Introduction of Regen Braking & Driver Braking

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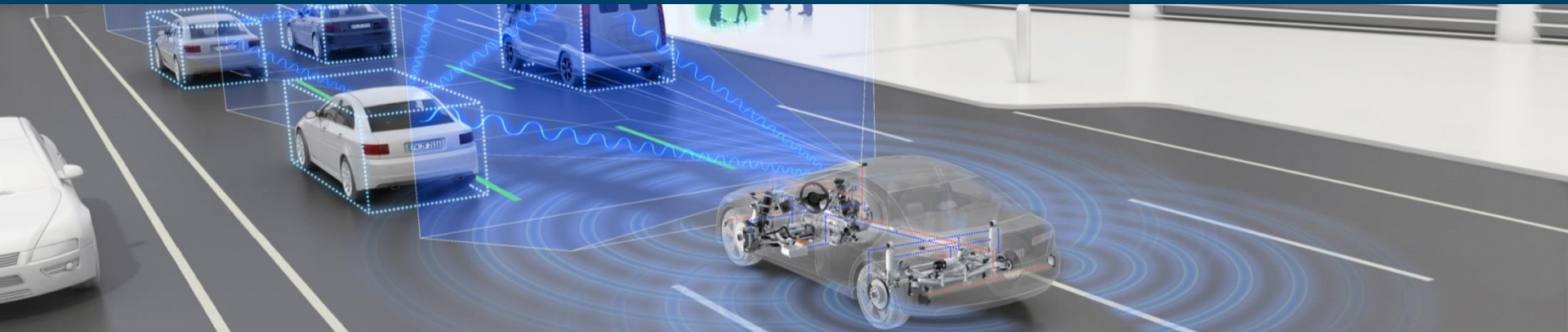


Regen Braking (RB) and Driver Braking (DB)

What do the abbreviations DB and RB mean?

- **DB = Driver Braking** → Identification of driver brake request
- **RB = Regen(erative) Braking** → Distribution of hydraulical and electrical brake request on generator and wheel brakes

- RB is „only“ needed in hybrid and electric cars
- In these cars it is active at every brake maneuver → comfort and pedal feedback are very important

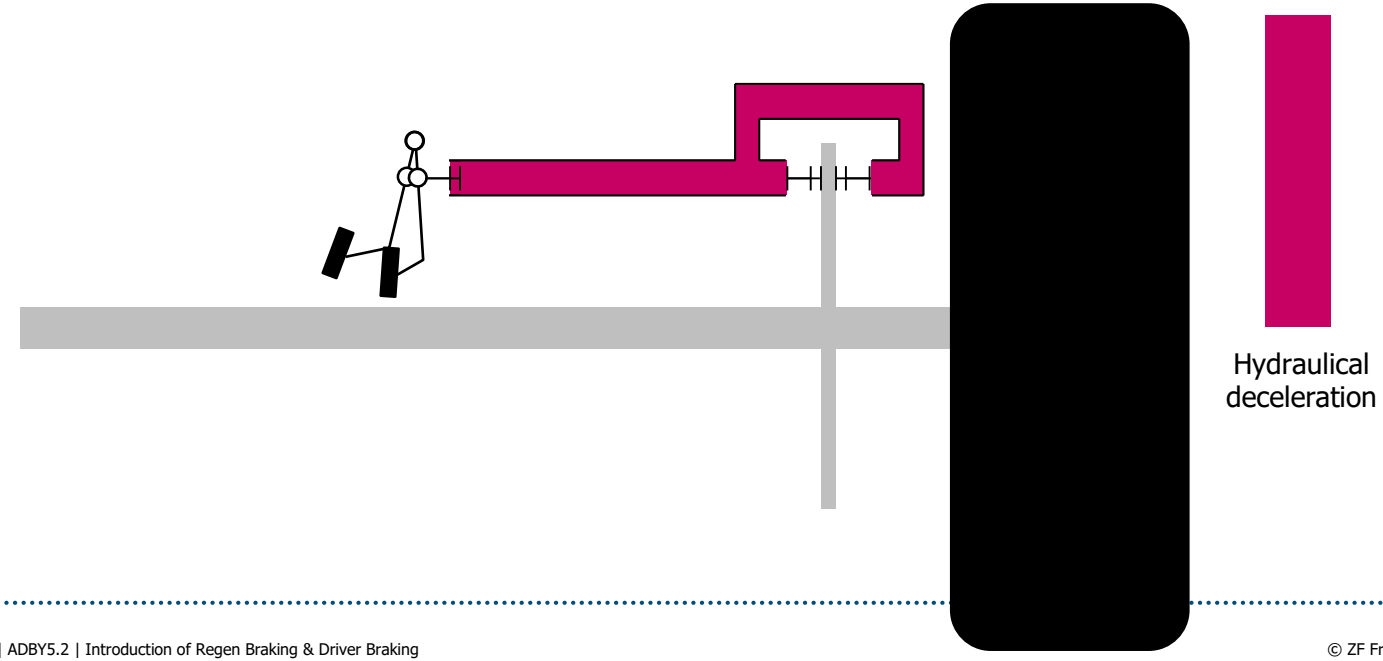
- This presentation is focused on „classical“ ESC (driver is directly connected with wheel brakes)

DB (Driver Braking):
How much deceleration does the driver want?

RB (Regen Braking):
How to distribute deceleration request of driver (or assistance systems) between generator and wheel brakes?

Regen Braking (RB)

Conventional braking: Driver pushes volume into wheel brakes

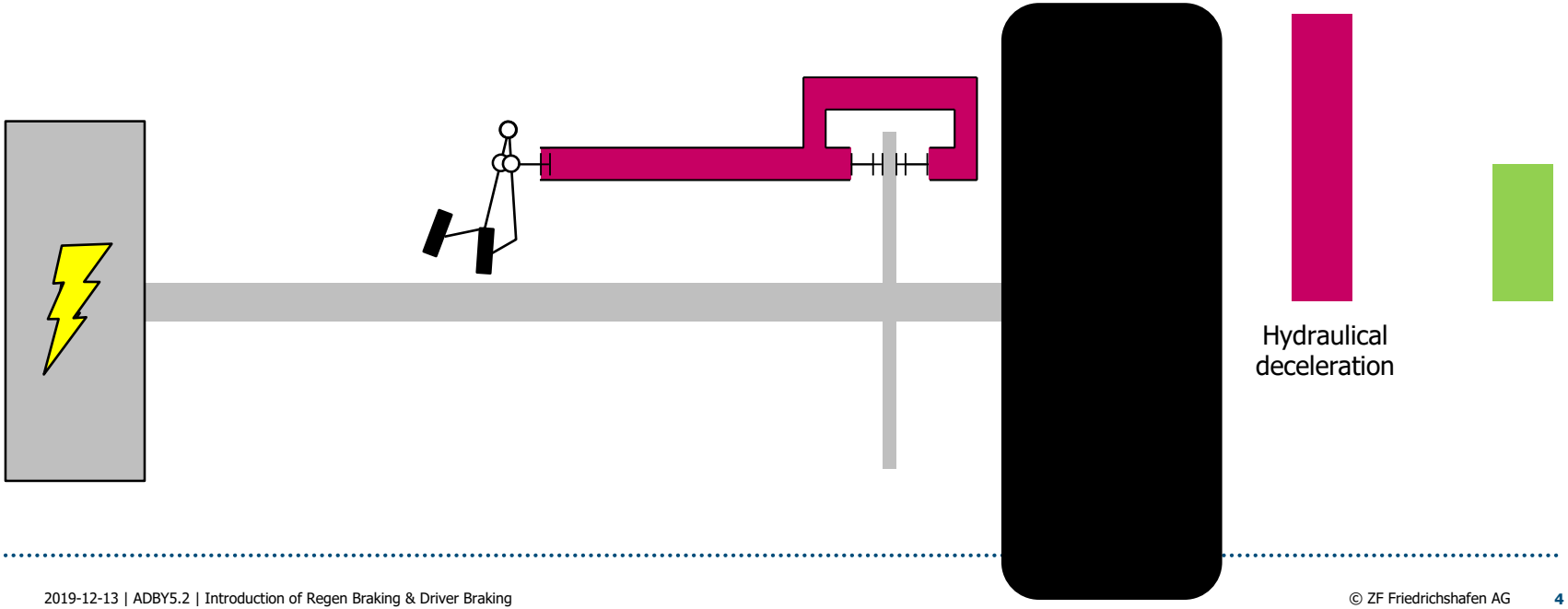


Regen Braking (RB)

Regenerative Braking: Generator shall brake on its own without wasting energy in the wheel brakes

→ **Problem:** How to prevent pressure apply in wheel brakes?

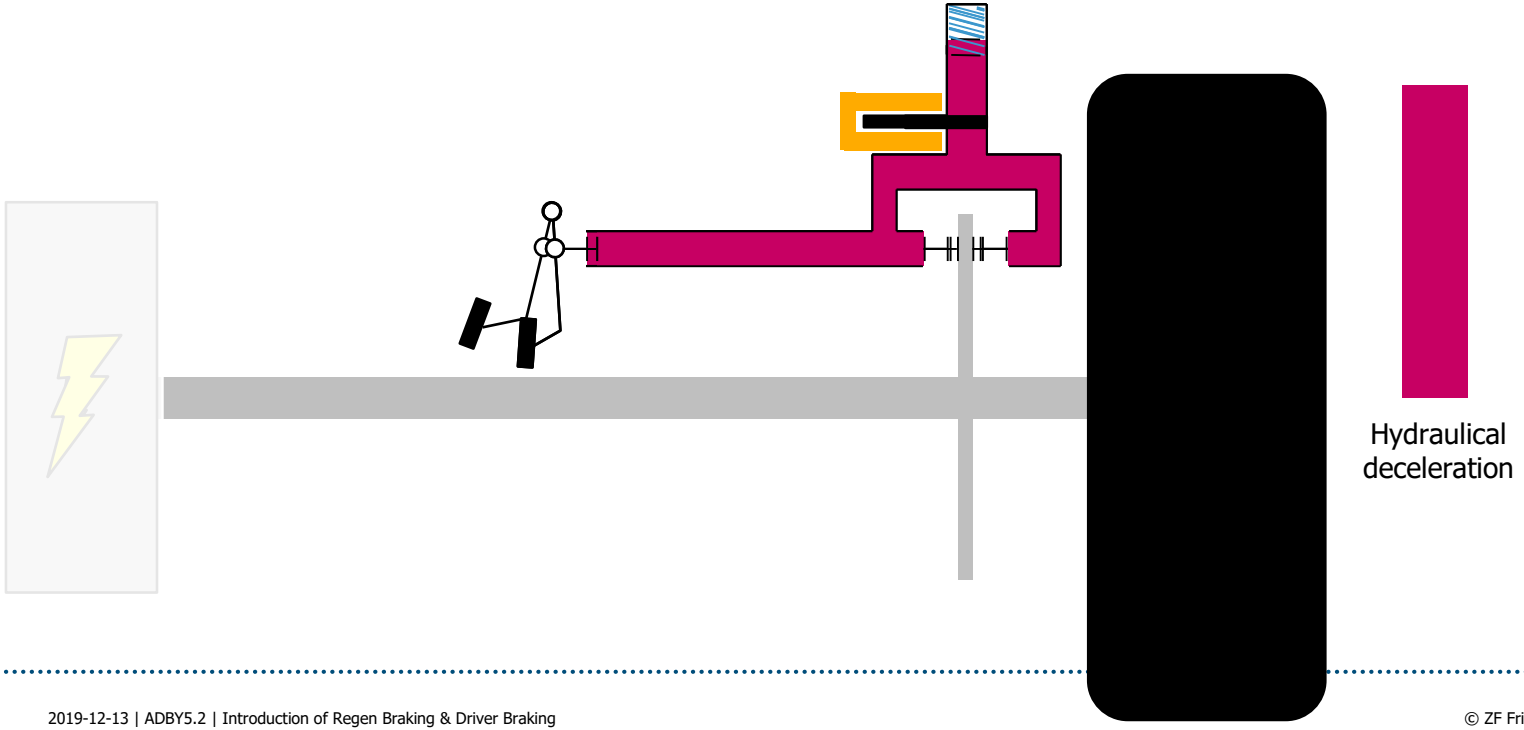
→ **Solution:** Usage of actuators that are normally used for other purposes



Regen Braking (RB)

ABS uses **dump valves** and **LPA** (Low Pressure Accumulator) for pressure reduction

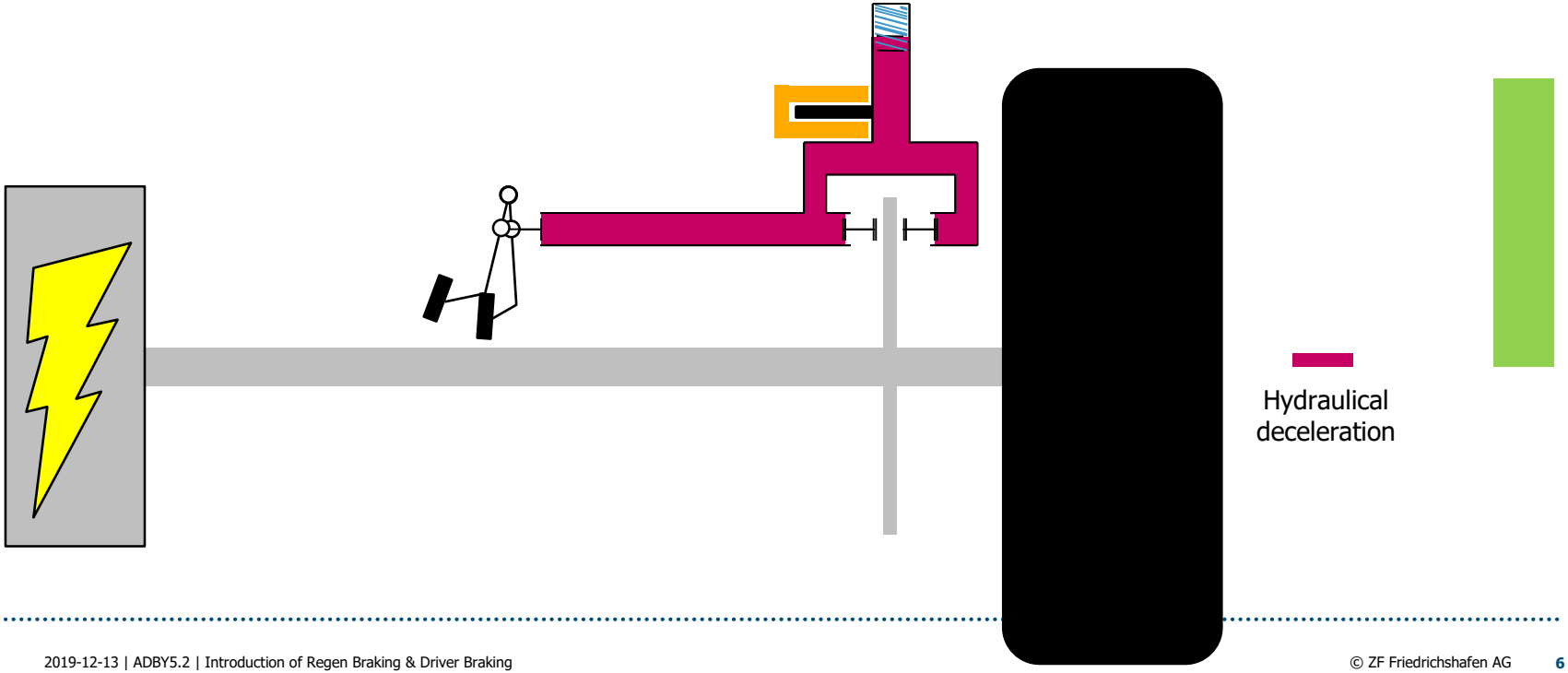
If one wheel blockades, dump valve gets opened, volume leaks into LPA and pressure decreases. Afterwards the wheel starts turning again.



Regen Braking (RB)

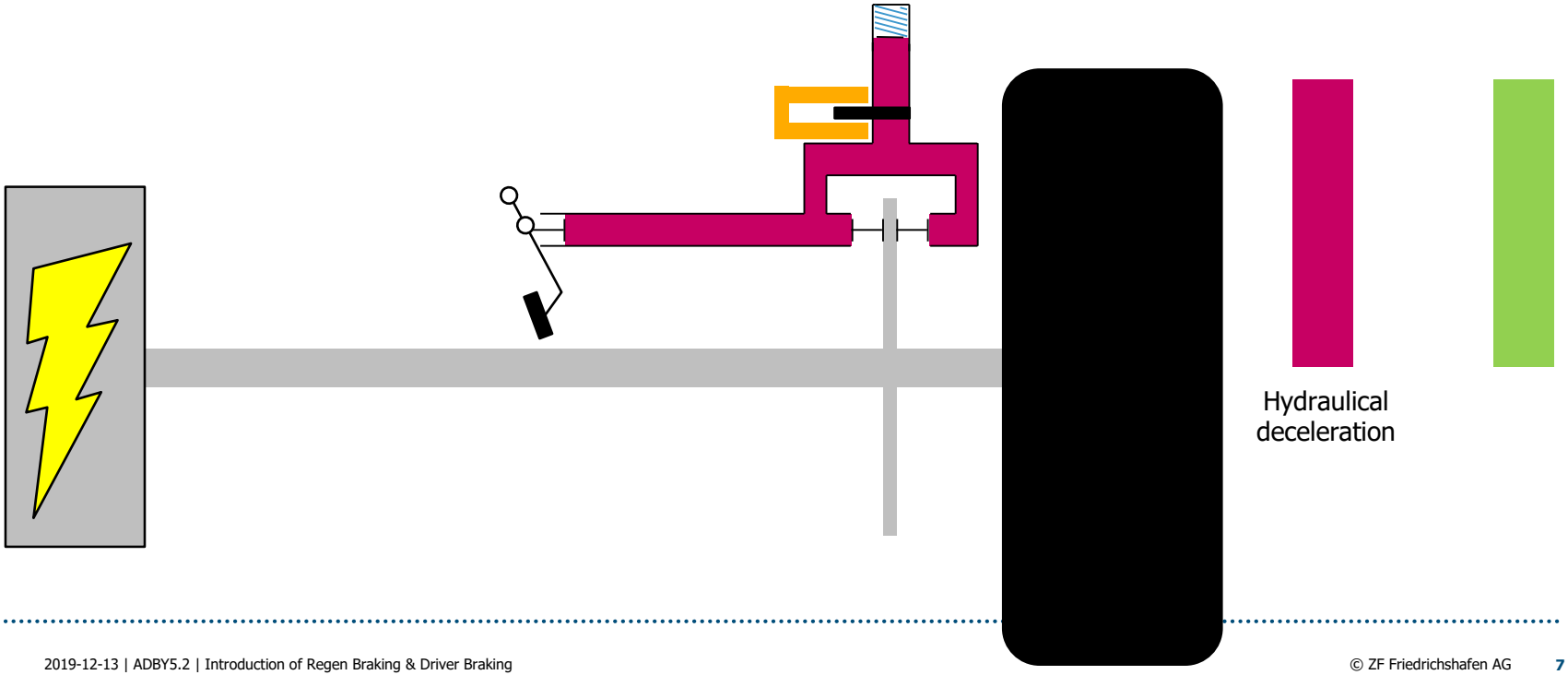
Regenerative braking: Dump valves are opened just from the beginning of a brake maneuver. Driver pushes volume into LPA. Brake pads do not apply pressure at caliper.

Volume is stored in LPA. It is needed later on.



Regen Braking (RB)

Hydraulically overlain braking: If generator is not able to apply more brake torque, dump valves get closed and driver pushes volume into wheel brakes (just like during conventional braking).



Regen Braking (RB)

What will happen if generator is not able to apply brake torque anymore?

- Standstill
- Completely charged battery
- Wheel slip

Disappearing electrical brake torque has to be compensated hydraulically. Otherwise the vehicle deceleration disappears, too.

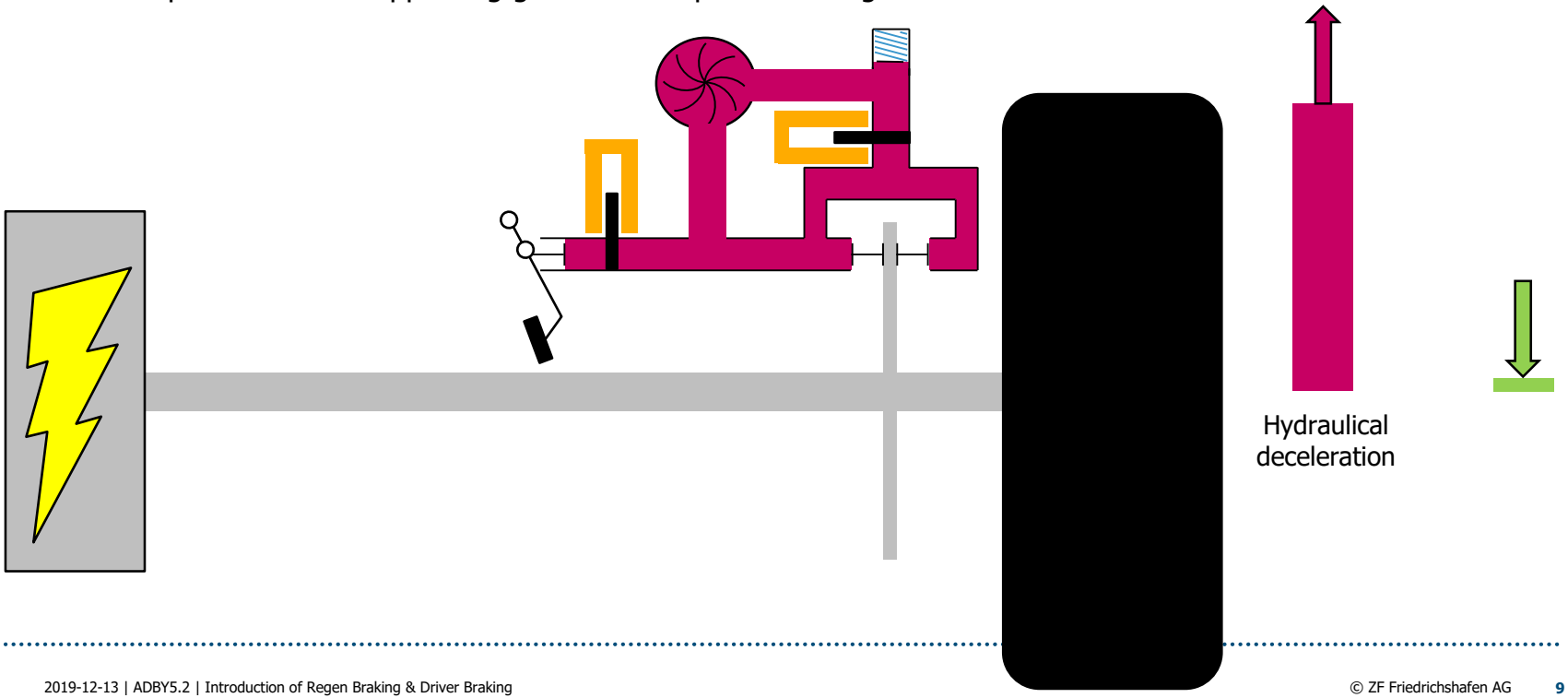
Question: How to compensate disappearing electrical brake torque?

Answer: Usage of actuators that are normally used for other purposes

Regen Braking (RB)

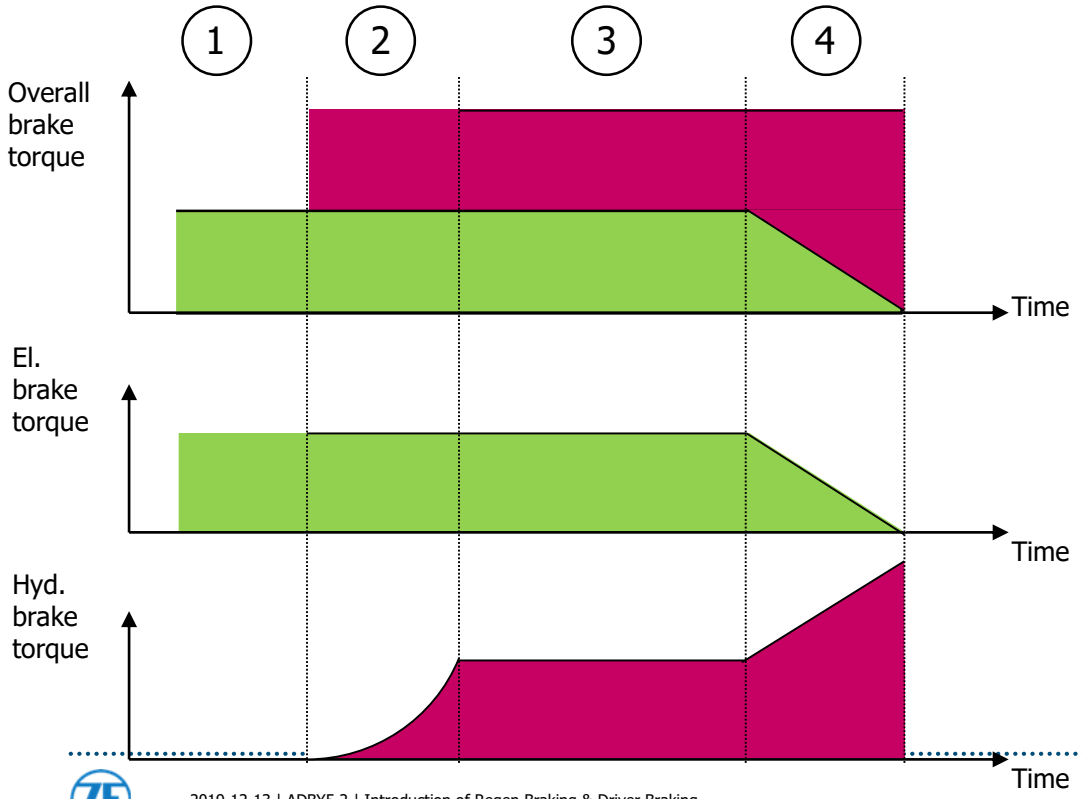
Cruise control (and other systems) use **isolation valves (TC ISOs)** and **hydraulic pump** for pressure apply in wheel brakes.

Hydraulical compensation of disappearing generator torque: „Blending"



Regen Braking (RB)

Typical process of brake maneuver until standstill:



(1) Only regenerative braking
- Dump valves opened
- Driver pushes volume into LPA

(2) Hydraulically overlain braking
- Dump valves closed
- Equal to conventional braking

(3) Phase of constant brake torque

(4) Hydraulical compensation (blending)
- Isolation valves closed
- Pump pushes volume from LPA into wheel brakes

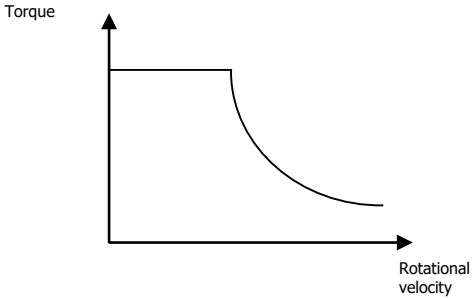
Electrical brake torque

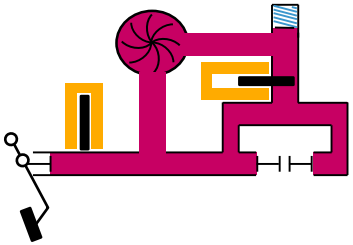
Hydraulical brake torque

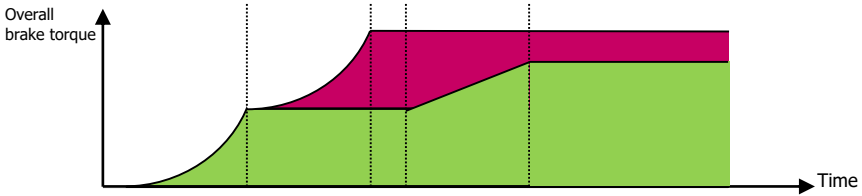
Regen Braking (RB)

Further functionalities:

- Simulation of combustion engine‘s brake torque
- Apply of deceleration requests from driver assistance systems → Cruise control, Traffic sign recognition
- Own wheel slip detection (more sensible than ABS, OBD compliant)
- Reverse blending: Pressure reduction in wheel brakes using analog controllable dump valves, adequate deceleration increment by generator



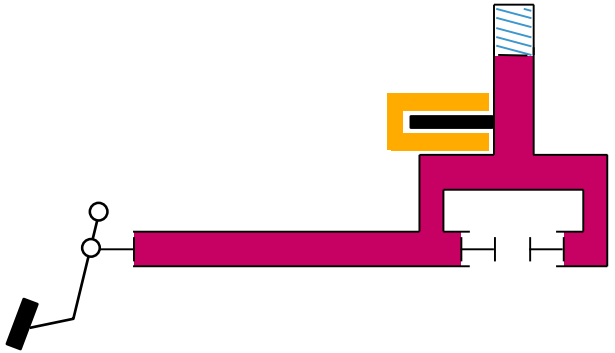




Regen Braking (RB)

Problems and boundaries:

- **Pedal feedback:** Little counterforce during electrical braking because of open dump valves (Solution: Electric brake boost with force blending)
- **Deceleration inhomogenities:** Especially during hydraulical compensation (blending)
- **Reproducibility:** Generator torque capacity variations → Different pedal feedback at different brake maneuvers
- **Interactions with other systems:** Generator has to be reduced if slip control becomes active
- **Stability:** Generator is mostly connected to rear axle



Regen Braking (RB)

- RB is active during every brake maneuver in electric and hybrid vehicles
- Open dump valves prevent pressure apply in wheel brakes during regenerative braking
- Generator is not capable of braking all the time
- Disappearing generator torque is hydraulically compensated (blending)
- Depending on customer project and hardware further functions are available (e.g. reverse blending)
- Biggest problems: pedal feedback, deceleration inhomogenities

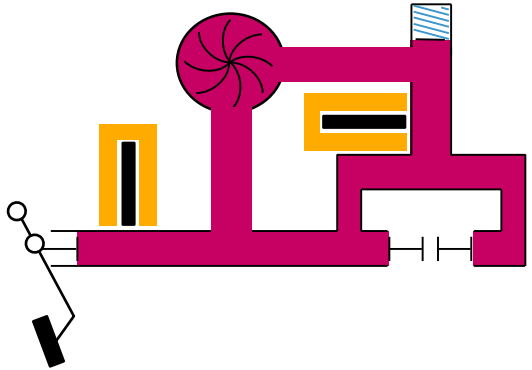
Driver Braking (DB)

What is a driver's deceleration request identification needed for? Pressure builds up on its own!

- During regenerative braking no pressure is applied in wheel brakes → **How much deceleration torque has the generator to apply?**

→ **How much deceleration does the driver want?**

→ **How to measure this deceleration request?**



Driver Braking (DB)

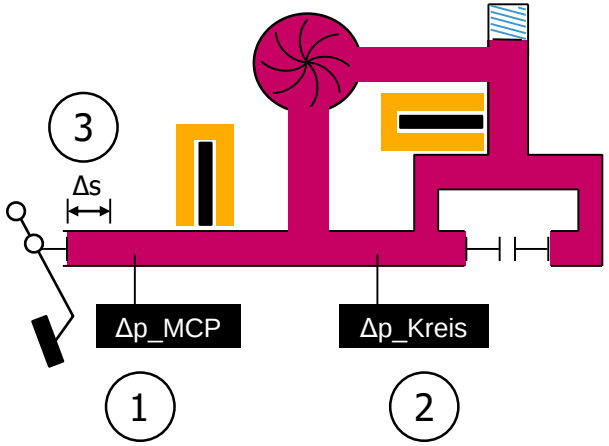
How to measure deceleration request?

Depending on ESC model different sensors are available:

(1) Main cylinder pressure (pressure in front of TC ISO valve)

(2) Circuit pressure (pressure behind TC ISO valve)

(3) Pedal travel



Driver Braking (DB)

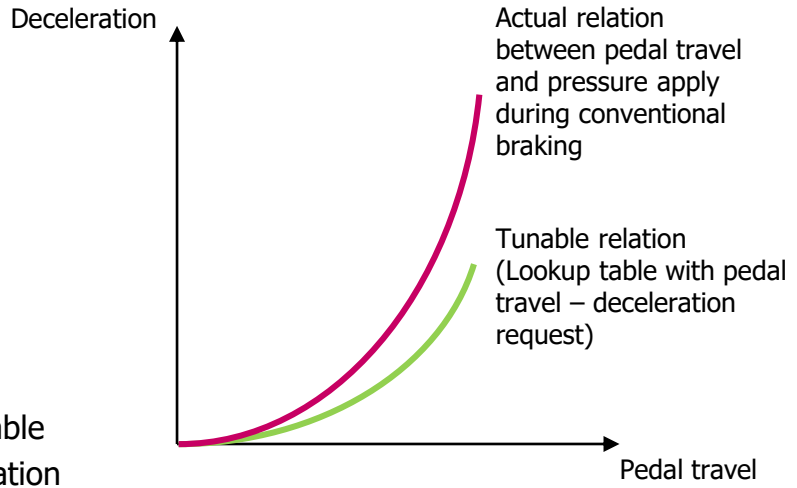
How much deceleration does the driver want?

Conventional braking in ESC:

- Main cylinder pressure describes deceleration request
- This pressure applies on its own

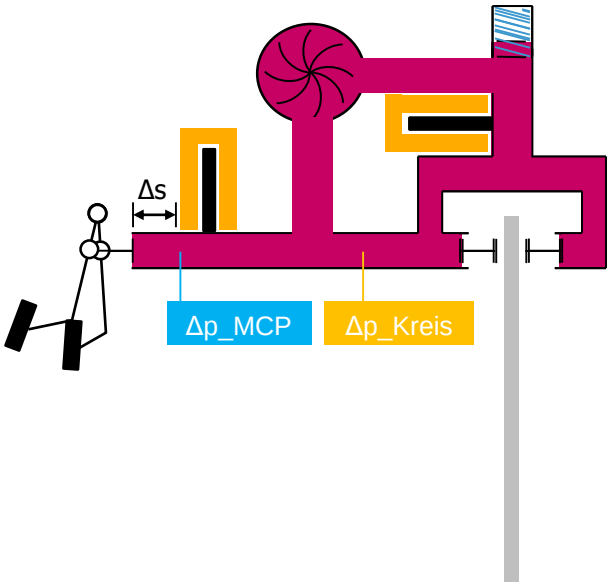
Regenerative braking

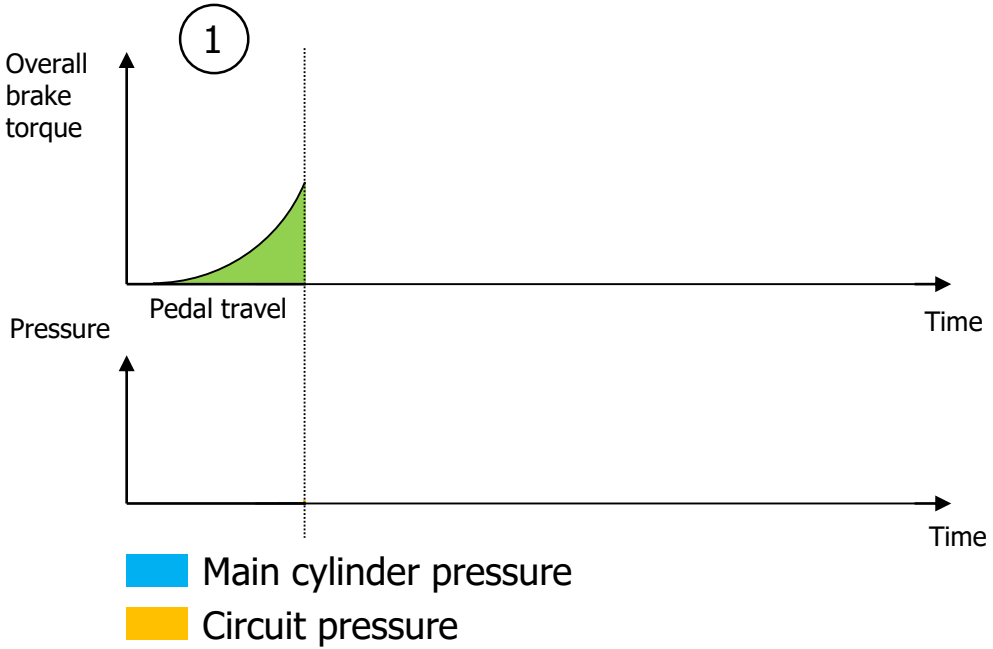
- Pressure does nearly not change during pedal apply
- Pedal travel changes
- Pedal travel is calculated into pressure request using lookup table
- Lookup table is tunable → Usually flater than conventional relation between pedal travel and pressure



Driver Braking (DB)

(1)Regenerative braking: Dump valves are opened just from beginning of brake maneuver, brake pads do not apply pressure at caliper

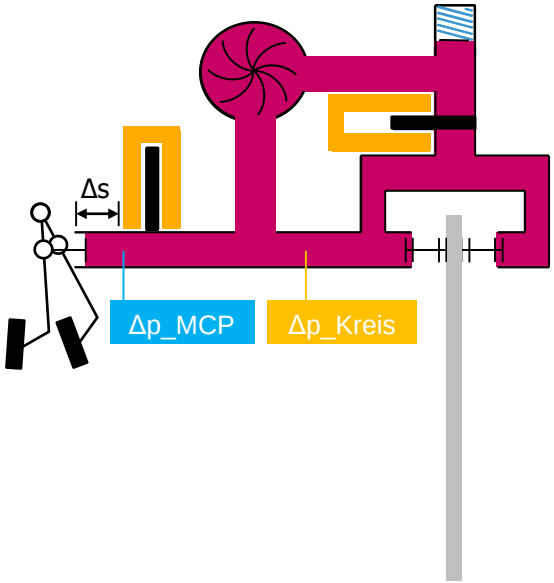


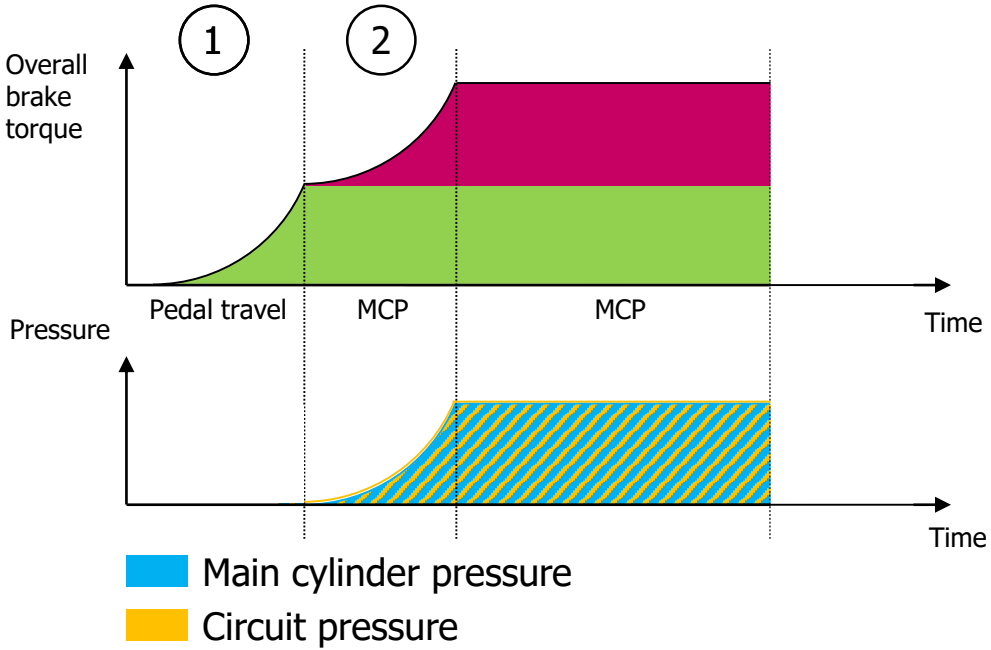


Driver Braking (DB)

(1)Regenerative braking: Dump valves are opened just from beginning of brake maneuver, brake pads do not apply pressure at caliper

(2)Hydraulically overlain braking: Pressure built-up in wheel brakes („Delta-MCP")



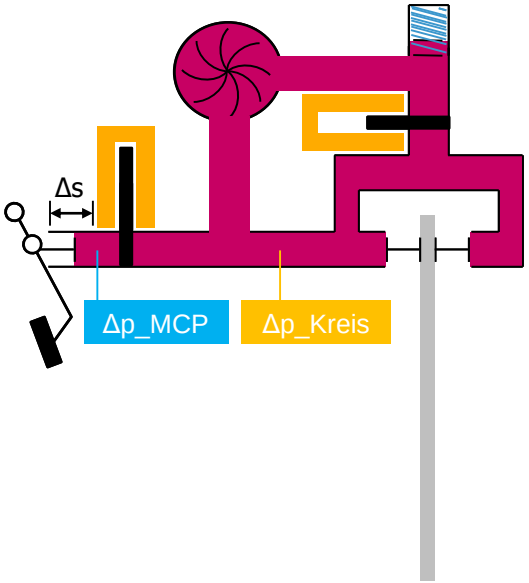


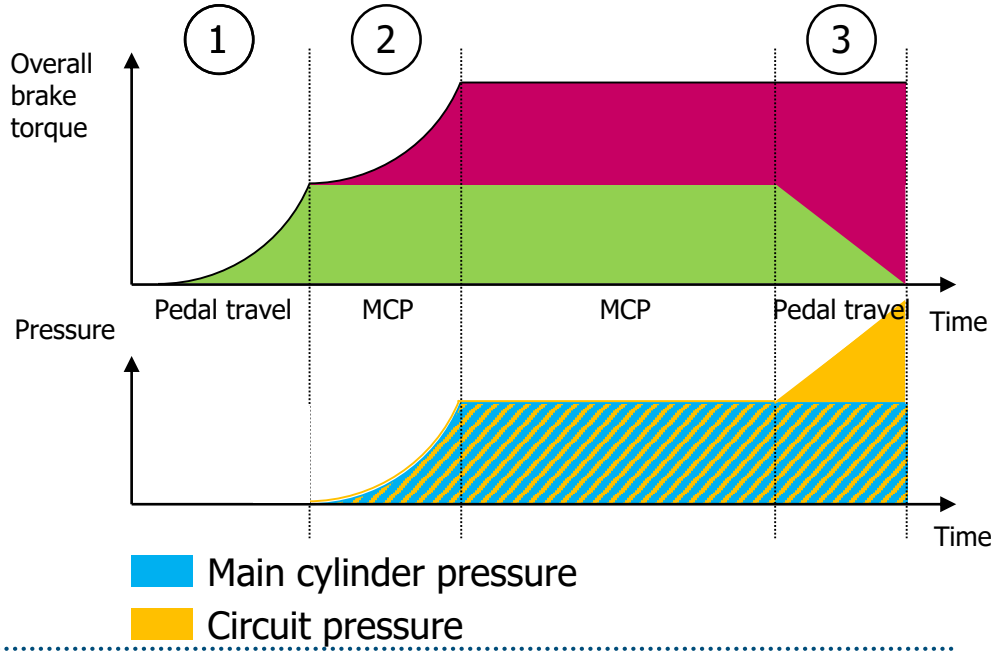
Driver Braking (DB)

(1)Regenerative braking: Dump valves are opened just from beginning of brake maneuver, brake pads do not apply pressure at caliper

(2)Hydraulically overlain braking: Pressure built-up in wheel brakes („Delta-MCP")

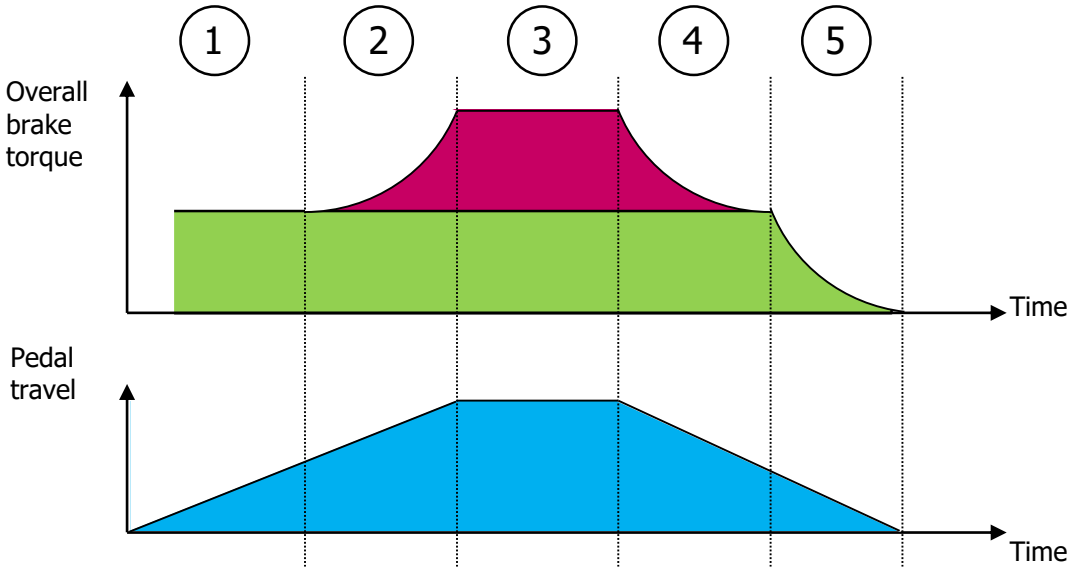
(3)Blending: Pump applies pressure in wheel brakes to compensate disappearing generator torque





Driver Braking (DB)

Typical process of brake maneuver with maximum efficiency utilization



(1) Regenerative braking
- Pedal travel sensor

(2) Hydraulically overlain braking
- Main cylinder pressure sensor

(3) Phase of constant brake torque
- Main cylinder pressure sensor

(4) Hydraulical pedal lift
- Main cylinder pressure sensor

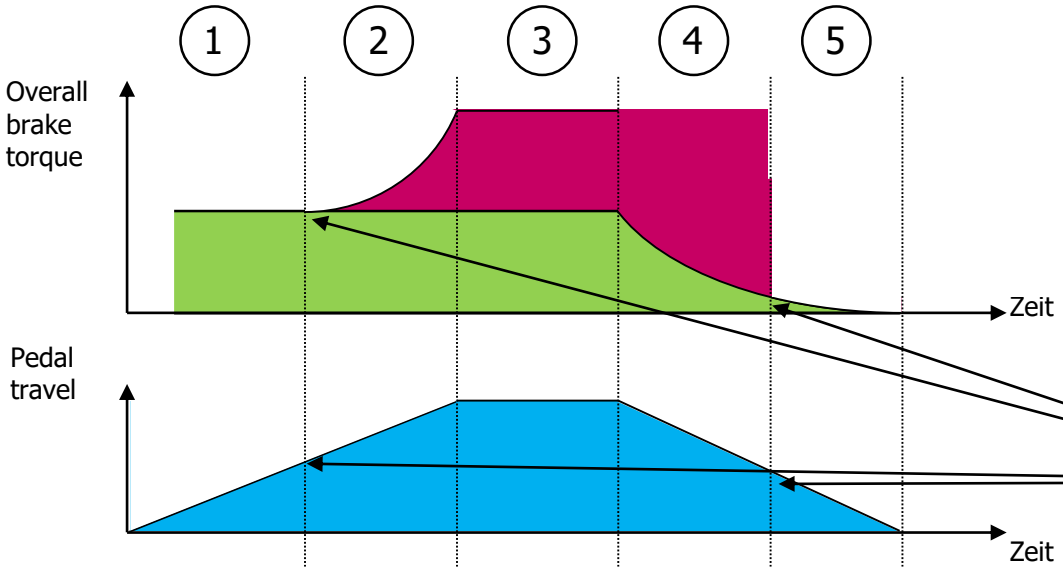
(5) Pedal lift without counterforce
- Pedal travel sensor
- Problem: Pedal feedback („sticky pedal“)

Regenerative brake torque

Hydraulical brake torque

Driver Braking (DB)

Typical process of brake maneuver with enhanced pedal feedback



(1) Regenerative braking
- Pedal travel sensor

(2) Hydraulically overlain braking
- Main cylinder pressure sensor

(3) Phase of constant brake torque
- Main cylinder pressure sensor

(4) Hyd. and el. pedal lift
- Pedal travel sensor (for generator)
- Pressure applies on its own
- Problem: lost pedal travel

(5) Pedal lift without counterforce
- No more pressure in system

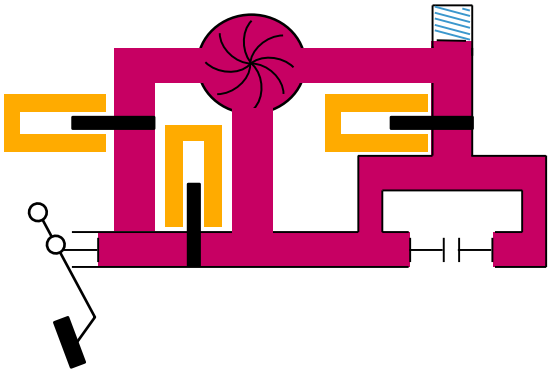
Regenerative brake torque

Hydraulical brake torque

Driver Braking (DB)

Problems and boundaries:

- **Lost pedal travel vs. sticky pedal**
- **Subsystem activity:** Running pump, closed isolation valves, pedal drop → Variations in pressure and pedal travel signals
- **Inconsistencies in signal run:** pressure decreases during increasing pedal travel → Does the driver want more or less deceleration?



Driver Braking (DB)

- Driver‘s deceleration request identification is especially needed for regenerative braking (no pressure in system)
- Different sensors are capable for identification of deceleration request (MCP and pedal travel)
- Signal runs sometimes are inconsistent (e.g. pedal drop while supply valves are open)
- Conflict of objectives: efficiency – pedal feedback/comfort

Thank you!