jumpstart

Theory Section

Heavy Vehicle Week 4

JUHV04TSTO-V01.0
6 January 2006

Advanced Apprenticeship Programme

CHAPTER 1

Layout and Components of Suspension Systems

The Operation of Suspension Systems and Components

Principles of Electronic Suspension Systems

INTRODUCTION

Purpose of the Suspension System

- Locate wheels and axle assembly.
- Enable wheels to move up and down freely.
- Allow wheels to steer freely.
- Absorb longitudinal, lateral and vertical forces.
- Distribute the vehicle weight to all wheels.
- Maintain contact between wheels and road.
- Isolate vehicles from road noise.
- Give passenger comfort.

The suspension system must create a balance between maximum passenger comfort and maximum safety along with meeting certain aspects of cost and reliability.

The suspension system must meet all technical requirements for a modern vehicle along with being relatively easy to maintain and as low in cost as possible.

The suspension system must have a low unsprung weight to maintain the best possible road holding and vehicle stability.

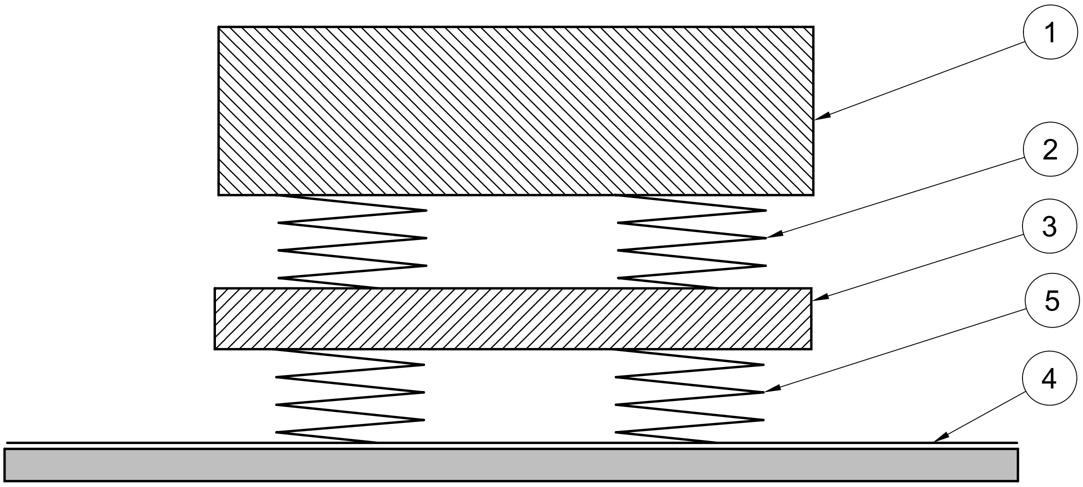
Unsprung Weight

The unsprung weight is all the weight not acting directly onto the spring, that is, suspension parts, axles and wheels. Large unsprung masses on a vehicle are undesirable as they have a negative effect on vehicle handling and behavior. For this reason, vehicle designers try to keep the unsprung weight as low as possible.

Low unsprung weight helps to produce a suspension system that responds sensitively to road

irregularities, giving maximum comfort.

Sprung and Unsprung Masses

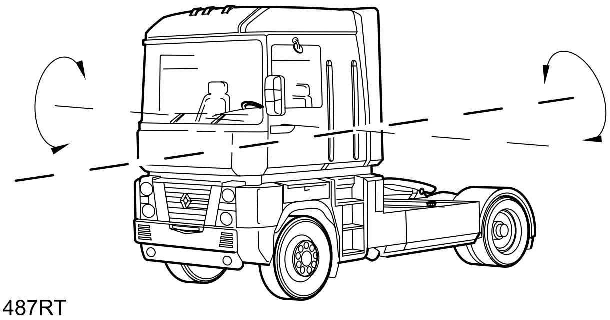


215

1. Body sprung mass
2. Chassis springs
3. Suspension parts (unsprung mass)
4. Road surface
5. Spring through tyres

SUSPENSION TERMS

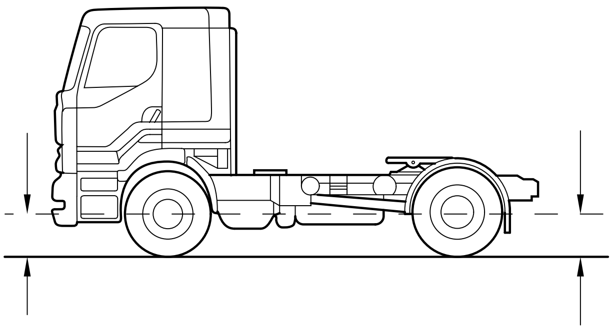
Vehicle Altitude



487RT

The relative levelness and/or tilt of the vehicle body, both side-to-side and front to back.

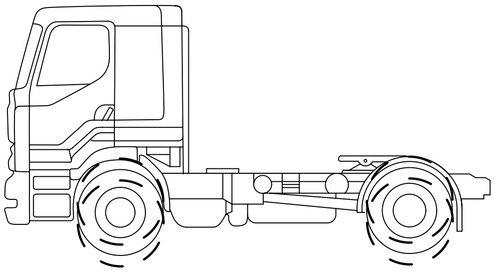
Vehicle Height



488RT

The height of the vehicle body in relation to the centres of the front and rear wheels. This is sometimes called the ride height and is measured from under the wheel arch to the wheel centre. Both measurements on the same axle must be the same.

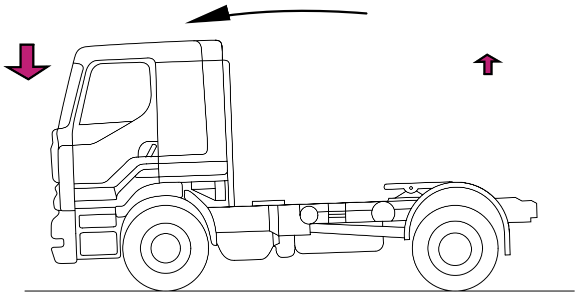
Damping



489RT

The resistance created as a shock absorber plunger moves through hydraulic fluid during compression and expansion.

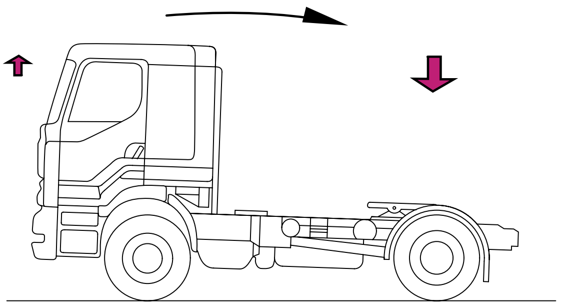
Dive



490RT

The downward movement of the front, and upward movement of the rear of the vehicle as the brakes are applied.

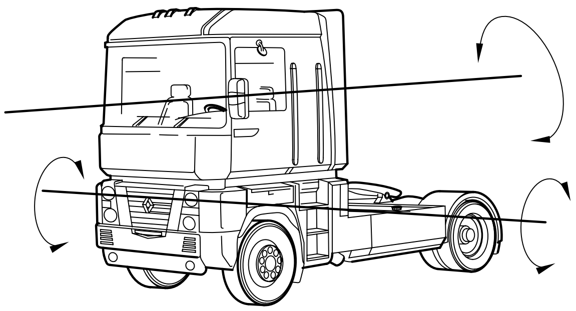
Squat



491RT

The upward movement of the front, and the downward movement of the rear during acceleration.

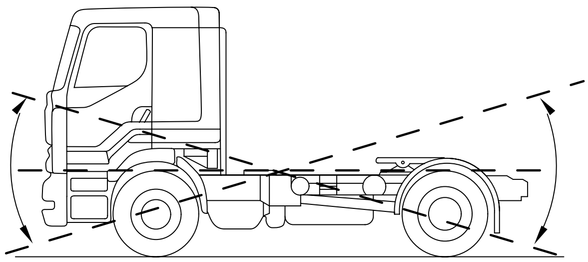
Roll



492RT

The leaning movement of the vehicle body when turning.

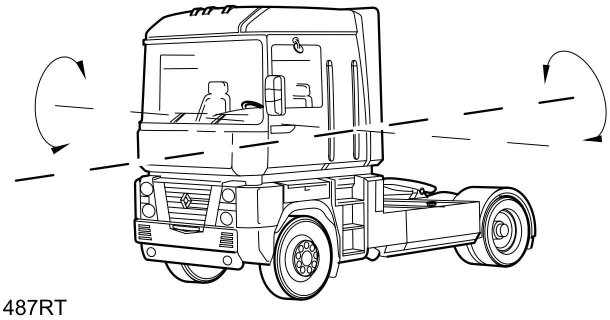
Pitching and Bouncing



493RT

The alternative rising and dipping of the front and rear of the vehicle body on uneven road surfaces. This is termed as ‘bump’ as a vehicle goes over a raised section in the road and ‘rebound’ as the wheel drops into a dip in the road surface.

Roll Centres and Axis



487RT

When cornering, the centrifugal forces acting at the centre of gravity (A), produce a rolling action transverse to the direction of travel. The amount of this roll is dependent of the spring rate, centrifugal force and the distance between the centre of gravity and the roll axis (leverage).

The roll axis can be approximated by establishing the parts of the body (through the front and rear axles), which remain at rest when being rocked sideways, known as roll centers.

The location of the roll axis (1) influences vehicle behavior in terms of steering and the tendency to roll, as well as dynamic wheel loads and their fluctuations, particularly while cornering. Requirements include smooth light steering, slight fluctuations in dynamic wheel load, small roll angles and as far as possible, neutral steering behavior.

Pure bounce, experienced mainly when traveling in a straight line, will occur if the front and rear sprung masses are equal and the front and rear springs have identical frequencies.

A vehicle could be designed to have an even weight distribution and identical springs all round but the phasing of the ripples in the road surface are beyond control. It is therefore inevitable that a degree of 'rocking of masses' (engine, gearbox and so on.) will resist the components that make up the sprung masses. This will contribute to the resistance exerted by the sprung masses in opposition to the pitching moment. If the major components are positioned near to the centre of the vehicle, then a reduced resistance to pitching will result. However, if a vehicle of the same total mass has the larger heavier components situated at a greater distance from the vehicle centre, it will offer greater resistance to pitching rotating around axis (2).

Yaw is the rotational or oscillatory movement (3) of a vehicle around a vertical axis passing through the centre of gravity. It can be affected by the location of the major components and side forces acting on the vehicle, such as crosswinds.

The heavier the components and the further apart they are in the vehicle chassis, the higher the moment of inertia. Therefore the vehicle will resist turnings or yaw motion to a greater extent than when the components are lighter and situated nearer the vehicle centre.

Independent and Non-Independent Suspension

Apart from the type of spring used and the arrangement of the suspension, another way one

suspension system may differ from another is when it is an independent arrangement.

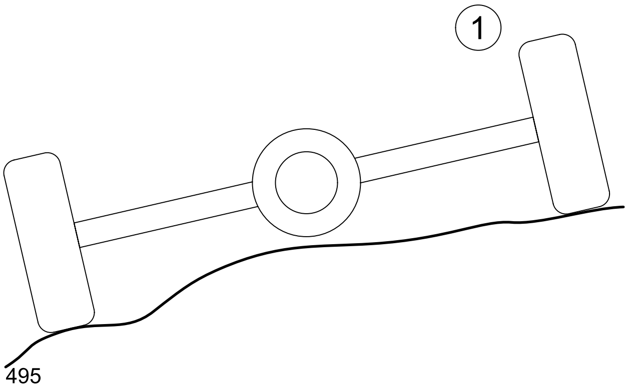
In a non-independent arrangement the wheels on the front or rear of the vehicle are connected usually by a tubular axle.

A disadvantage of this system is that the movement of one wheel affects the wheel on the other side and can have an adverse effect on the vehicle handling.

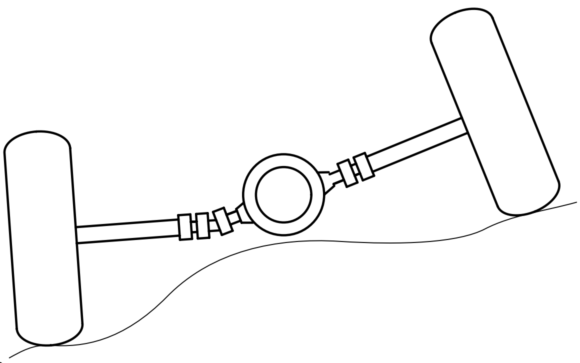
Three advantages are:

- it provides good wheel travel
- axle articulation
- ground clearance

which are essential attributes for off road application.



1. Beam axle system



2. Independent system

Independent suspensions are more suitable for road vehicles as the wheels are able to follow the

road surface more closely, giving improved handling and driver comfort.

IFS = Independent Front Suspension

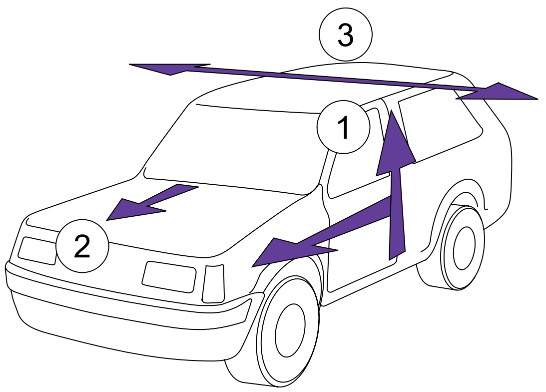
IRS = Independent Rear Suspension

Vehicle Stability (Terminology)

Vehicle stability depends on the performance of the suspension system. Suspension systems are designed to counteract the effect of forces acting on the vehicle, as these can cause body movement and in turn affect handling and stability. To a greater or lesser extent, the amount a vehicle designer counteracts these forces (and body movement) determines the ride and handling characteristics.

Compensation of Forces Acting on Suspension Systems

- The static and dynamic vertical loading of the vehicle. These are absorbed by the elastic compression, shear, bending or twisting action of the spring medium.
- The twisting reaction due to driving and braking torque. These reactions are usually absorbed by the stiffness of the spring alone, by stabilizer arms or by triangular wishbone arms.
- The driving and braking thrusts which must be transmitted between the sprung body and the road-wheels.
- Any side-thrust due to the centrifugal force, cross-winds, camber of the road, going over a bump or pot-hole etc. These forces are usually absorbed by the rigidity of the spring or the hinged linkage arms of the suspension.

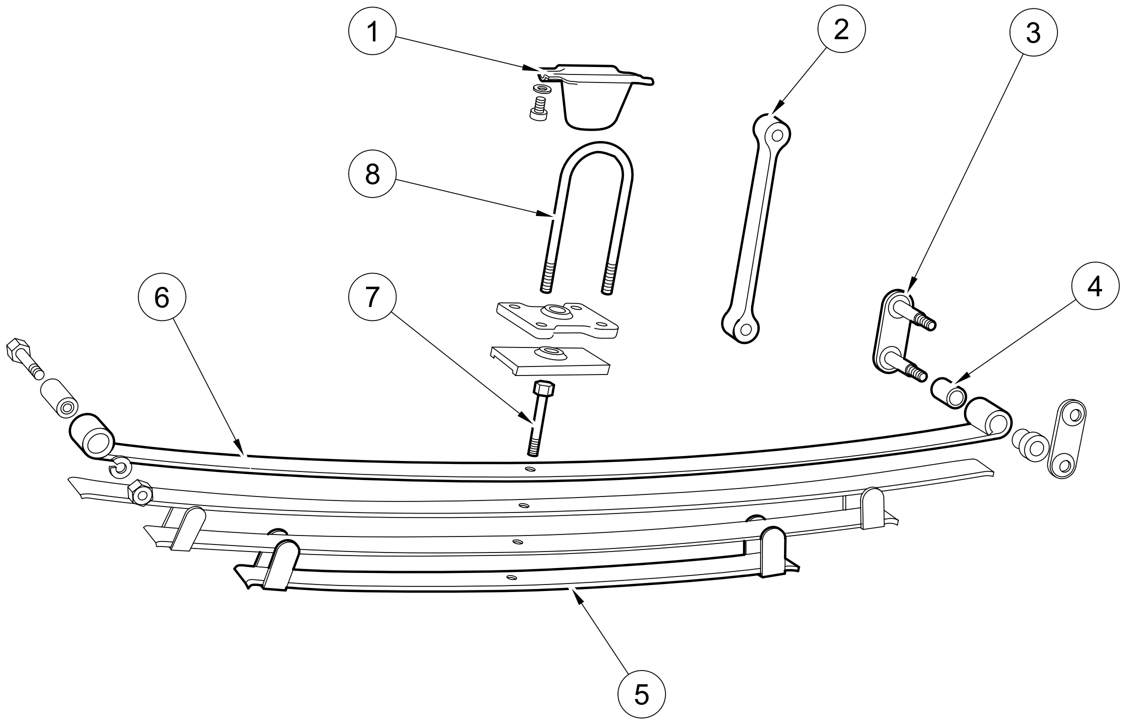


214

1. Vertical and longitudinal road reaction
2. Longitudinal brake reaction
3. Lateral reaction to cornering

TYPES OF SPRING

Metal Spring



216

1. Bump stop
2. Rebound strap
3. Swinging shackle
4. Bush
5. Rebound clip
6. Leaf
7. Retaining bolt
8. ‘U’ bolt

The laminated or leaf spring used to be the most popular type of spring and was used most recently for rear suspension on light and commercial vehicles. This type of spring is comparatively cheap because the spring can also be used to locate the rear axle.

The spring usually consists of a main leaf and below this are a number of leaves graduated in length.

Formed in this way, strength is given to the spring to overcome the tendency of the single main leaf to break half way along the length. Using a number of leaves ensures uniform stress throughout the spring. At each end of the main leaf is an eye into which is inserted a rubber bush to enable a bolt to be fitted for attachment of the spring to the frame. When the spring deflects the spring length alters so a swinging shackle is fitted at the rear end. A centre bolt passes through the leaves and a boss on the end locates into a hole in the axle casing. Two 'U' bolts clamp the spring to the axle.

Action

Upward movement deflects the main leaf and this bending is resisted by all of the lower leaves.

Downward movement (rebound) produced when the spring returns after deflection tends to open up the leaves. This concentrates the load on the main leaf. For this reason, rebound clips are fitted to make the shorter leaves take some of this load. One major problem of the laminated spring is friction between the leaves, causing noise and wear and the 'hard' ride. This is minimized by fitting flat buttons at the end of each leaf made from low friction material. Upward movement of the spring is limited by a bump stop. This is a rubber block, which cushions the axle travel when it reaches the limit of its travel.

Single Leaf Spring

497

To reduce weight (particularly unsprung weight) later designs of the semi-elliptic spring were constructed as a single leaf. This was made of either spring steel or carbon fiber. The location of the spring is the same as the laminated spring locations.

Composite Leaf Springs

Composite leaf springs are made from continuous glass fiber roving’s in epoxy resin.

They are used in the front and rear suspension systems of a vehicle to provide ride and handling comfort. Composites can be designed to conduct 50% less vibration than steel, and are more durable and corrosion resistant. Composite springs weigh less than steel and so help improve fuel economy and increase payload capacity.

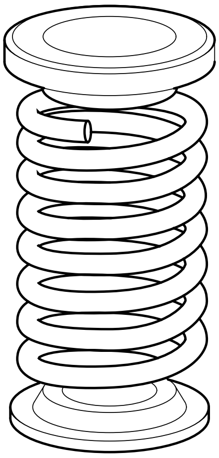
Composite leaf springs are three and one-half times more durable than steel, 50-75% lighter than steel depending on the application, and do not rust or lose strength with age.

Helical Spring (Coil Spring)

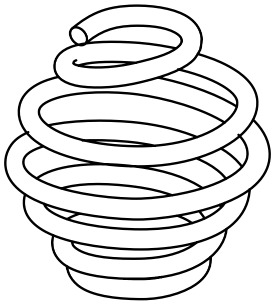
This type is a torsion bar wound in the form of a helical coil.

The absence of friction in the spring operation gives a smoother action. A disadvantage is that the spring cannot do the task that the leaf spring can, that is, acting as a torque reaction member. Because of this, extra suspension members are needed to support the spring and locate the axle. Another advantage is good range of movement.

Helical springs are used on a wide range of independent suspension systems.

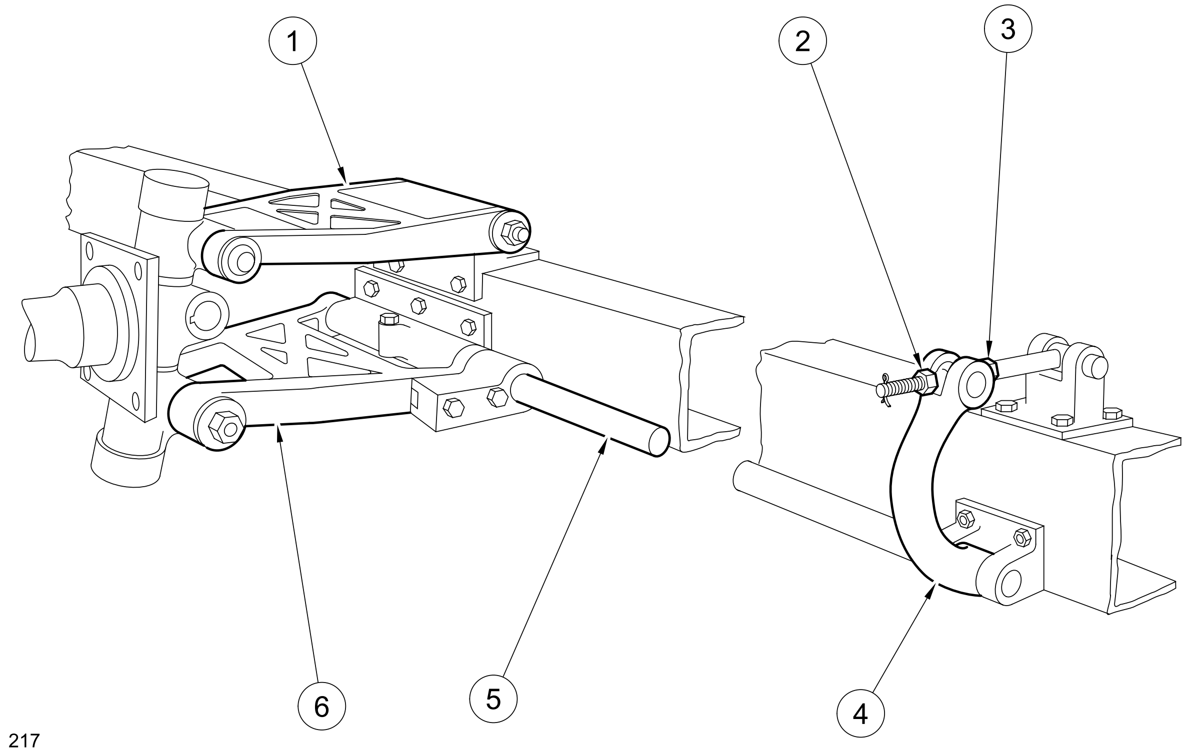


218



Constant rate coil spring *Variable rate coil spring*

Torsion Bar



1. Lower wishbone
2. Torsion bar
3. Locknut
4. Adjuster nut
5. Upper wishbone
6. (Pre-loading) adjuster

This is a circular bar anchored at one end to the vehicle frame (chassis) and attached at the other end by a lever to the road wheels hub assembly.

Spring action is caused by twisting of the bar, the resistance to twisting being governed by the diameter and length of the bar.

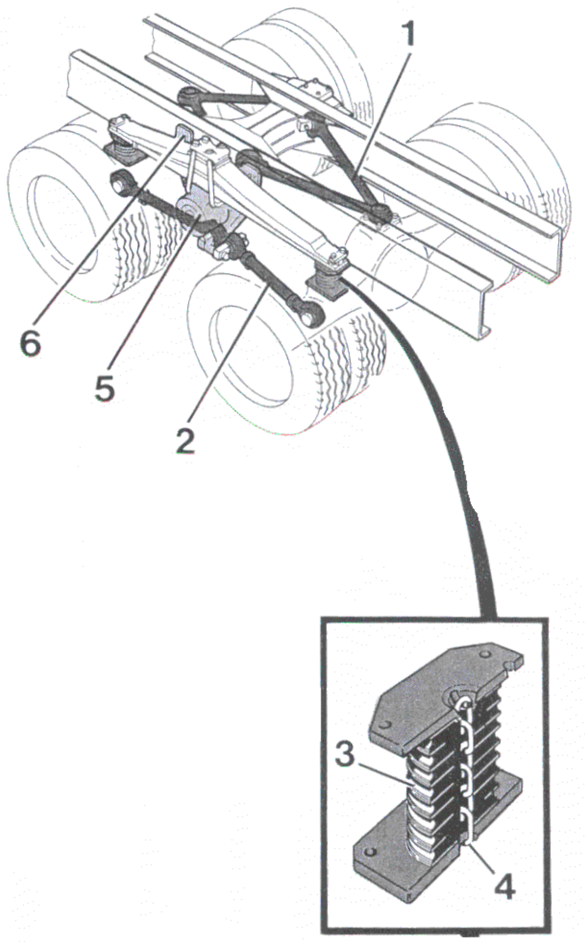
Long bar, narrow diameter = Soft spring

Short bar, wide diameter = Hard spring

This type of suspension used on the front suspension of older vehicles, is relatively cheap and light in weight giving low unsprung weight.

Rubber Springs

Rubber is a very effective spring material and is also extremely light and compact. It can also be made to absorb some of the energy given to it during bump movement. Due to this, the need for damping is minimal.



Rubber spring

1. V-stays
2. Reaction pads
3. Hollow rubber springs
4. Chains
5. Cradles
6. Bogie attachment

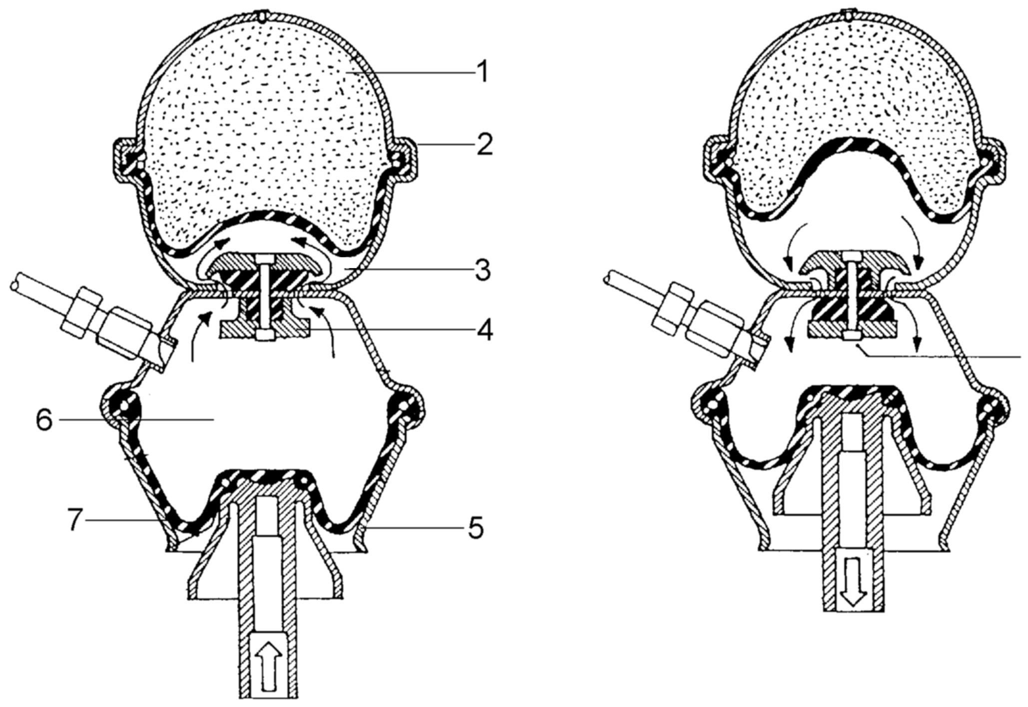
Rubber springs are said to be 'progressive'. This means that the more weight put on them, the stiffer the suspension becomes.

Hydrogas Suspension

Hydrogas is so called because it uses fluid and compressed gas in the suspension units. Each wheel has a separate hydro gas unit and although pipes are used to link the units 'front to rear'. Each hydro gas unit comprises of three chambers, one of which contains pressurized nitrogen, sealed with a special rubber diaphragm. This nitrogen filled chamber gives a progressive spring rate active (the more gas that is compressed, the rate of the spring will increase).

The lower and central chambers are filled with a special suspension fluid consisting of alcohol, water and a corrosive inhibitor.

This fluid is sealed at the base of the unit with another reinforced rubber diaphragm. An essential component in the hydro gas unit is the damper valve to prevent 'bounce'. If this valve was not fitted, serious 'pitching' would occur making the vehicle very unstable.



1. Nitrogen gas
2. Spherical spring chamber
3. Separator diaphragm
4. Bump valve and rebound valve
5. Tapered skirt
6. Fluid
7. Piston diaphragm

Air Spring

In commercial vehicles, more and more air-suspension systems are being used.

In commercial vehicles with interchangeable platforms they achieve a considerable reduction in loading and unloading times.

There are three main types used:

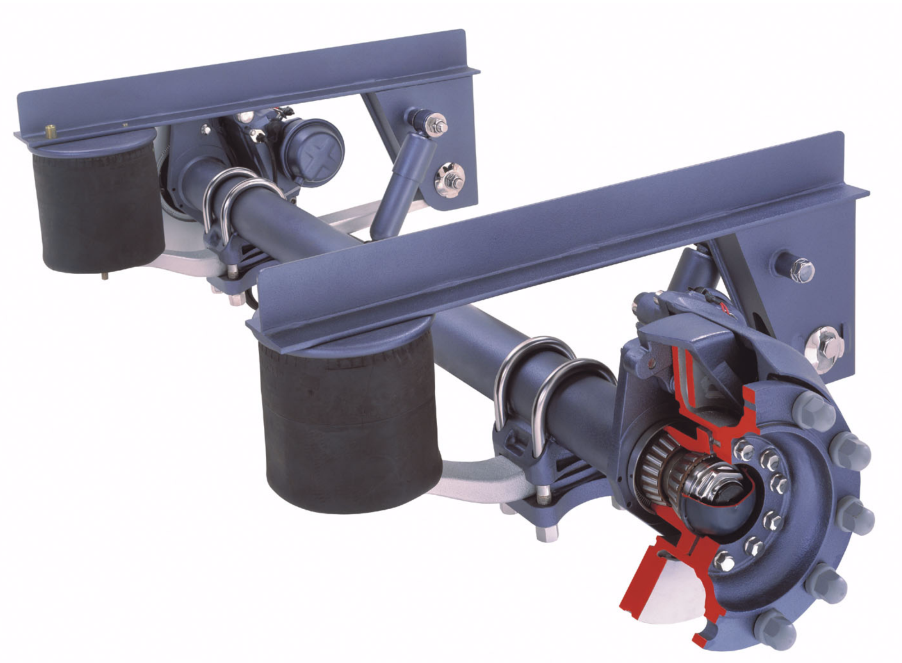
a) Air suspensions with a closed air circuit

b) Air suspensions with a semi-closed air circuit

c) Air suspensions with an open air circuit.

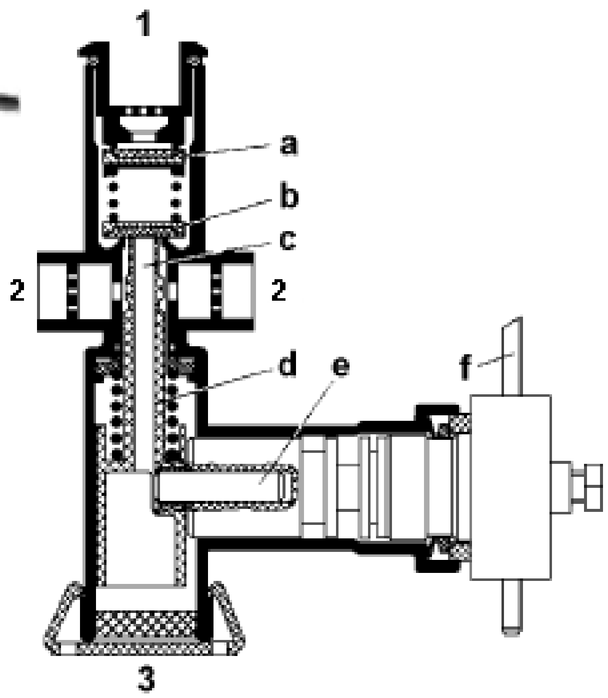
The systems mentioned under a) and b) are mainly used in passenger cars, their benefit being that they consume a small amount of air so that the compressor can be smaller due to its lesser delivery requirements. In addition, there is little condensate or dirt. These systems are technically complex and fairly expensive to buy.

Commercial vehicles use air suspension systems with an open air circuit. Since this system evacuates air which is not required back to atmosphere, the air compressor has to be larger. This type of air suspension system is straightforward in terms of its circuit and the valves it uses.



One of the main valves in the system is the Leveling Valve. Its purpose is to control the pressure in the bellows in proportion to the vehicles load. An adjustable lever arm is connected between the vehicle axle and the leveling valve. As the load on the vehicle body is increased the leveling valve will move down with the body. The lever arm is connected to an eccentric cam inside the valve. As the lever arm is raised the eccentric cam lifts a pin upwards opening a inlet valve allowing air from the reservoir to flow into the air bellows. As the pressure in the air bags is increased the chassis height of the vehicle is adjusted.

When the vehicle load is decreased the reverse process takes place. The excess pressure in the bellows causes the vehicle height to rise and the eccentric cam in the leveling valve now moves the pin downwards and away from its seat on the underside of the inlet valve. The pin has a drilling through its center to allow the air from the bellows to escape to atmosphere. The drop in pressure in the bellows allows the vehicle to return to its normal height and the leveling valve is now in a balanced position.



1. Air supply from reservoir
2. Connection to air bellows
3. Vent to Atmosphere

a. Check Valve

b. Inlet Valve

c. Vent Drilling

d. Lifting Pin

e. Eccentric Cam

f. Lever Arm

Benefits of Air Suspension Systems

- By adjusting the pressure in the bellows as a ratio of the load carried, the distance between the road surface and the vehicle's superstructure will always be the same. This means that not only is the boarding or loading level constant, but also the headlight setting.
- Due to the adjusting pressure in the bellows, spring comfort is not subject to any major changes, regardless of the load carried. Sensitive loads are carried without any major damage. An empty or partially laden vehicle will no longer 'jump'.
- Both steering stability and the transmission of brake forces are improved since tyre-road adhesion is always achieved for all wheels.
- The pressure in the air suspension bellows which is dependent on the load carried is also ideal for controlling load-sensitive braking ('ALB').
- In interchangeable platform operation, air suspension systems achieve efficient loading and unloading of container vehicles.
- Protects the road surface.

Electronically Controlled Air Suspension (ECAS)

ECAS is an Electronically Controlled Air Suspension system for vehicles and includes a large number of functions. The conventional system has been significantly enhanced through the use of an Electronic Control Unit (ECU):

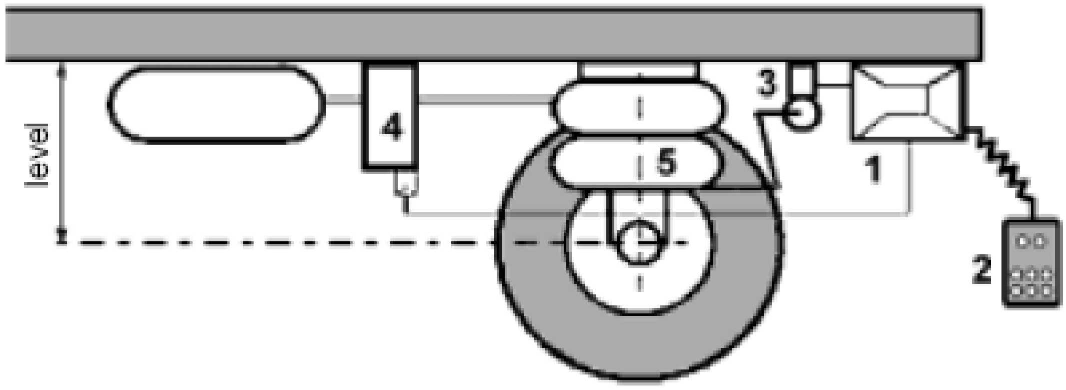
- Reduction of air consumed whilst the vehicle is moving
- It is possible to maintain different levels (e.g. ramp operation) by means of automatic readjustment
- In the case of complex systems, installation is easier
- Additional functions such as traction help, programmable vehicle levels, tyre deflection compensator, overload protection and automatic lifting axle control can easily be integrated
- Due to large valve diameters, pressurizing and venting processes are accelerated
- Easy operation and maximum safety for those operating the system due to one single control unit
- Highly flexible system due to the fact that electronics can be programmed via operating parameters (trailing end programming)
- A simple safety concept and diagnostic facility.

In a conventional air suspension system a leveling valve is used to measure the vehicle height and control the air entering the bellows.

In the ECAS system an electronic control unit is used to control the operation of the air bellows. Solenoid valves are used to allow air into and out of the bellows. The ECU uses information from ride height sensors fitted to the suspension units of the vehicle to operate these solenoid valves. The ECAS system can also control other functions which in a conventional air system would need other adjustment valves and height limiting valves such as different types of trailers.

The ECAS system will only work when the ignition is switched on. If the vehicle has a trailer then the power supply will normally be supplied by the ABS. The ECAS system also uses the vehicle speed signal supplied by the ABS connection.

To permit adjustment of the level of a trailer not connected to a towing vehicle, an optional facility for a storage battery may be provided for an additional power supply on the trailer.

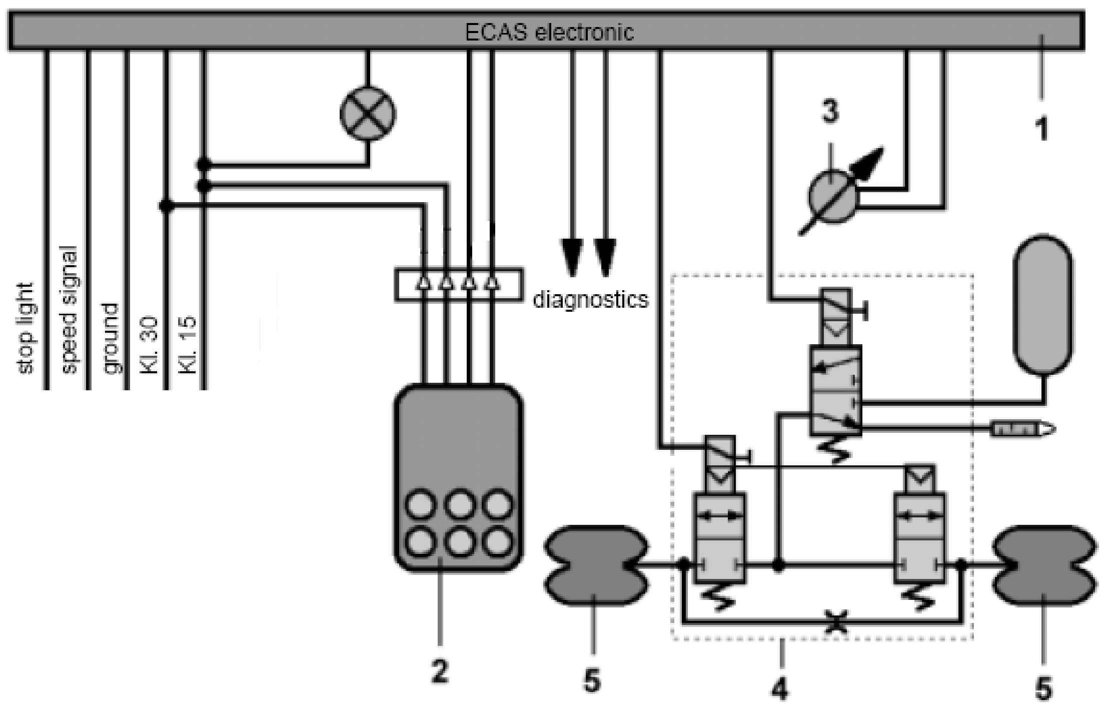


1. Electronic Control Unit
2. Remote control Unit
3. Height Sensor
4. Solenoid Valve
5. Air Bellows

The Height Sensor will continuously monitor the vehicle's height and send its readings to the ECU. In the event of the ECU finding that the normal level is not being maintained, a Solenoid Valve is activated in such a way that, by pressurizing or venting, the level is adjusted accordingly.

Below a pre-defined speed (and when vehicle is stationary), the RCU can be used to change the index level (useful for loading-ramp operation, for example).

An indicator lamp (situated on the front of the trailer and visible from the truck's cab through the rear - view mirror) is used to inform the driver that the trailer is outside its normal ride height and to inform about any faults the ECU may have discovered.



1. Electronic Control Unit
2. Remote Control Unit
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ECAS Solenoid Valve

Special solenoid valve blocks have been developed for the ECAS system by combining several solenoid valves in one compact block.

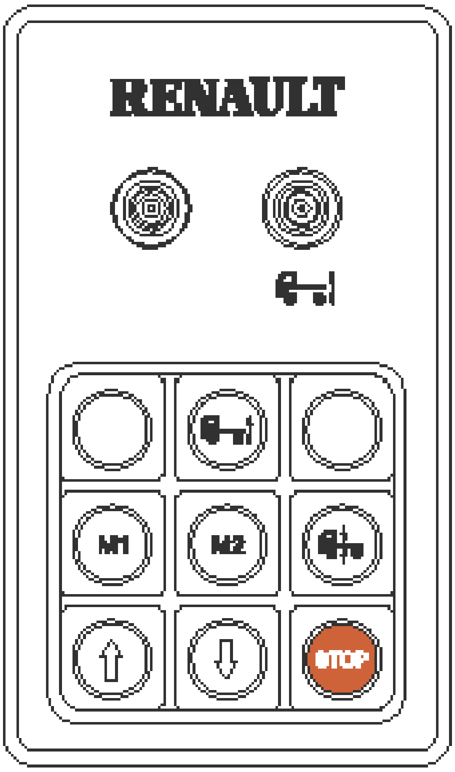
The solenoid valves are actuated by the ECU as a control element; they convert the voltage present into a pressurizing or venting process, i.e. they increase, reduce or maintain the air volume in the bellows.

In order to achieve a large throughput of air, pilot valves are used. The solenoids initially actuate those valves with a small nominal width, and their control pressure is then passed to the piston surfaces of the actual switching valves.

Different types of solenoid valves are used, depending on the application: For controlling a single axle, one seat valve is sufficient whilst a complex sliding valve is required for controlling the lifting axle.

Both types of solenoid valves are based on a modular principle: Depending on the application, the same housing is used to accommodate different parts of valves and solenoids.

Remote Control Unit



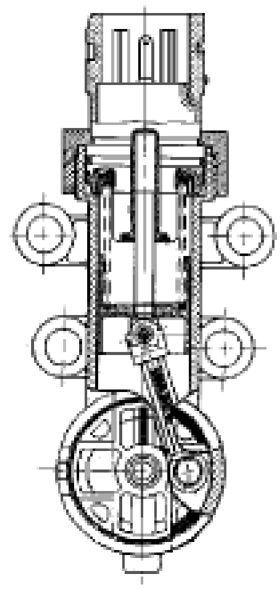
By means of the Remote Control Unit the driver can influence the vehicle's level within the permissible maximum limits. However, this can only be done whilst the vehicle is either stationary or has not exceeded the driving speed parameter.

The control keys for changing the vehicle's level are accommodated in a handy housing which is connected, via a coiled cable and a socket on the vehicle, with the ECU.

There are different RCUs depending on the type of system used. The functions of this RCU are:

- raising and lowering of the chassis
- setting normal level
- stop
- storage and actuation of two preference levels
- raising and lowering of the lifting axle, or unloading or loading the trailing axle
- switching automatic lifting axle operation on and off.

Height Sensor



The height sensor is fitted to the vehicle chassis in the same place as the leveling valve used in a conventional air suspension system.

Inside the sensor housing is a coil in which an armature moves up and down. A connecting rod connects the armature to the cam on the lever shaft. This lever shaft is connected to the vehicle axle.

As the axle moves up and down the lever turns and move the armature up or down inside the coil which changers its inductance.

The change in the inductance is measured by the control unit and converted into a height signal which is the processed into an output to the solenoid valves to control filling or emptying of the air bellows.

Pressure Sensor

The pressure sensor is fitted into the air bellows to measure the “settled” pressure in the bellows.

The sensor produces a voltage signal that is proportional to the pressure with in the bellows and sent to the ECU.

The sensor has a measuring range between 0 and 10 bar, and a maximum of 16 bar must not be exceeded.

The sensor must only be connected directly into the air bellows, as if fitted into the supply line between the solenoid valves and the air bellows, as incorrect readings could result when pressurizing or venting is in progress.

In some vehicle applications, such as refuse disposal, this signal can be used to calculate the individual axel loadings of the vehicle and inform the driver when the vehicle is nearing its maximum axel weights.

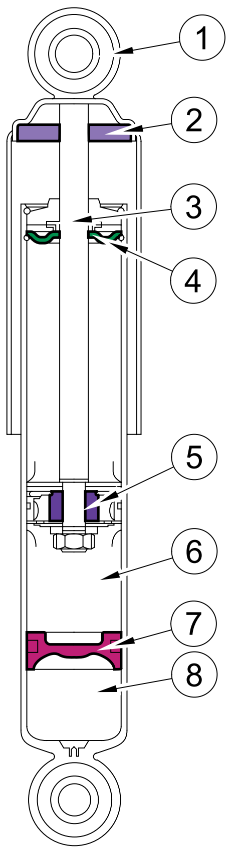
THE DAMPER

Purpose of a Damper

When the wheel strikes a bump energy is given to the spring which is deflected. When the bump is passed, a rebound or release of the stored energy will take place and will carry the spring past the normal position to set up an oscillating motion.

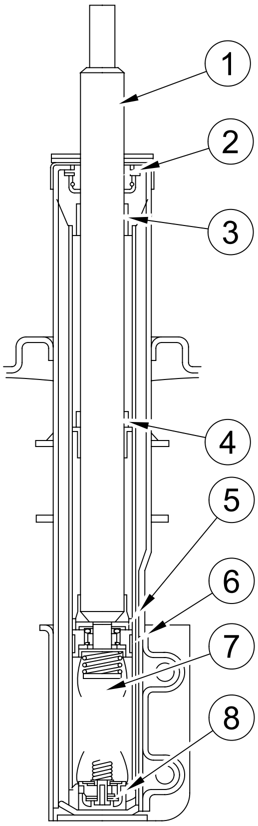
To give a comfortable ride, a device must be fitted to absorb the energy stored in the spring and so reduce the number of oscillations occurring between the initial bump and the return of the spring to the rest position. This is done by the damper (often misleadingly called a shock absorber).

Dampers are hydraulic devices that help to control the up-down and rolling motion of a car body. One damper is used on each wheel. Each damper must control one wheel and axle motion. The vehicle's springs support the body, but the dampers work with the springs to control movements of the vehicle. A damper is a device that controls energy stored in the springs under load.



499

1. Upper mounting
2. Compression stop
3. Piston rod
4. Integrated seal
5. Valve
6. Hydraulic oil
7. Floating piston
8. Gas chamber



1. Piston rod
2. Multi lip seal
3. Rod guide
4. Rebound stop
5. Piston valve
6. Bearing ring
7. Hydraulic oil
8. Base valve

Consequences of Worn Dampers

Drivers adapt their driving to the progressive deterioration of their shock absorbers and to the impaired road holding that this produces. Drivers are very often unaware that they are driving with shock absorbers in poor condition. Shock absorbers in poor condition increase the wear on the mechanical parts of the vehicle, such as suspension springs, steering gear, universal joints, differential, tyres, rubbers, suspension bushes, gear box, wheel bearing, suspension and steering arm ball joints.

Other consequences of worn shock absorbers can also be as follows:

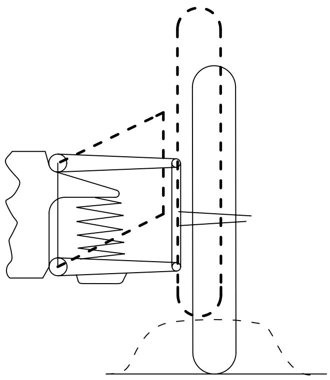
1. Increased braking distance
2. Poor road holding
3. Increased risk of aquaplaning
4. Decreased night visibility
5. Driver fatigue

SUSPENSION LAYOUTS

Coil Spring - Wishbone Suspension

This consists of two wishbone-shaped components, usually made from pressed mild steel or cast alloy. They may be fixed at the vehicle with rubber bushes and at the stub axle with ball joints. The wishbones locate the stub axle assembly to the vehicle and they also withstand side, braking, acceleration and cornering forces. The ball joints allow the stub axle to swivel as well as allowing for movement when the wheel moves up and down.

Parallel Link



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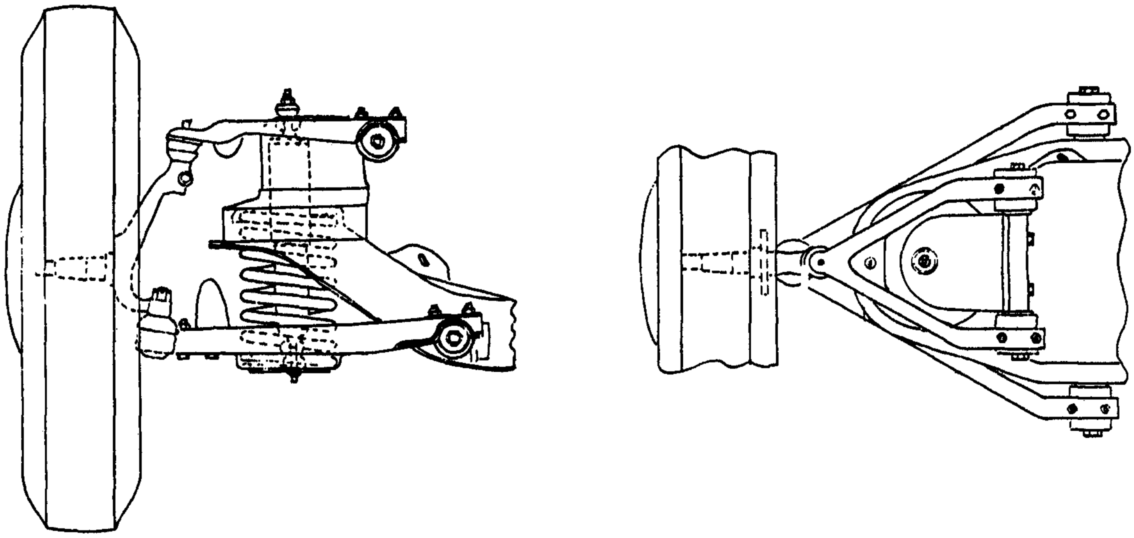
As shown from the diagram, this type of suspension linkage causes a change in vehicle track as it rises and falls due to road irregularities. This results in increased tyre wear.

Unequal Length



The wishbones are of unequal length so that during deflection the track and camber is not altered. Some vehicles also incorporate anti-dive geometry. This means that the tendency for the front of the vehicle to dive under braking is resisted by the alignment of the wishbones. Bump and rebound rubbers are incorporated to limit wishbone movement during both of these conditions.

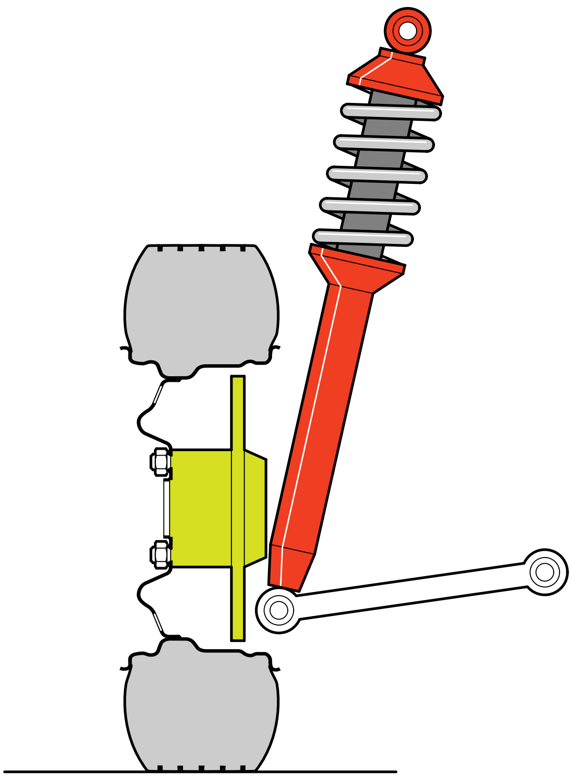
Macpherson Strut

This consists of an assembly in which the spring and damper are one unit. The assembly is located at the top of the vehicles inner wing by a bearing or bush. This bearing or bush allows the unit to swivel at the top. The lower part of the unit is located by a ball joint to a track control arm, allowing the unit to swivel and giving lateral location of the assembly and some control under driving and braking.

Additional support may be achieved by locating the anti-roll bar to the track control arm, or by using a tie rod. One disadvantage of this layout is that track alters during deflection and some side loading can cause premature wearing of the damper piston.

This assembly has two distinct variations. Firstly, the strut is fixed directly to the hub and not the bottom ball joint. This allows space for the driveshaft if it is off a front wheel drive vehicle.

The bottom part of the hub is located through a ball joint to the track control arm. It will also be noticed that the spring is off-set to the centre of the damper. This is to reduce side forces on the damper unit during deflection and so reduce wear to the damper.



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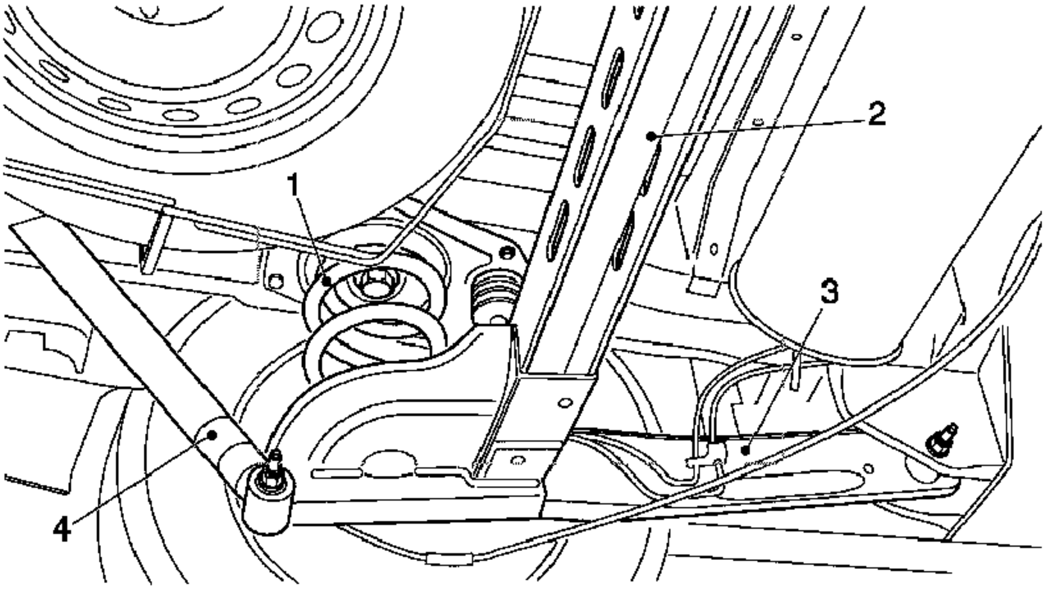
EXAMPLES OF SUSPENSION SYSTEMS FITTED TO VEHICLES

Semi-Independent Rear Suspension



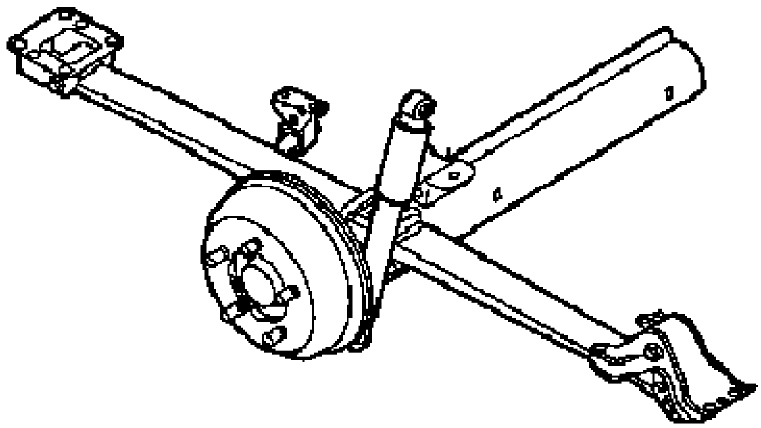
1. Spring
2. Axle Cross member
3. Trailing Link
4. Shock Absorber

This type of suspension layout may be used on light vans having a payload of between 1000Kg and 1200Kg.

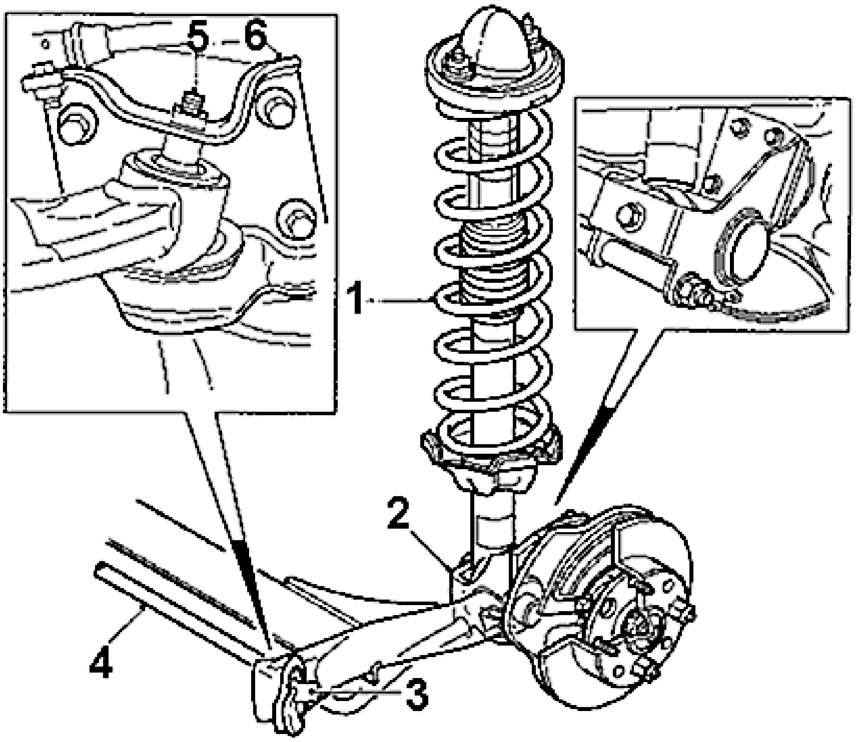
The rear suspension consists of a fabricated axle cross member with trailing links, coil springs and shock absorbers at each side. The trailing link is attached to a bracket on the body.

Light Van Leaf Spring Rear Suspension

The rear suspension comprises of single, semi-elliptic leaf springs and telescolpic shock absorbers. A rubber bump stop is installed on the underside of the frame above each spring.

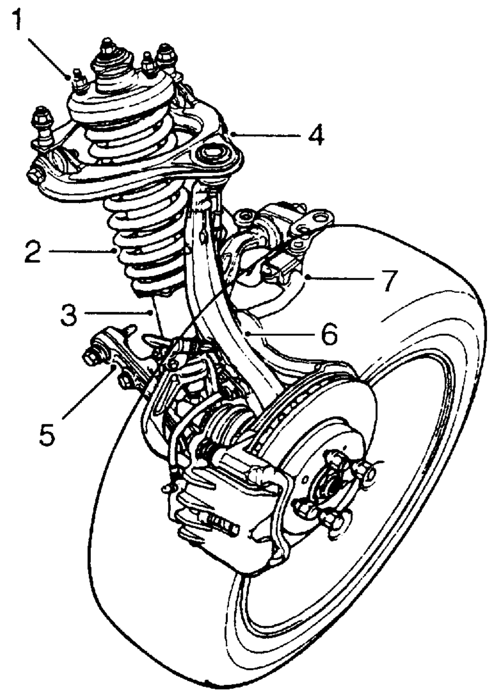


A completely different format suspension system comprising of front MacPherson struts, with an antiroll bar to limit body roll. At the rear it uses a very simple but effective design using an 'H' frame with coil spring and telescopic dampers. The rear suspension is tuned by the manufacturer to create a steering effect in the rear wheels when cornering hard (passive steer). This increases stability and improves vehicle handling. The passive steer feature is taken up by movement in the suspension pivots.



1. Helical spring
2. Strut location bracket
3. Bush
4. Anti-roll bar
5. Securing bolt
6. Securing bracket

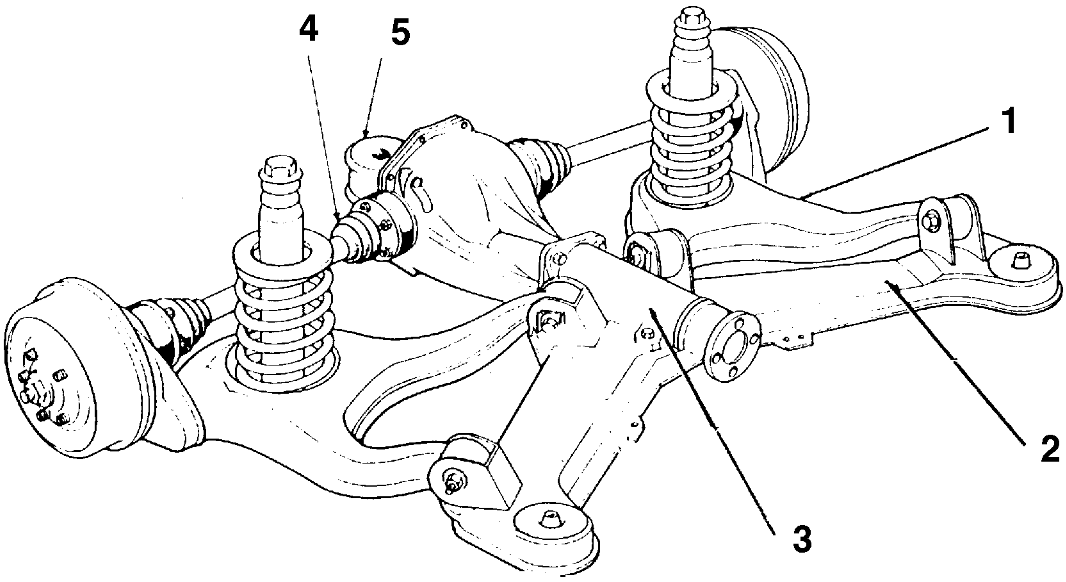
This suspension system uses a slightly more complicated arrangement combining independent double wishbone with coil springs and carefully selected dampers with an anti-roll bar at the front. At the rear, there is independent multilink with coil springs and dampers. The anti-roll bar only being fitted to the heavier models.



1. Strut unit mounting bolts
2. Coil spring
3. Damper unit
4. Upper wishbone arm
5. Radius arm
6. Swivel hub
7. Anti-roll bar

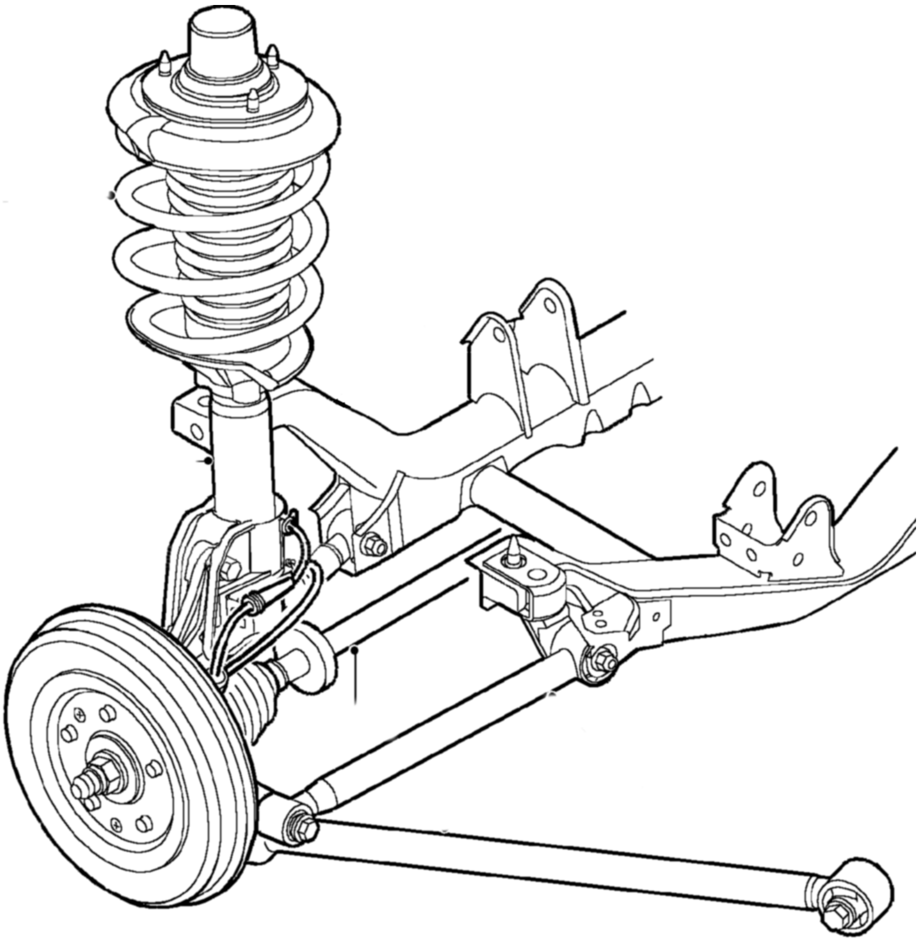
Semi-Trailing Arm and Coil Spring

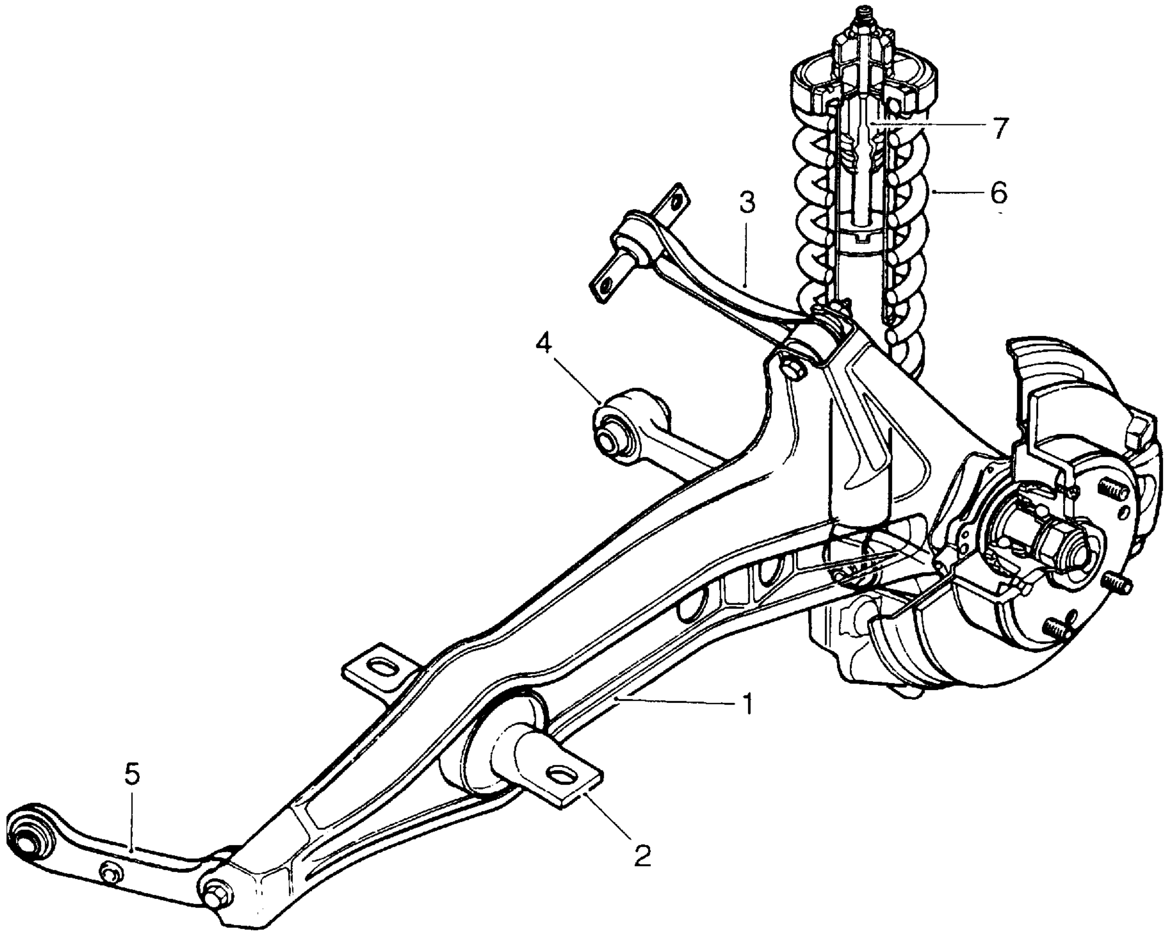
This is a fully independent unit. The final drive is mounted onto a sub frame and the hubs and driveshaft's are located to semi-trailing arms, which are fixed by bushes to the sub frame. Driving and braking forces are transmitted by the final drive housing and trailing arm. Therefore the springs are softer, as they only perform suspension duties. As the final drive is fixed to the body it reduces the unsprung weight.



1. Semi-trailing arm
2. Sub frame
3. Semi torque tube
4. Drive shaft and gaiter
5. Chassis mounting

The rear suspension comprises of two MacPherson strut dampers with coil springs and two sets of three links (known as "trapezoidal links"). A rear subframe is bolted to the body and provides the mounting points for the fixed and adjustable links. The third link is known as the trailing link and is attached from the hub carrier to the body. The suspension is designed to allow longitudinal movement of the wheel, which allows the wheel to move rearwards and upwards in response to surface undulations. The longitudinal movement allows the springs and dampers time to react to surface changes and improves ride quality.



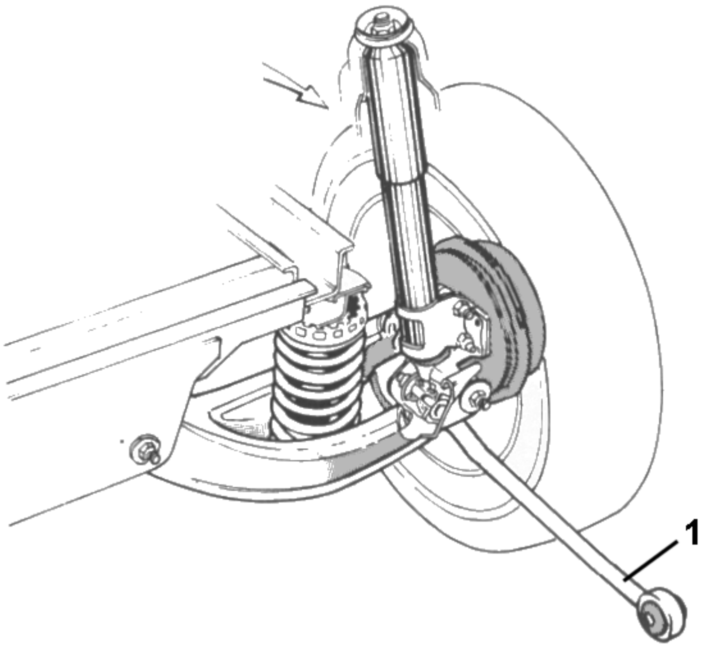


1. Trailing arm
2. Compliance bush
3. Upper radius arm
4. Lower radius arm
5. Compensating arm
6. Spring and damper assembly
7. Bump stop

The rear suspension system is Macpherson strut with a rear facing 'L' shaped lower arm mounted on a sub frame that is installed to the body via six rubber mounts. An anti-roll bar is installed off the sub frame and attached with a double ball jointed link to the strut spring pan.

Transverse Link and Strut

This arrangement can be used on the rear of a front wheel drive vehicle. It is a fairly similar arrangement to the Macpherson strut. Additional support is given by the tie bar (1).



The tie bar (1) locates the wheel assembly to prevent rearward movement of the wheel when the brakes are applied, during acceleration or when the wheel is subject to bump and rebound.

Anti Roll Bar

A 'torsion' anti-roll bar is incorporated into the suspension of a vehicle enabling low rate soft springs to be used. This gives a more comfortable ride under normal driving conditions. The torsion bar does not contribute to the suspension spring stiffness (the resistance to vertical deflection) when its unsprung weight is increased or the vehicle is subjected to dynamic shock loads caused, possibly, by gaps or ridges where sections of the road are joined together. However, the anti-roll bar does become more effective if one wheel is raised higher than the other or when the vehicle passes over a hump in the road or the body commences to roll while cornering. Under these conditions, the suspension spring stiffness (total spring rate) increases in direct proportion to:

- the relative difference in deflection of each pair of wheels when subjected to the bump.
- the rebound of individual wheels or body roll when the vehicle is moving in a circular path.

STEERING SYSTEMS

The steering system of a vehicle allows the driver to control the direction of the vehicle through a system of gears and linkages that connects the steering wheel with the front wheels.

The steering system must perform these functions:

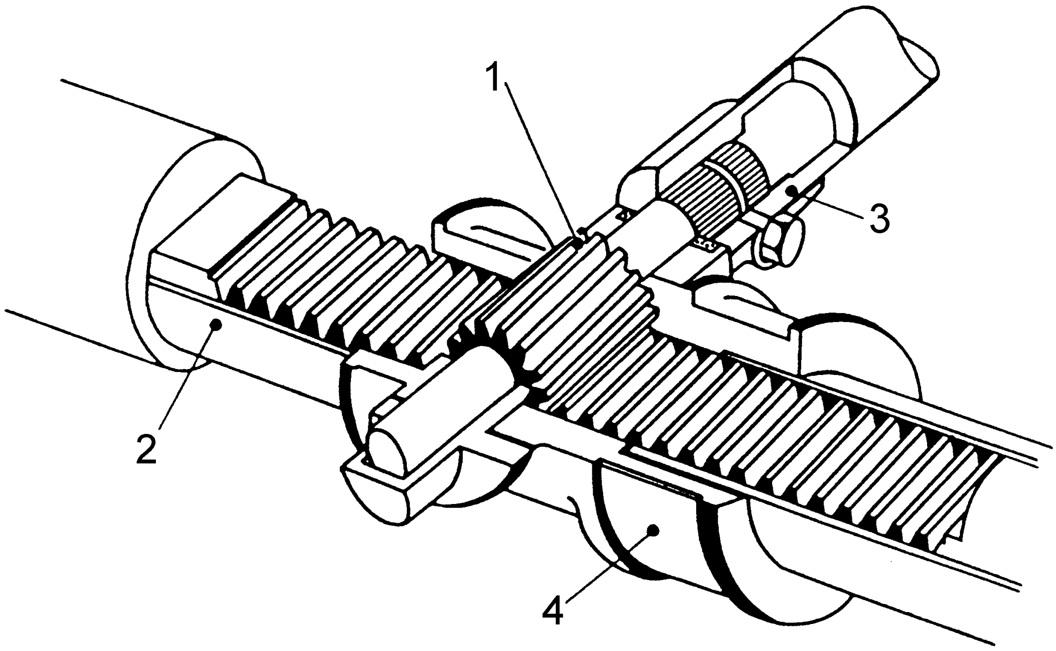
- Change direction of vehicle.
- Provide a degree of ‘feel’ of the road for the driver.
- Not transmit excessive shock back to the driver due to an uneven road.
- Not cause excessive tyre wear.

TYPES OF STEERING ARRANGEMENT

Rack and Pinion Steering

The most common arrangement for light vehicles is the rack and pinion assembly. This arrangement gives a compact layout, a direct connection to the road wheels and a very positive steering system.

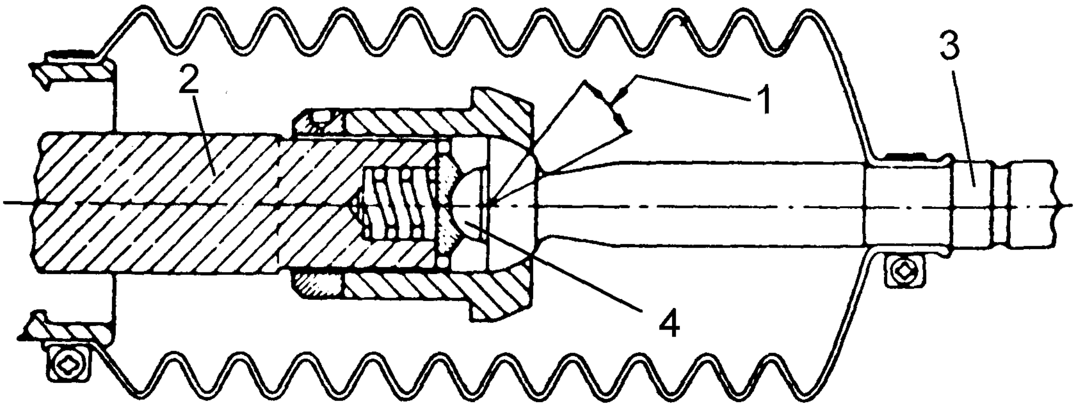
The rack and pinion system consists of a long helical gear called a pinion that is attached to the steering column. The pinion meshes with a long, flat, toothed bar called the rack. The ends of the rack are connected to the steering arms of the front wheels with ball joints and a track rod.



1. Pinion
2. Rack
3. Column
4. Case

When the steering wheel is turned, the pinion rotates causing the rack that meshes with it to move in a linear motion. This movement of the rack is conveyed to the steering arms through the track rod. This makes the road wheel hub swivel on its joints (ball joints, swivel joints or king pin and bush).

The ball joints in the end of the rack allow the rack rod to move up and down with suspension movement. The ball joint at the road wheel end (normally called the track rod end) allows for some hub deflection due to suspension and steering movement.

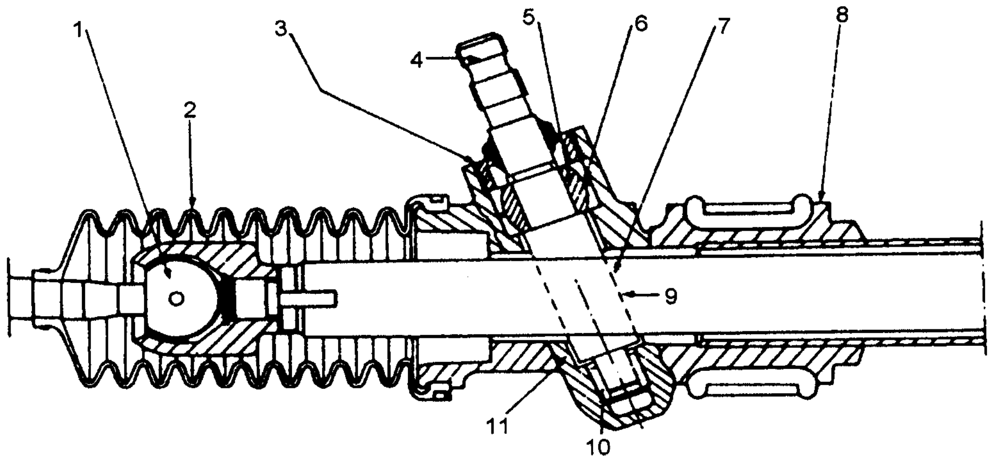


1. Angular movement possible each side of centre
2. Rack
3. Track rod
4. Ball joint

Rack and Pinion Construction

A two-point support is provided for the sliding rack gear. At the end of the rack housing an oil impregnated, sintered bronze-type bearing supports the rack. At the pinion end, the pinion gear and an opposed slipper bearing support the rack. This is spring-loaded to exert a friction damping effect on unwanted rack movement caused by road shock.

Bellow type gaiters retain rack lubricant. The complete assembly is either mounted across the front suspension cross member, or engine compartment bulkhead. The rack is located by 'U' shape clamps, which are rubber lined to prevent road shock being transmitted to the driver.



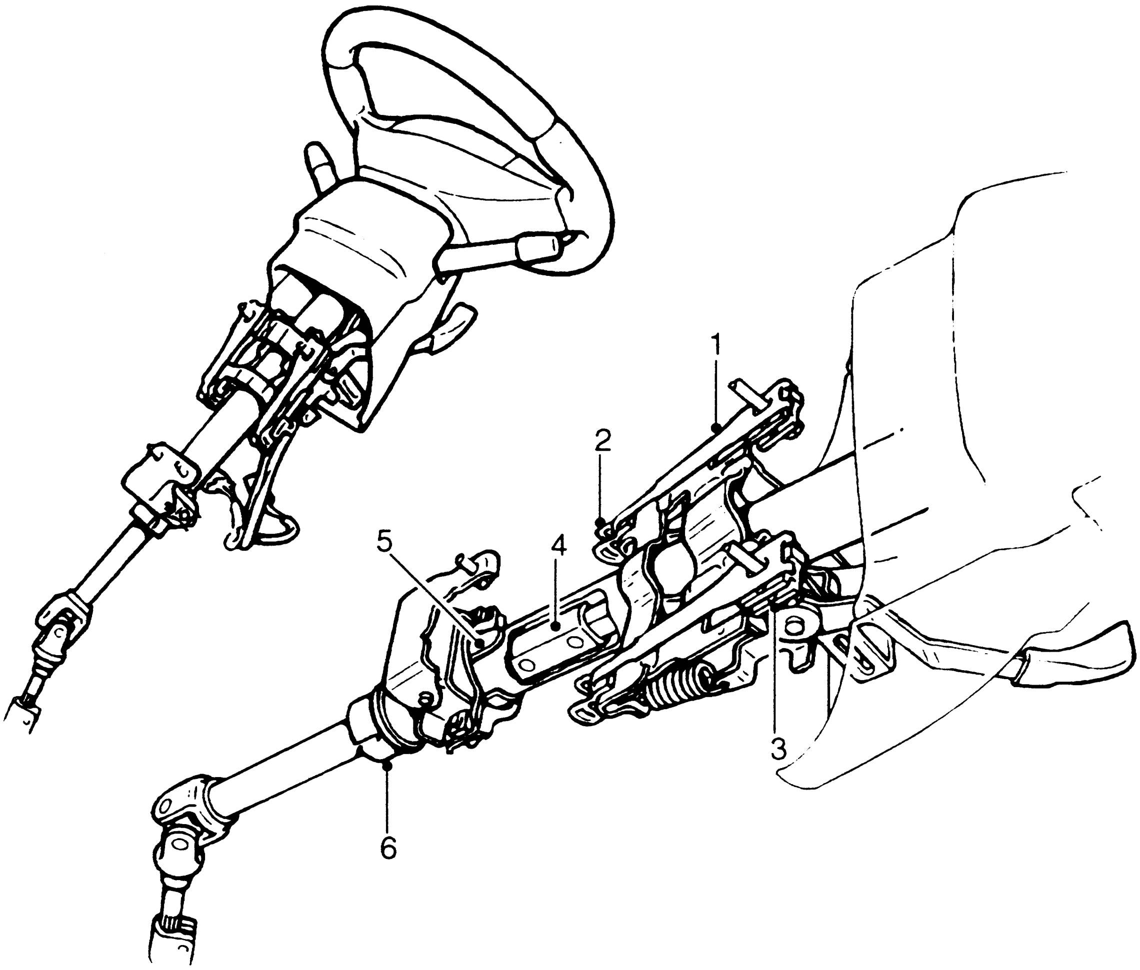
1. Track rod inner ball joint
2. Rubber sealing bellows
3. Pinion bearing retaining nut
4. Pinion shaft
5. Spherical bearing
6. Plastic bushes
7. Toothed rack
8. Mounting bracket
9. Pinion gear
10. Needle roller bearing
11. Pinion gear housing

Steering Column Bearings

Before International Safety Regulations specified the use of collapsible steering columns, the upper bearings were either a plain bush or a roller bearing.

In modern vehicles, the upper part of the collapsible column is carried in a pair of roller bearings. The design of the installation must be able to survive crash tests that require steering ability to be maintained.

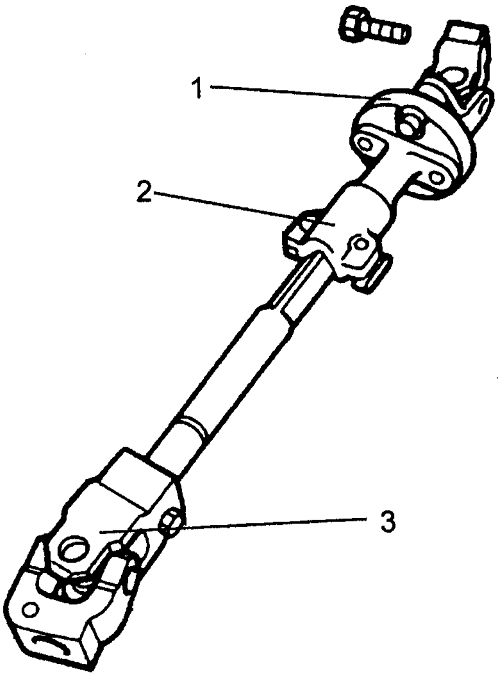
Shown below is a two piece collapsible steering shaft that is supported by a ball bearing in its upper end and a bush at its base.



1. Absorbing plates
2. Absorbing plate guides
3. Sliding capsules
4. Steering column telescopic joint
5. Column retainer collar - outer
6. Column retainer collar – inner

The steering column mountings are designed to deform and/or move, to absorb energy during an impact. At the base of the column, the clamp securing the column will allow the column to slide when under load. At the upper end of the column, the bracket is retained by sliding capsules and absorbing plates (1 & 3). During an accident, the column will move forward down the sliding capsules, bending the absorbing plates and absorb energy as they deform. Additional protection to the driver's face and upper torso is provided by the air bag (if fitted). The universal joints shown in this arrangement allow for the different relationship between rack and column, as well as allowing the rack to move on impact.

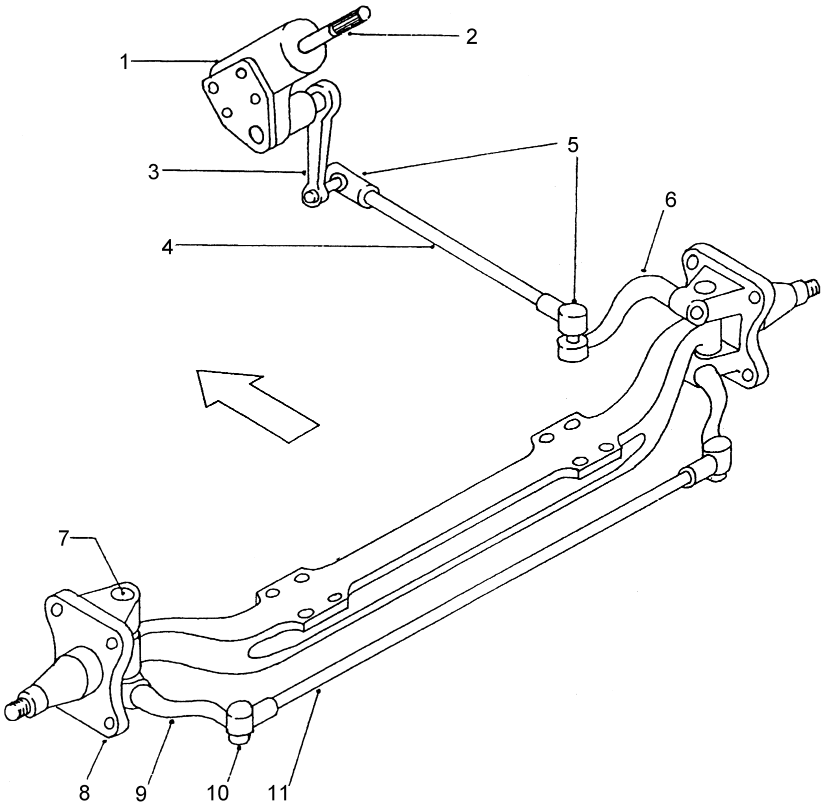
The system shown below uses a compression joint that is designed to collapse on impact. The rubber coupling helps to absorb road wheel shocks when driving.



1. Rubber coupling
2. Compression joint
3. Universal joint

Manual Steering Box

The steering box is mainly fitted to commercial light and heavy vehicles.



1. Steering box
2. To steering column
3. Drop arm
4. Drag link
5. Ball joints
6. Steering arm
7. King pin
8. Stub axle
9. Steering arm
10. Track rod end
11. Track rod

The steering box has a reduction gear to reduce the driver effort to an acceptable level while steering. The reduction gear also reduces road shocks transmitted back to the driver.

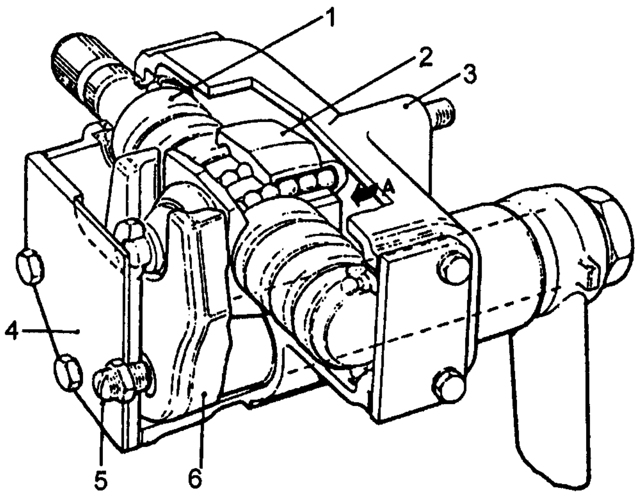
Steering Boxes

There are four main types of steering box:

- Recirculating ball
- Worm and roller
- Cam and peg
- Screw and nut

Some modern 4x4 light commercial vehicles and trucks use the recirculating ball type of steering box. Some older vehicles use worm and roller type arrangements.

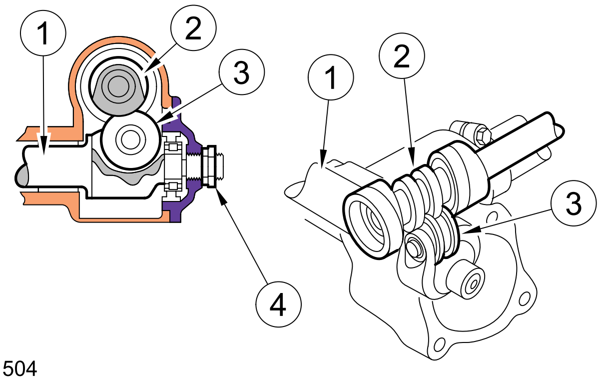
Recirculating Ball Type Steering Rod The recirculating ball type system uses a chain of ball bearings installed between the thread grooves of the rotating worm and its translating nut. Either a single or two independent ball bearings circuits may be used according to the severity of duty imposed. When the steering wheel is rotated, the column rotates inside the ball nut. As this happens the ball nut will move up and down the worm and this transmits movement onto the drop arm and then onto the drag link.



1. Worm
2. Nut
3. Steering box
4. Side cover
5. Adjust screw
6. Rocker arm

Worm and Roller Type Steering Box

A roller follower fitted to the rocker shaft engages with an hourglass worm. The small offset of the roller to the worm enables an adjusting screw to control backlash and end float of the rocker shaft.



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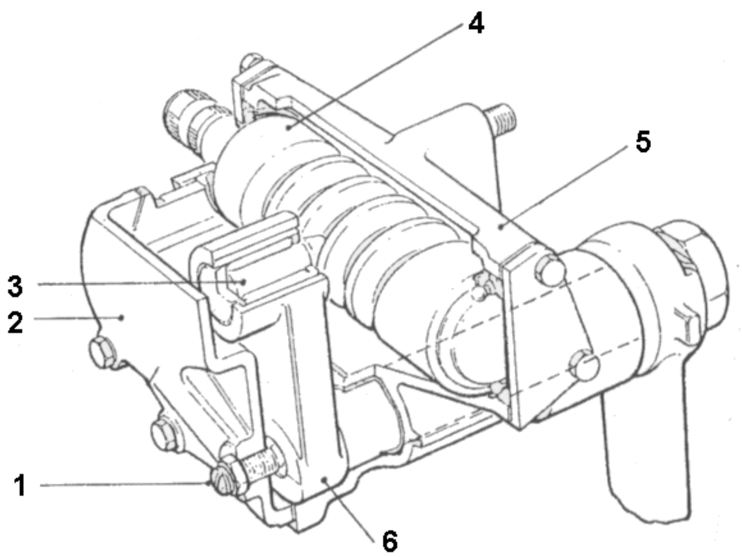
1. Rocker shaft
2. Worm
3. Roller
4. Backlash and rocker shaft adjustment

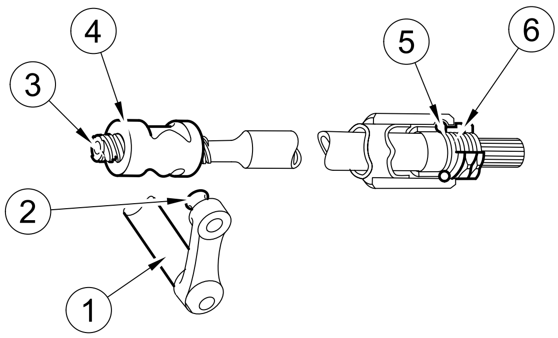
Cam and Peg Type Steering Box



1. Adjusting screw
2. Side cover
3. Peg
4. Cam
5. Steering box
6. Rocker shaft

A tapered peg in the rocker arm engages with a special cam formed on the inner column. The end float of the column is controlled by shims. An adjusting screw on the side cover governs the backlash and end float of the rocker shaft.

Screw and Nut Type Steering Box



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1. Rocker shaft
2. Ball
3. Screw
4. Nut
5. Ball race
6. Adjustment for end-float

A phosphor-bronze or steel nut (4) is screwed on to a multi-start thread (3) formed on the inner column. Rotation of the nut is prevented by a ball (2) fitted on the rocker shaft (1). Axial thrust is taken by a single ball race (5) fitted at the top end. The nut sliding in the housing supports the lower end. End float of the inner column is adjusted by the nut at the top end (6).

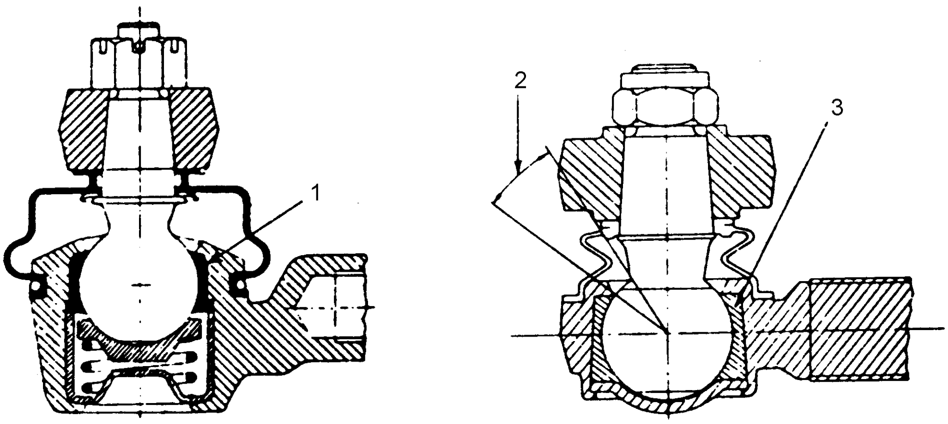
Ball Joints

The ball joints used in steering arrangements must do the following:

1. Allow for angular and rotational movement of steering and suspension components.
2. Provide a positive feel for the driver, without excessive free play.
3. Provide a limited amount of damping to reduce wheel wobble.
4. Be low maintenance and long-lasting.

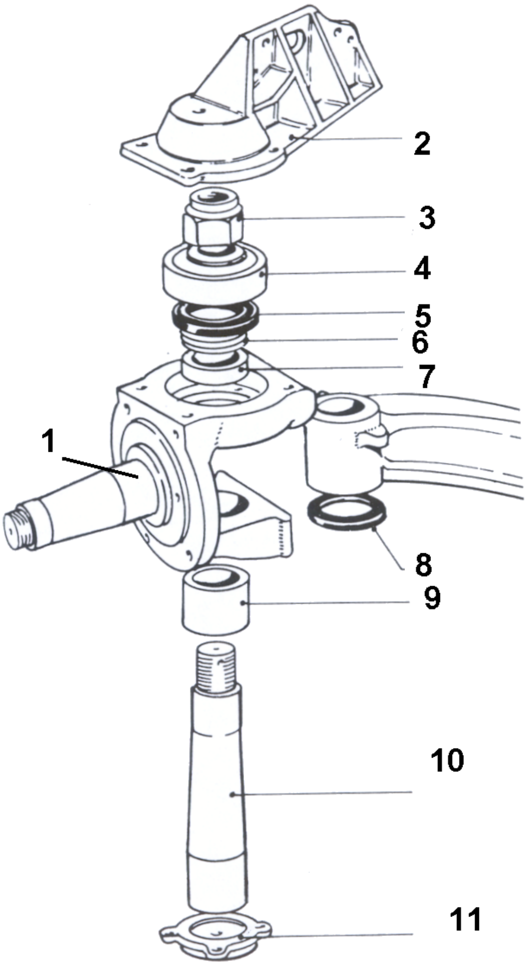
The ball joint has a tapered and threaded pin at one end and a ball at the other end. The ball end of the pin locates into either an almost fully enclosed plastic socket, or a plastic, spring-loaded seat at the bottom of the ball, with a plastic bush on the top of the ball. The pin end taper fits into a corresponding tapered fit on the steering arm.

The ball pins are made from heat-treated steel to give strength and a good finish. A dust cover or boot and gaiter keep dirt moisture out of the joint. An ingress of dirt or moisture would lead to premature wear and possibly failure of the joint. The joint is pre-packed with a lubricant and sealed for life.



1. Moulded plastic bushing
2. Angular movement possible each side of centre
3. Assembly compression of bush provides anti-rattle wear compensation and desired friction

Stub Axle

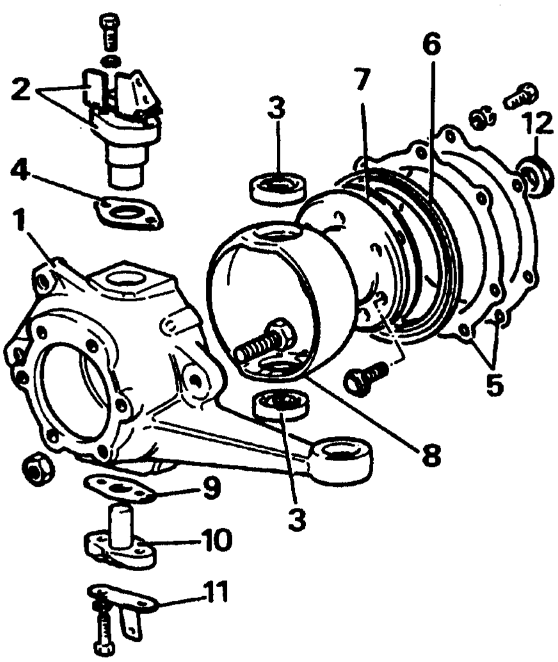


1. Stub axle
2. Upper swivel cap
3. Lock nut
4. Bearing
5. Upper seal
6. Space shims
7. Distance piece
8. Lower seal
9. Bronze bush
10. King pin
11. Lower swivel cap

Swivel Hub

To enable the swivel hub housing and stub axle to swivel there must be a swivel joint arrangement. Light vehicles normally have sealed ball joints, mounted on the top wishbone and lower track control arm/radius arm.

Vehicles with a solid beam axle normally have a kingpin and bush arrangement. In this system the stub axle is located to the axle by a pin that passes through a hole in the end of the axle. The stub axle has bushes fitted to the hole where the pin passes through. The pin is prevented from dropping down by a cotter pin. A bearing between the lower part of the stub axle and the main axle takes the weight of the assembly.



1. Swivel pin housing ....
2. Top swivel pin and brake hose bracket ....
3. Upper and lower swivel pin bearings ....
4. Shim ....
5. Retaining plate and washer ....
6. Oil seal ....
7. Joint washer ....
8. Swivel bearing housing ....
9. Joint washer ....
10. Lower swivel pin ....
11. Mud shield bracket ....
12. Swivel housing inner oil seal ....

Power Assisted Steering

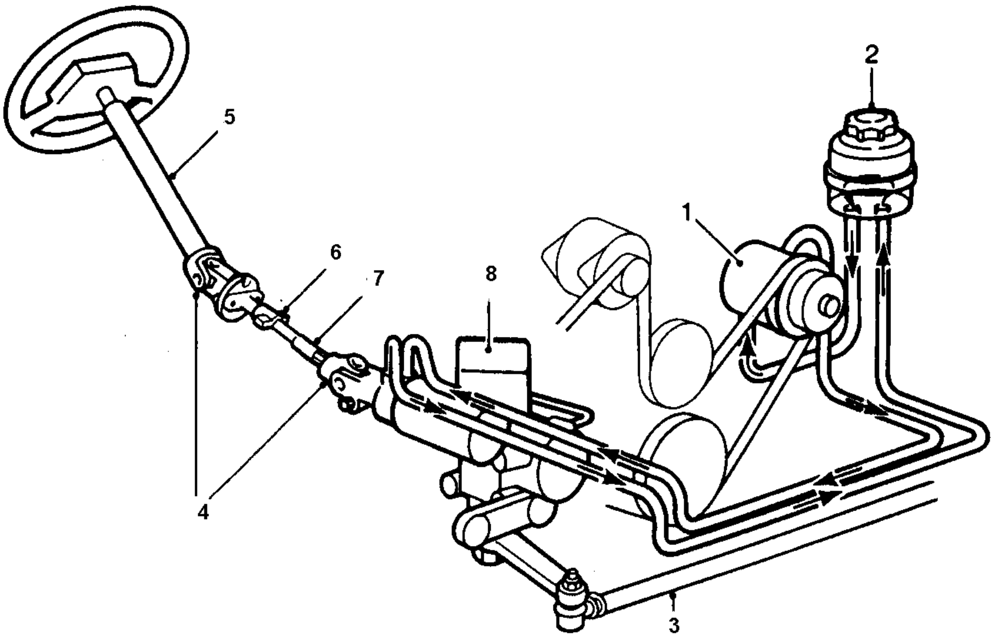
Power Assisted Steering (PAS) is fitted to some vehicles on the road today. This is an advance from manual steering.

Some advantages of Power Assisted Steering are as follows:

1. Minimise driver fatigue by lightening the action of the steering. This is more evident during parking maneuvers when resistance to turning the steered wheels is greatest.
2. Reduce the required number of turns lock to lock (the gear ratio can be higher than on manual steering).
3. Reduce “kick back” at the steering wheel by counteracting road shocks.
4. Improve safety by better resisting any sudden swerving of the vehicle during tyre deflation.
5. Permit heavier loading of the steered wheels to allow greater freedom in the overall vehicle design for optimum passenger and cargo space.

At the heart of many PAS systems is a hydraulic servo-mechanism. This operates whenever the resistance to turning the steering wheel exceeds a predetermined amount. It then gives additional effort to assist the manual operation of the steering and so reduces steering effort.

Steering Layout Components



1. Hydraulic pump
2. Fluid reservoir
3. Drag link
4. Universal joint
5. Universal column
6. Compression joint
7. Lower shaft
8. Steering box

An engine-driven pump circulates fluid around the closed circuit of the servo-mechanism. This gives a build up of pressure when needed.

As the steering wheel is turned, a hydraulic control valve admits the hydraulic pressure into a power cylinder arm where thrust is developed on one side or other of a servo piston that is connected to the steering mechanism.

Some modern vehicles now use an electro-hydraulic system where the power steering pump is driven by an electric motor in a combined unit.

Another system in use is a fully electronic system, where an electric motor acting directly on the steering column provides the power assistance.

The advantage of such systems is that the power steering force can be varied with road speed.

Therefore, maximum assistance is given at parking speeds and little or no assistance at motorway.

DESIRABLE FEATURES OF PAS OPERATION

Safety

Any PAS system must be fail safe. This is because, in the unlikely event of power assistance failure, the vehicle can still be steered due to a mechanical link from the steering column to the steered wheels.

Sensitivity

As well as providing adequate assistance, the steering system should give the driver '"feel" of the road, that is, in the event of tyre slippage, the driver must be able to feel the road and make appropriate corrections to control the vehicle.

Servicing

Servicing of the PAS system is normally minimal.

Inspections must be done every service.

Drive belts must be replaced either as recommended by specific manufacturers or when wear shows. Over tightening must be avoided to prevent bearing damage.

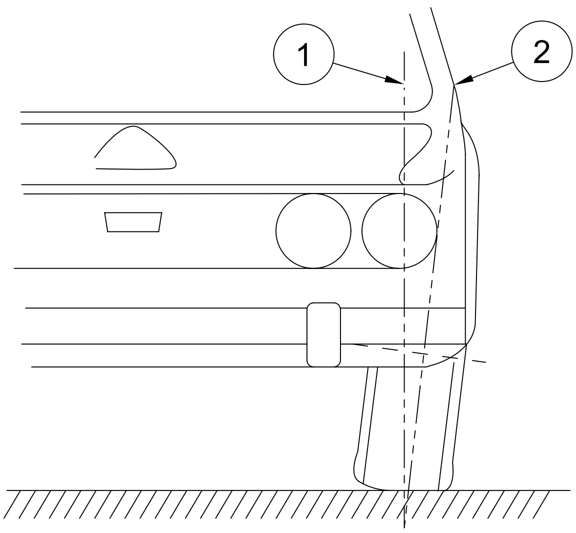
Fluid levels must be checked and hoses and unions checked for leaks.

STEERING AND SUSPENSION GEOMETRY

Introduction to Steering and Suspension Geometry

To get desirable features in a vehicle steering system, the various components must be arranged so that they have a "set up" or geometrical arrangement that will match the vehicle layout. The terms used and their effect on the vehicle's steering and stability are described below.

Camber Angle



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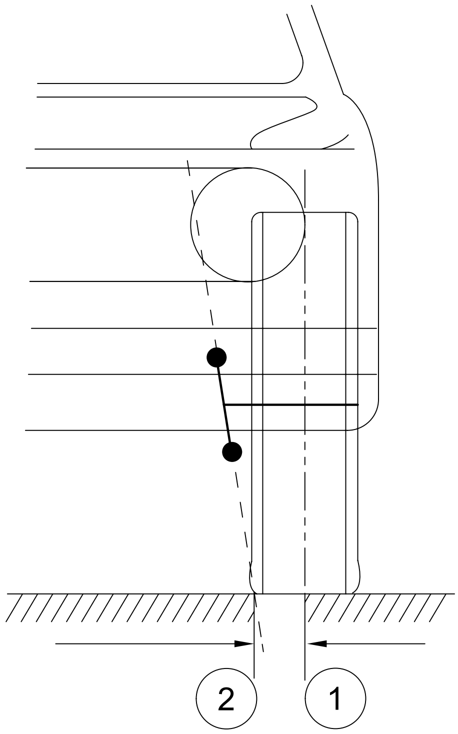
1. Vertical
2. Wheel

The camber angle is the inclination of the centre line of the wheel and tyre assembly from the true vertical, as viewed from the front or rear of the vehicle. The camber angle may be either a positive or negative setting as appropriate. The camber angle helps to reduce bending stress on the stub axle and loads the tyre to give a "feel" of the road. It also brings the centre line of the wheel near to the swivel axis, to give lighter steering.

The "splaying out" effect creates tyre wear, so the camber angle rarely exceeds 2°.

King Pin Inclination (K.P.I. or S.A.I.)



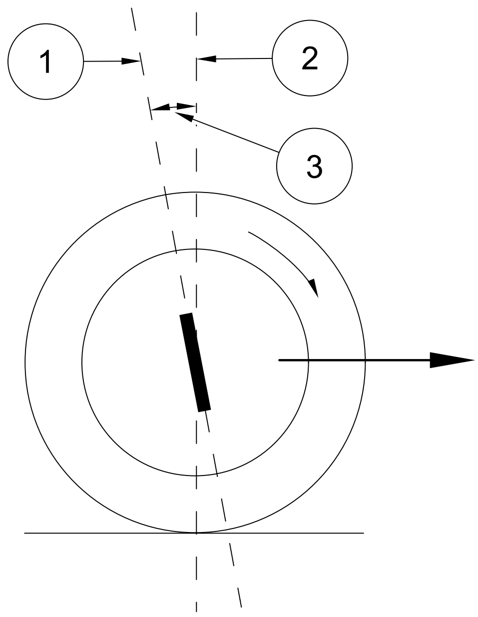
509

1. Vertical

2. Wheel

The inclination of the king pin or suspension leg from the true vertical as viewed from the front or rear. Used in conjunction with camber angle to give some of the same effects, as well as providing a selfcentring action of the wheels. May be between 5° and 10°, depending on manufacturer's hub design, and other factors

Castor Angle



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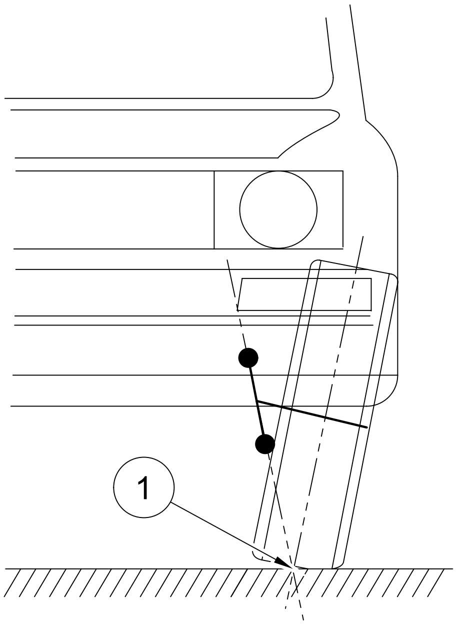
1. Kingpin centre line (tilted back at top)
2. Vertical through wheel centre
3. Castor angle

The castor angle is the forward or backward inclination of the centre line of the kingpin (or swivel axis) from the true vertical, as viewed from the side of the vehicle. The castor angle gives the self-centering action to the steering and keeps the wheels pointing straight ahead. Too much castor gives hard steering and too little creates wander. Positive castor is where the pivot centre line strikes the road in front of the wheels centre line and this set up is common for RWD. Negative castor is used for FWD vehicles but manufacturer specialist information must be checked in all cases.

Centre Point Steering



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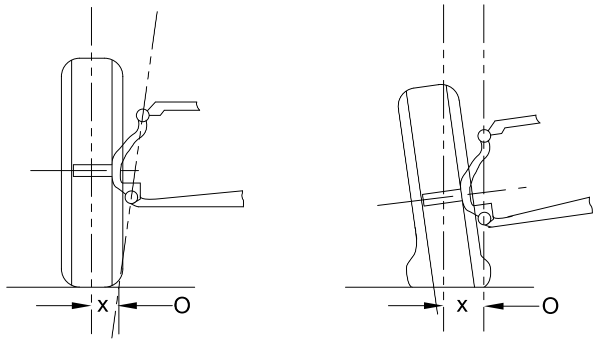
Centre point steering occurs when the extended axis of the kingpin intersects the ground at the centre point of the tyre contact area. This “zero offset” or centre point steering appears to be the ideal arrangement as it avoids the problems of splaying out of the wheels.

However, due to the “spread” effect of the pneumatic tyre, it causes the wheel to “scrub” and gives hard steering and tyre wear.

Positive Offset (Positive Scrub Radius)

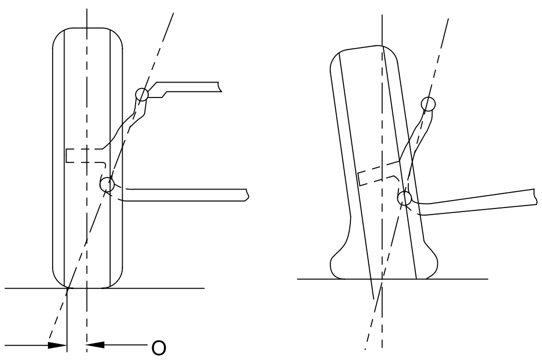
Positive offset is obtained by making the centre line of the wheel meet the swivel axis at the point just below the road surface.



512

The offset distance is measured at the road surface between the two centre lines. The offset must be equal on both sides to ensure that pull of one wheel is balanced by that of the other. However, when one front tyre deflates, the positive offset is increased on that side. This will cause the vehicle to pull violently to that side and make the vehicle difficult to control especially if the brake is applied. This is shown above.

Negative Offset (Negative Scrub Radius)



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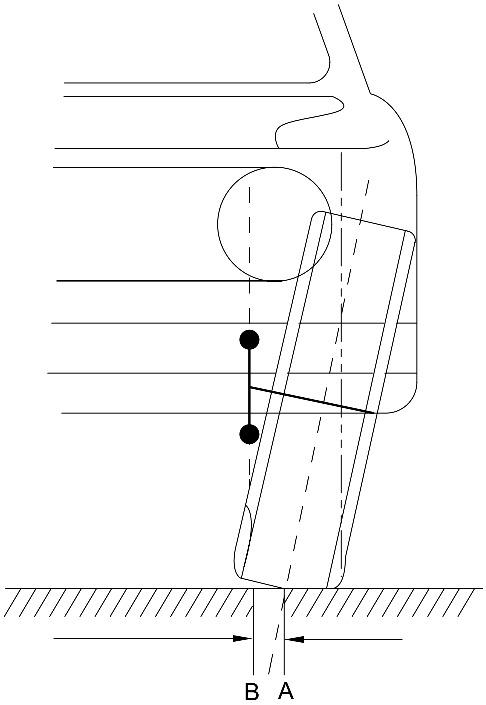
Negative offset obtained by making the centre line of the wheel meet the swivel axis at the point above the road surface. With this geometry, the effect of tyre deflation is to reduce the offset towards zero or slightly positive and therefore, removes the deflated tyres leverage and ability to change direction of the vehicle. Negative offset also helps to give straight-line stability when a front brake imbalance is present.

Scrub Radius



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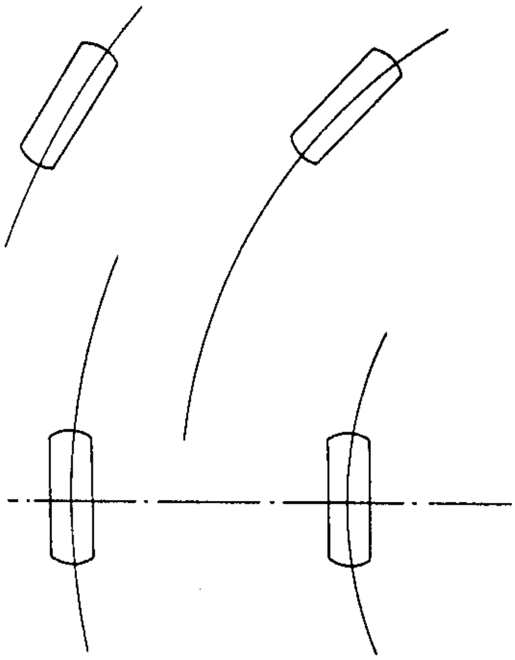
B to A Scrub radius

Scrub radius is the distance between the points of intersection of the centre lines of the wheel and tyre assembly and the king pin, with the ground.

True Rolling Motion



When a vehicle travels on a curved path during cornering, true rolling is only obtained when the wheels roll on arcs that have a common centre or instantaneous centre of turn. This is necessary to avoid tyre scrub or scuffing of the tread.

To achieve true rolling motion while cornering, the wheels have to be steered through different angles. The system used to obtain a difference in steered angle is called the “Ackerman System” or “Angle”. The figure above shows the path the wheels follow when cornering to give a true rolling motion.

Ackerman System

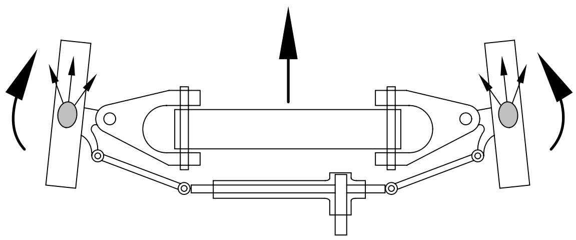
The “Ackerman System” is obtained by positioning the king pin and track rod joint on an imaginary line which is inclined to the centre line of the vehicle. If the steering rack is fitted to the rear of the swivel axis, the track rod is shorter. If the steering rack is fitted to the front of the swivel axis then the track rod is longer.

WHEEL ALIGNMENT

When the vehicle is travelling forward in a straight path, both wheels must be parallel. To achieve this, allowance must be made for movement and slight free play in the steering and suspension systems.

Otherwise forces generated may cause the wheels to splay in or out. To counter this tendency, the front wheel alignment is given a degree of “toe”. This is the difference in width between the extreme front and rear of the front wheels, measured at axle height.

Toe-In



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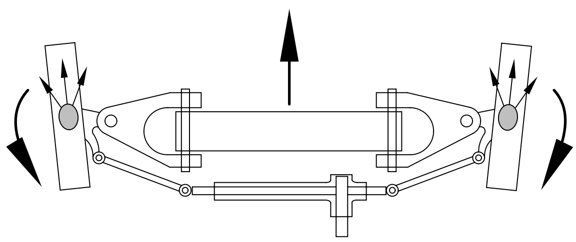
When the width at the front of the wheels are less than that of the rear, then the wheels are said to toe-in. This is usually used on RWD vehicles.

Toe-Out

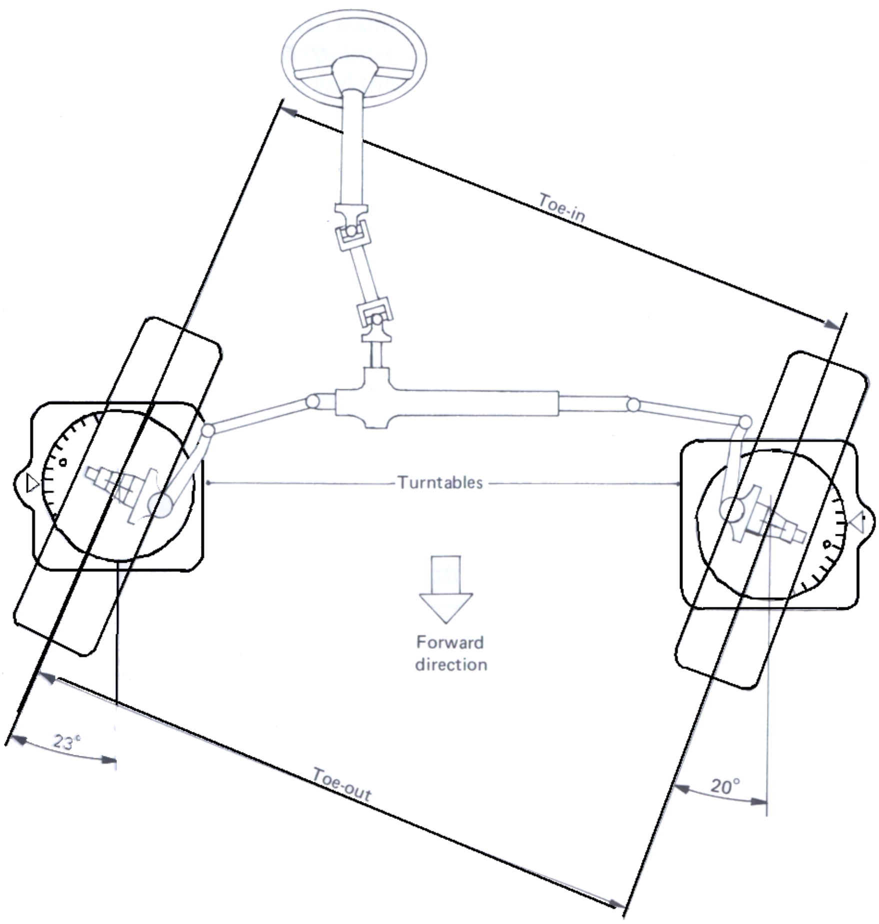


518

When the width at the front of the wheels are greater than that of the rear, then the wheels are said to be toe-out. This is usually used on FWD vehicles.

Note: Front wheel drive vehicles tend to want to toe-in. When stationary the wheels are set to toe-out. This enables the wheels to run parallel when the vehicle is moving. The opposite takes place on rear wheel drive vehicles. This is shown in the diagrams above.

Toe-out On Turns



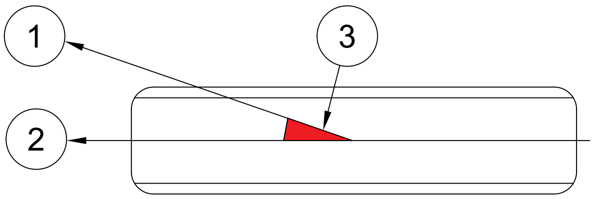
Toe-out on turns is the diverging in the forward direction of the front wheels when the stub-axles are rotated about their king pins. The difference between the angles of turn applied to the front steered wheels gives the size of the toe-out in degrees. The amount of toe-out on turns is obtained by the inclination or set of the track-rod arms and will depend upon the track length, its angular set and the track width.

This is checked by putting the vehicle on graduated turntables, turning it to 20° on the outer wheel and checking the inner wheel reading. This must give the same readings as when the steering is turned on the opposite lock.

Slip Angle

When a wheel and pneumatic tyre are subjected to a side force, the tyre will deflect and take a different path to that of which the wheel is steered in.

The angle between the actual path of the tyre along the ground and the plane of rotation of the wheels is called the "slip angle". This term is misleading as slip does not happen. "Creep Angle" might be a more accurate term to use.



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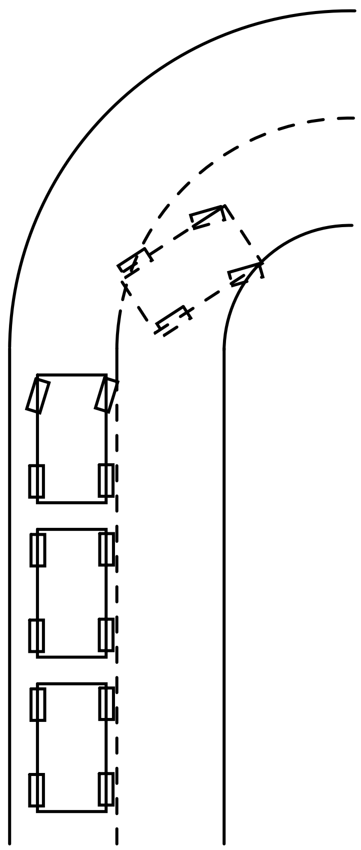
1. Direction of travel
2. Plane of wheel
3. Slip angle

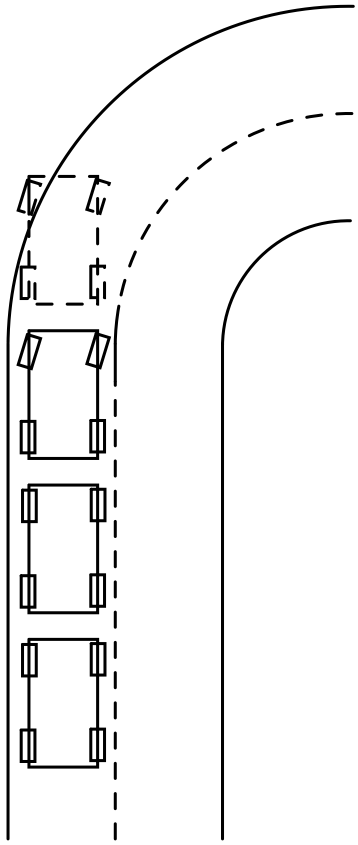
Oversteer



537

Oversteer occurs when the slip angle for the rear tyres is greater than for the front tyres. Under these conditions, the vehicle will turn more sharply into the curve and that will increase the side force acting on the tyres and this will, in turn, increase the slip angle, creating even more oversteer. To correct oversteer, the steering wheel has to be turned back or put on opposite lock.

Understeer



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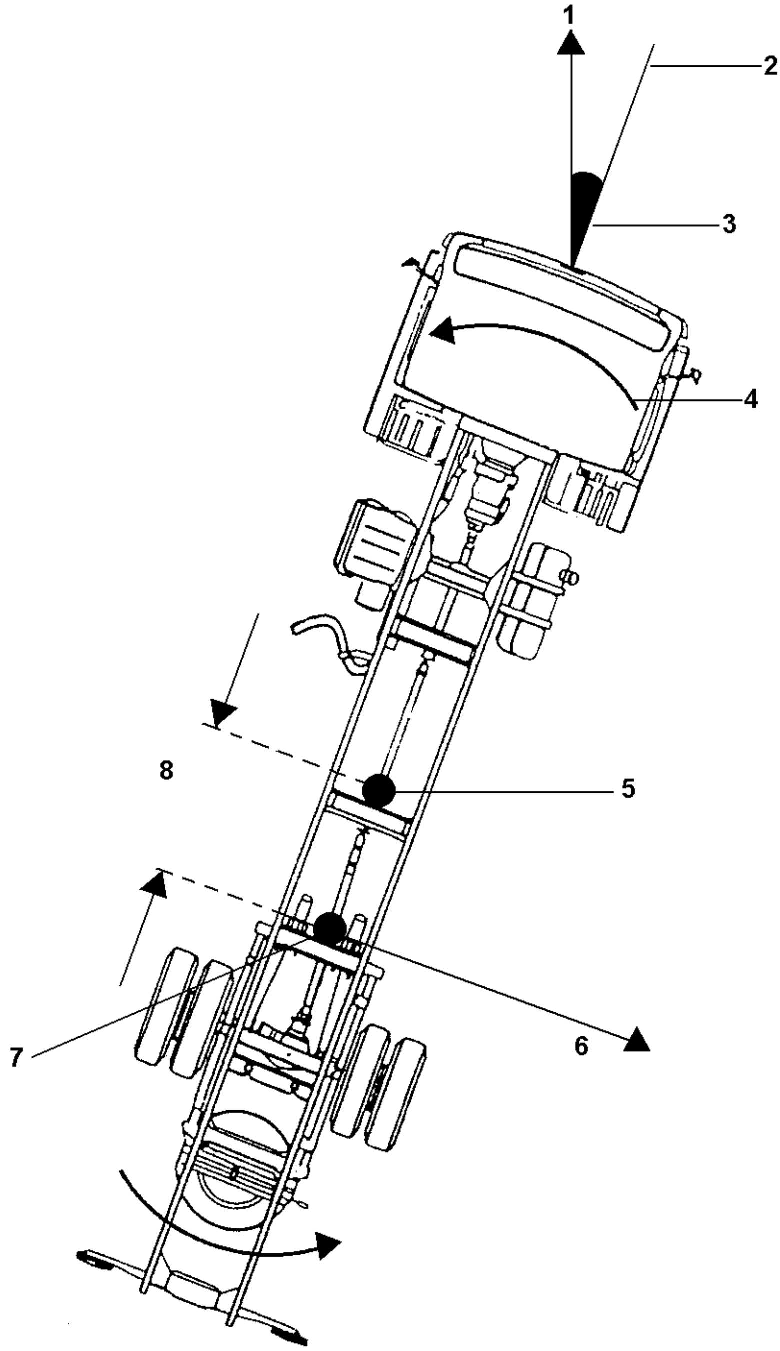
Understeer occurs when the slip angles for the front tyres are greater than for the rear tyres. Under these conditions, the vehicle has to be held into the curve. This is more desirable than oversteer as the steering wheel rotation is constant and in the direction of the curve.

Self-Aligning Torque



1. Direction of vehicle motion
2. Wheel plane
3. Slip angle
4. Self-aligning torque
5. Centre of tyre contact patch
6. Resultant cornering force
7. Centre of pressure
8. Pneumatic trail

When a side force acts on a tyre wall and deflects it to give a slip angle, an equal and opposite force is generated at ground level, at a point where the tyre leaves the road.

This produces what is known as self-aligning torque. It can be felt by the driver and is an inherent tyre property. This helps tyres to return to their original position after turning in the road.

Chapter 2
Written Assessment

MANUAL STEERING LEVEL 2

1. State two advantages of a rack and pinion steering arrangement compared to a steering box arrangement.

Answer:

Compact layout

Direct connection to the road wheels so giving a very positive steering system

2. State one purpose of the ball joint located at the rack end of the track rod.

Answer:

Allow for angular and rotational movement of steering and suspension components. Provide a positive feel for the driver, that does not give excessive free play. Provide a limited amount of damping to reduce wheel wobble. Be low maintenance and long lasting.

3. State the purpose of the following components:

- Steering column universal joint

Answer:

Allow for the different relationship between rack and column as well as allowing the rack to move on impact.

- Compression joint

Answer:

Designed to collapse on impact.

- Steering coupling rubber coupling

Answer:

The rubber coupling helps to absorb road wheel shocks when driving.

4. Name three types of steering box

Answer:

Screw and nut

Cam and peg

Worm and recirculating ball(or worm and roller)

POWER STEERING LEVEL 2

1. State the purpose of the torsion bar used in the valve assembly of a power steering system.

Answer:

To provide feel for the driver – to hold the valve in the neutral position during straight driving and give the driver a small amount of torque sensitivity.

2. On power steering systems, failure of the pump will result in complete loss of the steering, true or false?

Answer:

True / False?

3. Describe the method of maintaining steering operation if the torsion bar in the valve assembly of a PAS breaks.

Answer:

A coarse splined connection between the input shaft and worm ensures steering] control is maintained sufficient to allow the vehicle to be recovered.

4. State two functions of the track rod.

Answer:

Allow the rack rod to move up and down

Allow for hub deflection

SUSPENSION LEVEL 2

1. Name two types of suspension springs.

Answer:

Metal leaf spring, torsion bar

Helical spring, rubber spring

2. What is a damper more commonly known as?

Answer:

Shock absorber

3. Can an air wrench be used when refitting suspension components?

Answer:

No

4. Before fitting a new damper, what must be done?

Answer:

Check the part number on the product is correct according to the catalogue recommendation. Always prime the damper, by pulling out and pushing in the piston rod several times before installation. This must be done with the damper placed in the same position it will be in when installed under the car.