Vehicle Dynamics

Lesson n.3:

Longitudinal dynamics: braking manoeuvre

Secondary resistant forces

1. Rolling resistance:

$$R_X = R_{XF} + R_{XR} = f_V (W_F + W_R) = f_V W$$

Independent from load transfer phenomena

Contribution in the order of 0.01 g (f_V g)

2. Aerodynamic drag:

$$D_A = \frac{1}{2} \rho \, A \, C_X V^2$$

Contribution from negligible to 0.04 g

3. Powertrain:

Friction in bearings and gears

Engine brake

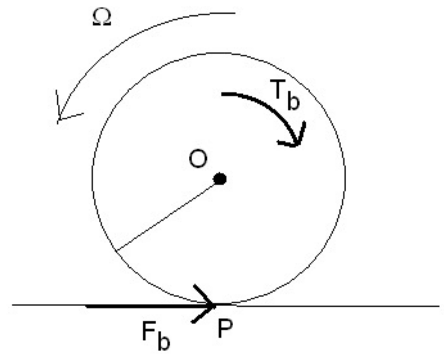
4. Road grade:

$$R_g = W \sin\Theta \cong W \, \Theta$$

Either resistant or traction force

Max contribution on highways of 0.04 g (Θ g)

Braking force

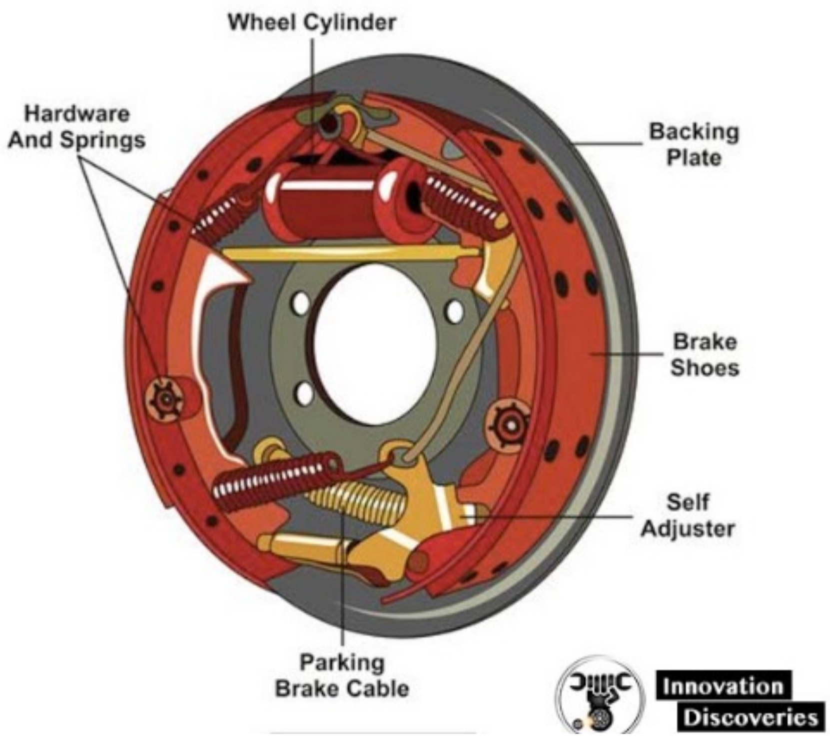


Second Newton's law for the wheel during braking (simple model, more details will follw)

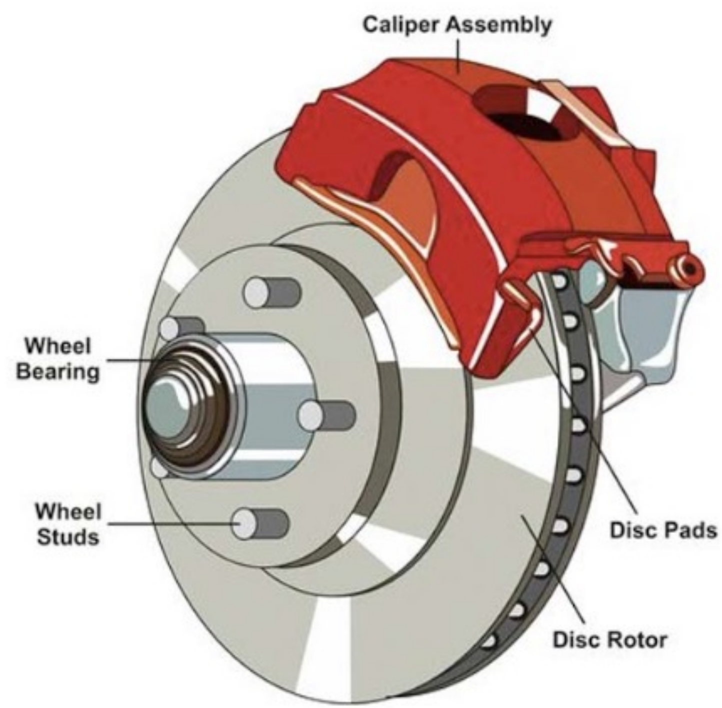
$$T_b - F_b r = I_w \alpha_w \quad \Rightarrow \quad F_b = \frac{T_b - I_w \alpha_w}{r} \cong \frac{T_b}{r}$$

where $T_b = f(P_a, Vel, Temp)$

Drum brake

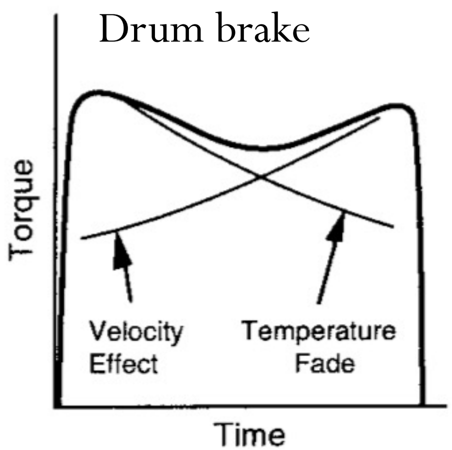


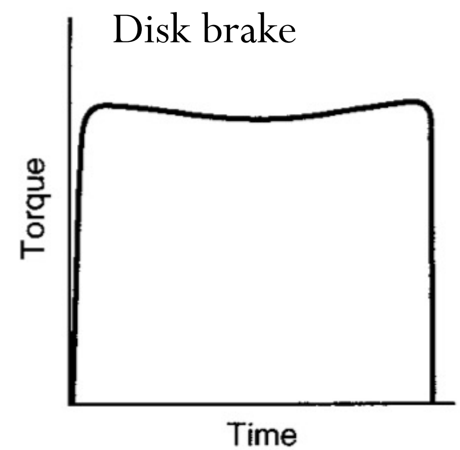
Disk brake



Disk brake vs drum brake

Measured braking torque

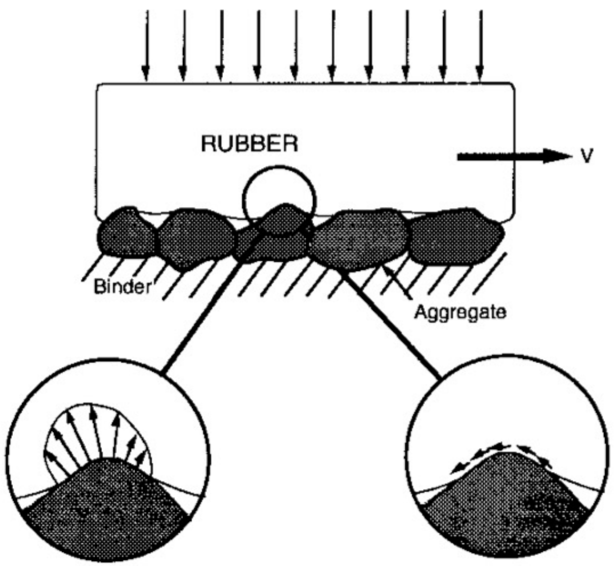


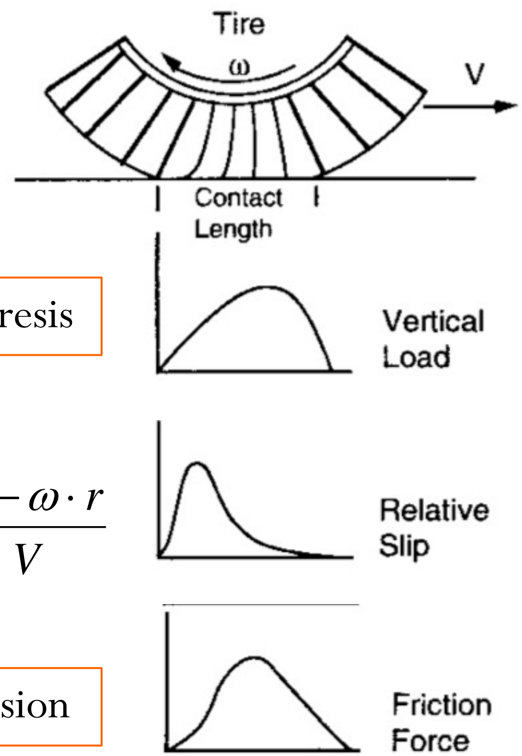


Drum brake	Feature	Disk brake
+	Amplification of actuation force	✗
−	Brake cooling (by ventilation	+
−	Braking torque variation	+

Tire-road friction: hysteresis and adhesion

Resistance phenomena in the contact patch





Hysteresis

$$Slip = \frac{V - \omega \cdot r}{V}$$

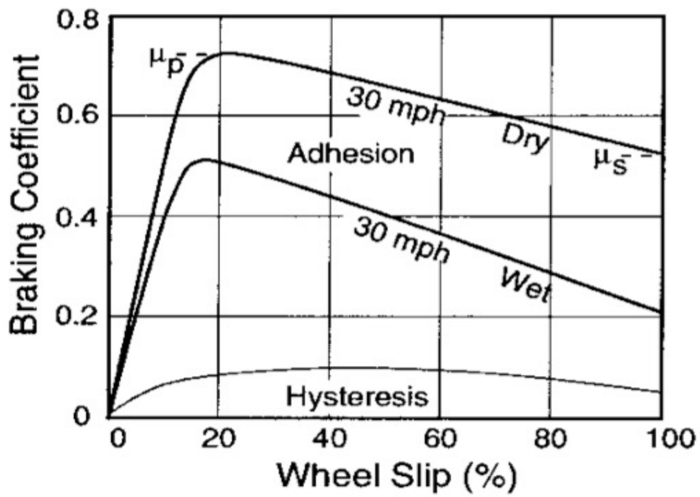
Adhesion

$$\mu = \frac{F_X}{F_Z}$$

Braking friction coefficient

Key elements for brakes design

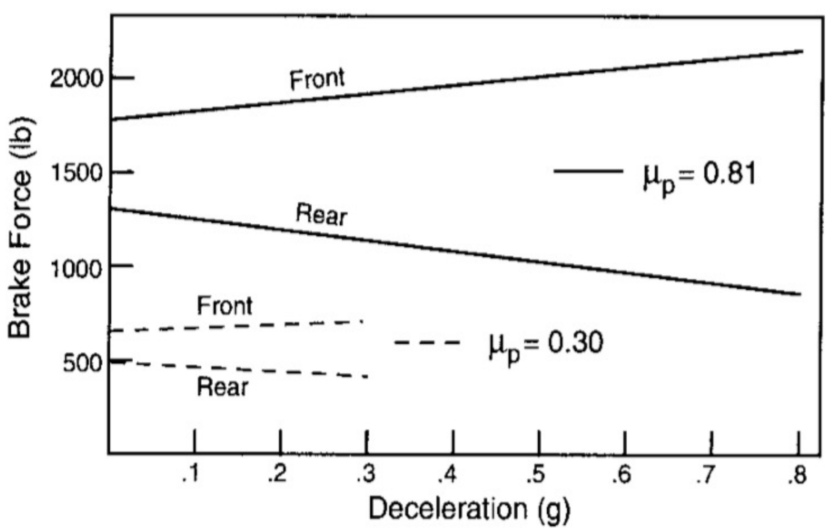
1. Braking coefficient variations



Key factors:

- Wheel Slip → $Slip = \dfrac{V - \omega \cdot r}{V}$
- Speed
- Pressure
- Vertical load
- Weather conditions

2. Variations of maximum braking effort

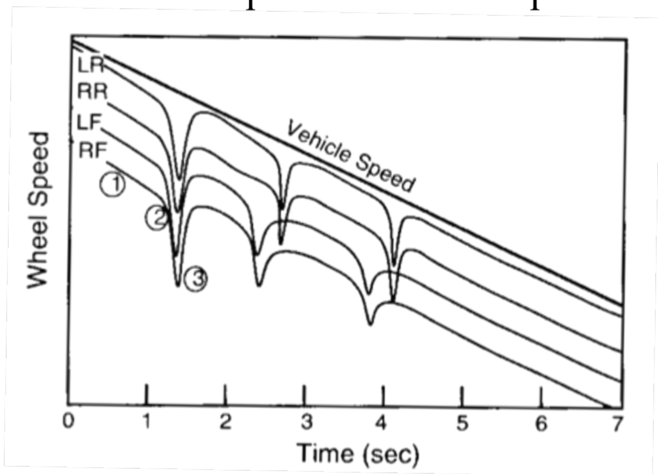


Key elements:

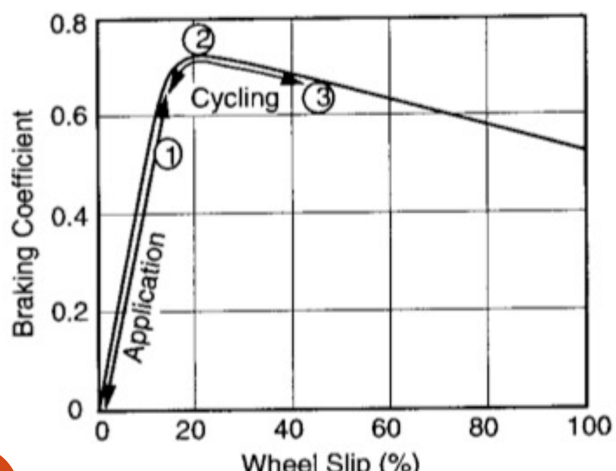
- Front wheels locking → Reduced steerability
- Rear wheels locking. → Vehicle spin

Anti-lock braking system (ABS)

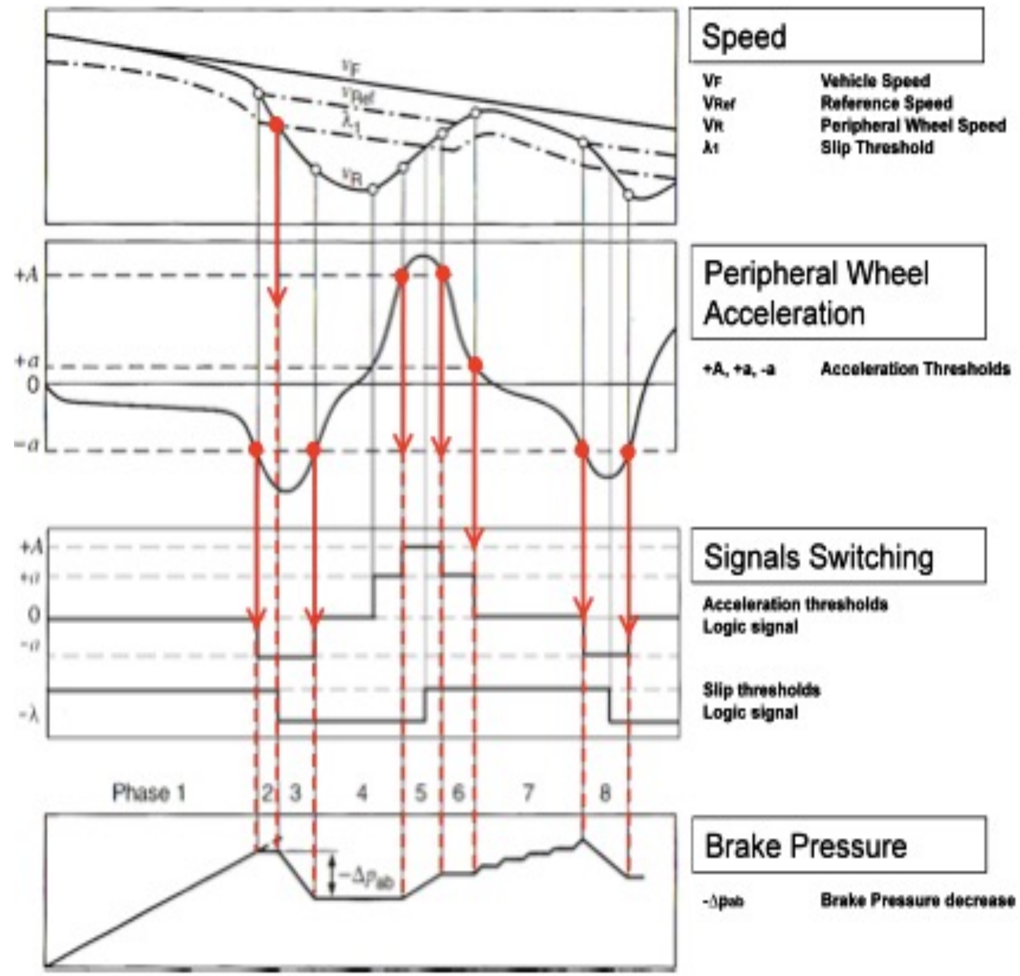
Wheel speed vs vehicle speed



Wheel slip operating range

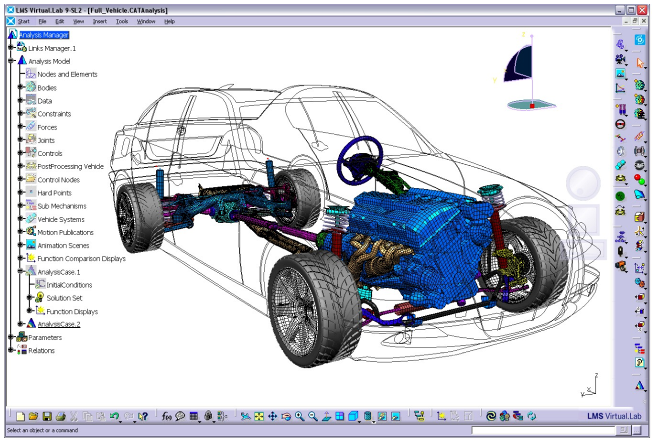


Control logic

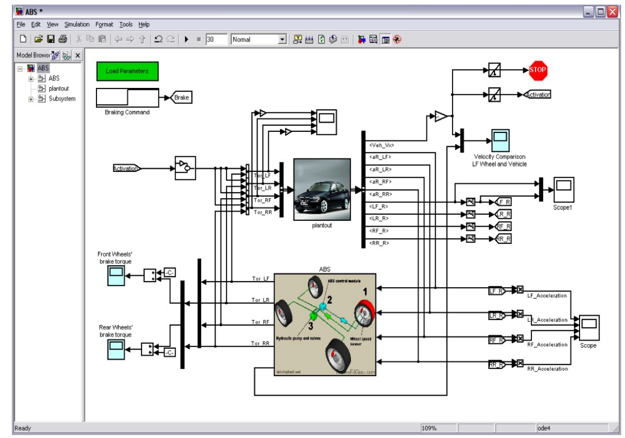


Example of ABS in a dynamic simulation

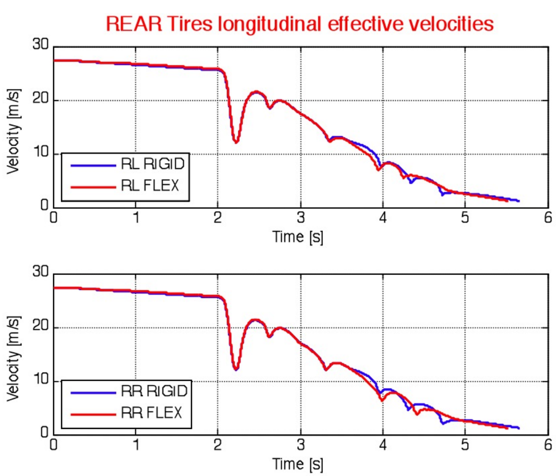
MultiBody vehicle model

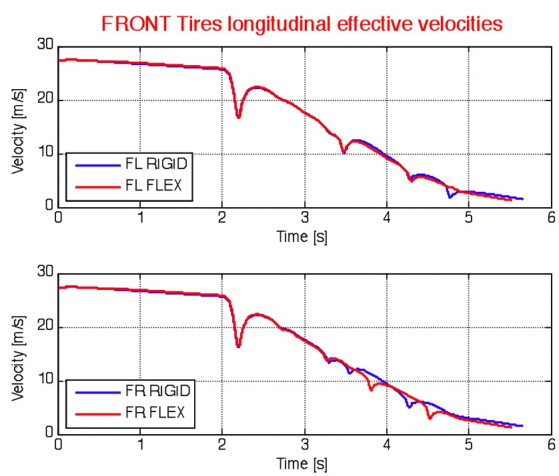


Control unit model

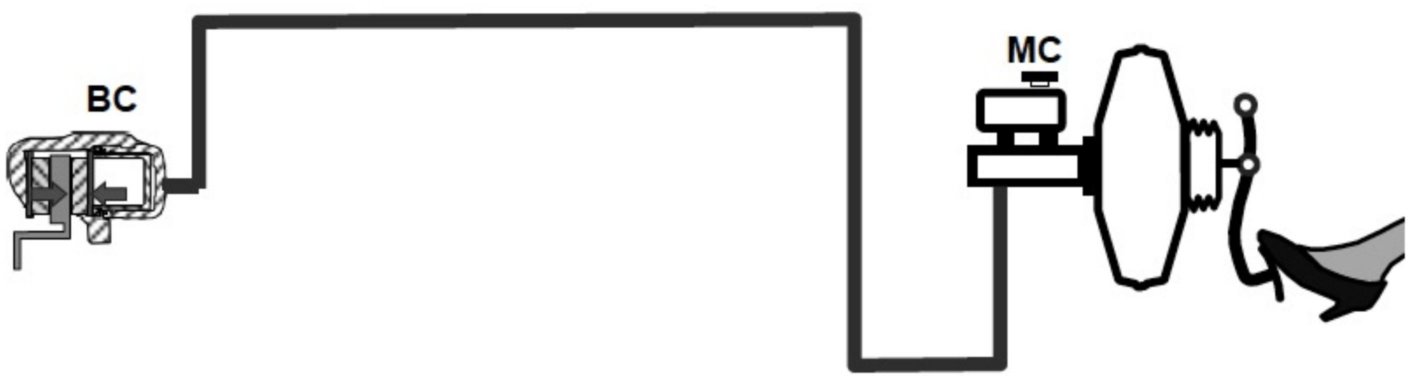


Tangentianl wheel speed

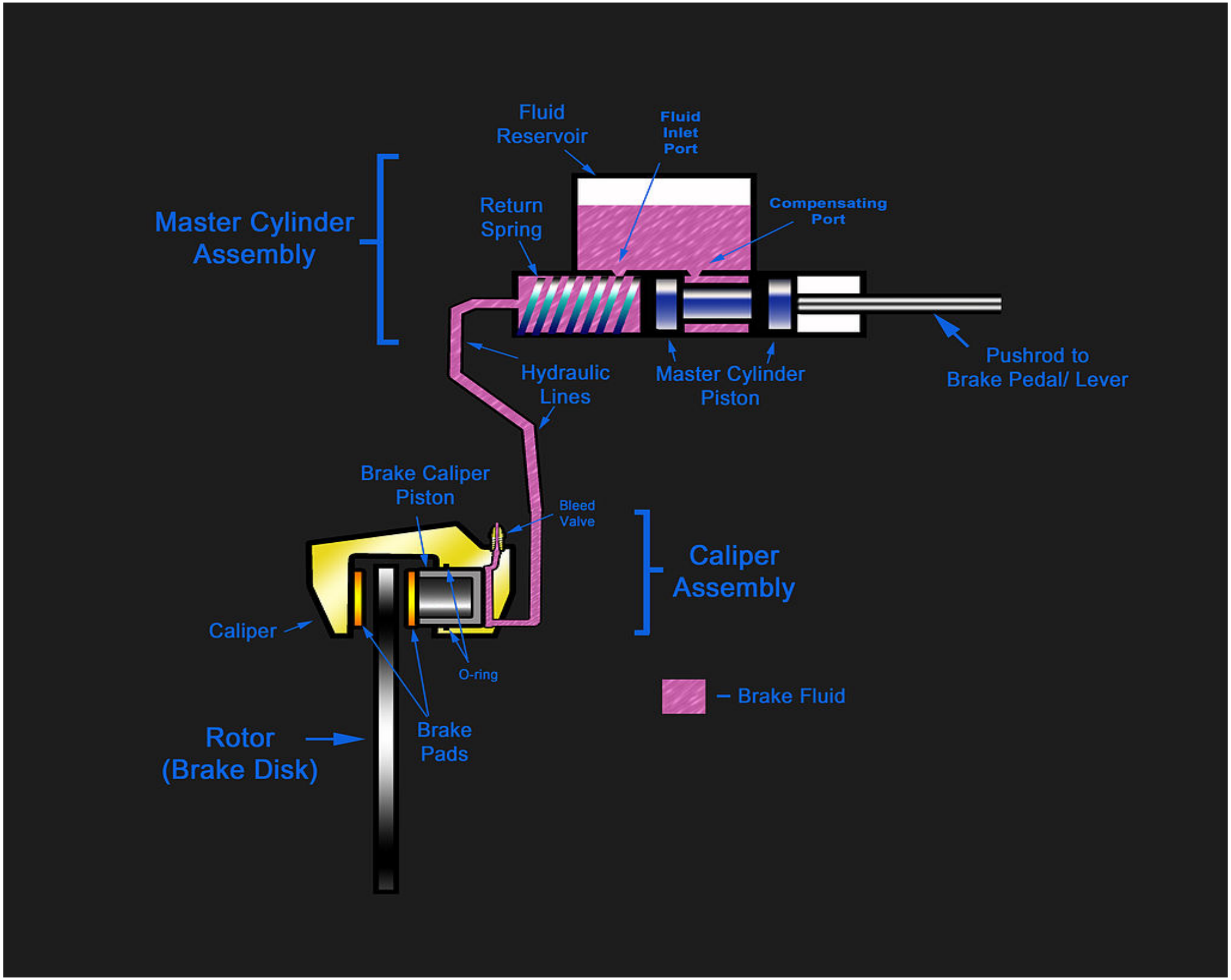




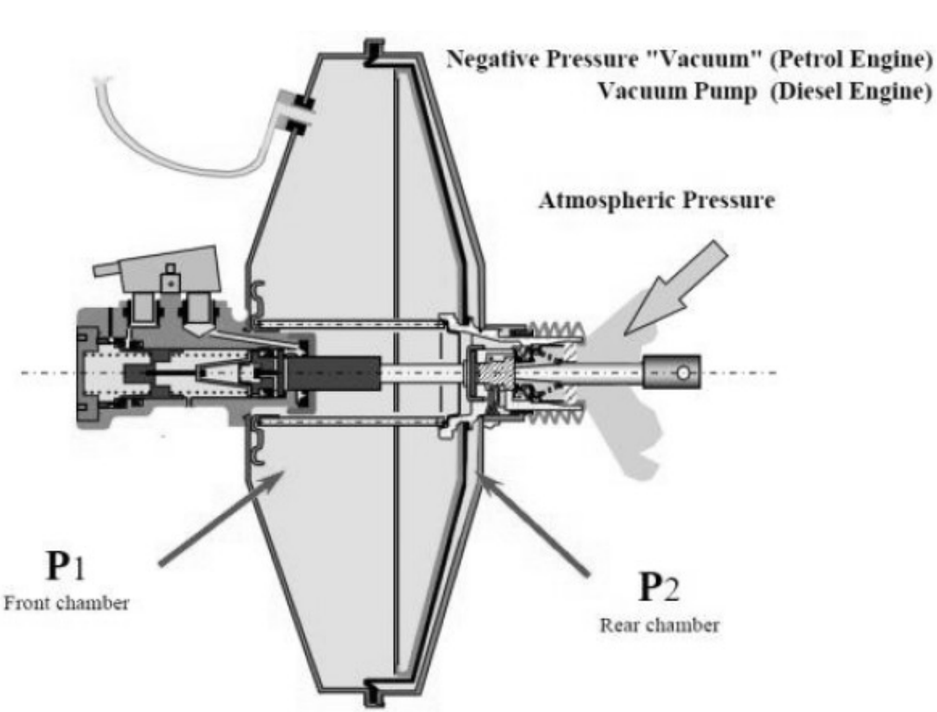
Braking system: normal braking action

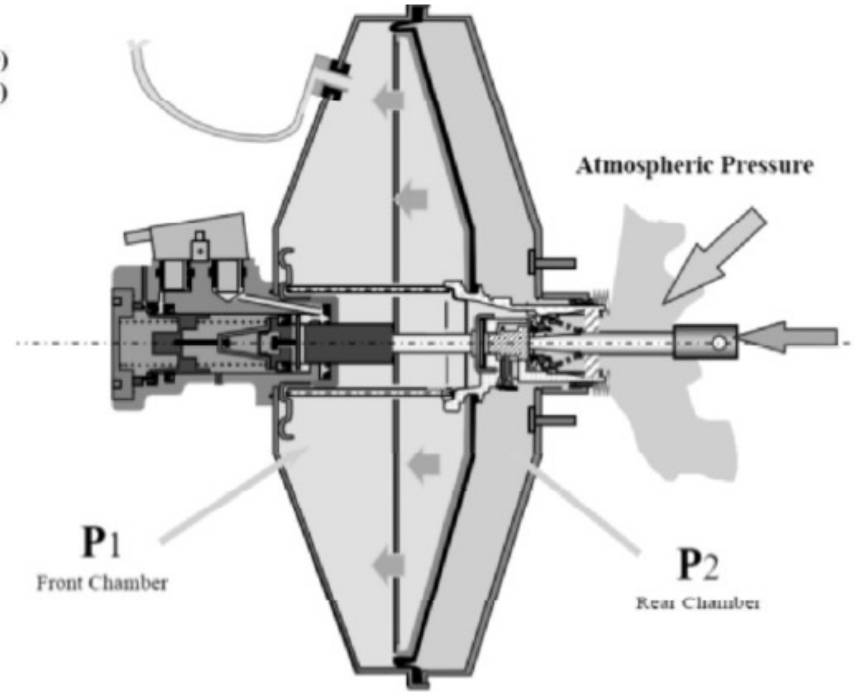


Braking system: hydraulic schematic



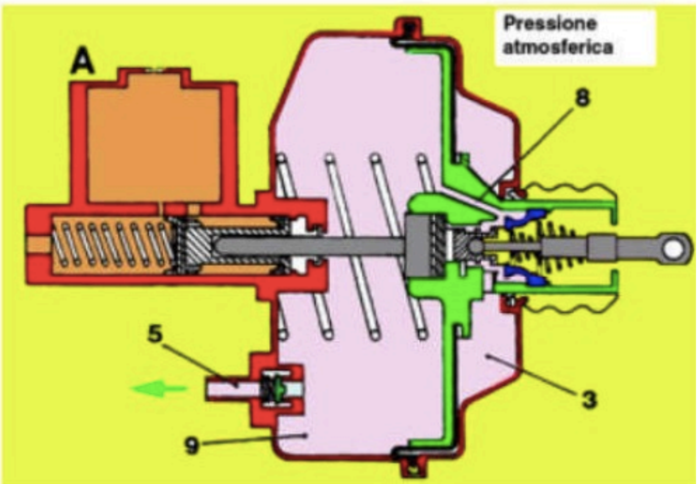
Braking system: auxiliary devices

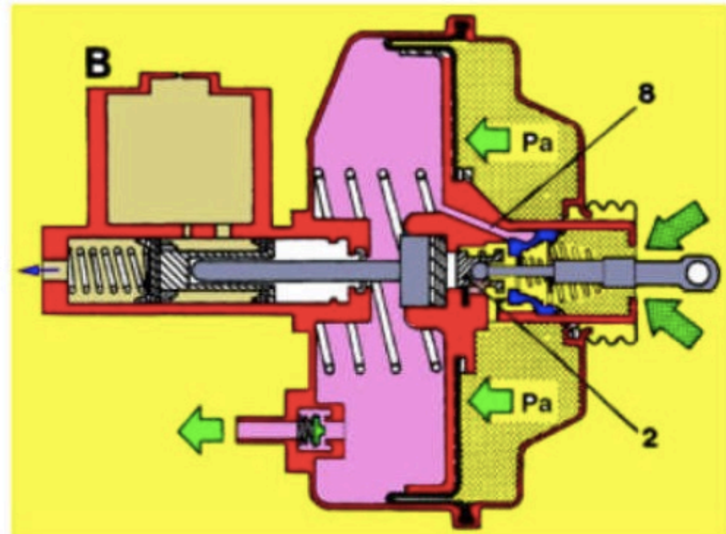


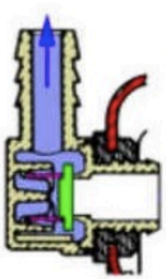


Booster
to amplify driver's pedal force effect on Tandem Master Cylinder (TMC)

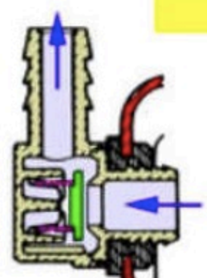
Braking system: auxiliary devices







3. Camera posteriore;
5. Valvola di ritegno depressione;
8. Canale di collegamento camere; 9. Camera anteriore.



2. Sede puntale;
8. Canale di collegamento camere.

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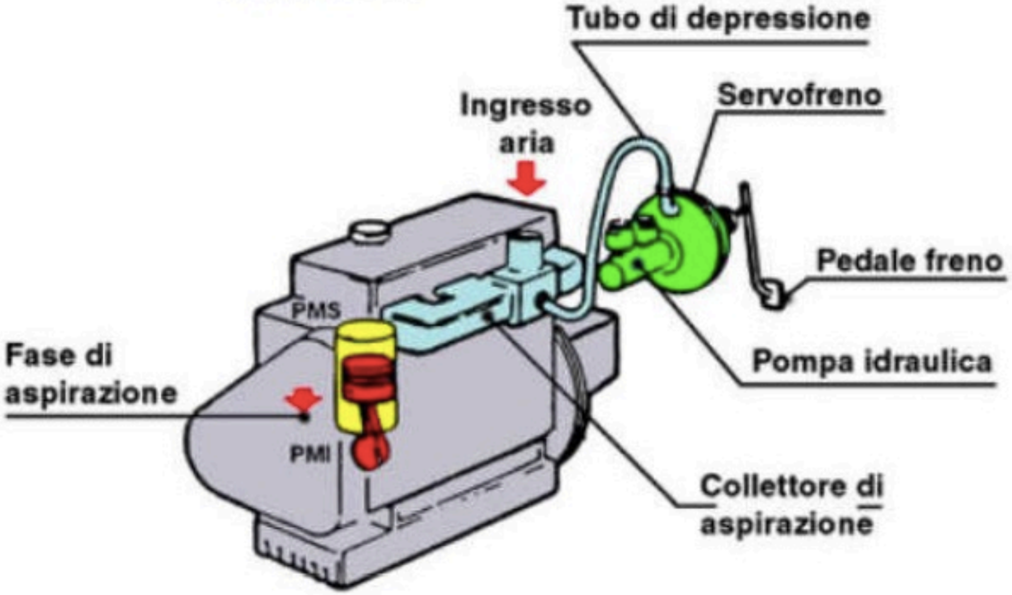
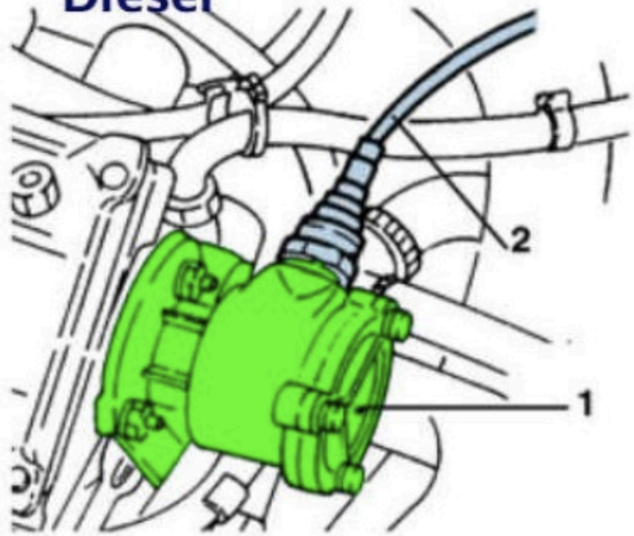
Braking system: auxiliary devices

Alimentazione benzina



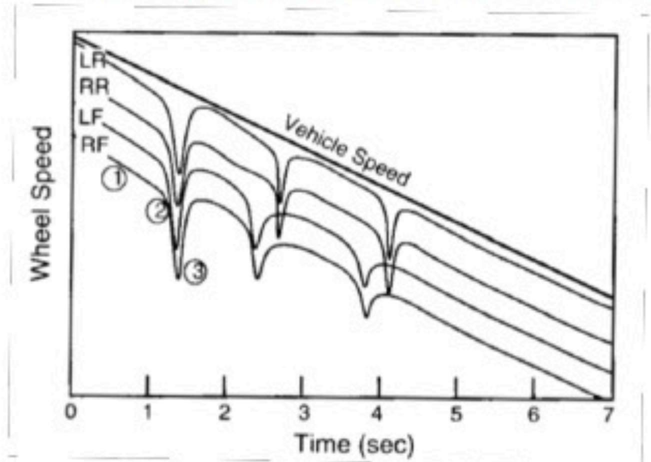
Alimentazione Diesel



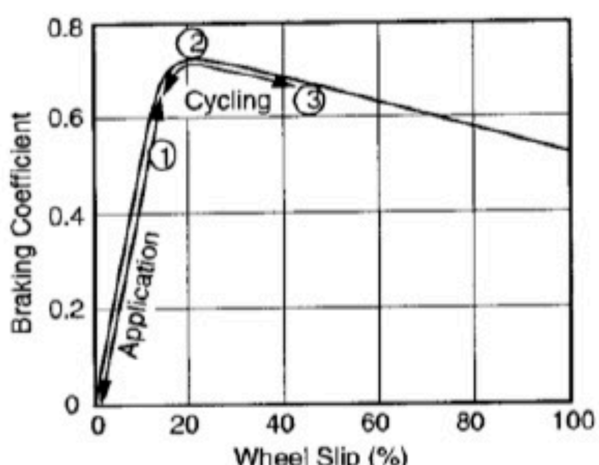
1. Depressore;
2. Tubo di depressione

Braking system: ABS control logics

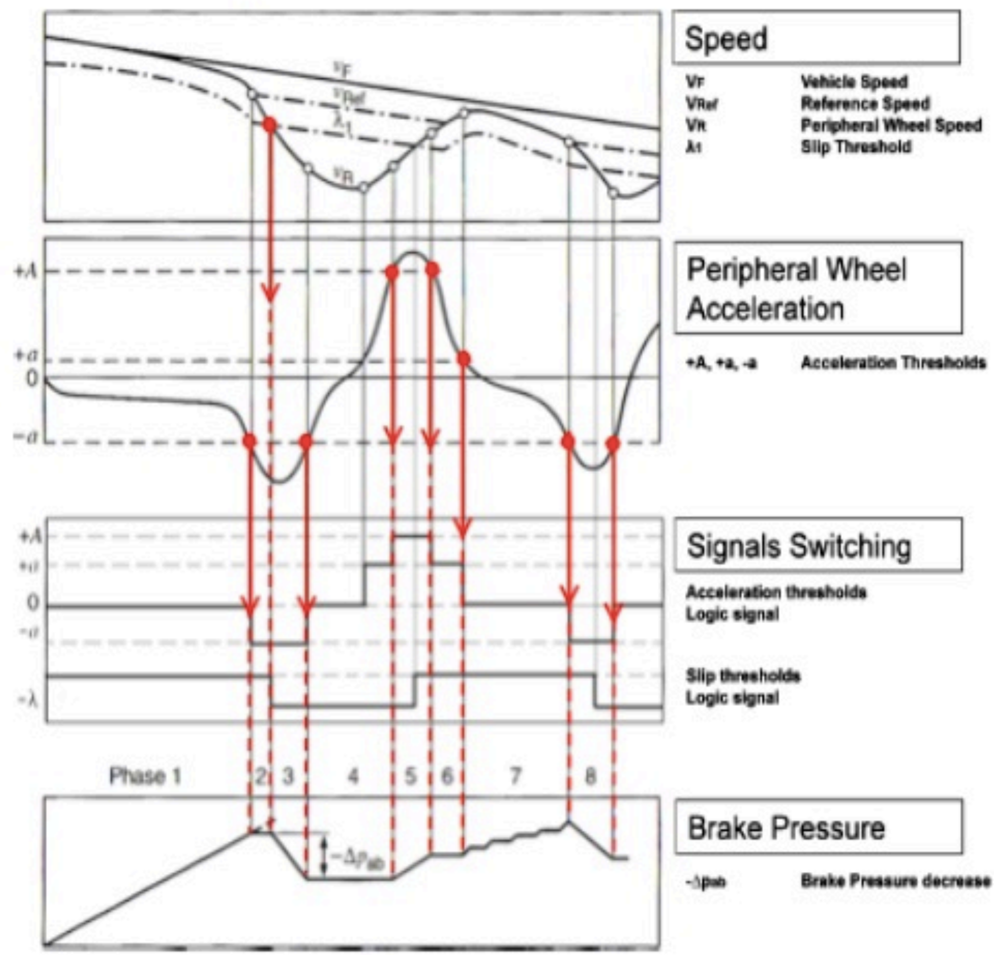
Velocità periferica della ruota nel tempo



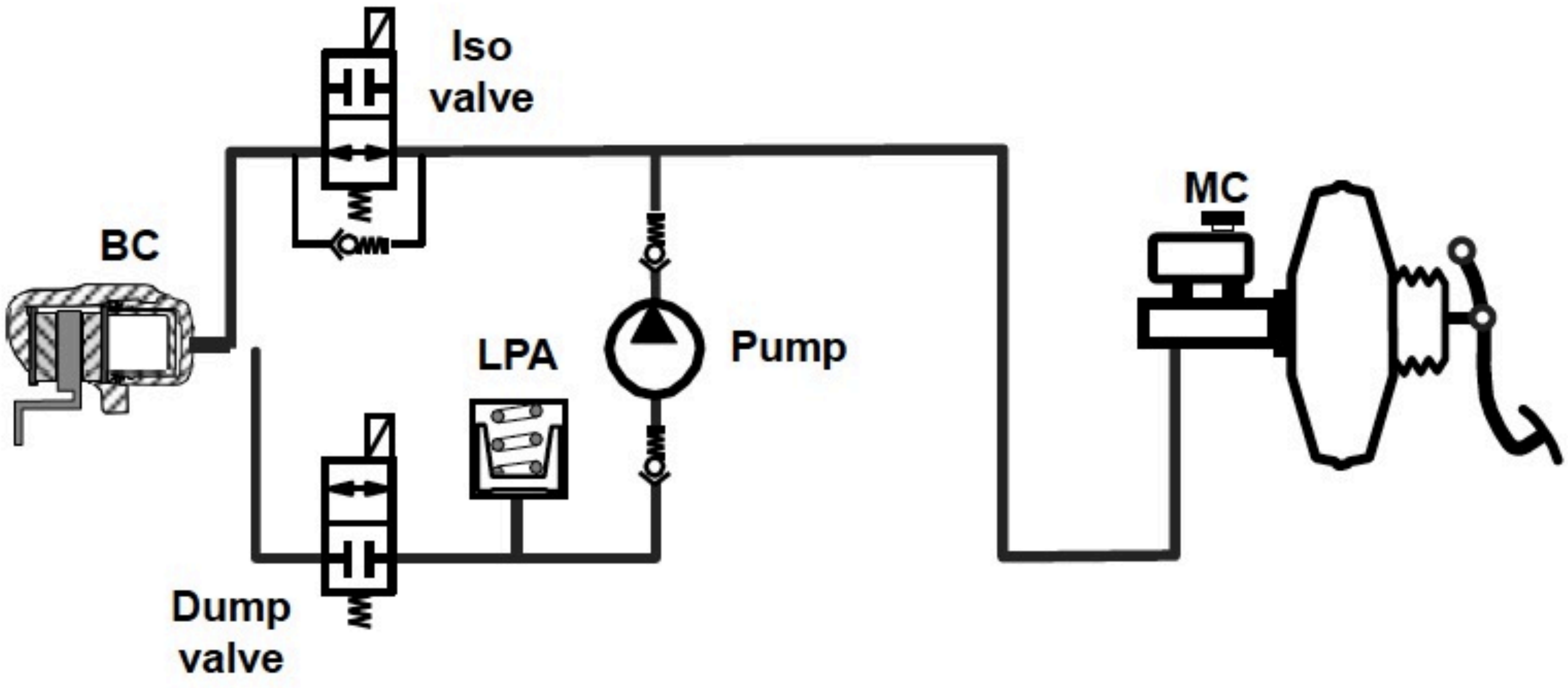
Zona di lavoro del freno



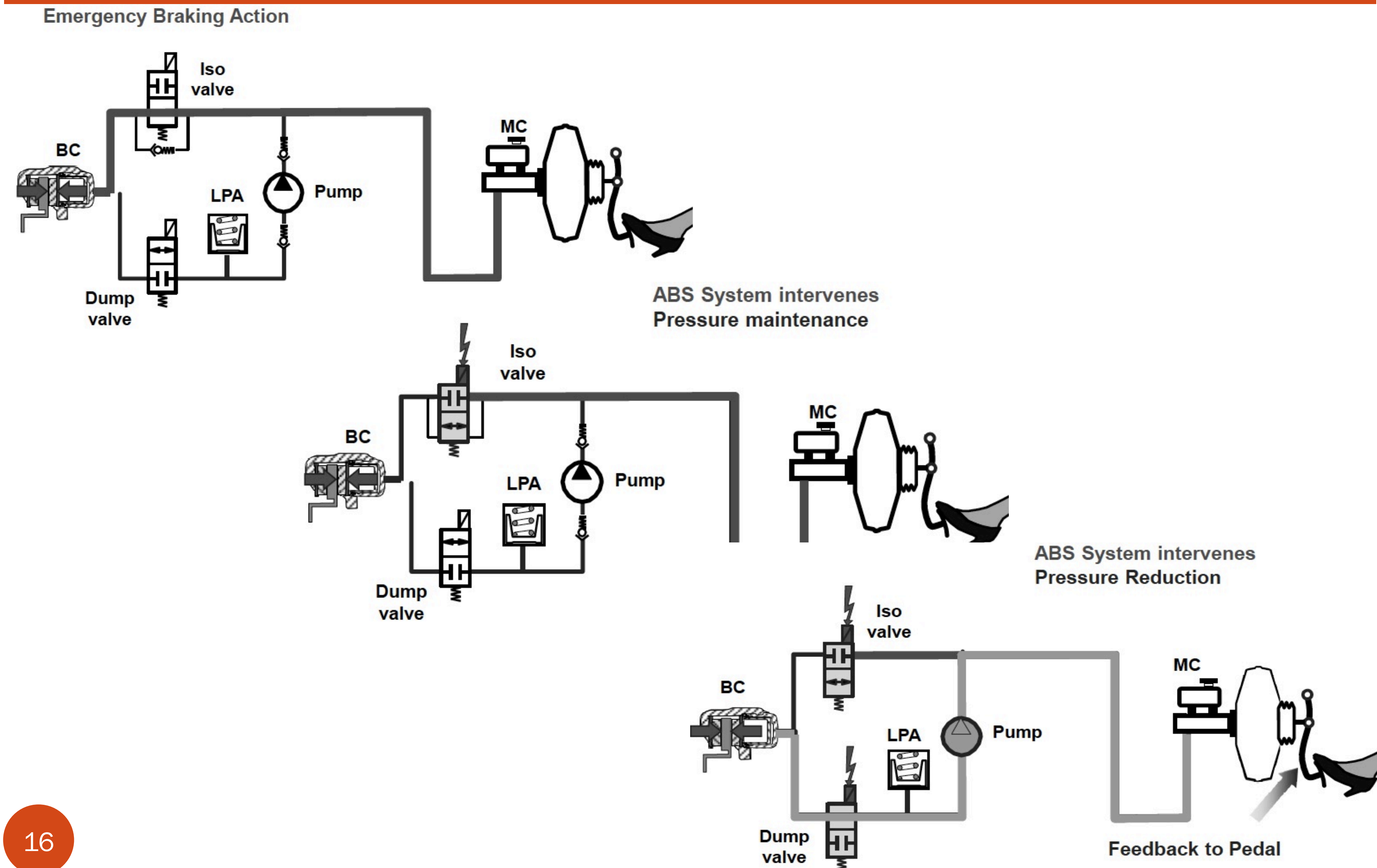
Logica di controllo



Braking system: ABS hydraulic circuit



Braking system: ABS hydraulic circuit



Anti-lock braking system: motion equations

A kinematic excercise

Assumption $$D_X = -a_X = \frac{F_{XT}}{M} = \boldsymbol{cost}$$

Stopping time $$t_S = \frac{V_0}{D_X}$$

Stopping distance $$SD = \frac{V_0{}^2}{2D_X}$$

Let's prove it!