SUSPENSIONS
Suspension Springs and Shock Absorbers

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Academic Year 2021-2022

References

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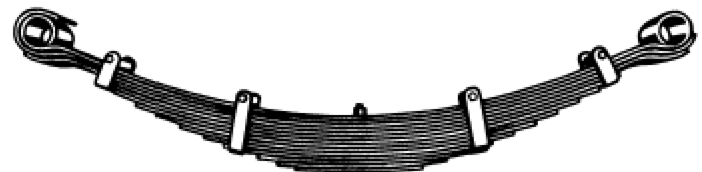
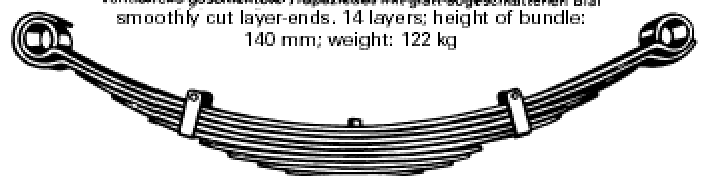
Outline

- SUSPENSION ELASTIC AND DAMPING ELEMENTS
  - Elastic elements
    - Leaf springs
    - Coil springs
    - Torsion bars
    - Oleo pneumatic systems
  - Damping elements and shock absorbers
    - Hydraulic shock absorbers
    - Mc Pherson strut

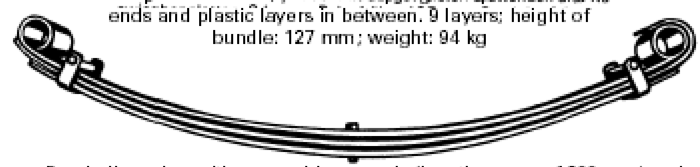
Leaf springs



a. Conventionally multi-layered leaf spring with smoothly cut layer-ends. 14 layers; height of bundle: 140 mm; weight: 122 kg



b. Improved multi-layered leaf spring with pressed layer-ends and plastic layers in between. 9 layers; height of bundle: 127 mm; weight: 94 kg



c. Parabolic spring with pressed layer-ends (length approx. 1200 mm) and plastic layers in between. 3 layers; height of bundle: 64 mm; weight: 61 kg

Leaf springs

- Traditional springs for heavy vehicles

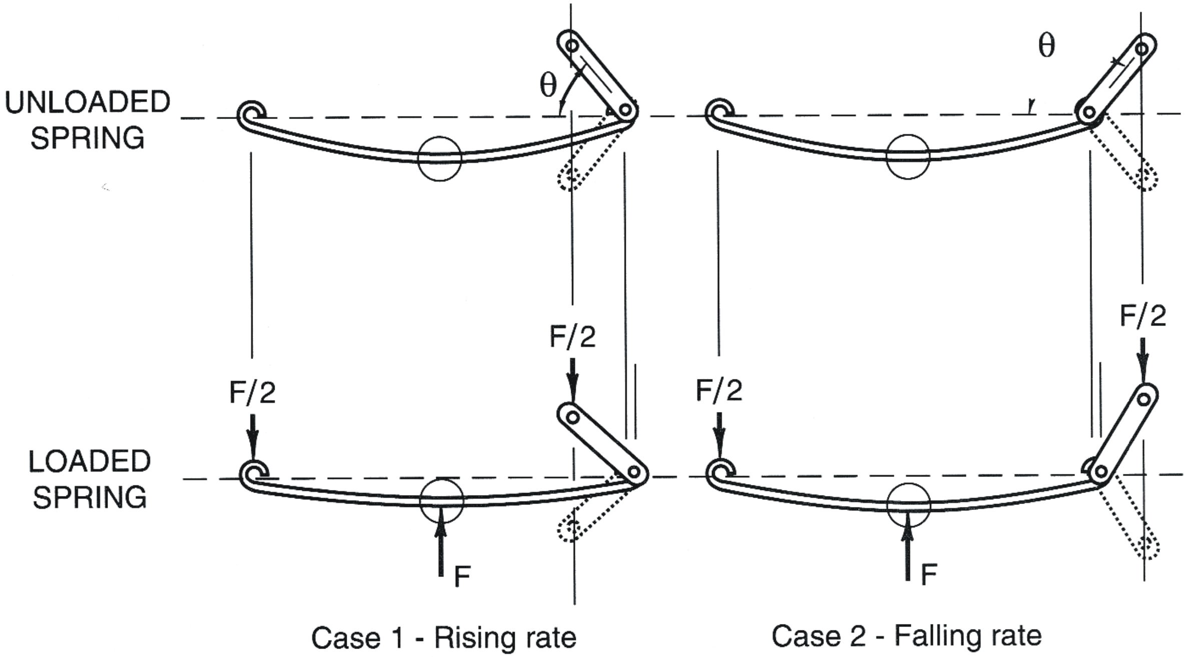
Advantages:

- (+) Simple to manufacture
- (+) They do not require additional links because
  - They provide some lateral guidance
  - They ensure a transfer of longitudinal loads
  - They have their own damping capability
- (+) Internal damping due to the friction between leaves

Disadvantages:

- (-) Rather heavy
- (-) May break or fail (compared to other systems)

Leaf springs



Milliken Fig 21.10 : Installation considerations. Shackle angles effect on spring rate

Leaf springs

Single parallel spring

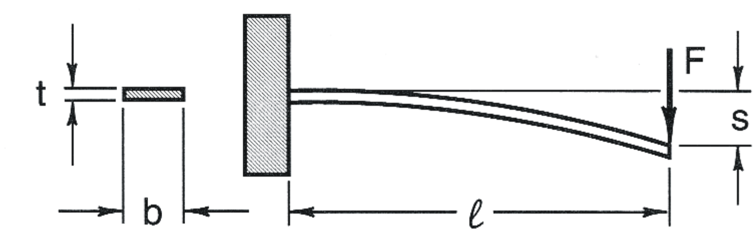
- Flexural stress

$$\sigma = \frac{6\,l}{b\,t^2} F$$

- Stiffness

$$c = \frac{F}{s} = \frac{E\,b\,t^3}{4l^3}$$

(a) Single flat parallel spring (constant cross section)



Single leaf spring with parabolic shape

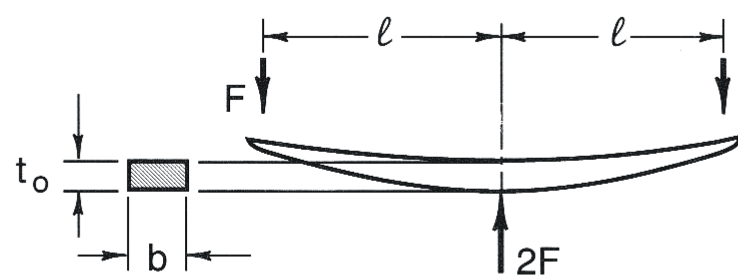
- Flexural stress

$$Q = 2F \qquad \sigma = \frac{3\,l}{b\,t_0^2} Q$$

- Stiffness

$$c = \frac{Q}{s} = \frac{E\,b\,t_0^3}{4l^3}$$

(b) Single leaf spring, rolled out parabolically (vehicle spring)



Milliken Fig 21.9

Leaf springs

Laminated leaf springs

- Flexural stress

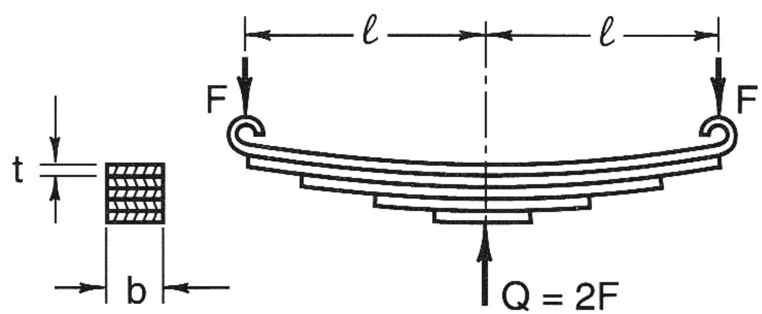
$$\sigma = \frac{3\,l}{n\,b\,t^2} Q$$

- Stiffness

$$c = \frac{Q}{s} = \frac{(2 + n/n')\,E\,b\,t^3}{6l^3}$$

n : number of leaves
n': number of leaves at the spring ends

(c) Laminated leaf spring (vehicle spring)

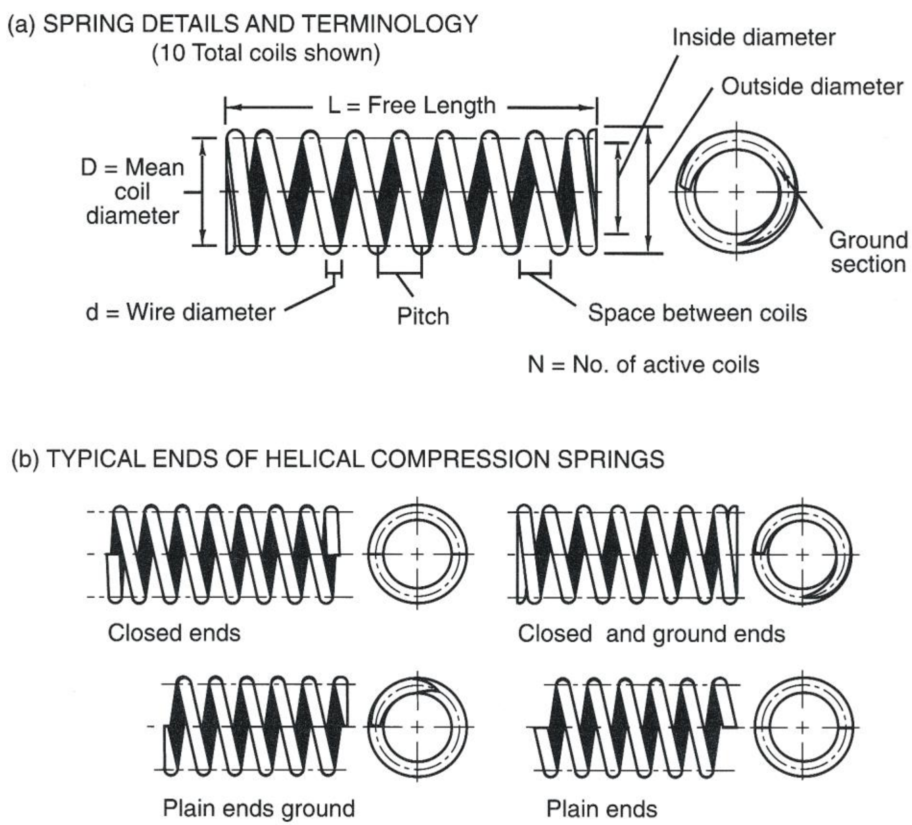


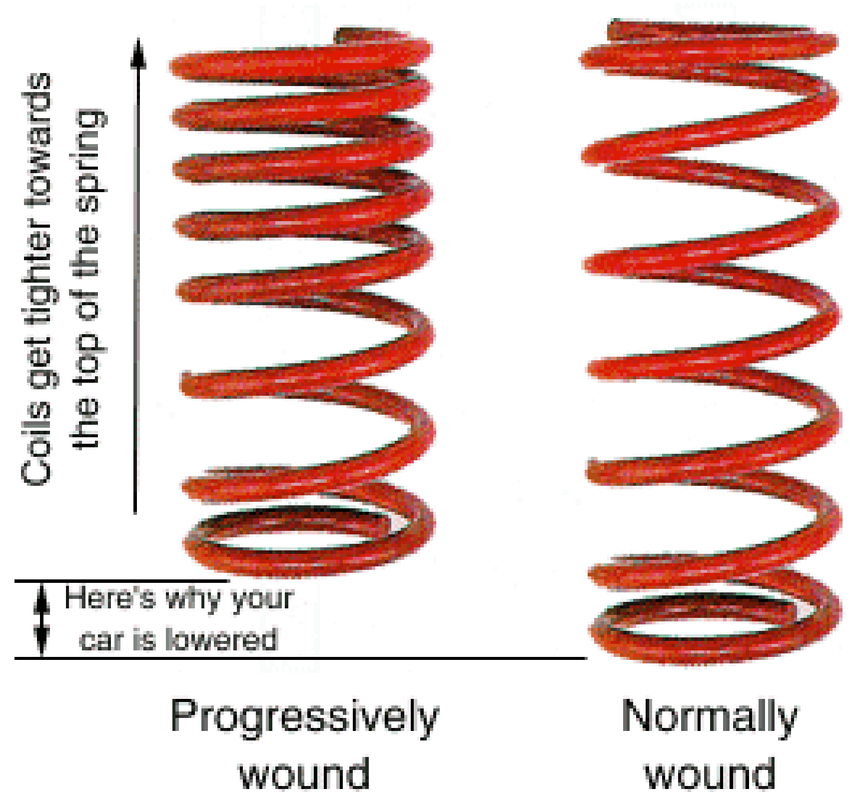
Milliken Fig 21.9

Efective stiffness of leaf springs

$$K = \frac{Q = 2F}{X} = \frac{(2 + n/n')\,E\,b\,t^3}{3l^3}$$

Coil springs



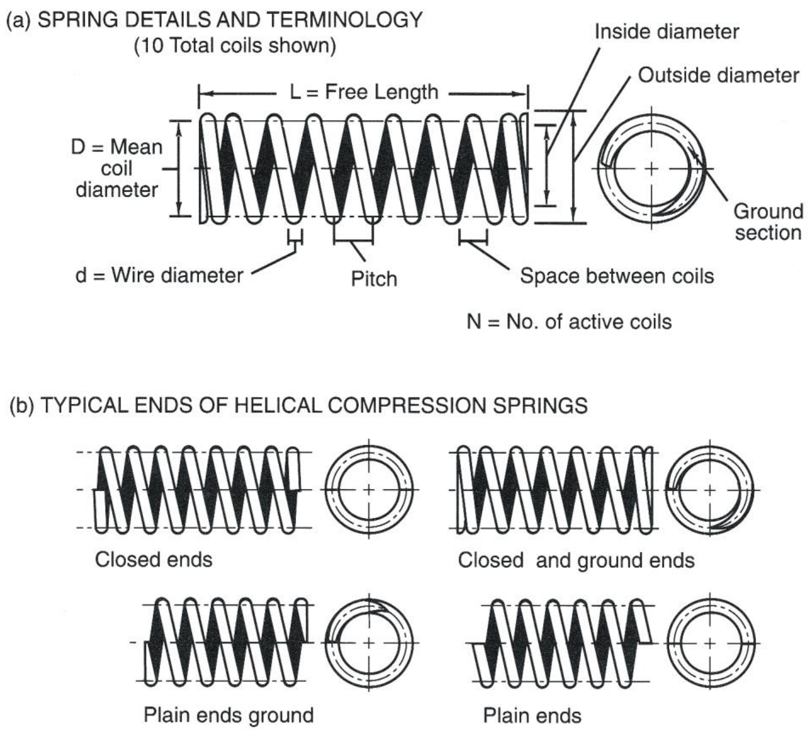


Milliken Fig 21.3: Helical coil compression springs

Coil springs

- Easy to fit the shock absorber inside the spring
- Much lighter than leaf springs
- Smaller packaging volume
- Break-proof, no maintenance
- No lateral guidance possible, hence it is necessary to make use of a combination of guidance bars and lateral restraints
- They require to be combined with certain suspension systems
- The natural frequency of the suspension decreases when the mass of the payload is increased.
- Non-linear stiffness is possible by changing the density of the turns or by giving a conical shape

Coil springs



Milliken Fig 21.3: Helical coil compression springs

- Shear stress (under static loading)

$$\tau = \frac{8\,D}{\pi\,d^3} F$$

- Shear stress (under alternated loading)

$$\tau_a = k\,\tau = \frac{8\,k\,D}{\pi\,d^3}\,F$$

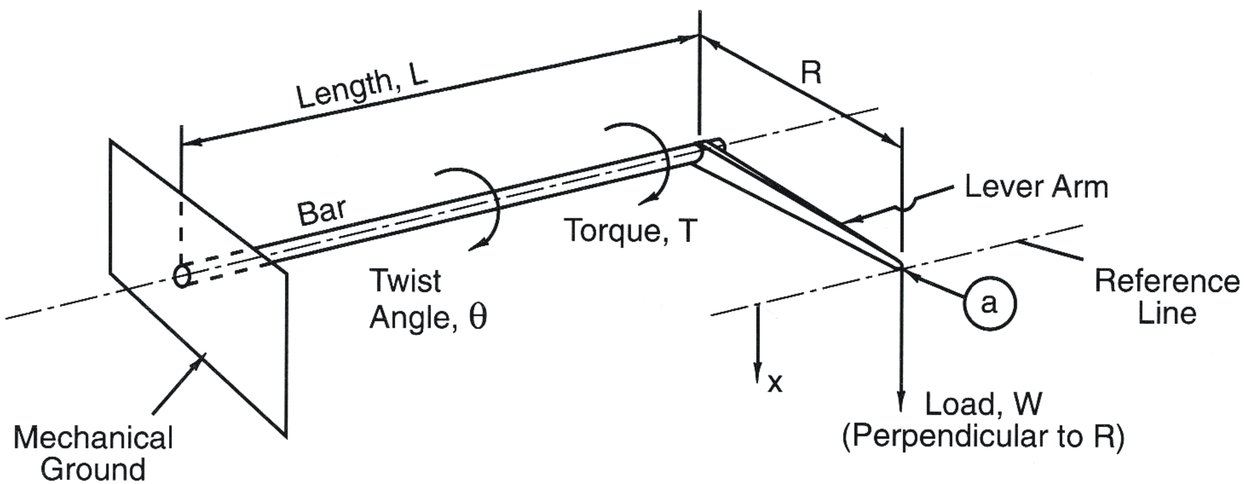
- Stiffness

$$C = \frac{F}{s} = \frac{G\,d^4}{8\,n\,D^3}$$

D/d	3	4	6	8	10	20
k	1.55	1.38	1.24	1.17	1.13	1.06

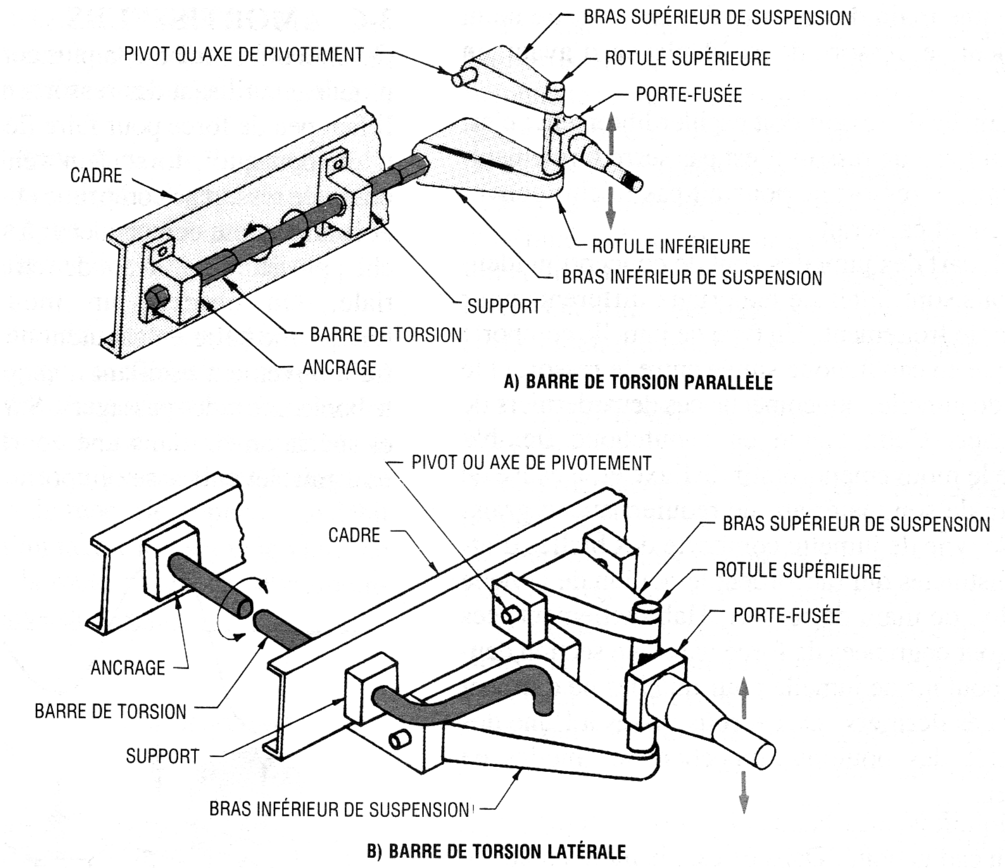
Torsion bars

- Consists of bars that twist during wheel travel.



Milliken Fig 21.1: Geometry of torsion spring

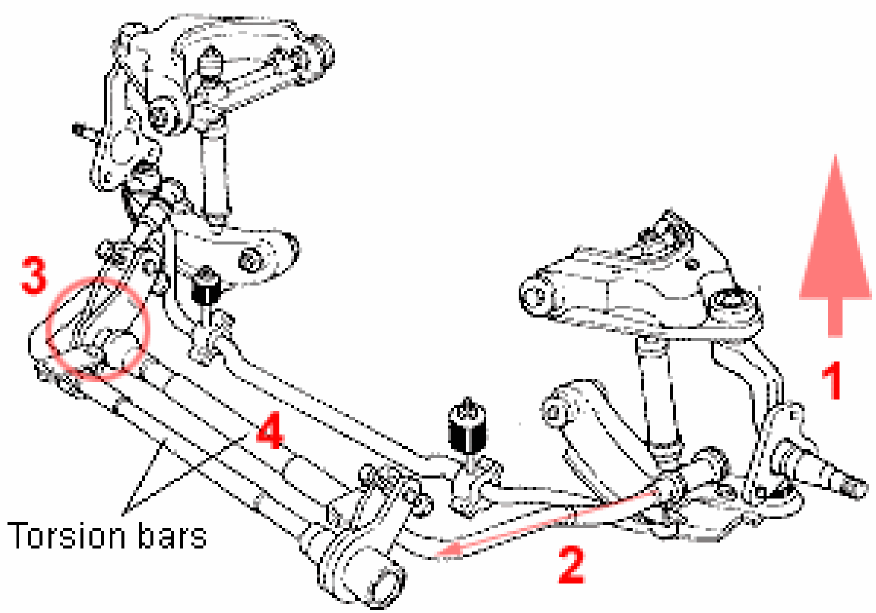
Torsion bars



Nash Fig. 3.12 Lateral or parallel torsion bars

Torsion bars

Transverse torsion arms mounted across the chassis



[1] Suspension compresses
[2] Control arm twists the torsion bar
[3] Torsion bar is anchored at one end
[4] Torsion bar resists twisting and provides spring

Torsion bars

Advantages

- Very small volume
- Possibility of adjusting easily the height of the vehicle
- Low weight
- Linear stiffness

Disadvantages

- Wheel guidance must be supplemented by lateral restraint systems
- Natural frequency decreases with the mass of the payload.

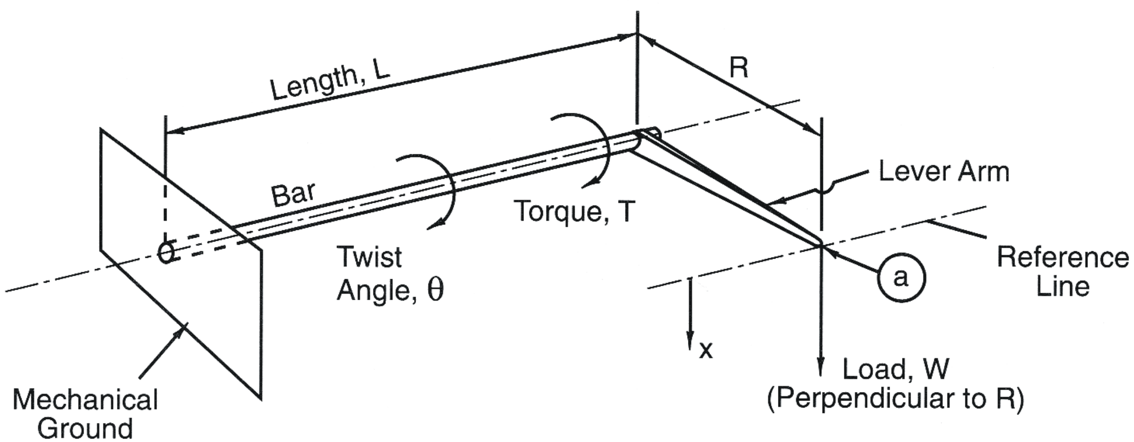
Torsion bars

- Torsion stress in the torsion bar

$$\tau = \frac{16}{\pi\, d^3} M$$

- Stiffness (N.m/degree)

$$C = \frac{M}{\theta} = \frac{G\,\pi\, d^4}{57.3\; 32\; l}$$

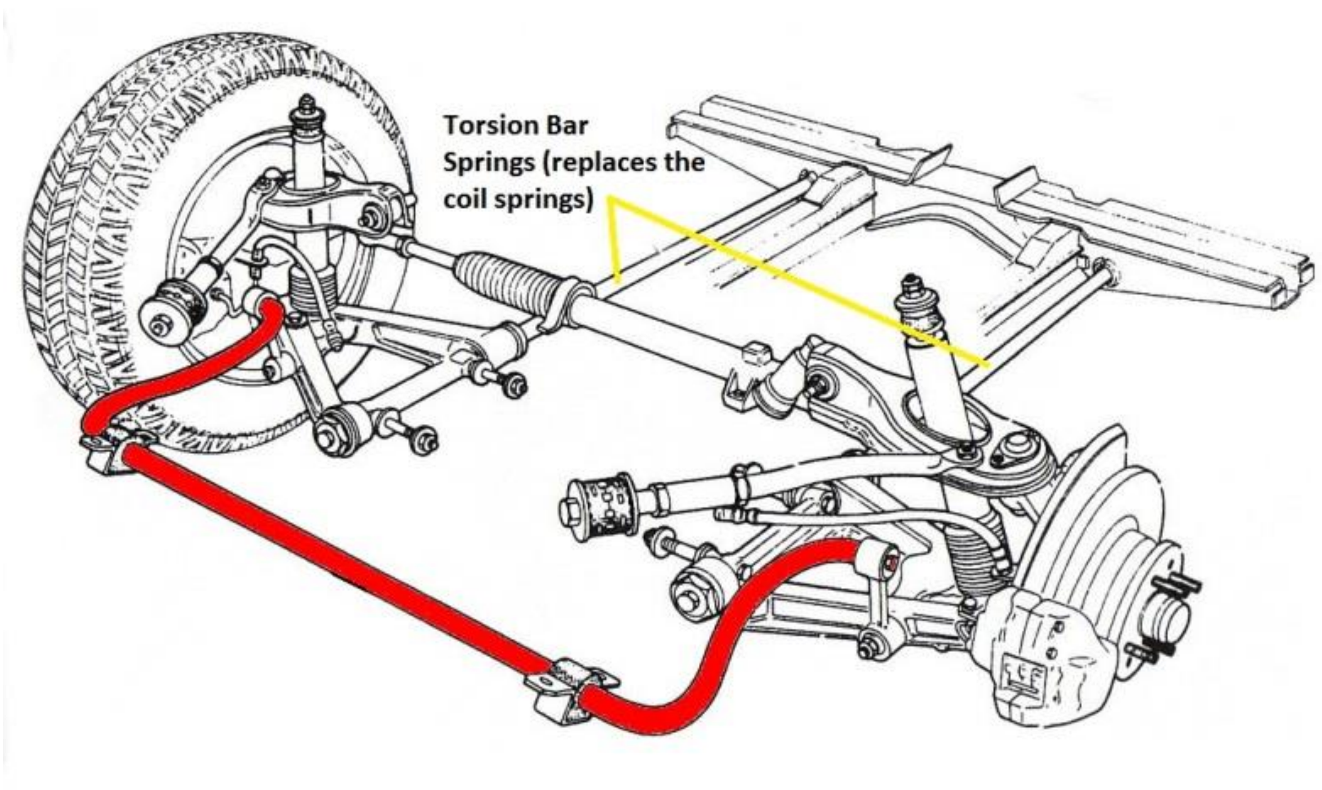


Milliken Fig 21.1: Geometry of torsion spring

Anti-roll bars

- Antiroll bars stiffen the suspension springing when the body rolls and when one wheel goes over a bump or dip in the road.
- Anti roll bars are pure roll stiffness elements
- Antiroll bars permits softer suspension springs to be used to ensure the desired ride comfort of passengers.
- Antiroll bars are generally made of a U-shape or circular cross section torsion bar mounted transversely on spaced out swivel bearings to the body and cranked arms attached to each swing arm via short vertical link-rod.

Anti-roll bars



Anti roll bar of Alfa Romeo Alfetta

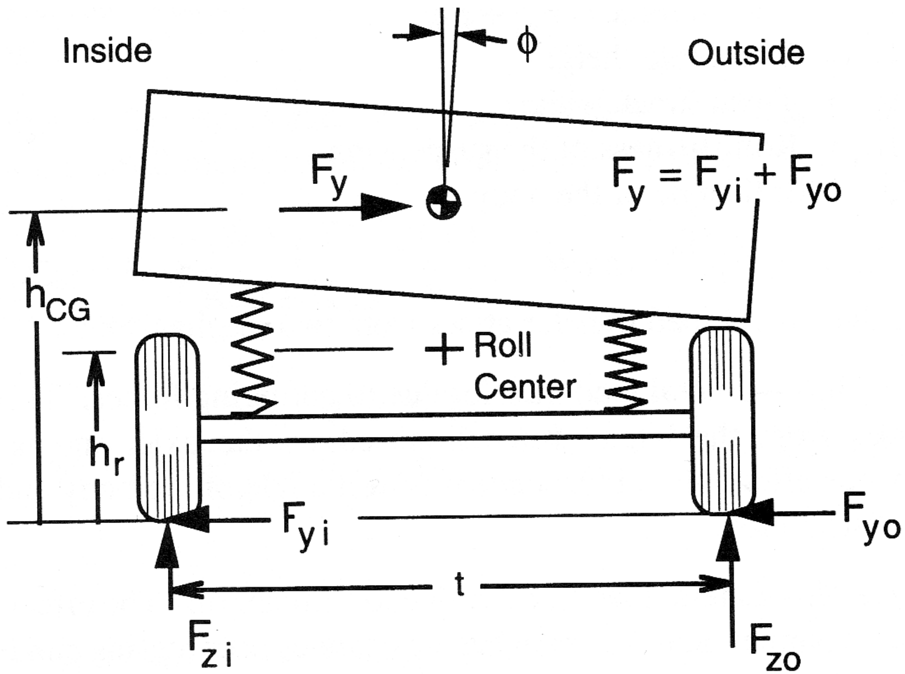
Anti-roll bars

- Antiroll bars can be made of U-shaped bars or circular cross section tubes.
- Connecting arm are flattened at their ends to accommodate bending loads.
- The attachment points on the wheel carrier should be as far apart as possible for maximum stabilizing effect.
- Suspension attachment systems must be arranged so that the anti-roll bars work only in torsion and not at all in flexion.
- In order to filter shocks and harshness, swivel bearing are mounted on rubber bushing and link-rod are pressing on swing arms using rubber bush joints.

Anti-roll bars

- Why using anti-roll bars?
  - Lower position of the roll center to limit the load transfers.
  - But a low roll center increases the body roll since it increases the distance between the roll center and the center of mass where the centrifugal forces are applied.
  - To reduce the body roll, the suspension must be stiffened in roll. For this purpose, anti roll bars are used to supplement the spring elements and increase the roll stiffness and to reduce the body roll under the action of centrifugal loads.
- Influence upon the cornering characteristics and contribution to the understeer gradient:
  - Anti roll bar on front axle → understeer contribution
  - Anti roll bar on rear axle → oversteer contribution

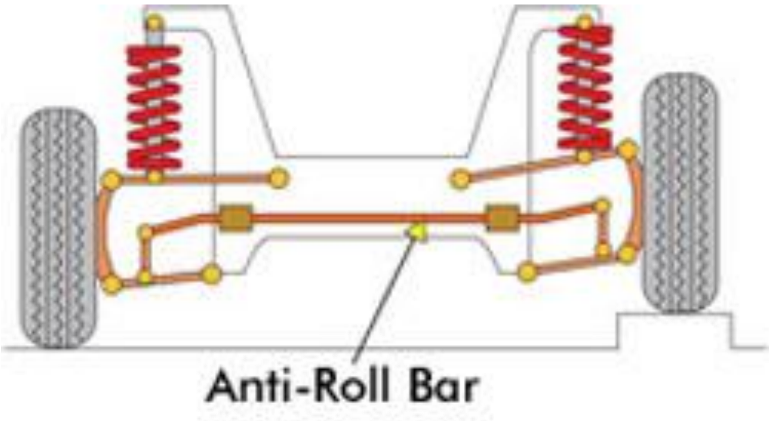
Anti-roll bars



$$F_{zo} - F_{zi} \;=\; 2\,F_y\,\frac{h_r}{t} \;+\; 2\,K_\phi\,\frac{\phi}{t} \;=\; 2\,\Delta F_z$$

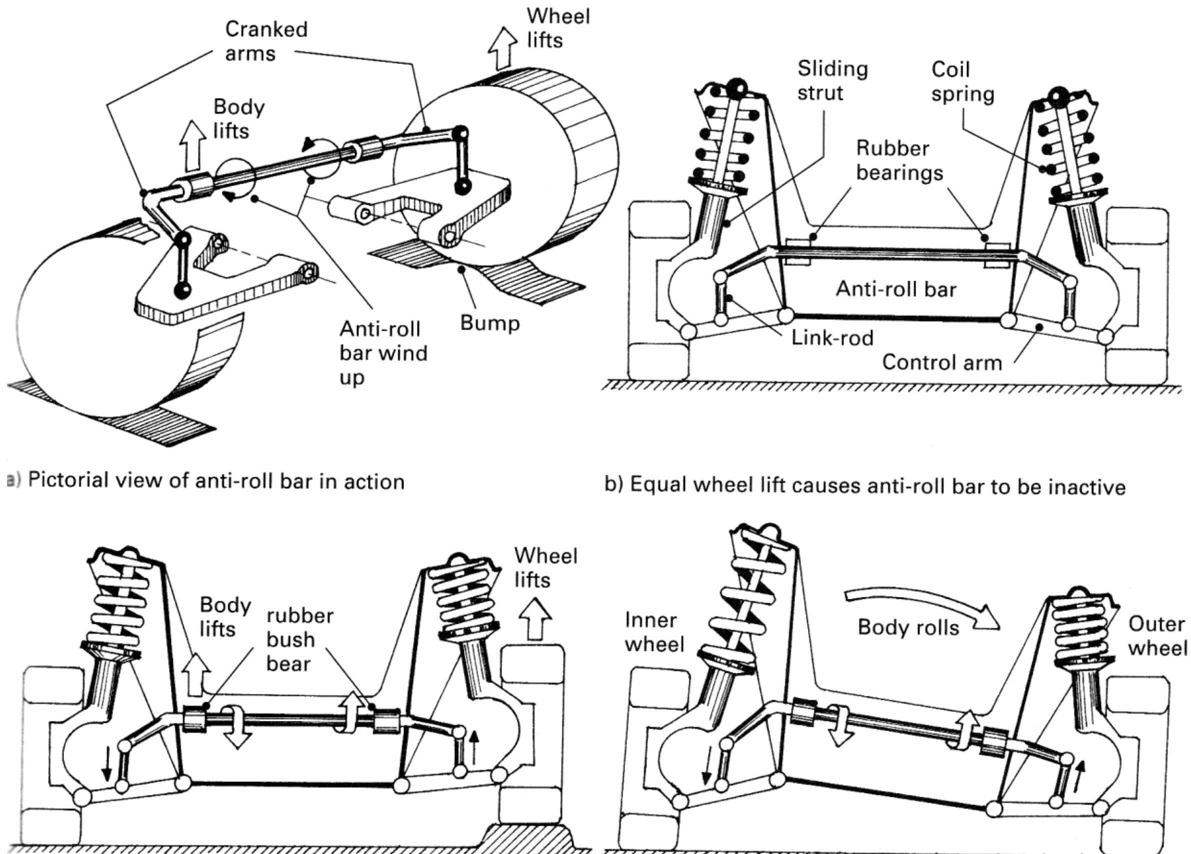
Anti-roll bars

- The anti-roll bar
  - It has no effect if both wheels move simultaneously (so no effect on vertical comfort)
  - It introduces a coupling between the left and right wheels if there is a differential movement
  - In case of movement of a single wheel: half of the effective stiffness. In case of opposite movement of the two wheels: full effective stiffness.



Anti-roll bars

Hillier Vehicle And engine Technology Fig 7.38



a) Pictorial view of anti-roll bar in action

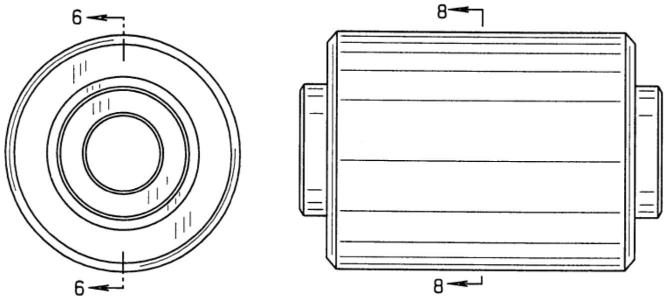
b) Equal wheel lift causes anti-roll bar to be inactive

c) Wheel lift causes anti-roll bar torsional twist

d) Body roll causes anti-roll bar torsional twist

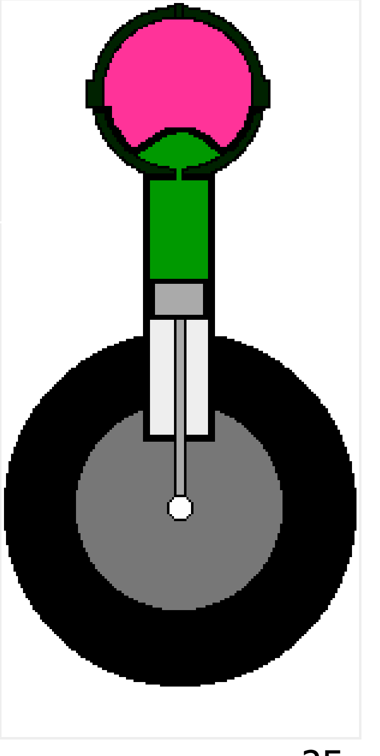
Bushing and compliances

- Bushings are a series of elastic elements placed at the junctions and joints between the various elements: on the suspension swing arm, at the ends of the shock absorbers, etc.
- Critical elements for comfort and safety
- Dampen vibrations and noise to improve the vehicle noise and harshness

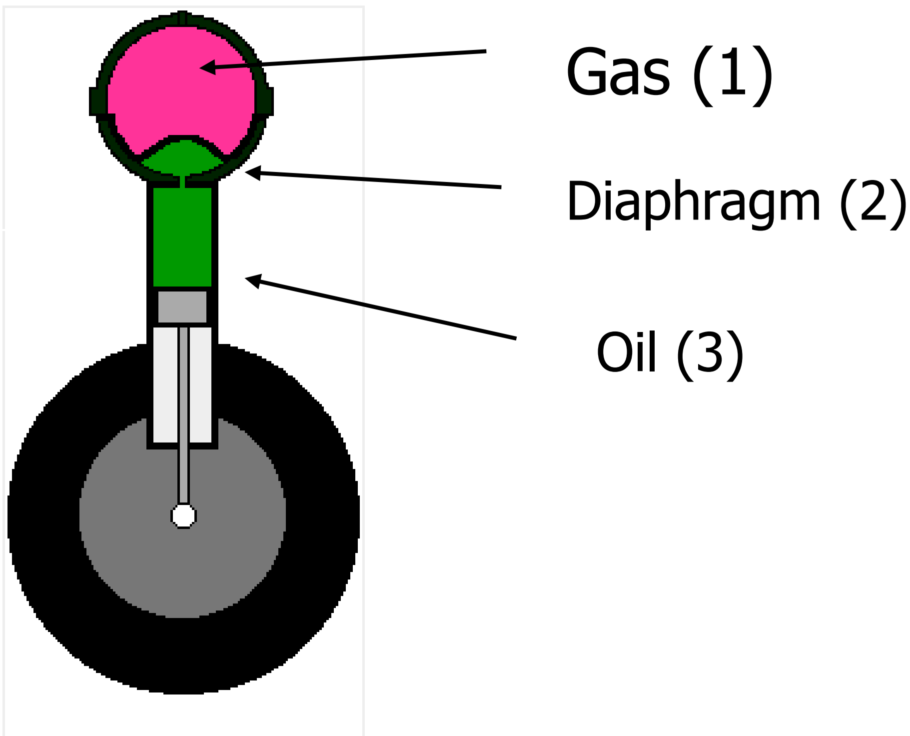


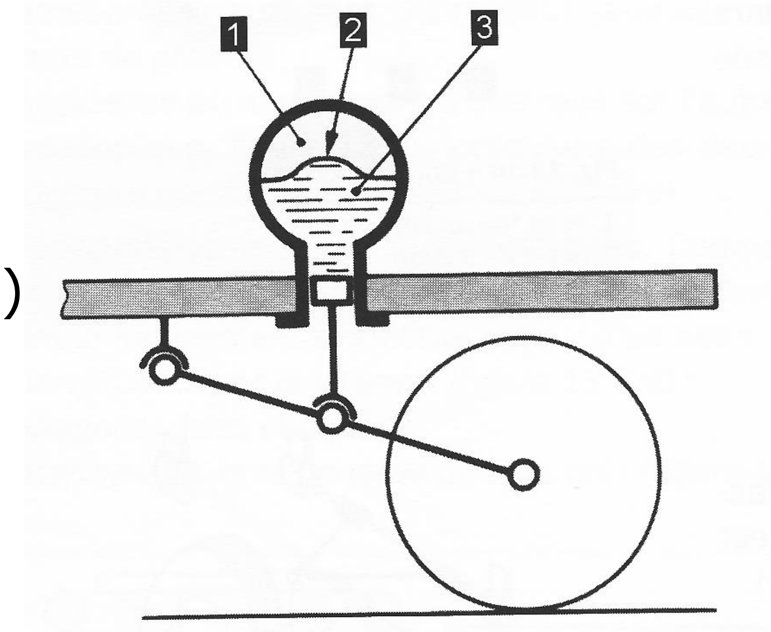
Oleo pneumatic system

- The heart of the system, the so-called spheres: acting as pressure sink as well as suspension elements. One per wheel and one main accumulator.
- Spheres consist of a hollow metal ball, open to the bottom, with a flexible desmopan rubber membrane, fixed at the 'equator' inside, separating top (gas) and bottom (fluid).
- The top is filled with nitrogen at high pressure, up to 75 bar, the bottom connects to the car's hydraulic fluid circuit.



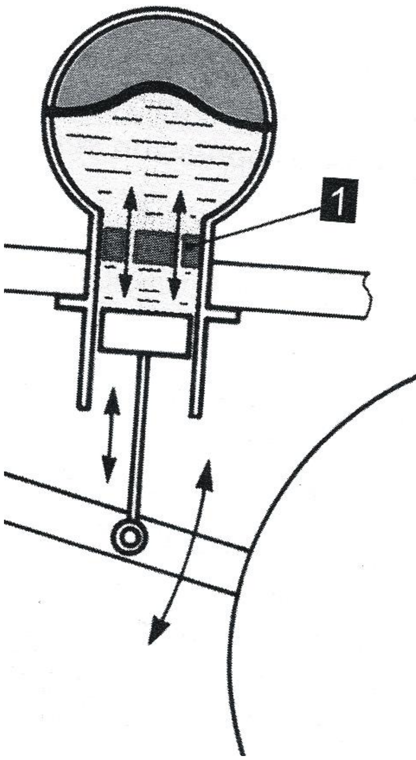
Oleo pneumatic system





Oleo pneumatic system

- Suspension works by means of a piston forcing hydraulic liquid into the sphere, compressing the nitrogen in the upper part of the sphere.
- Damping is provided by a two-way 'leaf valve' in the opening of the sphere. Valves with different settings (hard in expansion and soft in compression) allow energy to be dissipated and therefore act as a shock absorber.
- Liquid has to squeeze back and forth through this valve which causes resistance and controls the suspension movements.
- It is the simplest damper and one of the most efficient.



Oleo pneumatic system

- The stiffness is strongly non-linear.
- Thus the system does not possess any eigenfrequencies and associated dynamic instabilities, which need to be suppressed through extensive damping in conventional suspension systems.
- The natural frequency increases with the suspended mass. The characteristics are progressive and depend on the preset pressure in the tank.
- Ride height correction (self levelling) is achieved by height corrector valves connected to the anti-roll bar, front and rear. When the car is too low, the height corrector valve opens to allow more fluid into the suspension cylinder (e.g., the car is loaded). When the car is too high (e.g. after unloading) fluid is returned to the system reservoir via low-pressure return lines.

Oleo pneumatic system

Stiffness of an oleo-pneumatic system

- Isentropic compression

$$p\,V^{\gamma} = p_0\,V_0^{\gamma}$$

- Volume variation due to the displacement of the wheel connected to a piston

$$dV = S\,dx$$

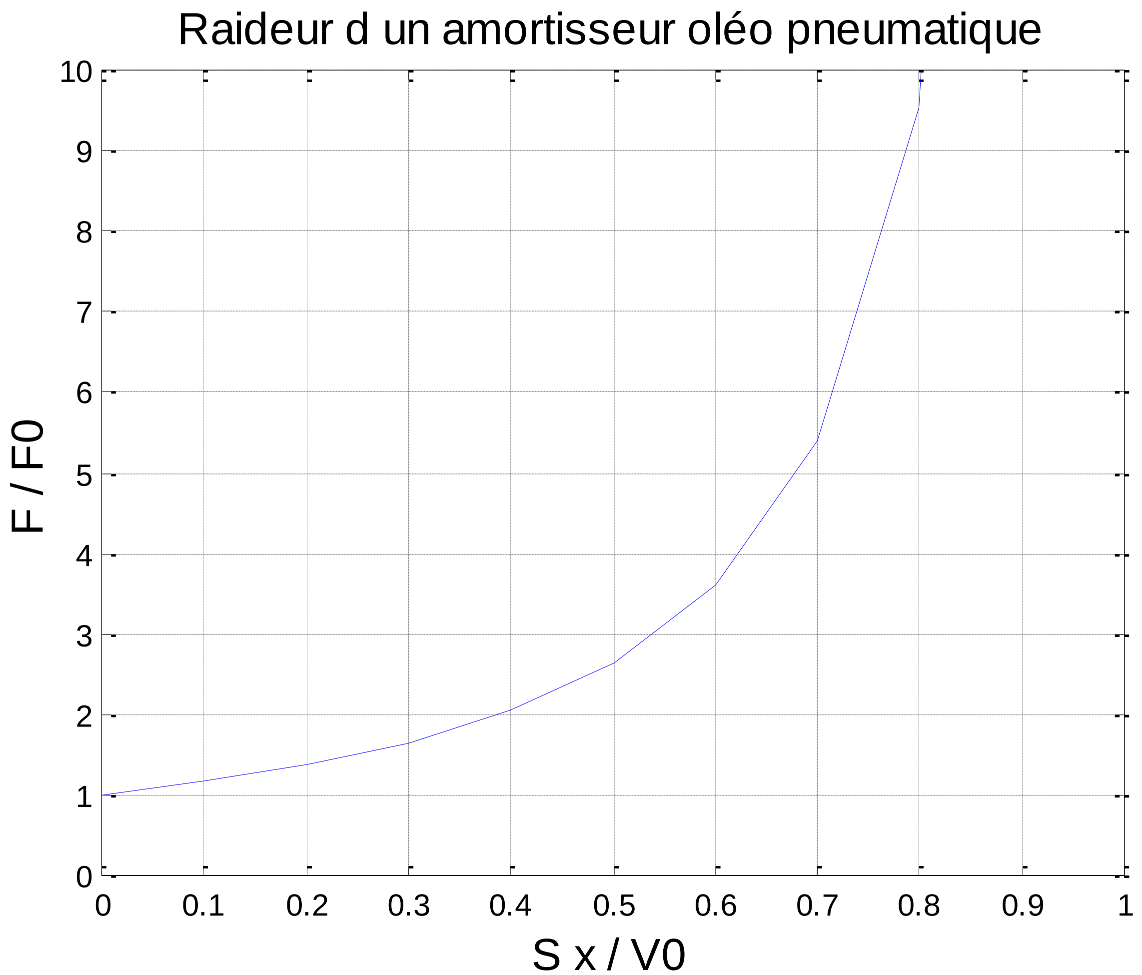
- Pressure in the fluid

$$p = \frac{p_0\,V_0^{\gamma}}{(V_0 - Sx)^{\gamma}}$$

- Force as a function of displacement

$$F = p\,S = \frac{p_0\,S}{(1 - \frac{Sx}{V_0})^{\gamma}} = \frac{F_0}{(1 - \frac{Sx}{V_0})^{\gamma}}$$

Oleo pneumatic system



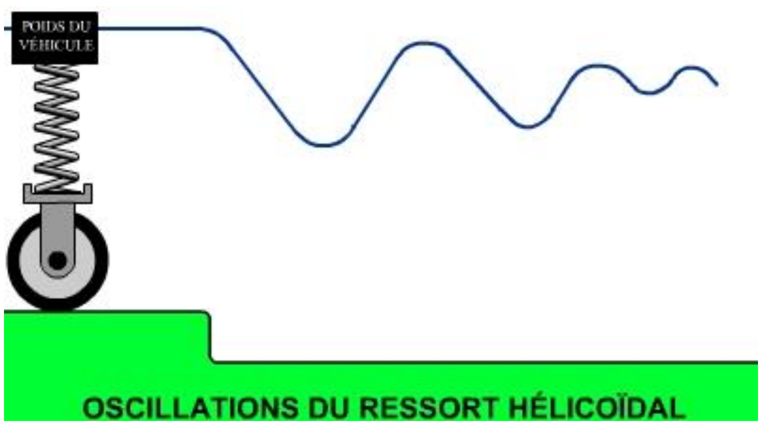
Oleo pneumatic system

- Hydropneumatic suspension is a type of motor vehicle suspension system, designed by Paul Magès, invented by Citroën, and fitted to Citroën cars but also under license by other car manufacturers, notably Rolls-Royce, Maserati or Peugeot.

- Hydractive Suspension is a new automotive technology introduced by the French manufacturer Citroën in 1990. It is available on models like XM or XANTIA, C5 and C6.

Shock absorber - damper

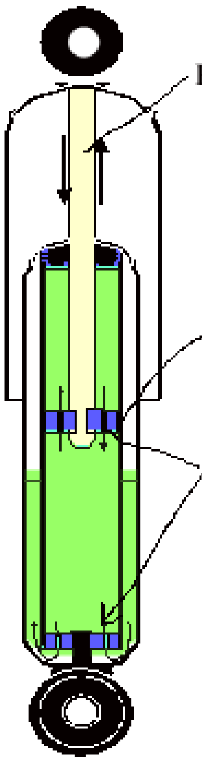
- Shock absorbers & Dampers are the main energy dissipating elements
- They are used to dissipate the accumulated kinetic energy when a wheel bumps into a pothole or overcomes an obstacle and tends to create an oscillating movement in the suspension. The vertical motion of the axle is absorbed and changed into heat.



Shock absorber - damper

- The damper shock absorber cannot support weight and has no resilience.
- If a damper is compressed, it will not rebound, and energy (shock) imparted to it will not be stored but dissipated as heat. Shock absorber have to be dampers are installed in spring assemblies.
- This reduces the amplitude and frequency of oscillation of the spring.
- This is an essential element in achieving a good compromise between a low level of vibration transmission to the suspended mass (comfort level) and adequate control of the unsprung mass in order to maintain good handling properties.

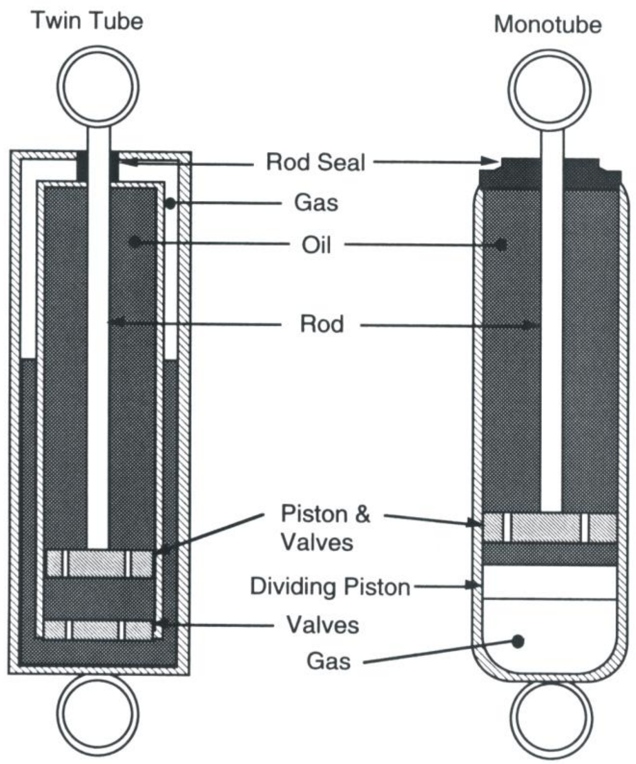
Shock absorber – damper: Working principle



- Telescopic systems containing hydraulic fluid. Shock absorbers are basically oil pumps.
- A piston is attached to the end of the piston rod and works against hydraulic fluid in the pressure tube. As the suspension travels up and down, the hydraulic fluid is forced through tiny holes, called orifices, inside the piston. However, these orifices let only a small amount of fluid through the piston. This slows down the piston, which in turn slows down spring and suspension movement.
- In addition, a rubber material pieces (bushing) are placed at the attachment ends to provide acoustic vibration isolation.

Shock absorber - damper

- We generally distinguish two main types of shock absorbers
  - Twin-tube shock absorbers.
  - Single tube shock absorbers
  - Single tube shock with floating piston.

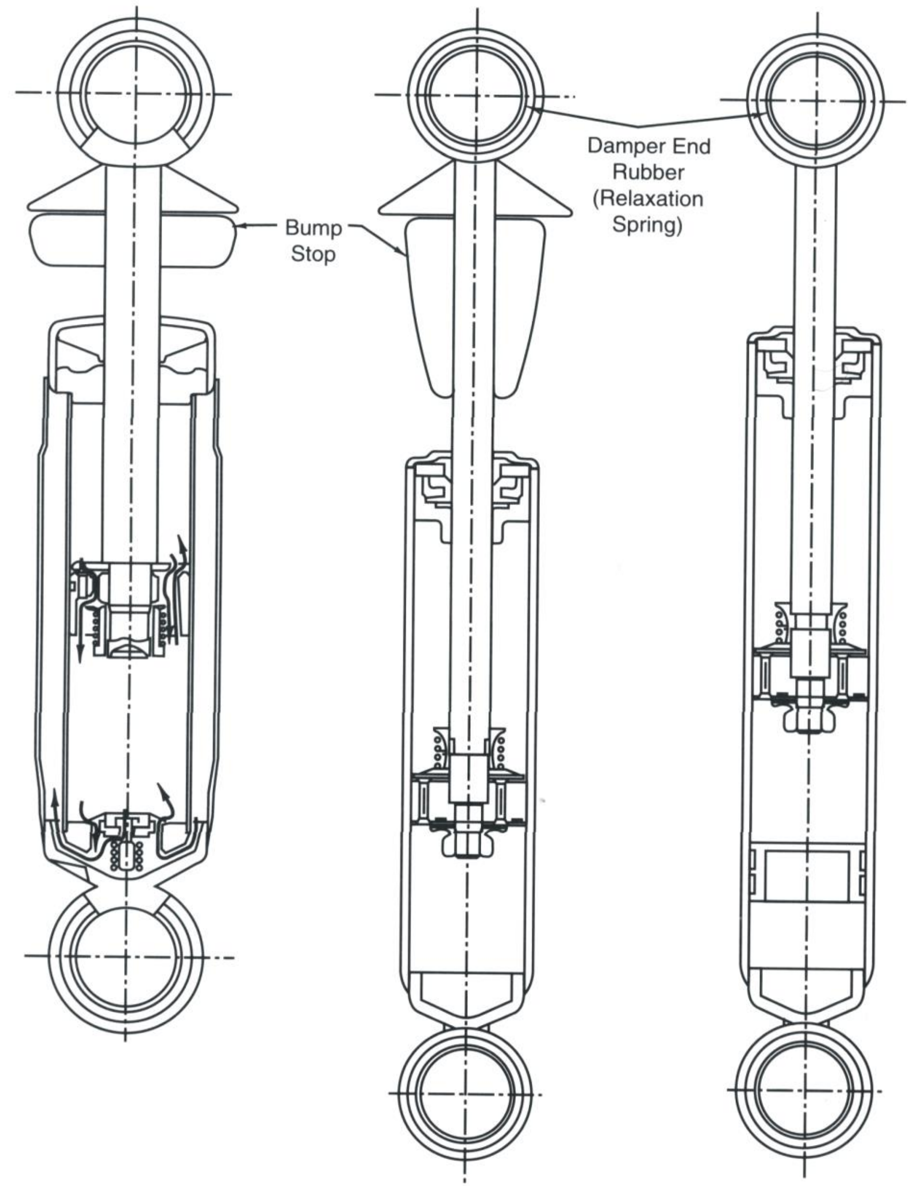


Gillespie Fig 5.20: Twin tube and mono tube

Shock absorber

Milliken Fig 22.23

(a) Twin tube
(b) Mono tube
(c) Mono tube with floating piston



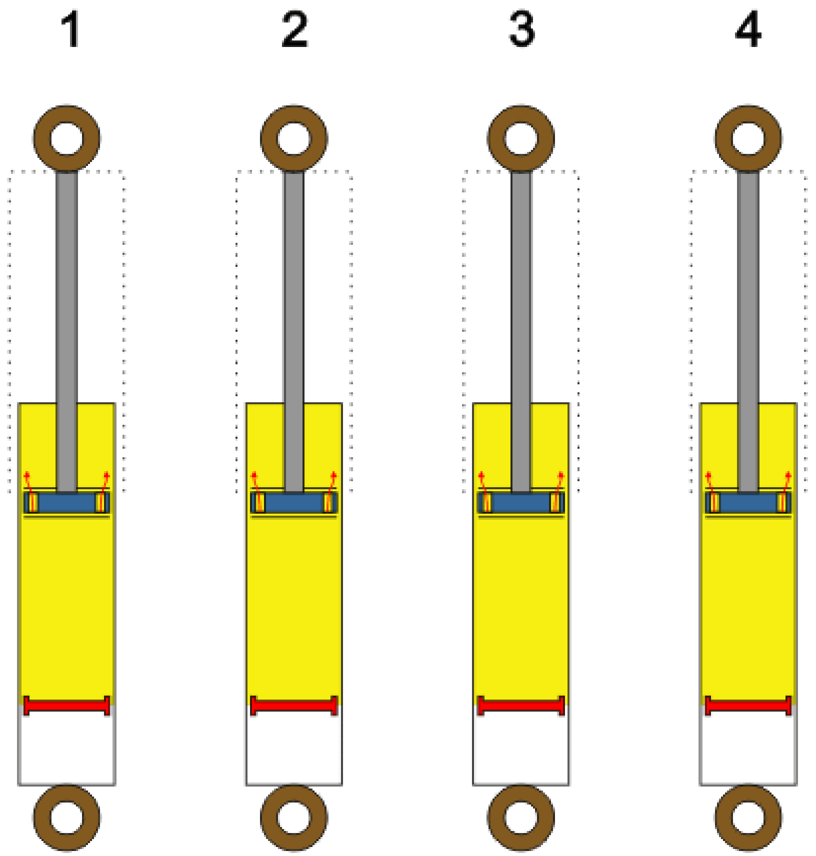
(a) Dual Tube Damper (b) Monotube Damper (c) Monotube Damper with Floating Piston

Shock absorber - damper

- Twin-tube shock absorbers :
  - The inner tube serves as a working cylinder
  - The outer cylinder serves as a reservoir to store the excess fluid that results from the difference in volume between the two sides of the piston when the rod moves up or down.

- Single tube dampers,
  - The excess fluid is accumulated in a free piston with pressurized gas.
  - Another technological solution is to use a working fluid containing a mixture of liquid and gas bubbles to absorb the difference in volume.

Shock absorber - damper



Work principle of a single tube with a floating piston

Shock absorber - damper

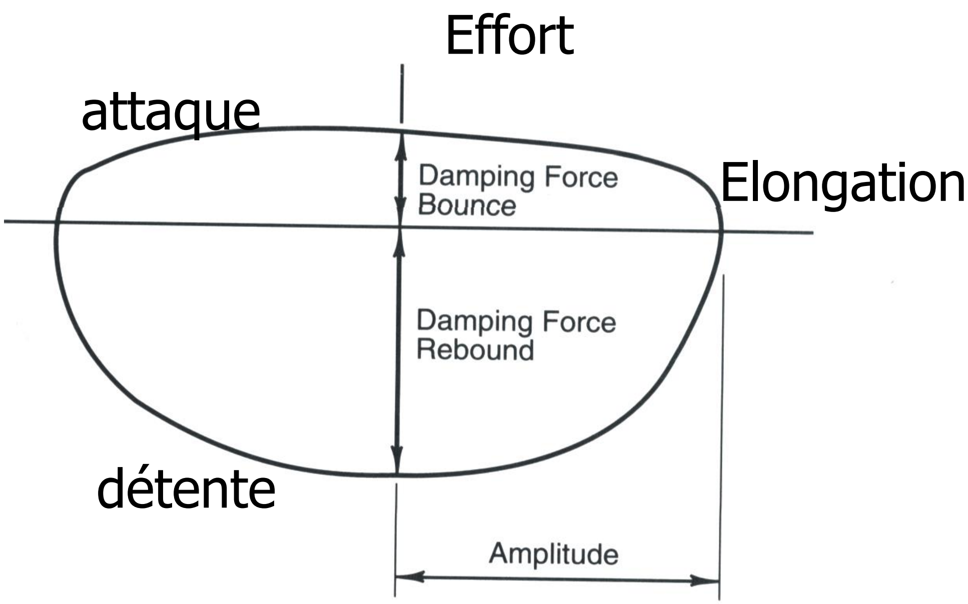
- Twin tube shock absorbers
  - Are more compact
  - Can be used in areas where there is less space.
  - Much more resistant to the penetration of small stones ejected by the wheels.

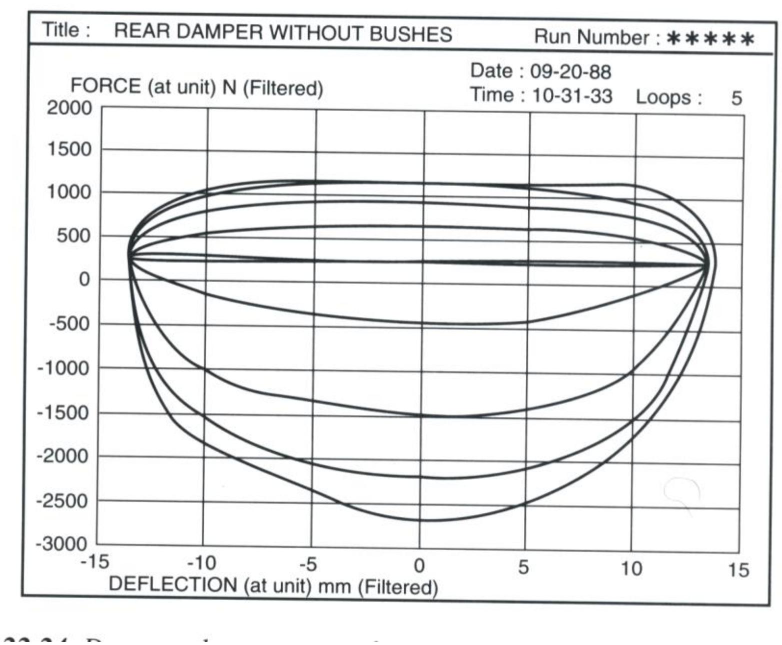
- Single tube shock absorbers
  - Improved energy dissipation capacity: single tubes dissipate heat directly through the wall of the tube containing the working fluid
  - Longer length: they often cannot fit in places where volume is limited.
  - The tube guiding the piston can be more easily damaged by small stones and dusts that would enter through the seal around the rod.

Shock absorber - damper

- Modern shock absorbers are double-acting systems with a damping characteristics that is generally lower in compression than in rebound for comfort reasons
- In a compression impact, the damping force tends to increase the acceleration of the suspended mass, whereas in extension (rebound) more dissipation force is necessary to dissipate the energy accumulated in the spring.
- No symmetric characteristics of shock absorber with respect to the compression/extension speed.
- The damping coefficient is defined as the slope of the characteristic curve.
- Usually a ratio of 2 or 3 to 1 for extension and compression.

Shock absorber - damper

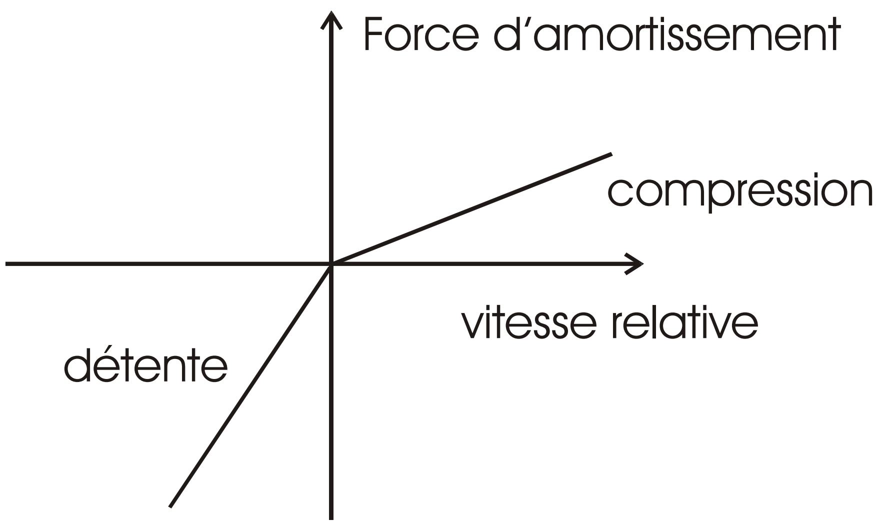


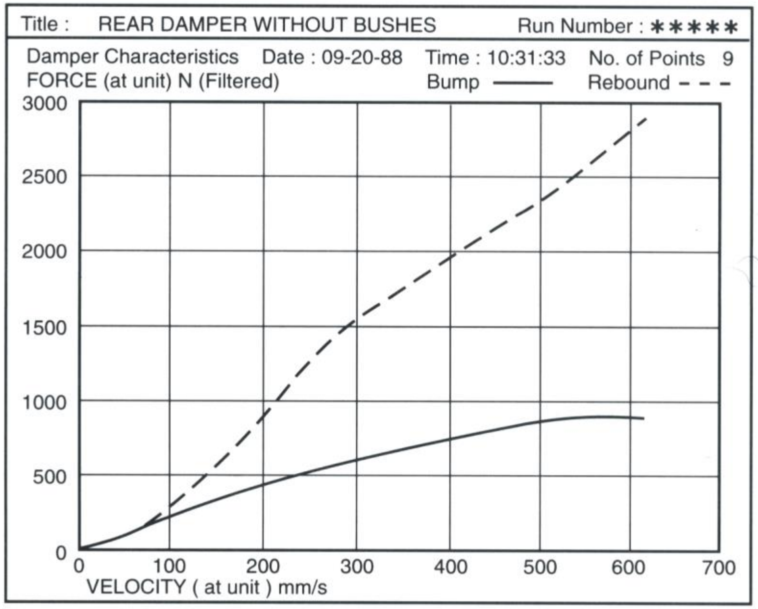


Milliken Fig 22.25: Damper characteristic. Single loop of classical measurement

Milliken Fig 22.24: Damper characteristics, forces vs deflection measured

Shock absorber - damper



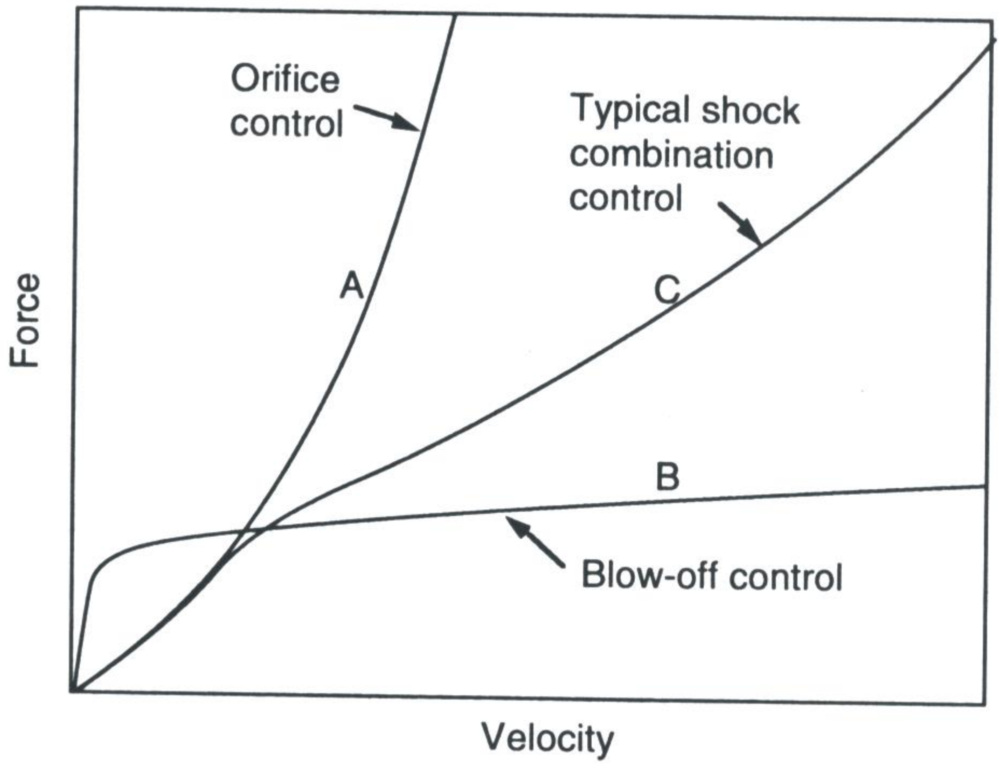


Milliken Fig 22.26: Damper characteristic plotted against velocity

Shock absorber - damper

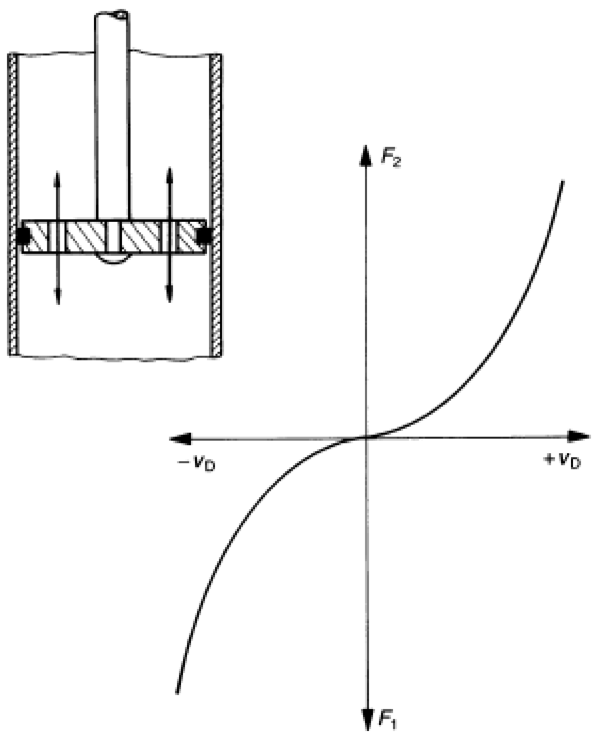
- The damping characteristics are achieved by a cumulative combination of damping functions in the ports and valves with controlled opening by pre-compressed springs.
- This allows a very wide range of shapes and adjustment of the damping force curves to be achieved depending on the extension or compression speed.
- For example, at low speed, damping is achieved by the orifices
- When the fluid pressure reaches a sufficient value, it opens the other pre-calibrated valves.
- A softening of the damping is usually sought for high speeds.

Shock absorber - damper

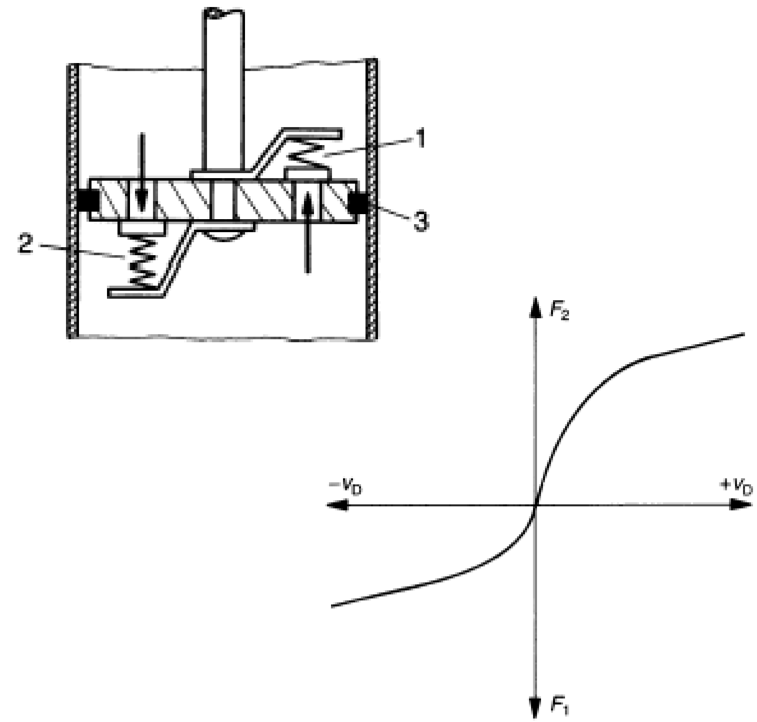


Gillespie Fig 5.21 : Adjustment of damping characteristics by combining port and valve openings

Shock absorber - damper



Reimpel et al. Fig 5.35 & 5.36: unshielded holes corresponds to a constant flow: highly progressive damping curve



Reimpel et al. Fig 5.37 & 5.38: Spring loaded valves over large holes : degressive damping curve

Shock absorber - damper

- Damping

$$F = \begin{cases} C_c\,\dot{x} & \text{compression,} \\ C_d\,\dot{x} & \text{extension.} \end{cases}$$

- For sinusoidal signal

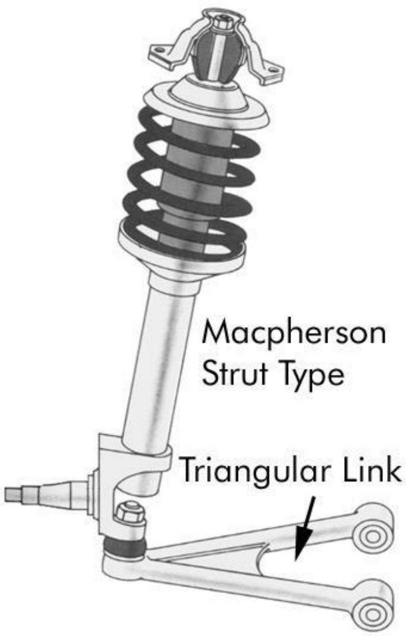
$$x = a \sin \omega t \qquad F = \begin{cases} C_c\,\omega\,a\ \cos\omega t & \text{compression,} \\ C_d\,\omega\,a\ \cos\omega t & \text{extension.} \end{cases}$$

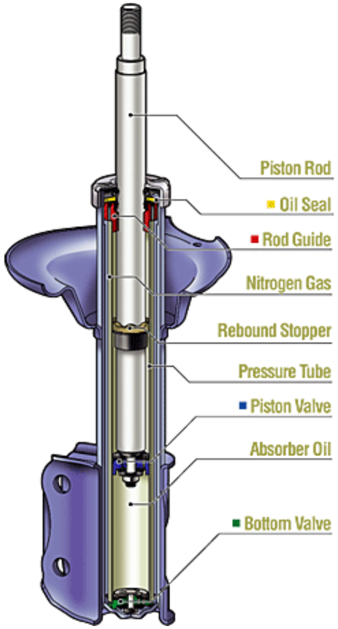
- Energy dissipation

$$\begin{cases} \mathcal{T}_c = \frac{1}{2}\,\pi\,C_c\,\omega\,a^2 & \text{compression,} \\ \mathcal{T}_d = \frac{1}{2}\,\pi\,C_d\,\omega\,a^2 & \text{extension.} \end{cases}$$

Mc Pherson struts and struts dampers

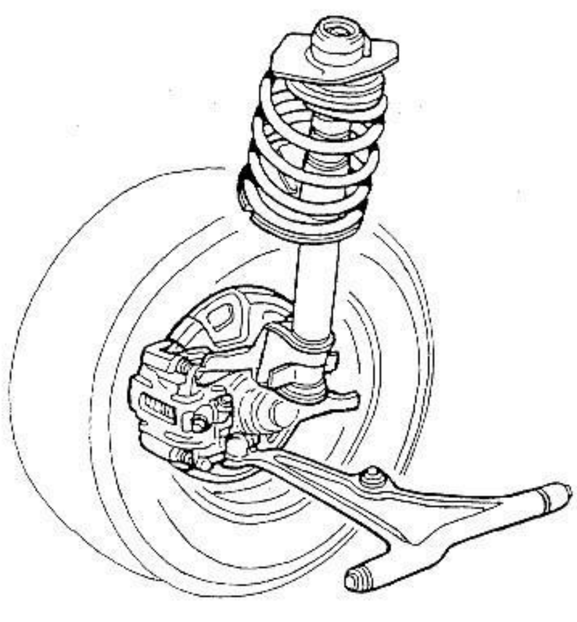
- Mc Pherson struts ensure several functions: damping vertical motion but also carrying and controlling the wheel path.
- The piston rod can absorb longitudinal and lateral forces replacing the upper suspension link including

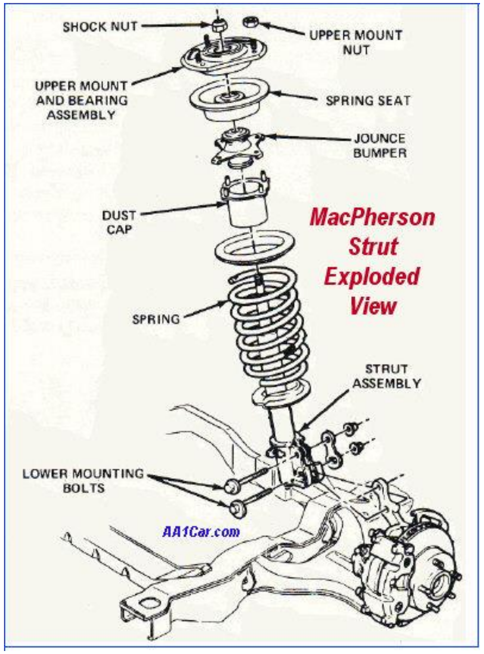




Mc Pherson struts and struts dampers

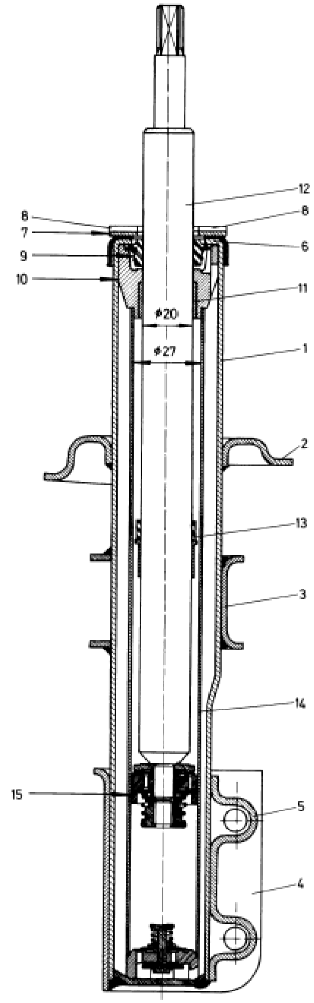
- Mc Pherson struts are divided into
  - Struts for which the outer tube is solidly fixed to the steering knuckle
  - Struts which are bolted to the steering knuckle





Mc Pherson struts and struts dampers

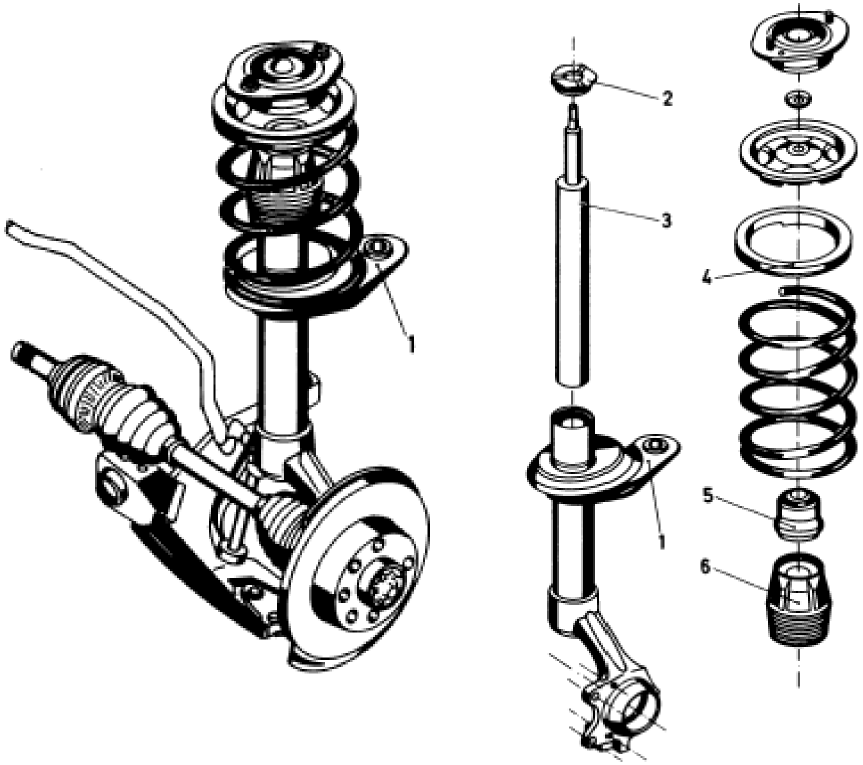
- The suspension strut operates on the twin-tube principle. It operates in the same way as non pressurized twin-tube damper.
- In order to have a sufficient minimum bearing in the fully jounced condition, the jounce stop (13) is set high.
- PTFE coated guide (11) reduces friction.



Reimpel et al. Fig 5.54: Mc Pherson strut of Fiat Panda by Monroe

Mc Pherson strut

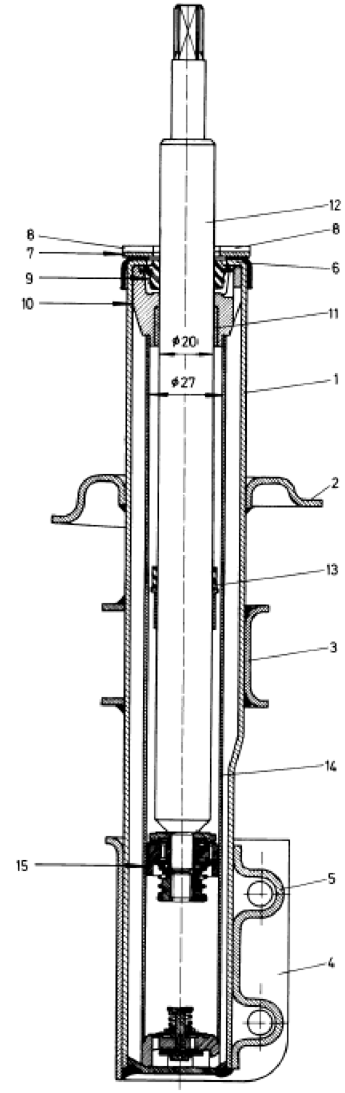
- Mc Pherson strut of Opel/Vauxhall. The outer tube is press fitted to the steering knuckle
- The shock absorber (3) ensuring the damping is inserted into the carrier tube and screwed together. This is the cartridge design.
- As the steering knuckle is press fitted to the steering knuckle, a screwed cap is necessary for exchanging the damper cartridge.



Reimpel et al. Fig 5.52 & 5.53: Mc Pherson strut front drive axle of Opel / Vauxhall

Mc Pherson strut

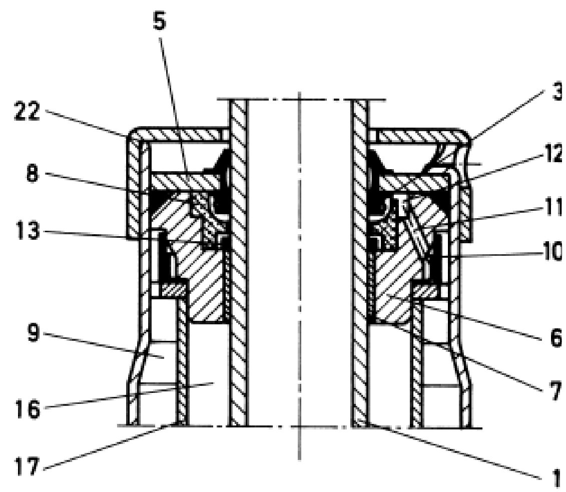
- Mc Pherson strut of the Fiat Panda uses a wet suspension strut on which the damper part is directly mounted into the carrier tube
- Wet suspension struts are better at conducting heat away from the damper.
- When are they detachable, they present the advantage that the damper can be easily exchanged.

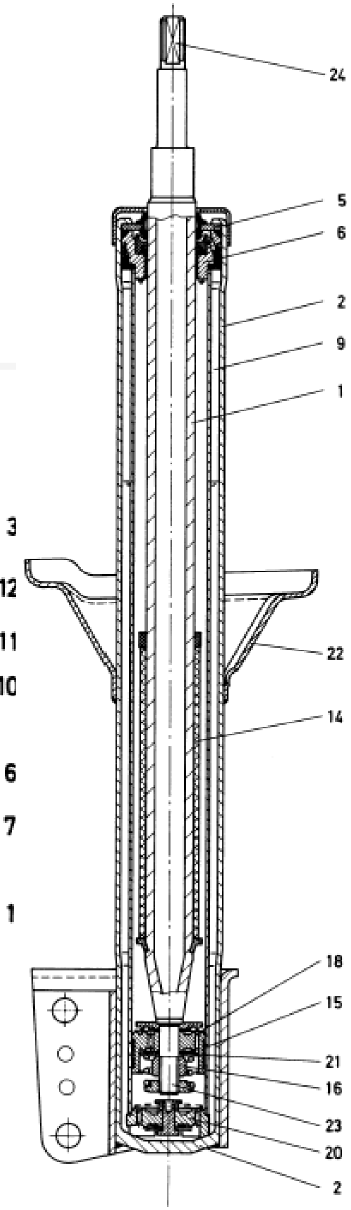


Reimpel et al. Fig 5.54: Mc Pherson strut of Fiat Panda by Monroe

Mc Pherson strut

- Low pressure twin tube Mc Pherson strut by Sachs.
- The strut is drawn with the piston rod 1 fully in.
- It uses also the concept of a wet suspension strut on which the damper part is directly mounted into the carrier tube.





Reimpel et al. Fig 5.55 & 5.56: Mc Pherson strut by Sachs