displaced by the piston rod to flow somewhere. On the twin tube damper the oil flows in to the outer tube. On the rebound stroke the action is reversed. In a gas filled mono-tube damper. As the oil is displaced during the bump action shown it forces down the free piston, which compresses the inert gas below the piston.

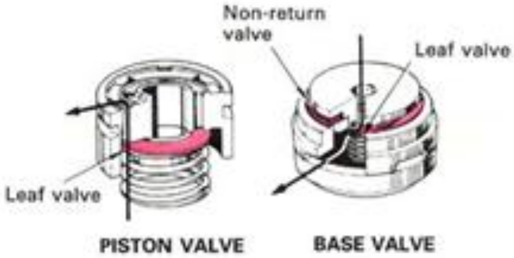


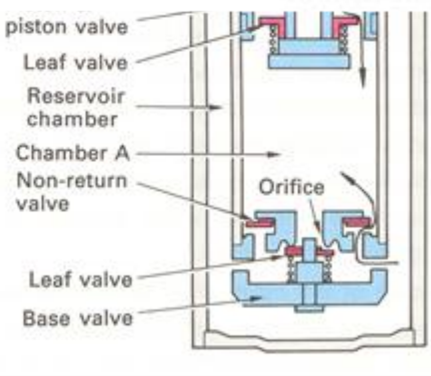


The illustration below shows details of the valve arrangements in a twin tube damper.



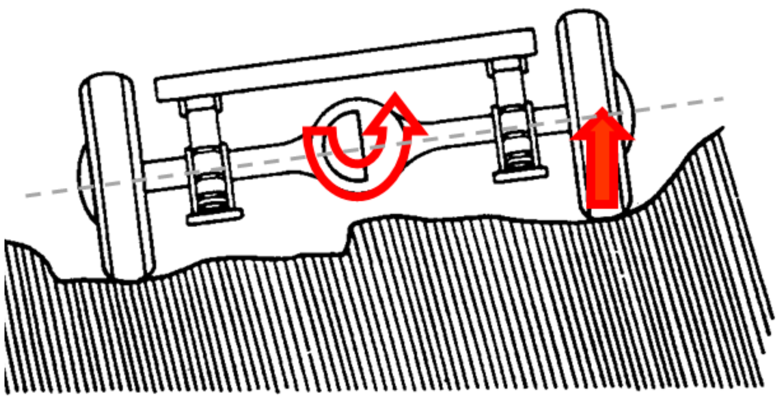






This diagram shows details of the base valve in a twin tube damper. The oil flow through the spring-loaded valves can be seen.

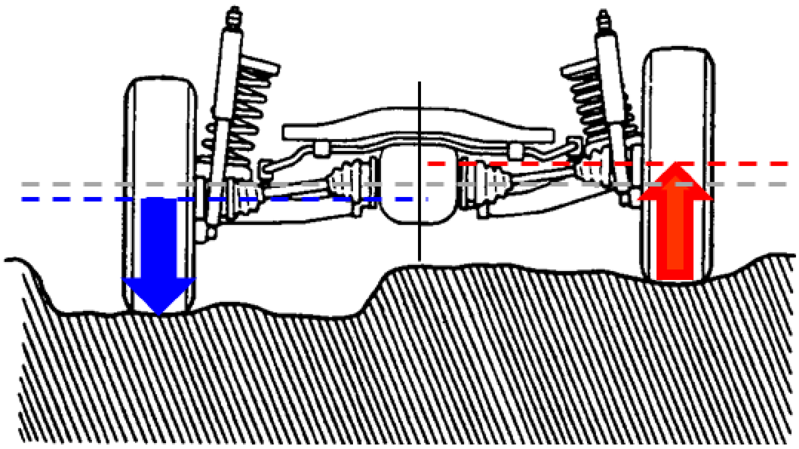
Non-independent suspension system



The diagram above shows the action of a non-independent suspension system. As you can see, vertical movement of the right hand wheel causes the axle, vehicle body and left hand wheel to move. The axle shown is a driven or live axle but the same principle applies to a steered or a non-driven rear axle. The non-independent suspension system has many disadvantages. The most significant faults being, relatively small spring deflection and poor control over the steering geometry. Other problems relating to this simple type of suspension system will be covered in later modules.

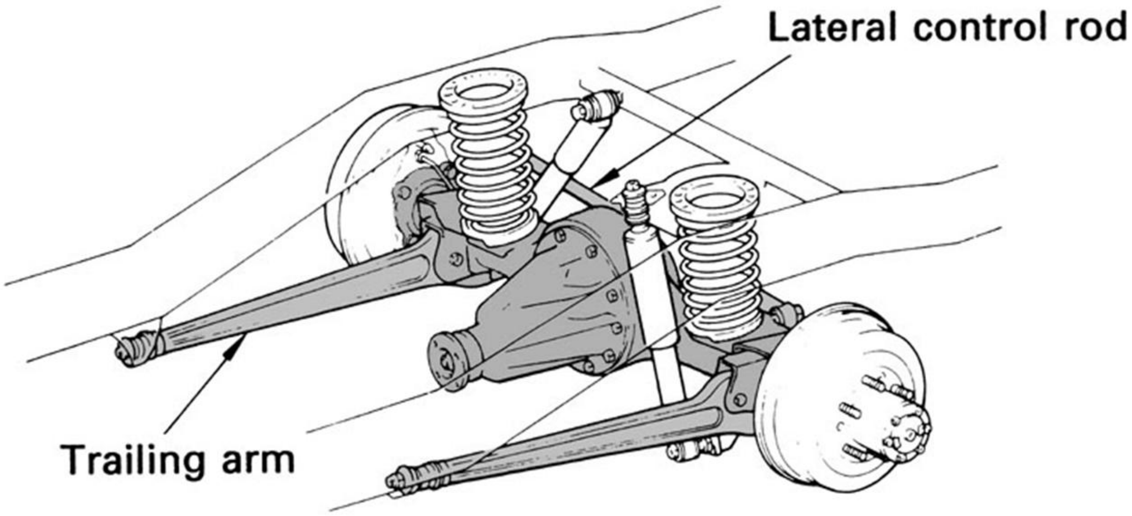
Note that the design and construction of both the steering and suspension are very much related.

Independent suspension systems

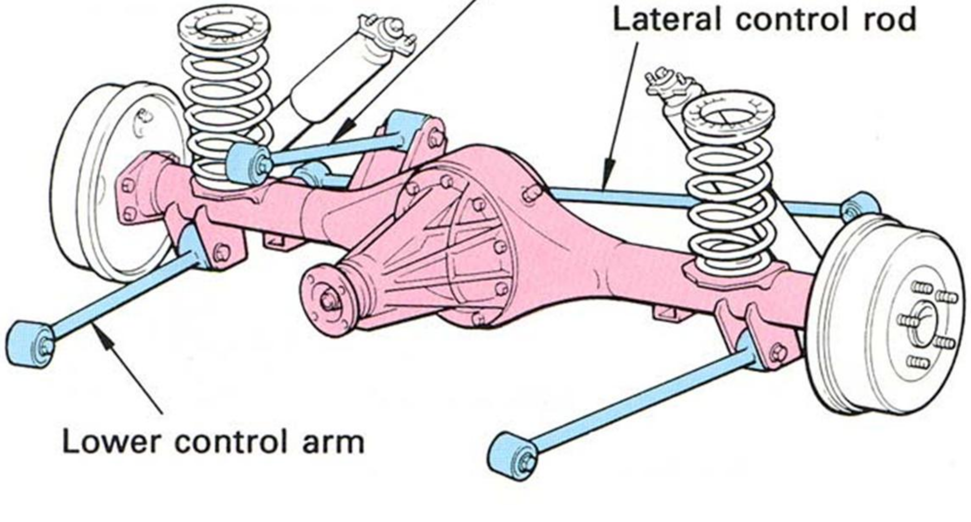


The diagram above illustrates the principle of the independent suspension system. You can see that each wheel moves up and down independently of the other wheel causing little movement of the body. This system is used almost universally on cars and light vehicles on both the front suspension, independent front suspension (IFS) and at the rear Independent rear suspension (IRS). The abbreviations (IFS) and (IRS) always tend to used.

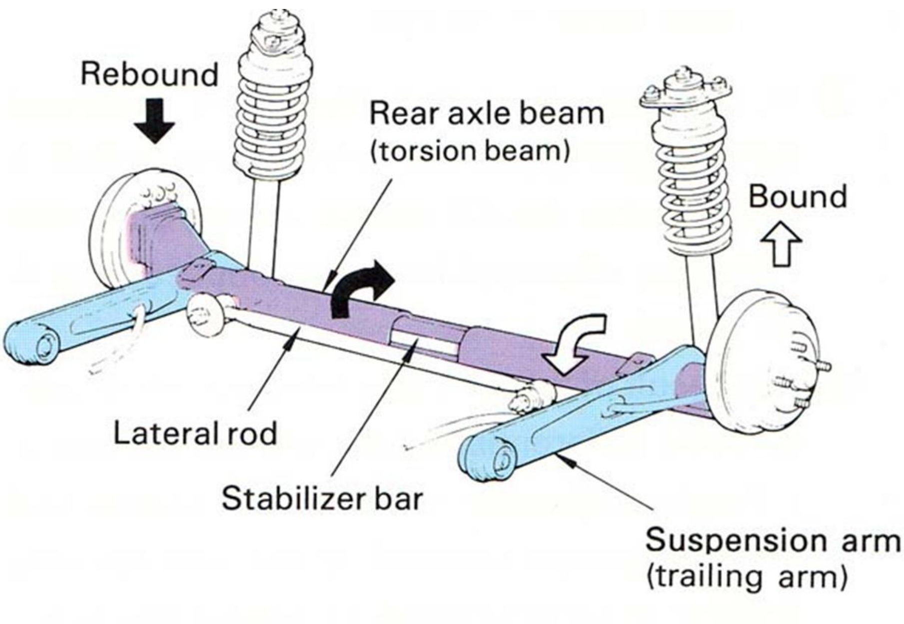
The diagram on the right shows a dead axle suspended on a single leaf parabolic spring. Any fears about failure of the single leaf are groundless with today's use of modern alloy steels and sophisticated manufacturing techniques. Composite materials such as Carbon Fibre are also used in the manufacture of some of these springs.



The diagram above shows the use of coil springs on a driven live axle. The axle is located longitudinally by the two large trailing arms, which are fixed to the axle. There is another arm behind the axle, which locates it and prevents it moving sideways. This is called a transverse link, lateral control rod or Panhard rod. The use of trailing arms and other suspension components will be covered later on in this module.



A further example of a driven live axle suspended on coil spring is shown above. Notice how the one upper control arm and the two lower control arms locate the axle. These take the place of the trailing arms. They are lighter in weight, fixed by means of rubber bushes and will allow the axle a greater degree of articulation. This last point is useful with an off road vehicle.



The torsion beam axle is shown above. It is used as a rear axle on small/medium cars, which employ front wheel drive. The axle beam acts like a torsion bar so in effect it is a semi-independent rear suspension. It is a very simple design, which is light in weight and takes up little space. It also helps to increase the roll stiffness of the car.

The need for wheel/axle location

To ensure proper control of the vehicle the road wheel should move only vertically over the bumps in the road.

There should be no lateral or side-to-side movement of the wheel

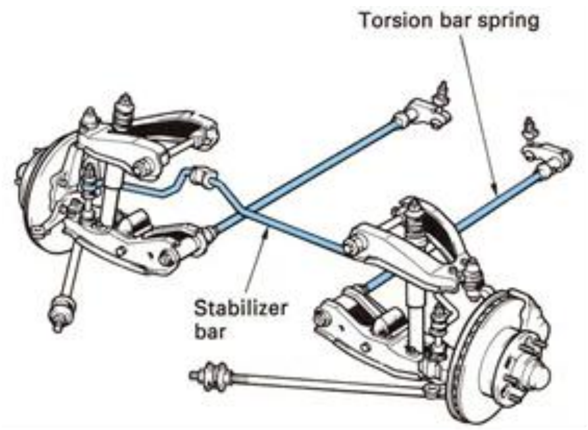
It should not move in a longitudinal or front to rear direction

Apart from leaf spring suspension all other suspension systems need some device to hold the axle/wheel assembly in position

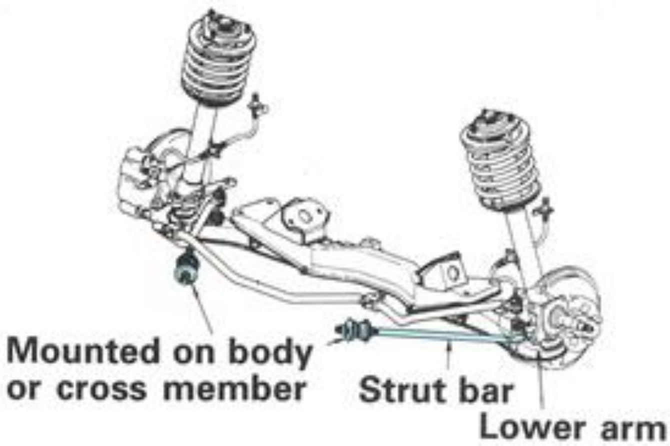
Some form of triangulation system will be seen in almost all types of suspension linkage. The three-sided figure is the only one that is always stable. If for example a four-sided figure was used then an applied force could cause it to move out of shape.

Try and identify this in the following layouts

An example of triangulation on a torsion bar front suspension.

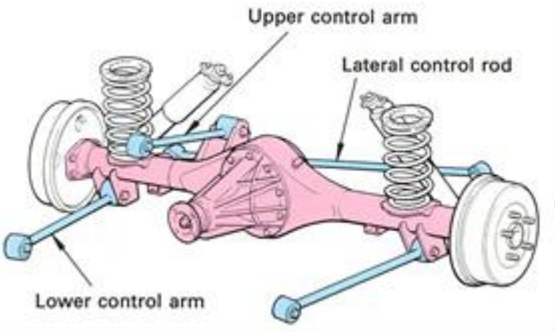


Draw in the triangle.



Draw in the triangle.

On this example the lower arm and strut bar form the triangle.

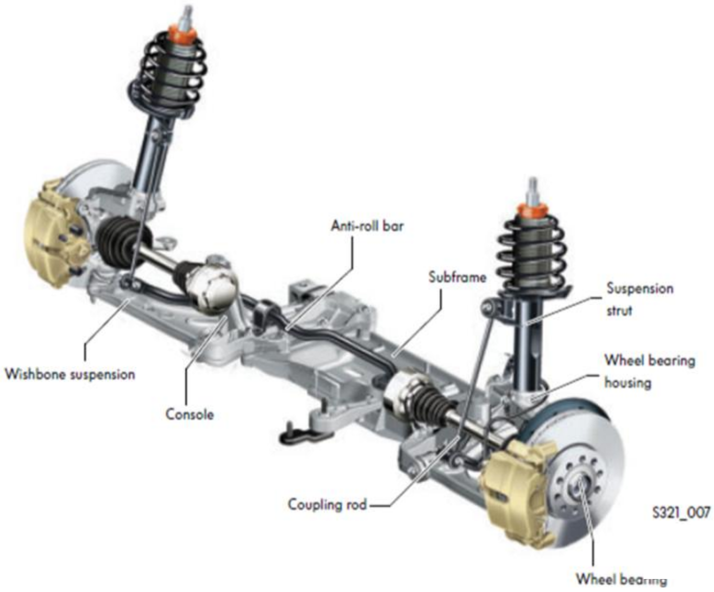


This diagram shows the final example of the use of triangulation.

Draw in the triangle again.

Independent suspension systems

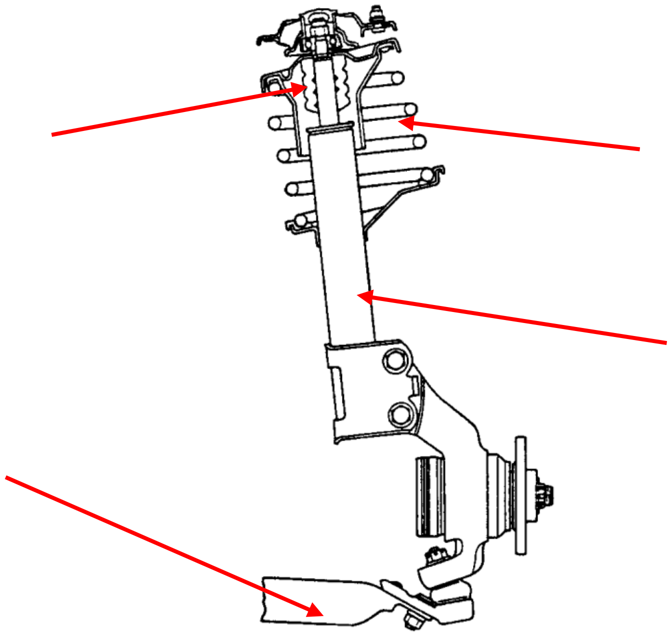
The following layouts are examples of both independent front suspension (IFS) and independent rear suspension (IRS).



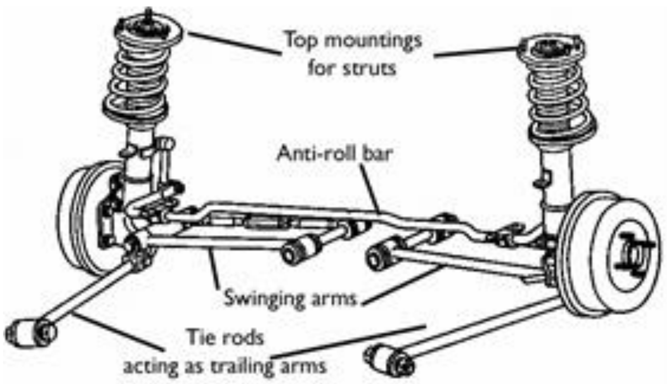
The diagram above is an example of the very popular MacPherson strut IFS An American engineer designed this suspension by the name of Earle MacPherson.

It employs a long strut, which houses the telescopic spring damper (or shock absorber) with the coil spring mounted at the top. A rubber mounted ball or taper roller bearing, above the spring, secures the suspension unit to a reinforced section of the body. Because of the length of the strut it is only necessary to use a triangulated linkage at the bottom of the suspension. There being very little change of road wheel angle as it moves up and down over the road surface.

The diagram below shows a more detailed drawing of the MacPherson strut. Apart from the simplicity of this suspension layout it is very easy to install a drive shaft for front wheel drive vehicles. You can see on the right where the drive shaft would fit since the spring/damper unit are well clear of the wheel/hub assembly.

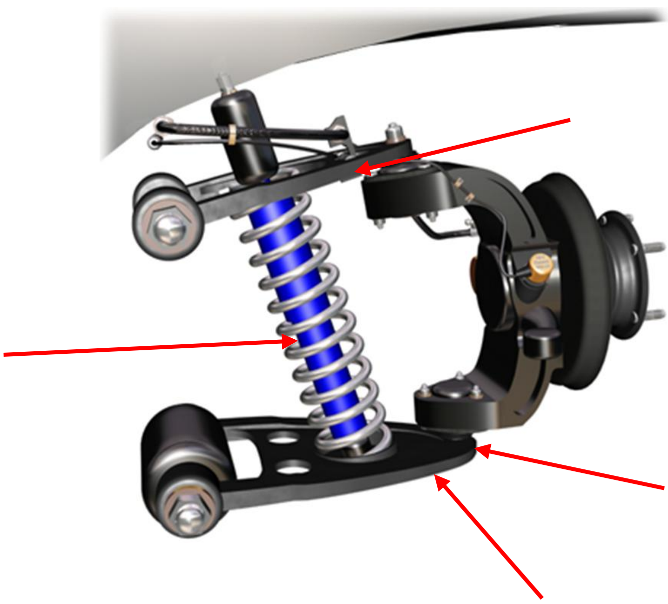


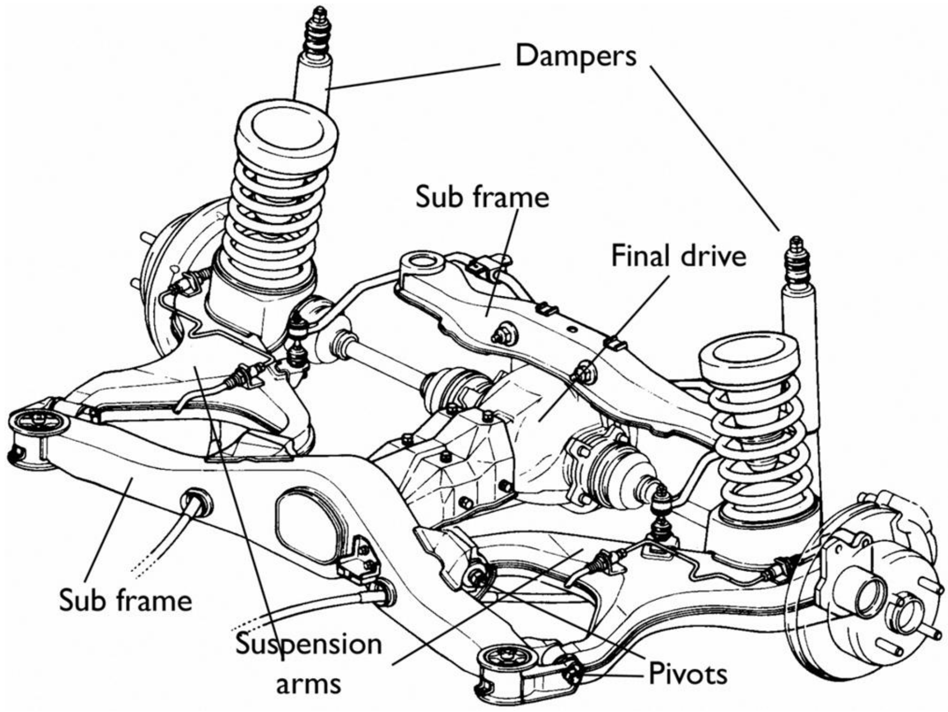
The diagram below shows a MacPherson strut rear suspension (non-driven axle). It uses simple rods with rubber bushes at the ends to locate the wheel and hubs. On each side are two rods, which form the swinging arms and a tie rod, which, acts as a trailing arm. The rod at the rear is adjustable for length in order to adjust the rear wheel alignment.



Wish bone suspension

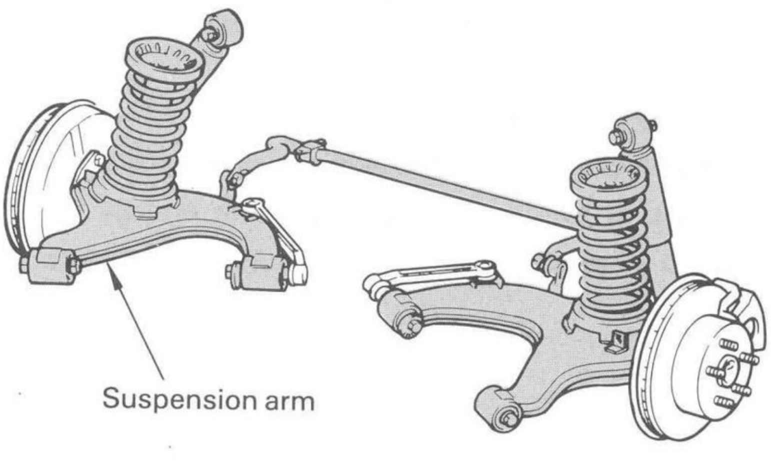
The IFS layout shown above uses a forged or fabricated wishbone at the top of the suspension in addition to the lower wishbone. Notice that the upper wishbone is shorter than the lower one. This is to ensure that the steering geometry is maintained within acceptable limits. The spring and damper units are only subjected to vertical loads were as on the MacPherson strut other loads may be imposed on the strut unit. This particular layout could be classified as heavy duty and is likely to have a long life with little maintenance.

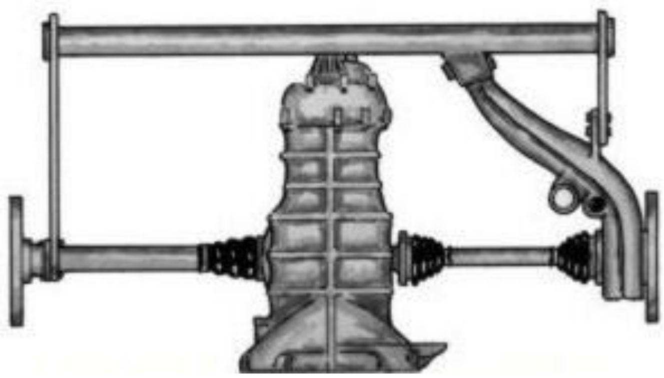




A semi-trailing arm IRS is shown above. The size of the large suspension arm gives immense strength to this arrangement and ensures that the change of wheel angle is kept to a minimum as rides over road irregularities
Extensive use is made of rubber bushes. The suspension arms use rubber bushes on the pivot points to the sub-frame and the sub-frame is rubber mounted to the vehicle body. This reduces both noise and vibration. The final drive unit is also rubber mounted to the sub-frame, since; as you can see from the diagram the rear wheels are driven.

The set up illustrated below is an almost identical suspension to the one shown above. In this example however the wheels are not driven.

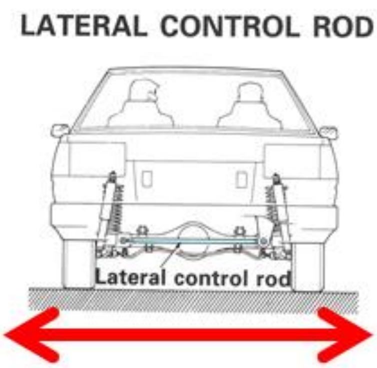


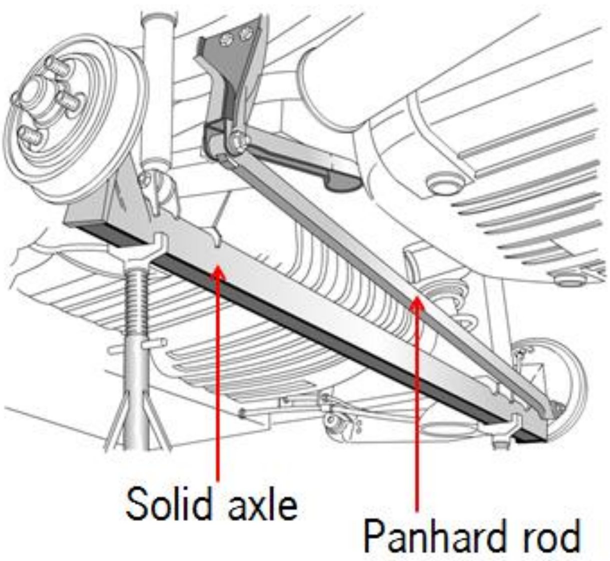


This is an example of a swinging half-axle design as used on a vehicle with a rear engine. Although a simple design it suffered from large changes in the rear track as the wheels moved up and down which adversely affected the road holding of the car.

Panhard Rod

A lateral control rod, or Panhard rod, is shown below. It is used as a mean of locating the axle laterally or sideways as the name implies. The lateral control rod is only fitted to some to live rear axles usually those mounted on coil springs. However leaf spring suspended axles also benefit from the fitment of this item, which gives improved location by relieving the springs of part of their secondary role.





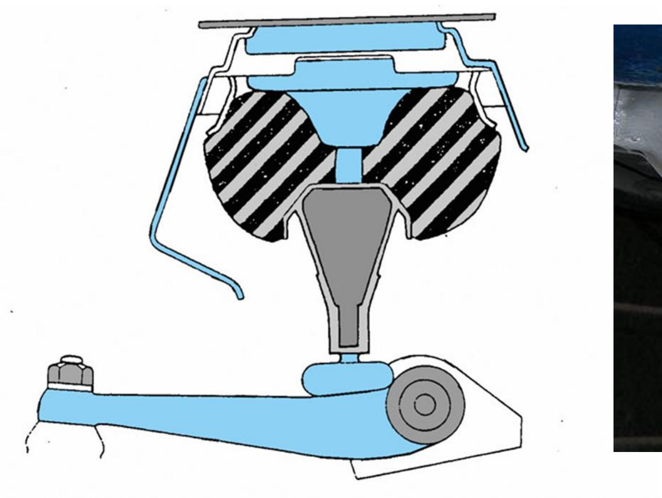
Non-metallic springs

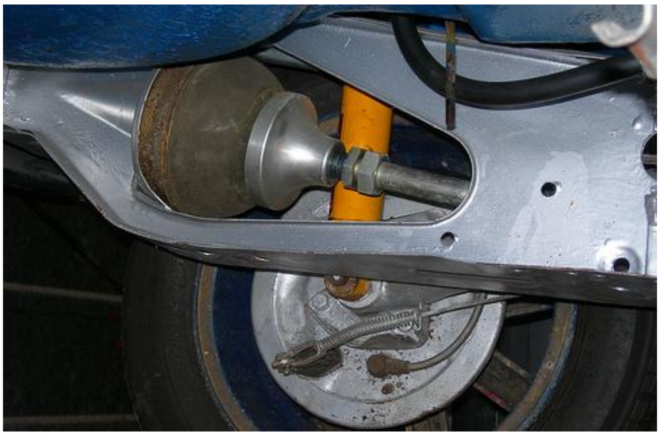
The following are examples of non-metallic spring
Materials commonly used on light vehicles:

- rubber springs
- hydro-pneumatic springs
- air springs.

These springs are used with independent suspension systems.

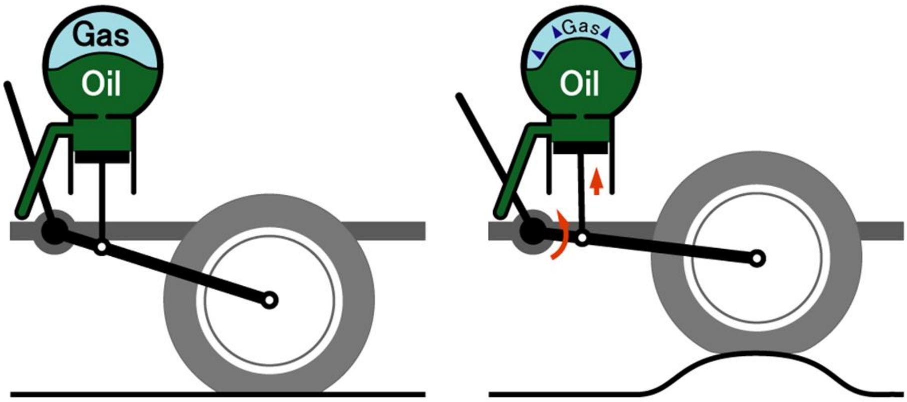
Rubber springs





The diagrams above show the arrangement of an IFS system using a rubber cone spring. The spring is very stiff, hence the large lever ratio of the upper suspension arm. This is around 5:1 but it has the advantage of a very small spring travel. The spring is progressive in its rate i.e. it is soft for small movements but gets stiffer as the travel increases.

Hydro-pneumatic suspension

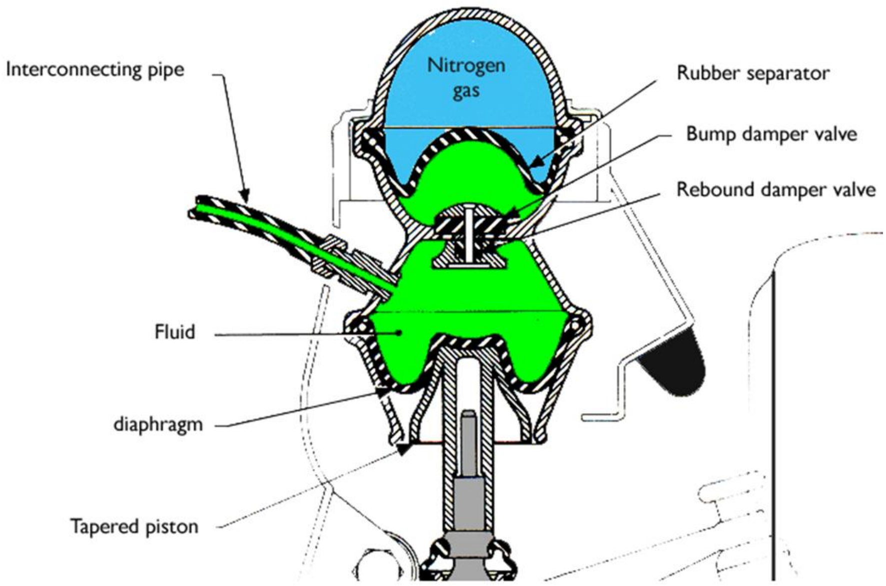


The diagram above illustrates a simple hydro-pneumatic suspension system using a Nitrogen gas spring. Nitrogen is used because of safety considerations. The gas being inert and will therefore does not support combustion.
The layout of the suspension linkage is very similar to that of the rubber suspension.

Operation

The force produced by the upward wheel movement is transferred to the spring by the water-based liquid. Remember that liquid is not compressible and is used to transfer force in a similar way to a hydraulic braking system. Some of these suspension systems are interconnected front to rear to reduce pitching of the vehicle. Other layouts operate alone without the use of the interconnecting pipe. The system shown is not self-levelling like some of the more sophisticated suspensions that use pumped hydraulic oil to transfer force to the gas spring and maintain a constant ride height.

The details of a liquid operated Nitrogen



gas spring unit are shown in the diagram on the right. Note the use of rubber diaphragms and damper valves for the liquid.

These suspensions systems are complex and relatively expensive.

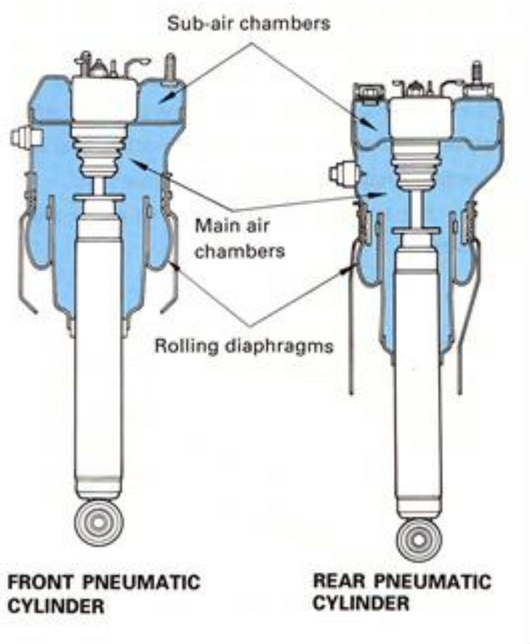
The have the following advantages

- constant ride height
- variable spring rate, which is dependent on load
- reduced body roll
- reduced pitching
- ride height can be automatically lowered with electronic control of air suspension giving improved road holding.

Air Suspension

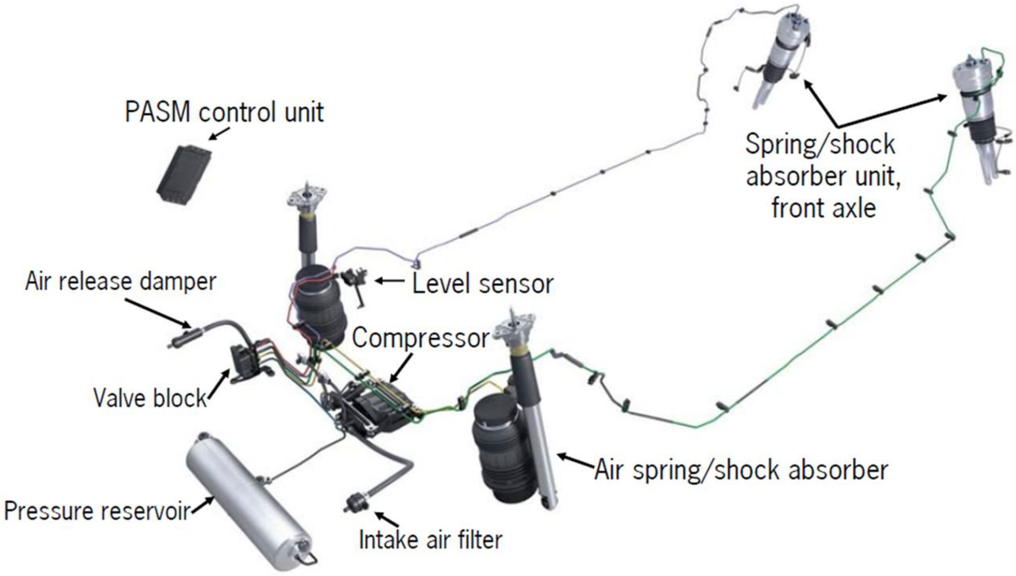
The principle of the air spring, or air suspension as it is generally called, is quite simple. An engine driven air compressor supplies air to the suspension units that are all interconnected via pipes and levelling valves or control actuators. The rate or stiffness of the springs is variable depending on the load that is applied. For example if the load is increased, by say three passengers getting into the car, then the ride height will drop. This will cause the actuators to open and air will be pumped into the system to restore the normal ride height.

The diagram above shows the layout of a car using air suspension. The relationship between the various components can be seen. Many luxury cars employ air suspension with electronic control where for example the ride height of the car is automatically lowered as the speed increases. This improves the stability of the vehicle.

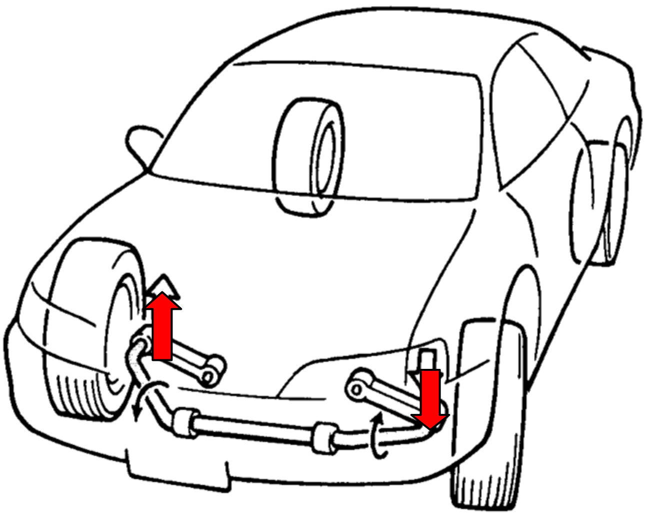


The diagrams above show the construction of a front and rear rolling bellows air spring or pneumatic cylinder unit. Note the concentric damper position, which also form the bottom suspension unit mounting, and the sub chamber mounted above the main chamber. The sub chamber can be connected and disconnected from the main air chamber to decrease and increase the spring rate respectively, i.e. make the spring softer or return it to normal. Open and closing the sub chamber is carried out by the suspension control actuators, which also control the damper settings.

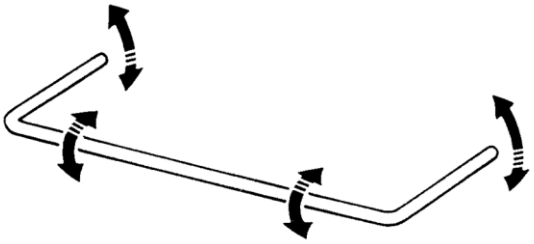
Typical system layout

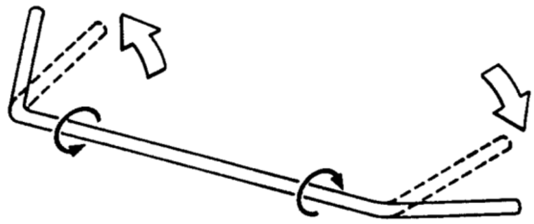


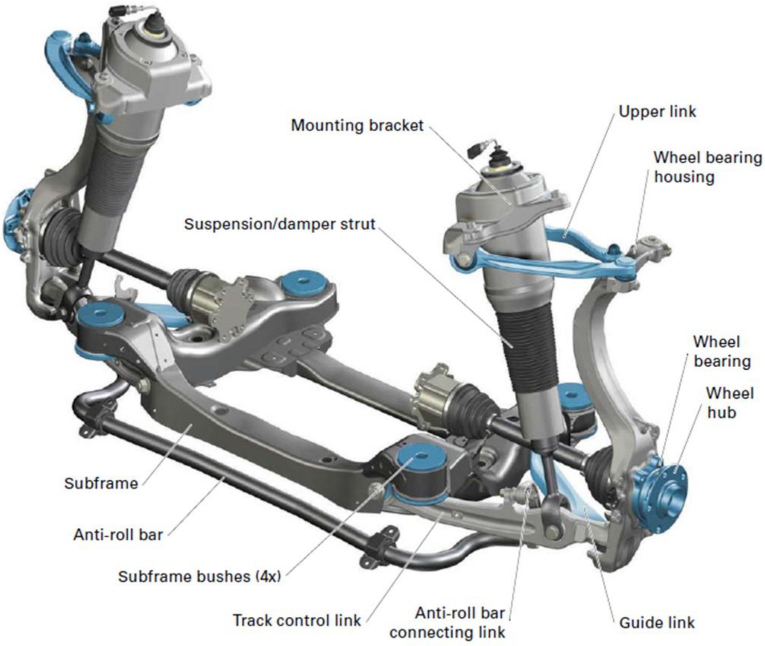
Anti-roll bars



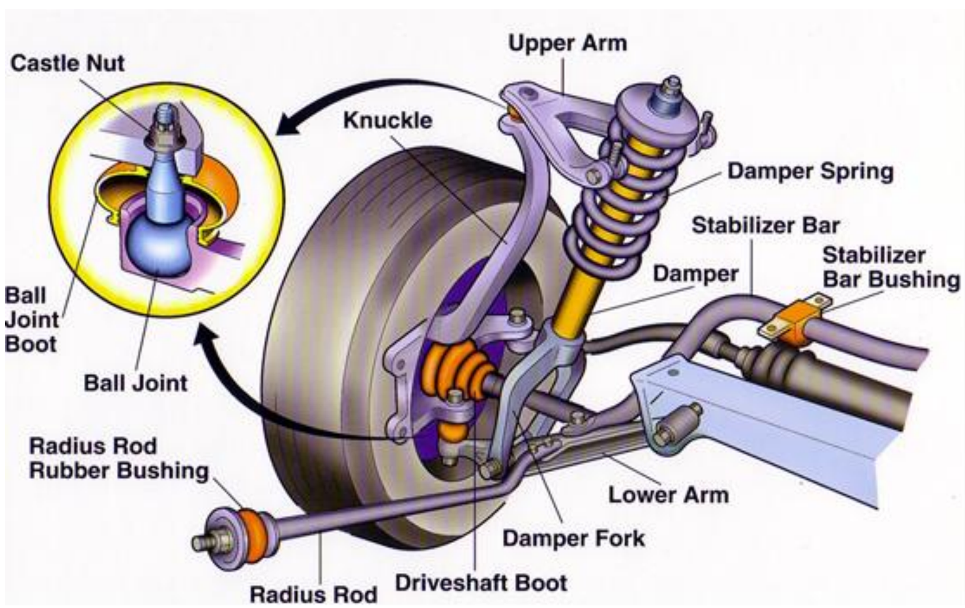
The diagram above shows an anti-roll bar fitted to the front suspension of a car. Vehicle body roll is reduced by the outside wheel pushing upwards on the end of the anti-roll bar. This causes it to twist like a torsion bar, which is in effect what it is. A torsion bar acts between the left hand suspension and right hand suspension. The diagrams below show the action of an anti-roll bar acting in its normal role and as a pair of tie rods.







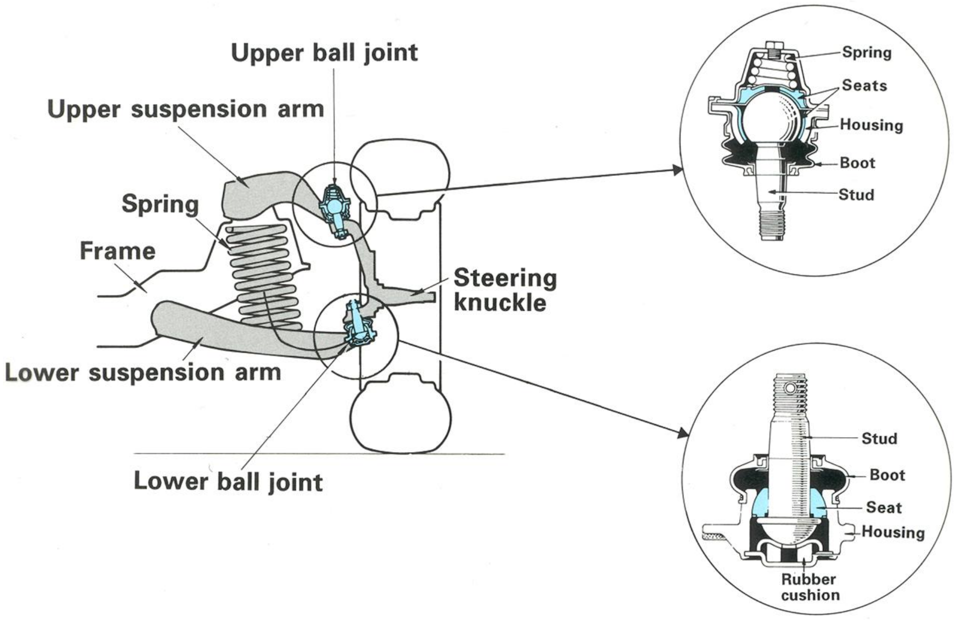
Use of suspension ball joints



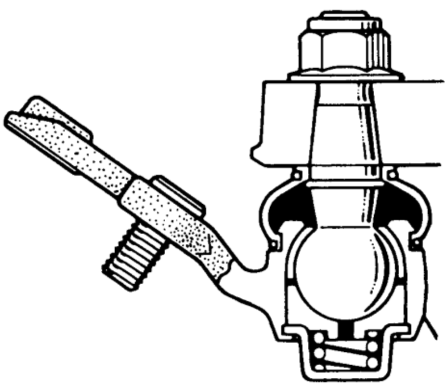
Ball joint are now almost universally used to allow movement of the suspension arms and act as steering pivot points.

They have the following advantages:

- simplicity
- self-adjusting for wear
- maintenance free



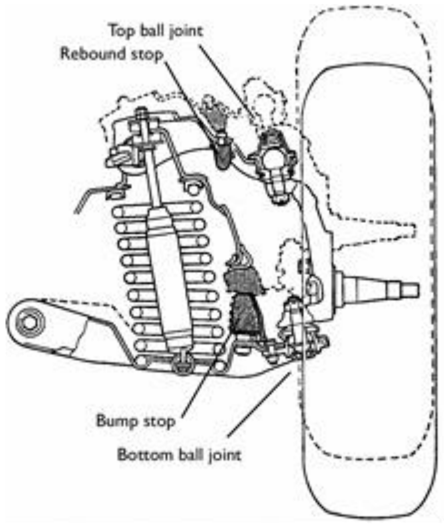
The diagram above shows a more detailed drawing together with sectioned views of the ball joints themselves.



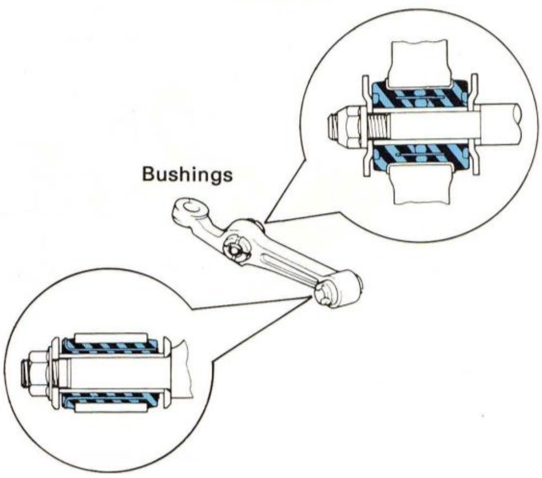
The diagrams above show sectioned views of typical suspension ball joints. In each case a spring-loaded cup acts against the ball. This eliminates any free play between the two parts and compensates for any slight wear that may take place. Most ball joints have the lubricant, such as grease, sealed in by the rubber gaiter and are maintenance free. Occasionally a grease nipple may be fitted.

Rubber bump and rebound stops

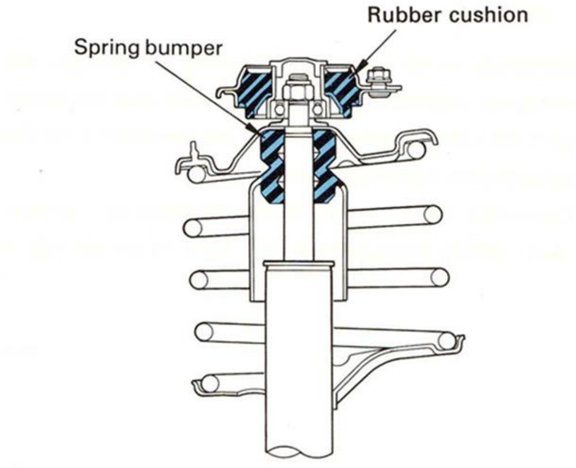
The use of rubber bump and rebound stops is illustrated below. These are used to prevent metal-to-metal contact between suspension arms and body when the system reaches the end of its travel. The bump stop is usually the biggest because it is subjected to the greatest load and it doubles as a supplementary spring.



Use of rubber bushes



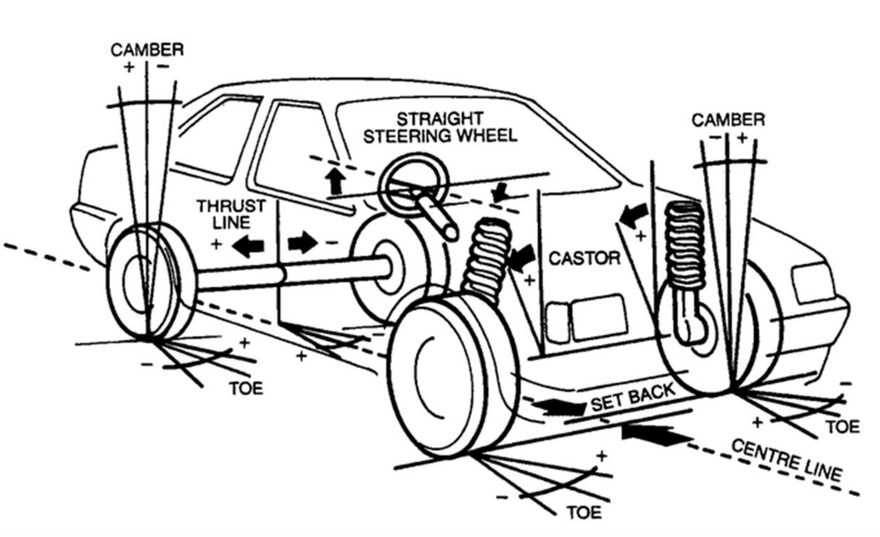
The diagrams above show the use of rubber bushes in suspension components. They are simple and maintenance free and insulate the vehicle body from noise and vibration.



The diagram above shows the upper mounting for a MacPherson strut and includes a rubber bump stop.

Wheel alignment and steering geometry

Wheel alignment



The steering system incorporated on a motor vehicle, enables the driver to turn the vehicle in any direction he wishes. This is essential if the driver is going to be able to control the vehicle. Just to be able to control the vehicle is not enough, the driver needs to be able to do it with as little effort as possible to reduce drive fatigue. The effort needed by the driver to steer the vehicle can be reduced by adjusting the position that the wheel is fitted in relation to the vehicle body. By changing the wheel angle not only is driver fatigue reduced but also straight-line stability is improved, as is tyre wear. The different angles needed to cause these improvements are grouped together and called "wheel alignment". If any of these angles become incorrect through either incorrect adjustment, or damage to components then problems with the steering will occur. The five angle grouped under the term wheel alignment are;

- camber
- caster
- kin pin inclination
- toe angle (toe in and toe out)
- turning radius (explained in Ackermann layout).

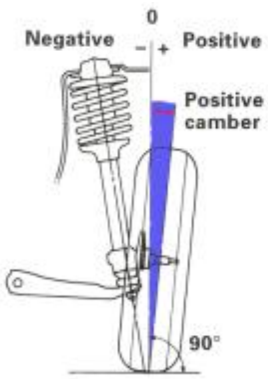
Camber

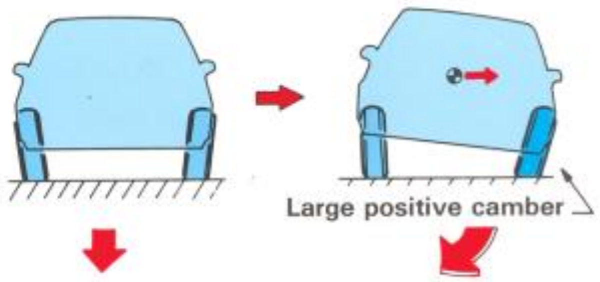
Camber is the amount of tilt on the top of the tyre with relation to a vertical line 90°

from the road surface. If the top tyre is tilted inwards it is called "negative camber" and if it is tilted outwards it is called "positive camber". The easiest way to see camber, is to look at a vehicle placed on a four poster ramp, raised to eye level, and look at the vertical positioning of the wheels.
On modern vehicles this has become harder, as the amount of positive or negative camber has become almost zero.

The amount of camber induced on vehicles has changed throughout the years, with early vehicles having positive camber. Early vehicles had positive camber as it reduced the loading on the front axle and also helped to reduce tyre wear. As modern vehicles were developed the strength of the axles was improved, through design and materials used. This eliminated the need for positive camber so vehicles began to move towards zero camber. On the latest vehicles manufacturers have begun to introduce negative camber as this improves the handling of the vehicle through the corners.

Positive camber





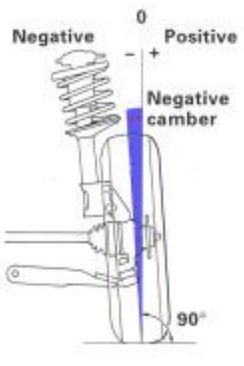
Positive camber has the following advantages:

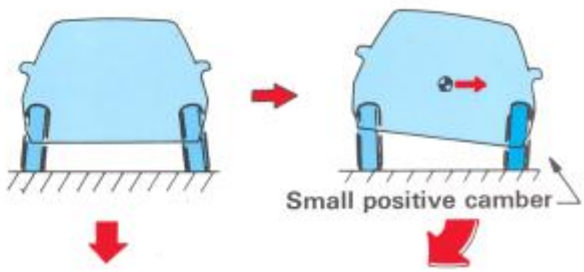
- Reduction of steering effort (tyre offset)
- Prevention of negative camber due to load

Positive camber has the following disadvantages:

- Increase tyre wear
- Under steer
- Torque steer
- Poor road handling

Negative camber





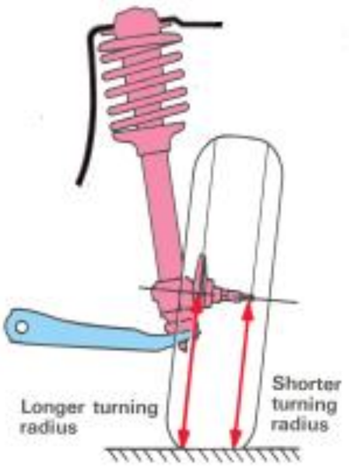
Negative camber has the following advantages:

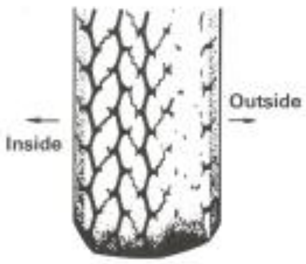
- Better road holding
- Reduction of torque steer

Negative camber has the following disadvantages:

- Increase steering effort
- Oversteer
- Tyre wear

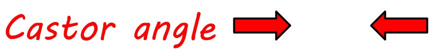
Development of camber angles

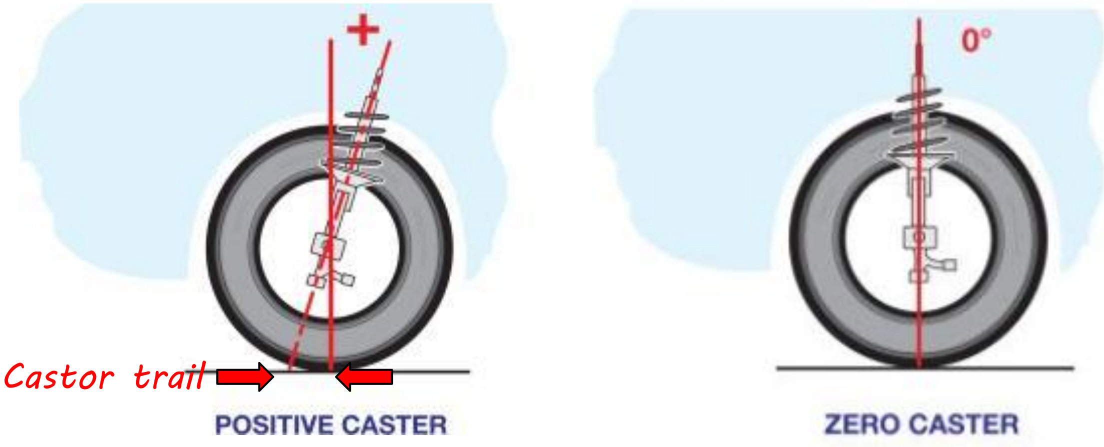




As described earlier modern vehicles have a camber setting of almost zero, as this helps to reduce tyre wear. If positive camber is induced on to a vehicle the inner and outer parts of the wheel will travel through different radii and thus travel at different speeds. As the inside of the tyre will actually travel less distance than the outside it will also travel slower. As the outside of the tyre is travelling faster it will constantly have to wait for the inside to catch up, and this will cause it to slip. As the outside of the tyre is now slipping wear will be induced as shown in the diagram at the bottom of the previous page. With negative camber the opposite is true.

Caster





Caster has the primary function of aiding the driver to keep the vehicle in the straight-ahead position. Caster can be seen by looking at the front suspension of the vehicle from the side, and obtaining whether the steering axis is tilted either forward or backwards. Forward tilt is called negative caster while backwards tilt is called positive caster. Although caster is beneficial to aid straight-line stability, too much camber will cause the steering to become hard.

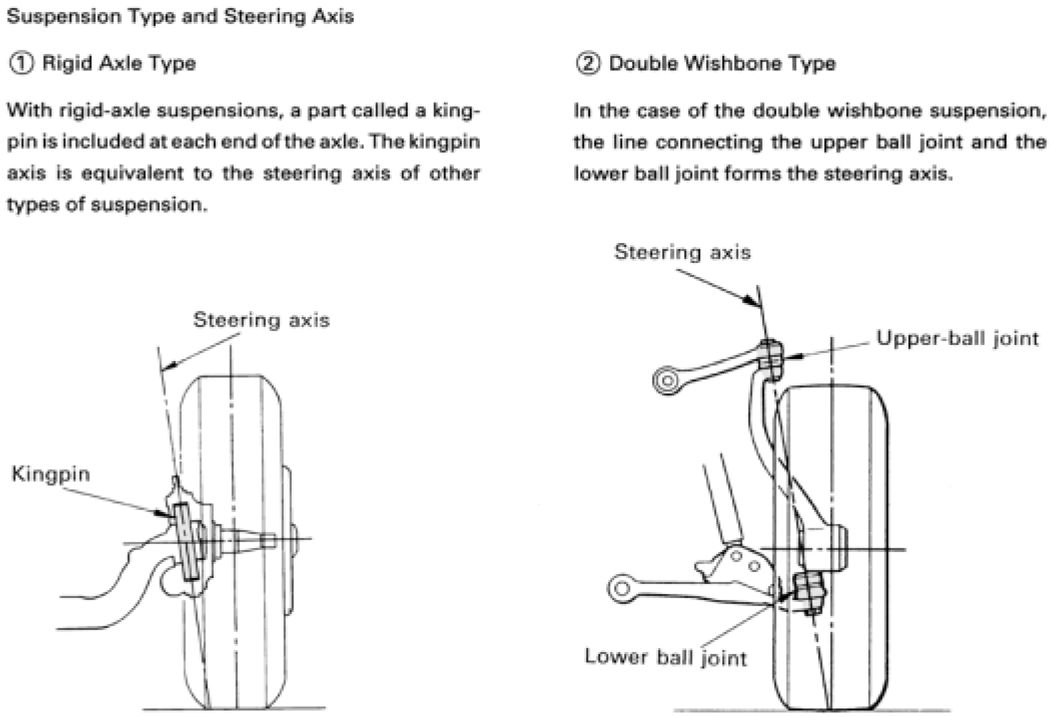
If a theoretical line is drawn through the steering axis, and a line at 90˚ to the road surface, then the point at which they meet is called the intersection point. The distance between the two lines when they meet the road is called caster trail.

King pin inclination

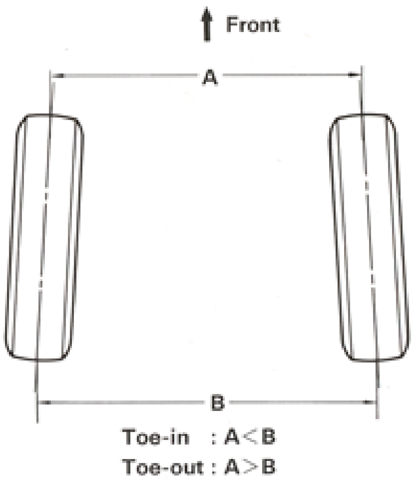
From the diagram you can see that king pin inclination is the angle between a theoretical line that is drawn through the top of the shock absorbers upper support and the lower suspension arm ball joint, and a line drawn at 90˚ to the road surface. If a solid king pin is used then the angle of the king pin is used to replace the shock absorber angle.

The distance between the two points that are generated when the lines contact the road is called offset. The smaller the offset the less effort the driver needs to use to turn the steering wheel, and this small offset also reduces the amount of road shocks felt by the driver. If a large offset is used, the rolling resistance or friction generated between the tyre and road, when it is being turned, will cause the steering to become hard. Increasing positive camber can also reduce this offset, although as described earlier positive camber is not always an advantage.

The diagram below shows other configurations of king pin inclination, for vehicles using other suspension systems.



Toe angle

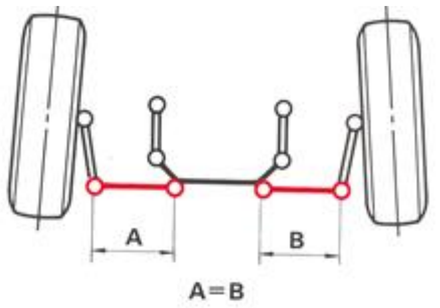


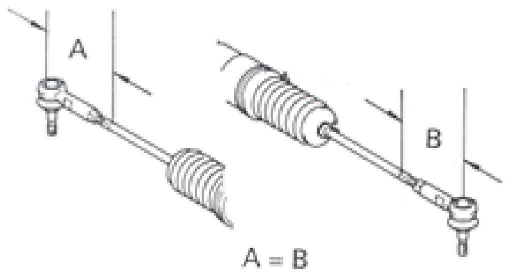
The toe angle can take two forms, either toe-in or toe-out. Toe-in was introduced on early vehicles, to cancel out camber thrust generated through the use of positive camber. On modern vehicles the use of positive camber has been removed, and either negative or zero camber has taken its place. Negative camber helps improve vehicle handling and reduces camber thrust; so on modern vehicles toe angle is used for straight-line stability.

Toe angle can be expressed as the difference in distance between the front of the front tyres and the rear of the front tyres as shown on the diagram. Toe-in is when the distance between the front of the tyres is less than the distance between the rear of the tyres. Toe-out is the opposite of toe-in.

Adjusting the toe angle (tracking) is one of the most common practices when abnormal tyre wear is reported. If a single tie-rod is used as with some ridged front suspension systems, then by changing the length of the tie-rod the toe angle can be adjusted. When two tie rods are used as with independent suspension, then the adjustment process becomes more complex.

Lengthening or shortening either one of the tie-rods can adjust toe angle, although this will result in the steering wheel position being incorrect.



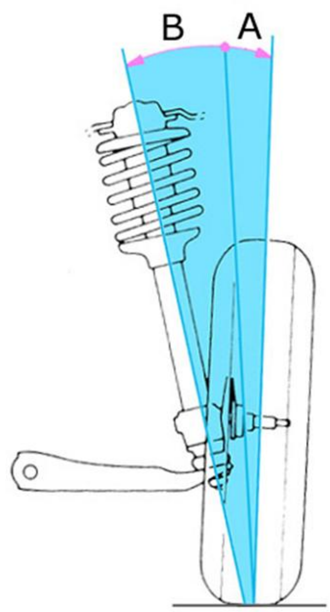


DOUBLE TIE ROD TYPE

The correct method of adjusting toe angle is to first set both of the tie-rods to the same length; this can be done by counting the amount of thread visible at each end of the tie-rod. When both tie-rods are at the same length then whatever you do to one you do to the other. By doing this the tie-rod length will be kept the same and although the toe angle will have been adjusted, the steering wheel position will not have changed. The main reason for keeping the steering wheel in the same position is to not obscure the speedometer and other dials while in the straight ahead position.

Included angle

The included angle can be used to diagnose possible faults with steering and suspension components. The included angle is the sum of the camber and the king pin inclination. As on most modern vehicles neither of these two steering angles is adjustable then the chart below will help with the diagnostic process. If camber can be adjusted independently to the king pin inclination then do not use this chart.



The included angle is the result of adding angle A (camber) and angle B (Steered Axes Inclination)

Steered Axes Inclination – Main role

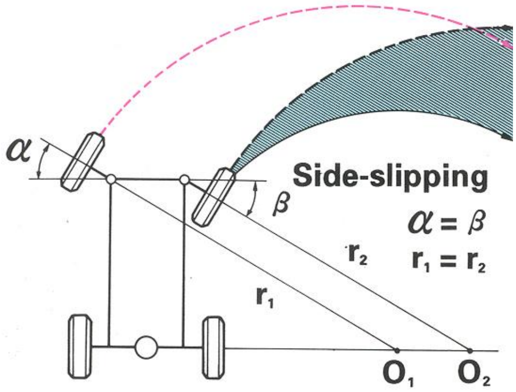
Reduction of steering effort

Reduction of kickback steering pull

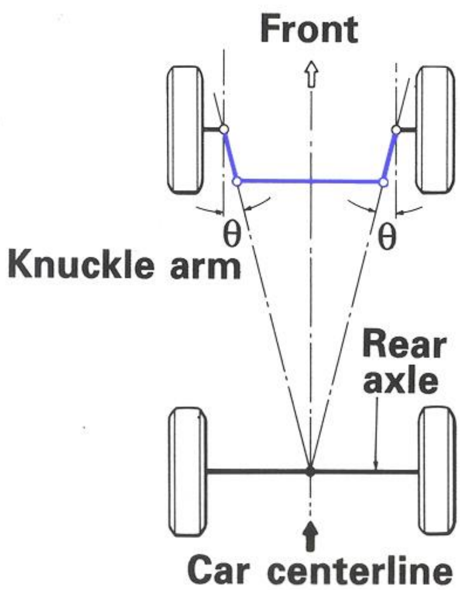
Improved straight-line stability

Reduction of torque steer

Ackerman's principle

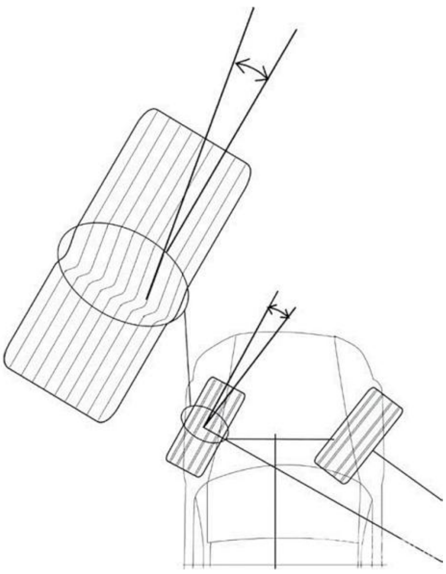


When a vehicle is turning a corner both the inner and outer wheels need to turn through different angles. If they turned through the same angle then slide slip of the inner wheel will occur. In very early swinging beam systems this was the case and tyre wear was immense. In 1817 a carriage builder named Lankensperger introduced a fixed beam, double–pivot system. In England Rudolph Ackerman took out a patent on this system in 1818 it was subsequently called Ackerman layout.



To remove this problem the knuckle arms and tie rods are place either in front or behind the wheel centres, this induces slight toe-out when the steering wheel is turned. As the position of the steering knuckles has now been changed, the inner wheel will turn through a slightly greater angle than the outer wheel, improving handling and reducing tyre wear. The position of the knuckle arm and this distance between the tie rod ends is dependent on the type of system used. If the tie rods and knuckle arms are place behind the wheel centres then the distance between the tie rod ends is reduced. If they are place in front of the wheel centres the opposite is true and the distance between the wheel centres is increased. The diagram above shows a configuration where the tie rods and steering knuckles are placed behind the wheel centres.

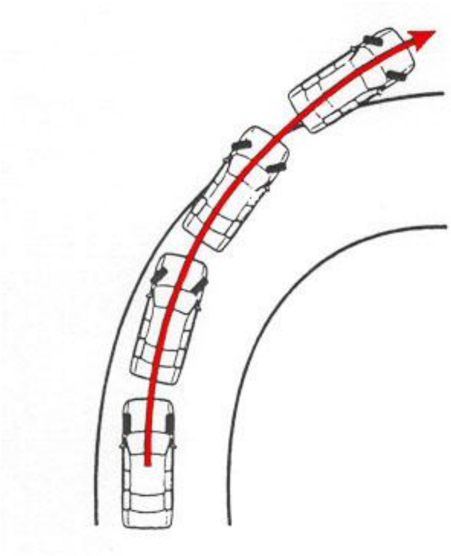
Slip angle



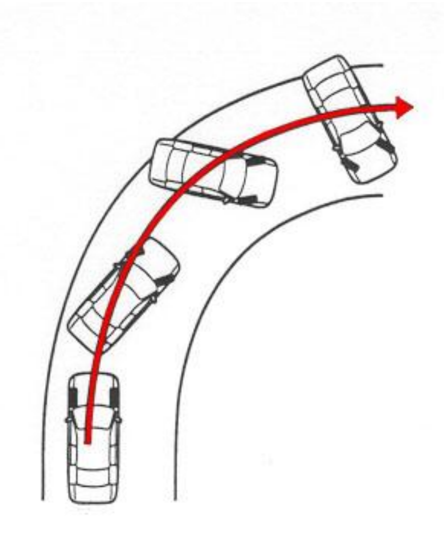
As tyre construction developed to cope with the demands of modern vehicles, vehicles moved away from hard tyres and low-pressure tyres were introduced. With the introduction of low-pressure tyres side wall deflection and tyre distortion as side forces were placed on them and became known as slip angle. This slip angle causes the tyre to travel through a slightly different angle to its original direction as slide forces are placed on it. The amount of side force place on the tyre is directly relevant to the amount of slip angle generated, up until the point that the friction between the tyre and road is lost and the tyre physically begins to slip.

Self–aligning torque is very closely linked to slip angle. As slip angle is induced by side force, the tyre wall begins to deflect. This deflection is greatest as the tyre actually leaves the road, causing the tyre to try and align itself and travel in the direction depicted by the steering wheel. This phenomenon is known as self-aligning torque. To demonstrate self-aligning torque drive along a road that has a highly cambered surface, the vehicle will begin to either pull to the left or right as the steering wheel is released.

Understeer and oversteer



Strong Understeer Tendency



Strong Oversteer Tendency

Understeer and oversteer as with self-aligning torque is very closely linked to slip angles. If the front slip angles are greater than the rear slip angles then the vehicle will tend to turn through a greater angle than intended by the driver. The driver can correct this by turning the steering wheel slightly further. The manufacturer quite often induces a small amount of understeer although if it is too great it will cause the steering to become hard.

Unlike understeer, oversteer is avoided. Oversteer is generated when the rear slip angle is greater than the front slip angle, causing the vehicle to pull towards the inside of the corner. As a vehicle begins to oversteer the driver will need to steer away from the corner and this is very unnatural to do. Also oversteer causes even more slip angle to be generated increasing cornering force, and possibly causing the vehicle to fish tail due to loss of friction between the rear wheel and the road.

Wheel alignment checks

Under normal conditions it is not necessary to check the wheel alignment at every service interval, although it must be checked during the pre-delivery inspection. Wheel alignment does need to be checked when a fault occurs, which will normally be evident due to abnormal tyre wear. The full process for carrying out a wheel alignment check will be outlined in phase three steering systems. In phase one we will look at items that can affect wheel alignment and the importance of ground clearance when carrying out checks.

There are numerous components and systems that can effect wheel alignment. If a component is physically worn then adjusting the wheel alignment will not solve the problem.

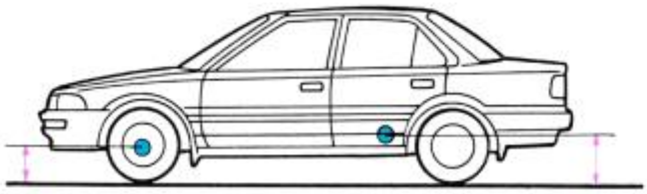
The components that suffer with wear and can effect the wheel alignment are:

- tie-rod ends

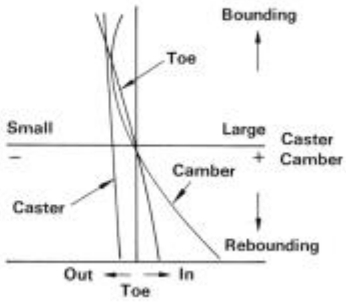
- steering linkage
- wheel bearings
- suspension components.

Other factors that can effect wheel alignment are:

- tyre pressure
- vehicle ground clearance
- tyre run out
- difference between left and right wheel base
- wheel alignment being carried out on uneven ground.



Most wheel alignment data supplied by the manufacturer is given with the chassis to ground clearance at a specified height. This height is usually with the vehicle unloaded. The reason for having the vehicle unloaded is that loading the vehicle will affect both the camber and caster angles.



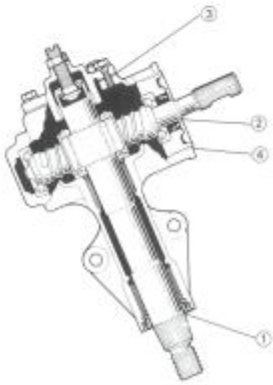
There are other checks that can be carried out during road tests to determine steering and wheel alignment faults. These include checking that the vehicle travels straight ahead without pulling to left or right, and also that the same is true while braking. Any abnormal noise from the steering and suspension components and unusual movement of the steering wheel may also signify a fault. If any of the above problems occur then wheel alignment must be checked, along with any suspected faulty components.

The following four diagrams show other checks that can be carried out on the steering system

Rods and arms for damage

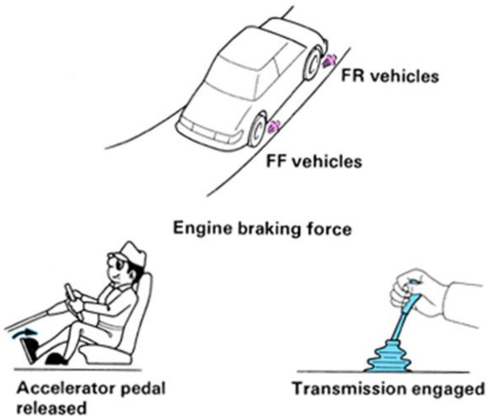
Gear housing for damage

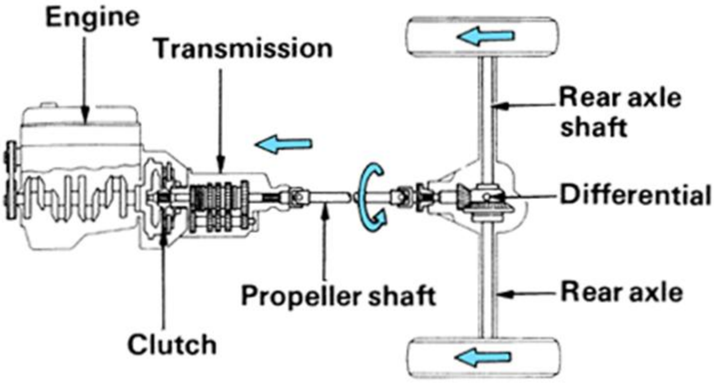
Steering linkage for looseness



Gear housing for oil leaks

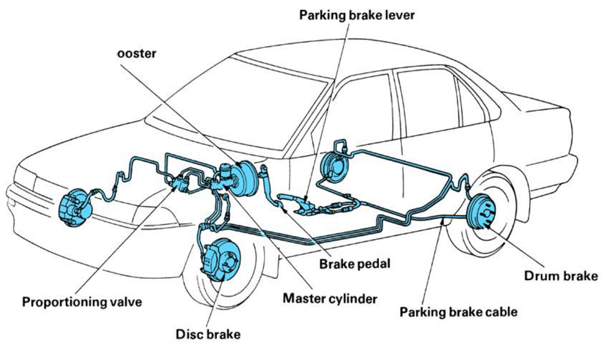
Braking principles





Brakes are considered as one of the most important areas of a motor vehicle, and with good reason. Without them the only means of deceleration would be pressing the clutch pedal in and waiting patiently, or not as the case may be, for the loud bang and the crunching noises. There are two main means of deceleration available to the drivers of small vehicles. The first is engine braking. This is the process of selecting a lower gear than is currently engaged and releasing the accelerator pedal. The drag and pumping effect of the engine reduces its revs quite quickly. As the engine is in gear (directly connected to the road wheels mechanically) when the engine speed decreases, so does the wheel speed, hence the car slows down.

The definition of a brake is something that connects a moving object to a stationary object.



The second means of decelerating a vehicle is the braking system. The diagram on the right features a typical braking system. Just as a heat engine fitted to modern vehicles, transfers heat energy into kinetic energy, the brake system transfers kinetic energy into heat energy. Kinetic energy is the energy stored in a vehicle as it is moves along. When the vehicle is moving and neutral is selected, the vehicle continues to move. The sheer fact that the vehicle continues to move shows that kinetic energy is in the vehicle. As the vehicle slows down, the kinetic energy is dissipated (used up) overcoming the frictional forces acting against it such as tyre to road resistance and wind resistance.

The efficiency of a brake depends upon its ability to dissipate the heat that it creates. The faster the rate that the heat can be dissipated, the more efficient the brake is. Pressing a friction surface against a moving object, i.e. shoe to drum or pad to disc generates the heat. The amount of heat dissipation is governed by the amount or air able to flow over the heated surface and the material the disc is made of. It is important to remember that the heat can only be generated if the tyres remain in adhesion to the road. If the tyre loses traction with the road surface, the disc or drum fails to revolve, and so the shoe to drum or pad to disc contact, will generate no heat. Due to this it is very important for the road wheels to continue revolving during vehicle deceleration. There are valves located in the brake lines to prevent this happening; this will be explained in more detail later on.

Basic scientific principles

In order to understand brakes, it is useful to understand the following scientific principles. It is necessary to understand the principles of the lever as this will help the understanding of the brake pedal, Pascal's law will assist the understanding of hydraulics (fluid) and an understanding of pneumatics (gas) will assist the understanding of the servo.

The lever

A lever enables a mechanical force to be increased at the expense of distance. This means a lever could be moved with light force and a large distance and act upon something that would have considerably more force but would not move as far as the lever originally needed to be moved. The formula for this is as follows:

The lever:

Formula:

$$MA = F_1 \times A = F_2 \times B$$

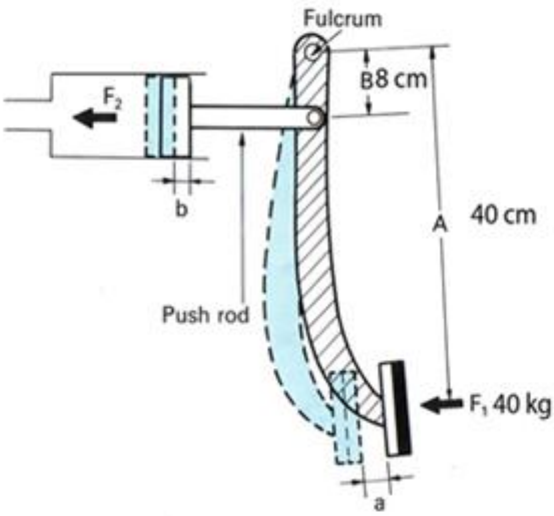
$$F_2 = F_1 \times \frac{A}{B}$$

$$F_2 = 40 \times \frac{40}{8}$$

$$F_2 = \frac{40}{8} = 5$$

$$F_2 = 40 \times 5$$

$$F_2 = 200kg$$



The pedal force has now increased from 40Kg to 200Kg

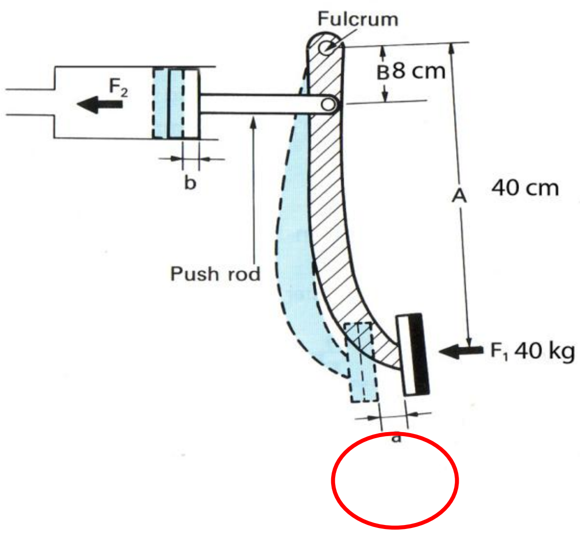
Operating force:

F_1 : Pedal force
F_2: Push rod output force
A : Distance from centre of brake pedal to fulcrum
B: Distance from push rod to fulcrum

Amount of movement:

$$10cm \times \frac{40cm}{8cm}$$

Therefore b = 2cm

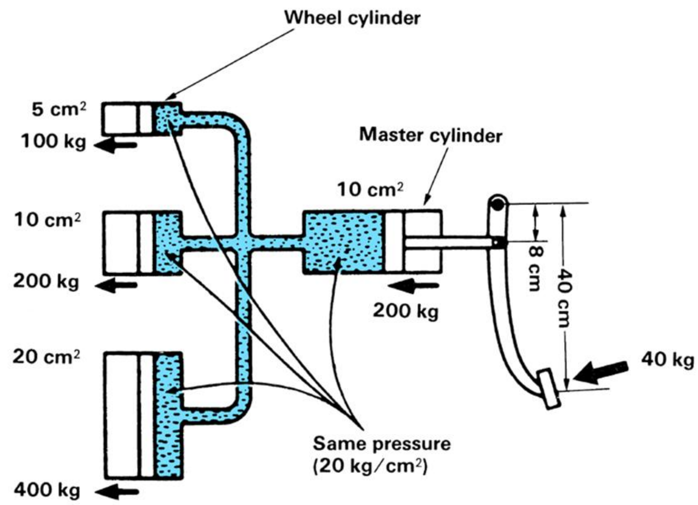


a: Amount of movement of pedal edge (in this case 10cm)
b: Amount of movement of push rod.

Using the above formulae, if we know how far the pedal is pressed and how hard it is pressed we can calculate what the output force will be and how far the output force will travel. As can be seen above, the force has been increased by using leverage. The output force is 5 times more than the input force. This force has been increased at the expense of distance which has decreased by five times. The pedal was moved 10 cm and the piston only moved 2cm.

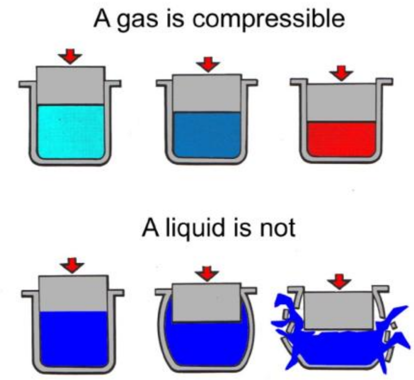
Hydraulics (Pascal's law)

Pascal's law states, externally applied pressure upon a confined fluid is transmitted uniformly in all directions. Using this principle the same amount of pressure that occurs in the master cylinder will occur in all of the wheel cylinders. The brake force varies however



depending upon the diameter of the wheel cylinder. As can be seen in the diagram, the larger the diameter of the cylinder, the higher the braking force.

Brake fluid



In a hydraulic braking system a special oil based fluid is used to transfer the force generated by the driver. This is possible because a liquid is not compressible and will act to transmit the braking force.

Brake fluid must be able to operate in harsh conditions without losing its properties.

Properties of brake fluid

Brake fluid has to meet a wide variety of requirements such as:

Viscosity index – the fluid must be able to maintain a constant viscosity over a wide temperature range. (-40°C - 271°C DOT 5.1)

Low freezing point / high boiling point - the fluid must be able to cope with extreme low operating temperatures without freezing. The fluid must also be able to cope with the extreme temperatures generated during braking without boiling.

Lubricant - the fluid must be compatible with all the materials it comes into contact with in the braking system and act as a lubricant for the moving internal parts.

Brake fluid is a glycol based fluid. (The exception being DOT 5 which is silicon based fluid commonly used in motorsport applications). Unfortunately it is hygroscopic which means that it continually absorbs water from the atmosphere. This is why many vehicle manufacturers recommend replacing your brake fluid every 2 years.

Maintenance

As part of routine maintenance the brake fluids boiling point should be tested. This boiling point test requires the use of special equipment such as the 'Brake fluid safety meter' shown to the right.

Brake fluid is available with varying temperature ranges which is represented by its codes, DOT 3, 4 and 5.1.

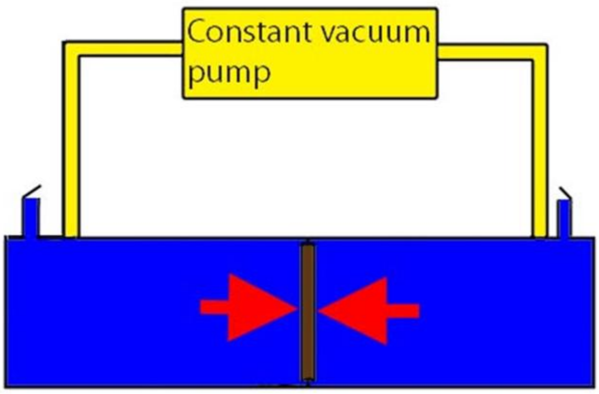
Brake fluid has to meet various international standards such as FMVSS 16 DOT 3 140/254. DOT refers to Department Of Transport (U.S. standard). 254 is a reference to the boiling point in Celsius of new uncontaminated fluid. The 140 refers to the wet boiling point. This is the boiling point in Celsius where the fluid has absorbed 3% water by volume of the system. This would be the minimum acceptable limit for DOT 3 brake fluid. The risks of having the minimum acceptable fluid in your system is that, if the temperatures generated by braking were high enough it could cause the water contained in the fluid to start to boil, this could cause a total loss of braking force as the vapour created is compressed by the drivers braking effort.

Replacement

When replacing brake fluid or fitting new hydraulic parts only use new brake fluid from a sealed container, fully flush the system with the fluid to ensure that the whole system is replenished. This guarantees all debris and moisture are removed from the braking system ensuring safety without compromise.

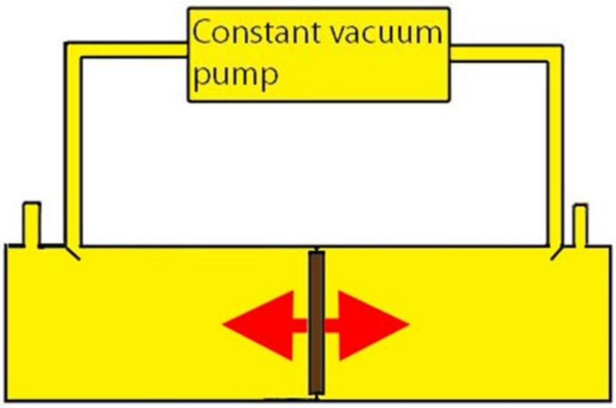
Always clean up any brake fluid spillages!

Pneumatics



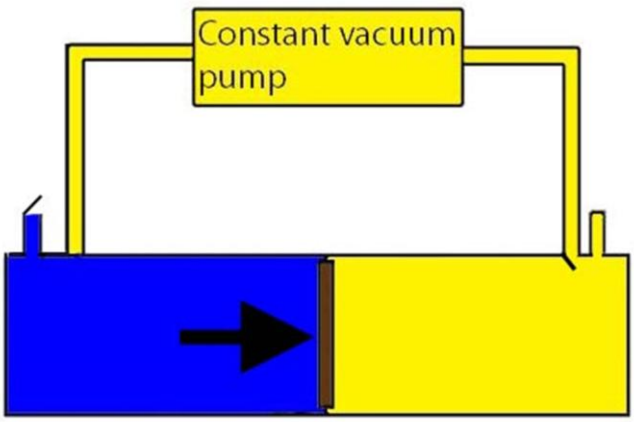
Piston will stay stationary

Like hydraulics is the science of the movement of fluids, pneumatics is the science of the movement of gases. A basic understanding of pneumatics will assist in the understanding of the servo. The diagrams show examples of pressure differential. Shown is a cylinder with two valves at either side of the piston. On each side there is one valve that allows in vacuum and the other valve allows in atmospheric pressure. If both the vacuum valves are closed and the atmospheric valves are open, there is atmospheric pressure acting upon both sides of the piston. This means there is no pressure differential and so the piston won't move.



Piston will stay stationary

Equally if both the atmospheric valves are closed and both the vacuum valves are open, both sides of the piston are being exposed to the same pressure. As there is no pressure differential and so the piston will not move.



Piston will move over to the right

It is only now, when the one side of the piston is exposed to atmospheric pressure and the other is exposed to vacuum that any piston movement will occur. As there is pressure acting upon the left side of the piston and vacuum on the other side of the piston. Atmospheric pressure is of a higher pressure than vacuum and so the piston is pushed over to the right.

Progress check

1. What are the two means of braking available to the driver of small vehicles?

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2. What is the definition of the brake?

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3. What governs the amount of heat dissipation over the heated surface of a brake?

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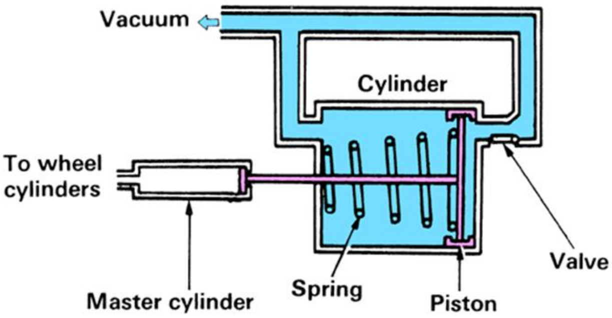
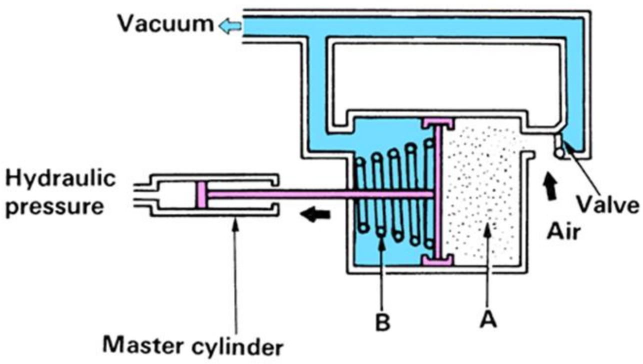
Brake booster (servo) basic principles

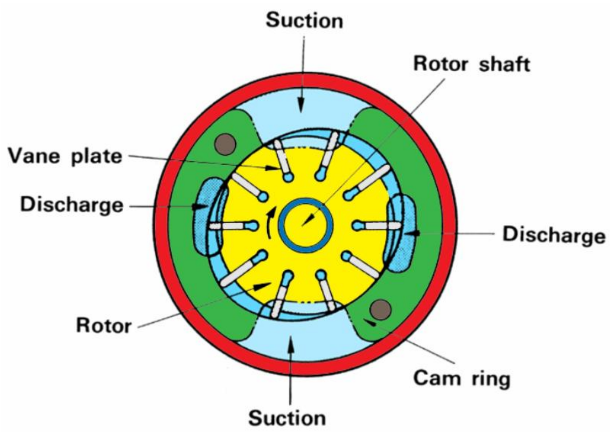
The brake booster is fitted to increase the pressure acting upon the pistons in the master cylinder at the same rate as the driver of the vehicle presses the brake pedal.

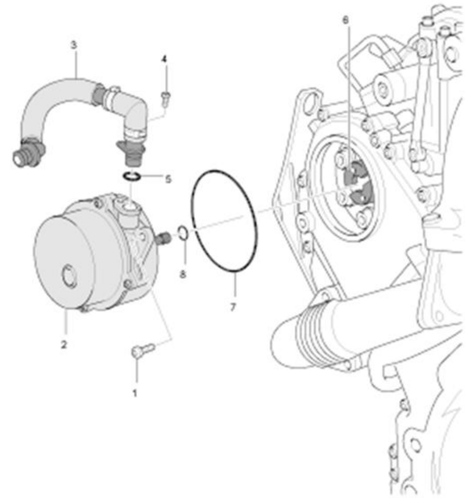




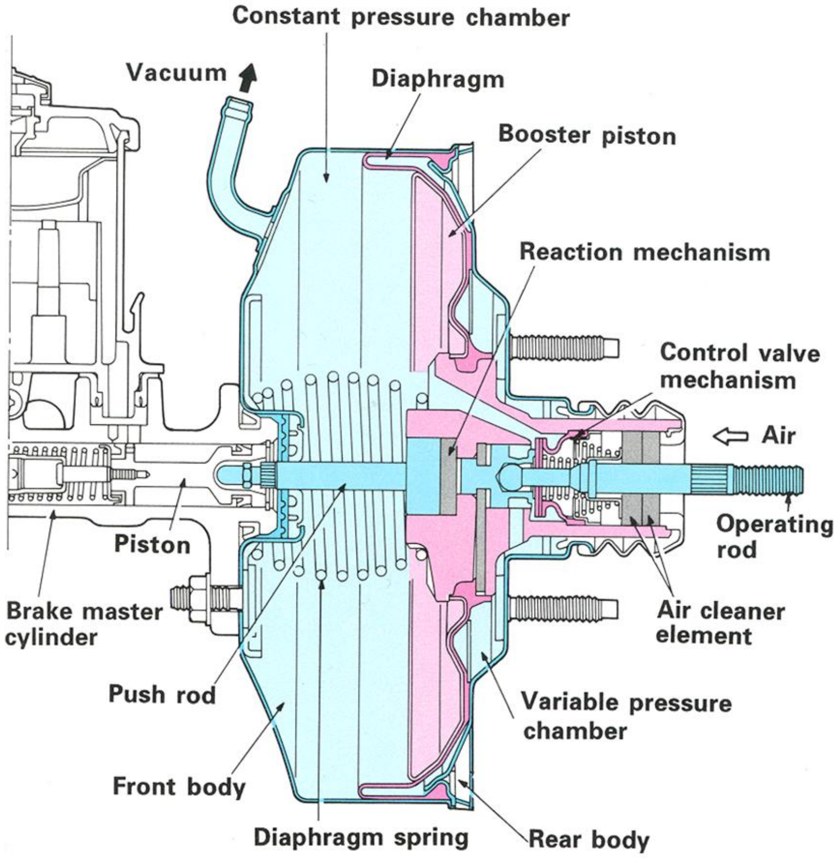
The brake booster is fitted in between the brake pedal and the master cylinder. It is made up of two main chambers. One of the chambers is a constant vacuum and the other is a variable pressure chamber. By means of opening and closing the relevant valves in the servo the pressure variation can be harnessed to increase the pressure acting upon the master cylinder pistons.

The vacuum is supplied via a hose from the inlet manifold on petrol engine vehicles and from a vacuum pump on diesel engine vehicles. The diagram below shows the common location of a vacuum pump on a diesel engine. A vacuum pump is necessary on diesel vehicles as there is no/little vacuum in the inlet manifold. Operation of the vacuum pump can be seen in the diagram below. There is a check valve fitted in between the brake booster and the inlet manifold/vacuum pump. This ensures whilst the engine is running there is always maximum vacuum in the constant side of the brake servo.



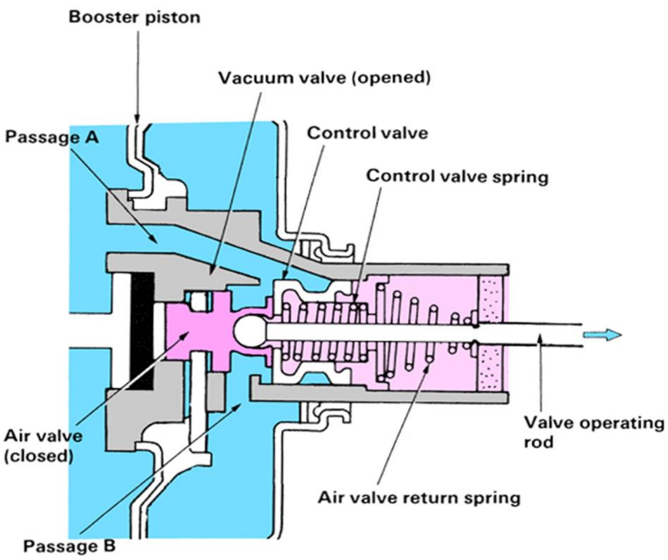


The brake servo

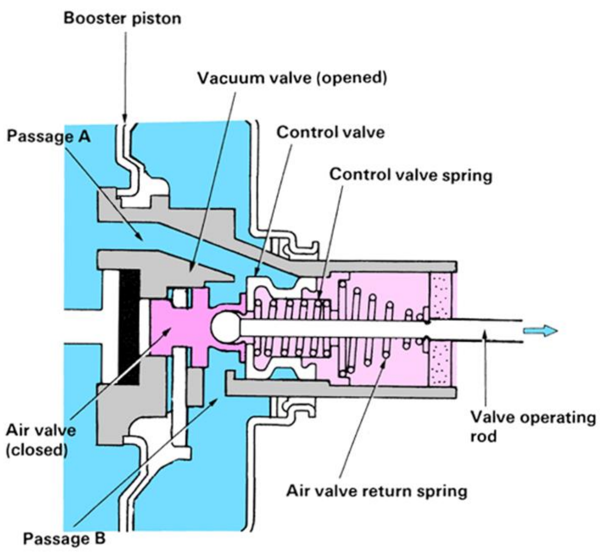


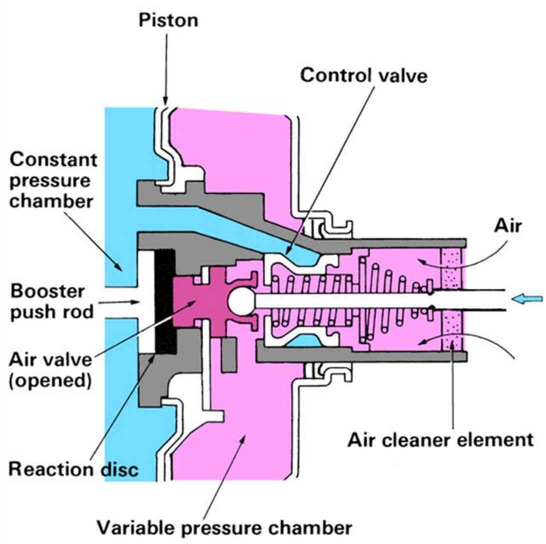
Brake booster operation brakes not applied

Whilst the brakes are not applied, the control valve is held off its seat by the air valve return spring allowing equal negative pressure in both sides of the brake booster. Additionally the air valve is held against the control valve by the control valve spring, this creates a seal and prevents any atmospheric pressure to be able to enter the variable pressure chamber. This allows the same level of vacuum to be in the constant pressure chamber and the variable pressure chamber. This means there is no pressure differential in the brake booster, and hence, no assistance.



Brake booster operation brakes applied

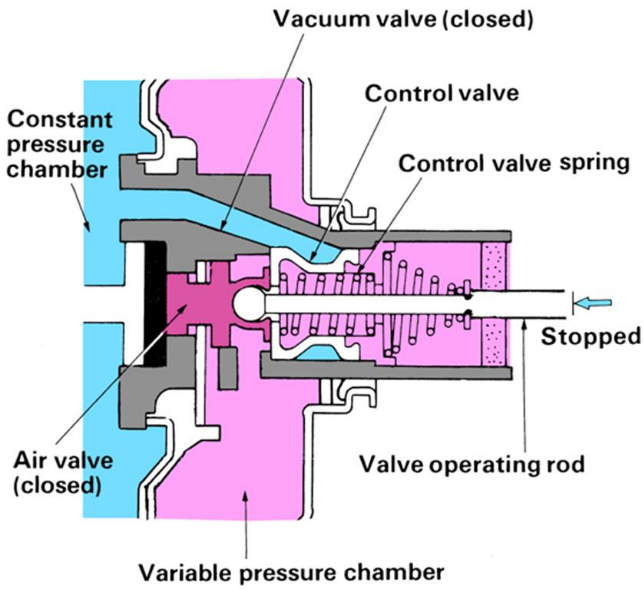




As shown in the diagram above as the brake pedal is pressed it overcomes the force of the air valve return spring and seats the control valve hence closing the vacuum valve. As the pedal is pressed further, see diagram on the right, it unseats the air valve from the control valve and allows atmospheric pressure into the variable pressure chamber via the air cleaner element. This has now created a pressure variation between the two main halves of the brake booster. This pressure variation pushes the piston over to the left; this acts upon the booster push rod, which now acts onto the right hand side of the piston in the master cylinder, hence creating brake booster assistance.

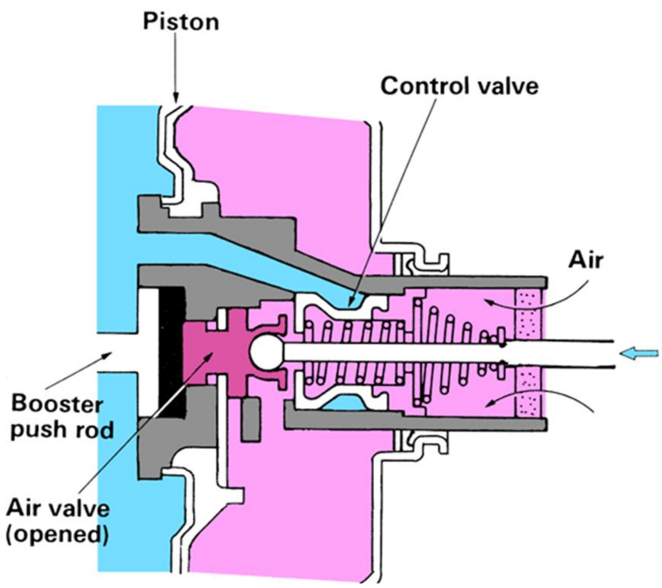
Brake booster operation brakes applied and holding

The pedal is now half way depressed and is held in the same position. This stops the valve operating rod and the air valve moving any further over to the left. As there is still a pressure variation between the constant pressure chamber and the variable pressure chamber the piston continues to move over to the left. This pulls the control valve body and control valve over to the left with it until the control valve comes into contact with the air valve. This now shuts the route off for the atmospheric air to enter the variable pressure chamber. The pressure in the variable pressure chamber will now stabilise. The piston is unable to move any further over to the left now and so the brake booster assistance will remain constant.



Brake booster operation brakes fully applied for maximum brake assistance

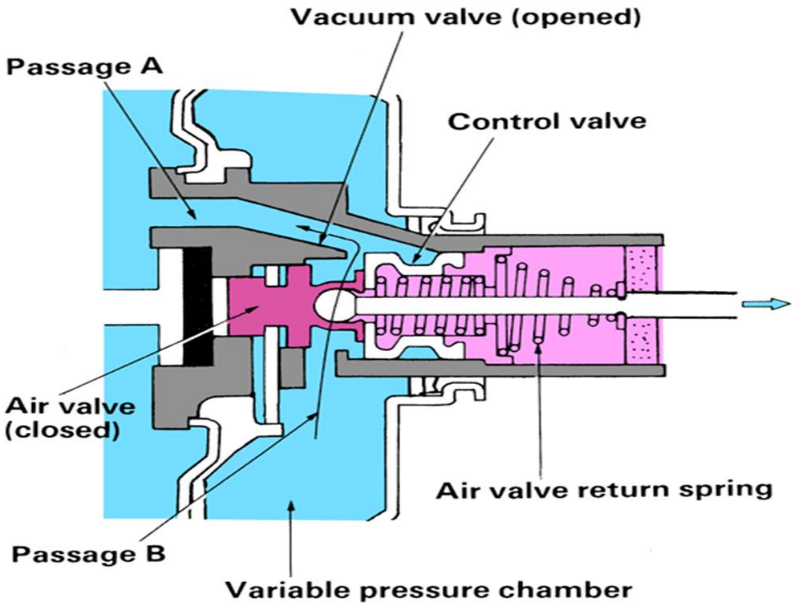
With the brake pedal fully depressed the control valve and the air valve are fully separated and remain separated. This allows as much air at atmospheric pressure to enter the variable pressure chamber as possible. This will drive the piston over to the left as much as possible and create as much booster assistance as possible. If the brake pedal is pushed harder still, no further brake assistance will be created by the booster and the foot pedal force will be transferred directly through the centre of the booster via the valve operating rod, air valve and booster push rod into the master cylinder.



Brake booster operation brakes released

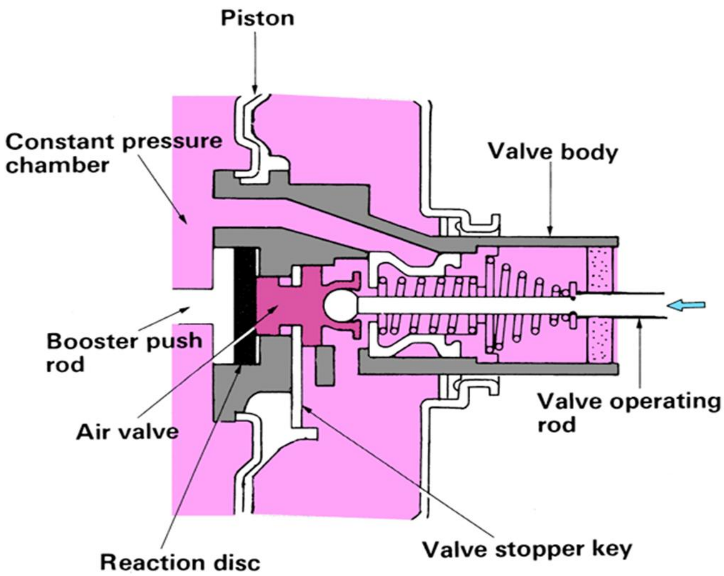
As the brake pedal is released the air valve and the valve operating rod travel over to the right. This occurs due to the force of the air valve return spring and the remaining pressure in the master cylinder. This causes the air valve and the control valve to seat together hence blocking the route for the atmospheric pressure to enter the variable pressure chamber.

Additionally the control valve and vacuum valve part, this opens up the constant pressure chamber up to the variable pressure chamber and eliminates the variation in pressure between the two chambers. The brake booster is now producing no assistance and the brakes are fully off.



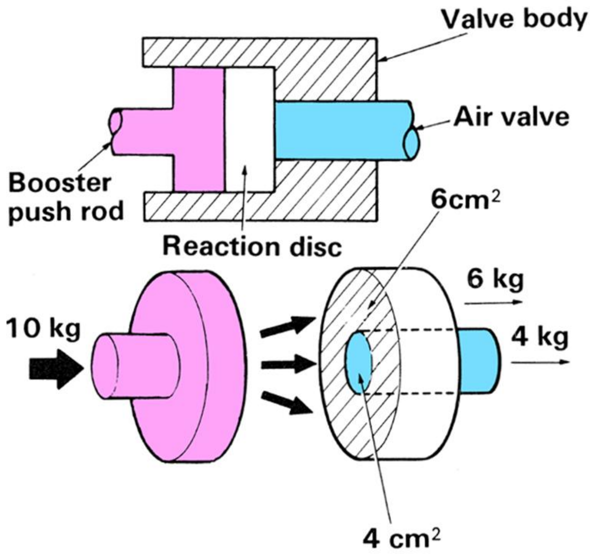
Brake booster fail safe vacuum failure

If, for example the vacuum hose splits or the vacuum pump loses drive it is still extremely important that the braking system still continues to operate. As explained earlier, we can't afford to be left without brakes. For this reason it is very important that when the brake pedal is pressed, the brakes are still applied. As there is no pressure variation between the two chambers, (they are both filled with air at atmospheric pressure) there



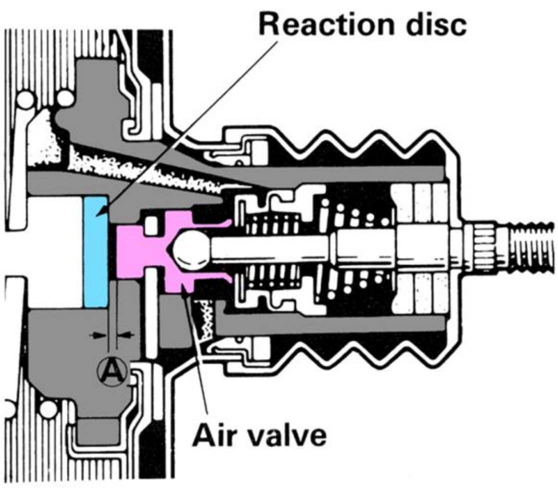
is no chance of brake assistance. In this situation the brake booster acts like one solid unit and the force from the brake pedal can travel directly through it as if it was just one shaft. The pedal pushes on the valve-operating shaft, straight onto the air valve, and then straight onto the booster push rod, that in turn acts upon the master cylinder. As has already been stated there will be no assistance and so when the brake pedal is pressed it will feel very heavy and the braking performance will be seriously impaired but the brakes will function enough to bring the vehicle to a halt.

Brake booster reaction mechanism



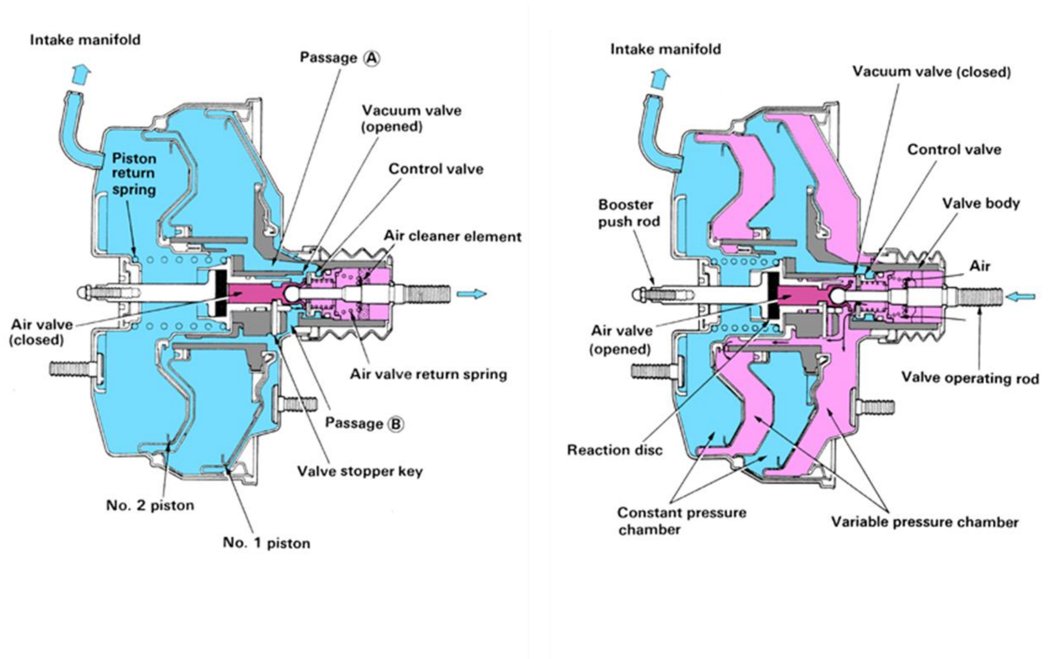
A brake booster mechanism is fitted to reduce brake pedal kick back. This reduces the force travelling from the master cylinder through the servo and into the brake pedal. This increases the sense of feel that the driver has and makes releasing the brakes a more comfortable experience. As the kickback travels through the booster push rod, the force is shared between the air valve body and the air valve. It is only the force that travels though the air valve that the driver would be able to feel. The force is shared between the two in proportion to the surface area that comes into contact with the reaction disc. The larger amount of surface area that the valve body has in contact with the reaction disc the less kickback the driver will feel.

Brake booster jumping mechanism



The jumping mechanism is designed in, to ease pressing the brake pedal during the early stages of braking. It is just a gap that allows the control valve to close and the air valve to open before any force from the pedal is pushed on the back of the master cylinder. This allows the pressure differential to exist in the brake booster very quickly. This means that in the early stages of braking no force from the foot pedal is exerted on the master cylinder, all the action on the master cylinder comes from the servo. This is the case until the air gap is taken up and there is direct contact between the brake pedal and the master cylinder via the valve operating rod, air valve, reaction disc and finally booster push rod.

Tandem brake booster



BRAKES NOT APPLIED | **BRAKES APPLIED**

The tandem brake booster is a compact method of increasing the assistance output of a single brake booster. It works in the same way as the single brake booster, except it has two variable pressure chambers and two constant pressure chambers. When the valve operating rod is acted upon it opens the air valve and at the same time closes the vacuum valve. This allows atmospheric pressure into both the variable pressure chambers and so increases the servo affect considerably over a dual chamber brake booster. All of the other steps in braking, holding, full boost, and release work in the same way as the dual chamber type of booster. The two dual chambers are each separated by two pistons that both act upon the valve body and then onto the reaction disc.

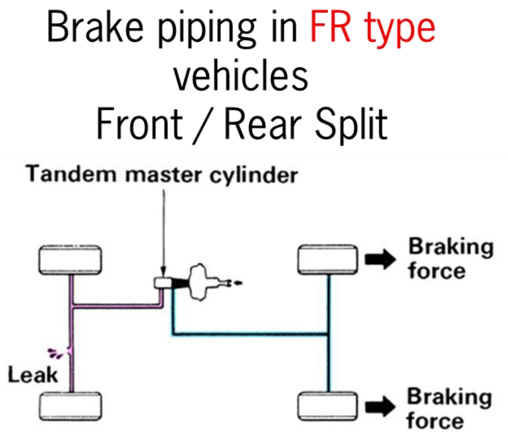
Brake booster output force =

The pressure contact area of pistons no. 1 and 2, multiplied by the pressure difference between the constant pressure chamber and the

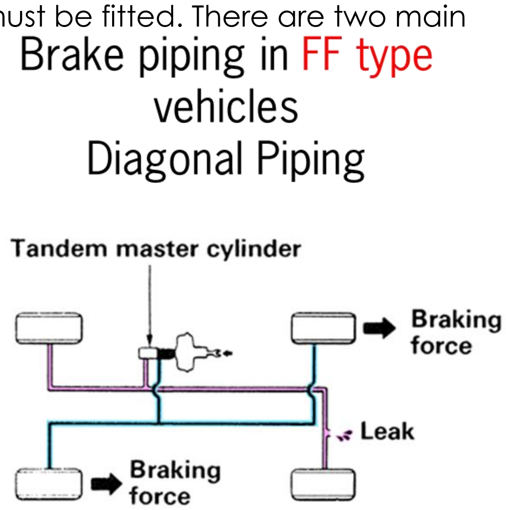
Brake lines single line

This is an unheard of system in modern vehicles. The reason for this is the fact that if there is a leak in the system anywhere, none of the road wheels will be braked. This could obviously lead to catastrophic braking failure with dire results. The only means of braking that the driver would have would be the handbrake system and if you have ever tried to stop a vehicle using only the handbrake you will know what an ineffective method it is of stopping a car. A much more commonly used system now is the dual line braking system.

Brake lines dual line



Dual line braking systems divide the hydraulic pressure in the braking system in two. This means two of the wheels are braked by hydraulic pressure in one brake line and the other two wheels are braked by hydraulic pressure in the other brake line. This makes the braking system far safer as even if there is a leak in one of the systems the other system will still be operable. In order for a dual line braking system to be possible, a dual line master cylinder must be fitted. There are two main splits. Front to rear, and diagonal split. The front to rear type tends to only be used on front engine rear wheel drive vehicles. This is because they have a more even front to rear weight distribution than front engine front wheel drive vehicles and so reduce the chance of a rear wheel lock up. Front engine front wheel drive vehicles are more likely to have a diagonal split so there is always one front wheel being braked.



Progress check

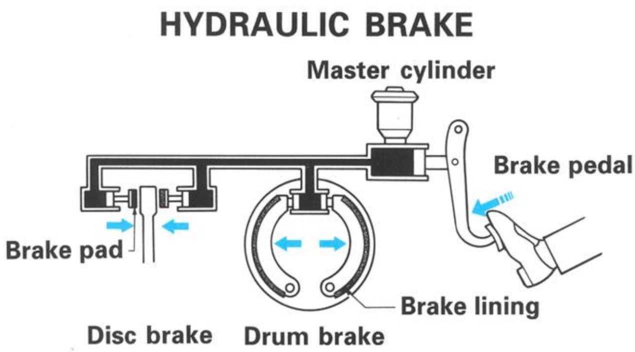
1. Fill in the missing words; There are two main chambers in a servo. The one is known as the …………….vacuum chamber and the other is a variable……………. chamber.

2. As a diesel engine produces little/no vacuum in the inlet manifold, what has to be fitted to the vehicle to supply the vacuum for the servo?

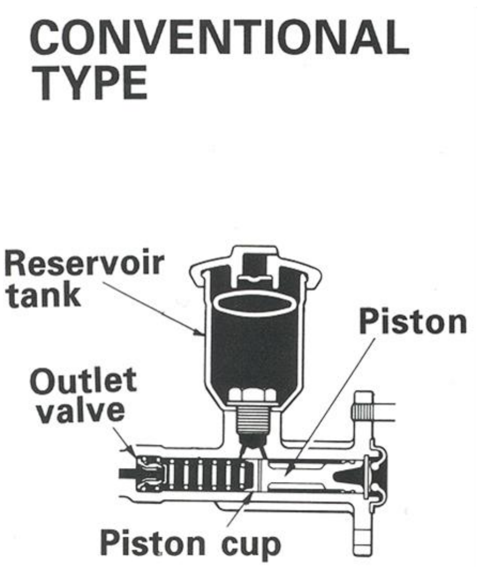
3. Why do most small vehicles have servos fitted?

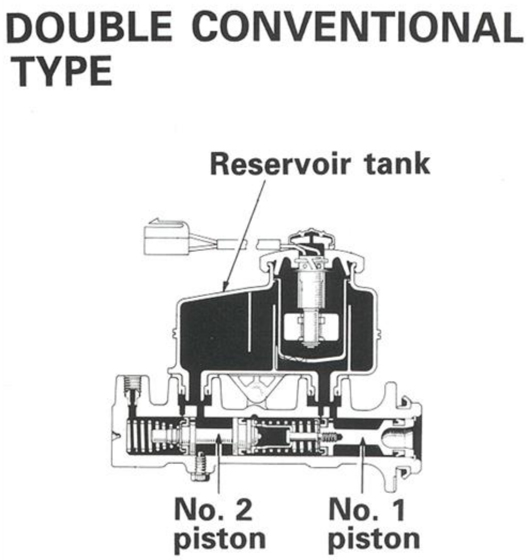
The master cylinder

The master cylinder is the component that converts the force generated by the depression of the brake pedal into hydraulic force suitable to activate the cylinders either in the drum brake or in the calliper on a disc brake.

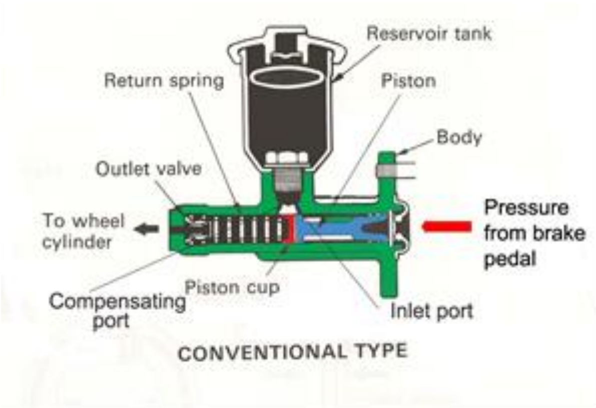


As shown in the diagram below, manufacturers use two types of master cylinder, conventional and tandem designs. The conventional type would only be suitable for a single line system, which is currently unheard of and so the double conventional type (tandem master cylinder) is the main master cylinder currently fitted. Single line systems are no longer used for safety reasons. If a leak was to occur anywhere in the system, system pressure would be lost, this would lead to a complete brake failure and for obvious reasons this is far from desirable. No brakes = serious accidents. For this reason the tandem system is used. This means that even if a serious leak occurred in the system, two of the four wheels would still have brakes.





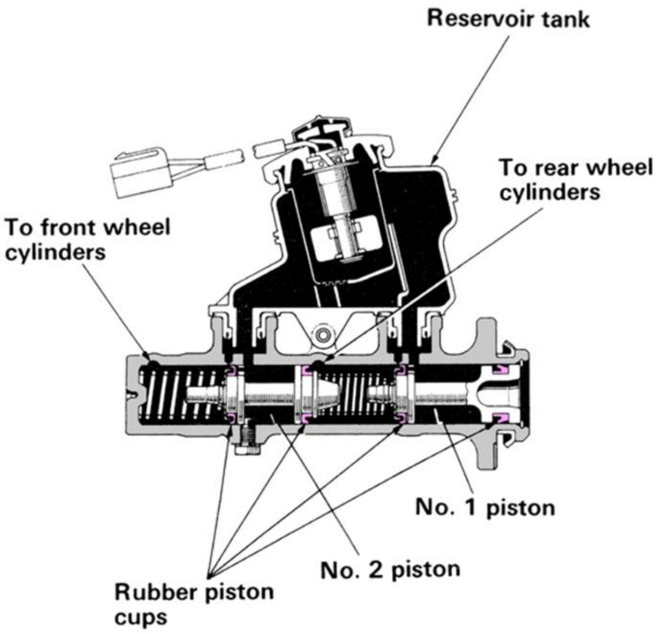
Operation of the master cylinder



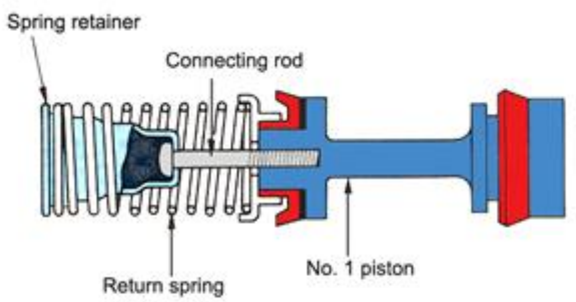
As can be seen in the diagram above, when the foot brake is pressed down it acts upon a piston, sealed with a rubber piston cup. As the piston moves over to the left it blocks off the compensating port. With the compensating port blocked off the fluid has nowhere to go except out of the outlet to the wheel cylinder. If the piston travels all the way over to the right hitting the stop more fluid can be forced into the pressure side of the master cylinder (where the spring is located) by passing through several drillings on the left hand side of the piston and past the piston cup. The piston cup works like a one-way valve, it allows pressure to build up on its pressure side but allows fluid to travel past it from the other direction.

To enable the fluid to pass from the non-pressure side to the pressure side the pedal has to be pumped. Once the pedal has been pumped and the extra fluid has been forced into the pressure side, extra fluid can travel out of the outlet valve and into the brake line. As the piston travels to the left it also opens up the inlet port. This allows fluid to travel into the non-pressure side of the piston. This creates the charge that can pass the piston cup, in case the pedal needs to be pumped. Once pressure has been released from the brake pedal, the spring in the pressure side of the master cylinder forces the piston back to the right. This forces the fluid back up the brake line and through the outlet port. Once the piston has travelled back past the compensation port the additional pressurised fluid can travel up the compensation port and into the reservoir tank. It should be noted, as a fluid increase in temperature it also increases in volume. The compensation port also allows for this heat expansion by letting any increase in volume to access the reservoir.

Tandem master cylinder



This works in principle very similar to two single line master cylinders placed end on end. This allows the one piston to create the pressure for the front brakes and the other piston to create the pressure for the rear brakes. This ensures that even if there is a leak in one side of the system the other side will continue to operate. During normal operation, piston number one is acted upon by the brake pedal; the pressure side of piston number one begins to get pressurised, this pressure increase not only forces the fluid out of the outlet valve, it also acts upon the right hand side of piston number two. This pressure in turn pushes piston number two over to the left. This creates a pressure increase in the pressure side of piston number two. This pressure increase forces the fluid through the outlet valve of the pressure side of piston number two. When the pedal is released the pistons travel back to the right. This occurs as the return springs in both sides of the master cylinder push them over to the right. Additionally number one return spring has a retainer fitted; this is necessary, as number one spring has to cope with a higher pre-load on assembly. The retainer prevents the spring from "buckling" over.



The assembly of the retainer can be seen above. The reason the spring is stronger is because it has to overcome the "rate" of spring number two when the brake pedal is pressed. It is very important that the pistons move equally during normal operation (no leaks) or else there would be a different hydraulic pressure exiting number 1 and number 2 outlet ports. As the pistons are returning to the right a reduction in pressure occurs (below atmospheric) in the pressure side of both of the pistons. This causes fluid to flow down through the inlet port and past the piston cups through a group of small holes at the tip of the piston and around the circumference of the piston cup. Any additional fluid that flows into the cylinder after the piston has returned to its stationary position is able to enter the reservoir through the compensating port.

The whole reason for having a tandem master cylinder is if there is a leak in the system pressurised by number one, the piston will travel all the way over to the left and will eventually butt up against the stop on the right hand side of piston number two. Piston number two will now work in exactly the same way as a single line master cylinder. Vice versa is also the case, if there is a leak in the line pressurised by piston number two, the pressure generated by piston number one will act against piston number two and force it over to the left until it hits the stop. Piston number one will now act in the same way as a single line system. If either of the two events do occur it will be noticeable to the driver as the brake pedal will have extended travel until one of the pistons butts up against their relevant stop and additionally the stopping power of the vehicle will be considerable reduced.

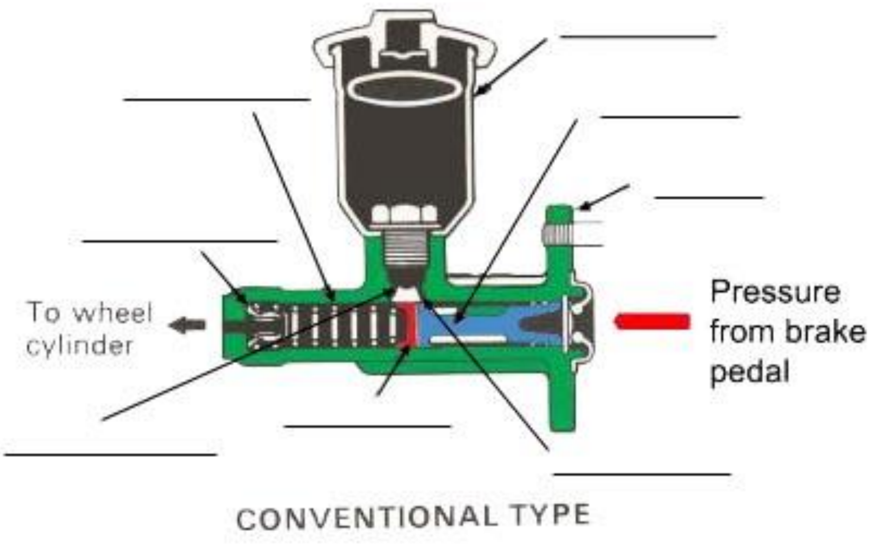
Progress check

1. Name the two main types of master cylinder manufacturers fit to small vehicles?

2. Why is the tandem master cylinder design used?

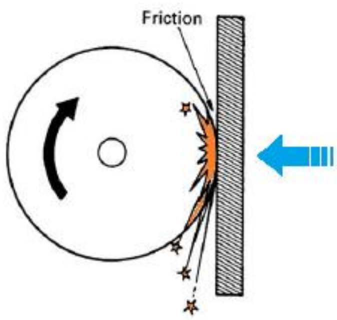
3. If a leak occurs in one of the brake lines the driver would be able to tell due to two factors. The first is a long pedal when the brakes are applied. What is the second?

4. Label this conventional master cylinder.

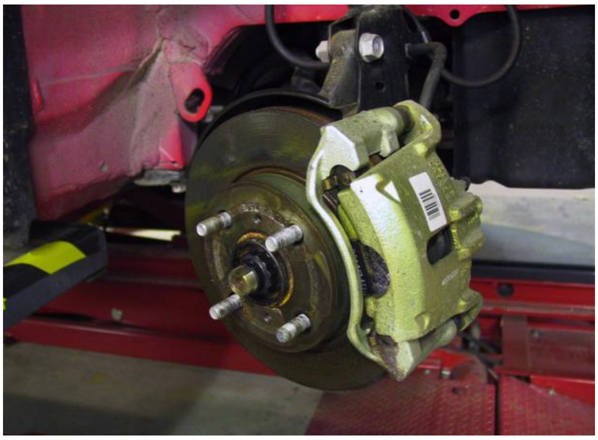


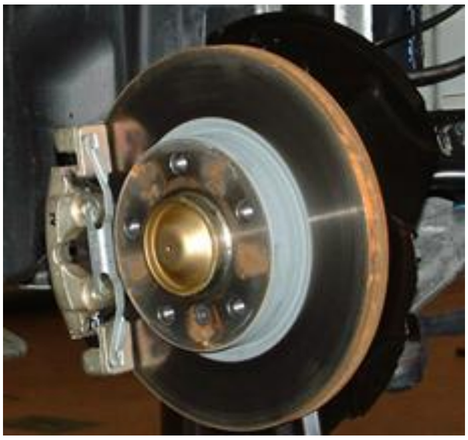
Disc brakes

The engine of a vehicle converts thermal energy into kinetic energy (energy of motion) to move the vehicle. The brakes therefore have the job of converting kinetic energy back into thermal energy to stop the vehicle. Generally vehicle braking systems involve a fixed object to be pressed against a rotating object. The braking effect is obtained from the friction that is generated between the two objects.



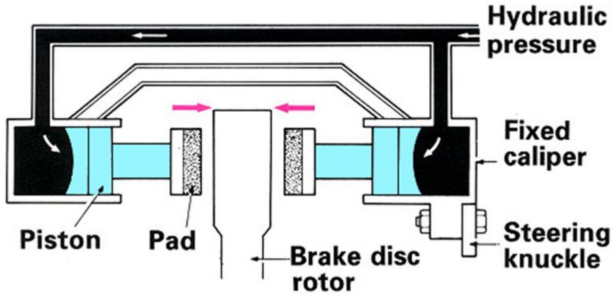
Disc brakes are in many ways a far superior form of brake for the road wheels for several reasons. Firstly as the disc is largely exposed to the air, heat dissipation is much better than the drum brake. They are also easy to maintain as most of the components that are regularly replaced are easily inspected and easily replaced.





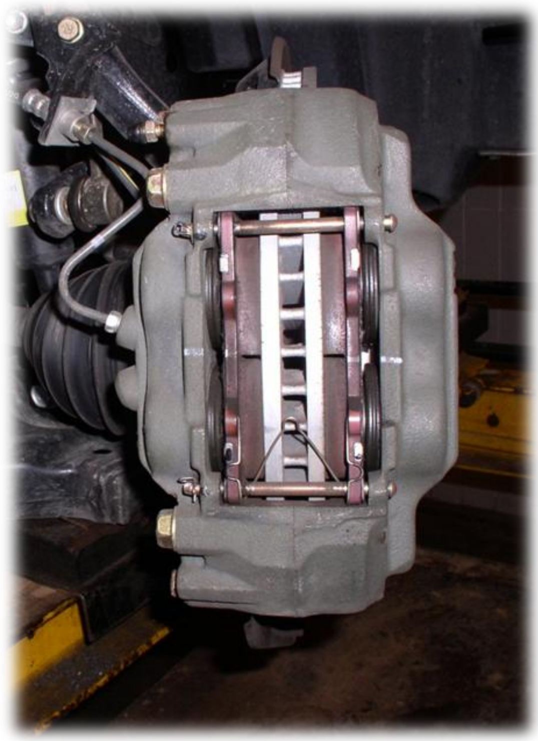
There is a viewing hole in the calliper that allows the brake pad thickness to be checked without any brake disassembly being required. The disc is also in view and so it can be inspected for width, grooving and run out very simply.

Operation of the disc brake



The disc or rotor is bolted solidly to the stub axle. It is free to turn and the road wheel is bolted to it. Two friction surfaces known as brake pads are pushed towards the revolving disc by an equal clamping force created by hydraulic pressure inside the calliper forcing the piston out. As the pads come into contact with the revolving disc, friction creates heat and the revolving disc slows down.

As the pads wear, the cylinder does not retract into the calliper fully and so the pads stay very close to the disc at all times. As the piston does not fully retract with each operation there is no need for manual adjustment. As the calliper is of a floating design itself centralises in relation to the disc and so the pads stay at an equal distance to the disc.



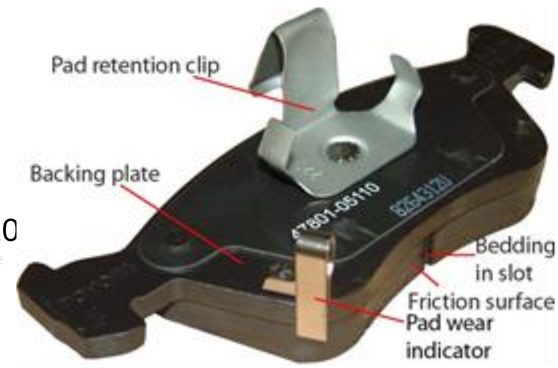
Some designs have a fixed calliper. This type of calliper will have one or more pistons pushing towards the disc on each side of it. Providing the pistons are of equal size they will push the pads towards the disc with equal force. Unlike the drum brake there is no self-servo affect with disc brakes and so the rate of retardation is proportional to the amount of force generated by the pressure put on the brake pedal.
As has been stated earlier, the more heat that can be dissipated from a brake the better the vehicle retardation will be (providing the wheel doesn't lose traction with the road). For this reason vented and cross drilled discs are fitted to vehicles that need very good stopping power as they provide much better heat dissipation properties.

The diagram to the right shows a high performance system would consist of a multi piston calliper. An advantage of a multi piston calliper is that several pistons have a larger surface area than one big one in the same size calliper and so more force can be exerted onto the pad. The leading edge of a brake

pad is susceptible to wearing out first, with multi cylinder callipers the pistons on the leading edge of the pad are smaller and get progressively bigger as they go down the length of the calliper. This allows there to be less force exerted on the leading edge of the brake pad and so uniform pad wear should occur. Unlike a floating calliper a multi piston calliper is fixed in position and it is the opposing pistons that move. As the calliper is fixed it makes it more rigid, this assists the braking performance, pedal feel and pad wear. In very high performance applications cross-drilled and grooved discs are commonly used.

There are several advantages of using cross-drilled discs; the first is better heat dissipation, caused by the additional ventilation created by the holes. The edges of the holes continuously clean the friction surface of the pad; this assists the bite of the pad. The holes or grooves in the disc will prevent any gas build up between the disc and the pad. The build-up can reduce the amount of heat generated between the pad and the disc. Finally the disc is lighter; this means it has less inertia (a body's unwillingness to slow down). Less inertia means it will be more willing to slow down hence better braking. A lighter brake disc will also lead to a reduction in un-sprung weight. Un-sprung weight is any weight below the suspension springs on a vehicle. A vehicle with low un-sprung weight will handle better and provide better comfort, as the wheels will be more inclined to stay in contact with the road. The gyroscopic affect will also be reduced with a lighter disc, this helps the feel of the steering. Gyroscopic affect is best understood by holding a bicycle wheel with a hand on each side of the axle. Spin the wheel up and try to turn the wheel as if your arms are the forks of a bicycle. The resistance to turn will be very noticeable. This is caused by the spinning wheels gyroscopic affect. The lighter the wheel the less the gyroscopic affect will be. This is also the case with discs on a vehicle. Lighter discs assist the feel and operation of the steering.

Brake pad



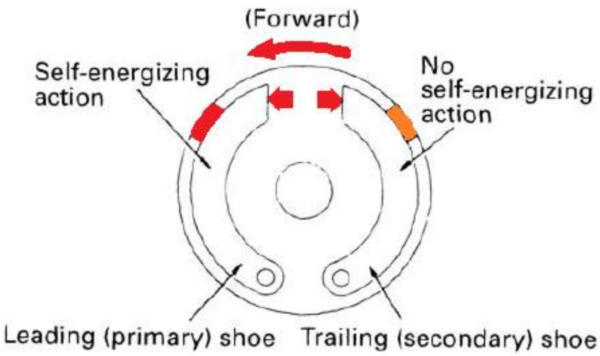
Shown in the diagram to the right is an example of a brake pad. These vary in shape, size and friction material but they all do the same job. They are pushed against the disc and the friction between the friction surface and the rotating disc produces heat, and slows the rotation of the disc down. The friction surface is the part of the pad that comes directly into contact with the disc. It used to be made out of asbestos but as asbestos is carcinogenic, other materials are now used. Care should still be taken to avoid inhalation of brake dust when maintaining the brakes. Brake cleaner should be sprayed onto any areas where brake dust may be, and a face mask should also be warn whenever carrying out any work on the discs or drums of a vehicles braking system. Most of the pad manufacturers produce the friction material out a combination of steel and mineral fibres, however some manufacturers have started working with composite materials such as Kevlar. The coefficient of friction in the latest pads are in the region of 0.43 whereas in the past it was more in the region of 0.3. Coefficient of friction is best described as a materials resistance to slide. The higher the figure, the more its resistance to slide. As the friction surface is comparatively rigid it can cause some bedding problems. For this reason a bedding in slot is cut into the friction surface. The high coefficient of friction can cause squeal, to combat this the backing plate often has a rubberised coating or copper compound covering. The backing plate is the part of the pad that comes into contact with the calliper and the calliper carrier. The area that comes into contact with the piston, calliper and calliper carrier should be greased with the recommended grease; this will prevent any seizing and can reduce any squealing. Additionally the pad retention clip and wear indicator is attached to this. The friction surface used to be attached by rivets but now it is attached by means of a special heat resistant glue.

Pad wear indication

It is recommended to replace pads when the friction surface has worn down by 70%. It is common now for brake pad warning indicators to be fitted to pads, usually on one side of each axle. The indicator tends to be of two types. The first type is shown in the photo.
As the pad wears down the end of the indicator comes into contact with the disc. This produces and audible warning and so indicates to the driver of the vehicle that the pads need replacing.
The second is an electronic sensor. The sensor slots into a machined area on the backing plate or friction surface. As the pad wears down, the end of the sensor gets ground down by the rotating disc. Once the sensor has been worn down to a certain point either the wire is earthed or an open line is created, either way, a warning light will come on, on the dash and indicate excessive pad wear. Circled in the photo is the warning light that illuminates when the pads have worn down excessively.

Drum brakes

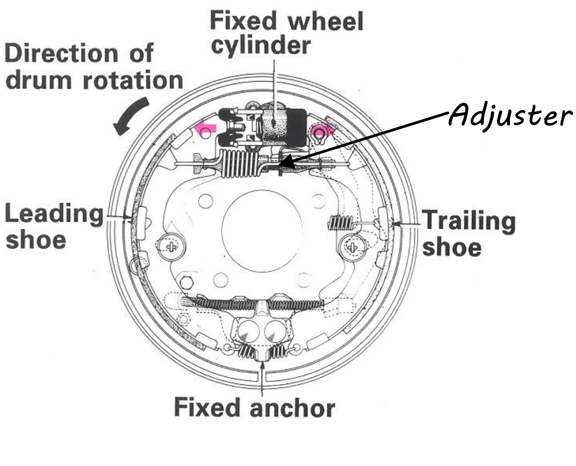
In a drum brake type system, braking power is obtained by causing non-rotating shoes to be pushed against the inner surface of a drum that rotates together with the wheel. This type of set up creates a 'self-servo' effect due to the rotating force of the drum and the expanding force of the shoe. This 'self-servo' action results in a large braking force generated from a relatively small pedal effort.



The main components comprising of a drum brake are the drum, brake shoes and the cylinder. The drum revolves around the fixed shoes and cylinder. As hydraulic pressure enters the wheel cylinder it pushes the piston/pistons out. The piston in turn pushes the shoes outwards about a fixed point that they pivot on. As the shoes move out they come into contact with the revolving drum. The contact creates friction between the friction surface on the shoe and the drum. And slows down the rate at which the drum is turning. As the drum is fixed to a road wheel, and the road wheel is in contact with the ground the vehicle decelerates.

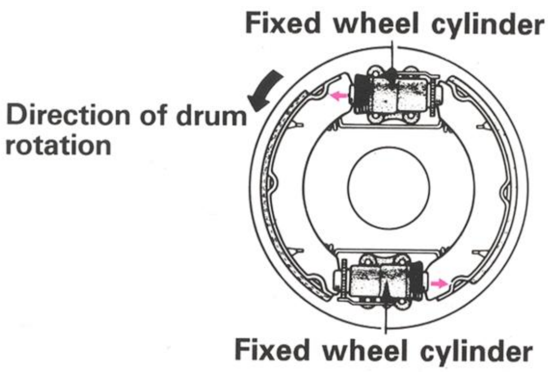
There is just one cylinder located in this type of drum brake. The cylinder has a piston exiting on both sides. The shoes pivot about the fixed anchor point shown in the diagram to the right.

As the piston on the left hand side of the cylinder travels over to the left it



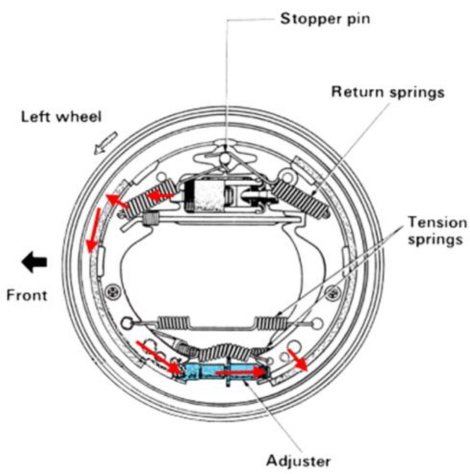
pushes the top of the left hand shoe into contact with the drum first. It is not only the pressure of the piston that holds the shoe against the drum. Due to the direction of the drums rotation it pulls the shoe tighter against it and so increases the amount of friction between the drum and shoe. This action is known as a ‘self-servo’ effect. The top part of the shoe does by far the majority of the work and so wears down much quicker than the bottom of the shoe. At the same time as the left hand piston travels out so does the right hand piston. This also presses the top of the shoe against the rotating drum. There is no ‘self-servo’ effect on this side due to the direction of the drums rotation and so the only force holding the shoe against the rotating drum is the hydraulic pressure from the cylinder. Please note, providing the brakes are adjusted correctly all of the friction area of the shoes come into contact with the drum when the cylinder pushes them outward, it is just at the top where the pressure is exerted on the shoe from the cylinder. This type of drum is particularly suited to the rear of vehicles as when the vehicle is reversed the right hand shoe has the ‘self-servo’ action and so a good braking affect is created from this type of drum whether the vehicle is travelling forward of backwards.

Twin leading drum brake single action



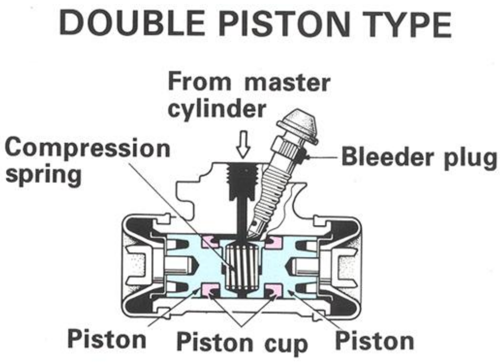
This type of drum is most suited to installation at the front of a vehicle. This type of brake has two cylinders and they both only have one piston in them. The top cylinder has a piston exiting out of the left hand side. The left hand shoe pivots at the back of the bottom cylinder and as the piston moves out it pushes the top of the shoe out to the left until it comes into contact with the drum. As soon as it comes into contact with the rotating drum the self-servo affect occurs and the braking affect is increased. The bottom cylinder has a piston exiting out of the right hand side. The right hand shoe pivots about a point at the back of the top cylinder. When the piston comes out of the bottom cylinder it pushes the bottom of the right shoe over to the left until it comes into contact with the drum. When it comes into contact with the drum the self-servo affect occurs again, hence increasing the braking affect further. This drum configuration is a very powerful brake when the vehicle is moving forward. When the vehicle is reversing there is no self-servo affect and so the brake efficiency if very poor.

Duo servo drum brake



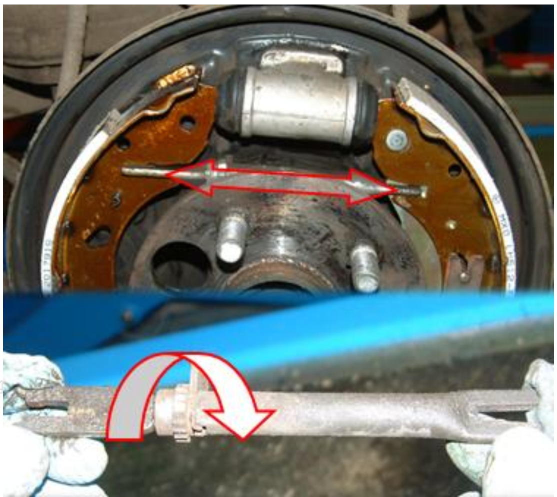
This drum brake system is also a very powerful drum brake. The diagram on the right shows a typical system. It has one cylinder that operates a piston out of its left hand side. As hydraulic pressure enters the cylinder it forces the piston out. This in turn pushes the shoe until it comes into contact with the drum. As the shoe comes into contact with the drum the self-servo action occurs and tries to twist the shoe down. The shoe is free to travel round with the drum slightly as it does not have a solid fixing at the bottom. As the shoe moves down and round it pushes the adjuster over to the right, which in turn pushes the right hand shoe against the drum. As the right hand shoe comes into contact with the drum it in turn is pulled tighter against the drum by the self-servo action. The shoe on the right is not free to move round with the drum as it pivots about a fixed point at the back of the cylinder. One major point that should be noted about this drum is that its effectiveness goes down drastically with the reduction in friction value. This is particularly the case with this brake as if the leading shoe doesn't grip the drum at the top when it is pushed out by the piston it will reduce the self-servo affect. This will cause the trailing shoe to not be pushed as hard against the drum and so the amount of friction/heat generated will reduce. The more heat generated, the higher the stopping power of the brake.

Drum brake cylinders



The brake cylinder is the hydraulic part of the drum brake. It is fixed to the back plate rigidly with two bolts. As hydraulic pressure enters the cylinder the piston(s) is/are pushed outwards. It is this outwards movement that moves the shoes into contact with the drum. A bleeding plug is fitted to the highest point of the cylinder to allow any air in that part of the hydraulic system to escape. The seal that prevents any brake fluid escaping from the cylinder is designed in such a way that hydraulic pressure pushes it tighter against the piston. If it is installed the wrong way around the hydraulic pressure will be free to escape, and so care must be taken to fit the seal correctly. It tends to be usual practice to replace the whole wheel cylinder if any fault occurs rather than recondition it.

Drum brake adjustment



It is necessary to be able to adjust the shoes manually. As the drum wears, a shoe wide groove is created. This makes drum removal very difficult, and so there must be a way of adjusting the shoes manually with the drum in place. Adjustment is normally carried out by a ratchet on the shoe separating linkage. The ratchet is accessed through a hole in the drum. The ratchet can be turned by a screwdriver through a hole in the back plate or the drum. Once the ratchet is backed off sufficiently the shoes will have retracted sufficiently to be out of the groove worn in the drum and the drum can be removed. The ratchet must be re-adjusted once the drum has been fitted, to ensure the brake will operate correctly. Correct adjustment is to tighten the shoes up until the drum cannot be turned and then backed off until there is very slight/no "drag".

Progress check

1. Is the friction surface of a drum brake internal or external?

2. Why is a twin leading drum brake poor at braking a wheel when the vehicle is reversing?

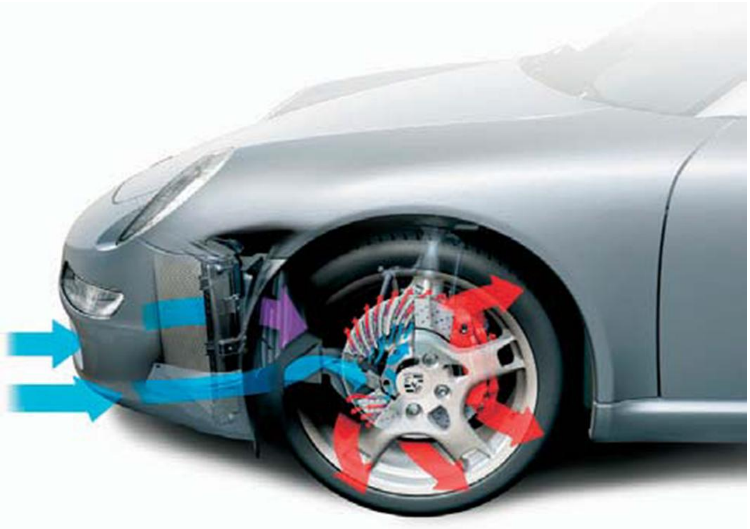
3. How many wheel cylinders are fitted in a single leading and trailing drum brake assembly?

4. When a leading and trailing drum brake is operating correctly, which shoe will wear out first?

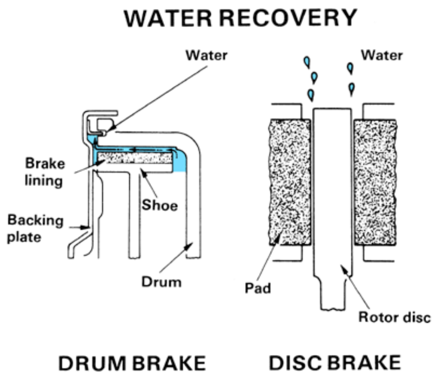
5. What maintenance should be carried out if the internal diameter of a drum is above the manufacturer's specification?

Advantages of the disc brake over the drum brake

The heat dissipation qualities of the disc brake are far better than the drum brake; this is caused by the friction surface of the disc being exposed to the air directly. The drums friction surface is internal and so the cooling air doesn't have direct contact with the friction surface. This makes fading due to reduction in the coefficient of friction less likely to occur with the disc.



The disc has much better water dissipation qualities, if any water gets onto the disc it is flung off by the centrifugal effect of the disc rotating. If water gets into the drum it struggles to escape. Water in the drum affects the friction between the shoe and the drum and so the braking characteristics



are hampered considerable. The disc is considerably easier to maintain, as all of the serviceable items are easy to access. Additionally the components are all visible and so disc run out, disc width and pad wear are simple to check.

A disc is self-adjusting and so the amount of time maintaining them is considerably less than drums.
When a disc heats up and its width expands, the friction surface of the disc is expanding in the direction of the pad. This has no detrimental effect. Whereas with the drum brake, when heat expansion occurs, the diameter if the drum expands. This expansion is driving the friction surface away from the shoe. This can lead to a long pedal in heavy braking conditions.

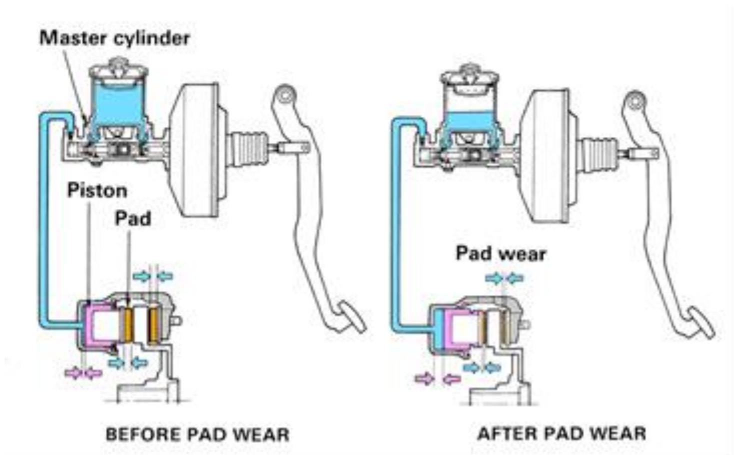
Disadvantages of the disc brake over the drum brake.

The surface area of the shoe is much larger than that of the brake pad. This means greater hydraulic force is needed to create the same amount of friction between the surfaces. Therefore the pad must be able to resist higher quantities of friction and heat.

Disc brakes are more likely to squeal than a drum brake caused by the way the pad comes into contact with the disc.

The piston size needed to press the pad against the disc as a pose to the shoe against the drum needs to be of a considerable larger diameter in order to exert the sufficient force. Due to this factor a brake booster is needed in the system.

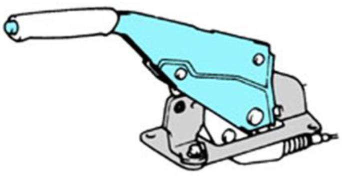
As the pad width reduces the piston sits further out of the calliper. This increases the volume of the hydraulic circuit and so the brake fluid level will go down in the reservoir. The reservoir must be monitored to make sure the level doesn't drop too low. If this occurs air will enter the system and complete brake failure could occur.

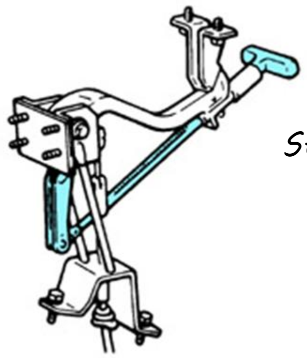


Parking brakes

It is a legal requirement for vehicles with hydraulic braking systems to have a mechanically operated handbrake that acts on at least two wheels. A rod or cable is usually used to activate the handbrake mechanism. By far the most common is a cable.

Lever type

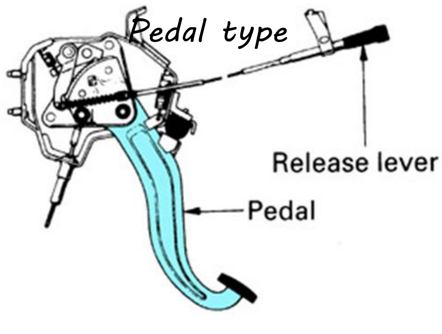




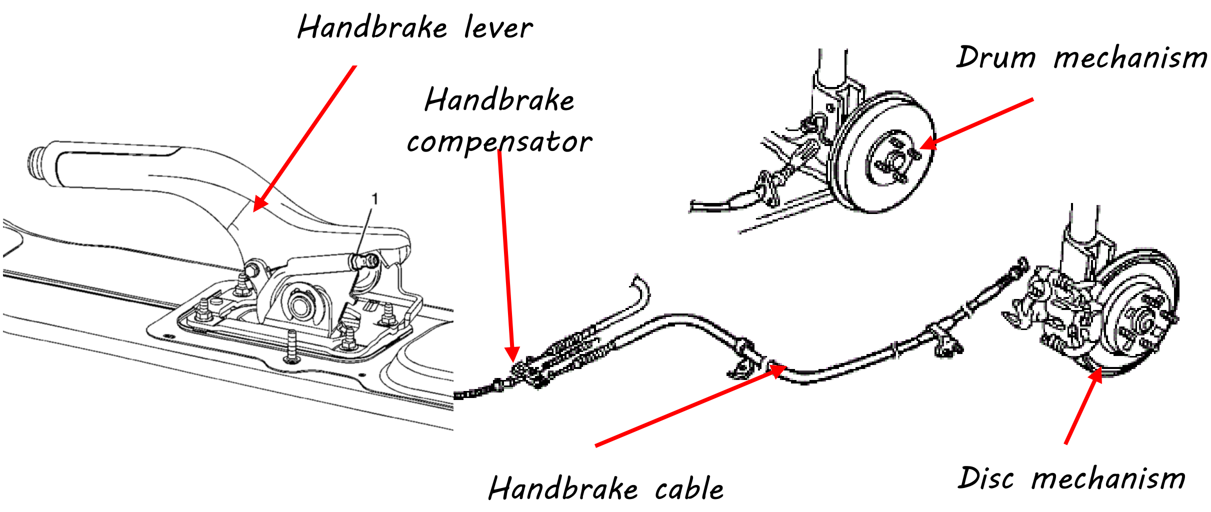
Stick type

Electronic handbrake

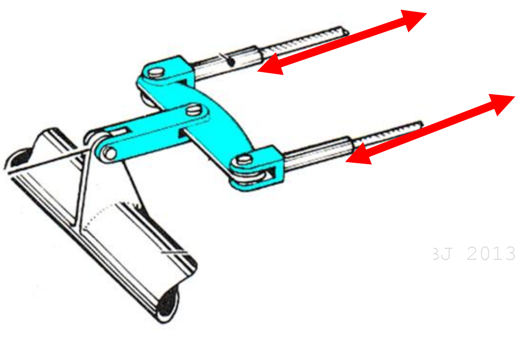
Pedal type

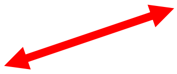


The diagram below shows a typical layout of a handbrake mechanism.



In between the handbrake and the cables is the handbrake cable equalising pivot (compensator), similar to the one shown below.

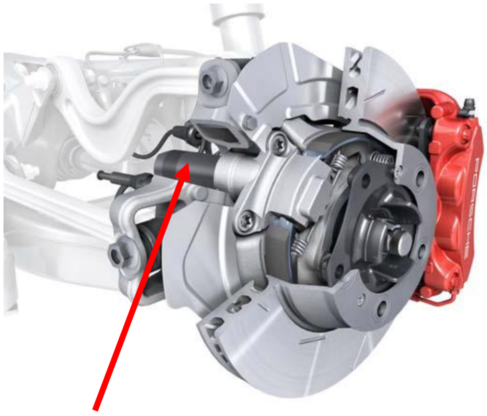




As the handbrake lever is pulled up the cables leading to the rear brakes are also pulled. It is the action of the handbrake compensator that ensures that the levers force is distributed evenly to each handbrake mechanism.

Electronic handbrake

In recent times the electromechanical handbrake has become a popular option favoured by vehicle manufacturers. The benefits are to be able to do away with the bulky levers and effort required to operate the handbrake. This was replaced with the action of a simple switch. Most of the electromechanical systems require the use of electric motors to mechanically apply the handbrake or release the mechanism.



Handbrake actuator (motor)

Braking efficiency

Part of an MOT test requires every vehicle that is tested to undertake a performance test. The performance test ensures that every vehicle presented for an MOT test is measured against a minimum level based on the vehicles weight and braking force.

To calculate the performance requires the following formula

$$\text{Braking Efficiency (\%)} = \frac{\text{Braking effort (kg)}}{\text{Weight of vehicle (kg)}} \times 100$$

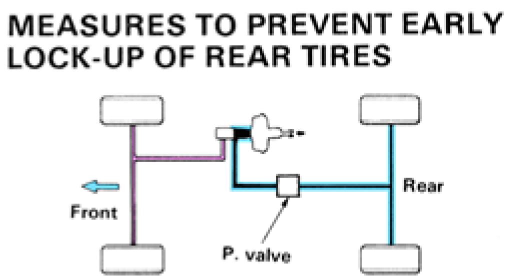
The MOT performance requirements

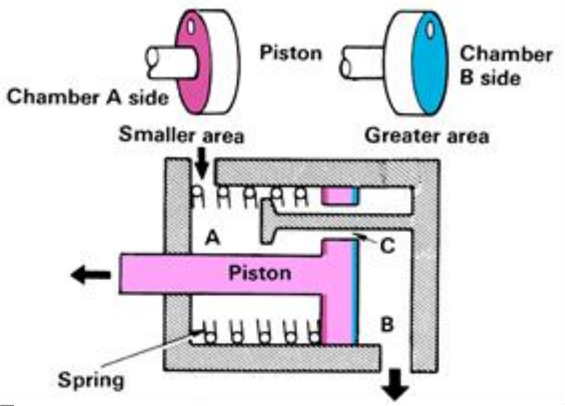
- Minimum Braking efficiency service brake (foot brake) 50%
- Maximum Braking efficiency deviation between steered wheels 25%
- Minimum Braking efficiency parking Brake (handbrake) 16%

This test must be carried out using a roller brake tester or a decelerometor type test equipment.

Operating principle of the proportioning valve (p-valve)

Shown in the diagram below is the basic operating principle of how a p valve works. The piston moves left and right depending on the amount of pressure acting upon each side of the piston. Not allowing for the spring, if there was even pressure either side of the piston the piston would travel over to the left as there is a larger surface area on the right side of the piston for the pressure to act against.





With the spring in position the piston will move to the left until the hydraulic pressure is equal to the springs force.
During light braking the pressure on either side of the piston is equal, the piston is driven to the left until the hydraulic pressure and the spring pressure equalise. The piston moves slightly over to the left but not sufficient to block the valve off. At this point the p valve is doing nothing to affect the hydraulic pressure getting to the rear brakes.

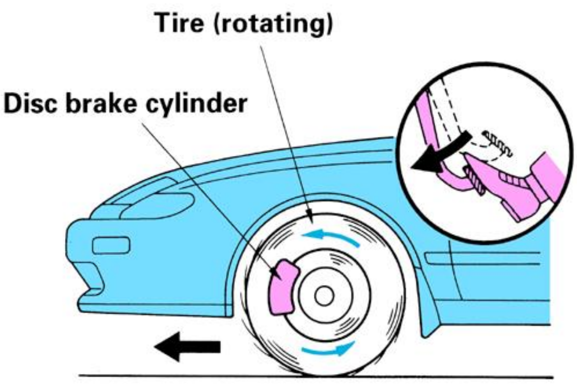
During heavy braking there is a higher pressure both sides of the piston. The variation in force is now sufficient to fully overcome the spring and push the piston over to the left until it closes the valve off. If the pressure now increases in chamber A the pressure increase will push the piston over to the right. Once it has travelled over to the right the pressure is allowed to equalise and will once again push the piston back over to the left. This procedure is repeated regulating the pressure able to get to the rear brakes. The point when rear brake pressure is controlled is set by the manufacturer and can be varied by changing the size of the area each side of the piston or the rate of the spring.

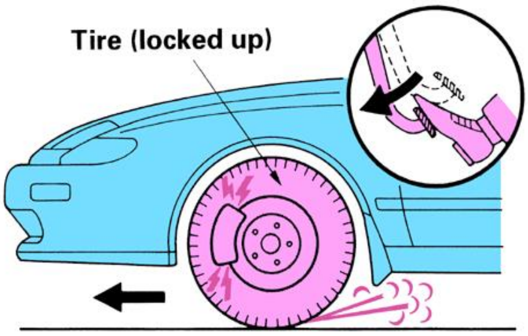
What is ABS?

Braking is achieved through the medium of two types of friction:

1. The friction between the brake linings and the brake drums / disc's

2. The friction that exists between the tyre and the road.





Braking can be controlled in a stable manner as long as the friction between the brake linings and brake drums / discs, is less than the friction created between the tyre and the road surface.
In other words the amount of braking does not exceed the stopping capacity of the tyre to road contact.
If the braking force is greater than the tyre to road contact can handle, then the wheels will lock up.
If the front wheels lock up, then the vehicle will become impossible to steer. If the rears lock up, then the vehicle will lose grip at the rear and a, 'tail spin' will occur.
The ABS controls the hydraulic pressure acting on individual wheel cylinders / brake callipers to prevent the wheels from locking up under heavy braking. This will allow the driver to maintain control when steering might have otherwise been lost.

Operating Principles of ABS

When a vehicle is being driven along a road in a straight line its wheels rotate at virtually identical speeds. The vehicles body also travels along the road at this same speed. When the driver applies the brakes in order to slow the vehicle, the speed of the wheels becomes slightly slower than the speed of the body, which is travelling along under its own inertia. The difference in speed is expressed as a percentage, and is called the 'slip ratio'.

The way to calculate the slip ratio is as follows: -

$$\text{Slip Ratio \%} = \frac{\text{Vehicle speed} - \text{wheel speed}}{\text{Vehicle speed}} \times 100$$

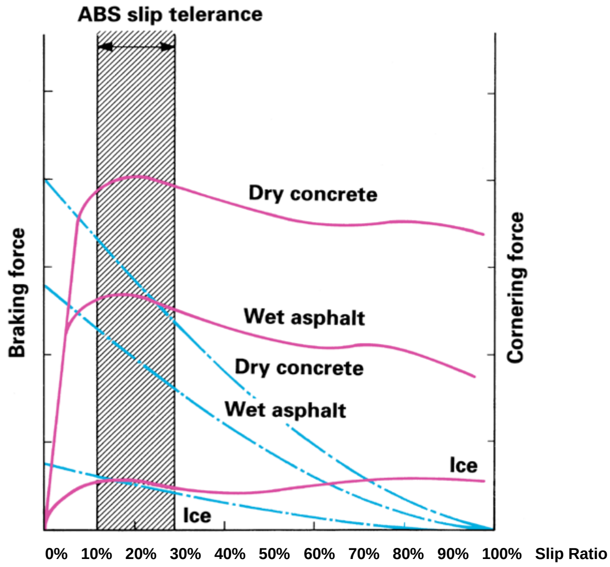
The easiest way to understand this principle is to look at the extremes i.e.

- 100% slip ratio is the equivalent of a locked wheel. In other words the vehicle body is still moving at 30 mph but the wheels are not rotating and so are considered to be stationary

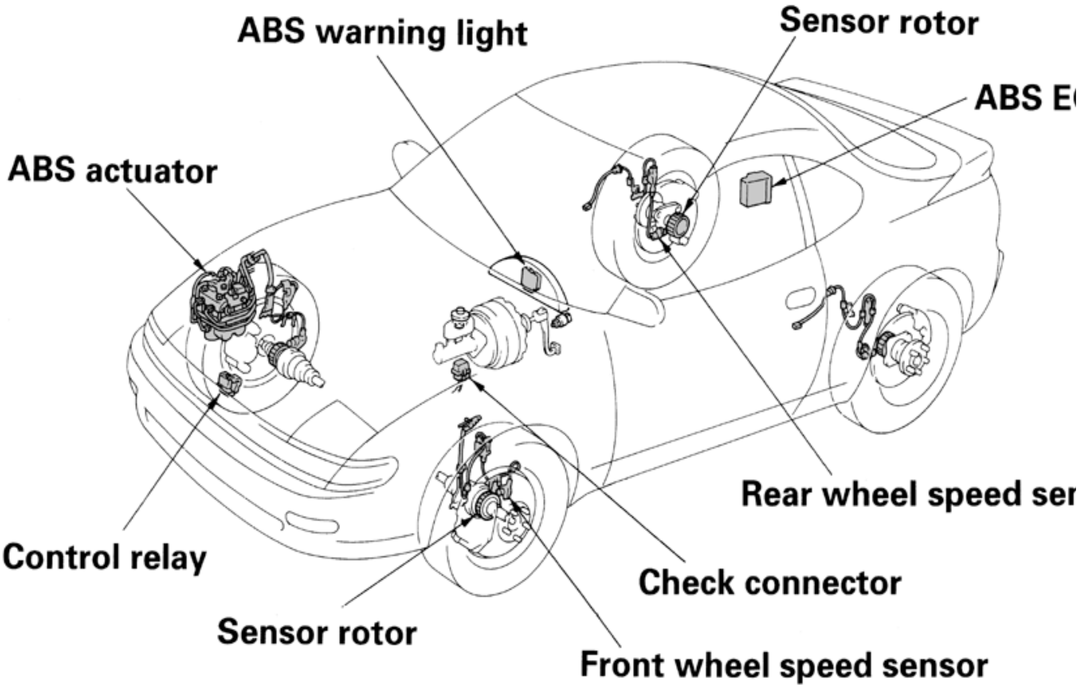
- 0% slip ratio is the equivalent to a freely rotating wheel. The vehicle is travelling at 30 mph and the wheels are also travelling at 30 mph.

When braking, if the slip ratio becomes too large then the vehicle will begin to lose control (as previously mentioned). The ideal slip ratio for the best possible braking would be between 10% and 30%. The reason for this is a small amount of slip will create heat, which will improve the tyres grip. However, if the slip ratio exceeds 30% then the braking force will begin to decline.
In addition to braking force, we need to consider cornering force without which we would not be able to steer the vehicle. The same slip ratio of 10% - 30% is also ideal. The ABS system is designed to maintain a slip ratio of between 10% and 30%, which will explain why under ABS operating conditions it is sometimes noted that the tyres appear to skid slightly.
It should also be noted that when a vehicle is driven on slippery or snowy roads, the vehicle might actually have a longer stopping distance than a vehicle that is not equipped with ABS. This is due to the fact that a vehicle without ABS locks its wheels and therefore creates a 'snow plough effect' i.e. snow builds up in front of the locked tyre slowing it down which cannot happen on an ABS equipped vehicle.

The slip ratio is not only affected by the condition of the vehicles tyres and its physical weight, but also by the condition of the road surface.



ABS component layout



ABS ECU (Electronic Control Unit)

The ABS ECU monitors wheel speed and determines wheel lock up. It sends commands to the hydraulic actuator to reduce, hold or increase the brake fluid pressure. It carries out a self-check of the system at start up and informs the driver of any abnormalities via the dashboard ABS warning light. It stores any diagnostic information for later retrieval by a technician.

Wheel Speed Sensors

These detect individual wheel speeds and send this information to the ABS ECU.

Sensor Rotor

Attached to the hub or drive shaft, it has teeth that when passed in front of the ABS wheel speed sensor causes a signal to be generated.

ABS actuator / modulator

This controls the hydraulic brake fluid pressure to the individual brakes dependent upon signals received from the ABS ECU.

ABS Warning Light

This alerts the driver of system malfunctions. It can also be used as a diagnostic code indicator on some makes of vehicle.

Control Relays

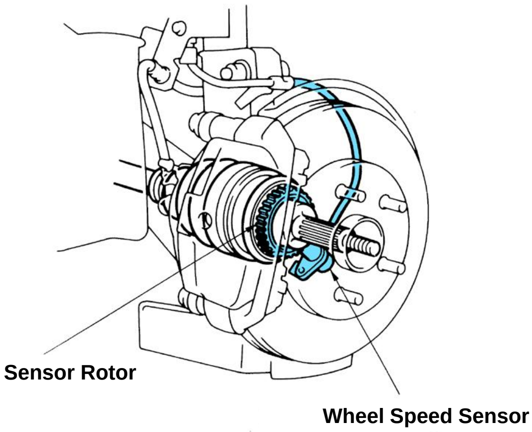
Some early systems feature two relays that are required to provide electrical power to the ABS. One relay is the actuator pump relay and the other one is for the actuator solenoids. They can be located on the actuator itself or an adjacent fuse / relay block.

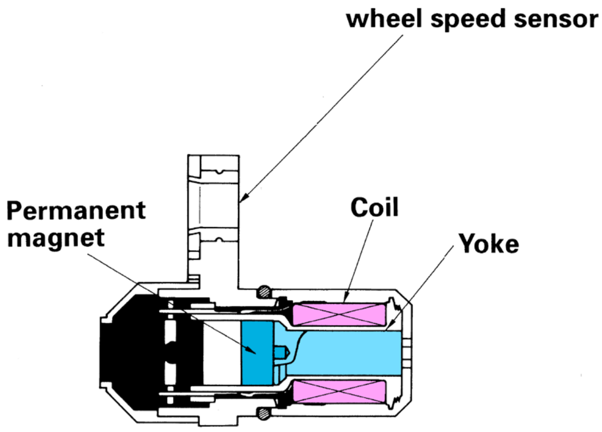
Diagnostic Connector

The diagnostic connector allows access to ABS diagnostic codes and live data readings.

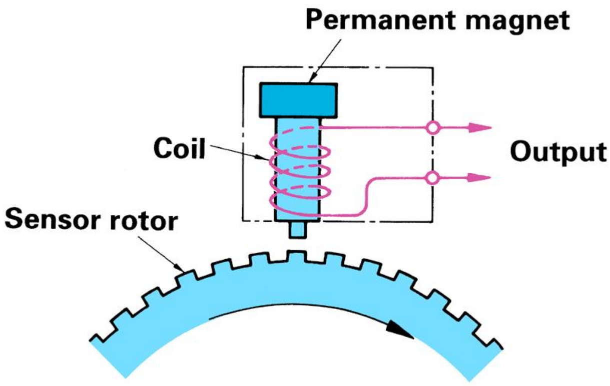
Wheel speed sensors

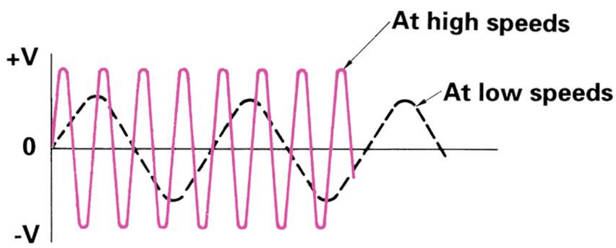
The front and rear wheel speed sensors consist of a gear-shaped sensor rotor and a sensor element. The element contains a bar magnet around which a copper coil is wound. The sensor is installed in the backside of the brake disc / rotor.





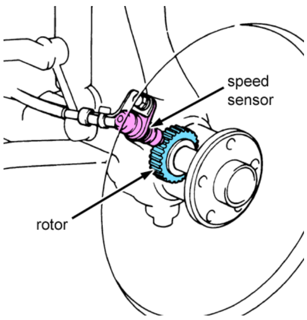
Alternating current is generated in the copper winding as the teeth of the rotor pass the sensor.

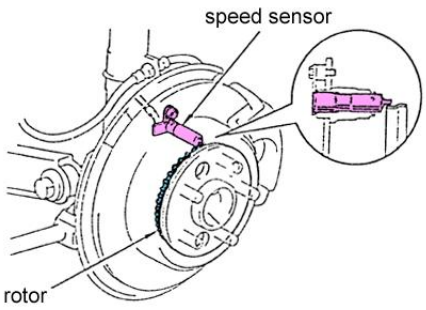




The frequency and voltage increase as the rotational speed of the rotor increases. It is the frequency of this signal that the ABS ECU interprets as rotational speed of the wheel.

The location of the sensors can be varied; they can be fitted onto driveshafts, inside brake drums or inside transmission cases. This illustration opposite also demonstrates that a sensor can be located either square on to the rotor, or at 90° to it.



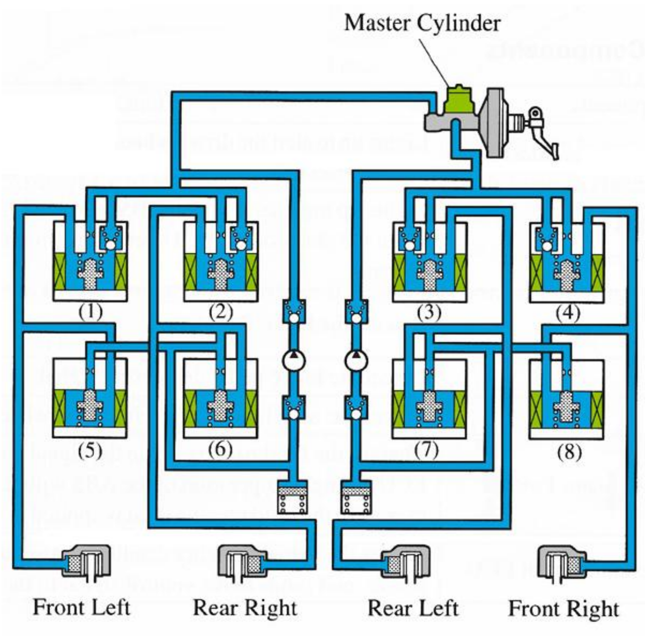


ABS Actuator / modulator

2 – position solenoid valve type

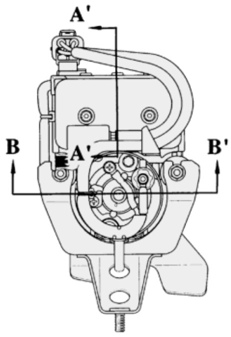
The modern ABS actuator contains two position solenoids that are simply on or off, depending upon whether battery voltage is applied or not. These are much simpler to produce but more of them are needed. However, installing eight rather than the original three or four is still considerably more cost effective.

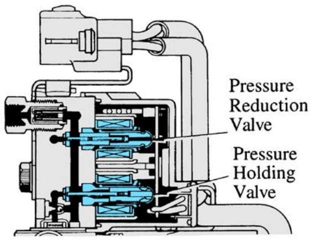
Hydraulic circuit



It can be seen from the diagram to the left that two ‘on’ or ‘off’ valves have replaced the original three-position solenoid valve. One is called the ‘pressure holding valve’ (the four on the top row on the diagram), whilst the other is known as the ’pressure reduction valve’ (the four on the bottom row on the diagram). If we have two valves for each wheel then we have a total of eight.

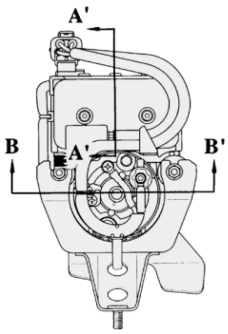
Actuator construction (solenoid valves)

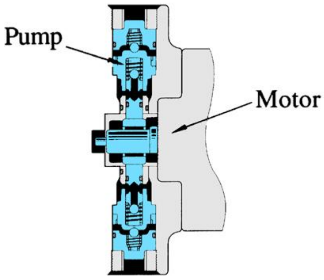




The construction of the two- position valves has been simplified further by building them all into one unit. The diagram to the left shows a sectioned view. It can be seen that there are two rows of four solenoids built in to the actuator.

Actuator pump

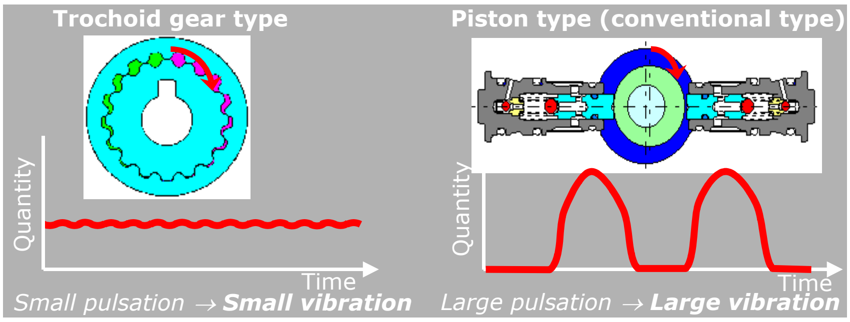




B-B' Cross Section

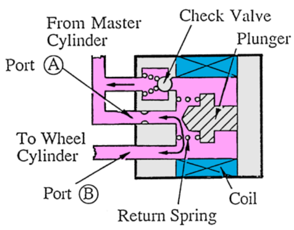
The pump mechanism did not change initially. There are two horizontally opposed pump plungers running on a single cam.

The latest pumps are now a 'trochoid gear type'. These reduce operating noise significantly. They also lower the vibration felt through the brake pedal during ABS operation, which has been accepted as 'normal' in the past.

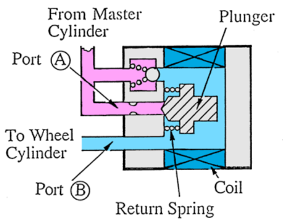


2 – Position solenoid valve

Pressure holding valve



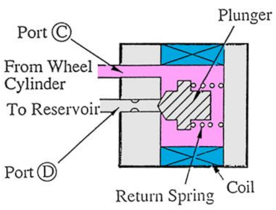
OFF Position



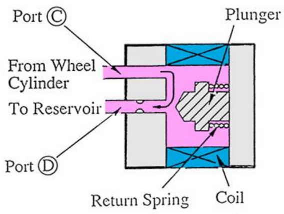
ON Position

The pressure holding valve is normally open. The spring shown in the diagram moves the plunger to the right. When the valve has battery voltage applied to the solenoid, the plunger moves to the left, blocking the passageway from the master cylinder.

Pressure reduction valve



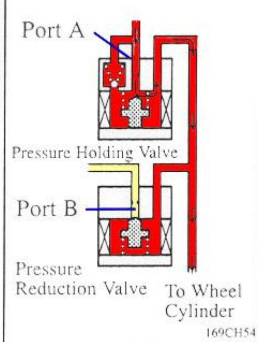
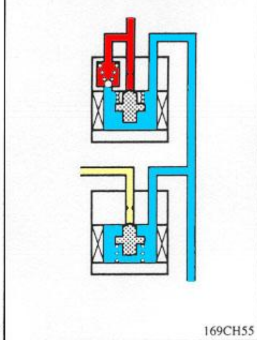
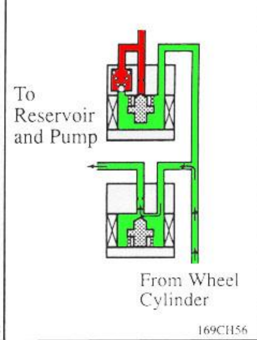
OFF Position



ON Position

The pressure reduction valve is normally closed. The spring shown in the diagram moves the plunger to the left. When battery voltage is applied to the solenoid, the plunger moves to the right, allowing fluid in the calliper to move to the reservoir.

Hydraulic circuit

Not Activated	Normal Braking	—	—
Activated	Increase Mode	Holding Mode	Reduction Mode
Hydraulic Circuit			
Pressure Holding Valve (Port A)	OFF (Open)	ON (Close)	ON (Close)
Pressure Reduction Valve (Port B)	OFF (Close)	OFF (Close)	ON (Open)
Wheel Cylinder Pressure	Increase	Hold	Reduction

Pressure increase mode

Hold valve off (open)
Reduction valve off (closed)

Pressure hold mode

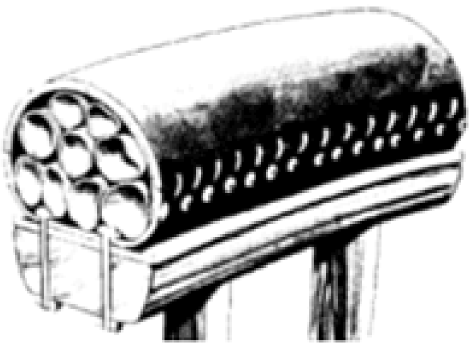
Hold valve on (closed)
Reduction valve off (closed)

Pressure reduction mode

Hold valve on (closed)

Reduction valve on (open)

The History of the Tyre



Tyres have not always been as we know them today. RW Thomson invented and patented the Pneumatic Tyre in 1845. His first design used a number of thin inflated tubes inside a leather cover as illustrated. This design actually had its advantages over later designs. It would take more than one puncture to deflate the whole tyre, and varying the pressures could alter the ride conditions.

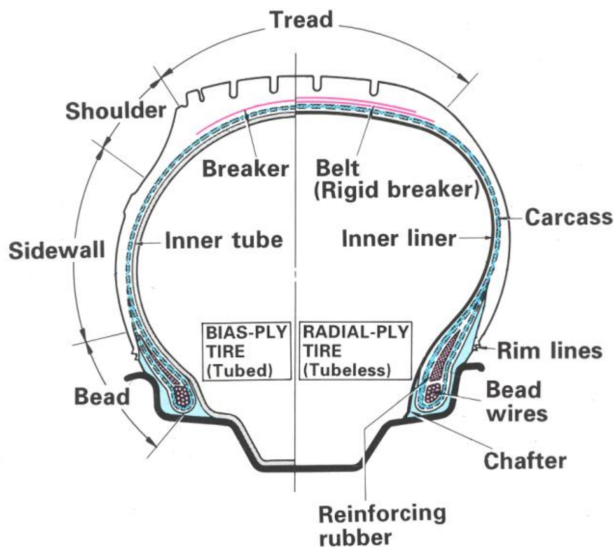
It was not until the late nineteenth century, 1888, that John Boyd Dunlop invented the Rubber Pneumatic Tyre. Despite these technological breakthroughs the solid rubber tyre continued to be the dominant tyre and it was not until 1889 that the pneumatic tyre caught on.

Dunlop first advertised his tyres in December 1888. In May of the following year the Tyre had its first breakthrough. A Belfast Cycle Race was won on pneumatic rubber tyres, and by now the public were starting to take note.

Unfortunately the original tyre had its drawbacks. The inner tube was difficult to get at because the tyre was stuck to the wheel. In 1890 CK Welsh patented the design of a wheel rim and outer cover with inextensible lip. By now we had the basics for today's tyre. Over the years the tyre has developed into today's high technology offerings. Two of the most important technical developments include Michelin's creation of the radial tyre with its vastly superior grip in 1948, and when Dunlop did away with the inner tube on car tyres in 1972. Time has given the motor industry tyres capable of many different applications. This ranges from High Speed Racing such as Formula One to Heavy Plant Usage on vehicles as large as a house.

Pneumatic tyre construction

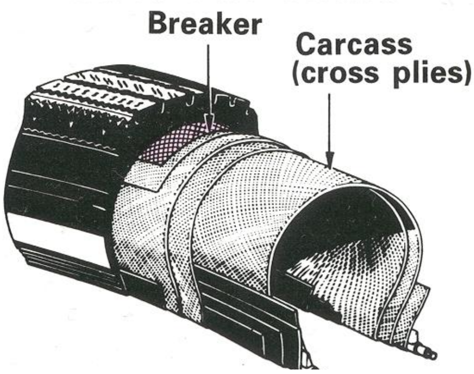
Vehicles tyres perform a vital role. The tyre is the only point of contact between the vehicle and the road surface and therefore acts as a medium through which all vehicle actions such as steering, acceleration and braking occur. A vehicle may well be equipped with an excellent steering system, a very powerful engine and good brakes, but this will all amount to nothing if the tyres are not up to the job. Tyres also act as shock absorbers between the road surface and the vehicles body.



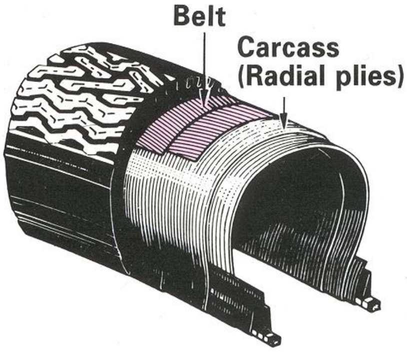
Tyres can be broadly grouped into two types: Radial-ply and cross-ply. These names are references to the tyres construction. The tyres carcass (see illustration) consists of layers of cord plies bound together with a synthetic rubber compound, and the angle of the cords set against the tyres circumference, dictates the type of tyre give it certain characteristics. A radial-ply tyre has these plies set at an angle of 90 degrees (hence the name – they radiate out from the centre), whereas the cords of a cross-ply tyre has the cords set at an angle of approximately 40 degrees. Through this construction, a radial ply tyre tends to have a large amount of flexibility in the radial direction but which would lend to the tyre excellent shock absorption characteristics.

The flexibility of tyres would be excessive if left unchecked, so layers of belts are added which are often made of cord also but occasionally steel. This gives the tyre its strength while maintaining good flexibility to reduce harshness of ride. The angle of the cords of a cross-ply tyre and the fact that these layers are built up in an alternating fashion give it a good deal of natural rigidity, so the belts that are used to brace such a tyre can be a little bit more flexible. This results in improved ride comfort over the radial-ply tyre. It is, however, the only advantage that such a tyre has.

Cross – ply tyres



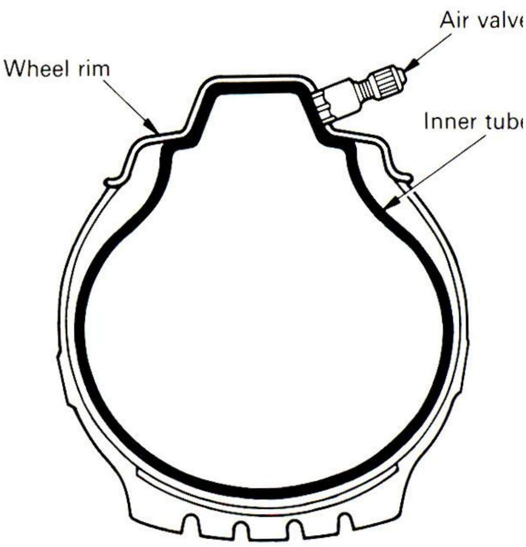
Radial – ply tyres



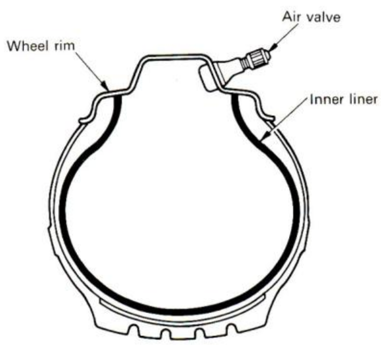
Radial-ply tyres offer superior cornering performance; better wear characteristics and lower rolling resistance. Rolling resistance means a higher top vehicle speed and better fuel economy, and also fewer emissions.

It should be noted that most countries refer to cross-ply tyres as bias-ply tyres and also spell 'tyre' as 'tire'. A useful tip if researching tyres on the Internet!

Tube and tubeless tyres

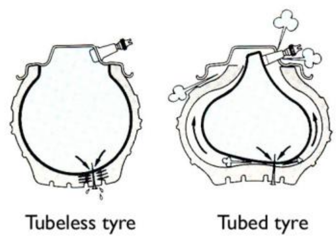


Some tyres use inner tubes to retain the air and others do not (tubeless). The illustration shows a tube tyre. It can be seen that the tube assembly has been integrated with the tyre valve. A major disadvantage of tyres that use inner-tubes is that when punctured the tyre tends to deflate very quickly – the tyre itself cannot seal in the air and the inner tube tends to rip when punctured.

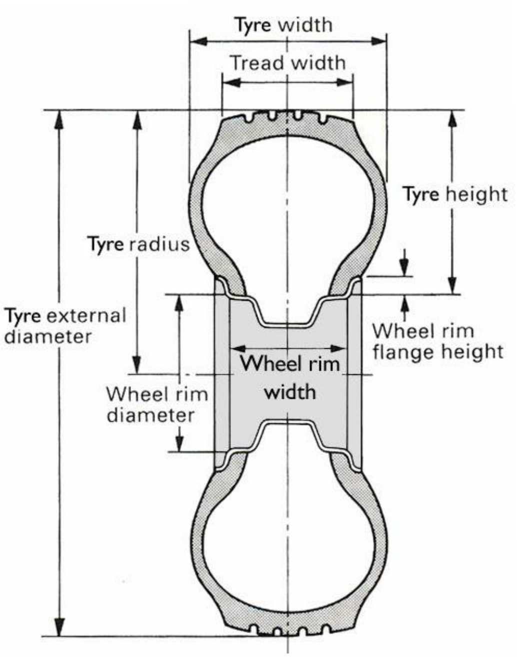


If the inner tube does rip a loss of control may occur. The illustration shows the effect of a puncture on a tubed and a tubeless tyre.

Tubeless tyres seal in the air through the use of airtight bead seals and an inner liner. These tyres deflate in a much more controlled manner when punctured – a considerable safety improvement. It can be seen from the pictures that part of the wheel rim forms a sealing surface. This is a disadvantage with alloy wheels as aluminium alloy is slightly porous. This will affect tyre pressures over time. Extra emphasis, therefore, should



be placed on regular tyre pressure checks on vehicles fitted with tubeless tyres and alloy wheels.



Markings on tyres

Tyres are available in many different sizes and grades. These differences are now described using a standardised coding system (ISO codes – International Standards Organisation). The illustration shows the major dimensions associated with a tyre.

The picture on the left shows an ISO code that would typically describe some of these key dimensions.
The first part of this code indicates the tyres width in millimetres (205mm in the case of the example). After the forward slash, the '55' indicates that aspect ratio of the tyre. This figure is a percentage value and represents the relationship between the tyre height and its width. This value is calculated using the following formula:

Aspect ratio % =<u>Section height</u> x 100

Section width

It can be seen through the application of this formula that the wider the tyre when compared to its height, the lower the aspect ratio figure will be. Some high performance cars will have an aspect ratio as low as 35%. This is more commonly referred to as a low profile tyre. Such tyres have enormous amounts of rigidity. This gives the vehicle excellent 'turn in' characteristics (very responsive steering). The trade-in is unfortunately ride comfort that will often be harsh to the point of irritation.
The 'R' in the ISO code indicates that this is a Radial ply tyre and the final part of the code, '16' indicates the tyre bead diameter, in this instance 16 inches. It is unusual for the International Standards Organisation to use a mixture of imperial and metric units but with tyres they do!

Load index and speed rating

This illustration shows the load index and speed rating of a tyre. The load index (the two figures in the code) is the maximum load that that individual tyre can withstand. The manufacturer closely matches the tyres to suit the overall weight, and the weight distribution on a vehicle.

The table shown below gives the index of load ratings for tyres. This is the maximum load that the tyre is designed to cope with and must never be exceeded. Exceeding this load could result in catastrophic failure of the tyre.

75	387	104	900
76	400	105	925
77	412	106	950
78	425	107	975
79	237	108	1000
80	450	109	1030
81	462	110	1060
82	475	111	1090
83	487	112	1120
84	500	113	1150
85	515	114	1180
86	530	115	1215
87	545	116	1250
88	560	117	1285
89	580	118	1320
90	600	119	1360
91	615		
92	630		
93	650		

The full range of speed ratings can be seen in the adjacent table. The table gives the index of speed ratings for tyres. This is the maximum speed that the tyre is designed to cope with and must never be exceeded. Exceeding this load could result in catastrophic failure of the tyre.

It should be noted that modern tyres are often designed to rotate at speed in only one direction. These tyres are described as unidirectional. It is more to do with tread design than any other factor – the tread can only disperse water effectively in one direction. Such tyres are clearly marked with a direction arrow on the sidewall that indicates forward rotation. These tyres must be fitted the correct way round otherwise control could be lost in wet conditions.

Speed symbol	Maximum speed km/h	mph
N	140	87
P	150	93
Q	160	99
R	170	106
S	180	112
T	190	118
H	210	130
V	240	149
W	270	168
Y	300	186

Speed category	Maximum speed km/h	mph
ZR	240	149
	and	above

Progress check

1) What does the following tyre code represent?

   225 / 45 / R17 86W

   ____
   ____
   ____
   ____

2) Which part of a tyre comes into direct contact with a wheel rim?

   ____
   ____
   ____
   ____

3) Calculate the aspect ratio of the following tyre:

   Section height – 100mm

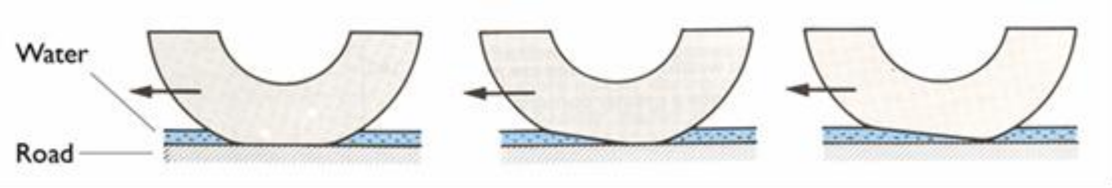
   Section width – 200mm

Tyres – the legal requirements

There is a good deal of legislation governing the manufacture, remanufacture (remoulding) and resale of part-worn tyres. The laws discussed here is orientated towards that which the technician has to be aware of during the inspection of tyres.
The rules exist to reduce the risk to the vehicles occupants and other road users through the use of dangerously worn or damaged tyres.

Tyre tread

A tyre has tread to enable it to disperse water effectively. The tread disperses the water from front to rear and to the sides of the tyres contact patch (the area in contact with the road surface). There are many different designs of tread pattern on offer from manufacturers, all of which claim to have attributes bettering their ability to do this.



No matter how effective the tread pattern, once the tread is worn beyond certain limits its abilities are seriously reduced. If the tyre cannot shift the water properly the tyre will aquaplane. This is a condition where the water builds up at the front of the contact patch and acts like a wedge, eventually lifting the tyre completely clear of the road surface. Once road contact is lost, control is lost soon after. This is because fluids are capable of transmitting huge amounts of force. Moving water can turn massive hydro-electric generators, trapped fluid makes the brake work on cars, and if it's an automatic, fluid transmits all drive between the engine and the transmission. Its abilities should not be underestimated.

The law states that the tread of a tyre must be at least 1.6mm in depth across a minimum of 75% of the tyres width for the whole of the tyres circumference. It should be noted that this is a legal minimum and even with tread thickness in excess of this but nonetheless worn, a tyres efficiently will be drastically reduced.

Other visible damage

Any cuts to the tyres surface must not exceed 25mm in length and at no point should that cut be through to the cords. Any visible tyre deformation such as bulging sidewalls renders the tyre weak, dangerous and therefore illegal.

Tyres should be inspected for visible signs of damage and deformation and tread depth should be checked using a tyre tread depth gauge.
Great care should be taken when inspecting tyres. Do not run your hands around the tyre as any exposed steel bracing or perhaps even

slivers of glass stuck in the tread can cause serious injury.

Some tyres have tread wear indicators which are simply raised portions of tread which when worn down to, indicate a tyre approaching it's safe wear limit. It should be noted that these are merely indicators for the driver and should not be relied upon during inspection.

Maintenance requirements

The maintenance requirements of tyres are simple but often overlooked. Tyres should be checked on a regular basis for damage, excessive wear and correct inflation pressure. Tyre pressures should always be checked with the tyres cold (unless otherwise stated). This is because the air in the tyre expands with heat generation (through rolling resistance friction) and this will temporarily increase the pressure within the tyre. Tyre pressures should also be checked with the normal weight of the vehicle acting on the tyres – do not check and adjust the pressures with the vehicle suspended on a wheel-free lift. Any reduced loading will influence the tyre pressure.

Progress check

1) What function do bead wires perform?

____

____

____

2) What does the law state about tread depth?

3) What factors contribute to the likelihood of aquaplaning?

Types of wheel and rim construction

The tyres are of course mounted on the wheels. The wheels have to have a combination of properties: high strength, lightweight, good balance, corrosion resistance and must also be designed to keep the tyre securely mounted.

There are three main types of wheel – pressed steel, alloy and wire spoke. A manufacturer from new seldom fits wire spoke wheels unless the vehicle has been designed with a retro-look. However, there are numerous after-market companies that build such wheels to a specific customer’s requirement.

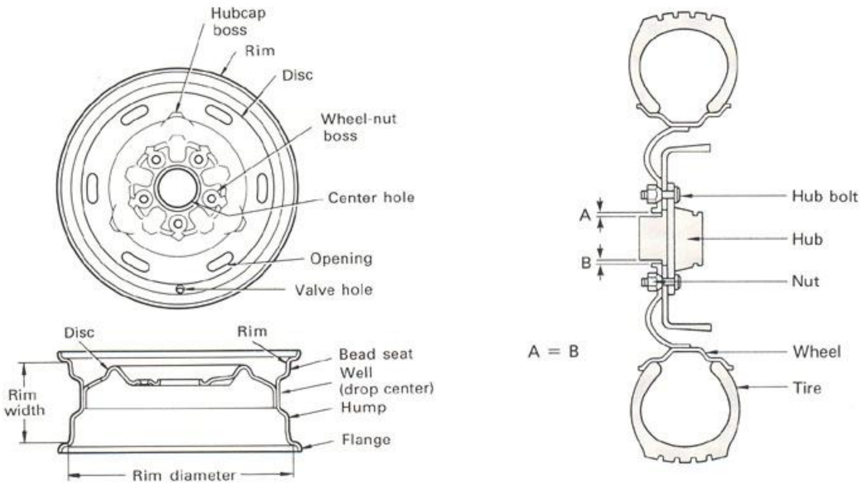


A pressed steel wheel is formed from a steel pressing (the disc) which is welded to a rim assembly. This is a very cost-effective method of wheel production that enables a manufacturer keep prices lower on their mass-produced vehicles. Such wheels lack aesthetics (they’re ugly) so plastic wheel trims are regularly used to create an acceptable look.

Alloy wheels are cast from an alloy of aluminium and sometimes magnesium. Magnesium alloy wheels (mags) are very lightweight and strong, but can suffer from corrosion if the surface is not treated correctly. Aluminium alloy wheels do not corrode.

Features and dimensions

This Illustration shows the main dimensions and features of a pressed steel wheel assembly. The wheel nut boss is the point at which the wheel is mounted to the hub.
The bead seat provides the sealing surface for the bead of the tyre. The well or drop-centre is to aid removal and fitting of the tyre assembly and the wheel rim flange is designed to keep the tyre secure in its place. The rim flanges are designed in differing ways to ensure the secure mounting of the tyres.



It is generally the tyres aspect ratio that dictates the design of flange. The illustration bellow shows a typical wheel code assigned to a wheel. It can be seen that the letters used in this code describe the wheel rims flange design. Generally, the wider the tyre, the higher the rim flange design (JJ, JK and K) as this helps to keep the tyre securely in place.

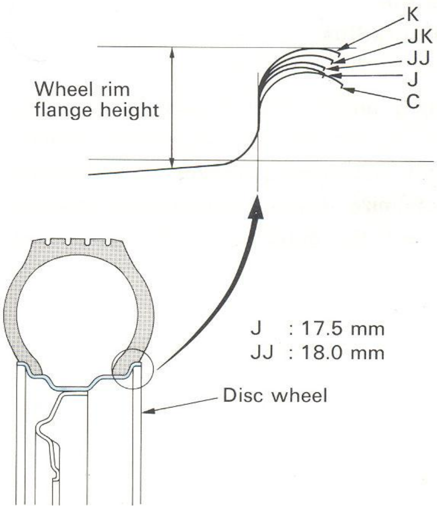
Example of wheel code

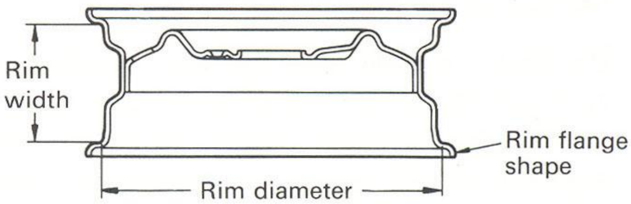
4 ½ J x 13

4 ½ = wheel rim width in inches

J = wheel rim flange shape

13 = wheel rim diameter in inches

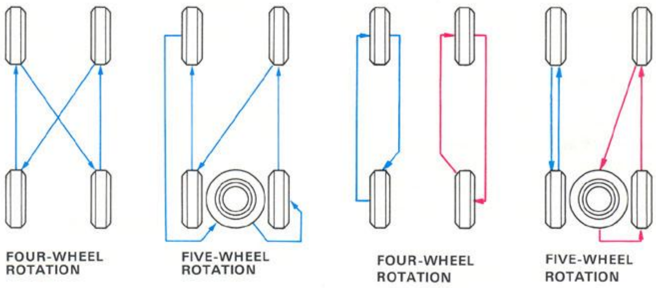




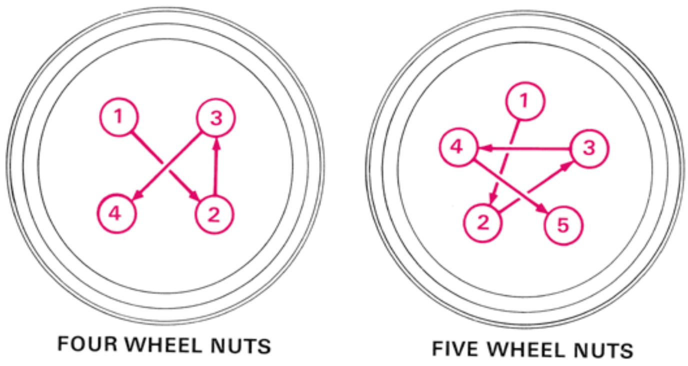
Interchanging wheels and tyres

Interchanging wheels and tyres (tyre rotation) is a process where the wheels are swapped around on the vehicle to promote even wear on the tyres. No matter how well balanced the vehicles chassis is, tyre wear will always be more prevalent on some tyres than others. Generally the front tyres wear quicker as they have to withstand cornering forces, driving forces (on front wheel drive cars), braking forces and steering forces.

The picture shows different options that can be adopted when rotating tyres.
It should be noted that tyres should only be transferred across the centre line of the car if the tyres are not unidirectional. The spare tyre should only be included in the exercise if it is a standard spare and not a space-saver.



When tightening wheel nuts, the correct tightening sequence should be observed to ensure even pull-down and seating of the wheel on the hub assembly. A diametrically opposite tightening sequence should be adopted.



Progress check

1) What does the following wheel code represent?

   4 ½ JJ x17

2) List the benefits of alloy wheels:

3) List the disadvantages of alloy wheels: