

Service.



Self-Study Programme 275

The Phaeton Air Suspension with Controlled Damping

Design and Function



Contact between the road and the vehicle is established by the components of the suspension system.

Requirements for maximum comfort for vehicle occupants, optimum driving safety and minimum noise transmission from the road to the vehicle interior place heavy demands on the suspension system's designers.

Vehicles expected to meet high standards of comfort therefore represent a special challenge which entails reaching a compromise between the various requirements on the suspension system.

One solution is a controlled running gear comprising ...

- a full load-bearing self-levelling suspension system 4-Corner Air Suspension (**4CL**)

in combination with

- **Continuous Damping Control (CDC)**.

Control takes place based on the "skyhook control strategy".

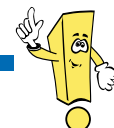
A running gear design of this type is being used for the first time by Volkswagen in the Phaeton.

The system is described in this Self-Study Programme.



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NEW



**Important
Note**



This Self-Study Programme explains the design and function of new developments! The contents will not be updated.

Please refer to the relevant Service Literature for up-to-date inspection, adjustment and repair instructions.



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Basics of spring/damper system

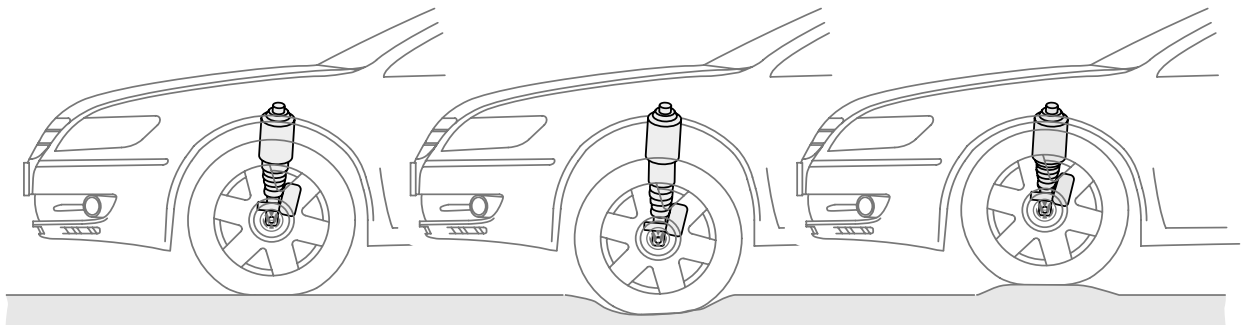


Vehicle suspension

When moving, external forces and impacts act on the vehicle, producing movements and vibrations in the direction of the vehicle's three spatial axes (transverse, longitudinal and vertical axes). The aim is to minimise the impact of these forces on driving comfort, driving safety and operating safety by striking a good balance between the suspension system and the vibration damping system.

A basic distinction can be drawn between the suspension system and the vibration damping system.

The task of both systems is to absorb and reduce the forces produced and, if possible, to keep them away from the vehicle body.



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Driving safety

They maintain continuous contact with the road, which is important for steering and braking.

Driving comfort

Harmful or unpleasant vibrations are kept away from the passengers and the cargo remains intact.

Operational safety

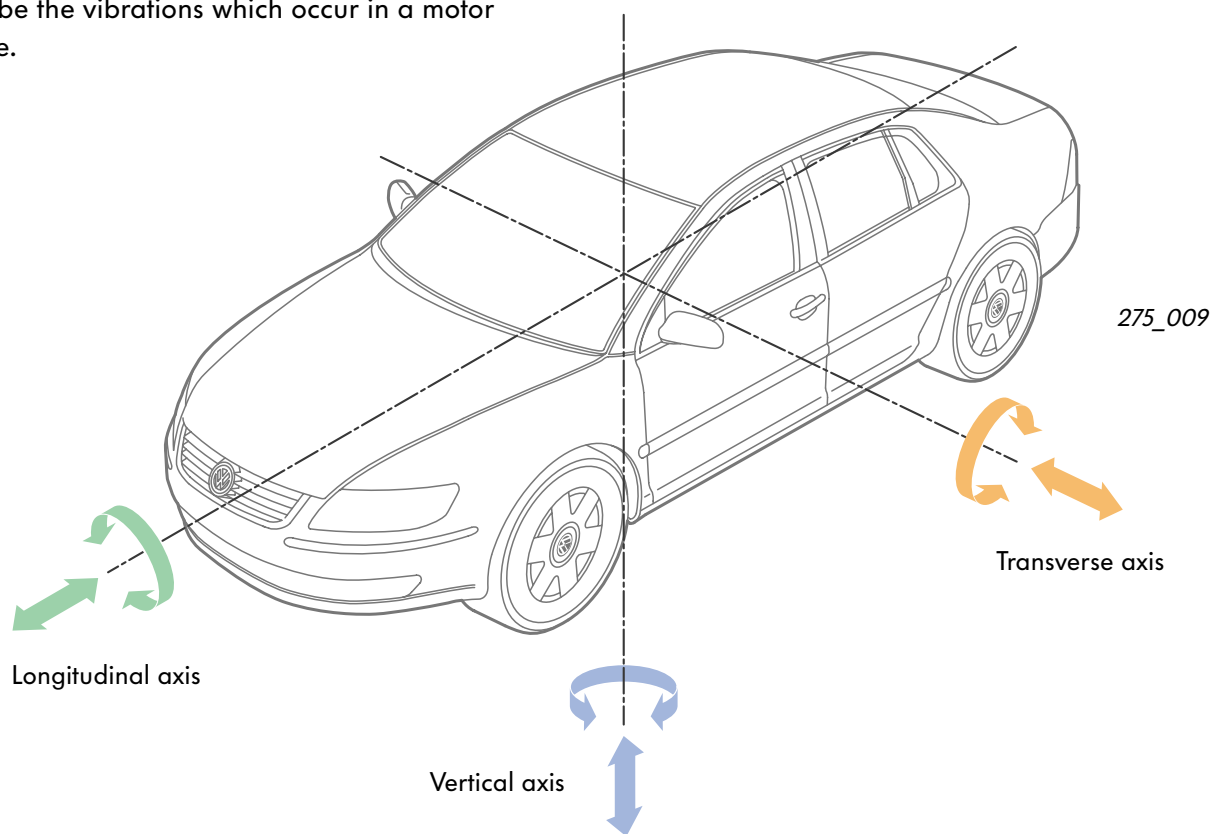
The vehicle body and assemblies are protected against high impact and vibration loads.



Types of vibration acting on the motor vehicle

Apart from the upward and downward movement of the vehicle, vibrations occur about and in the direction of the three spatial axes (longitudinal, transverse and vertical axes) of the vehicle while travelling.

The following terms are generally used to describe the vibrations which occur in a motor vehicle.



Twitching Roll

Vibration in the direction of the longitudinal axis (shudder)
Torsional vibration about the longitudinal axis (snaking, rolling, tilting)

Drifting Pitching

Vibration in the direction of the transverse axis
Torsional vibration about the transverse axis (pitching)

Bouncing Yawing

Vibration in the direction of the vertical axis (impacts, vertical vibration)
Torsional vibration about the vertical axis

Basics of spring/damper system



Vibrations

The tyres, suspension elements, body and vehicle seat forms a system which is capable of vibration, i.e. when an external force such as a bump on the road acts on this system, it oscillates back and forth about its position of rest. These vibrations repeat themselves until they die away due to inner friction.

The vibrations are defined by their amplitude and frequency.

Intrinsic body frequency is self-levelling adjustment button.

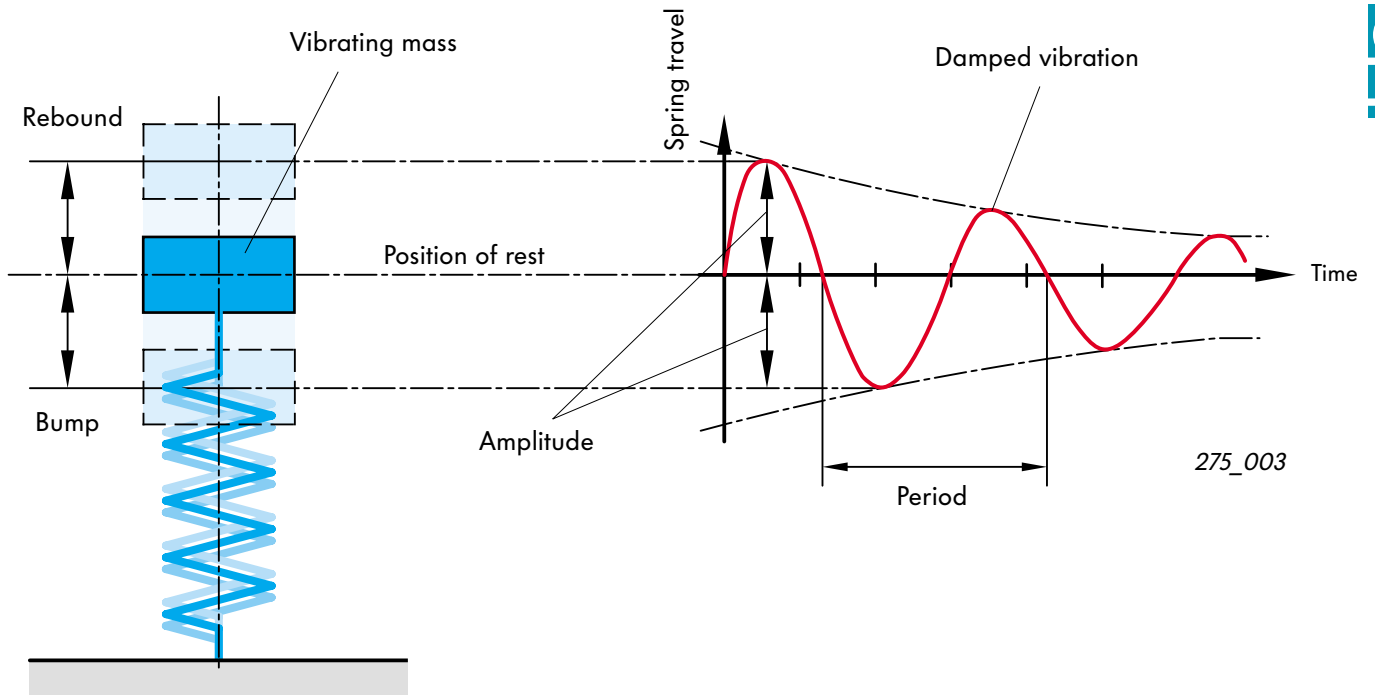
An intrinsic body frequency of less than 1 Hz can cause nausea, depending on one's predisposition.

Frequencies above 1.5 Hz are detrimental to driving comfort, and frequencies higher than 5 Hz are perceived as shocks.

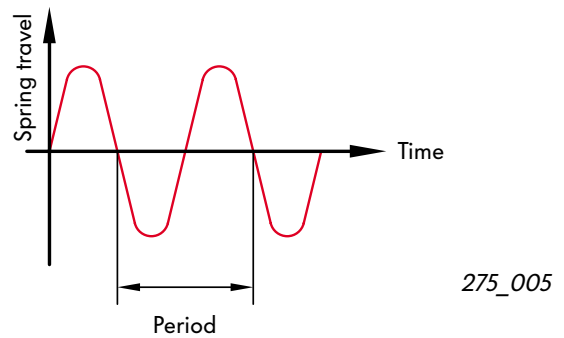
Intrinsic body frequency is essentially determined by the spring rate and the size of the sprung mass.

Definitions:

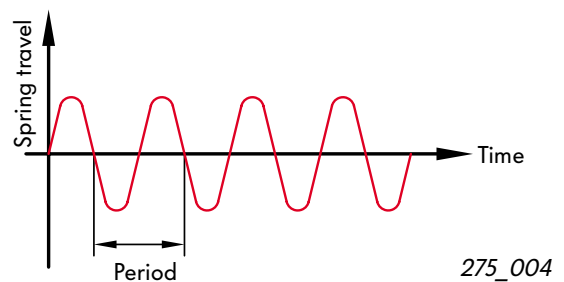
Vibration	Upward and downward movement of a mass (e.g. bump and rebound of the vehicle body)
Amplitude	Maximum distance of an oscillating mass from its position of rest (vibration displacement, spring travel)
Period	Duration of a single, complete vibration
Frequency	Number of vibrations (periods) per second 1 vibration per second = 1 Hz (Hertz)
Intrinsic frequency	Number of free vibrations of the sprung mass per second
Resonance	Occurs when a system capable of vibration requires a minimum of excitation to reach maximum amplitudes (rolling as intrinsic frequency approaches).
Shock abs.	Describes the decay of vibrations



Larger masses or softer springs produce a lower intrinsic body frequency with increasing spring travel (amplitudes).



Smaller masses or firmer springs produce higher intrinsic body frequencies with decreasing spring travel.



The intrinsic wheel frequency (intrinsic frequency of unsprung masses) is approx. 10 to 16 Hz.

Basics of spring/damper system



Suspension system

The tyres, the springs and the seats with their cushioning effect collectively form the vehicle's suspension system.

As key components of this system, the spring damper elements are the link between the wheel suspension and the vehicle body.

Suspension elements include:

- steel springs (leaf springs, helical springs, torsion bar springs),
- air springs (gaiter springs and toroidal bellows springs),
- hydropneumatic springs (piston and diaphragm type hydraulic accumulators),
- rubber springs,
- anti-roll bars or
- combinations of these elements.

On the vehicle, a distinction is made between **unsprung masses** (wheels, brakes, final drive shafts, wheel bearings and wheel bearing housings) and

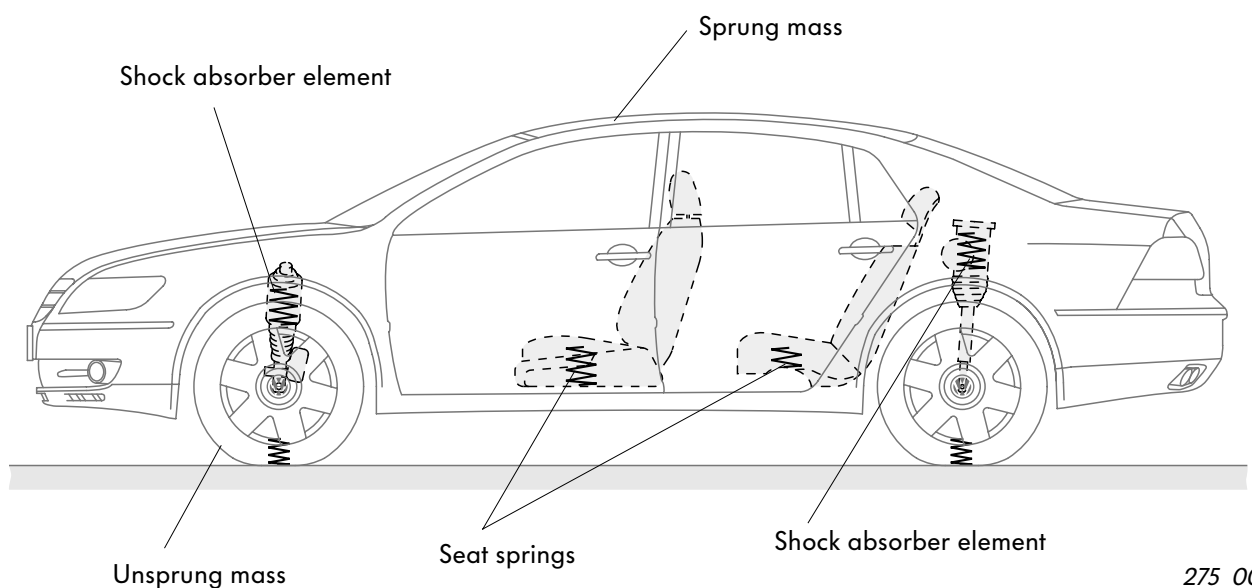
sprung masses (vehicle body with suspension and drive train parts).

The general aim of vehicle tuning is to keep unsprung masses to a minimum.

This minimises interference with the vibrational characteristics of the vehicle body and improves suspension response (and also driving comfort).

The following components contribute to reducing unsprung masses:

- light-alloy suspension parts,
- light-alloy brake calipers,
- light-alloy hollow-spoke wheels and
- weight optimised tyres.



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Spring characteristics

The characteristics of a spring are obtained by applying a force of increasing magnitude to a spring in a spring press and plotting the change in spring travel against force applied.

The spring rate c is calculated from the ratio of change in force and change in travel.

$$c = \text{force} : \text{distance} \text{ [N/cm]}$$

A "firm" spring has a steeper spring characteristic than a "soft" spring.

If the spring rate is constant over the full distance travelled by the spring, then the spring has a linear characteristic.

If the spring rate increases over the distance travelled by the spring, then the spring has a "progressive" characteristic.

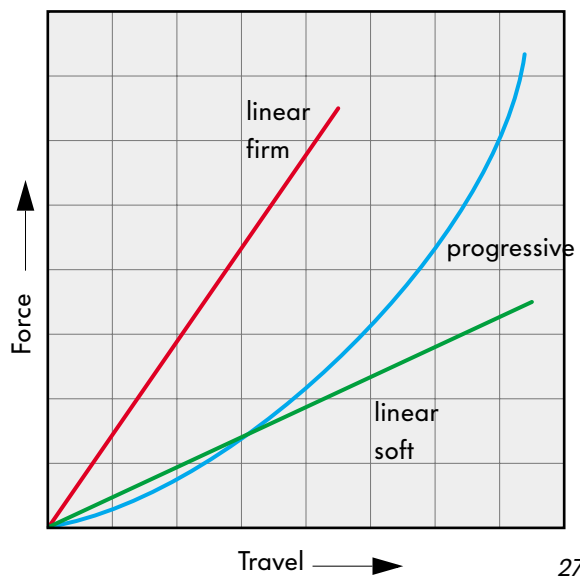
The characteristic of a coil spring can be influenced as follows:

- the spring diameter
- the spring wire diameter and
- the number of windings in the spring

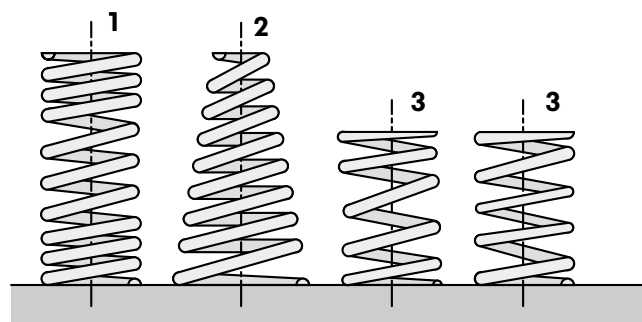
Characteristic features of springs with progressive characteristic include:

- uneven winding pitch (1),
- conical winding shape (2),
- conical wire diameter (3) and
- combinations of several suspension elements.

Examples of spring characteristics



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Basics of spring/damper system



Spring travel

The necessary spring travel s_{tot} of a vehicle without self-levelling suspension comprises the static bump s_{stat} and the dynamic spring travel s_{dyn} resulting from vehicle vibration when the vehicle is fully laden and unladen.

$$s_{\text{tot}} = (s_{\text{stat}}(\text{full}) - s_{\text{stat}}(\text{unladen})) + s_{\text{dyn}}$$

The static spring travel s_{stat} is the distance which the spring is compressed when stationary depending on payload. This is the difference between the static compression of the fully laden vehicle $s_{\text{stat}}(\text{full})$ and the static compression of the unladen vehicle $s_{\text{stat}}(\text{unladen})$.

$$s_{\text{stat}} = s_{\text{stat}}(\text{full}) - s_{\text{stat}}(\text{unladen})$$

Where a spring characteristic is flat (soft spring), the difference, and so the static compression, between the unladen and fully laden vehicle is large.

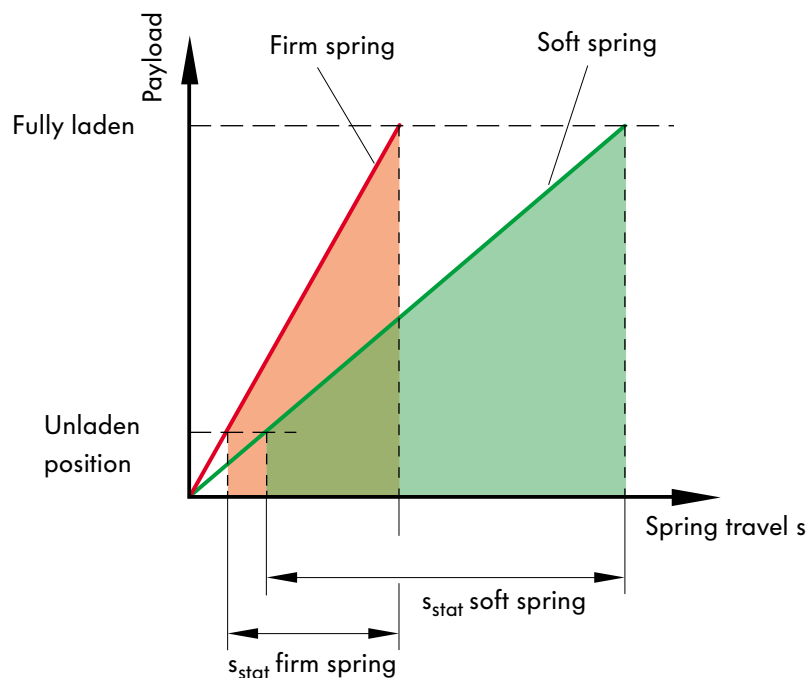
Where spring characteristic has a steep gradient (firm spring), the static compression is small.

Definition:

The **unladen position** is the compression of the spring when the serviceable vehicle (incl. full tank of fuel, tool kit and spare wheel without driver) is standing on its wheels.

The **design position** is the position which the unladen vehicle adopts when additionally laden with three persons each weighing 68 kg.

The **controlled position** is the position in which the vehicle is held by the self-levelling suspension of the air suspension system, regardless of payload.



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Basics of air suspension

Air suspension

The air suspension is a variable-height vehicle suspension system and can be combined with controllable vibration damper systems.

It is relatively easy to implement a self-levelling air suspension system.

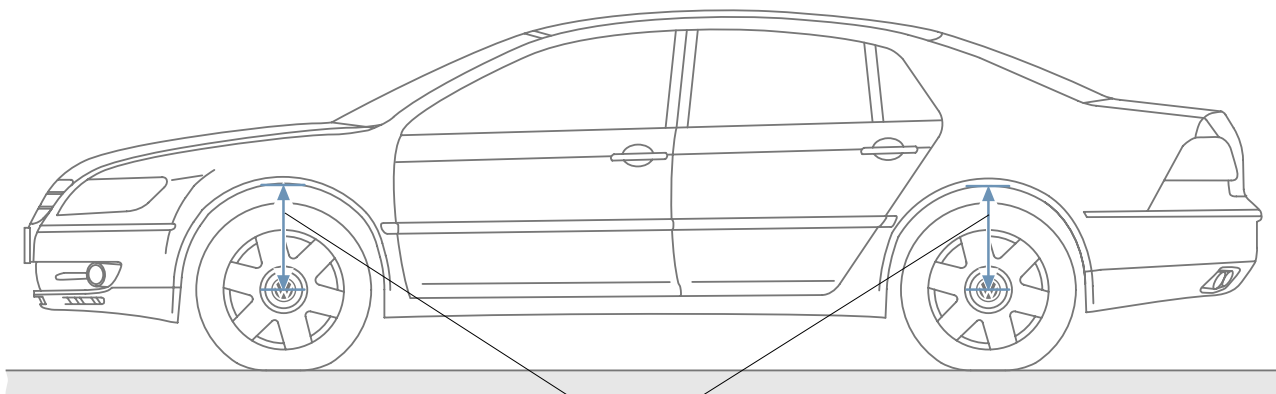
The self-levelling suspension keeps the vehicle body at constant level (controlled position = constant distance between centre of wheel and lower edge of wing), i.e. at a pre-defined ground clearance.

The vehicle level is controlled by adapting the pressure acting on the air springs and the associated change of air volume in the air spring struts.

Static compression is always set to $s_{\text{stat}} = 0$, regardless of payload.

The advantages of a self-levelling suspension are:

- the vehicle can be sprung comfortably
- the static level of the vehicle is constant, regardless of payload
- reduced tyre wear
- no payload-dependent change of drag coefficient c_d
- maximum rebound and bump travel are maintained in all load states
- full ground clearance is maintained (even at maximum payload) and
- no changes of toe and camber due to changes in payload.



Controlled position

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Basics of air suspension

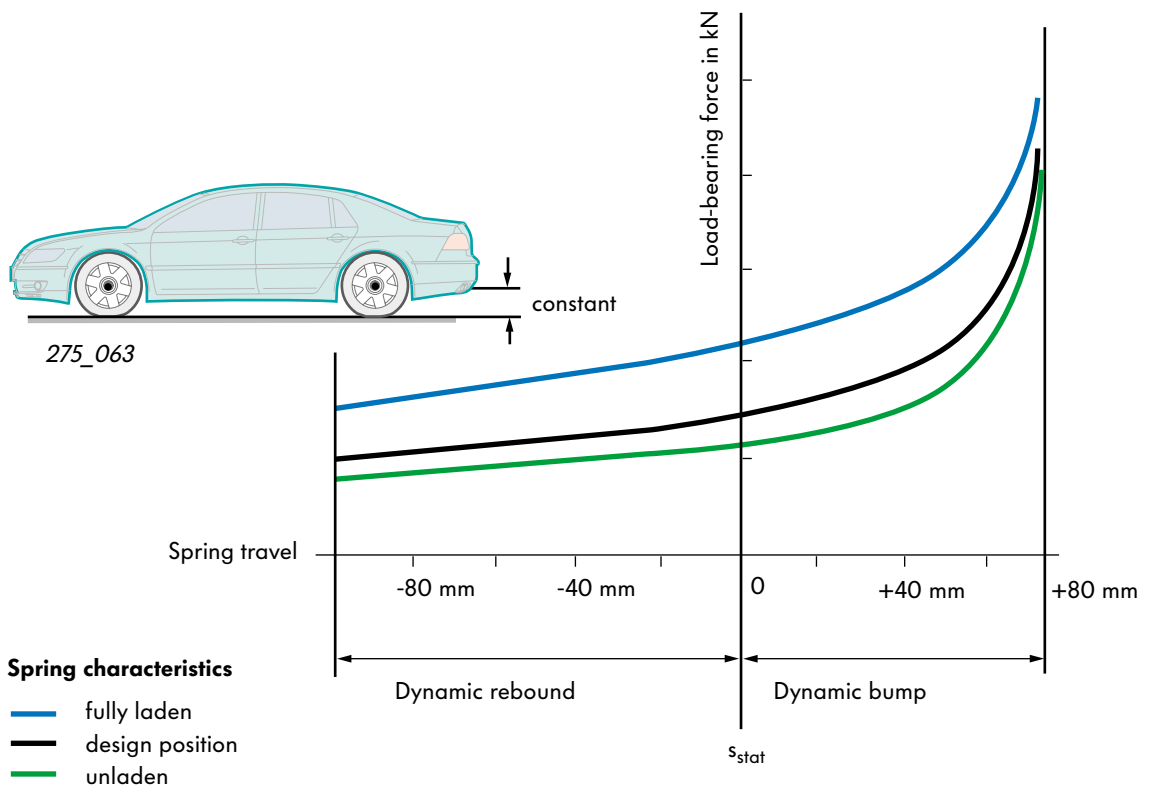
In addition to the basic advantages of variable-height, full load bearing air suspension as described above, it is also possible to set different vehicle level heights by means of the air suspension.

Three level heights have been implemented on the Phaeton:

- the normal suspension level
- a raised suspension level for poor road surfaces or rough terrain, and
- a low suspension level that is set automatically while travelling at high motorway speeds



"Full load-bearing" means that only air springs are used as load-bearing spring elements on all wheels. Combined suspension systems, which consist of a combination of hydraulically or pneumatically controlled steel and gas struts, are described as "partially load-bearing".



Characteristics of air springs

Spring force/spring rate

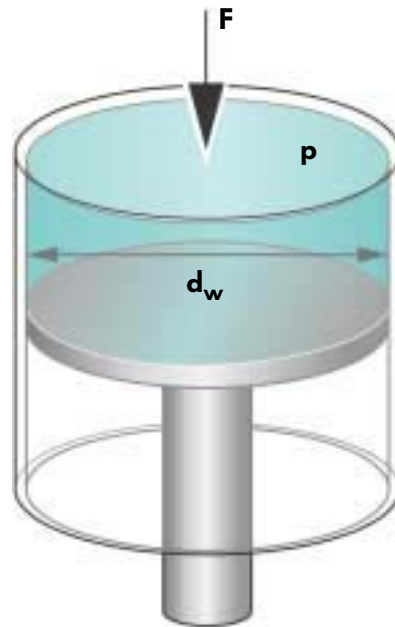
The spring force **F** (load-bearing force) of an air spring is defined by its geometric dimensions (the effective circular area **A_w**) and the excess pressure acting on the air spring **p**.

$$F [N] = A_w [cm^2] \times p [N/cm^2]$$

The effective circular area **A_w** is defined by the effective circle diameter **d_w**.

$$A_w [cm^2] = \pi \times (d_w)^2 : 4 [cm^2]$$

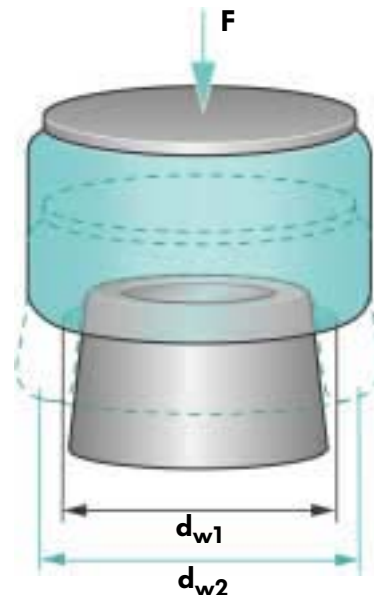
$\pi = 3.14...$ constant "pi" for calculating the circle area



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In a piston in the cylinder, the piston diameter corresponds to the effective circle diameter.

The effective diameter of the air spring gaiter is defined by the diameter at the lowest point of the gaiter (**d_{w1}** rebounded and **d_{w2}** compressed). Since this effective diameter **d_w** is squared in the equation for **A_w**, minor changes in this diameter lead to relatively large changes in the area of the circle, and so the load-bearing force of the air spring.



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Basics of air suspension

The load-bearing force of the spring can be adapted to the load situation by simply changing the effective internal pressure p in the air spring.

The different pressures - depending on payload - result in different spring characteristics or spring rates.

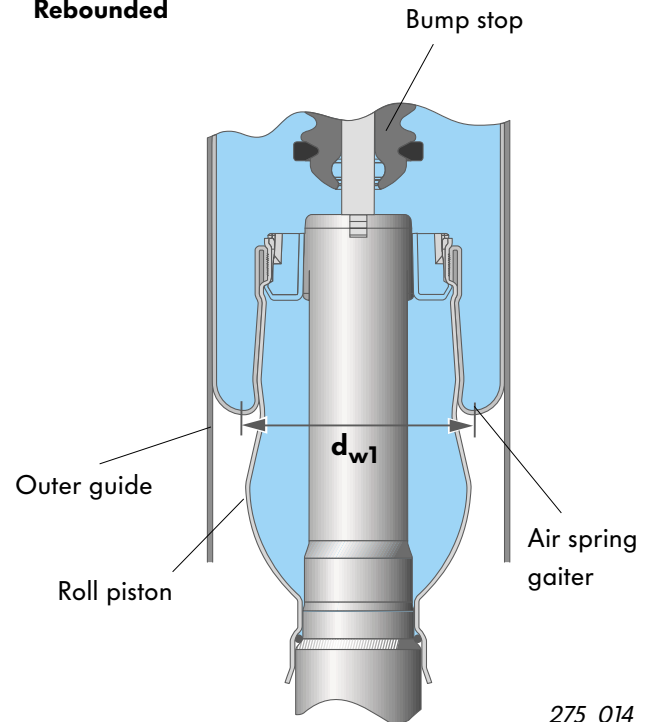
The spring rates do not change in direct proportion to total body weight.

The intrinsic body frequency, a key factor in handling performance, remains almost constant.

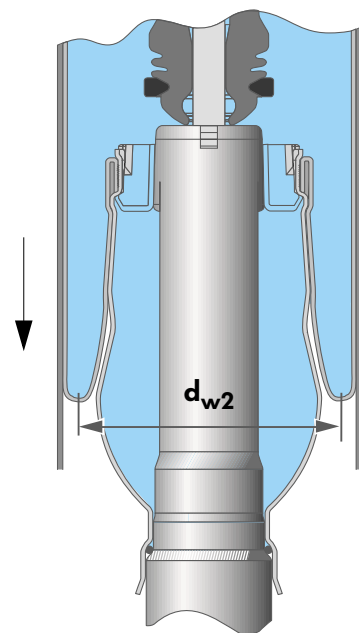
Spring compression changes the effective air spring gaiter diameter (d_w from d_{w1} to d_{w2}) because it rolls back on the roll piston.

Example showing the effect of roll piston contour on effective diameter d_w

Rebounded



Compressed



Spring characteristic

In principle, the spring characteristic of an air spring for cylindrical pistons is progressive.

The spring characteristic curve (steep or flat) is governed by the air spring volume.

The existing air volume is compressed by dynamic compression. Assuming that bump travel is constant, the pressures in a low volume system rise more rapidly than in a system with a large air spring volume.

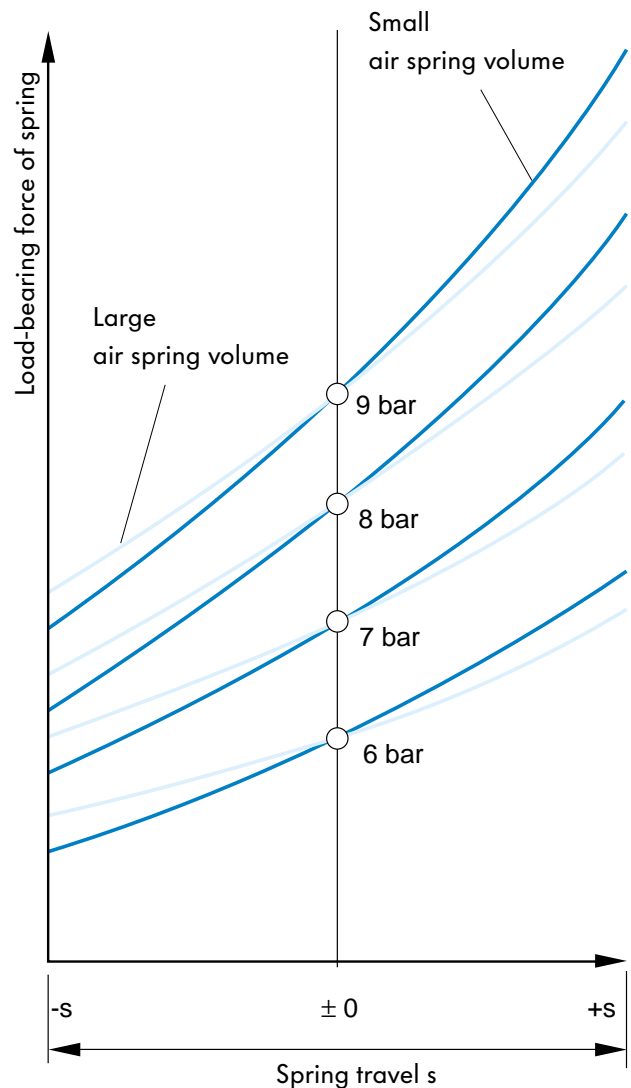
A flat spring characteristic curve (soft spring) is produced by a large air spring volume. A steep curve (firm spring), on the other hand, is produced by a small air spring volume.

The characteristic curve can be influenced by the roll piston contour.

Modifying the contour of the roll piston changes the effective diameter, and so the load-bearing force (spring force), of the air spring.

An air spring can be tuned for the required application by adjusting the following parameters:

- size of effective area A_w
- size of air spring volume (air volume) and
- outer contour of roll piston.



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Basics of air suspension

Design of an air spring

A distinction can be made between two air spring variants:

- "partial load-bearing" and
- "full load-bearing"

In partial load-bearing variants, a combination of steel and gas struts generates the load-bearing force of the air spring.

A full load-bearing variant as used in the Phaeton exists only when air springs function as load-bearing spring elements.

The air spring basically comprises

- an upper housing with an outer guide
- the air spring gaiter
- the roll piston (lower housing)
- an auxiliary accumulator (where required), and
- the integrated vibration damper (shock absorber)

Gaiter

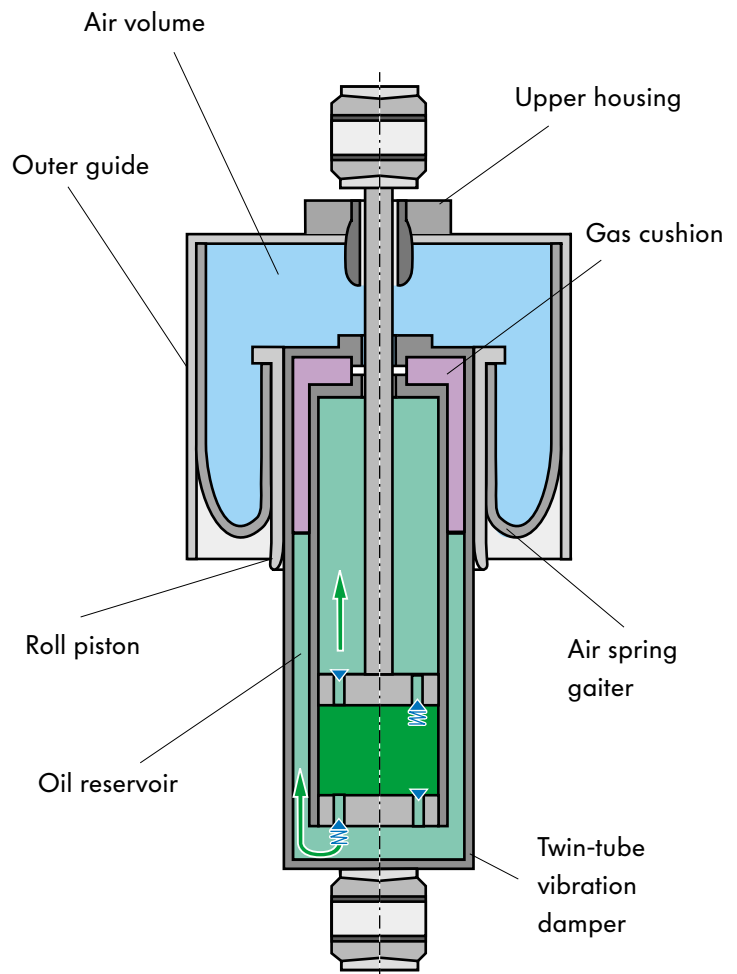
The air spring gaiter comprises a special, high-quality multi-layer elastomer material with fabric inlays of nylon cord as reinforcing material. The reinforcing material absorbs the forces arising in the air spring.

The inner overlay is specially designed for air tightness.

A special combination of individual layers lends good rolling characteristics to the air spring gaiter and precise response to the suspension.

The materials are resistant to all external influences in a temperature range from $-35\text{ }^{\circ}\text{C}$ to $+90\text{ }^{\circ}\text{C}$.

Example of an air spring strut with outer guide (full load-bearing)



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If the metallic sleeve of the outer guide used to absorb circumferential forces is left out, the air springs are referred to as "externally guided" as opposed to "unguided" air springs.

Basics of the damping system

Vibration damper

The task of the vibration damper (often referred to as the shock absorber) is to reduce the vibration energy of structural and wheel vibrations as rapidly as possible by converting vibration energy to heat.

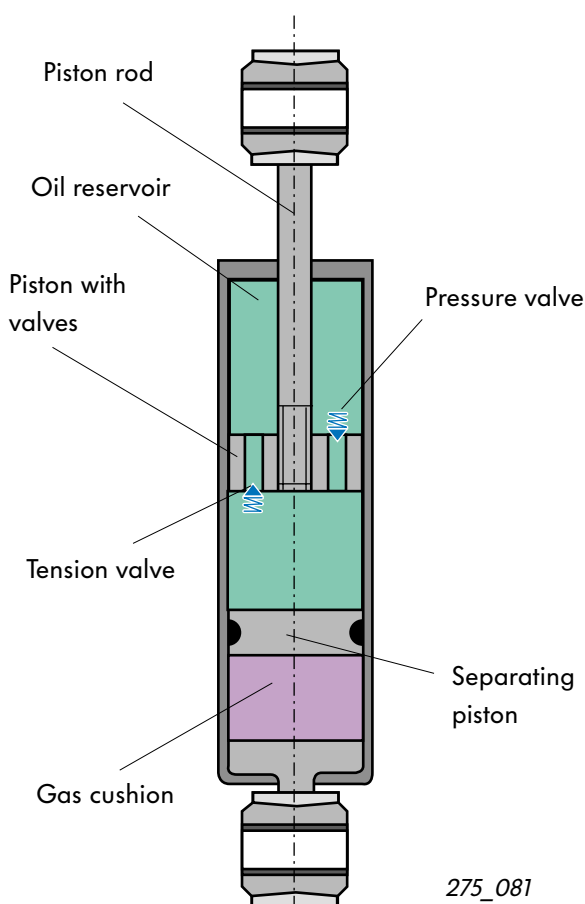
Without vibration dampers, the vibrations introduced into the vehicle would "build up" to the extent that the wheels could lose contact with the road surface. As a result, the vehicle would no longer be steerable.

There are several different types of vibration damper.

Single-tube gas pressure vibration damper

With this damper variant, the working and oil reservoirs are located in a single cylinder (single-tube damper). Changes in oil volume, due to temperature effects and plunging of the piston rod when the springs are compressed, are equalised by the gas in the pressurised gas cushion (approx. 25 to 30 bar).

The damping valves for the compression and tension stages are integrated in the piston.



Schematic diagram of a single-tube gas pressure vibration damper



Basics of the damping system

Twin-tube gas pressure vibration damper

This damper variant has established itself as the standard vibration damper.

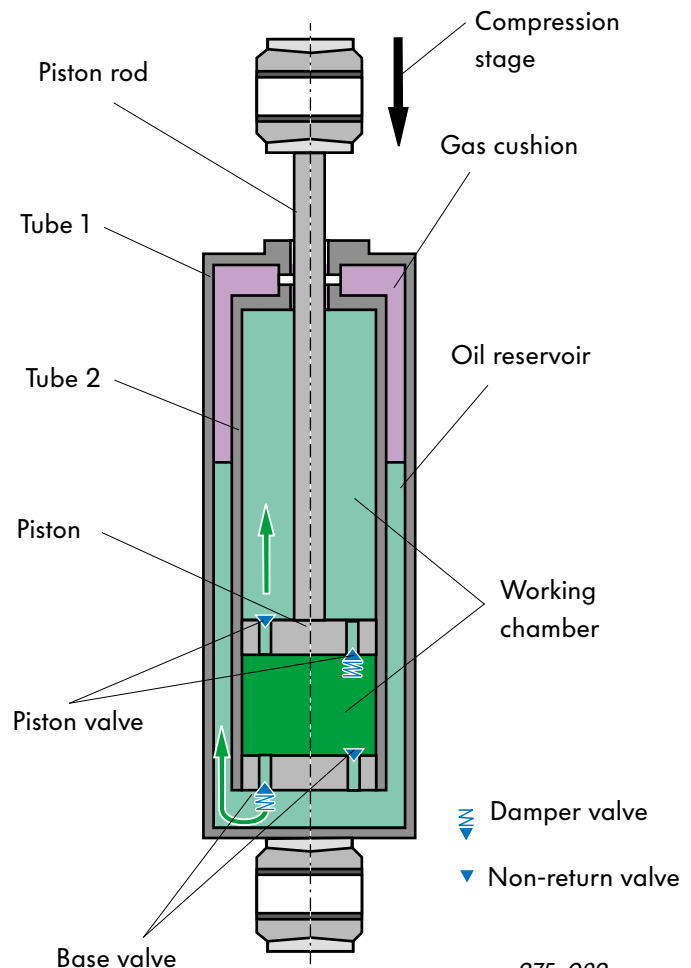
As the name indicates, it consists of two tubes fitted into each other (twin-tube damper). The inner tube acts as the working chamber. It is completely filled with hydraulic fluid. The pistons together with the piston valves and the piston rod move up and down inside the working chamber. The base of the working chamber comprises the base plate and base valves. The outer tube surrounds the oil reservoir. It is only partially filled with oil. There is a gas cushion above the oil filling.

The oil reservoir equalises changes in the volume of oil in the working chamber.

Vibrations are damped by the two damping valve units located on the piston and at the base of the working chamber. They comprise a system of spring washers, coil springs and valve bodies with restrictor bores.

During a bump event (compression stage), damping is defined by the base valve and partly by the flow resistance of the piston.

During a rebound event (tension stage), vibrations are damped by the piston valve alone. This valve produces a defined resistance to the oil as it flows downwards.



Schematic diagram of the twin-tube gas pressure vibration damper (compression stage)

Damper tuning

As regards damping, a distinction is made between the compression stage (bump) and the tension stage (rebound).

The damping force during the compression stage is less than during the tension stage.

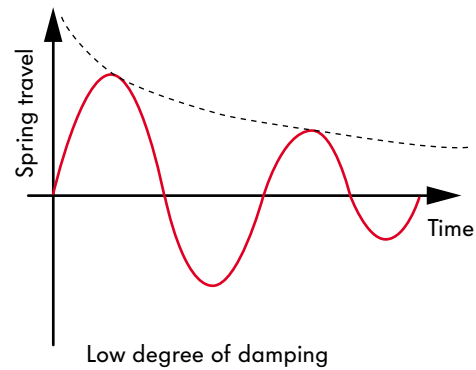
As a result, jolts caused by rough road surfaces are transmitted to a lesser degree to the vehicle. Because the shock absorber tuning is fixed, there is a close relationship between driving comfort and driving safety.

Dampers with adjustable damper tuning and continuous control are fitted to luxury vehicles. The control unit determines within a matter of milliseconds what degree of damping is required and for what wheel.

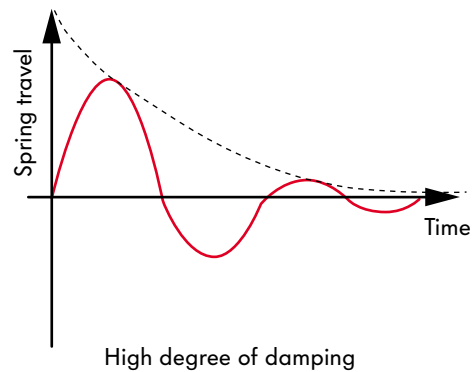
The **degree of damping** indicates how quickly the vibrations must be reduced. It is dependent on the damping force of the vibration damper and the size of the sprung masses.

Increasing the sprung mass reduces the degree of damping, i.e. the vibrations are slowly reduced.

A reduction in sprung masses increases the degree of damping.



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Basics of the damping system

Damping force

The damping force of a vibration damper is determined using a test apparatus.

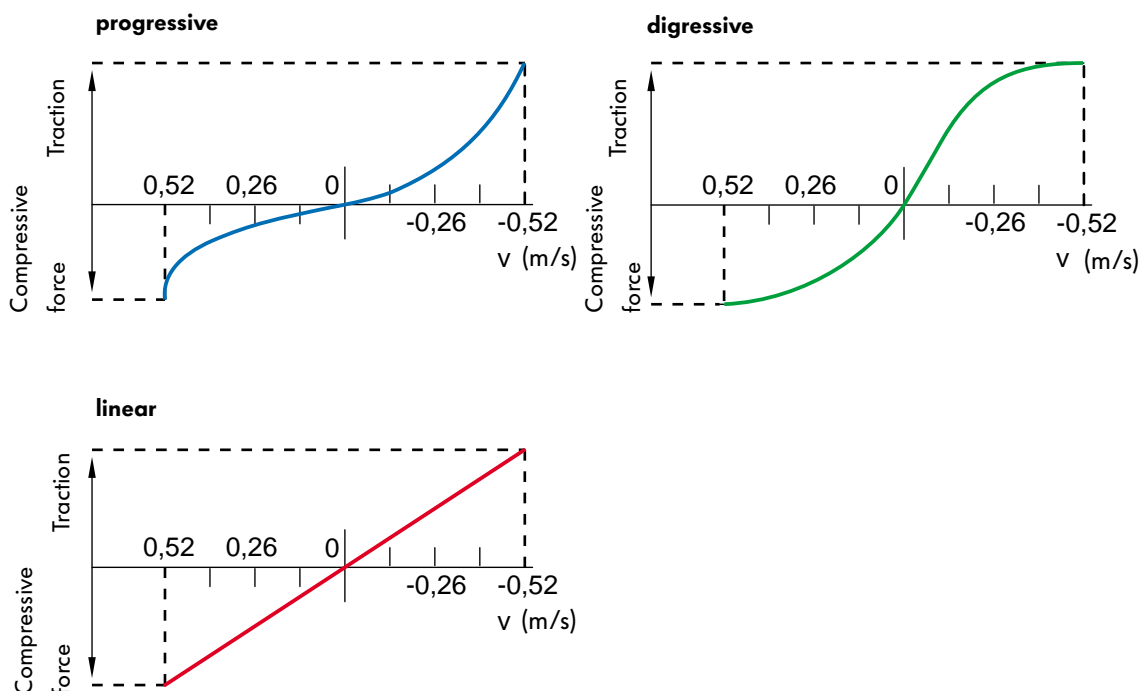
The machine produces different engine speeds, and therefore different rebound and bump rates of the damper, whilst maintaining a constant stroke.

The values determined in this way can be represented in force-speed diagrams (F-v diagrams).

These diagrams clearly show the characteristic of the vibration damper.

A distinction is made between progressive, digressive and linear action vibration dampers.

F-v diagram showing characteristic curves



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System description

The full load-bearing **4-Corner** air suspension (**4CL**) with Continuous Damping Control (**CDC**) keeps the vehicle at a constant level above the road, regardless of payload.

In other words, a constant, static ground clearance adapted to the driver's input or vehicle's road speed is maintained between the road and the vehicle floorpan.

The overall system comprises:

- a control unit for the 4CL/CDC
- an air spring and a vehicle level sender in each corner
- an adjustable vibration damper integrated into the air spring strut in each corner
- a compressor with air drier and temperature sender
- a solenoid valve block with 4 valves, a drain valve, a pressure accumulator valve, as well as an integrated pressure sensor,
- a pressure accumulator
- air lines from the compressor to the individual air spring struts and to the pressure accumulator
- a wheel acceleration sender on every air spring strut (measurement range ± 13 g) and
- three body acceleration senders (measurement range ± 1.3 g).

Three level heights have been implemented in the Phaeton (of which NN and HN are driver selectable):

- a **normal suspension level (NN)**,
- a **high suspension level (HN)** which is 25 mm above NN and intended for driving on bad roads and
- a **low suspension level (TN)**, 15 mm below NN. Ride height is selected automatically depending on road speed (while driving at high speeds on a motorway), and is also deselected automatically.

The system also switches automatically to other levels depending on the driving situation by means of a special control strategy. Ride height adjustments are made in the background and are not normally noticed by the driver.

When driving at high speeds, the ground clearance is automatically lowered from the high suspension level to the dynamically more stable normal suspension level. At even higher speeds, the ground clearance is automatically reduced to the low suspension level which is not selectable by the driver.

When a pre-determined road speed is undershot, the low suspension level is automatically deselected.

The "Comfort" damper setting is automatically adjusted in the direction of "sporty/firm" at higher speeds in order to ensure safe handling and track stability.

