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

– **C**ontinuous **D**amping **C**ontrol (**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.

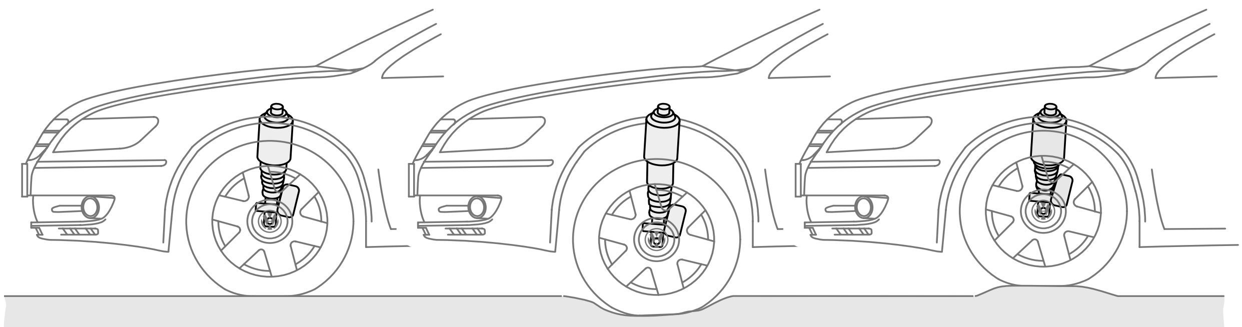
Contents

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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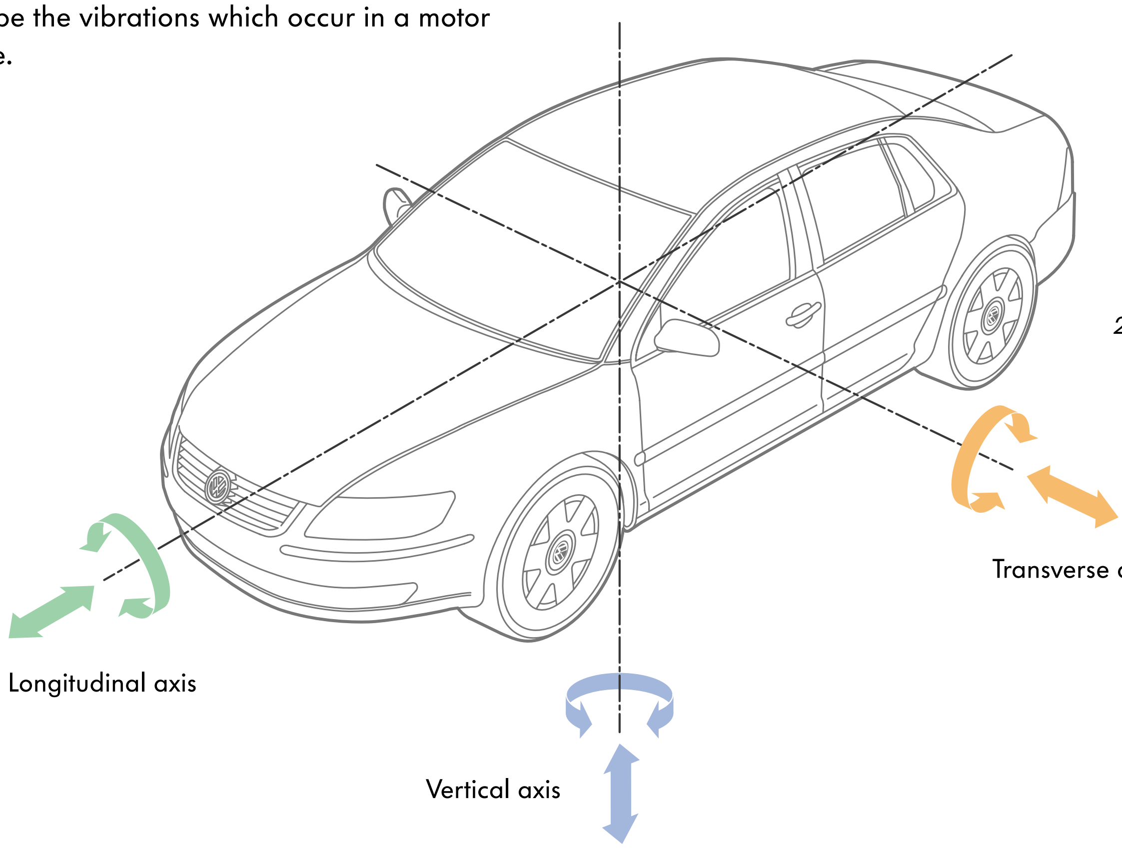
Driving safety	They maintain continuous contact with the road, which is important for steering and braking.
Driving comfort	Harmful or unpleasant vibrations are kept away from the passengers and the cargo remains intact.
Operational safety	The vehicle body and assemblies are protected against high impact 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.



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Twitching	Vibration in the direction of the longitudinal axis (shudder)
Roll	Torsional vibration about the longitudinal axis (snaking, rolling, tilting)
Drifting	Vibration in the direction of the transverse axis
Pitching	Torsional vibration about the transverse axis (pitching)
Bouncing	Vibration in the direction of the vertical axis (impacts, vertical vibration)
Yawing	Torsional vibration about the vertical axis

Basics of spring/damper system

Vibrations

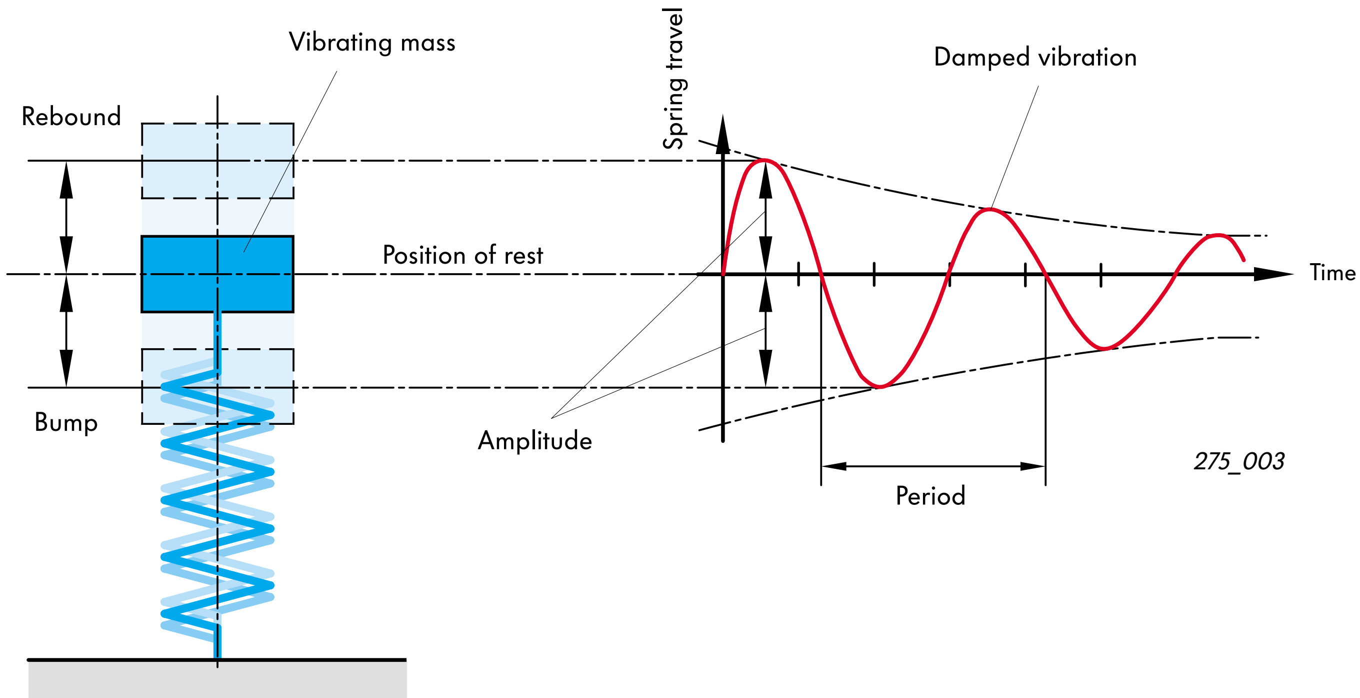
The tyres, suspension elements, body and vehicle seat forms a system which is capable of vibration, i.e. when an external force such as a bump on the road acts on this system, it oscillates back and forth about its position of rest.
These vibrations repeat themselves until they die away due to inner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



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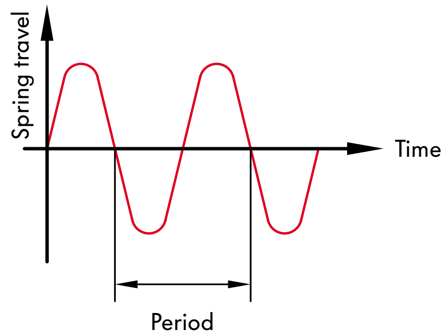
Larger masses or softer springs produce a lower intrinsic body frequency with increasing spring travel (amplitudes).



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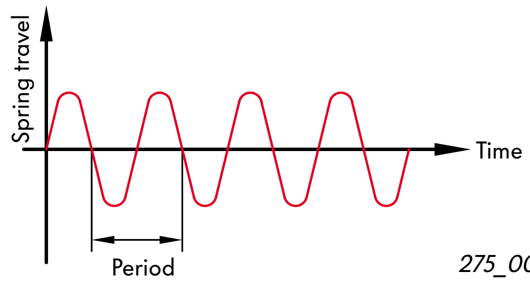
Smaller masses or firmer springs produce higher intrinsic body frequencies with decreasing spring travel.



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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:

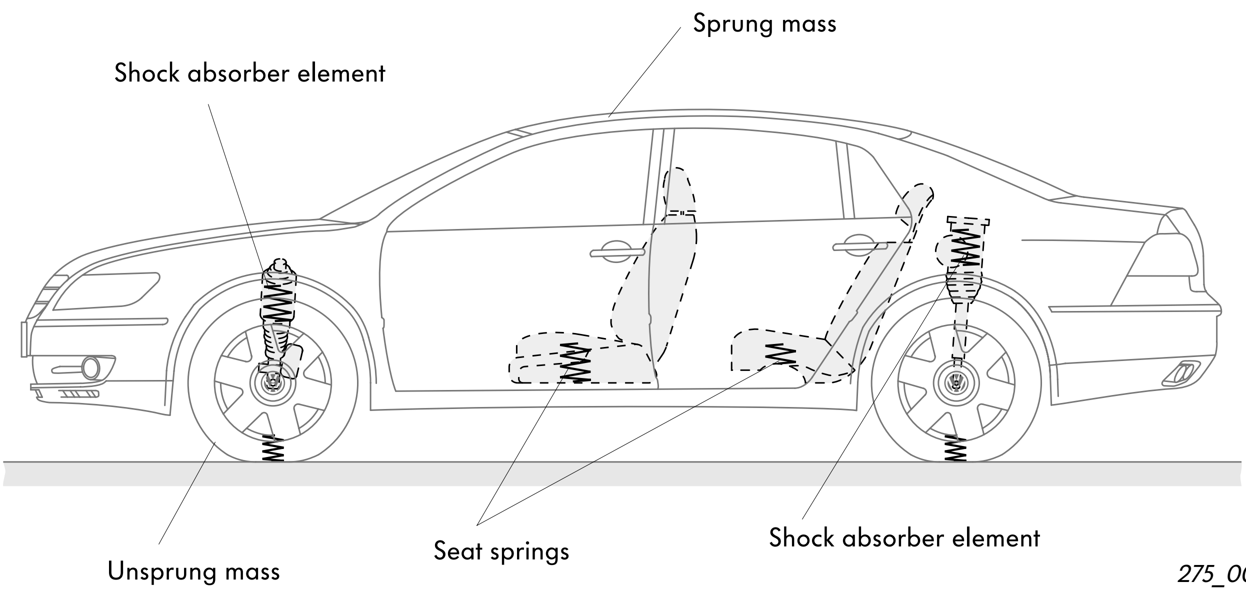
- steel springs (leaf springs, helical springs, torsion bar springs),
- air springs (gaiter springs and toroidal bellows springs),
- hydropneumatic springs (piston and diaphragm type hydraulic accumulators),
- rubber springs,
- anti-roll bars or
- combinations of these elements.

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 = force : distance [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.

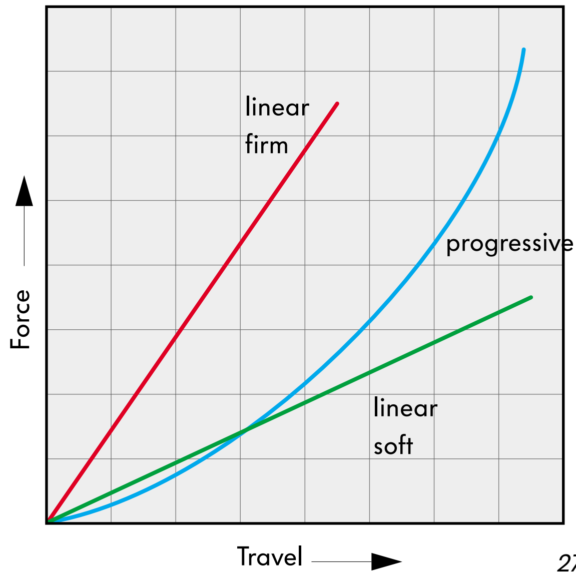
The characteristic of a coil spring can be influenced as follows:

– 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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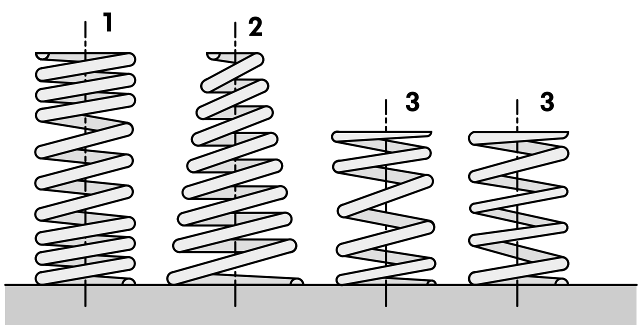

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Basics of spring/damper system

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.

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

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 $s_{stat(full)}$ and the static compression of the unladen vehicle $s_{stat(unladen)}$.

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

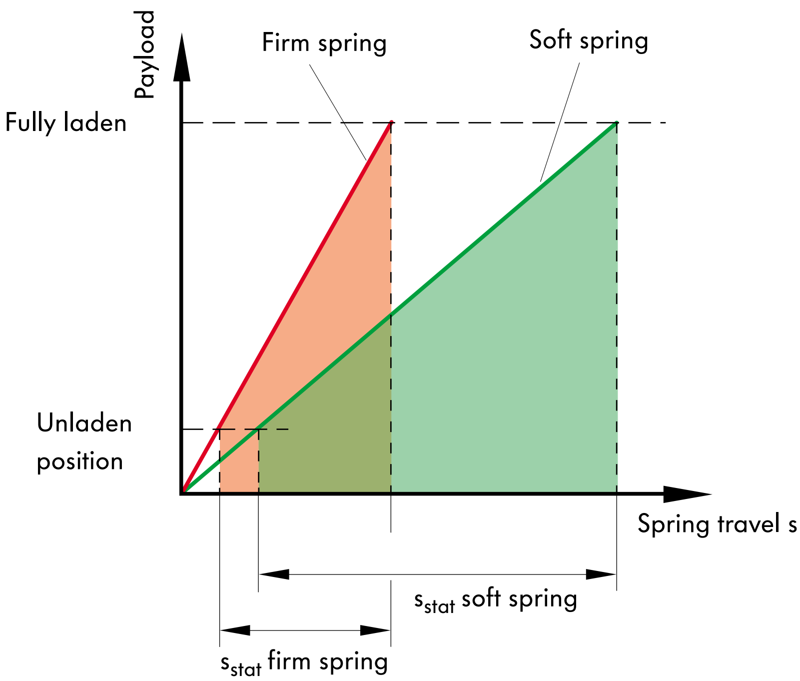
Where a spring characteristic is flat (soft spring), the difference, and so the static compression, between the unladen and fully laden vehicle is large.
Where spring characteristic has a steep gradient (firm spring), the static compression is small.

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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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 $s_{stat} = 0$, 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

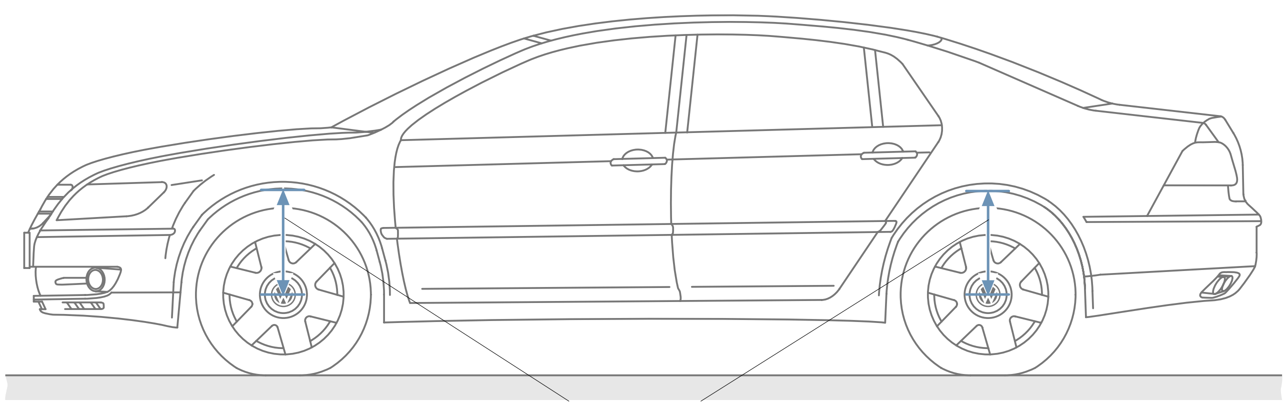
– reduced tyre wear

– 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.



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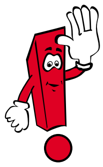
Basics of air suspension

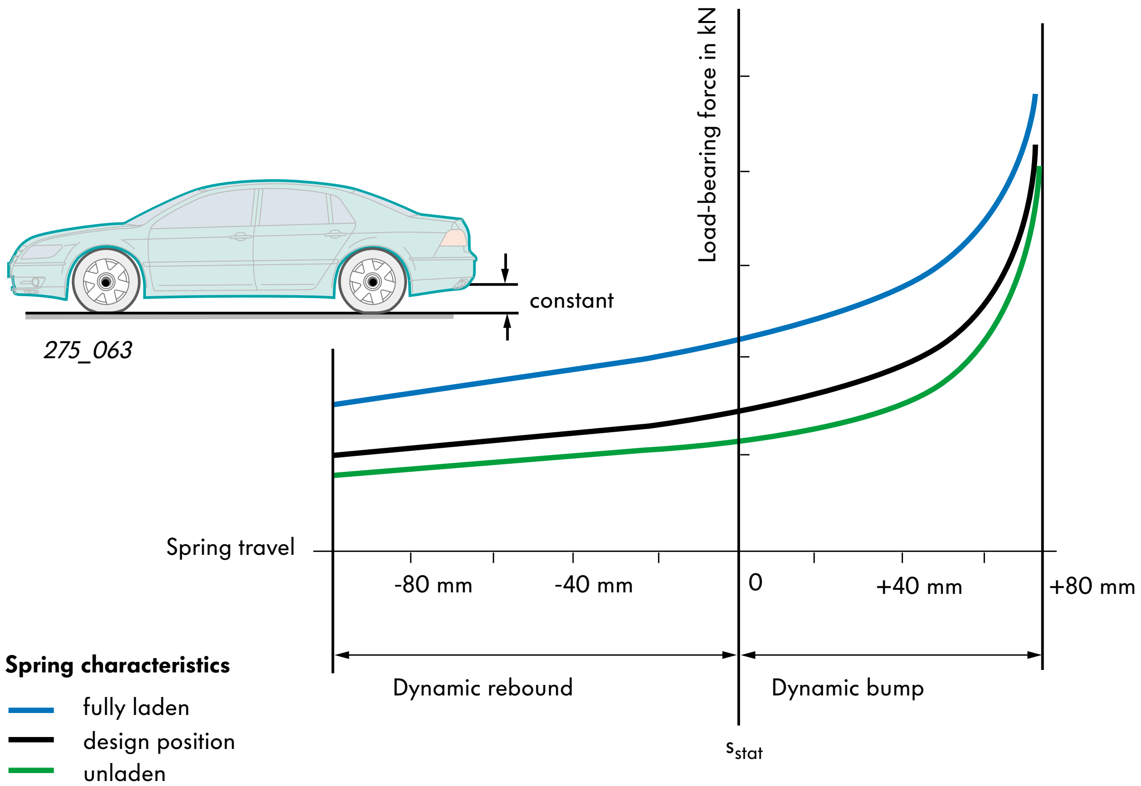
In addition to the basic advantages of variable-height, full load bearing air suspension as described above, it is also possible to set different vehicle level heights by means of the air suspension.

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

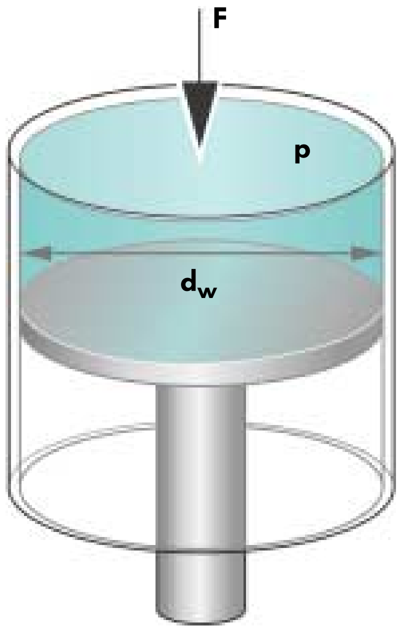
The spring force **F** (load-bearing force) of an air spring is defined by its geometric dimensions (the effective circular area $\mathbf{A_w}$) and the excess pressure acting on the air spring **p**.

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

The effective circular area $\mathbf{A_w}$ is defined by the effective circle diameter $\mathbf{d_w}$.

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

π = 3.14... constant "pi" for calculating the circle area



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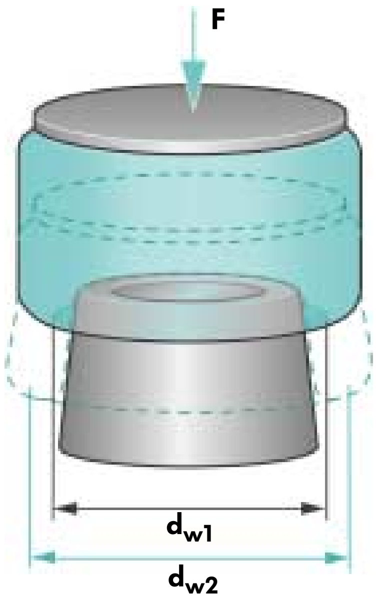
In a piston in the cylinder, the piston diameter corresponds to the effective circle diameter.

The effective diameter of the air spring gaiter is defined by the diameter at the lowest point of the gaiter ($\mathbf{d_{w1}}$ rebounded and $\mathbf{d_{w2}}$ compressed). Since this effective diameter $\mathbf{d_w}$ is squared in the equation for $\mathbf{A_w}$, 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

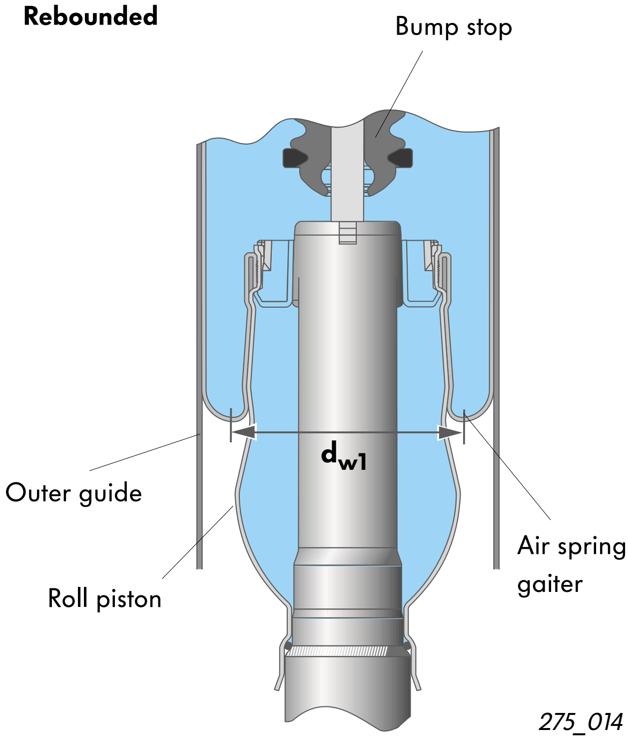
The load-bearing force of the spring can be adapted to the load situation by simply changing the effective internal pressure **p** in the air spring.

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 **$d_{w\,1}$** to **$d_{w\,2}$**) because it rolls back on the roll piston.

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

Rebounded



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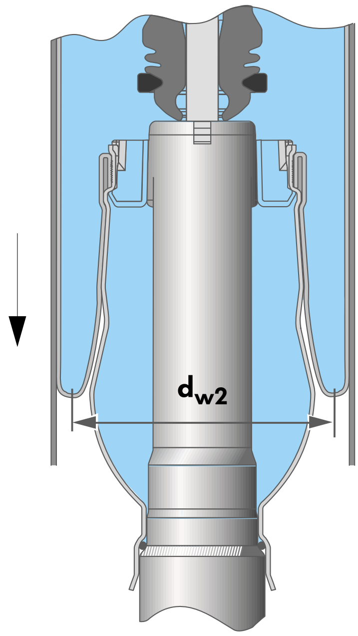
Compressed



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Spring characteristic

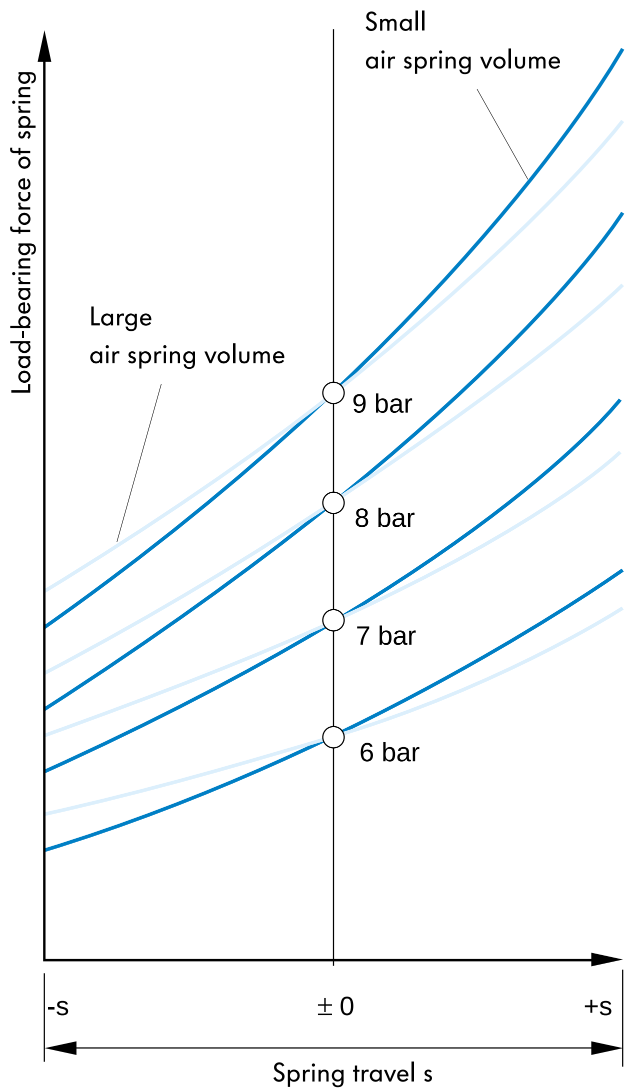
In principle, the spring characteristic of an air spring for cylindrical pistons is progressive.

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.



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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.

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

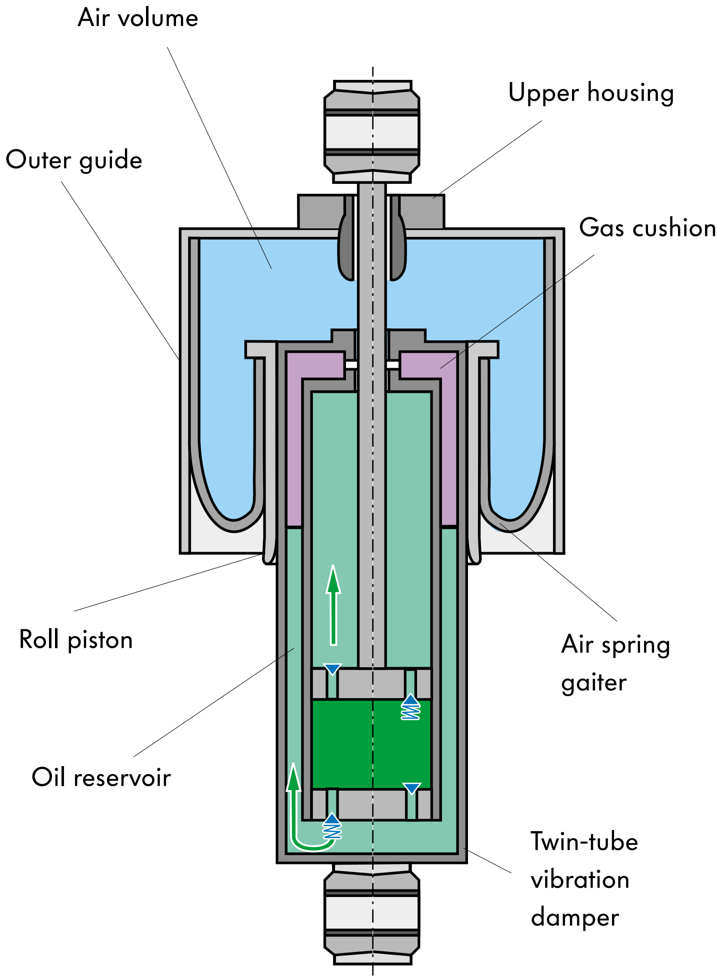
- an upper housing with an outer guide
- the air spring gaiter
- the roll piston (lower housing)
- an auxiliary accumulator (where required), and
- the integrated vibration damper (shock absorber)

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 °C to +90 °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.

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.

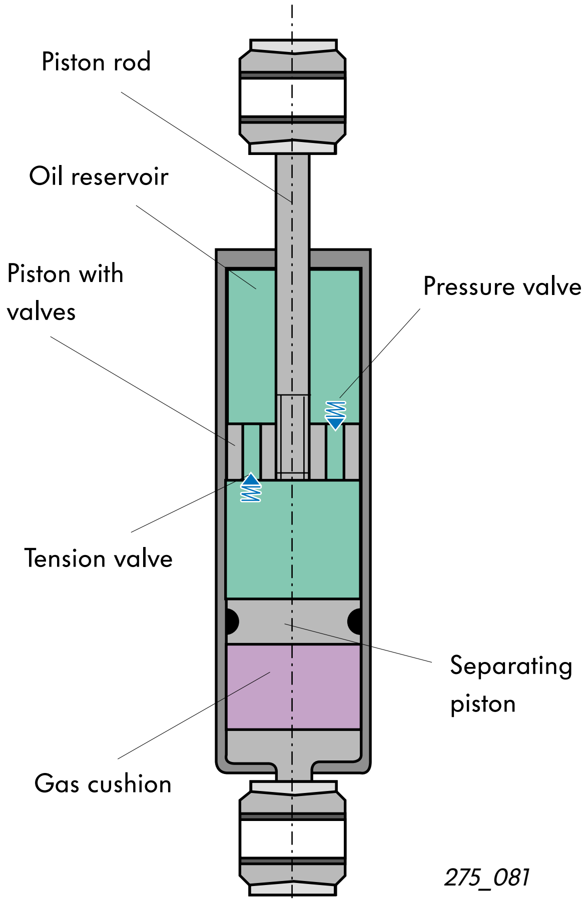
Without vibration dampers, the vibrations introduced into the vehicle would "build up" to the extent that the wheels could lose contact with the road surface. As a result, the vehicle would no longer be steerable.

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.

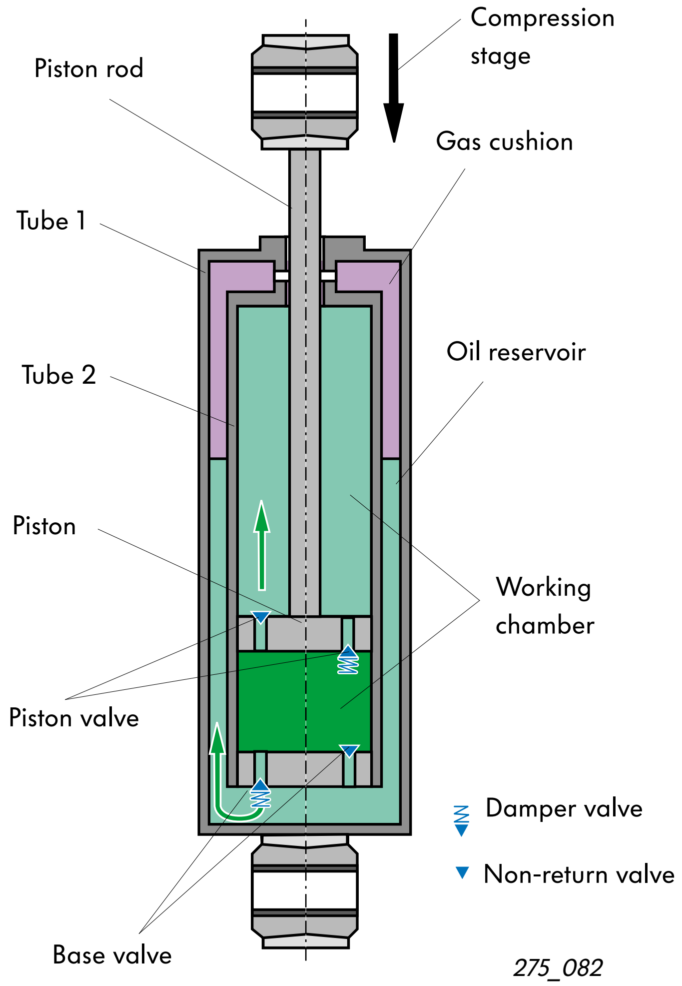
As the name indicates, it consists of two tubes fitted into each other (twin-tube damper).
The inner tube acts as the working chamber.
It is completely filled with hydraulic fluid.
The pistons together with the piston valves and the piston rod move up and down inside the working chamber.
The base of 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).

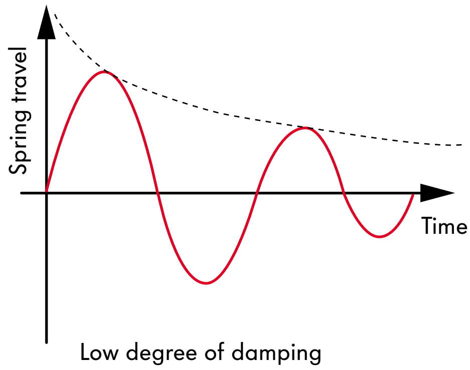
The damping force during the compression stage is less than during the tension stage.

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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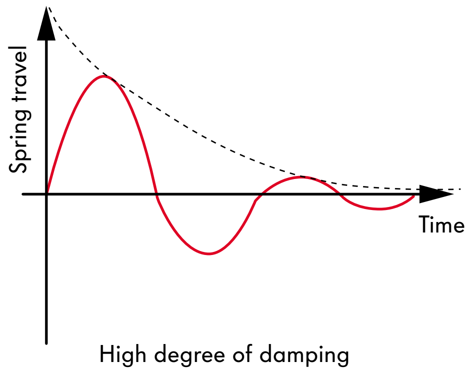

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Basics of the damping system

Damping force

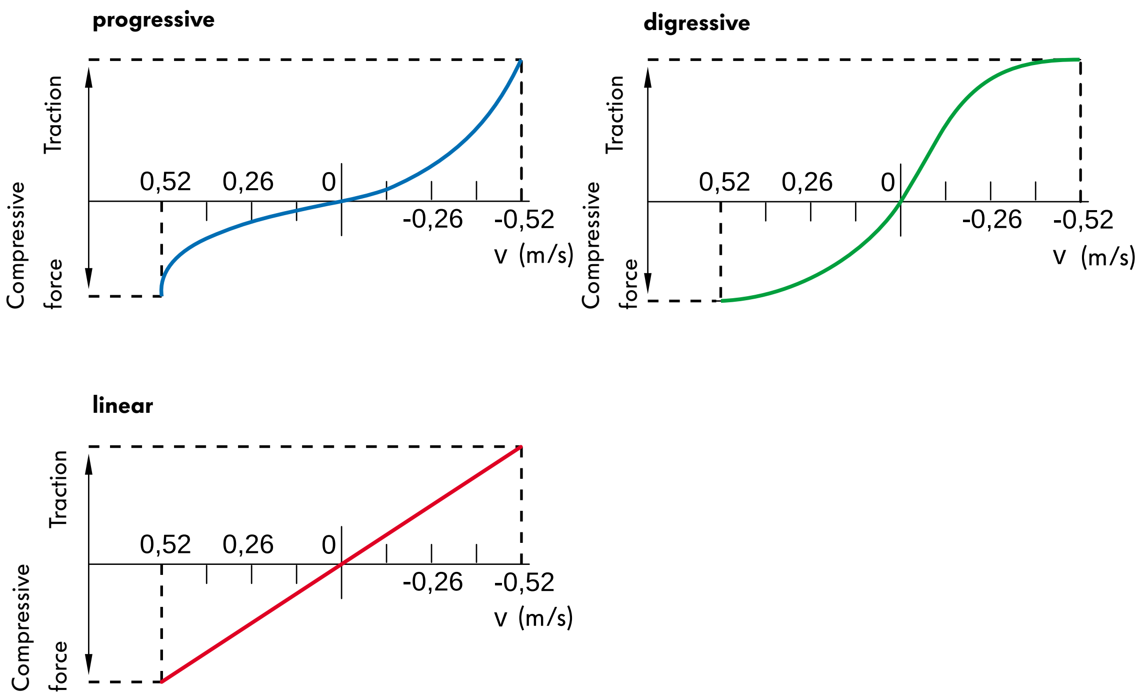
The damping force of a vibration damper is determined using a test apparatus.
The machine produces different engine speeds, and therefore different rebound and bump rates of the damper, whilst maintaining a constant stroke.

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-C**orner 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

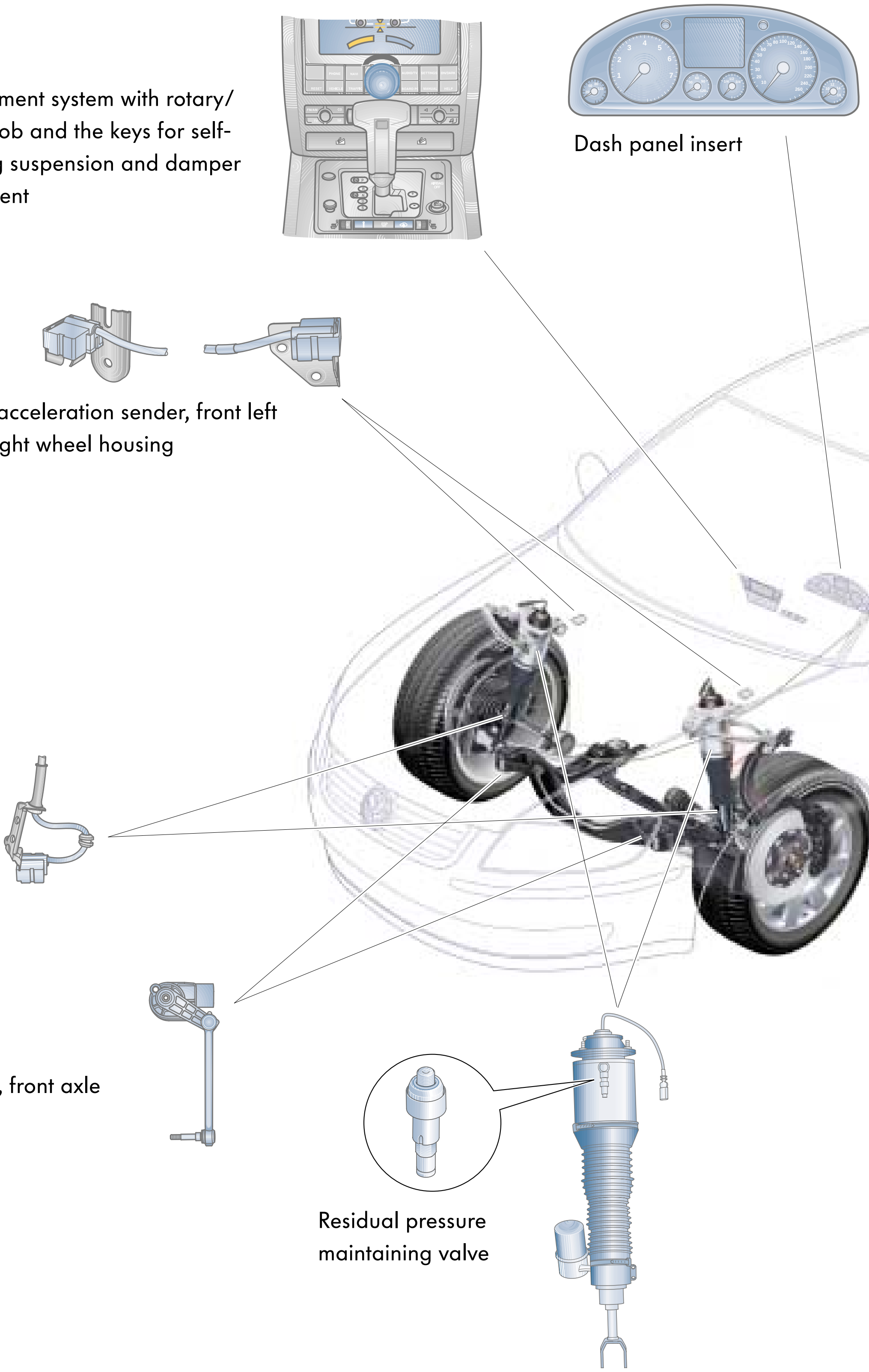
– a **low suspension level** (**TN**), 15 mm below NN. Ride height is selected automatically depending on road speed (while driving at high speeds on a motorway), and is also deselected automatically.

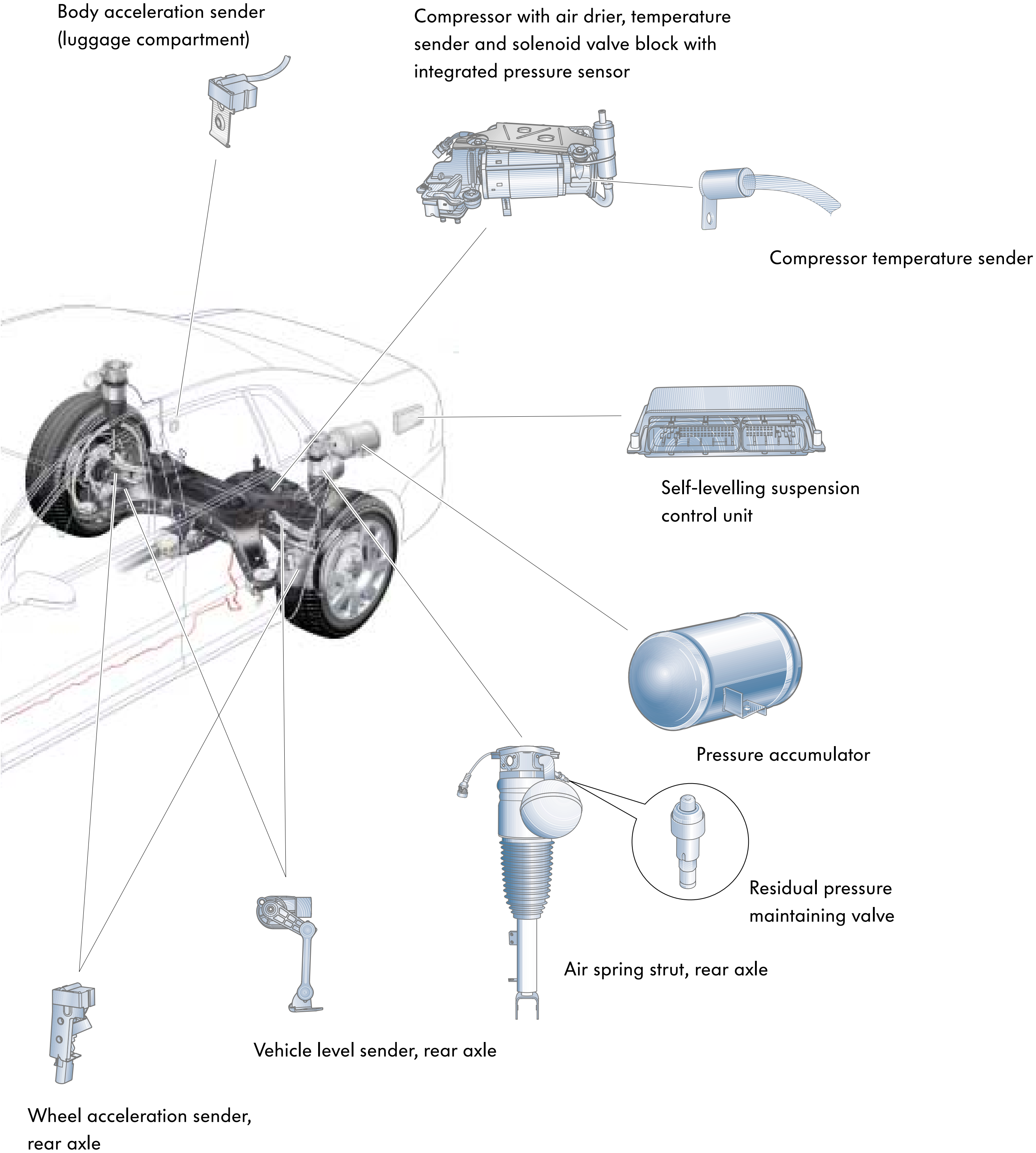
The system also switches automatically to other levels depending on the driving situation by means of a special control strategy. Ride height adjustments are made in the background and are not normally noticed by the driver.
When driving at high speeds, the ground clearance is automatically lowered from 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.

System description

The system and its components




Body acceleration sender
(luggage compartment)
Compressor with air drier, temperature
sender and solenoid valve block with
integrated pressure sensor
Compressor temperature sender
Self-levelling suspension
control unit
Pressure accumulator
Residual pressure
maintaining valve
Air spring strut, rear axle
Vehicle level sender, rear axle
Wheel acceleration sender,
rear axle

275_020

System description

Operation and display

The Phaeton is the first Volkswagen vehicle to be equipped with a self-levelling suspension.

For the front and rear axles, the system comprises a

- full load-bearing air spring with self-levelling suspension in combination with
- a continuously adjustable vibration damper

The central control unit for the system is self-levelling suspension control unit J197.

The system is operated by the damper adjustment button or the self-levelling suspension button as described in the operating manual.

These keys are located on the centre console behind the gear selector lever.
Pressing the appropriate key opens a pop-up menu in the Infotainment display select between

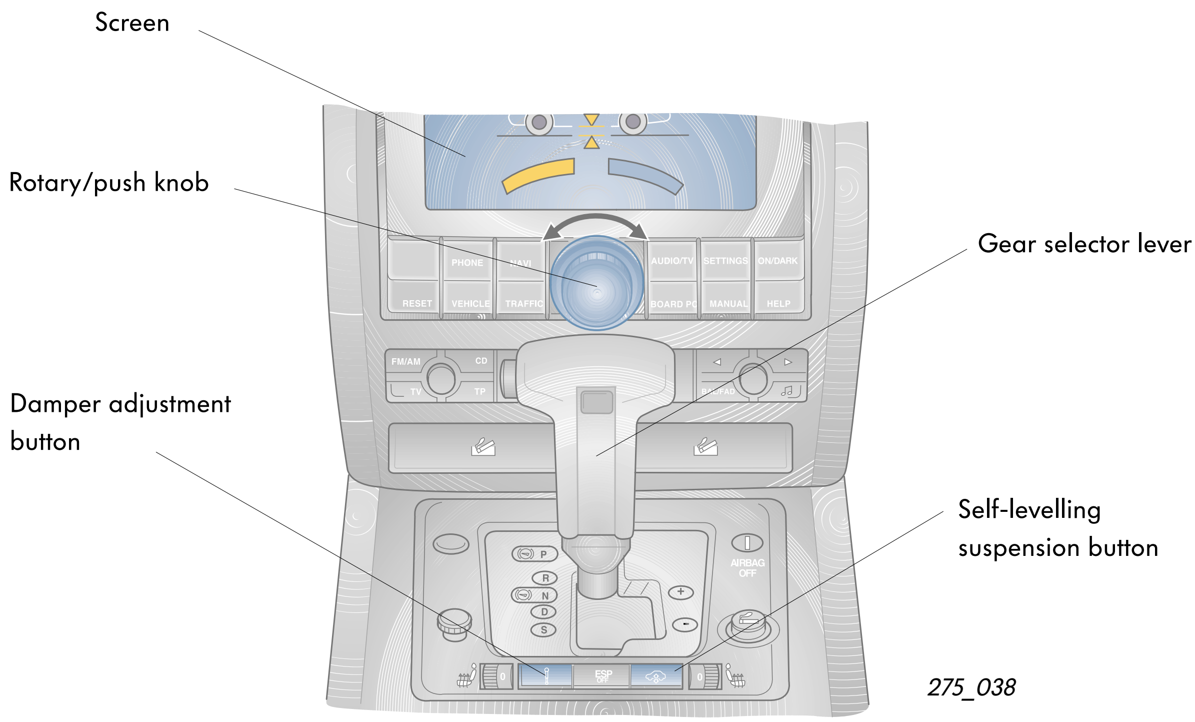
two suspension levels

- normal suspension level **NN** (preset) and
- high suspension level **HN**

and four **damper tunings**

- Comfort,
- Basic (preset),
- Sport 1 and
- Sport 2.

using the rotary/push knob.



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Self-levelling suspension

The button for self-levelling suspension must be pressed to set the level.
By turning the rotary/push knob, the driver can select between high suspension level **HN** or normal suspension level **NN**.
The screen corresponding to the level selected is displayed.

When the high level is set, the self-levelling suspension button is lit.
The driver can exit the menu by pressing the rotary/push knob.

Normal level

275_034

High level

275_035

Damper tuning

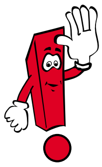
To select damper tuning, press the damper adjustment button.

Turn the rotary/push knob, the driver can select one of the following four damper tunings:

- Comfort,
- Basic (preset),
- Sport 1 and
- Sport 2.

The corresponding screen is displayed.

The driver can exit the menu by pressing the rotary/push knob.
In the Comfort, Sport 1 and Sport 2 settings, the key is lit.

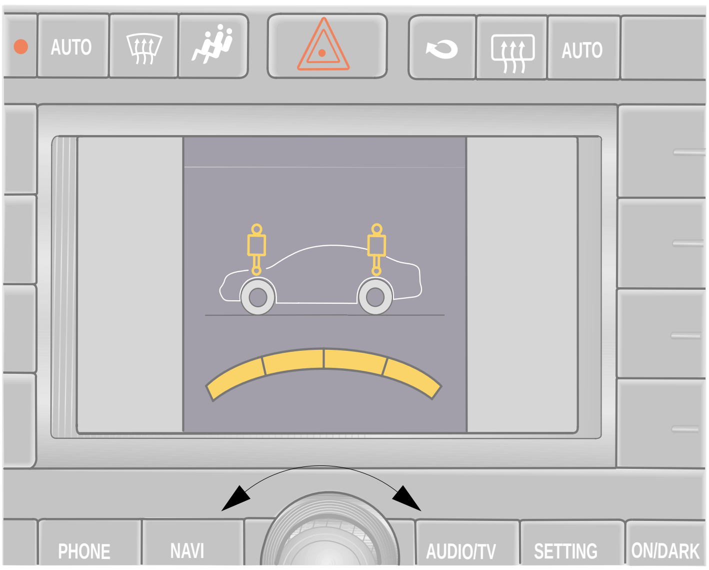


The level always resets from the "Sport 2" position to the "Basic" position when the ignition is turned off.

Comfort

275_036

Sport 2



275_037

Control strategy of the self-levelling suspension

The position of the vehicle body in relation to the wheel is measured by four vehicle level senders located between the axle carriers and the lower wishbones and compared with defaults for each wheel stored in the control unit.
The vehicle control unit must "learn" these defaults.

The air required for self-levelling is normally provided by the compressor (maximum pressure 16 bar).

At road speeds above 35 kph, adjustments are controlled by the compressor.
The pressure accumulator is also topped up as required.

At road speeds below 35 kph, adjustments are controlled by the pressure accumulator (5 litre capacity).
A sufficient pressure difference (approx. 3 bar) between the pressure accumulator and the air spring is required for this purpose.

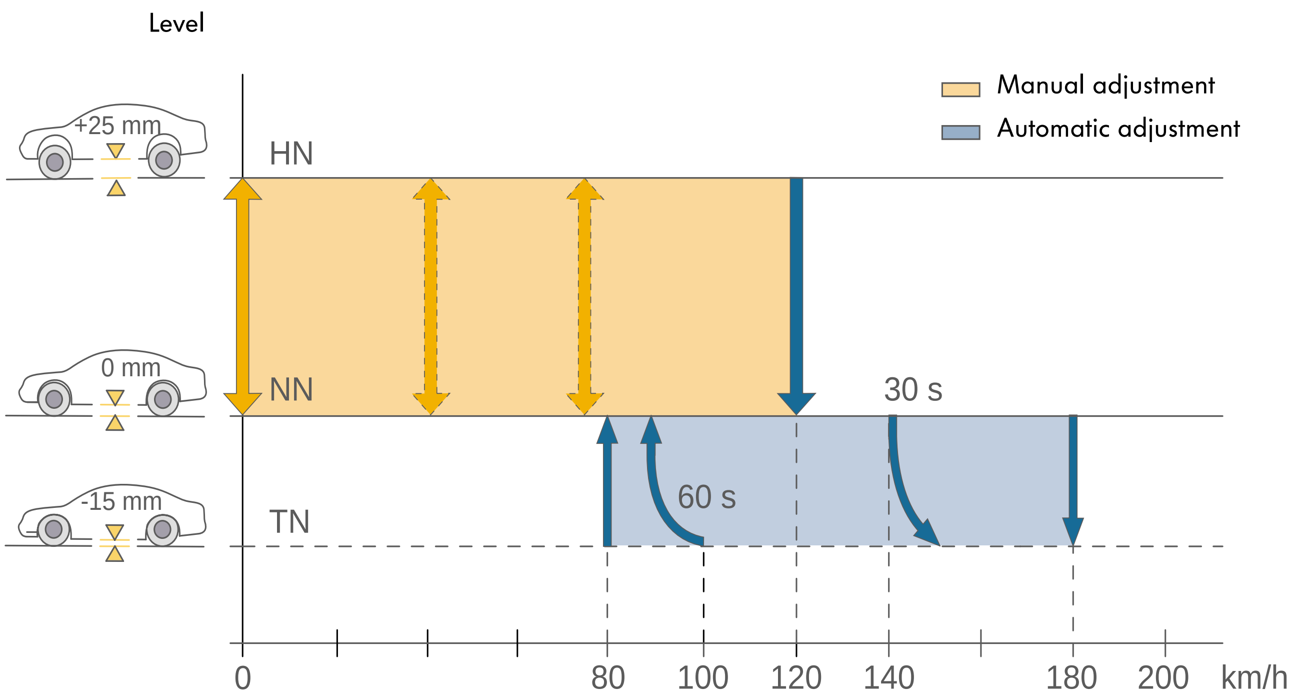
Loading and unloading

If the height of the vehicle changes in relation to the road surface due to loading or unloading processes, the control unit re-adjusts the vehicle's level height to the nominal level.
For this purpose, air is channelled via a solenoid valve into the air spring or discharged via the drain valve.

The compressor for topping up the pressure accumulator comes on independently of the levelling adjustments.

System description

Schematic diagram of the automatic up/down adjustments



275_021

HN - high level
NN - normal level
TN - low level

Level is automatically **decreased** from

HN to **NN**: at v ≥ **120** kph

NN to **TN**: takes place at v ≥ **140** kph after 30 seconds and/or immediately at v ≥ **180** kph.

Level is automatically **increased** from

TN to **NN**: at v ≤ **100** kph after 60 seconds and/or immediately at v ≤ **80** kph.

Special modes of the self-levelling suspension

Deactivating self-levelling suspension system
In special situations, it may be necessary to deactivate the suspension, e.g. to change a wheel or to carry out work on the vehicle whilst raised on a lifting platform.
The self-levelling suspension can be deactivated by simultaneously pressing the keys for self-levelling suspension and damper adjustment for about 5 seconds.

A message indicating that the self-levelling suspension has been deactivated appears in the dash panel insert.

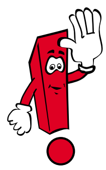
Activating the self-levelling suspension
The suspension system is re-activated by pressing both keys for approx. 5 seconds, or automatically when the control unit determines that the vehicle is travelling at a speed of v ≥ 10 kph.

Lifting platform:
When the vehicle is raised on a lifting platform at the jack and lifting platform locating points, air is allowed to escape from all four air springs until the control unit determines that the vehicle is in elevated state.

The self-levelling suspension initially detects when the vehicle body is too high in relation to the wheels and adjusts the vehicle height accordingly by allowing air to escape from the springs.

As a result, the vehicle may have a very low ground clearance when it comes off the lifting platform.

The vehicle is automatically raised to the normal level (NN) again after the engine, and therefore the compressor, has been running for a short period of time.



To avoid this discharge of air, therefore, the self-levelling suspension must be deactivated before starting lifting platform activities.

Actions of air suspension after "ignition OFF"

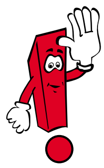
Loading and unloading

After "ignition OFF", the control unit remains active for approx. one minute and can execute suspension adjustments, e.g. to compensate for increases/decreases in payload, provided that sufficient pressure is available in the pressure accumulator.

The control unit always remains active for one minute until no further door or bonnet/bootlid operations are detected.

Gradual level changes

To compensate for gradual level changes, which can occur due to air in the air springs heating up during the trip and cooling down again at the end of the trip, three adjustments are made to achieve optimum ground clearance after " ignition OFF".



These adjustments are made after approx. two, five and ten hours, provided that sufficient pressure is available in the pressure accumulator.

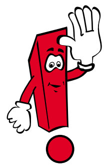
Vibration damper control

The damper control system registers the condition of the road surface and the movements of the vehicle via four wheel acceleration sensors and three body acceleration sensors.
The characteristics of the individual vibration dampers are adjusted according to the calculated damping requirements.
In this case, the dampers function as semiactive components during bump and rebound cycles.

Continuous damping control is based on vibration dampers whose characteristics are electrically adjustable.
These vibration dampers are integrated in the air spring struts.
Damping force can be set depending on the characteristic map via the proportional valve built into the vibration damper.
As a result, it can adapt the damping force to the driving situation and road condition within milliseconds.

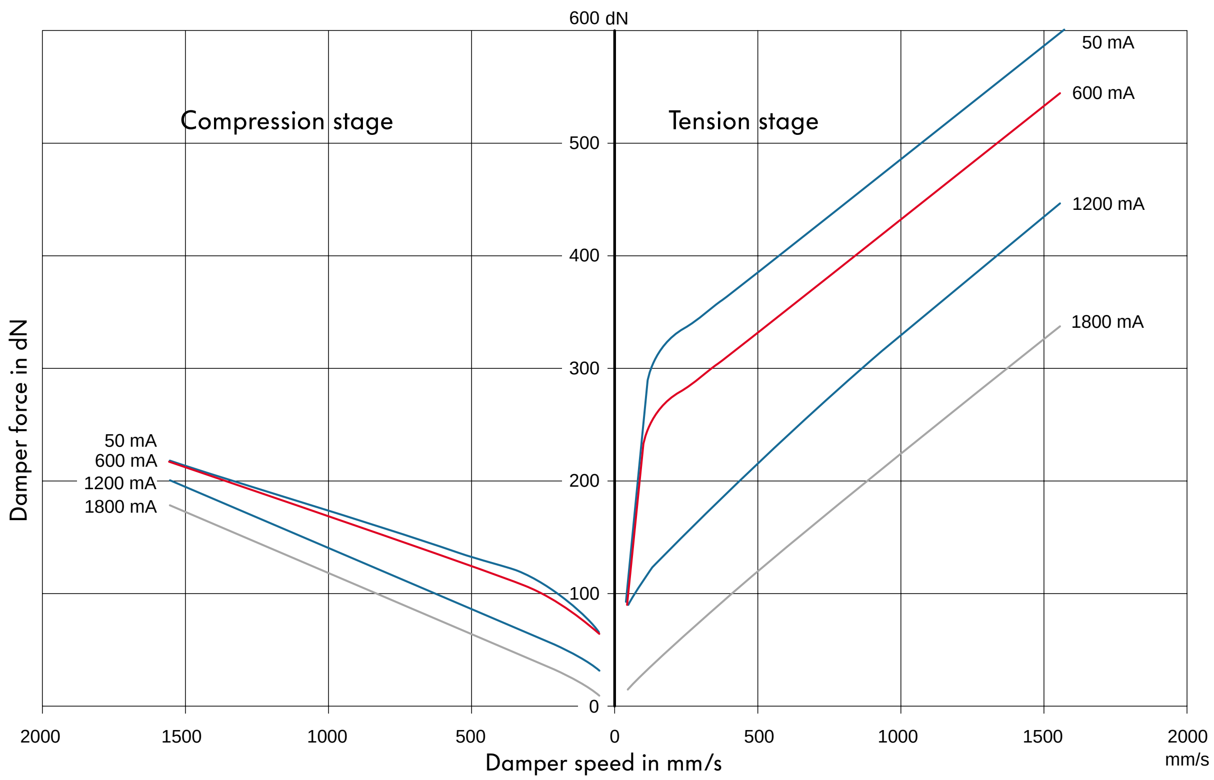
The control always attempts to set the damper force according to the so-called "skyhook control strategy".
The damper is adjusted depending on the vertical acceleration rates of the wheels and the vehicle body.
Ideally, damping would be controlled as if the vehicle body were suspended by a hook in the sky and were hovering above the road almost without any interfering movements.

Maximum driving comfort is achieved in this way.



Firm damping is achieved by low control rates.
Soft damping is achieved by high control rates.

Characteristic map of damper force in Phaeton front axle

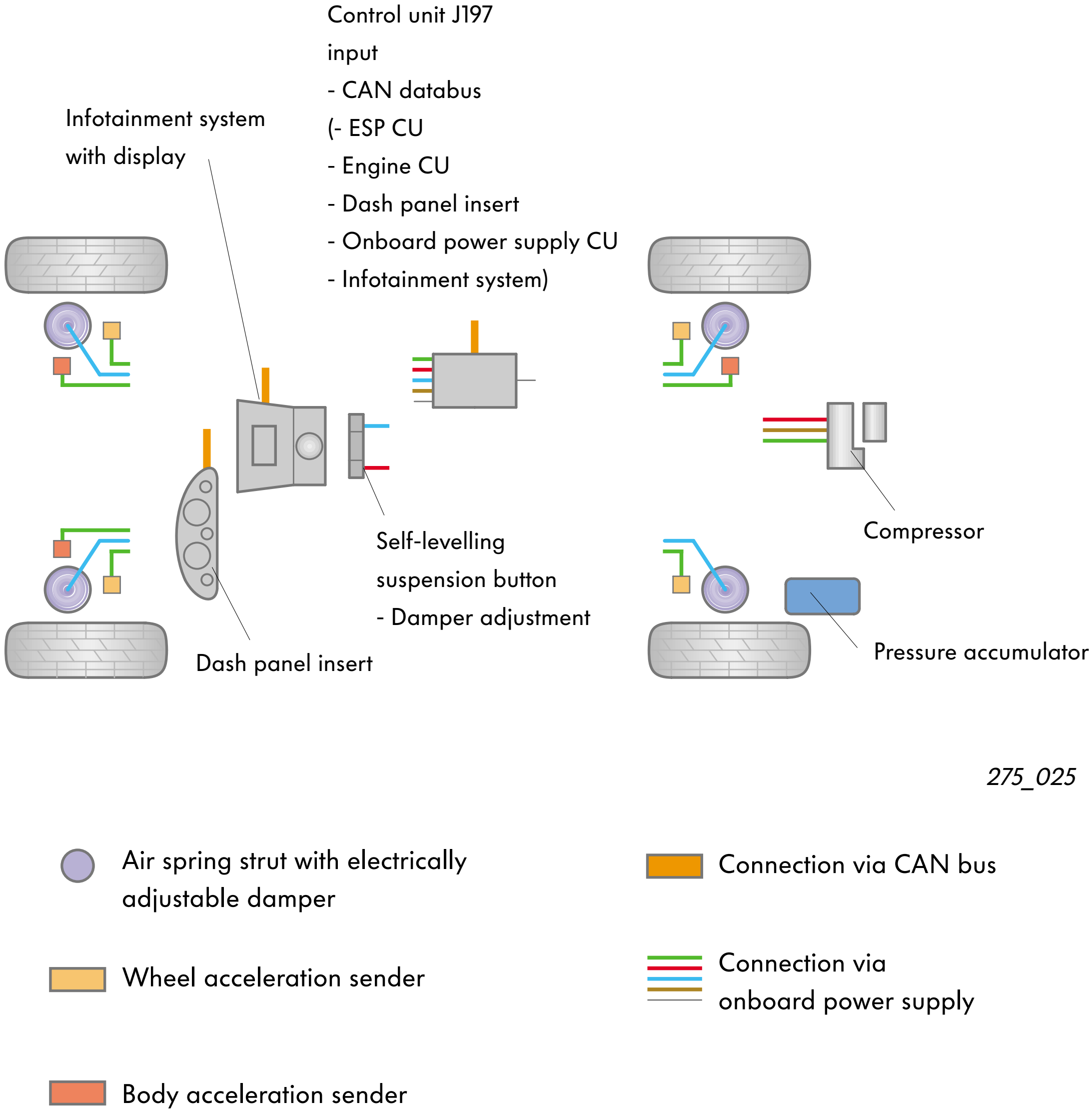


275_022

System description

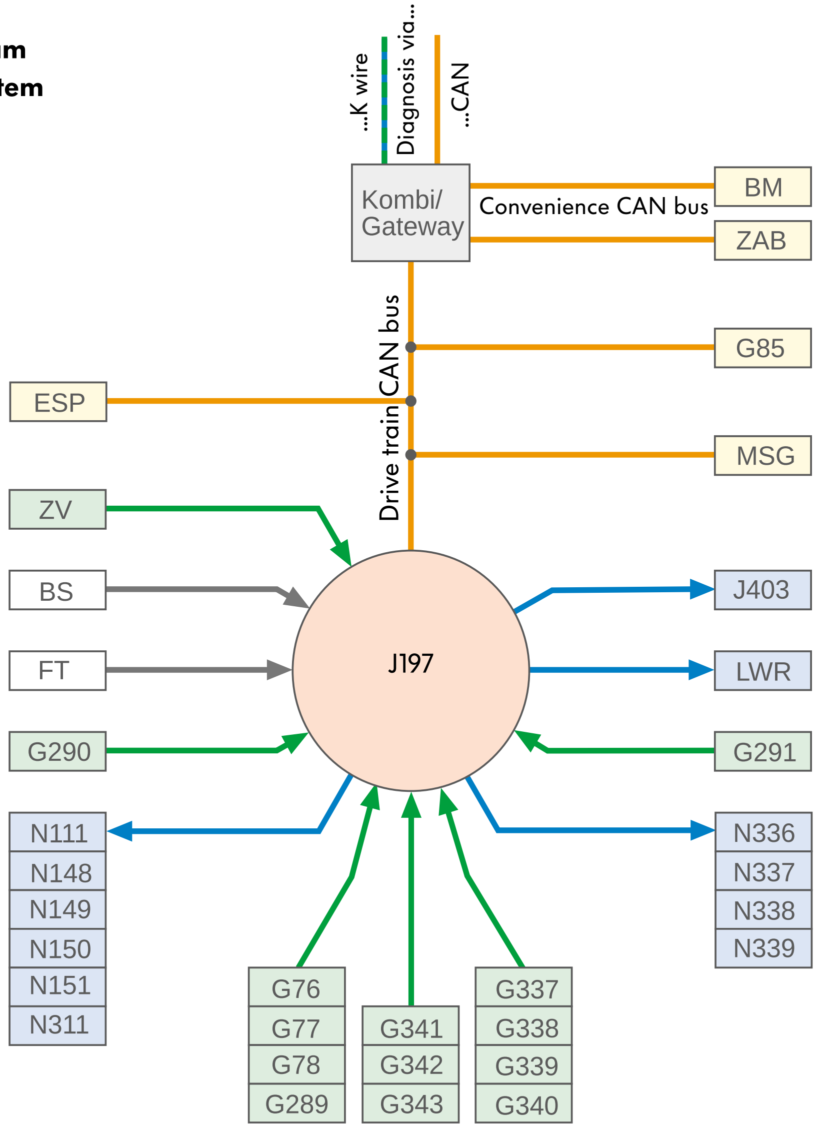
Diagram of the suspension system with controlled dampers

The system diagram below highlights the relationships with other vehicle systems as well as display and operating elements.



275_025

Schematic diagram of the overall system



275_023

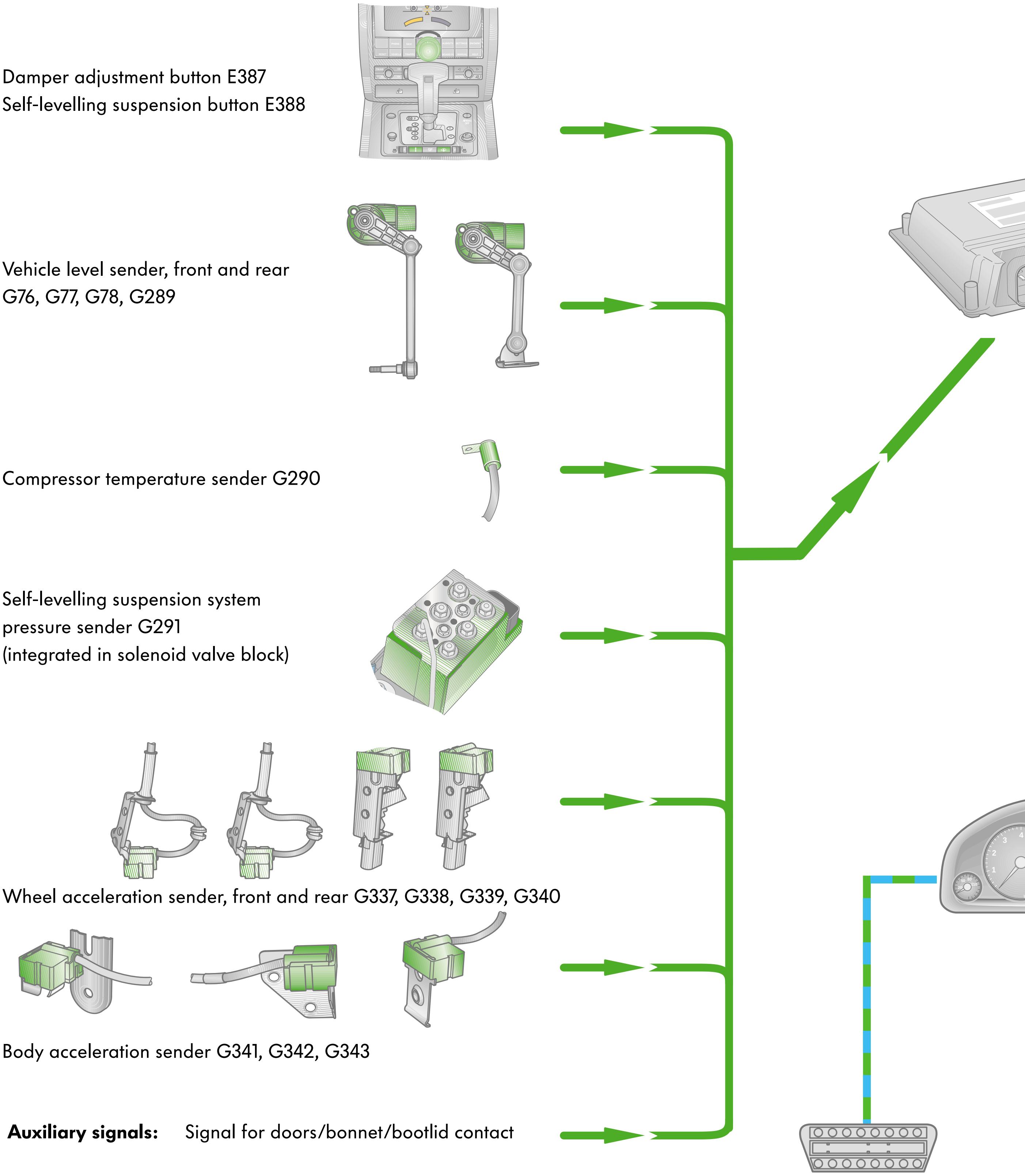
Legend

BM	- Battery management	J197	- Self-levelling suspension control unit
BS	- Status signals T.30, T.15	J403	- Self-levelling suspension compressor relay
ESP	- Electronic Stability Programme	Combi	- Dash panel insert
FT	- Self-levelling suspension button and damper adjustment button	HRC	- Headlight range control
G76...78, ... G289	- Vehicle level senders	MSG	- Engine control unit
G85	- Steering angle sender	N111	- Drain valve
G290	- Compressor temperature sender, self-levelling suspension	N148 ... N151	- Damper adjustment valve
G291	- Self-levelling suspension system pressure sender	N311	- Self-levelling suspension pressure accumulator valve
G337 ... G340	- Wheel acceleration sender	N336 ... N339	- Damper adjustment valve
G341 ... G343	- Body acceleration sender	ZAB	- Infotainment
		ZV	- Door/bonnet/bootlid signal

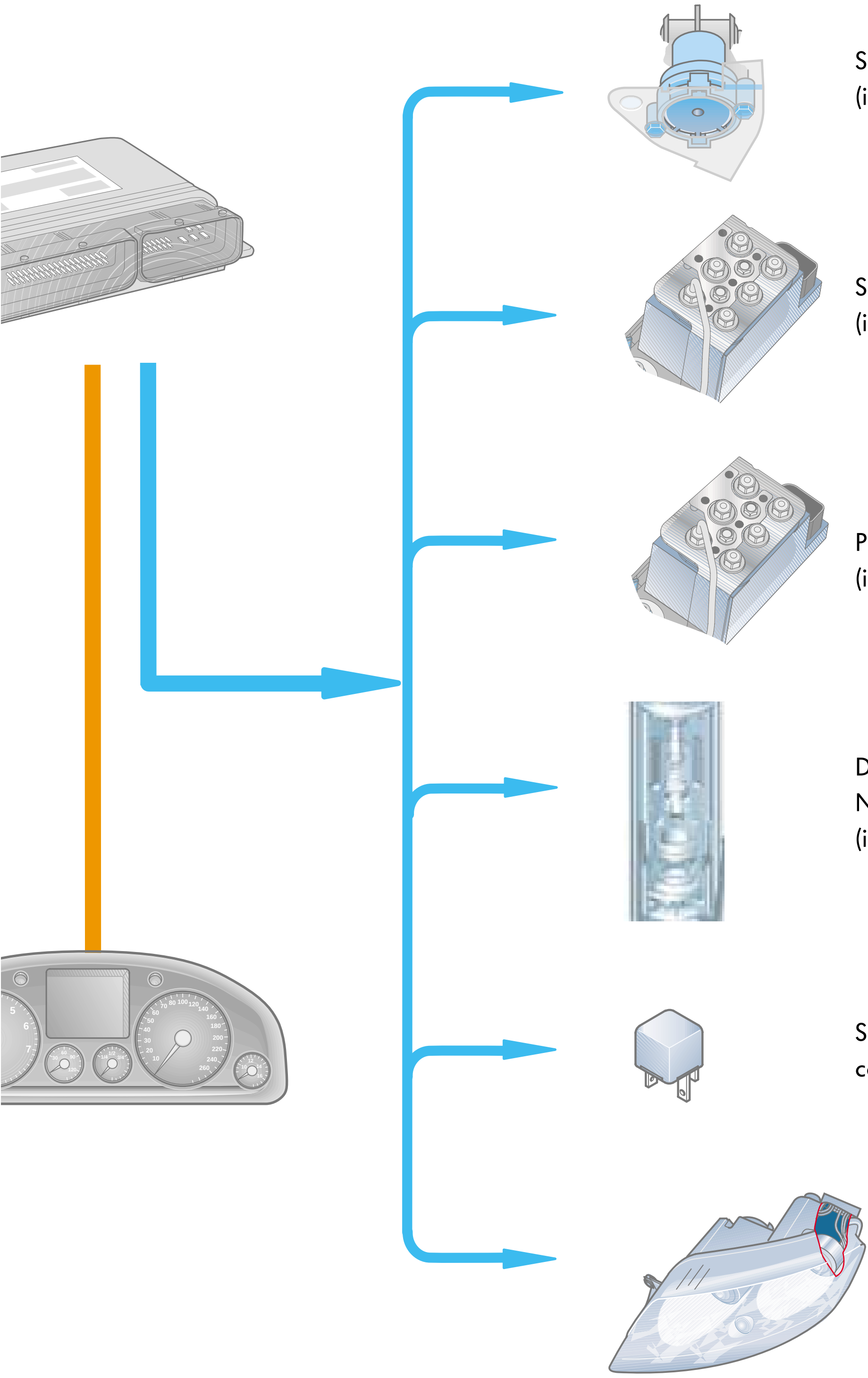
System description

System overview

Sensors



Actuators



Self-levelling suspension drain valve N111
(integrated in solenoid valve block)

Suspension strut valves N148, N149, N150, N151
(integrated in solenoid valve block)

Pressure accumulator valve N311
(integrated in solenoid valve block)

Damper adjustment valves
N336, N337, N338, N339
(integrated in air spring struts)

Self-levelling suspension
compressor relay J403

Gas discharge lamp control units with HRC
J567 and J568 integrated in the headlights

275_026

Self-levelling suspension control unit J197

This control unit is located in the luggage compartment on the left-hand side behind the side trim. It is bolted behind the relay and fuse carriers.

As a central control unit, it has the following tasks:

– to control air suspension and the vibration dampers,
– to monitor the overall system,
– to diagnose the overall system, and
– to communicate via the CAN databus (drive train CAN databus).

275_083

The self-levelling suspension control unit has a redundant processor design (dual processors); the air spring algorithm runs primarily on the first processor and damping control runs primarily on the second processor.

Air spring struts

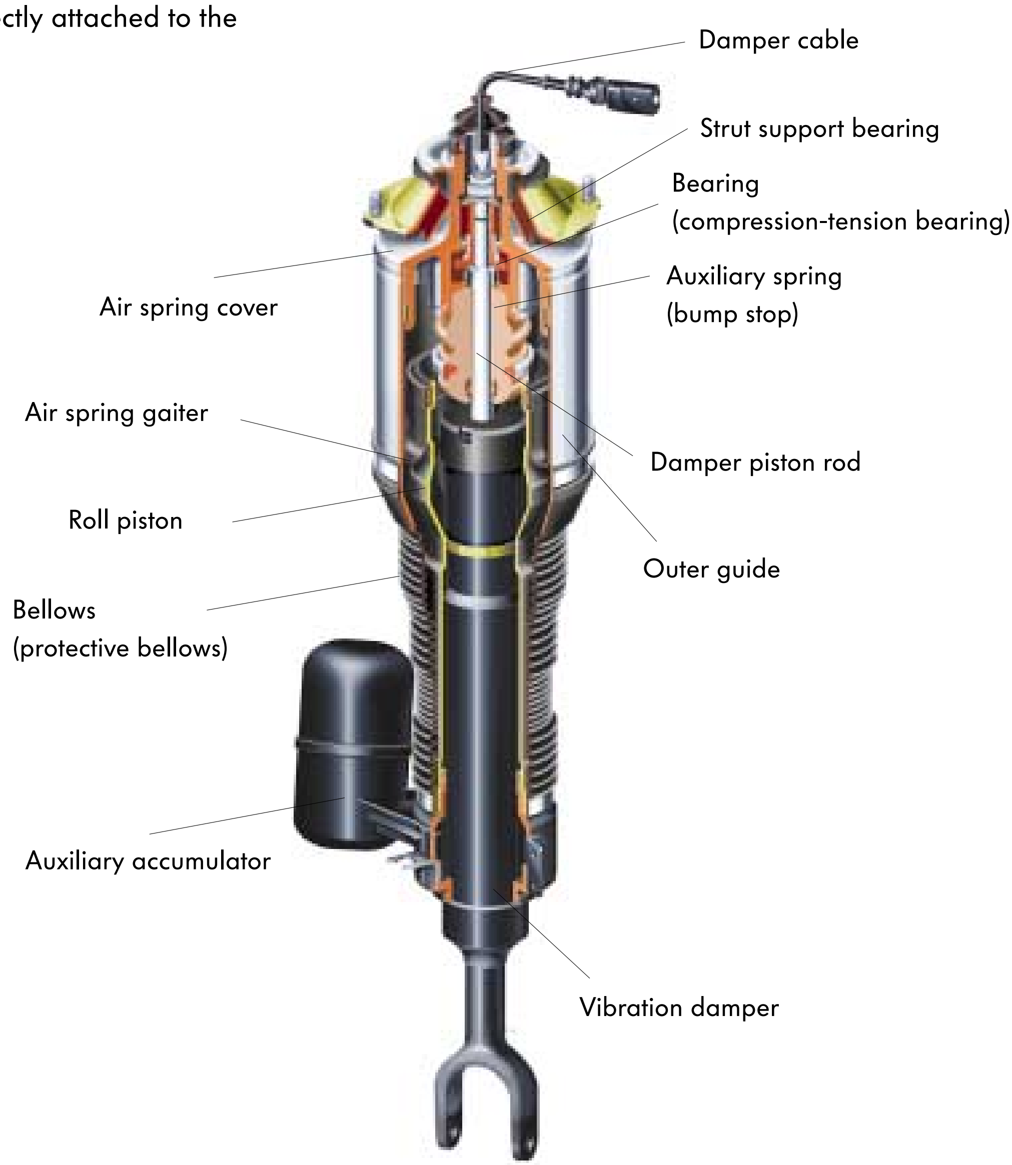
Air spring struts with externally guided, two-layer air spring gaiters are used on the front and rear axles.

The air spring gaiter is arranged concentrically around the gas-filled shock absorber (twin-tube gas-filled shock absorber).

The small wall thickness of the air spring gaiter provides excellent suspension response.
The desired spring rate is achieved by combining the roll piston contour, the outer guide and an auxiliary accumulator directly attached to the strut.

Different auxiliary accumulators are used on the front axle and rear axles.
The accumulator on the front axle - recognisable as a small cylinder - has a capacity of 0.4 litre and the ball accumulator on the rear axle has a capacity of 1.2 litre.

Strut, front axle



275_027a

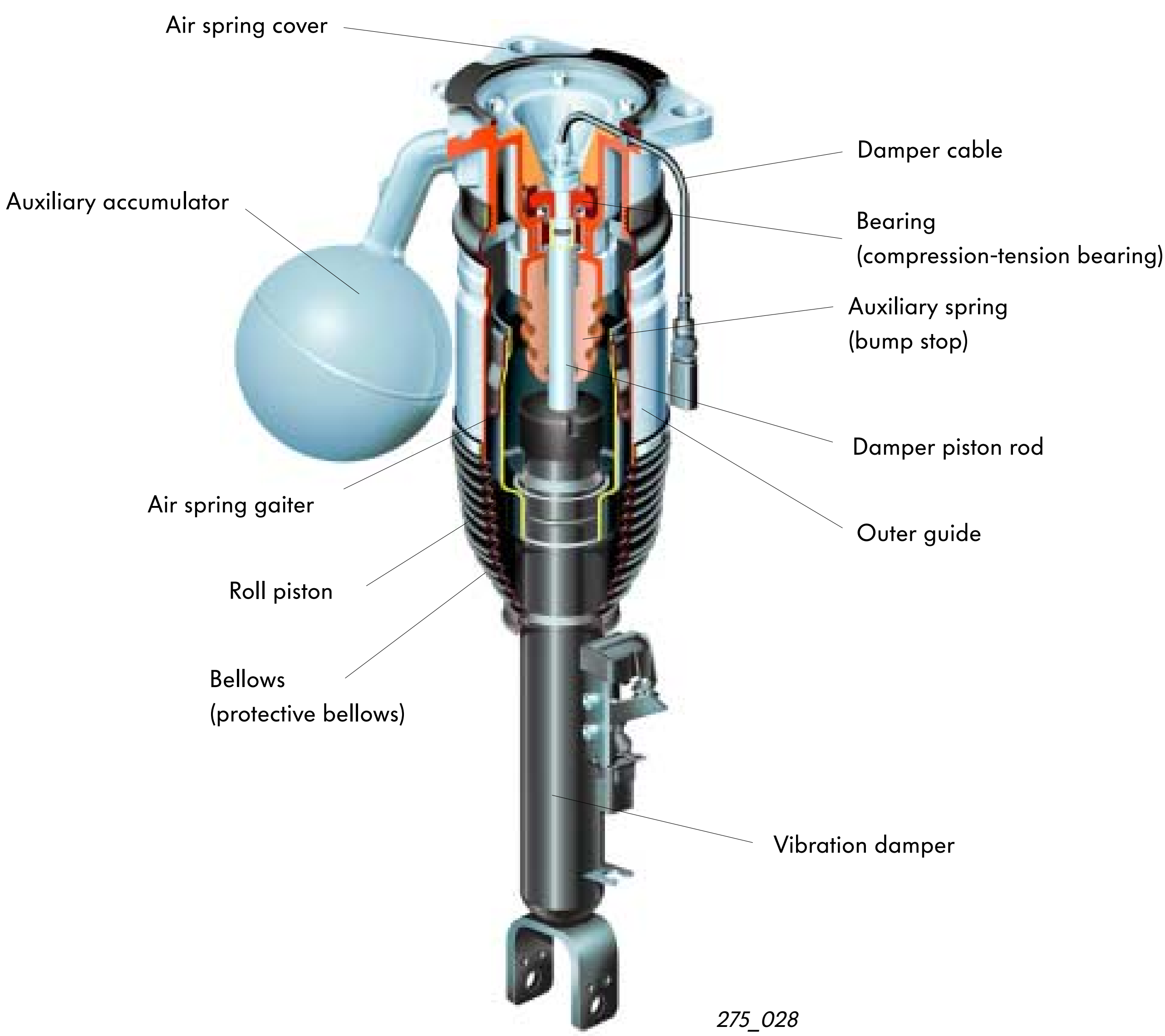
Design and function

The struts are designed to minimise the effect of transverse forces on the dampers. The special design of the strut support bearing on the front axle and the cardanic acting hydro-mounted version on the rear axle help reduce the effects of transverse forces on the dampers.

Residual pressure maintaining valves are mounted directly on the air connection of each air spring strut.
They maintain a residual pressure of about 3.5 bar in the air spring strut. This permits easy assembly and mounting of the components.

The outer guide protects the air spring gaiter against soiling and damage besides its function of guiding the air spring gaiter and bellows.

Strut, rear axle



275_028

Damper adjustment valve

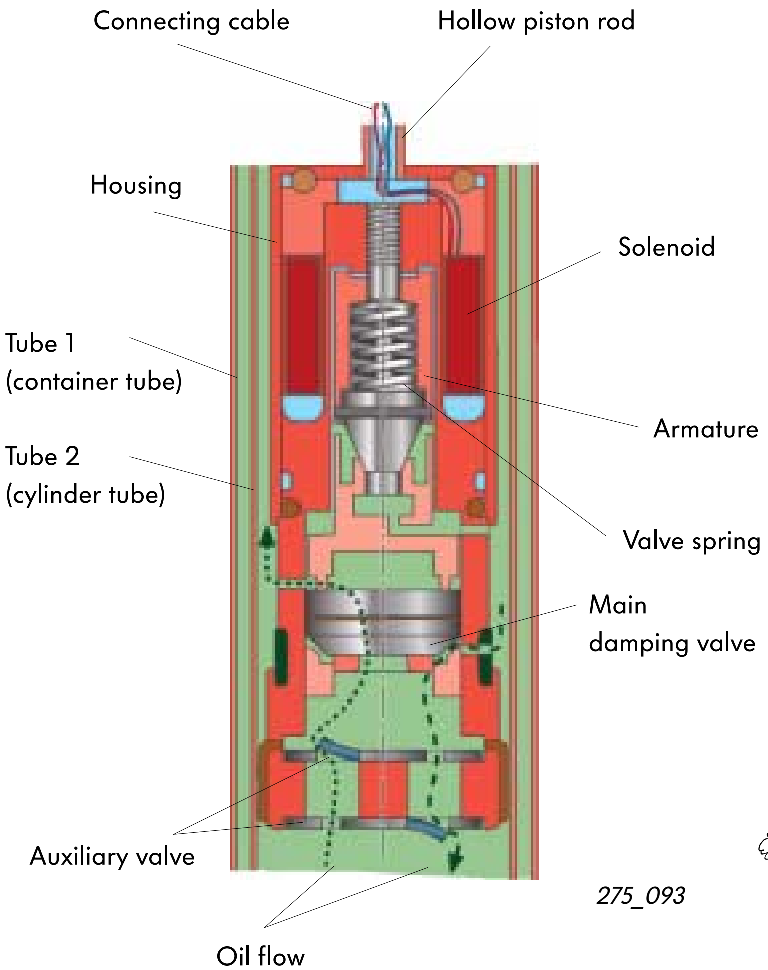
The CDC twin-tube gas-filled damper is adjustable over a wide range of damping forces via an electrically controlled valve integrated in the piston.
The oil flow through the piston valve, and hence the damping force, can be adapted to momentary demand within a few milliseconds by varying the electric current flowing through the solenoid.

The wheel acceleration senders mounted on each damper generate signals which, together with the signals supplied by the body acceleration senders, are used to calculate the required damper setting.

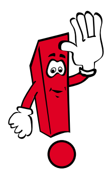
Since the system can rapidly detect and control tension and compression stages, it permits adjustment of the damping force required for the momentary driving situation.

The driving situation dependent maps are stored in the self-levelling suspension control unit.

Example of a piston valve



275_093

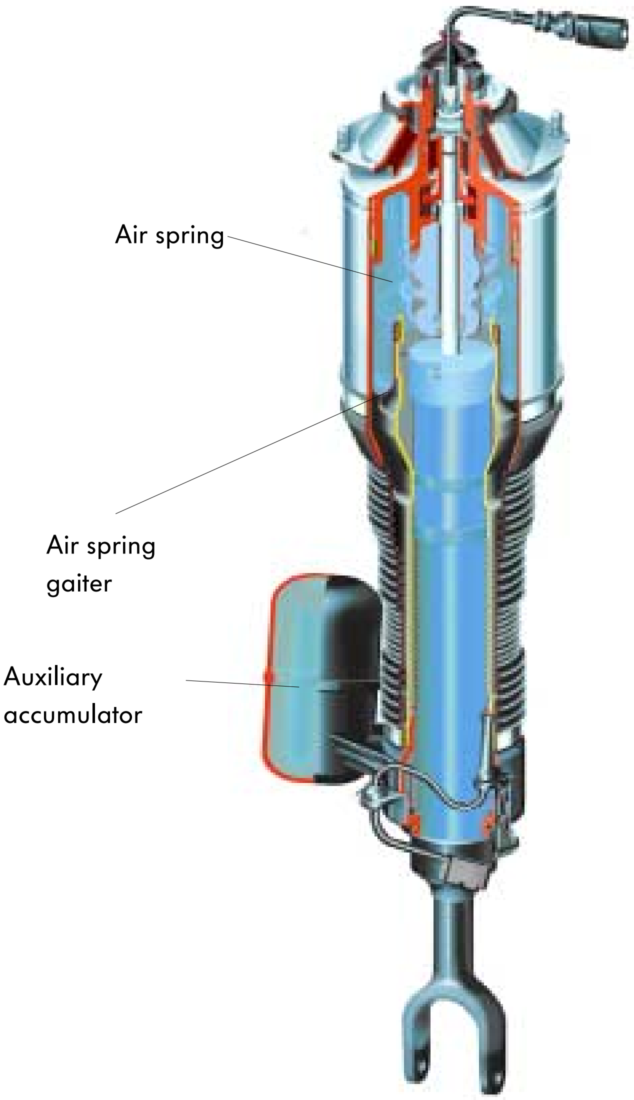


In certain driving dynamic states - e.g. longitudinal and/or transverse dynamics - the "skyhook control" is deactivated and the dampers are controlled by other dynamic modules.

Design and function

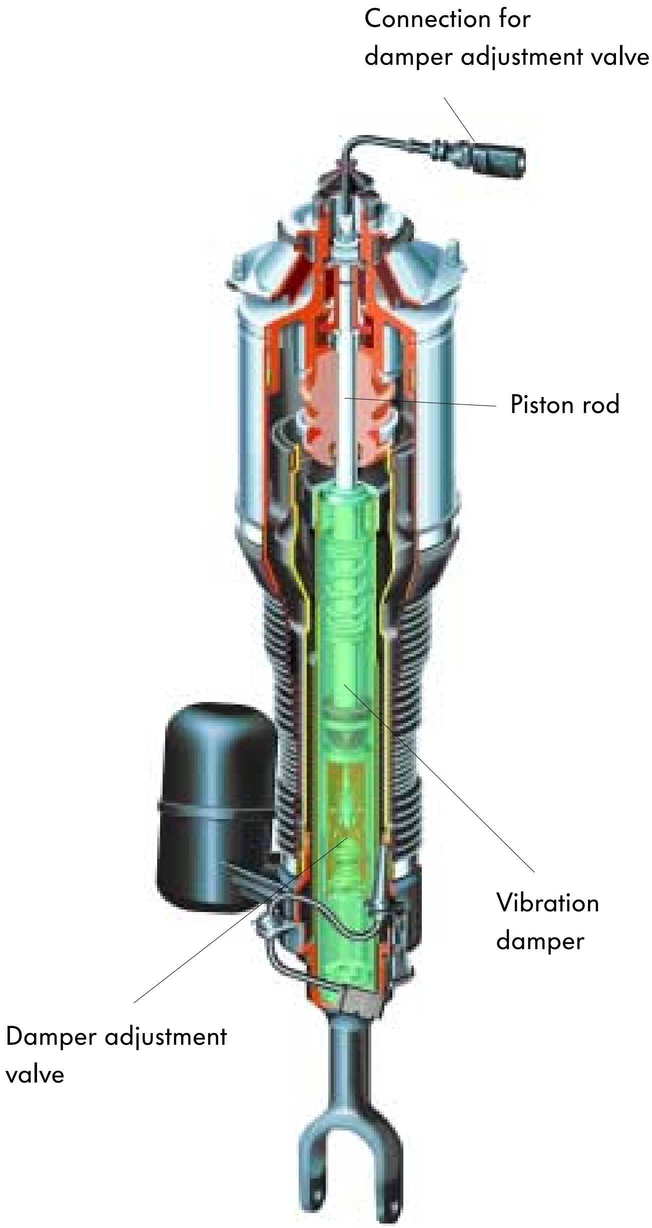
Air spring strut, front axle

Air spring part (blue)



275_086

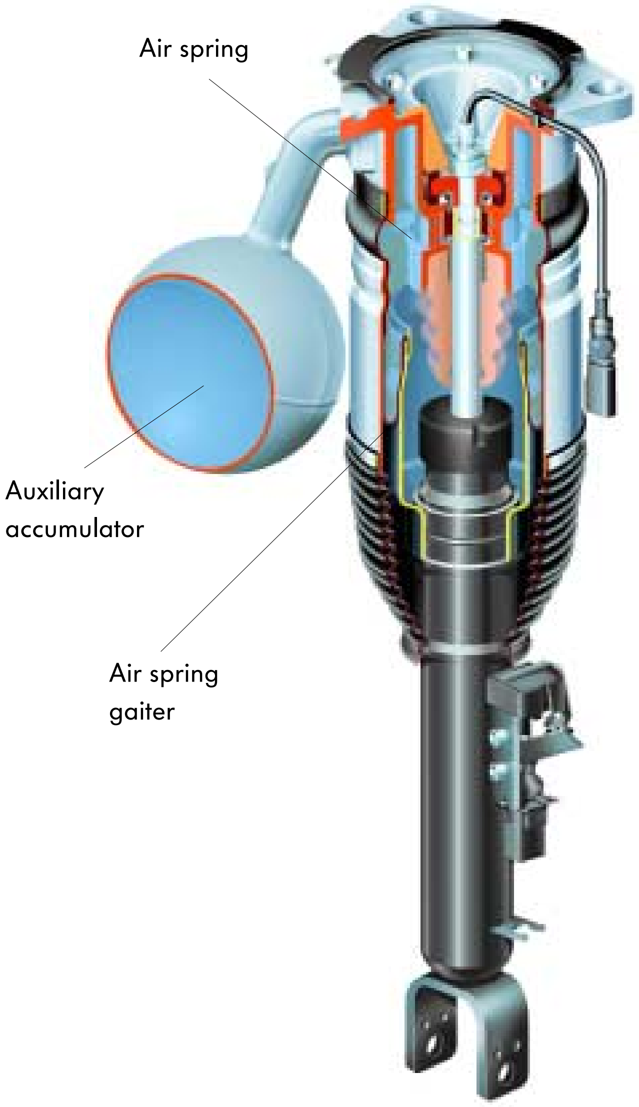
Damper part (green)



275_084

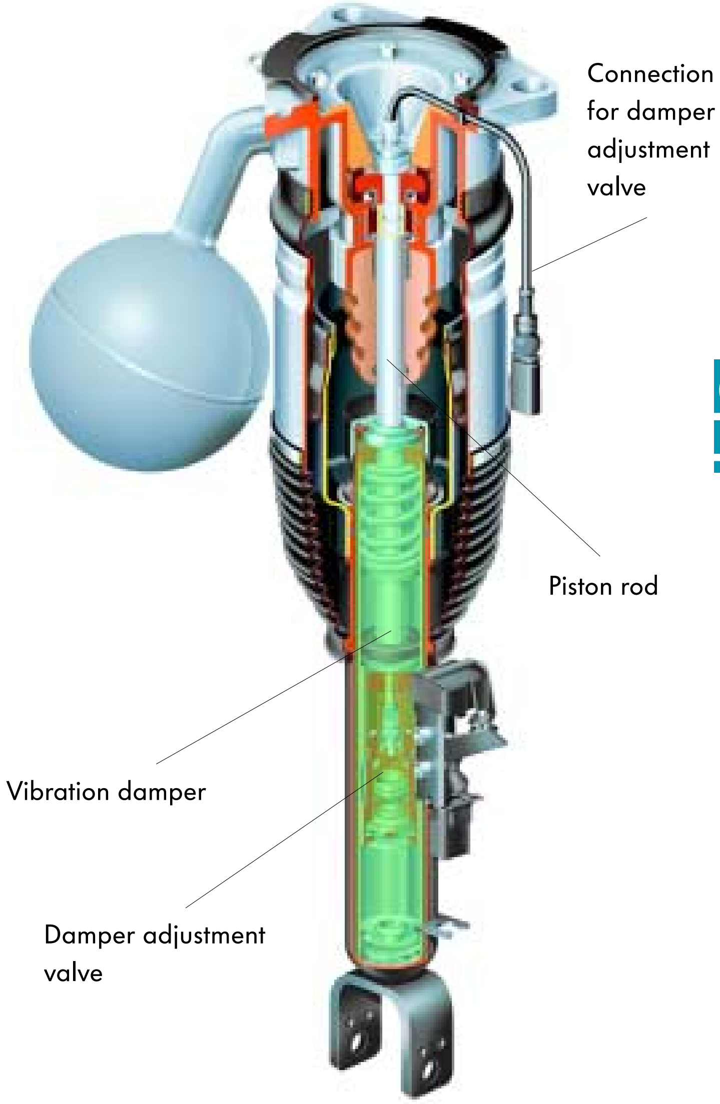
Air spring strut, rear axle

Air spring part (blue)



275_087

Damper part (green)



275_085

Design and function

Air supply unit

The air supply unit (ASU) is a compact unit. It is mounted to the underbody on an anti-vibration mounting in the spare-wheel well adjacent to the activated charcoal filter.

A plastic cover with vents provides protection against soiling.

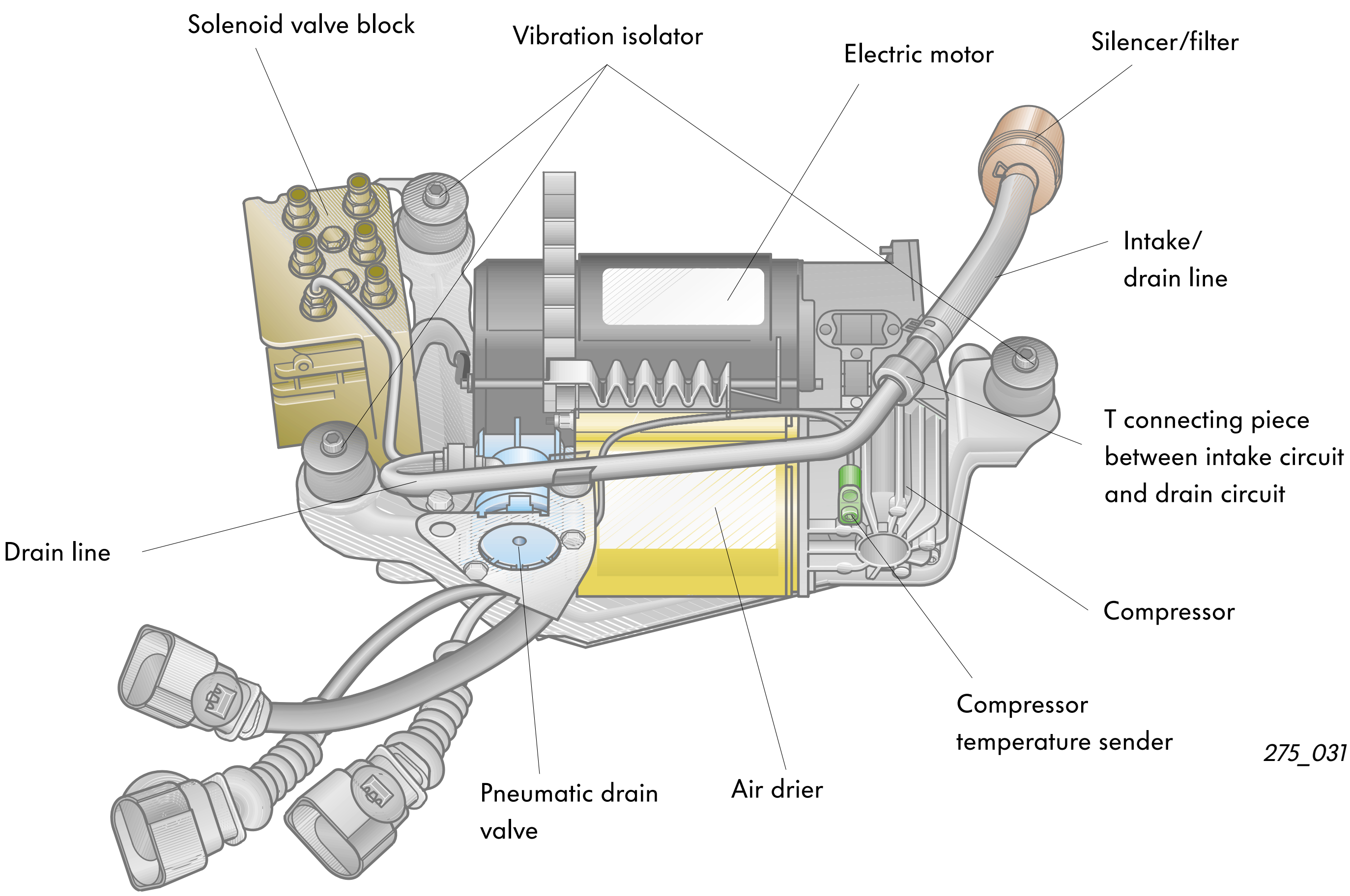
The compressor is supplied with air via the luggage compartment. Air is drawn in via the silencer/filter, cleaned and discharged.

A temperature sender protects the compressor against overheating and ensures availability of the air supply for the air suspension in all climatic and driving conditions.

The air supply unit comprises:

– the compressor unit with
  electric motor,
  dry-running compressor,
  air drier,
  residual pressure maintaining unit,
  maximum pressure limiter,
  drain circuit/valve,
  silencer with air filter,
  compressor temperature sender (temperature sender for overheating protection),
  pneumatic drain valve with pressure relief valve and

– the solenoid valve block with
  control valves for each air spring strut and for the pressure accumulator as well as
  an integrated pressure sender for monitoring the pressure accumulator.



275_031

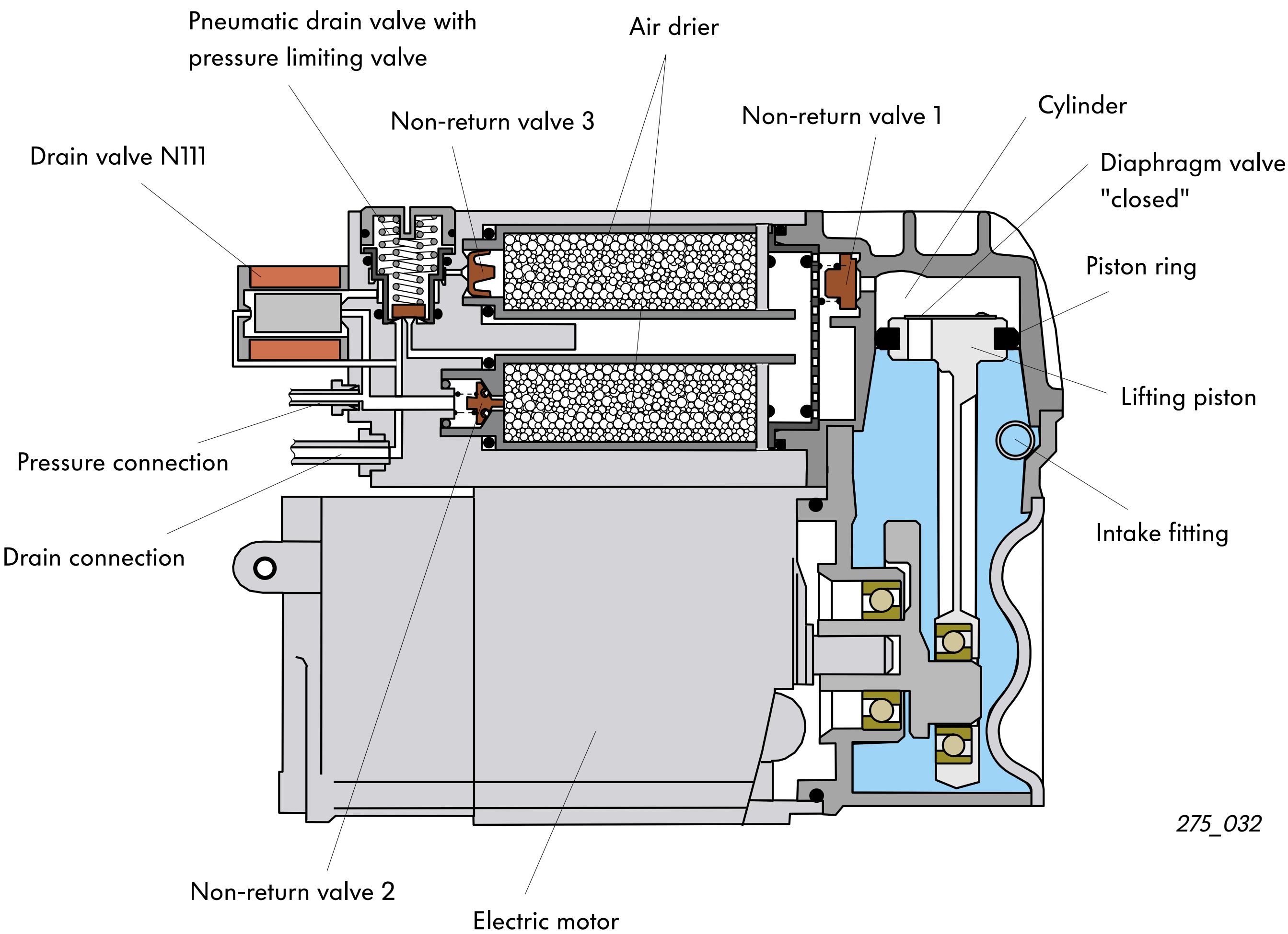
Compressor unit

Compressed air is produced by means of a single-stage piston compressor with integrated air drier.
To prevent soiling of the gaiters and the air drier (drier cartridge), the compressor is designed as a so-called dry-running compressor.

Lifetime-lubricated bearings and a piston ring made of PTFE (polytetrafluorethylene) ensure a long service life.

The drain valve N111, a pneumatic drain valve with pressure limiting valve and 3 non-return valves are integrated in the air drier housing.

To protect the compressor against overheating, it is switched off if excess temperature occurs.



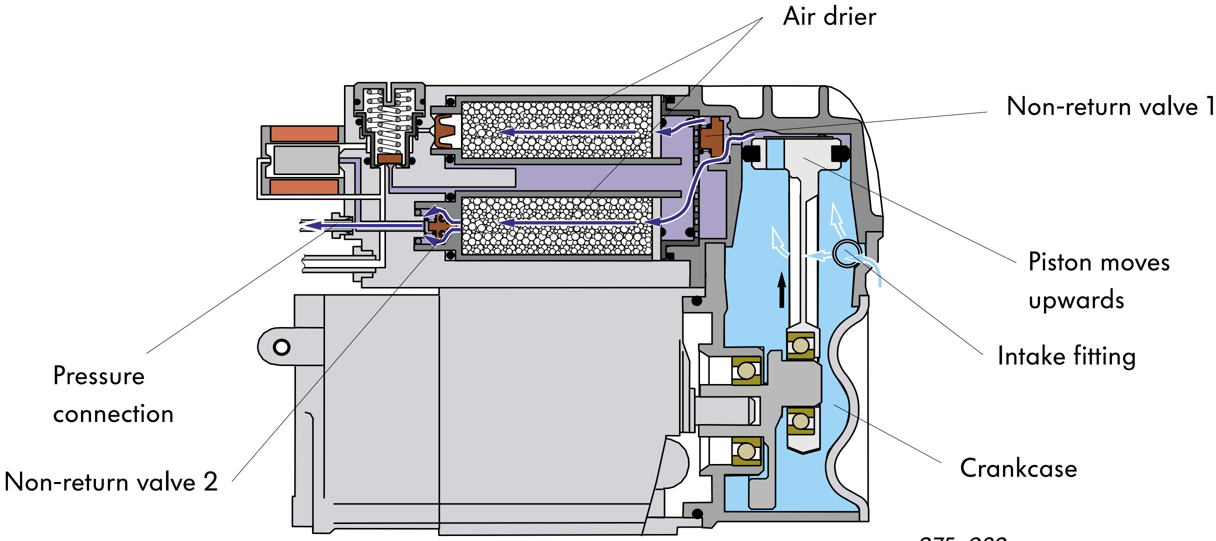
275_032

Design and function

Intake/compression cycles

During the upwards movement of the piston, air is drawn into the crankcase through the intake fitting via the silencer/filter. Air in the cylinder is compressed above the piston and flows into the air drier via non-return valve 1.

The compressed and dried air flows via non-return valve 2 and the pressure connection to the valves and the pressure accumulator.



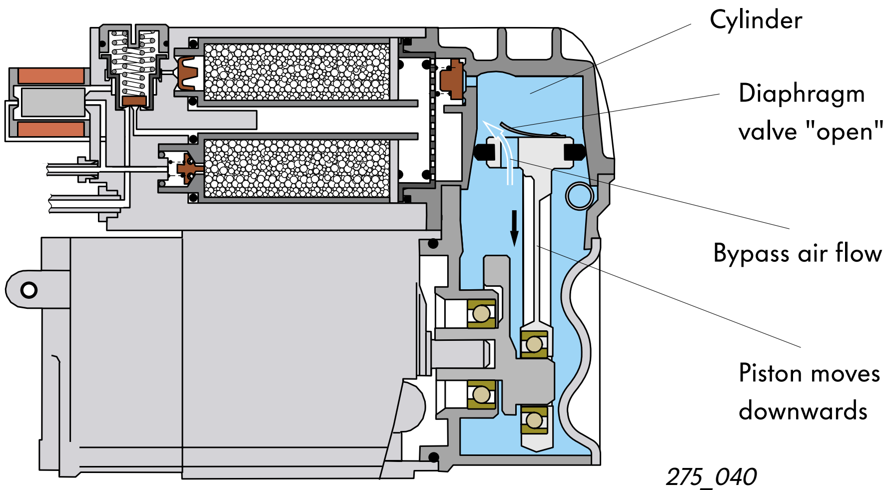
275_039

Bypass air flow

During the downwards movement of the piston, air drawn into the crankcase bypasses the diaphragm valve and flows into the cylinder.

Fill/lift cycles

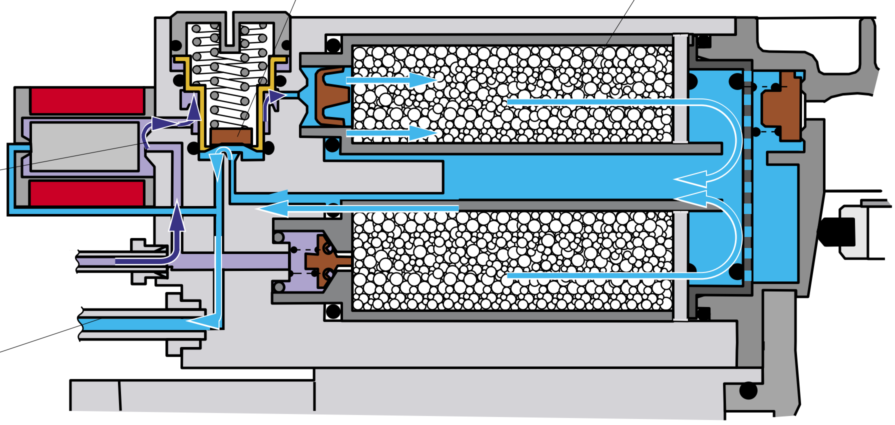
To fill the springs (i.e. raise the vehicle), the control unit activates the compressor relay and the air spring valves at the same time.



275_040

Drain/lowering cycles

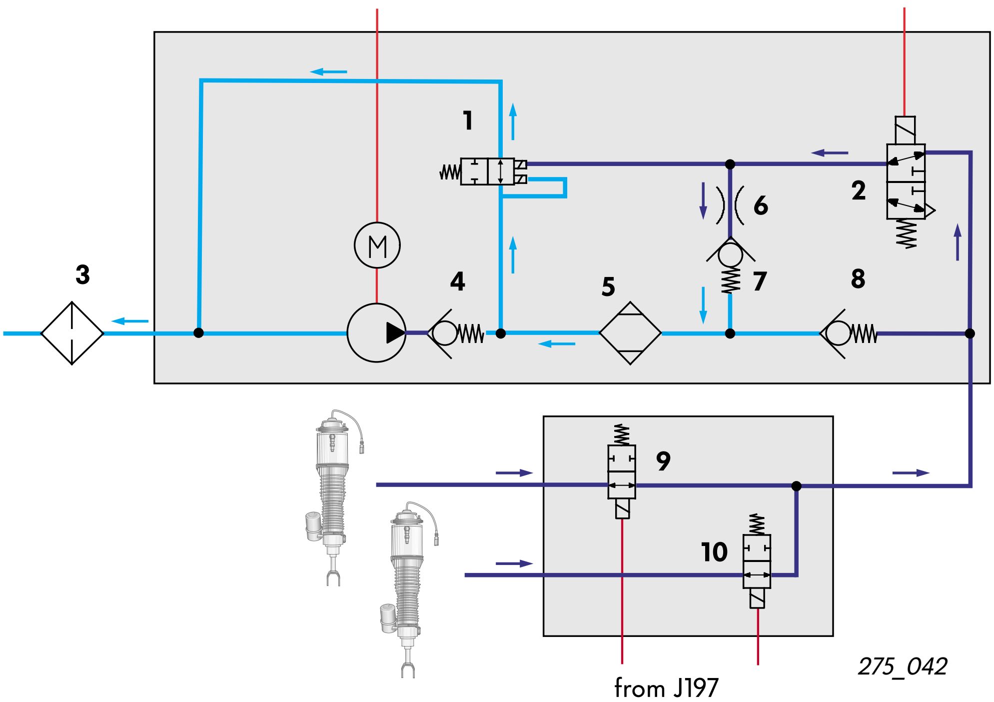
Suspension strut valves N148 and N149 and drain valve N111 are activated (open) during the drain cycle. The air spring pressure flows towards the pneumatic drain valve and from there into the spare-wheel well in the luggage compartment via the air drier, the pressure limiting valve and the silencer/filter.



275_041

Pneumatic diagram of "drain" cycle
(example: rear axle)

1 - Pneumatic drain valve
2 - Electric drain valve N111
3 - Silencer/filter
4 - Non-return valve 1
5 - Air drier
6 - Drain restrictor
7 - Non-return valve 3
8 - Non-return valve 2
9 - Suspension strut valve N148
10 - Suspension strut valve N149



275_042

Design and function

Pneumatic drain valve

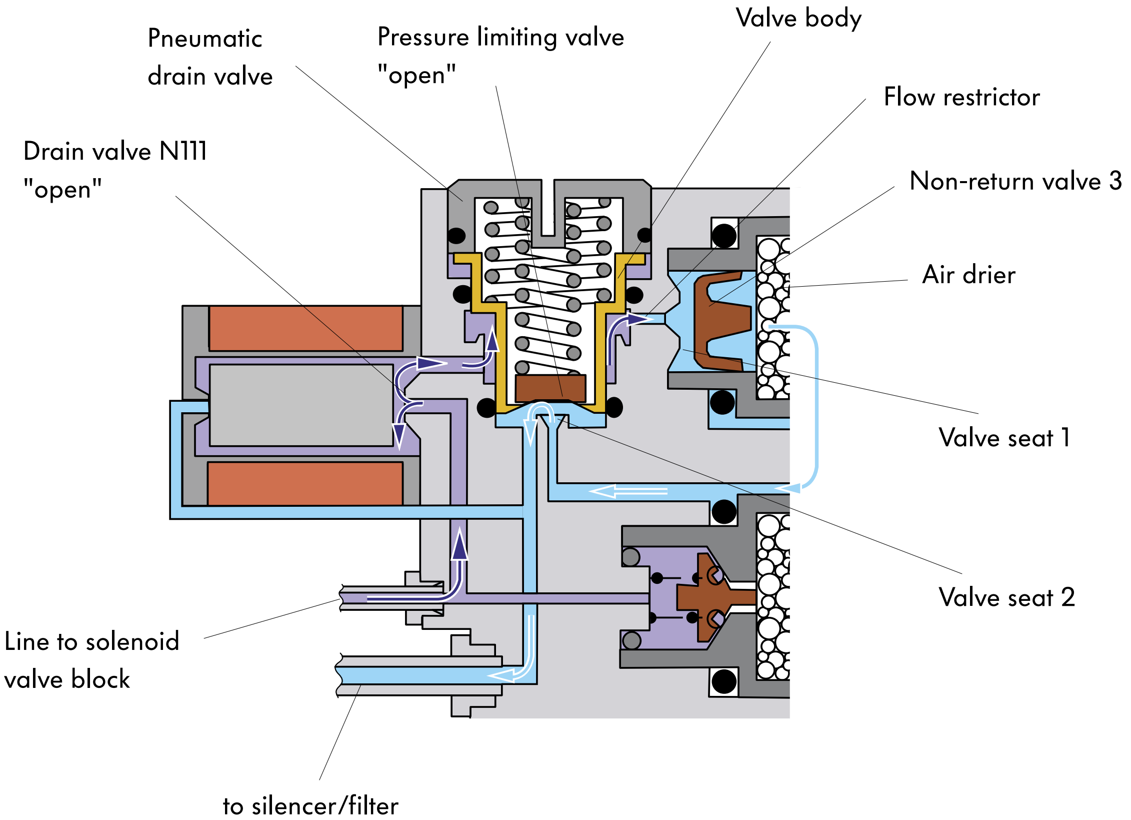
The pneumatic drain valve performs two functions:

– residual pressure maintenance and
– pressure limitation.

To prevent damage to the air springs (air spring gaiter), a specific minimum pressure of > 3.5 bar (residual pressure) must be maintained.
The residual pressure maintenance function ensures that pressure in the air spring system does not drop below 3.5 bar during pressure relief (except in the case of leaks which occur upstream of the pneumatic drain valve).

When an air spring pressure of > 3.5 bar is applied, the valve body lifts against the spring force of the two valve springs and opens valve seats 1 and 2. The air spring pressure is now admitted into the air drier via the flow restrictor and non-return valve 3. After passing through the air drier, the air bypasses the valve seat of the pressure limiting valve and the drain filter in the spare-wheel well in the luggage compartment.

A sharp decrease in pressure downstream of the flow restrictor leads to a reduction in relative atmospheric humidity, thereby increasing the amount of moisture absorbed by the "waste air".

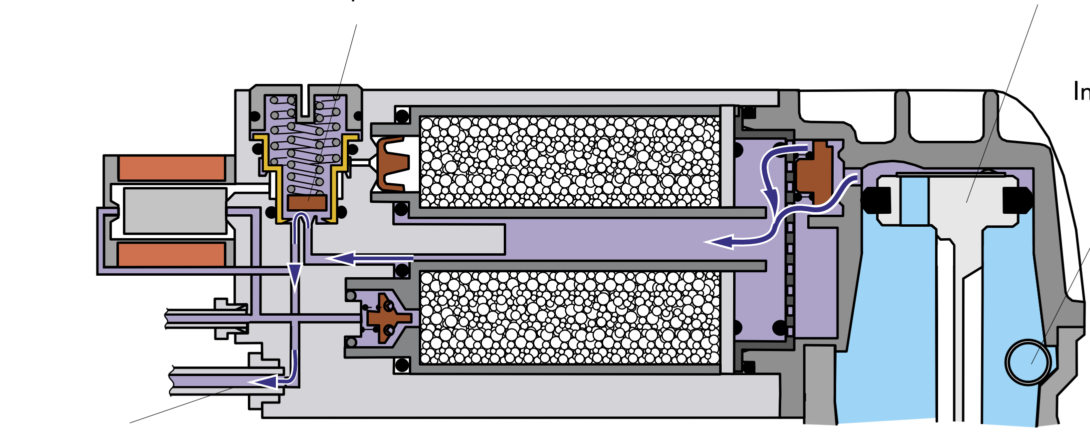


275_043

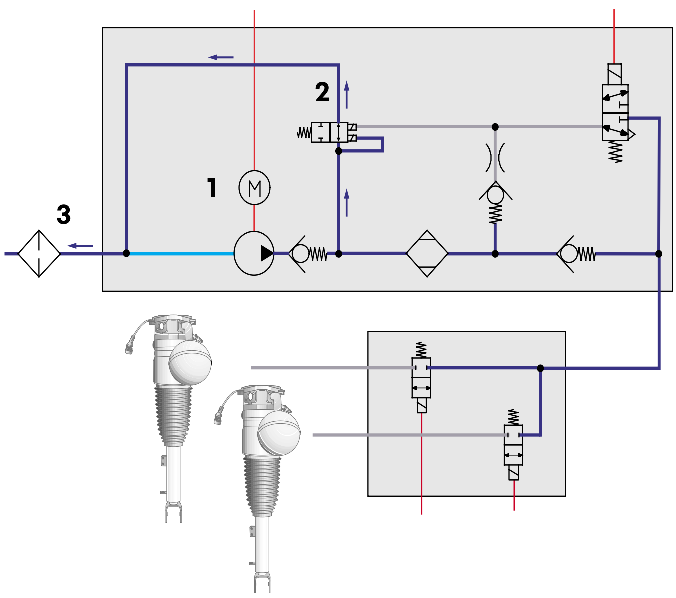
Pressure limiting valve

The pressure limiting valve protects the system against excessively high pressures, e.g. if the compressor fails to cut out due to a defective relay contact or a defective control unit.

In this case, the pressure limiting valve opens against the spring force when the pressure exceeds approx. 20 bar, and air conveyed by the compressor escapes via the filter.



275_044



1 - Compressor
2 - Pneumatic drain valve with pressure limiting valve
3 - Silencer/filter

275_044a

Air drier

The air in the pressure system must be dehumidified to avoid problems with

- corrosion and
- freezing

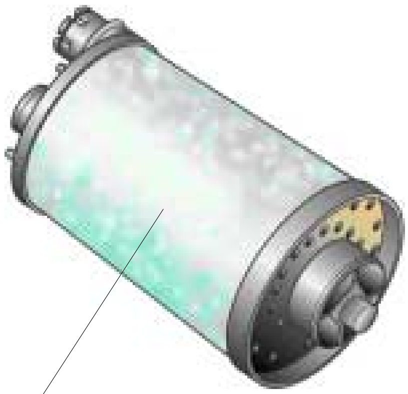
due to condensation water.

An air drier is used to dehumidify the air.

The air drier uses a regenerative process, i.e. the air compressed in the self-levelling suspension system is ducted through a silicate granulate and dried in the process.
This granulate is able to absorb atmospheric humidity amounting to over 20 % of its natural weight, depending on temperature.
If the dried air is discharged again due to operating requirements (to lower the springs), it flows back through the granulate and extracts from it the moisture which it has absorbed when it is discharged to atmosphere.
As a result of this regenerative process, the air drier requires no maintenance.
It is not subject to a replacement interval.

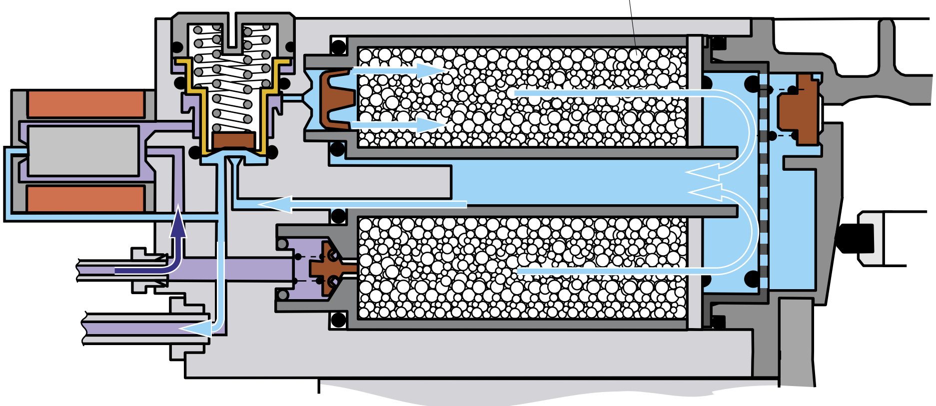
Since the air drier is only regenerated via discharged air, the compressor must not be used to fill other vessels with compressed air.

Water or moisture in the system are signs that the air drier or system has malfunctioned.



275_033

Air drier with granulate filling



275_045

Pressure accumulator

Extraction of compressed air from the pressure accumulator allows the vehicle level to be raised quickly with a minimum of noise.
The pressure accumulator is only filled while the vehicle is moving. As a result, compressor operation is barely audible.

Provided that sufficient pressure is available in the pressure accumulator, the vehicle level can be raised even if the compressor is not running. Pressure is sufficient when the pressure difference between the pressure accumulator and the air springs is at least 3 bar before increasing the level.

The pressure accumulator is made of aluminium and has a capacity of 5 litres.
The maximum operating pressure is about 16 bar.

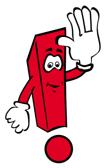
Air supply strategy

At road speeds of < 35 kph, air is primarily supplied via the pressure accumulator (provided that sufficient pressure is available).

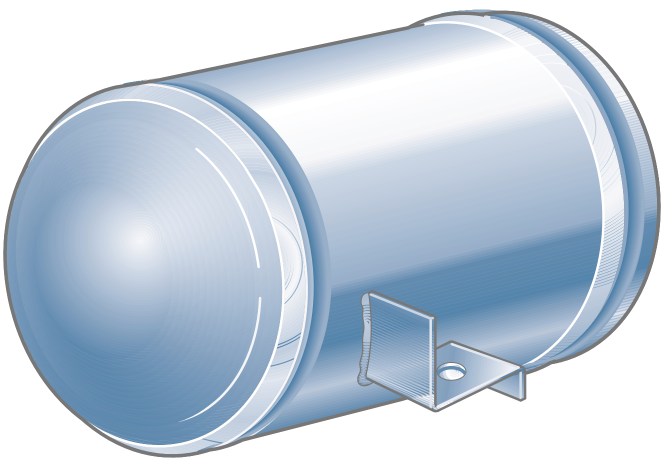
The pressure accumulator is only filled when the vehicle is travelling at speeds above > 35 kph.

At road speeds > 35 kph, air is primarily supplied by the compressor.

This supply strategy ensures that the system operates silently and conserves vehicle battery capacity.



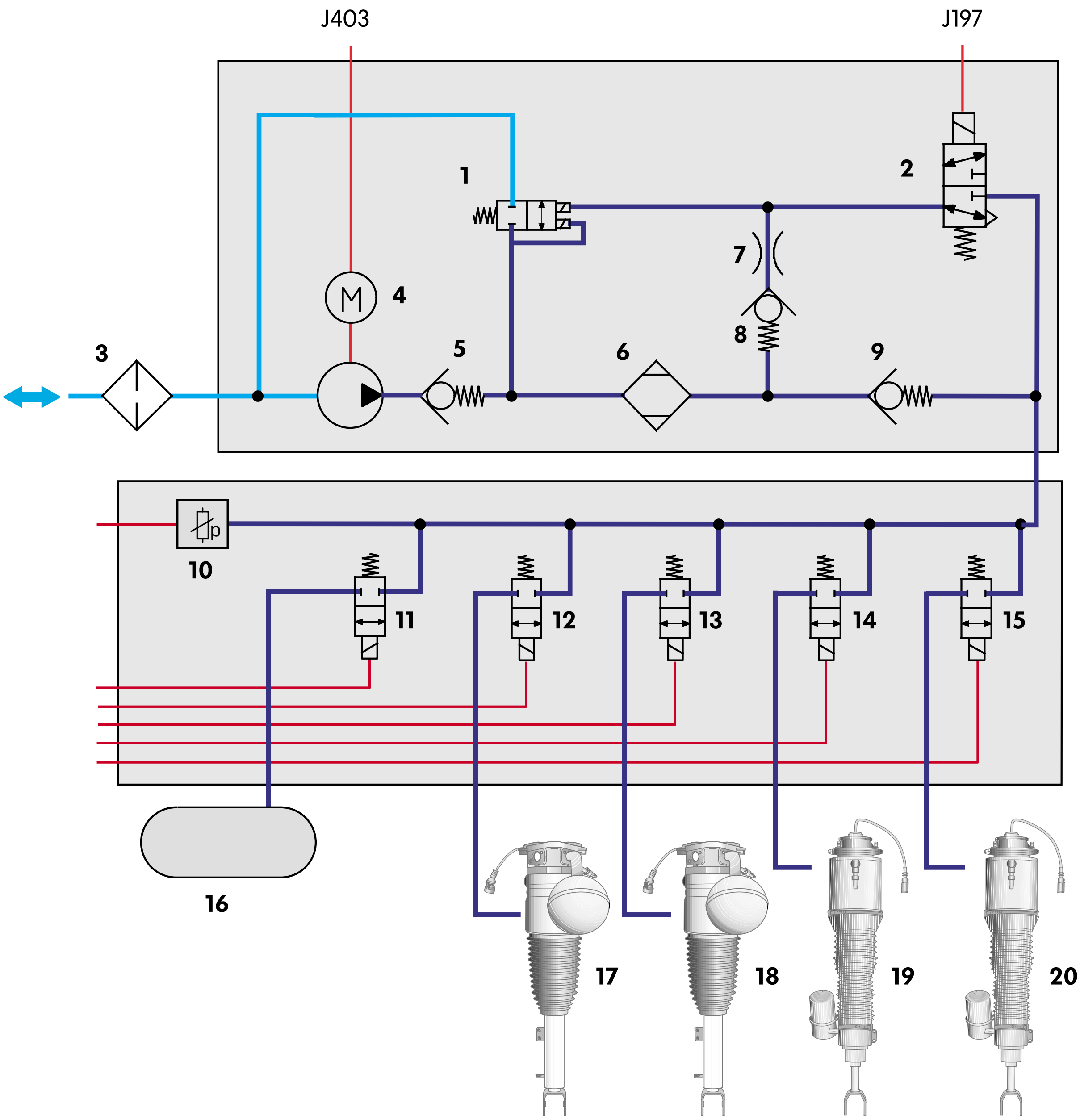
The compressor starts running when compressed air is extracted from the pressure accumulator even if the driver has not adjusted the vehicle's level.



275_064

Pneumatic diagram

1 - Pneumatic drain valve
2 - Electric drain valve N111
3 - Silencer/filter
4 - Compressor V66
5 - Non-return valve 1
6 - Air drier
7 - Drain restrictor
8 - Non-return valve 3
9 - Non-return valve 2
10 - Pressure sender G291
11 - Pressure accumulator valve N311
12 - Suspension strut valve, rear left N150
13 - Suspension strut valve, rear right N151
14 - Suspension strut valve, front left N148
15 - Suspension strut valve, front right N149
16 - Pressure accumulator
17 - Strut, rear left
18 - Strut, rear right
19 - Strut, front left
20 - Strut, front right



275_065

Solenoid valves

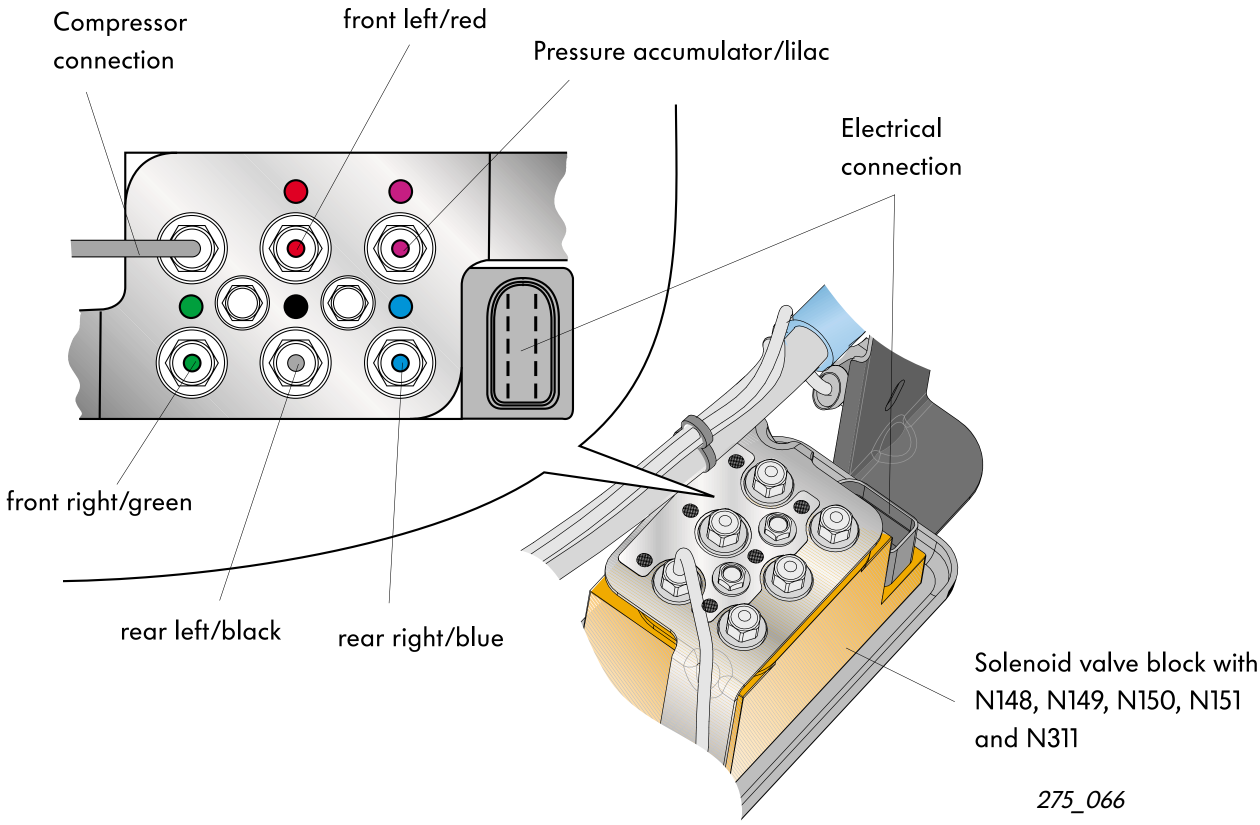
All in all, the air suspension has six solenoid valves.

The drain valve N111 together with the pneumatic drain valve form a functional unit which is integrated in the drier housing. The drain valve N111 is a 3/2 way valve and is de-energised when closed.

The pneumatic drain valve has two tasks: to limit pressure and to maintain residual pressure.

Together with the self-levelling suspension pressure accumulator valve N311, the four air spring valves N148, N149, N150 and N151 are combined in the solenoid valve block. The valves in the solenoid valve block are designed as 2/2 way valves and are de-energised when closed.
The pressure on the air spring side/accumulator side acts in the closing direction.

To avoid confusion when connecting the pressure lines, the pressure lines are colour coded.
The matching connections on the solenoid valve block are also colour coded.

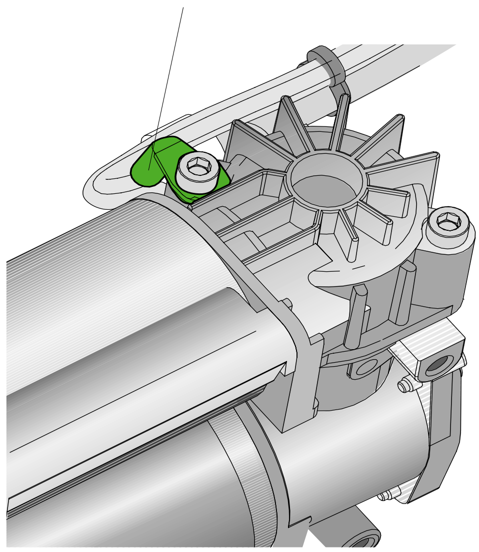


275_066

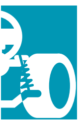
Compressor temperature sender G290 (overheating protection)

To ensure system availability, compressor temperature sender G290 is attached to the compressor cylinder head.

The control unit J197 shuts the compressor down and inhibits starting when a max. permissible compressor temperature is exceeded.



275_067

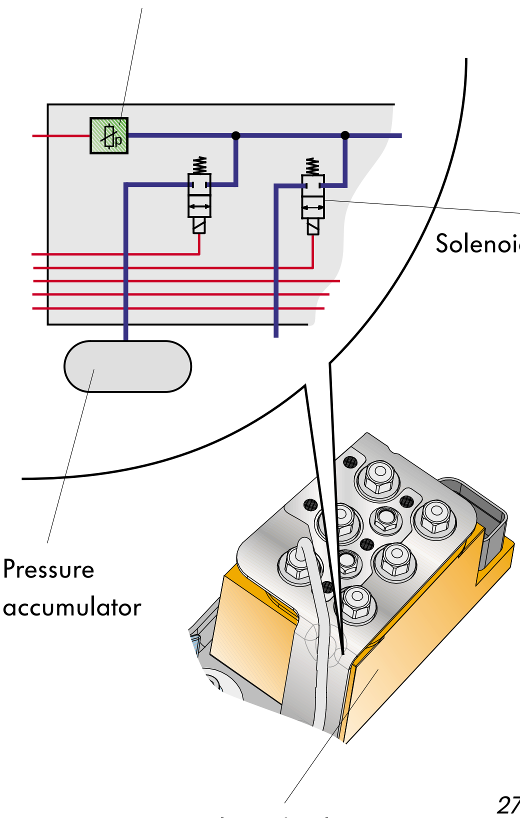


Self-levelling suspension system pressure sender G291

The pressure sender G291 is integrated in the valve unit and monitors pressure in the pressure accumulator and the air springs. Information on accumulator pressure is required to make plausibility checks on the up-control functions and perform self-diagnosis. The individual pressures of the air springs and the pressure accumulator can be determined by activating the solenoid valves accordingly.

The individual pressures are measured while evacuating or filling the air springs or the pressure accumulator. The pressures determined in this way are stored and updated by the control unit.
Accumulator pressure is additionally determined every six minutes (updated) during vehicle operation.

G291 generates a voltage signal proportional to the pressure.



275_068

Vehicle level senders G76, G77, G78, G289 (level sensors)

The vehicle level senders are so-called wheel angle sensors. Changes in the level of the vehicle body are registered and converted to angular changes by means of the coupling rod kinematics.

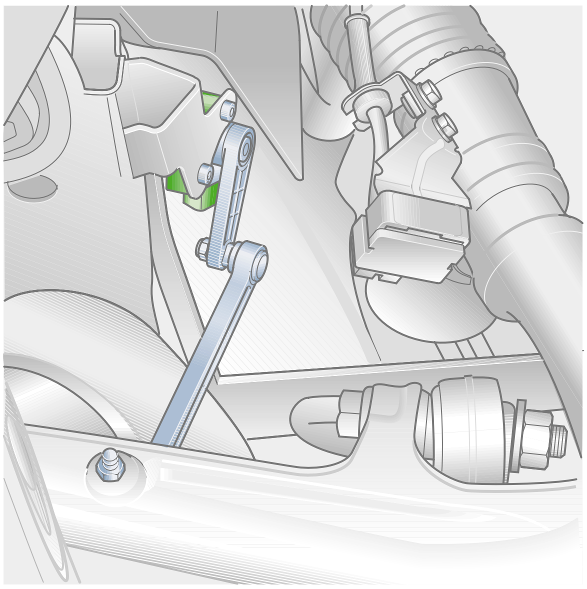
The wheel angle sensor used operates according to the induction principle.

The signal output provides an angle-proportional PWM (pulse-width modulated) signal for the self-levelling suspension.

The four level sensors are identical; only the mountings and the coupling rod kinematics are specific for each side and axle.

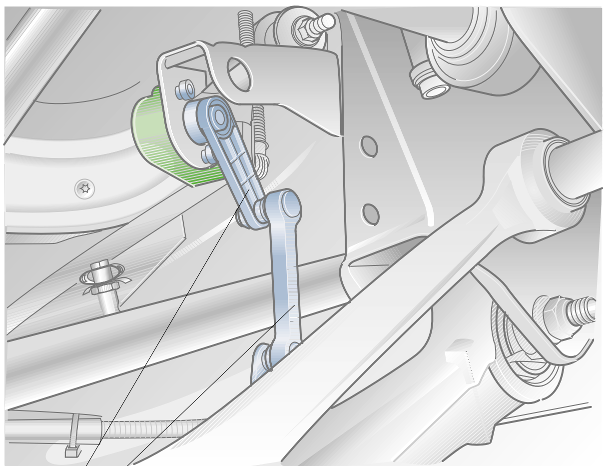
Deflection of the sender crank, and hence the output signal, is opposed on the left and right. As a result, the output signal rises on one side and drops on the other side during suspension compression, for instance.

Vehicle level sender, front axle



275_075

Vehicle level sender, rear axle



275_076

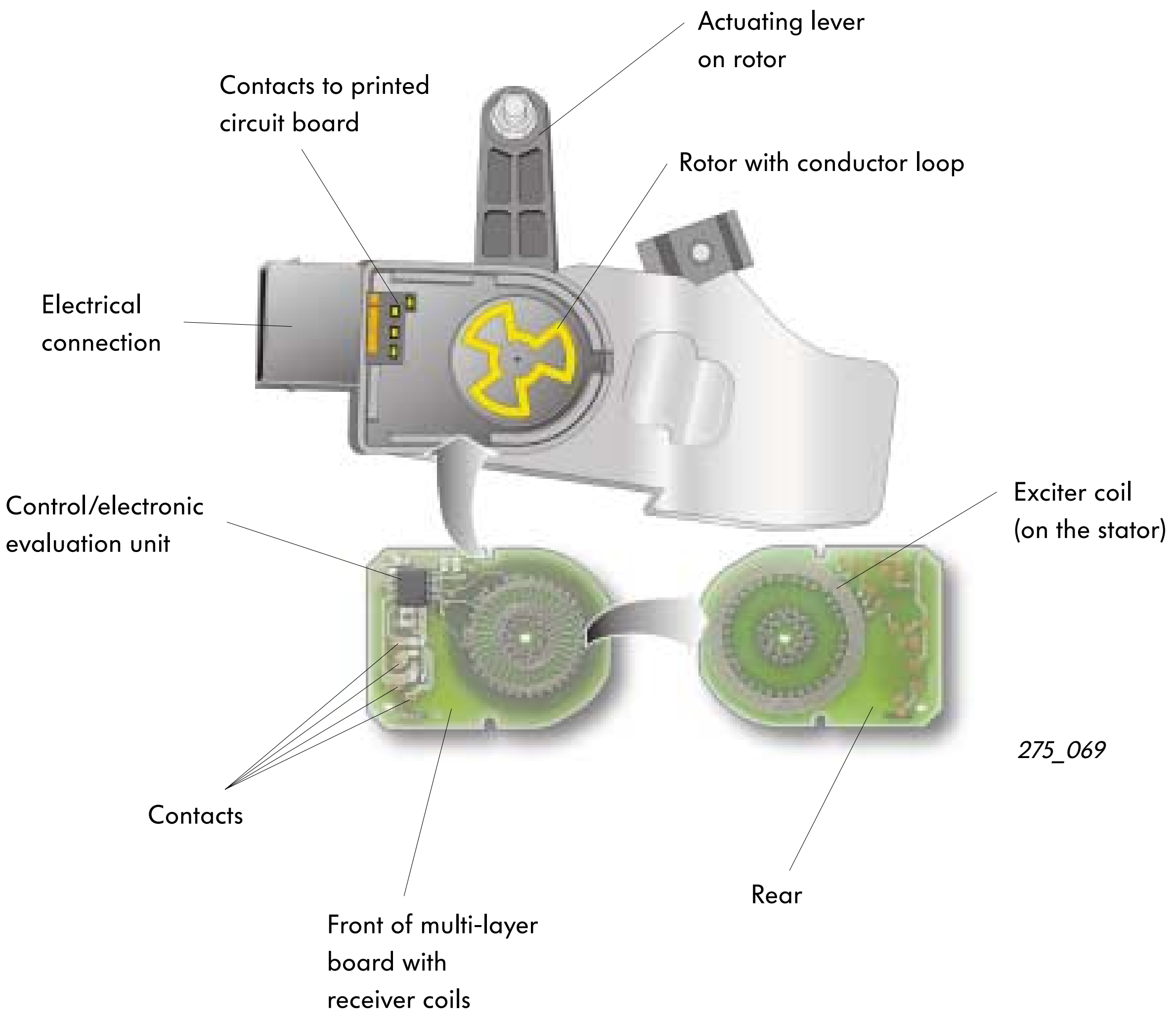
Design and function

Design of level sensors

A sensor basically comprises a stator and a rotor.

The stator comprises a multi-layer board that houses the exciter coil and three receiver coils, as well as the control and electronic evaluation unit. The three receiver coils are star-shaped and arranged in an offset pattern.
The exciter coil is located on the back of the board (stator).

The rotor is connected to the actuating lever and moves with it.
A closed conductor loop is located on the rotor. The conductor loop has the same geometric shape as the three receiver coils.



275_069

Function

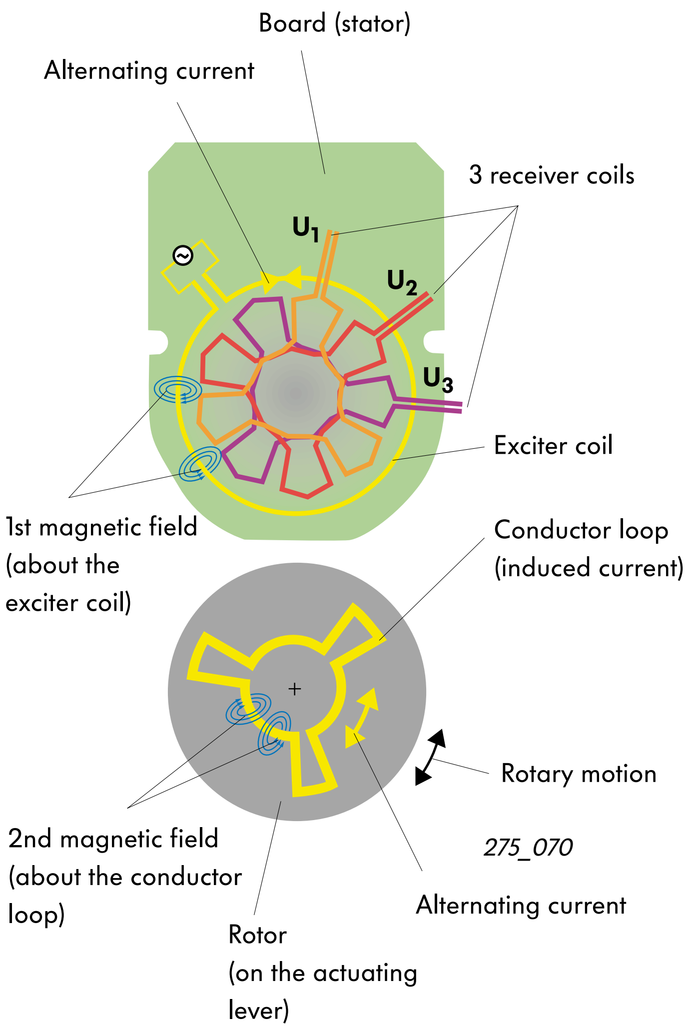
An alternating current flows through the exciter coil (stator) and produces an electromagnetic alternating field (1st magnetic field) about the exciter coil. This alternating field permeates the conductor loop of the rotor.

The electric current induced in the conductor loop of the rotor produces, in turn, an electromagnetic alternating field (2nd magnetic field) about the rotor conductor loop.
The alternating fields of the exciter coil and the rotor act upon the three receiver coils and induce position-dependent AC voltages in the receiver coils.

Whereas induction in the rotor is independent of the rotor's angular position, induction in the receiver coils is dependent on their distance from the rotor, and hence their angular position in relation to the rotor.

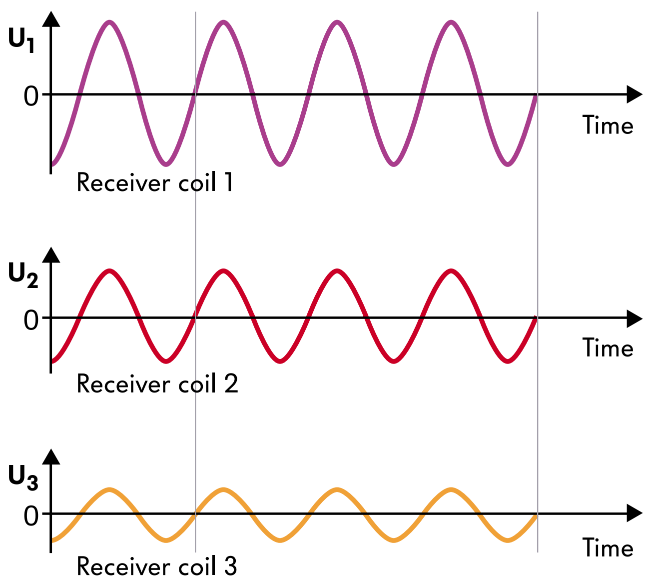
Since rotor overlap in relation to the individual receiver coils varies depending on angular position, the induced voltage amplitudes in the receiver coils vary according to their angular position.

The electronic evaluation unit rectifies and amplifies the AC voltages of the receiver coils and proportions the output voltages of the three receiver coils (ratiometric measurement). After the voltage is evaluated, the result is converted to output signals from the level sensor and made available to the control units for further processing.



275_070

Voltage amplitudes in the receiver coils depending on rotor position (example)



275_071

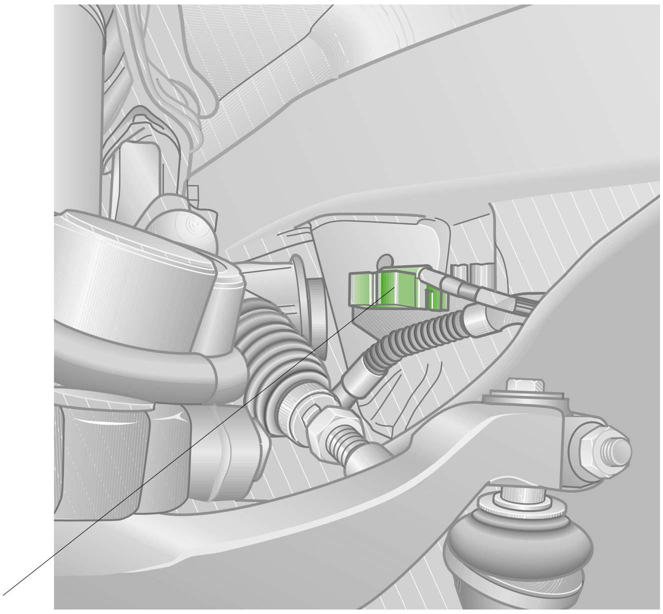
Body acceleration senders
G341, G342, G343

The body acceleration senders measure the vertical acceleration of the vehicle body.
The senders are located:

- in the front left wheel housing G341 and in the front right wheel housing G342

and

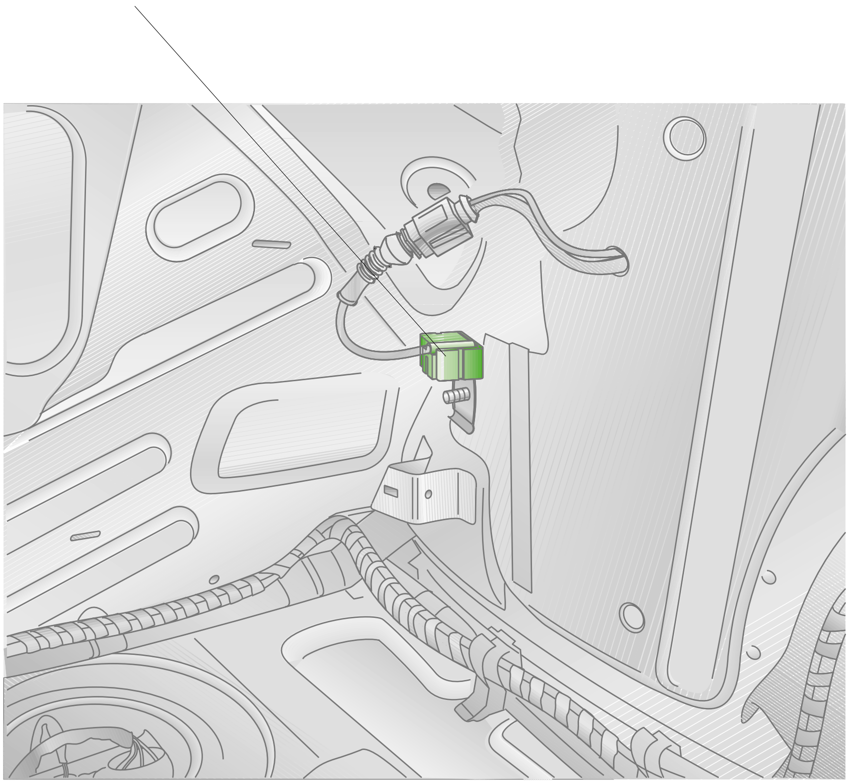
- in the luggage compartment at the front right, behind the luggage compartment lining G343.



Body acceleration sender in front left wheel housing

275_079

Body acceleration sender in luggage compartment

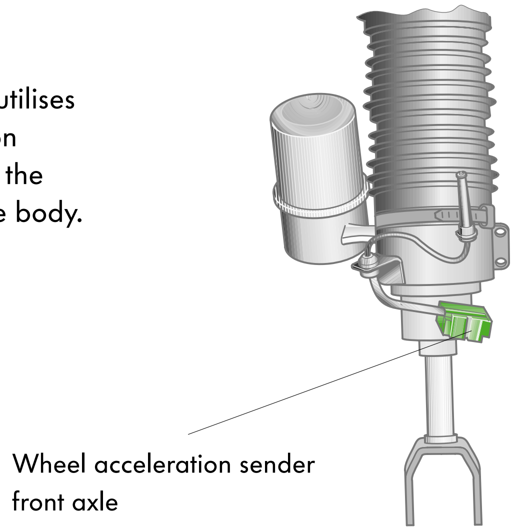


275_080

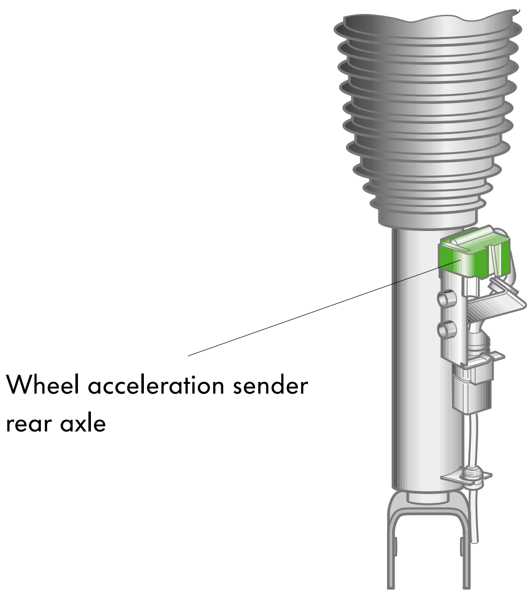
Wheel acceleration senders G337, G338, G339, G340

The wheel acceleration senders are mounted directly on the air spring struts of the front and rear axles.

They measure wheel acceleration.
The self-levelling suspension control unit utilises these signals along with body acceleration signals to calculate the direction in which the struts are moving in relation to the vehicle body.



275_088



275_089

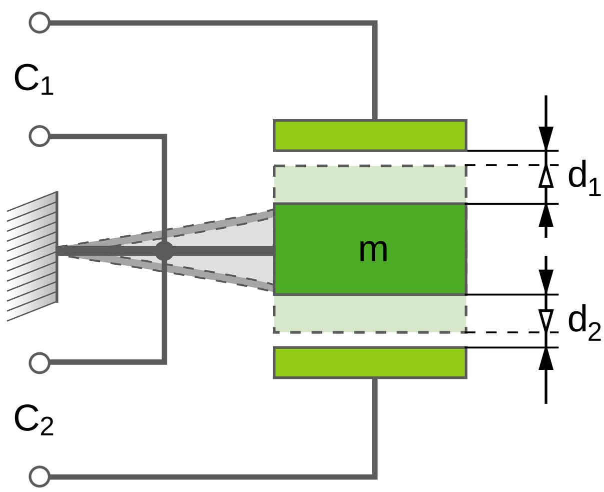
Design and function

Function and design of the acceleration senders

The body and wheel acceleration senders are identical.

The acceleration senders operate according to the capacitive measurement principle.
A flexibly mounted mass **m** acting as a centre electrode oscillates between capacitor plates and detunes the capacitance of capacitors $\mathbf{C_1}$ and $\mathbf{C_2}$ in the opposite direction at the same rate as their oscillation.
The plate distance $\mathbf{d_1}$ of the one capacitor increases by the same amount as the distance $\mathbf{d_2}$ decreases in the other capacitor.
The capacitance in the individual capacitors change as a result.
An electronic evaluation unit supplies an analogue signal voltage to the self-levelling suspension control unit.

Capacitive measurement principle of the acceleration senders



275_091

The senders have different mechanical attachments and measurement ranges (sensitivity).

Sender measurement ranges:

Sender for ...	Sender measurement range
... body acceleration	± 1.3 g
... wheel acceleration	± 13 g

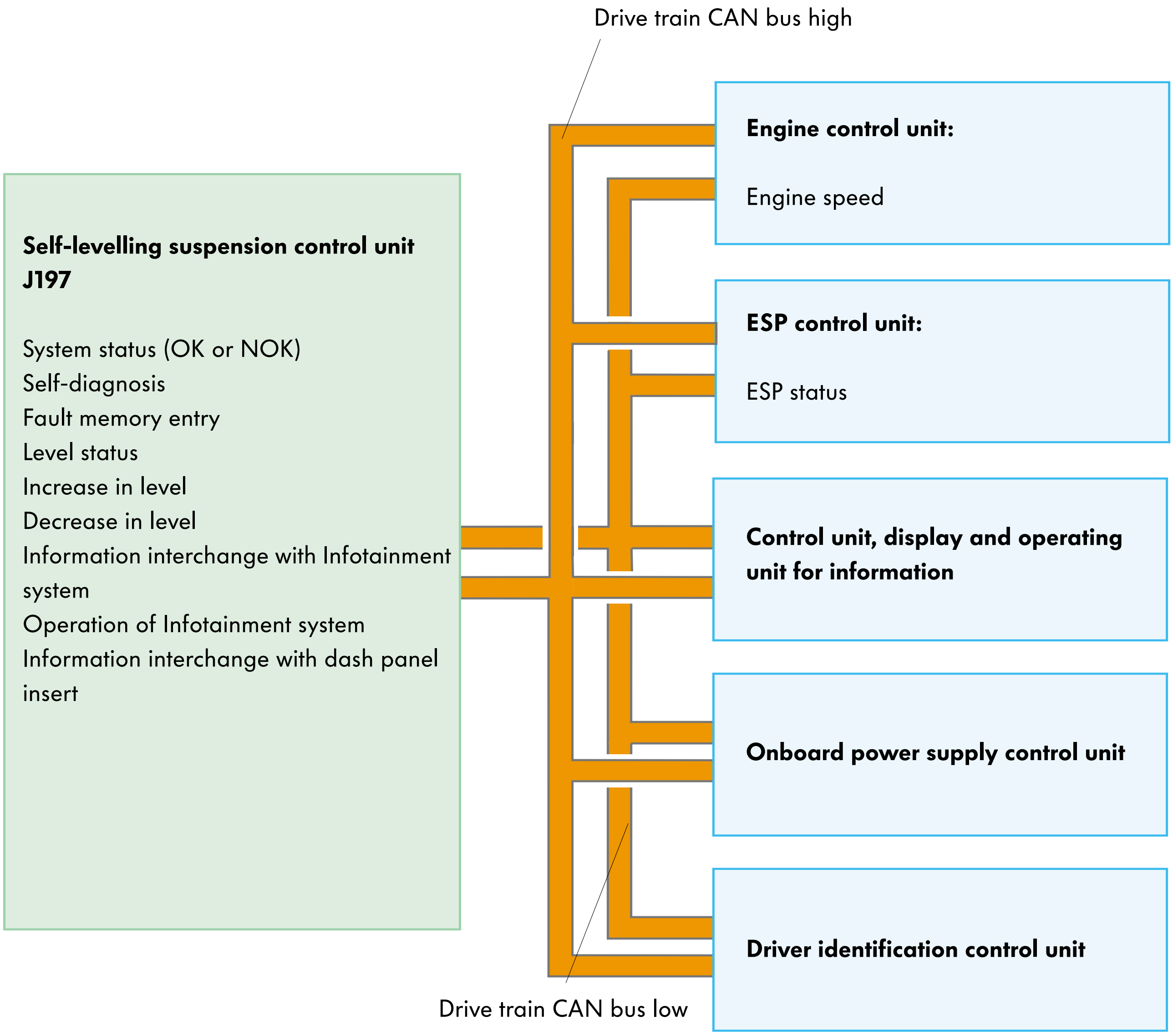
g = unit of measurement for acceleration
1 g = 9.81 m/sec^2 = standard value of acceleration due to gravity

Interfaces

CAN information exchange

Information on air suspension and damping control is exchanged between the self-levelling suspension control unit J197 and the networked control units via the drive train CAN bus, with the exception of a few interfaces.

The system overview shows by way of example the information provided via the CAN bus and received and used by the networked control units.



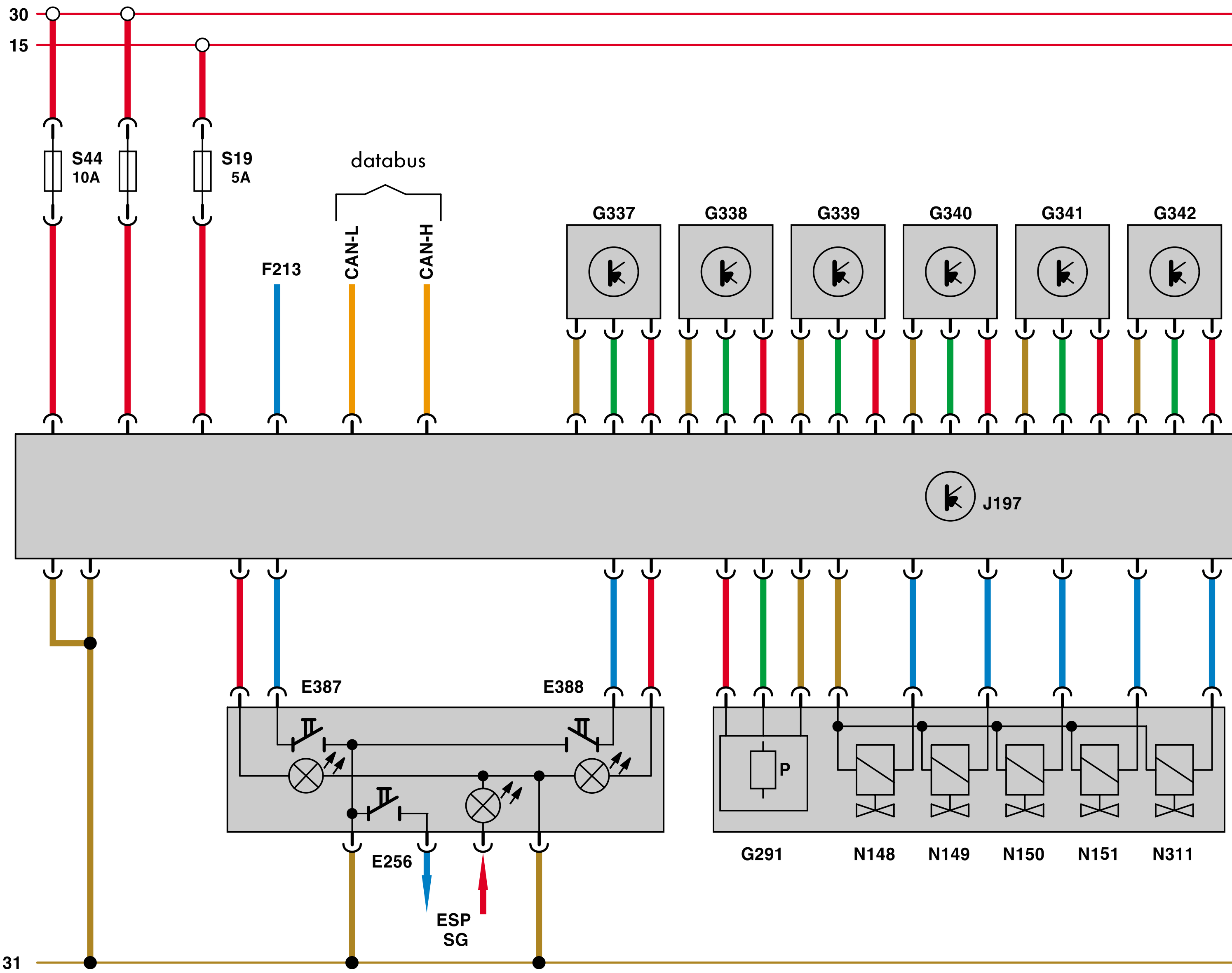
275_074

Information sent from control unit J197.

Information received and evaluated by control unit J197

Design and function

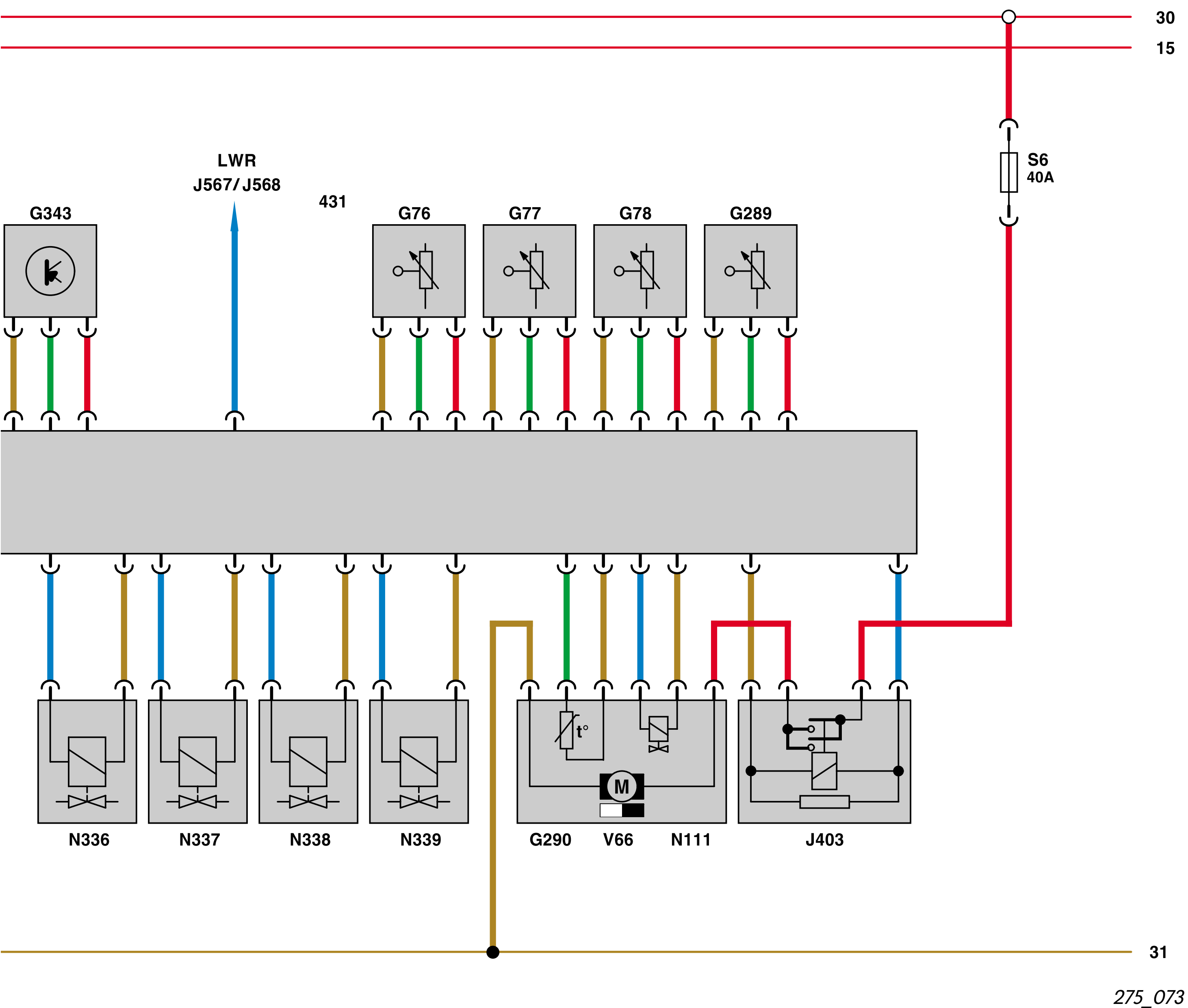
Function diagram



Legend:

E256 - TCS/ESP button
E387 - Damper adjustment button
E388 - Button for self-levelling suspension
F213 - Driver's door contact switch
G76 - Vehicle level sender, rear left
G77 - Vehicle level sender, rear right
G78 - Vehicle level sender, front left
G289 - Vehicle level sender, front right
G290 - Compressor temperature sender, self-levelling suspension
G291 - Self-levelling suspension system pressure sender

G337 - Wheel acceleration sender, front left
G338 - Wheel acceleration sender, front right
G339 - Wheel acceleration sender, rear left
G340 - Wheel acceleration sender, rear right
G341 - Body acceleration sender, front left
G342 - Body acceleration sender, front right
G343 - Body acceleration sender, rear
J197 - Self-levelling suspension control unit
J403 - Self-levelling suspension compressor relay
J567 - Gas discharge lamp control unit with HRC and J568 in the associated headlight unit



N111 - Self-levelling suspension drain valve
N148 - Suspension strut valve, front left
N149 - Suspension strut valve, front right
N150 - Suspension strut valve, rear left
N151 - Suspension strut valve, rear right
N311 - Pressure accumulator valve, self-levelling suspension
N336 - Damper adjustment valve, front left
N337 - Damper adjustment valve, front right
N338 - Damper adjustment valve, rear left
N339 - Damper adjustment valve, rear right
V66 - Self-levelling suspension compressor motor

= input signal

= output signal

= positive

= earth

= CAN databus

Further interfaces

Door contact signal

This signal is an earth signal from the onboard power supply control unit. It indicates that a vehicle door or the bootlid has been opened.

It serves as a "wake up signal" for the transition from Sleep Mode to Standby Mode.

Terminal 50 signal (via CAN)

This signal indicates that the starter has been activated. It shuts down the compressor during the start-up routine.

This safeguards the start-up routine and conserves the battery.

K wire

Self-diagnosis information is exchanged between the self-levelling suspension control unit J197 and the Diagnostic Testing and Information System via the CAN connection (Key Word Protocol 2000) to the dash panel insert and from there to the Diagnostic Testing and Information System via the K wire.

Headlight range control signal

Level height adjustments are made for each axle. This would temporarily reduce the range of vision while driving at night.
The Phaeton is equipped with a headlight range control (HRC).
The automatic dynamic headlight range control keeps the light cone at a constant angle.

To avoid constant, unnecessary adjustments in level height due to surface unevenness, such as bumps or potholes, the self-levelling suspension has long reaction times when the vehicle is travelling at relatively constant road speed and if there is little or no wheel acceleration.

If level height is adjusted in Motorway Mode for example, the air suspension control unit J197 sends a voltage signal to the headlight range control unit J431.
The HRC reacts immediately and adjusts the angle of the light cone depending on the change of body position.

Level change procedure

Raising - the rear axle is raised followed by the front axle.

Lowering - the front axle is lowered followed by the rear axle.

Emergency running mode

Both the air spring control system and the damping control system adopt stored emergency running strategies in the event of faults in the sensors, the actuators or internal faults in the control unit.
Control actions are limited under certain circumstances and an entry is made in the fault memory.

In these cases, a warning

"Level Fault" or "Damper Fault"

is issued and a warning symbol appears in the dash panel insert.

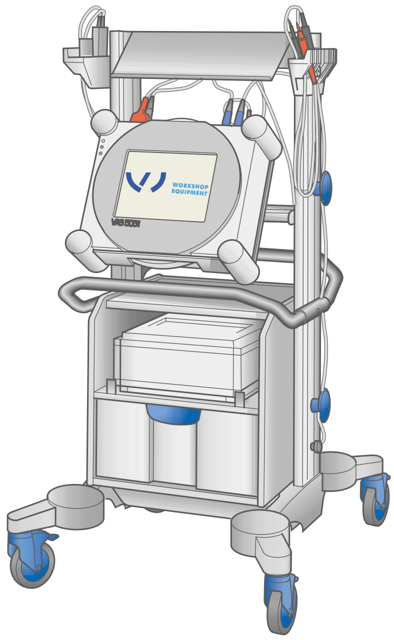
The vehicle must be taken to the workshop for repair.

Self-diagnosis

Self-diagnosis

Address word: 34 - Self-levelling suspension

Diagnostic Testing and Information Systems VAS 5051 and VAS 5052 are suitable for communication with the air suspension control unit.



275_050a

Resetting the adjustment position

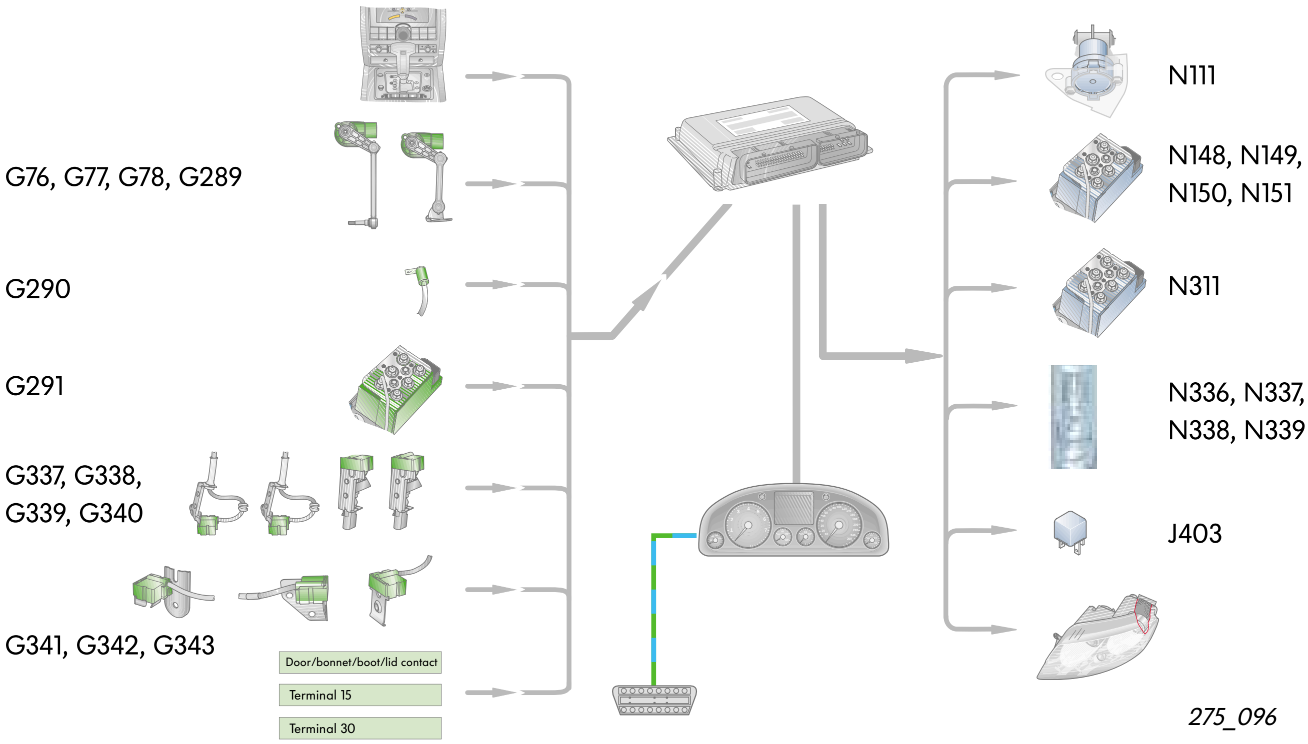
If the control unit, a vehicle level sender or the entire air supply unit are replaced, then the adjustment position must be reset.

The adjustment position is reset using the "Basic setting" function (see "Guided fault-finding").

275_050b

Please note that Repair Group 01 is integrated in "guided fault-finding".

The colour coded sensors, actuators and auxiliary signals are tested as part of the self-diagnosis and "guided fault-finding".



275_096

G76, G77, G78, G289	-	Vehicle level sender, front axle and rear axle
G290	-	Compressor temperature sender
G291	-	Self-levelling suspension system pressure sender
G337 ... G340	-	Wheel acceleration senders, front axle and rear axle
G341 ... G343	-	Body acceleration sender

J403	-	Self-levelling suspension compressor relay
N111	-	Self-levelling suspension drain valve
N148 ... N151	-	Suspension strut valves, front axle and rear axle
N311	-	Pressure accumulator valve
N336 ... N339	-	Damper adjustment valve
Auxiliary	-	Door/bonnet/bootlid contact signal terminal 15 and terminal 30

Test your knowledge

Which of the following answers is true?

One or more, or even all, answers may be true.

1. The self-levelling suspension system fitted in the Phaeton is

☐ a) "full load-bearing".

☐ b) "partial load-bearing".

☐ c) "self-supporting".

2. The auxiliary accumulators attached to the struts serve

☐ a) as a back-up for the central pressure accumulator of the self-levelling suspension system.

☐ b) to increase the effective air spring volume of the individual suspension struts.

☐ c) as air cushions during assembly work.

3. The driver can actively select the

☐ a) low suspension level (TN).

☐ b) normal suspension level (NN).

☐ c) high suspension level (HN).

4. The air drier in the air supply unit

☐ a) must be maintained at regular intervals.

☐ b) is not subject to a maintenance interval on account of its regenerative drying process.

☐ c) must be replaced after 30,000 km.

5. **The signals generated by the vehicle level sender are used for**

- [ ] a) self-levelling suspension.
- [ ] b) headlight range control.
- [ ] c) seat height adjustment.

6. **The controlled position must be reset after**

- [ ] a) replacing the self-levelling suspension control unit.
- [ ] b) replacing the convenience control unit.
- [ ] c) replacing a vehicle level sender.

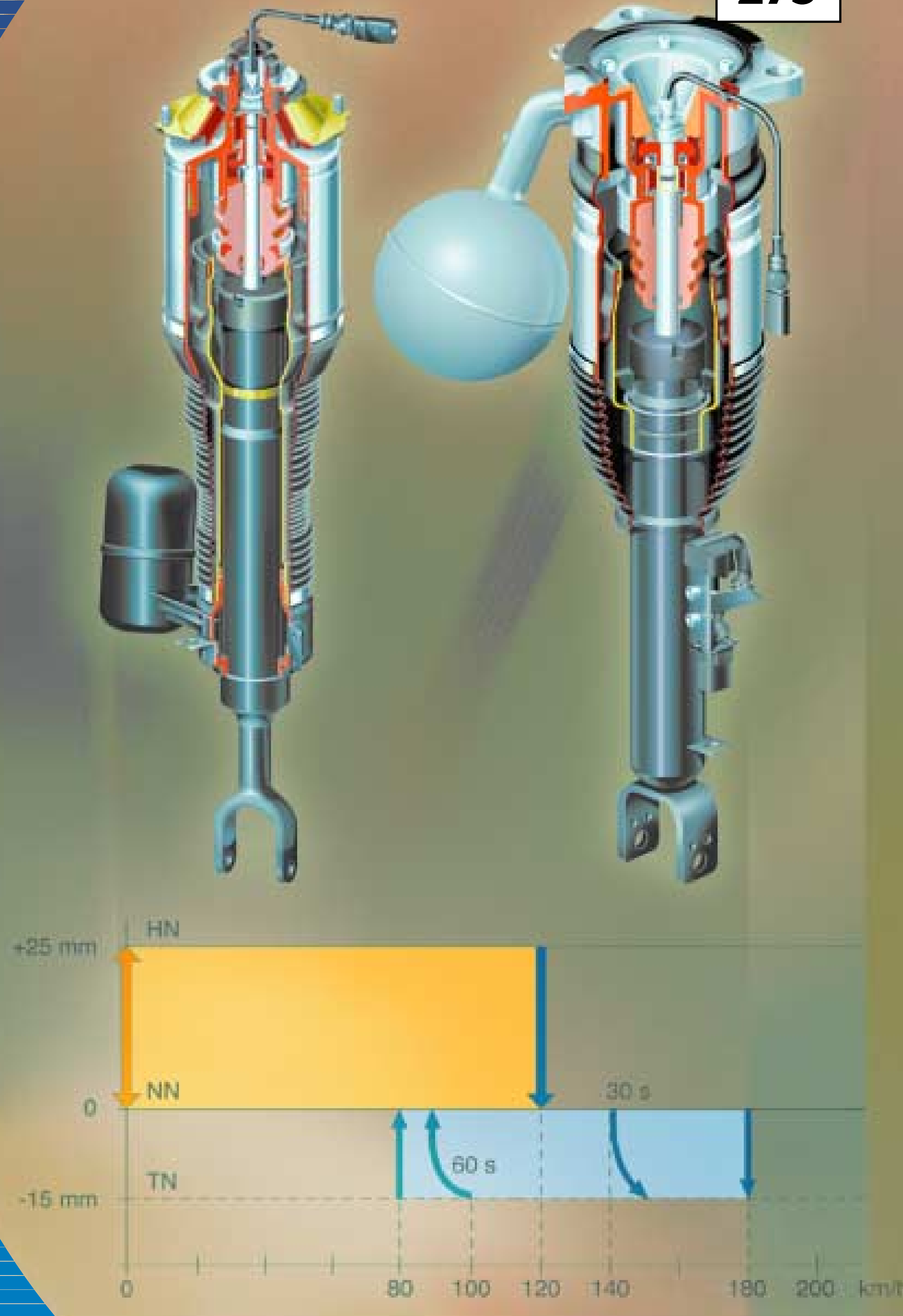
7. **The air supply unit compressor starts**

- [ ] a) only when activated by the driver.
- [ ] b) after turning off the ignition.
- [ ] c) whenever required for air supply control.

8. **Before commencing work on the lifting platform**

- [ ] a) only the air supply unit compressor need be shut off.
- [ ] b) the self-levelling suspension must be deactivated.
- [ ] c) no special precautions are necessary.

Solutions:
1. a; 2. b; 3. b, c; 4. b; 5. a, b; 6. a, c; 7. b, c; 8. b



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