A Short Introduction to Automotive Shock Absorbers

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Agenda

1. Introduction: Why Does a Car Need Shock Absorbers?
2. Basics of Vertical Dynamics
3. How Does a damper Work?
4. Passive, Semi-active and Active
5. Summary

Sources

(1) Heising, Ersoy: Chassis Handbook, Vieweg und Teubner, 2011 (please note that there is a more recent German edition: Ersoy, Gies: Fahrwerkhandbuch. 5. Auflage. Wiesbaden: Springer Vieweg, 2017).

(2) Causemann: Automotive Shock Absorbers, Verlag Moderne Industrie, 2001

(3) If not otherwise labelled: internal material ZF Friedrichshafen AG

01

Introduction: Why Does a Car Need Shock Absorbers?

Why Does a Car Need Shock Absorbers?
Look back in history

(Source: 1)

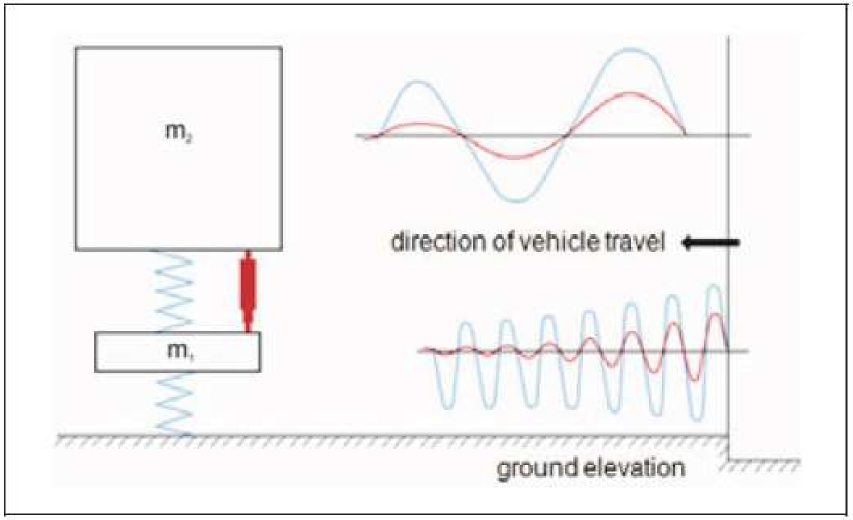
Sumerian parade wagons (2700 BC)

Main functions:

- Propulsion
- Steer
- Brake
- Provide comfort
- …

By the way: the terms "coach" (English) and "Kutsche" (German) come from the name of the town Kocs in Hungary (14th century).

Why Does a Car Need Shock Absorbers?
Damping of vibrations in a dual-mass system



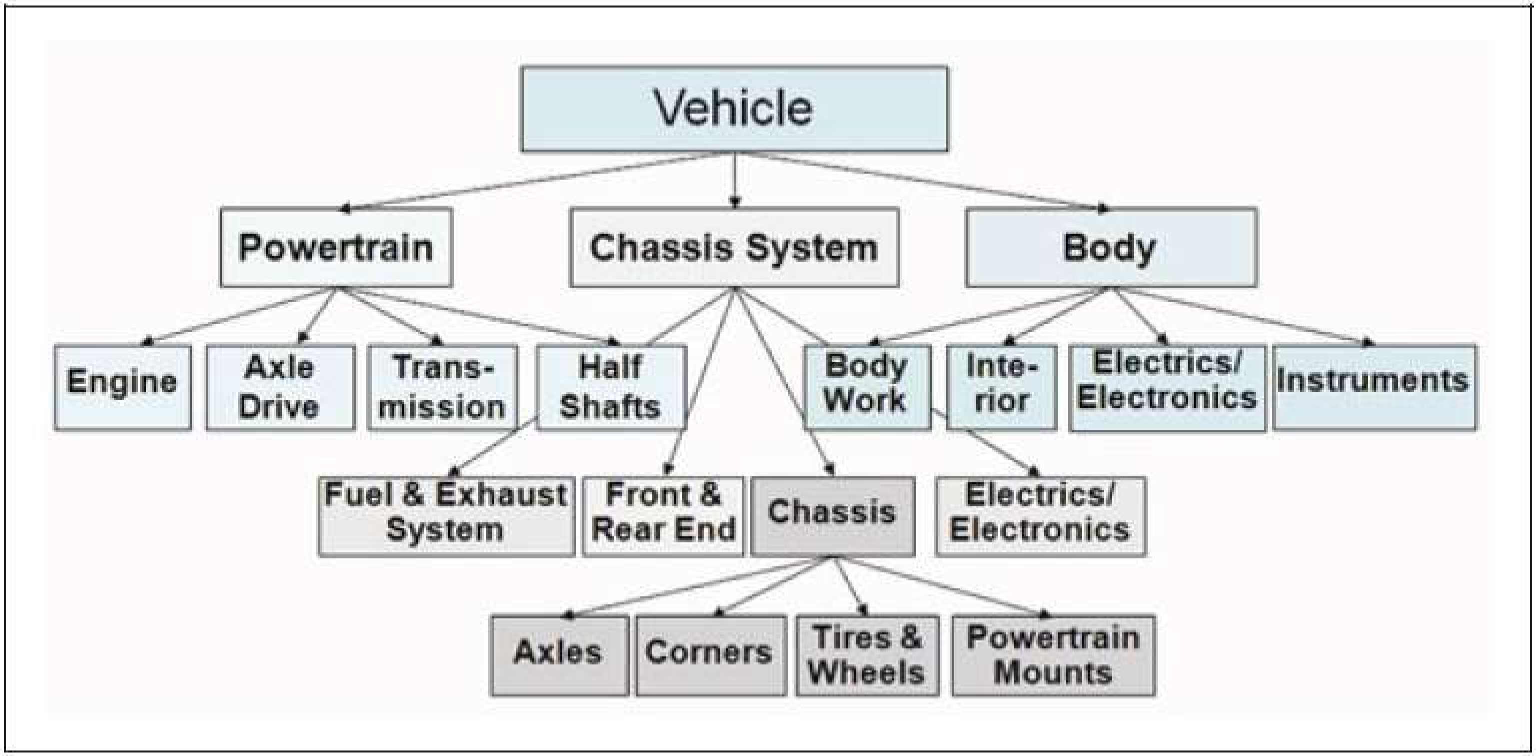
(Source: 1)

Fig. 3-229: Coupled chassis and body mass vibrations

- Some sort of spring is needed to isolate the "body" with the passengers from the wheel and the road.
- Some sort of damping is needed to quickly reduce the amplitude of the road-induced vibration
- Coaches and early motor vehicles used leaf springs, which also provided some inherent friction.
- **Technically correct terms:**
  - ~~Shock absorber~~
  - Vibration damper
  - Schwingungsdämpfer (German)
  - ~~Stoßdämpfer~~ (German)

02
Basics of Vertical Dynamics

Components and systems of a car



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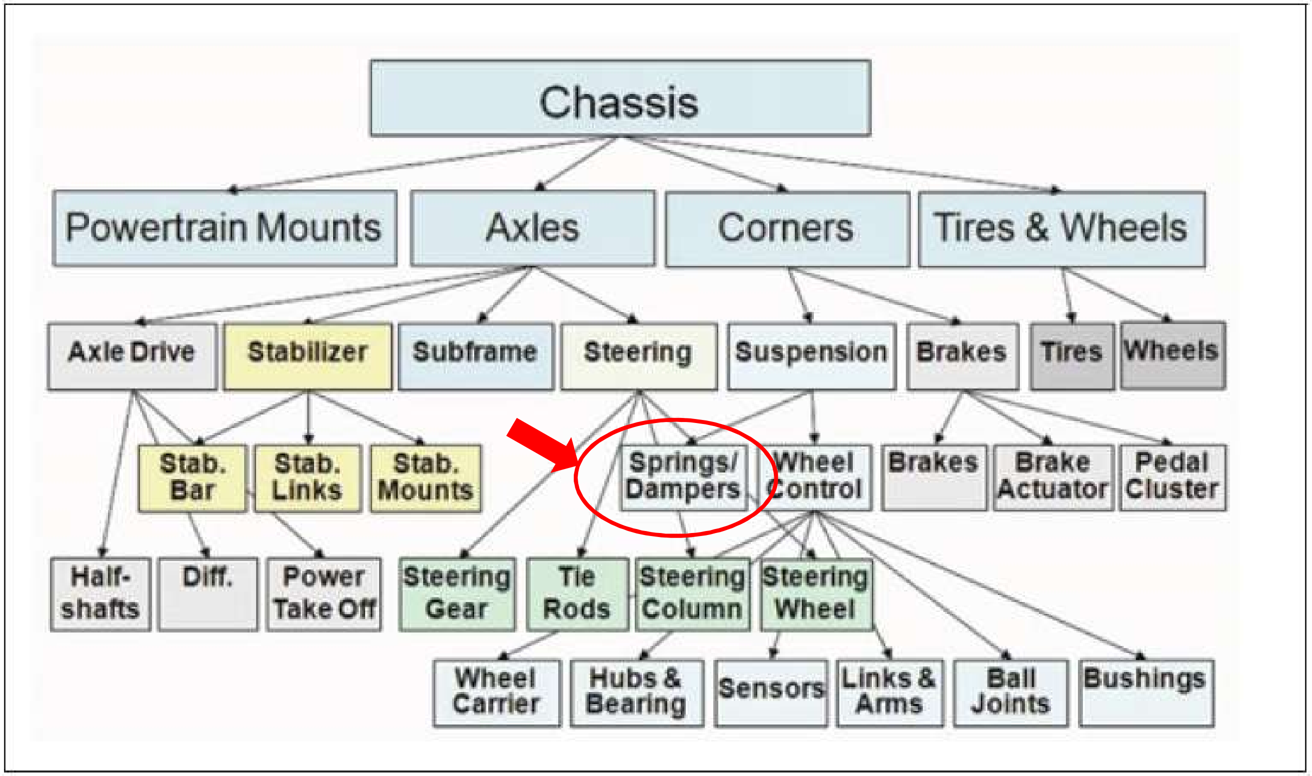
Internal

Components of a chassis



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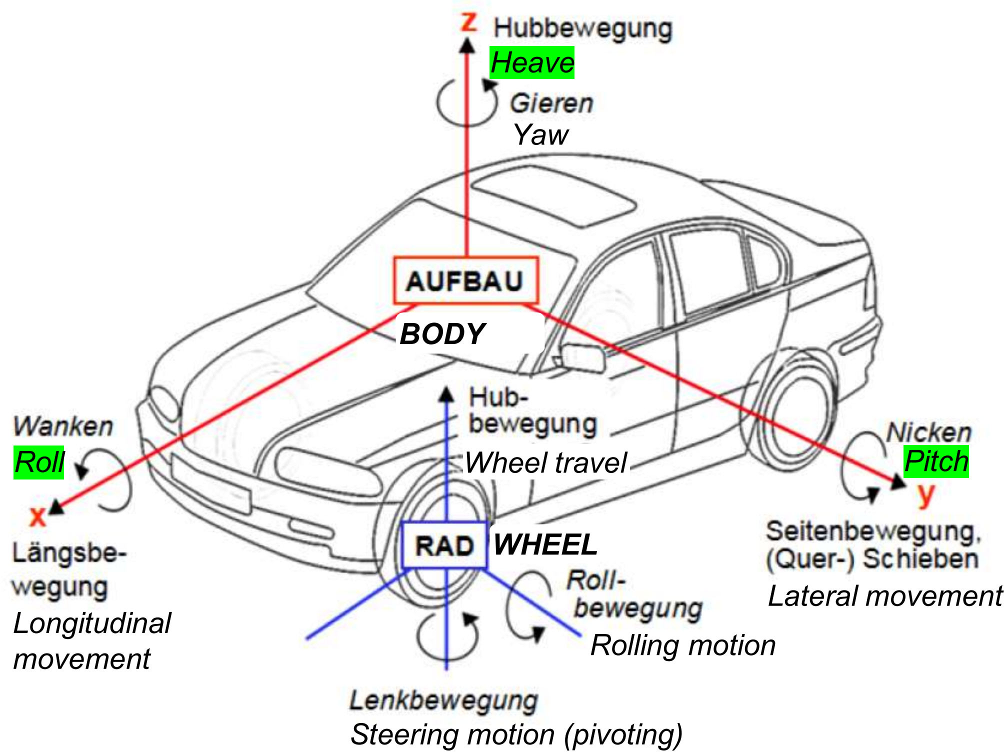
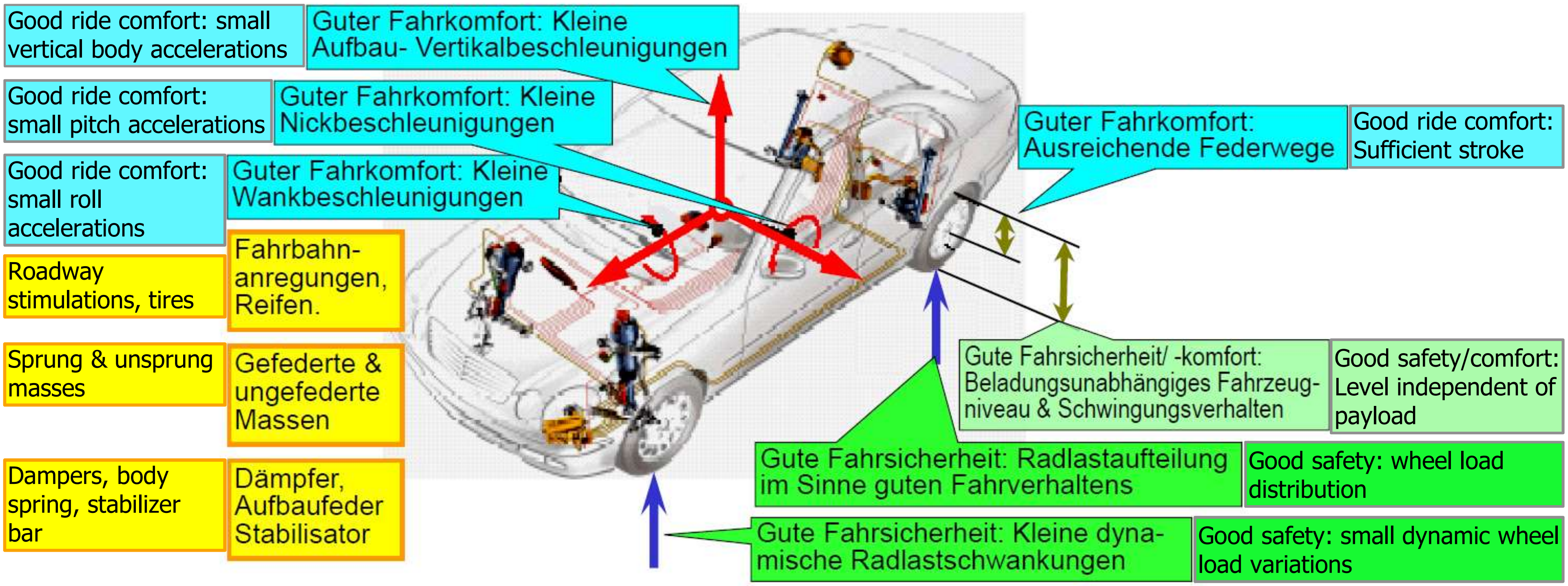
Coordinate System and Modes



Vertical Dynamics: Main Targets



Springs

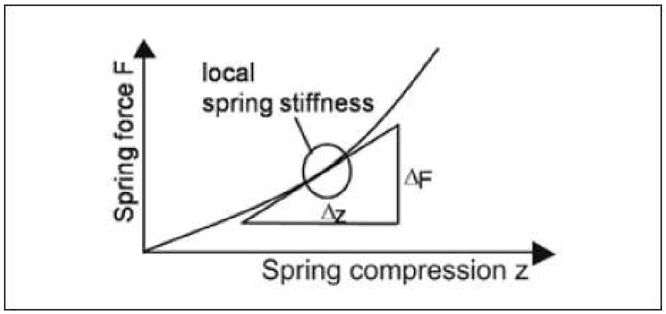


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Fig. 2-58: Definition of the spring stiffness c_{spring}

$$c_{\text{spring}} = \frac{dF}{dz}$$

$$F_{\text{spring}} = c_{\text{spring}} \cdot \Delta f_{\text{spring}}$$

Typically, helical steel springs are used!

Translation ratio of the suspension:

$$i = \frac{\Delta f}{\Delta z_W}$$

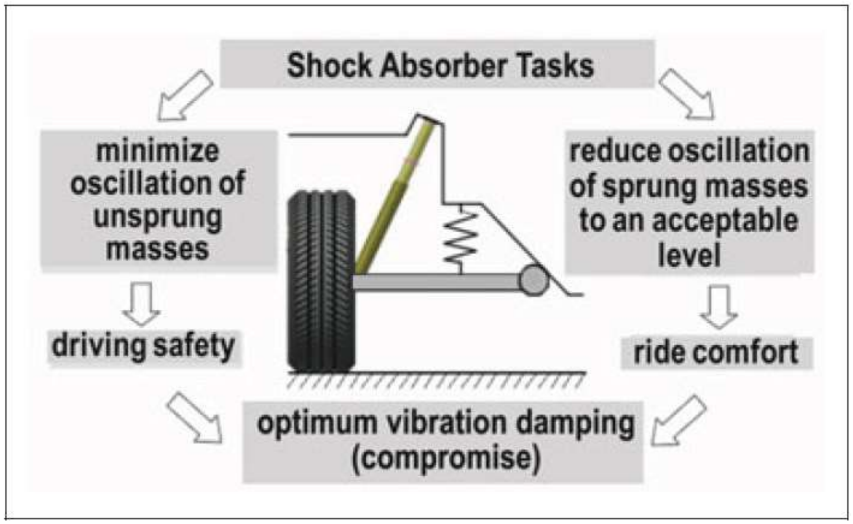
$$F_{sp} = \frac{F_W}{i}$$

Eigenfrequency:

$$\omega = \sqrt{\frac{c}{m}}$$

Increase payload => m ↑ => ω ↓

Dampers



(Source: 1)

Telescopic hydraulic dampers were introduced around 1926 by Monroe in the US

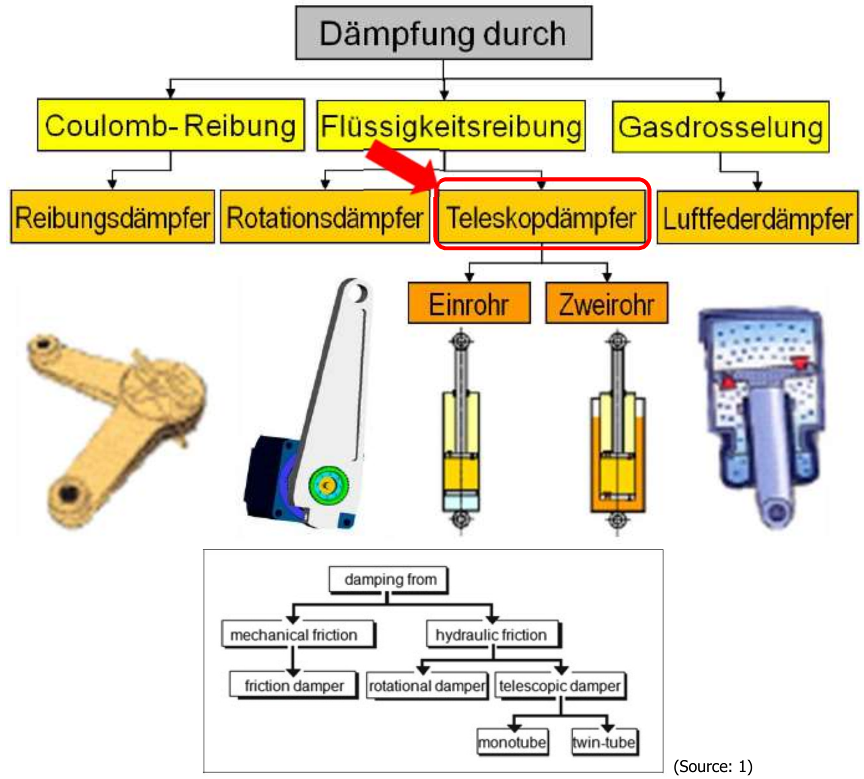


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Fig. 2-61: Various possibilities for physical damping

03

How Does a damper Work?

How does a damper work?
Design of a so-called twin-tube damper

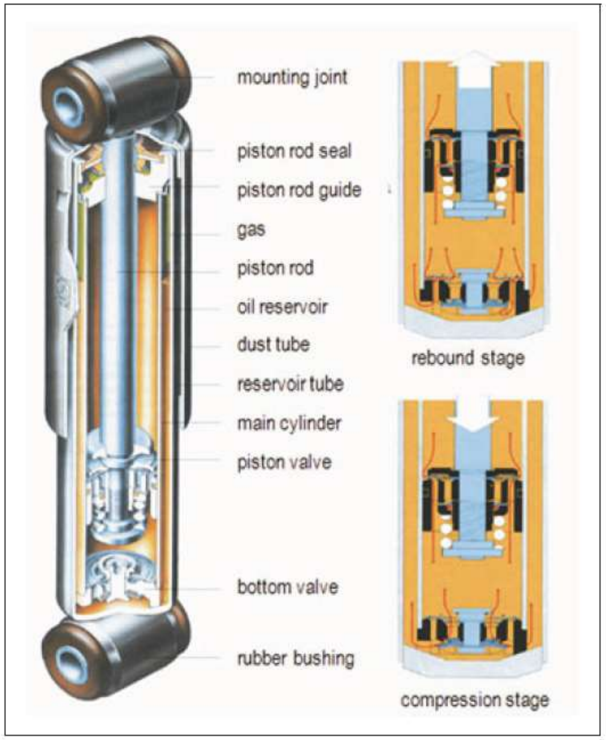

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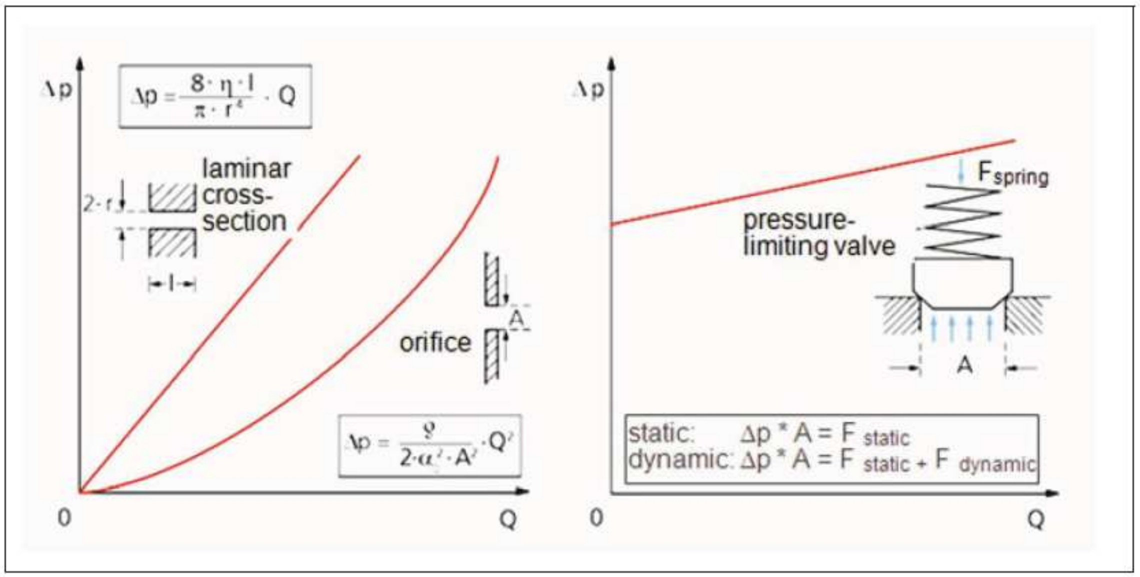
Fig. 3-235: Cutaway view of a twin-tube shock absorber

- A piston rod with a piston moves up and down in a cylinder filled with oil.
- Up = extension or rebound (German: "Zug")
- Down = compression ("Druck")
- The damping is produced by valves in the piston and in the so-called bottom valve.

- The oil is a mineral oil with special additives.
- The volume of the piston rod has to be compensated by a gas charge (accumulator).
- The stroke is limited. Several types of end stops and additional springs are used to increase the damping force near the end of the stroke.

- You need some sort of bushings (with elastic and damping properties) to connect the damper to the wheel and the body
- Another type of damper is the so-called monotube.

How does a damper work?
Valves



(Source: 2)

- In general, the damping behavior is based on the hydraulic resistance of an oil volume flow through some sort of valve.
- Laminar flow is not used.
- Typically, turbulent flow through a small orifice is used, resulting in a relationship $\Delta p \sim Q^2$
- Pressure relief valves (right hand side of graph)

- Δp corresponds to the damping force F via the area of the piston
- Q corresponds to the velocity with which the piston moves

How does a damper work?
Damping curves (twin-tube damper)

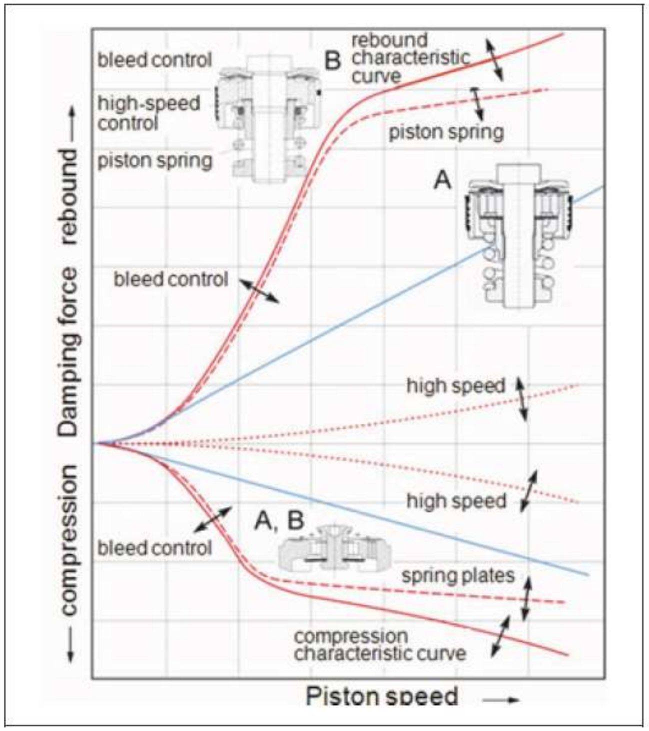


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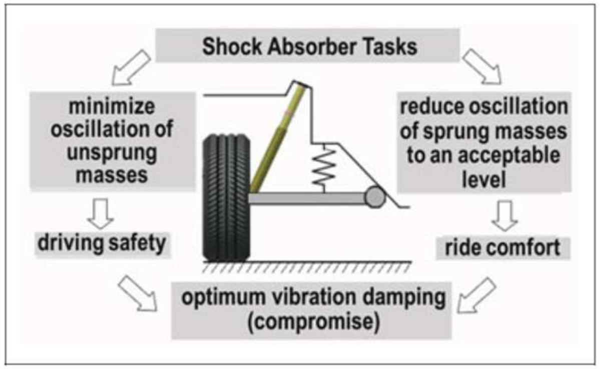
Fig. 3-236: Damping curves of twin-tube dampers

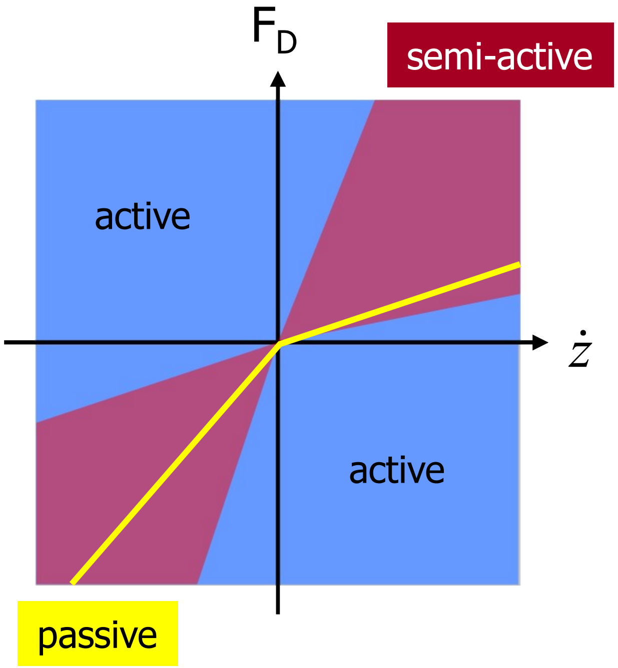
- In reality, the damping characteristic is a non-linear curve.
- Typically, it is desired to have a higher damping force for rebound/extension than for compression. Degressive curves are preferred.
- Damper engineers are lazy and try to save paper. The compression curve is drawn in the 2. quadrant instead of the 3rd.
- The damping force is always opposite to the movement of the piston. No damping without piston movement!
- The damping curves can be tuned in detail by using a large variety of tuning parts (orifices, springs …). This ride work is done with prototype cars.

- Typical values:
  - Diameter of cylinder (piston) = 24 mm, … 36 mm
  - Diameter of piston rod = 11 mm, 13 mm, … 25 mm

04
Passive, Semi-active and Active

Control Systems – passive, semi-active and active dampers



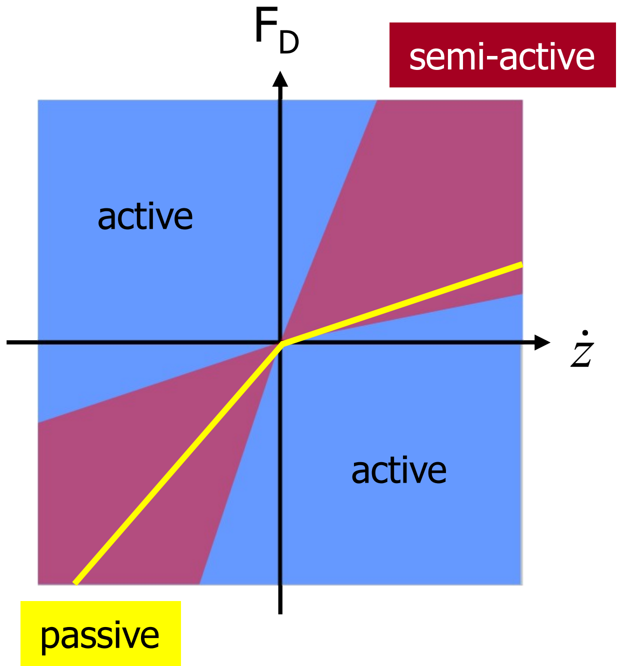


- As already explained, the design of a conventional damper is always a compromise.
- Beginning in the 1980s ride engineers found solutions to overcome the drawbacks of dampers with a fixed characteristic curve.

Control Systems – passive, semi-active and active dampers

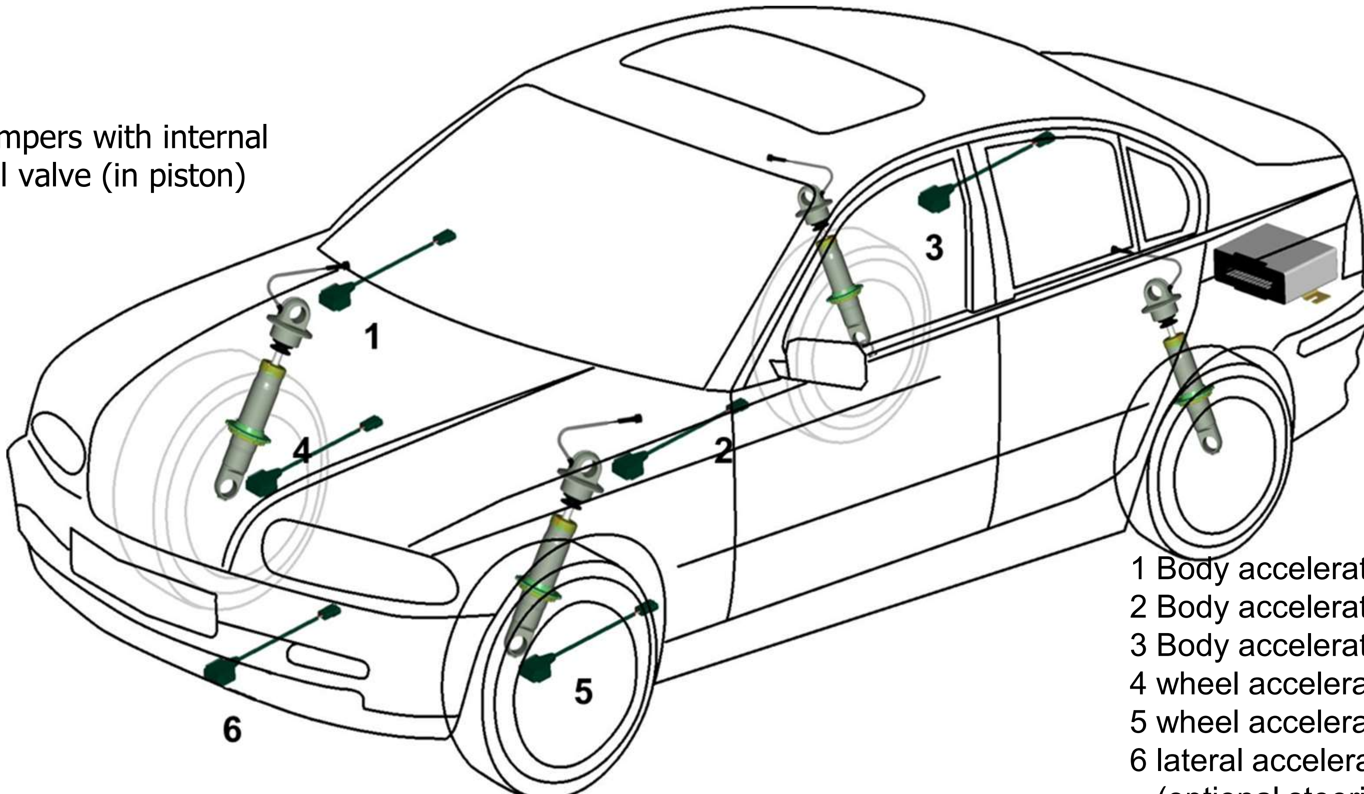
	1982	1990	2000
Properties	Characteristic curve partially modified	2…4 characteristic curves	Continously variable characteristics
Actuator	Electric motor, magnetic switch	Magnets in damping valves	Electro-hydraulic proportional valves
Control	Switch operated by driver	Threshold valves, based on vehicle velocity, brake signal…	Skyhook control, body + wheel accelerometers

- Yellow: conventional, passive damper with fixed damping
- Red: characteristic can be continuously varied, depending on driving conditions
- Blue: an active system works in the 2. and 4. quadrant by applying energy from an external source (hydraulic pump, electric motor …)



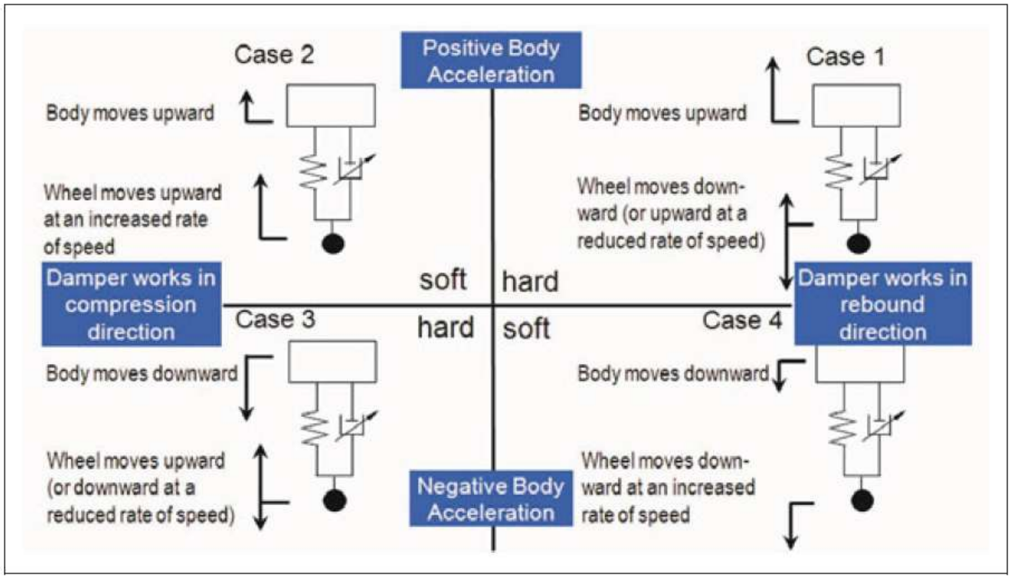
ZF CDC System
CDC = Continous Damping Control

Variable dampers with internal proportional valve (in piston)



1 Body acceleration FR
2 Body acceleration FL
3 Body acceleration R
4 wheel acceleration FR
5 wheel acceleration FL
6 lateral acceleration
(optional steering wheel angle)

Control Strategies: Skyhook



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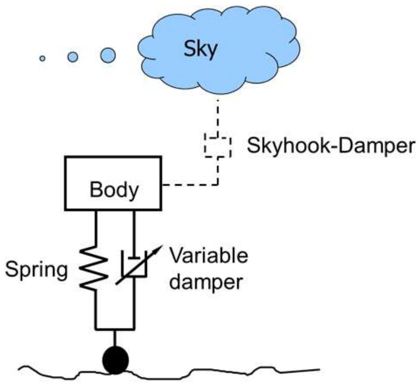


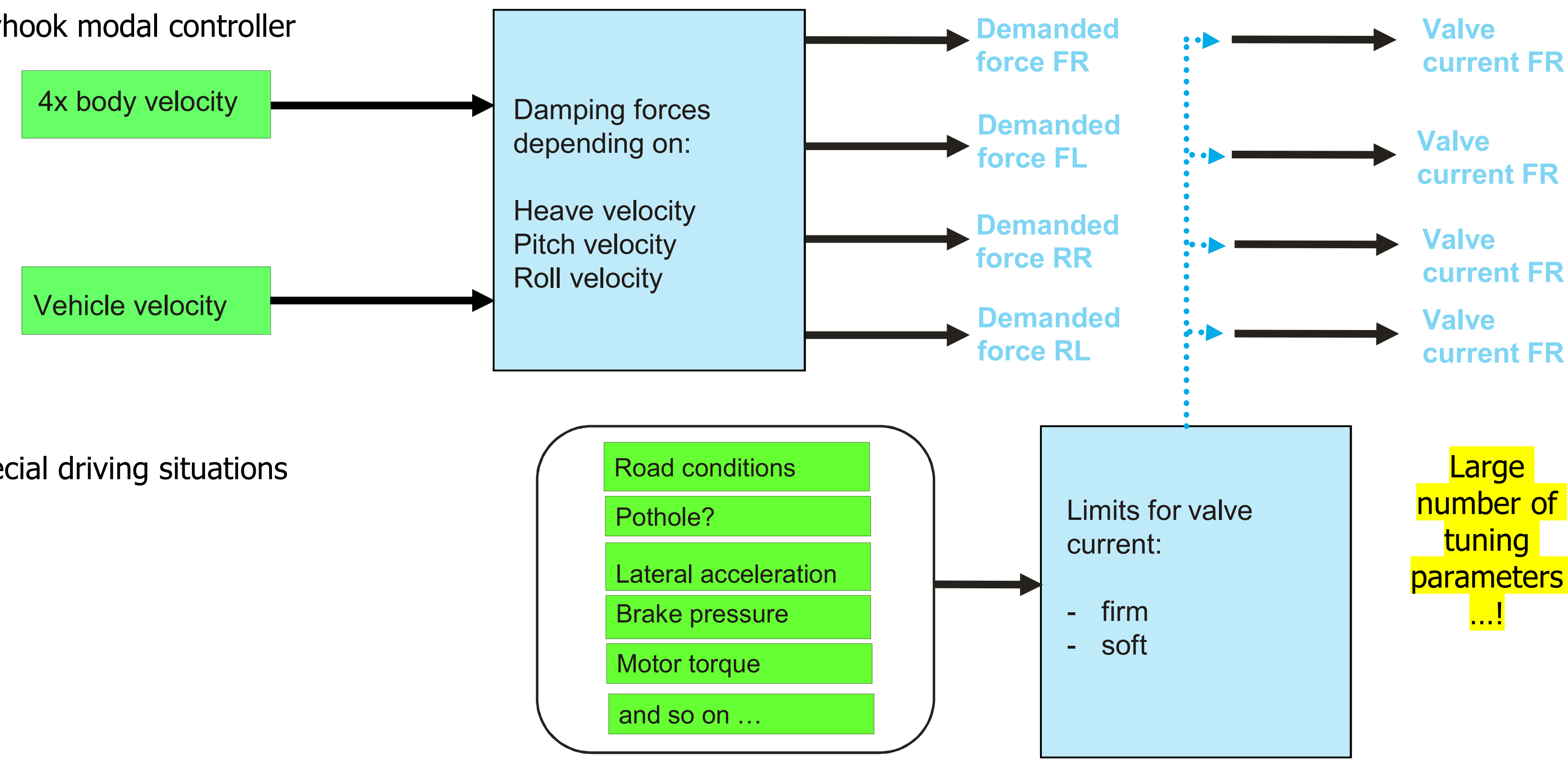
- Idea:

$$F = k_{\text{sky}} \cdot v_{\text{body}} = k_{\text{damper}} \cdot v_{\text{relative}}$$

$$\Rightarrow k_{\text{damper}} = k_{\text{sky}} \cdot \frac{v_{\text{body}}}{v_{\text{relative}}}$$

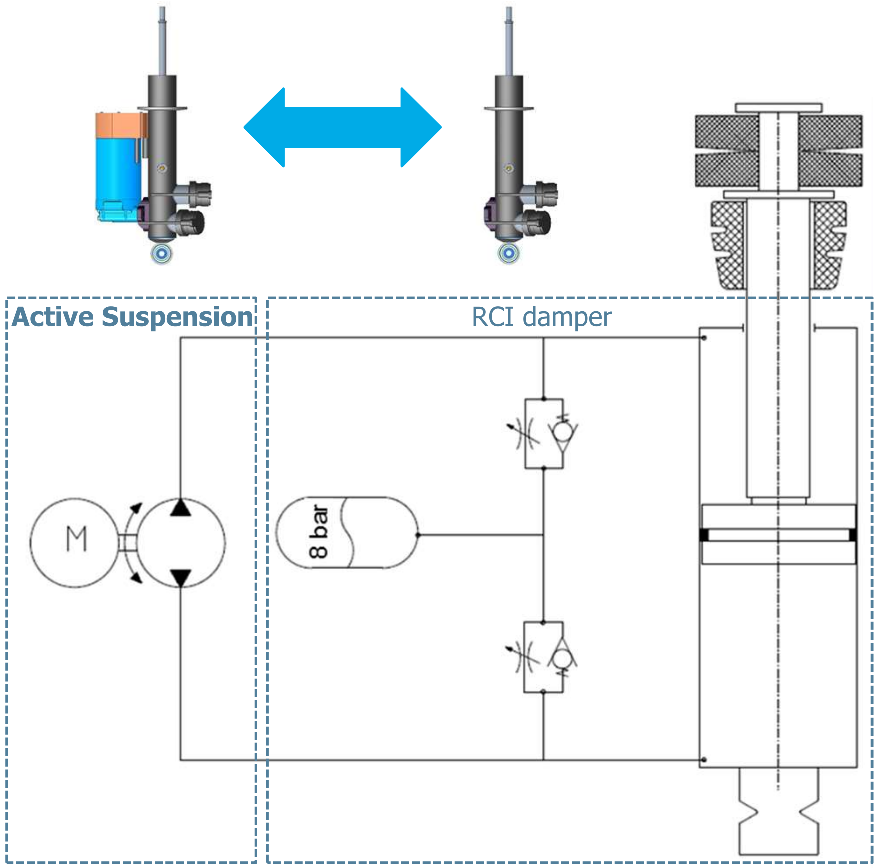
CDC Control Strategy in Reality

- Skyhook modal controller
- Special driving situations

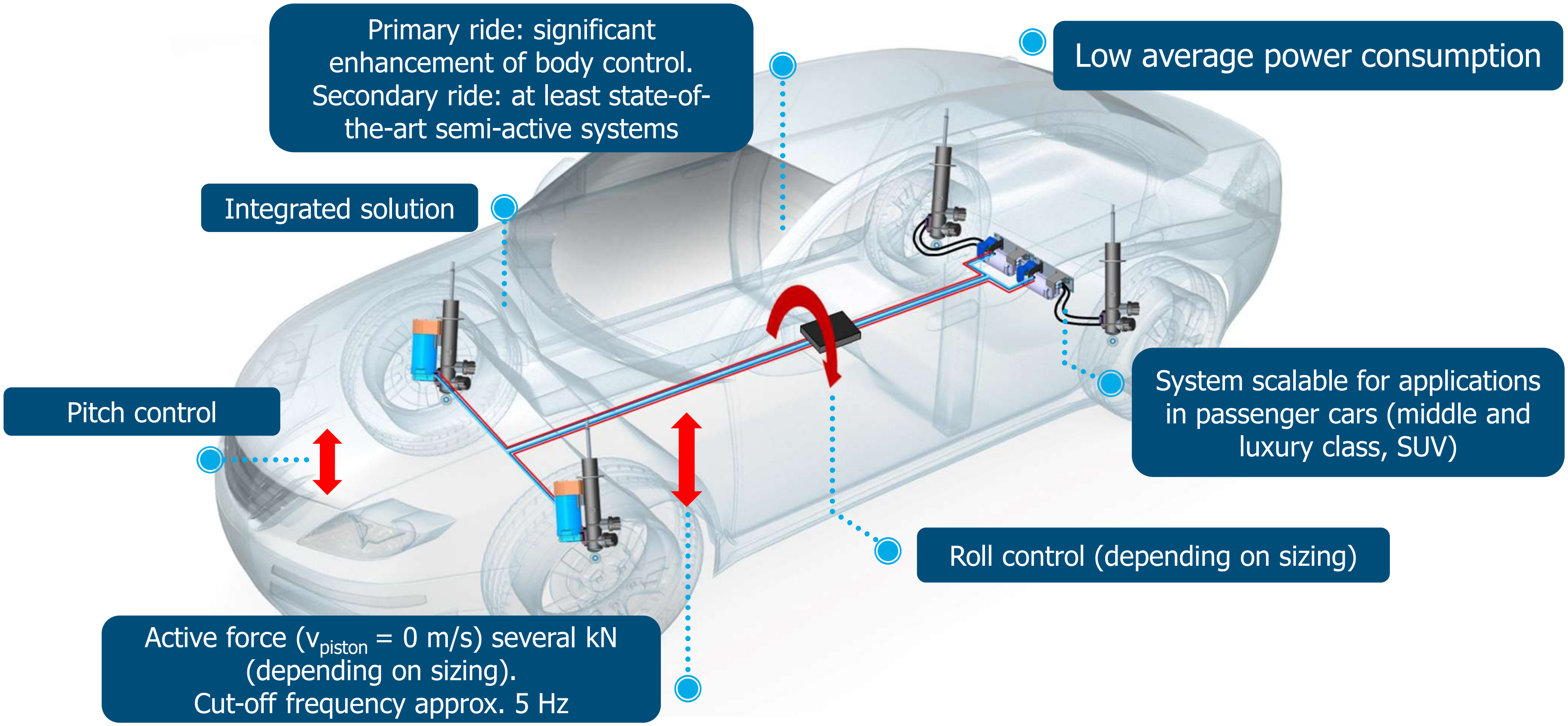


ZF sMOTION: an Active System

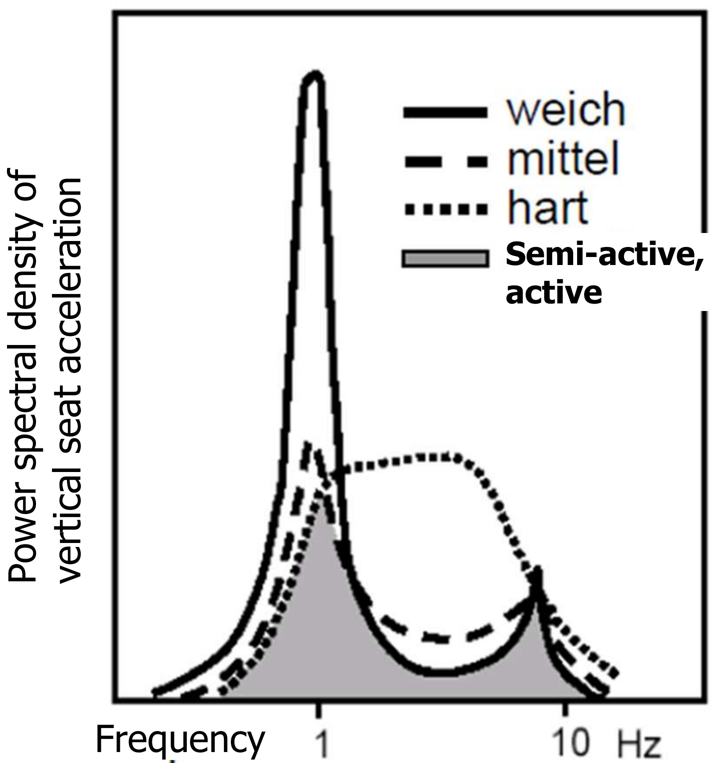
- Separate control paths for body and wheel control
- Hydraulic parallel connection of pump and valves
- short overall length
- Main dimensions (for sedan application) 32/15
- Maximum force determined by pump pressure and piston diameter
- Accumulator is always connected to the suction side of the pump
- Low system pressure (approx. 8 bar)
- Modular kit:
  - •RCI CDC-damper + active suspension



Overview System and Functions



Evaluation



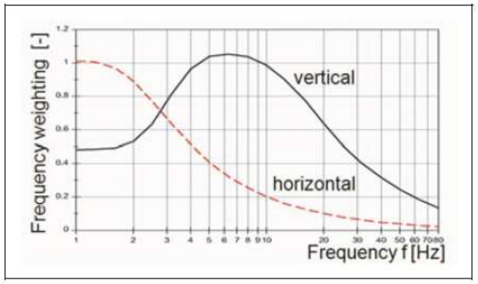


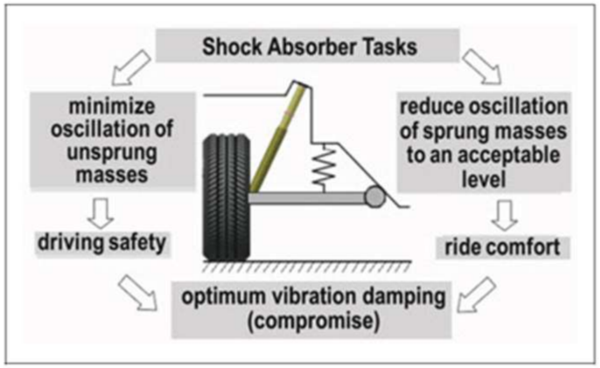
Fig. 2-88: Frequency weighting curves for horizontal and vertical oscillations applied to a seated or standing human being (from VDI 2057 (2002)) [25]

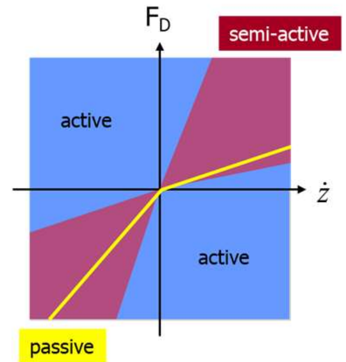
(Source: 1)

- How does one know whether a damper / control system is good or bad?
- Subjective evaluation by experienced ride engineers, with 10+ criteria typically on a scale 0 … 10
- Measure vertical acceleration at the drivers seat -> calculate and plot power spectral density over frequency
- The human perception of vibrations depends on the frequency. Pay attention to the middle range!

05
Summary

Summary





- Tasks of a shock absorber are to dampen vibrations of the vehicle's body caused by uneven roads or driving conditions
- .. and to quickly reduce wheel vibration in order to provide contact between the tire and the road

- Telescopic dampers are used, where the damping is produced by hydraulic resistance in valves

- The design of passive dampers is always a compromise to fulfill both two main tasks
- The compromise can be resolved by semi-active and active damper systems

- The tuning of dampers is a time-consuming, iterative and process in most cases based on experience and subjective evaluations.

Thank you for your attention!