

School of Engineering

Introduction to Kinetic Energy and Kinetic Energy Recovery Systems (KERS) or Regenerative Braking

Linear Motion

Linear Motion

Position x

Velocity v

Acceleration a

Motion equations $x = \bar{v} t$

$$v = v_0 + at$$

$$x = v_0 t + \frac{1}{2} at^2$$

$$v^2 = v_0^2 + 2ax$$

Mass (linear inertia) m

Newton's second law $F = ma$

Momentum $p = mv$

Work Fd

Kinetic energy $\frac{1}{2}mv^2$

Power Fv

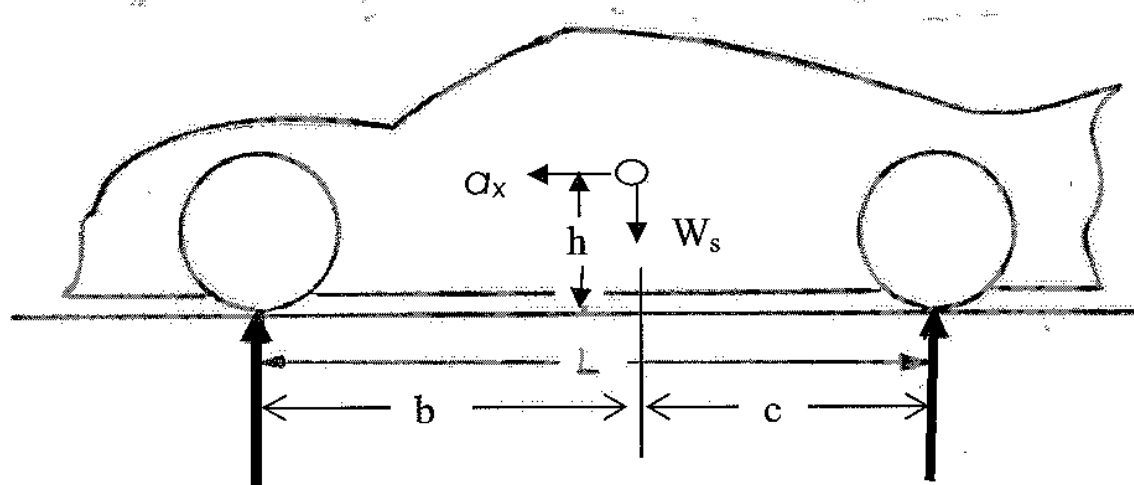
Kinetic Energy Recovery

- A Mechanism that stores (some of) the vehicles kinetic energy during braking and than allows it to be used to re-accelerate the vehicle.
 - There are different types
 - Mechanical
 - Electrical
 - Hydraulic
 - Chemical - Or combinations there of.
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Kinetic Energy Recovery

- Regenerative braking systems cannot replace friction brakes
 - Limited energy storage capacity
 - Limited power flow capacity
 - Limited ability to distribute braking torque.

 - The vehicle friction braking capability must be retained.
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$$W_{fb} = W_{usf} + \frac{W_s \times c}{L} + \frac{W_s \times a_x \times h}{L \times g}$$

$$W_{rb} = W_{usr} + \frac{W_s \times b}{L} - \frac{W_s \times a_x \times h}{L \times g}$$

Fig 1 SAE convention for forces on the vehicle

Determination of the maximum brake force possible for a given deceleration

If it is taken into account that the vehicle has suspension then for the vehicle shown above, which is assumed to be braking, is on level ground and ignoring aerodynamic effects the total reaction at the front wheels of the braking vehicle is given by :

$$W_{fb} = W_{usf} + \frac{W_s \times c}{L} + \frac{W_s \times a_x \times h}{L \times g}$$

Similarly for the rear

$$W_{rb} = W_{usr} + \frac{W_s \times b}{L} - \frac{W_s \times a_x \times h}{L \times g}$$

Maximum Brake Force transmittable $F_b = \mu t \times$ vertical reaction with front wheels about to lock.

For front wheels:

$$F_{bf} = \mu t \left[W_{usf} + \frac{W_s \times c}{L} + \frac{W_s \times a_x \times h}{L \times g} \right]$$

Similarly for rear wheels:

$$F_{br} = \mu t \left[W_{usr} + \frac{W_s \times b}{L} - \frac{W_s \times a_x \times h}{L \times g} \right]$$

Total weight of the vehicle = W

Where $W = W_{usf} + W_{usr}$

$$\mathbf{Fbpf} = \frac{\mu t}{Mg} \left[(M_f \times g) + \frac{M_s \times a \times h}{L} \right] \quad \text{Eqn 1}$$

Maximum Brake Force transmittable Fbpr at rear wheels as a proportion of vehicle weight.

$$\mathbf{Fbpr} = \frac{\mu t}{W} \left[W_{usr} + \frac{W_s \times b}{L} - \frac{W_s \times a_x \times h}{L \times g} \right]$$

Again this can be simplified as:

$$\mathbf{Fbpr} = \frac{\mu t}{Mg} \left[(M_r \times g) - \frac{M_s \times a \times h}{L} \right] \quad \text{Eqn 2}$$

Where $M_{f/r}$ are the total masses at front and rear of the car as would be measured on corner weight scales

2. Determine required front and rear brake torques

Knowing the Maximum Brake Force ratio at 1g and hence the ideal Brake Effort ratio for $\mu = 1$ the torque that each brake needs to produce needs to be determined.

The required brake torque for each front wheel is given by:

$$T_{bf} = \frac{F_{bpf} \times r \times W}{2} \quad \text{Eqn 3f}$$

Where:

T_{bf} = Required front brake torque per wheel [Nm]

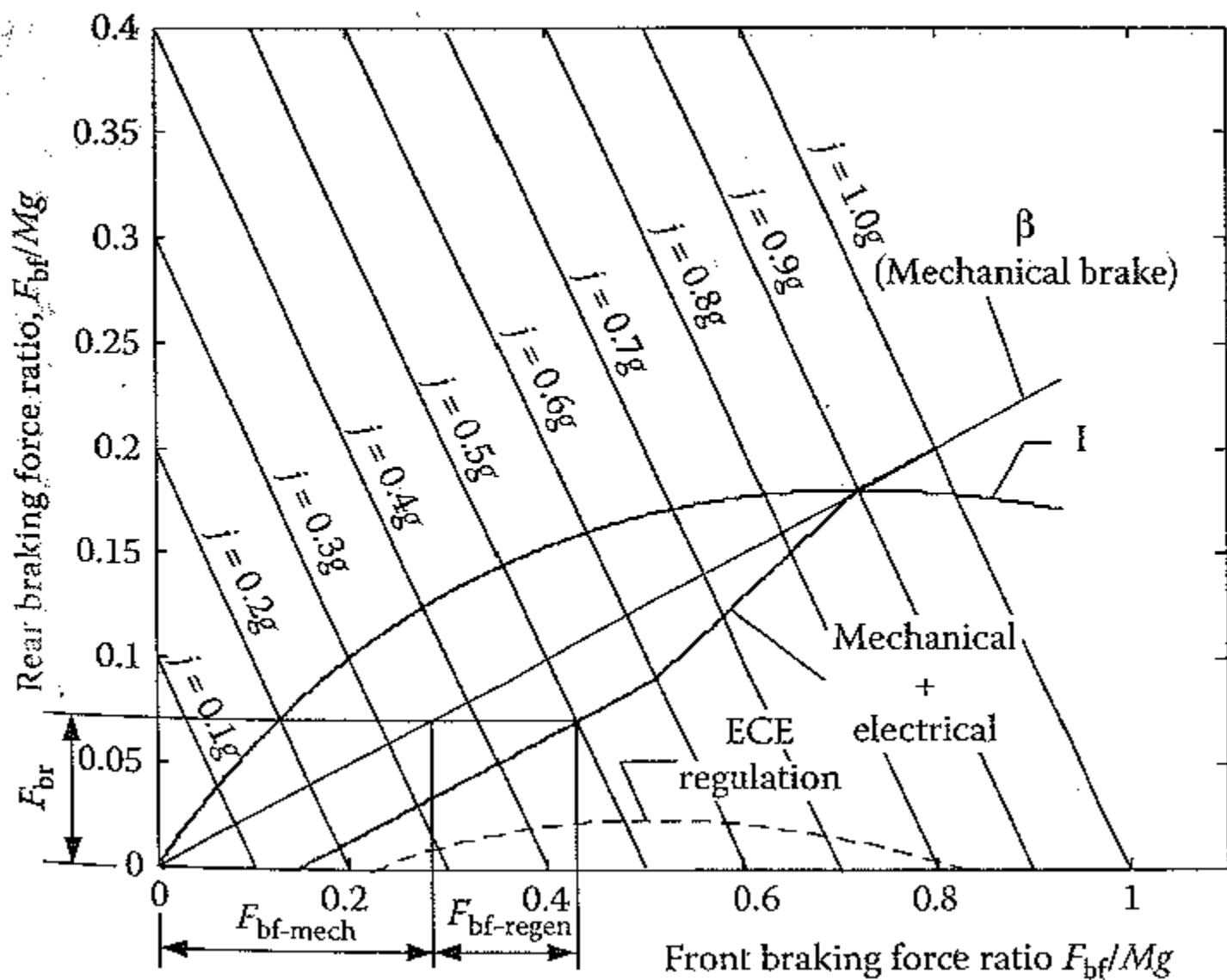
r = Rolling radius of tyre [m]

Similarly for each rear wheel

$$T_{br} = \frac{F_{bpr} \times r \times W}{2} \quad \text{Eqn 3r}$$

Where :

T_{br} = Required rear brake torque per wheel [Nm]



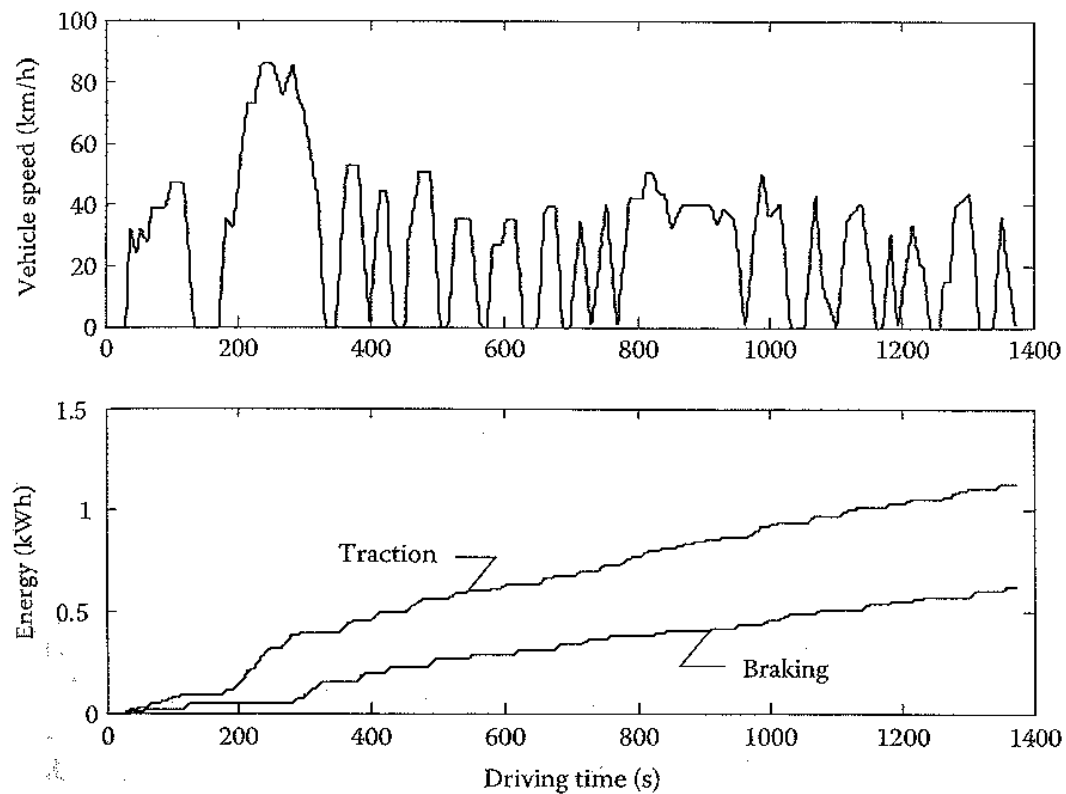
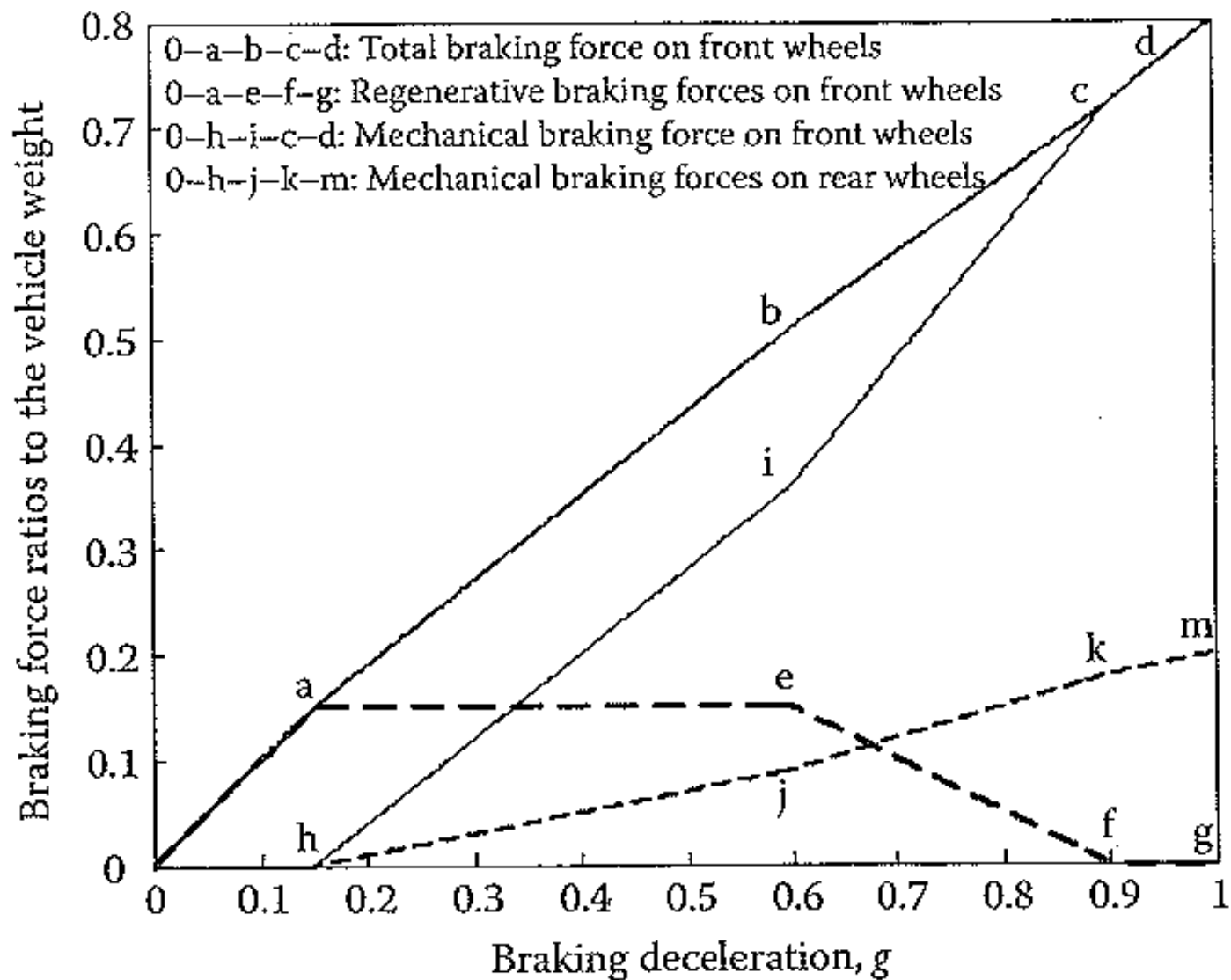


FIGURE 13.2 Traction and braking energy dissipation in an FTP75 urban driving cycle.

TABLE 13.2

Maximum Speed, Average Speed, Total Traction Energy, and Energies Dissipated by the Drag and Braking per 100 km Traveling Distance in Different Drive Cycles

	FTP75 Urban	LA92	US06	New York	ECE15
Max. speed (km/h)	86.4	107.2	128.5	44.6	120
Ave. speed (km/h)	27.9	39.4	77.4	12.2	49.8
Traveling distance per cycle (km)	10.63	15.7	12.8	1.90	7.95
Traction energy (kWh)					
Per cycle	1.1288	2.3559	2.2655	0.2960	0.9691
Per km	1.1062	0.15	0.1769	0.1555	0.1219
Braking energy (kWh)					
Per cycle	0.6254	1.3666	0.9229	0.2425	0.3303
Per km	0.0589	0.0870	0.0721	0.1274	0.0416
Percentage of braking energy to traction energy	55.4	58.01	40.73	81.9	34.08



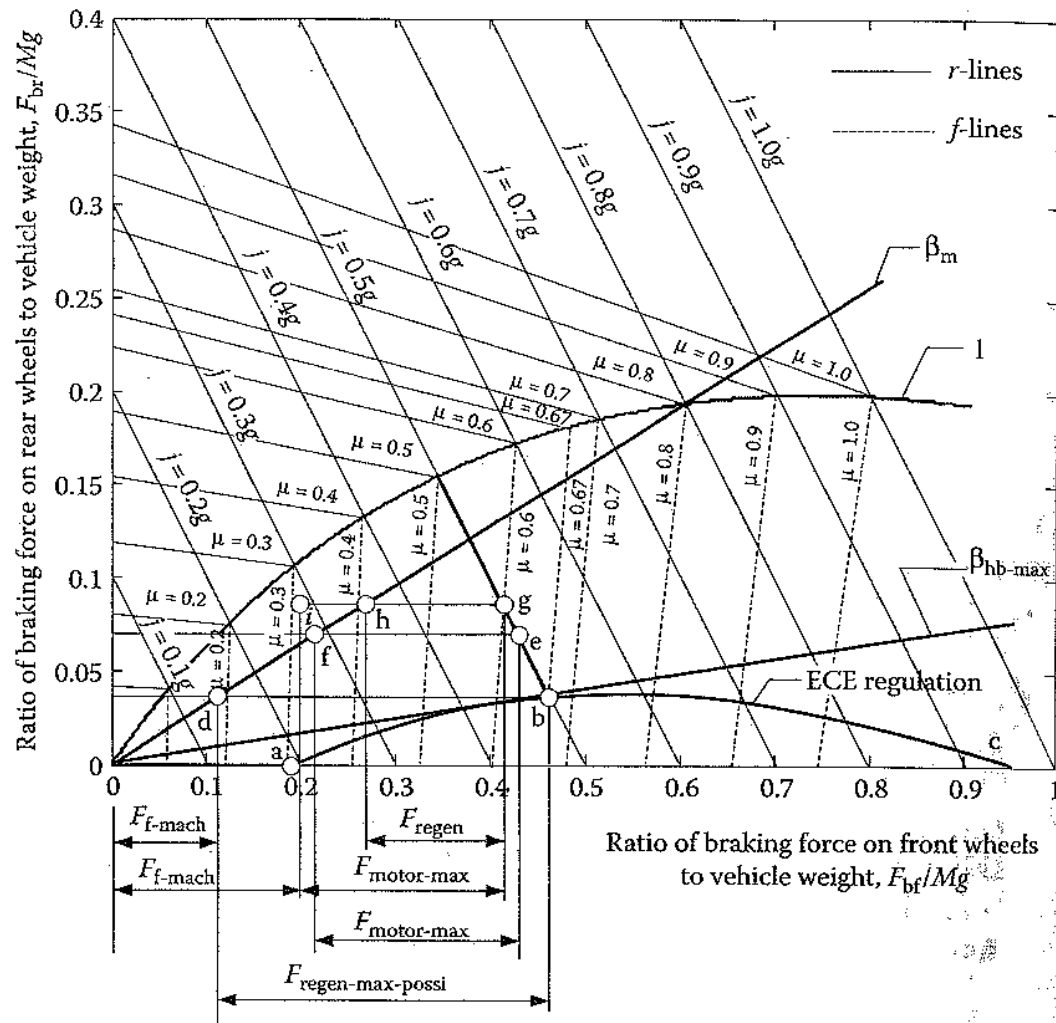


FIGURE 13.12 Schematic illustration of braking force distribution on the front wheels (electrical + mechanical) and the rear wheels.

Two main types

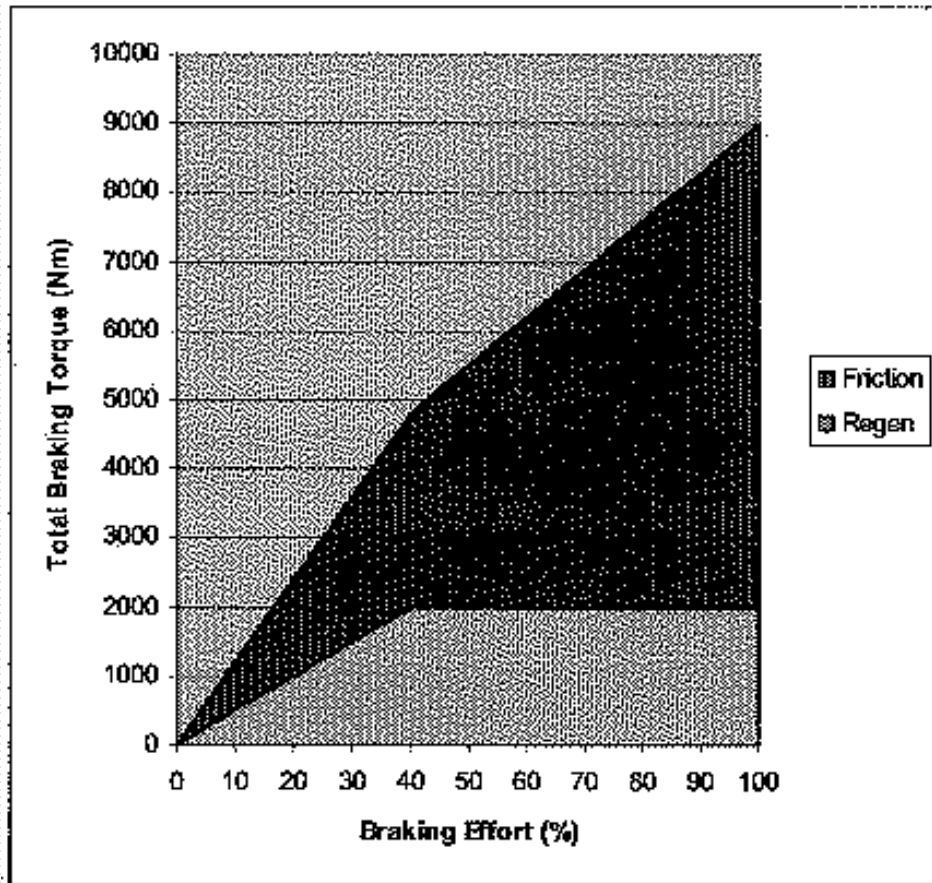
☐ Parallel

- Cheap
- Poor pedal feel
- Poor brake feel
- Lower energy recovery

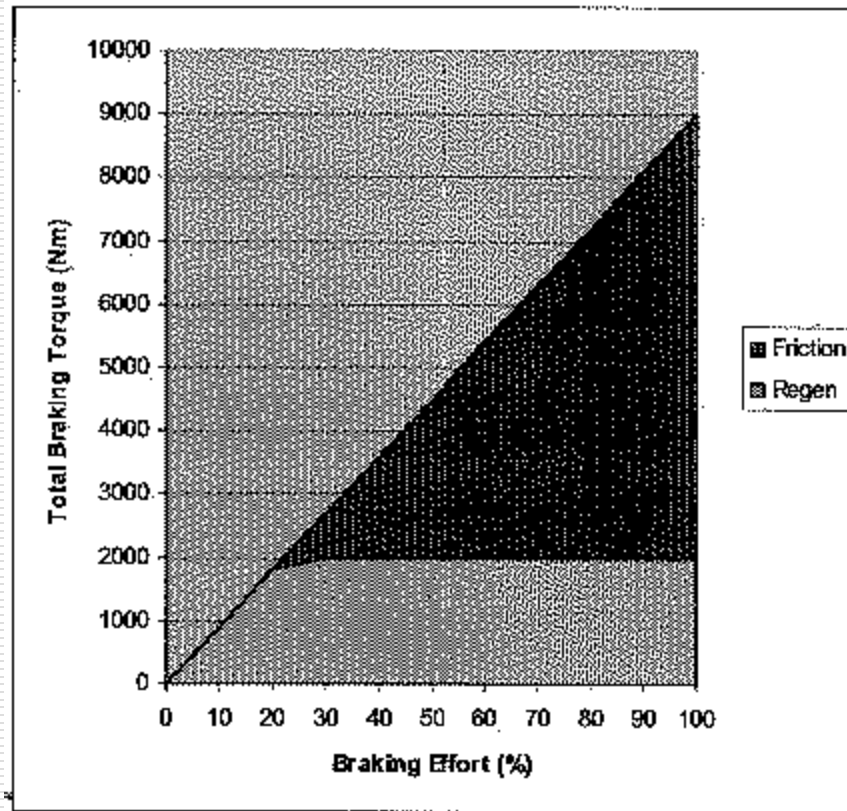
☐ Series

- Expensive
 - Consistent feel
 - Consistent response
 - Maximum energy recovery
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Parallel



Series

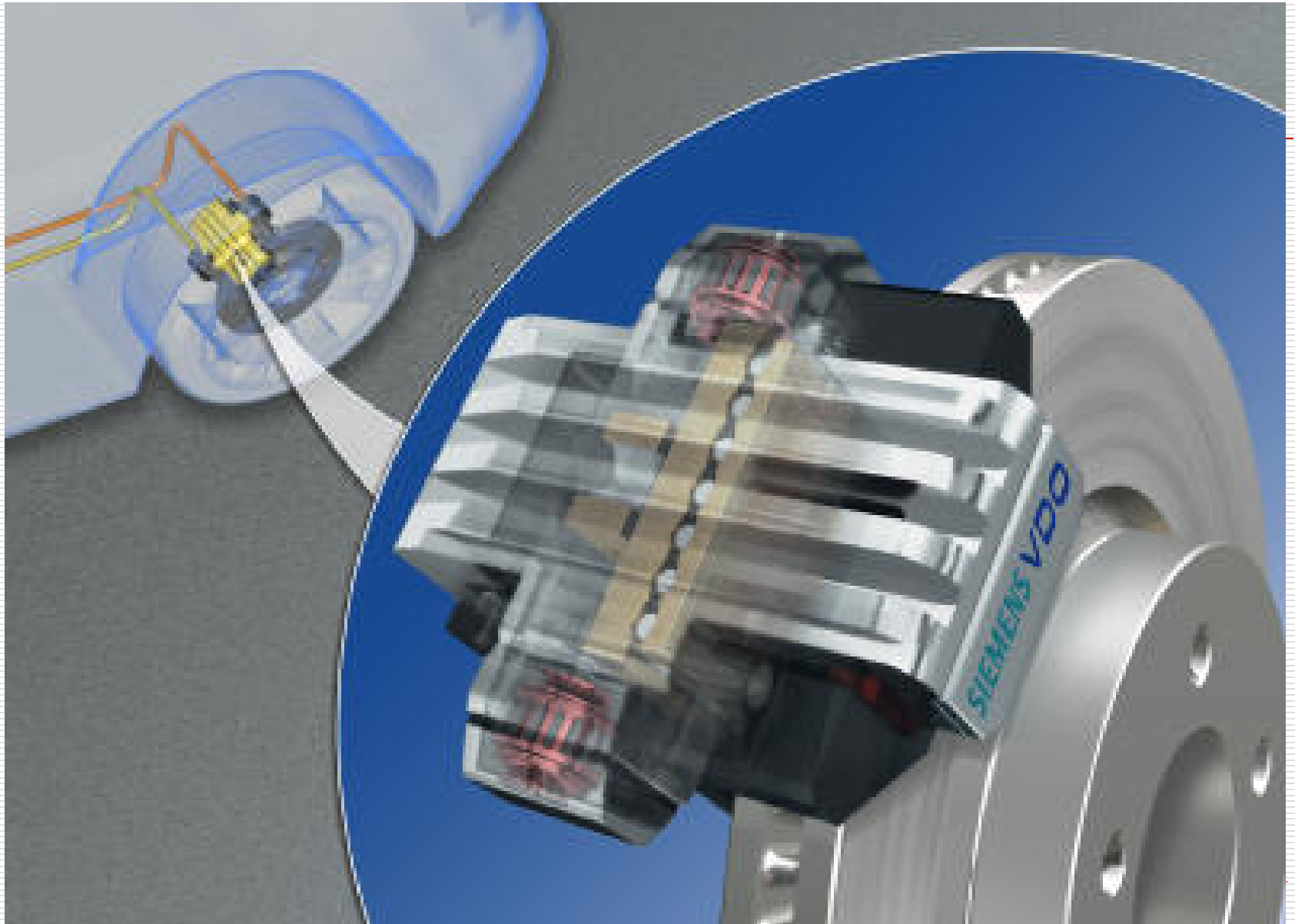


Series Braking Systems

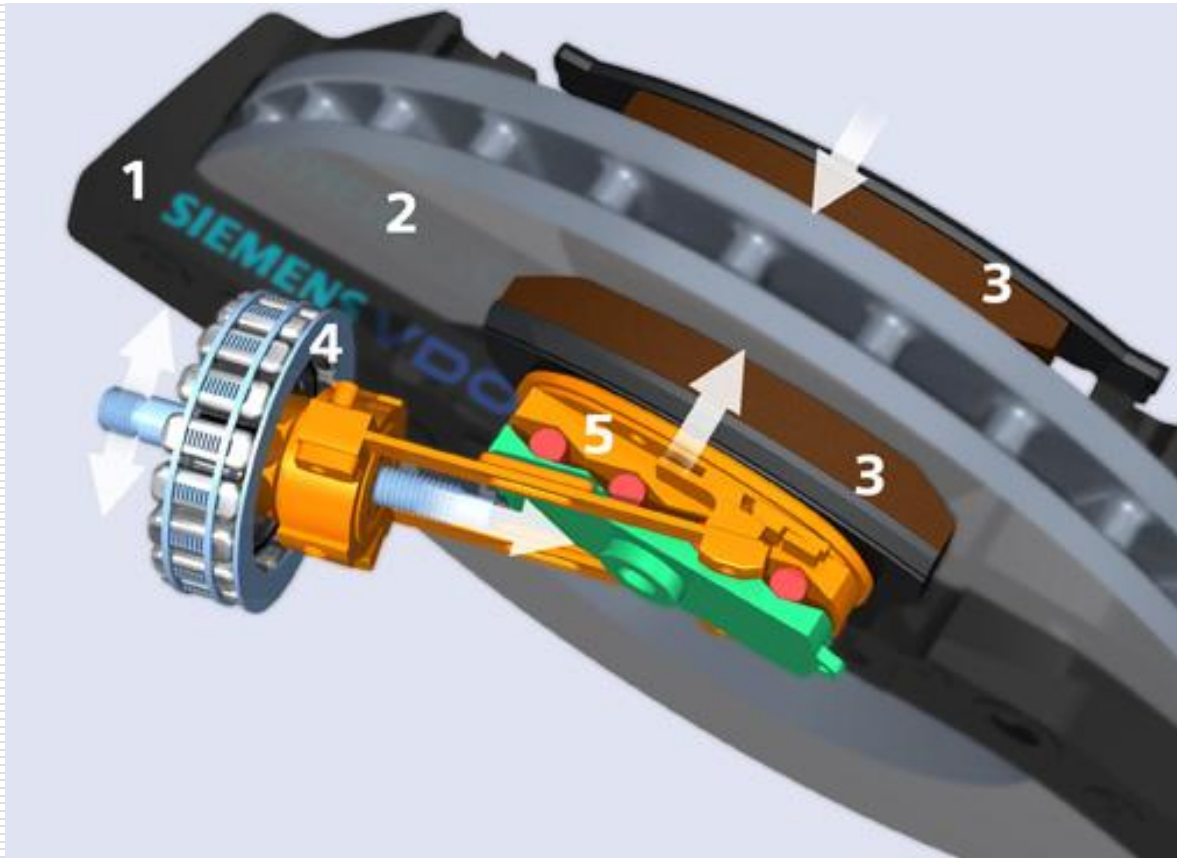
- Allow friction brakes to be held off until regen braking limits have been reached.
 - When will limits be reached ?
 - Ideally the regen brake system should:
 - Deliver similar pedal feel to std system
 - Deliver similar brake torque to pedal effort.
 - Regen & friction braking seamlessly blended
 - Allow front rear torque independence
 - Allow ABS/ESP/TCS functionality
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Series Braking Systems Solutions

- Electro Mechanical brakes
 - Full brake by wire
 - Electrical friction brake application
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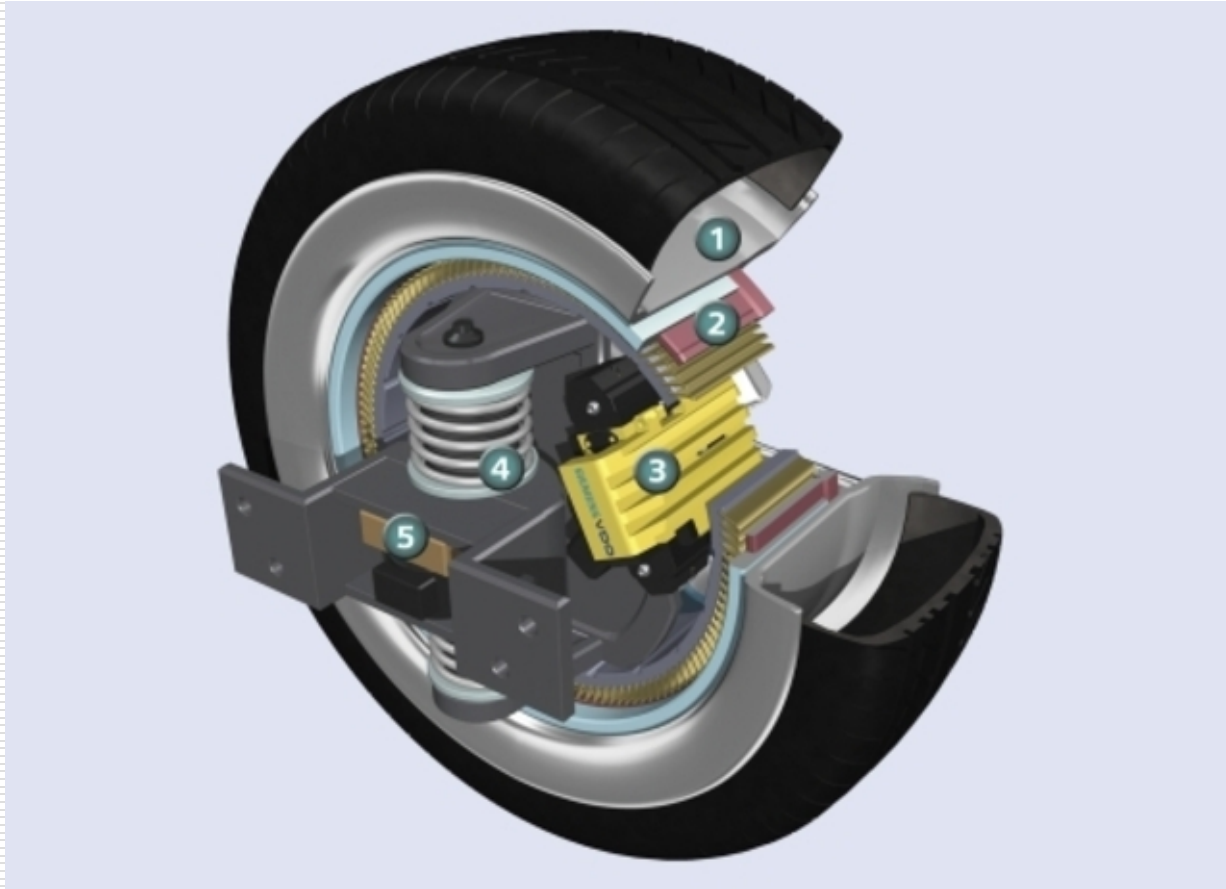






EWB. *The brake calipers (1) span the brake disk (2) from two sides. The brake disk is braked by a pad (3) which is moved by an electric motor (4) by several rollers (5) along wedge-shaped inclined faces. Click to enlarge.*

Siemens e corner

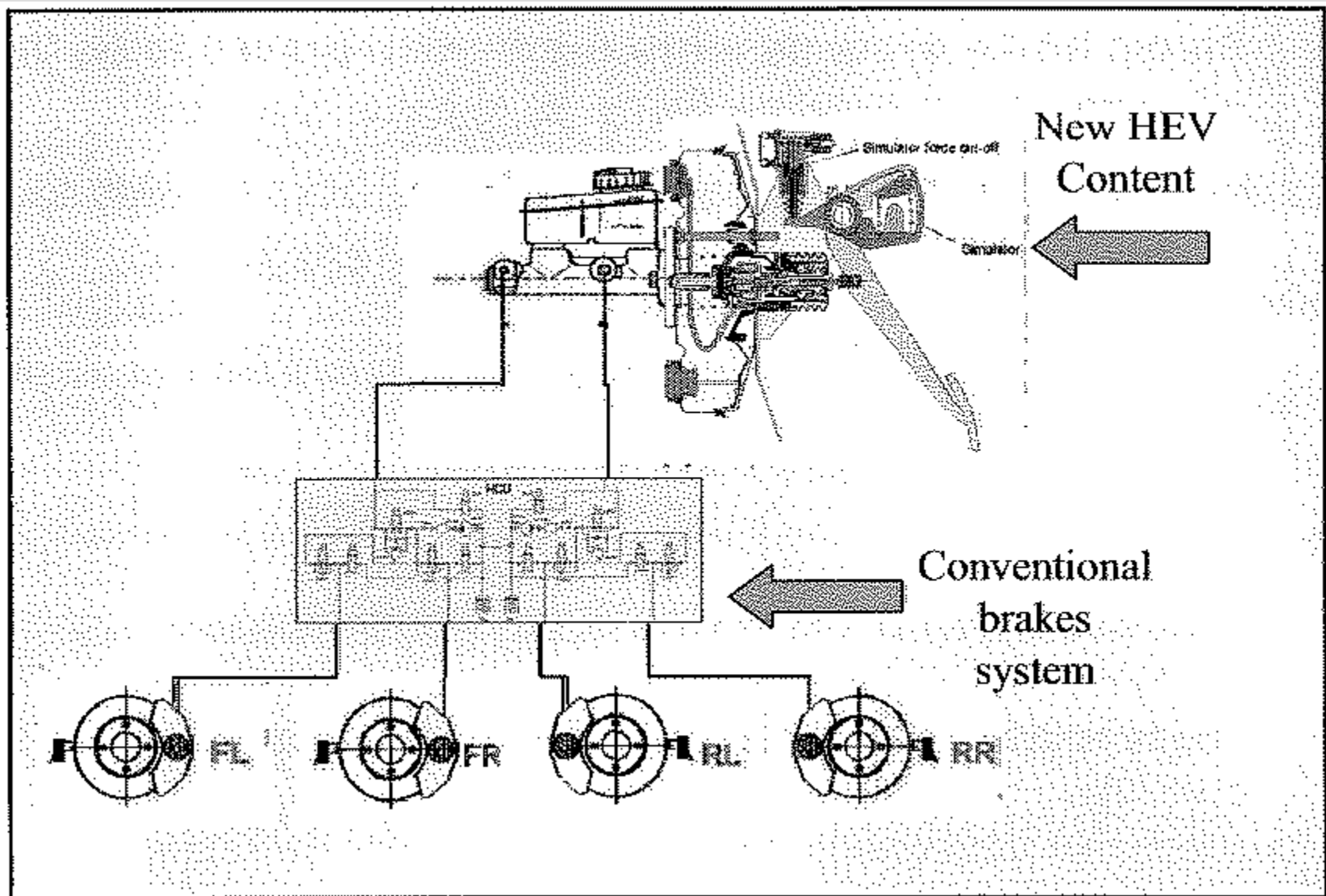


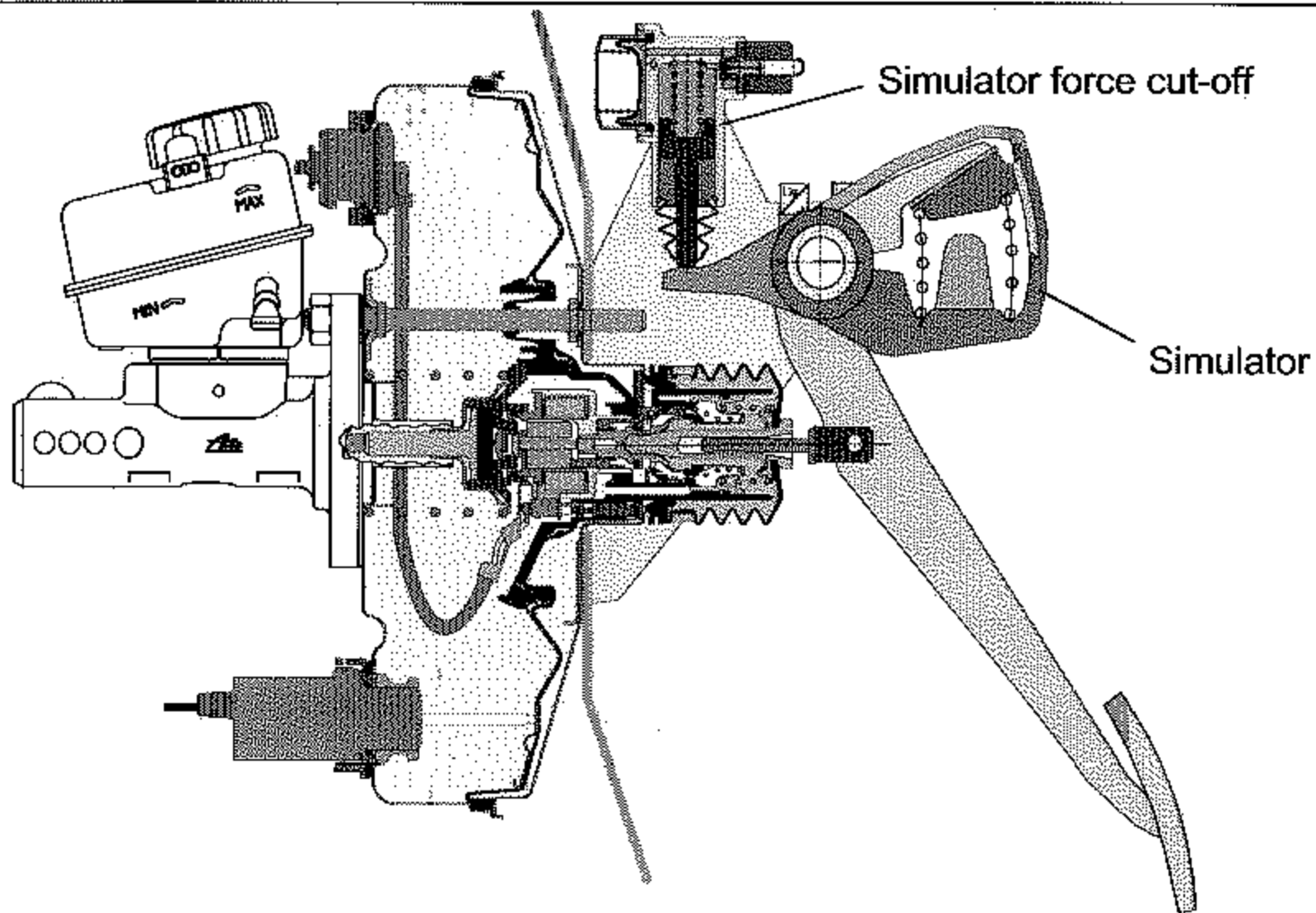
eCorner. *The wheel rim (1) remains the same. Beneath is the wheel hub motor (2). Braking is via **electronic wedge brake** (3). The active suspension (4), like the electronic steering (5), replaces the conventional hydraulic system*

Series Braking Systems Solutions

□ Active boosters

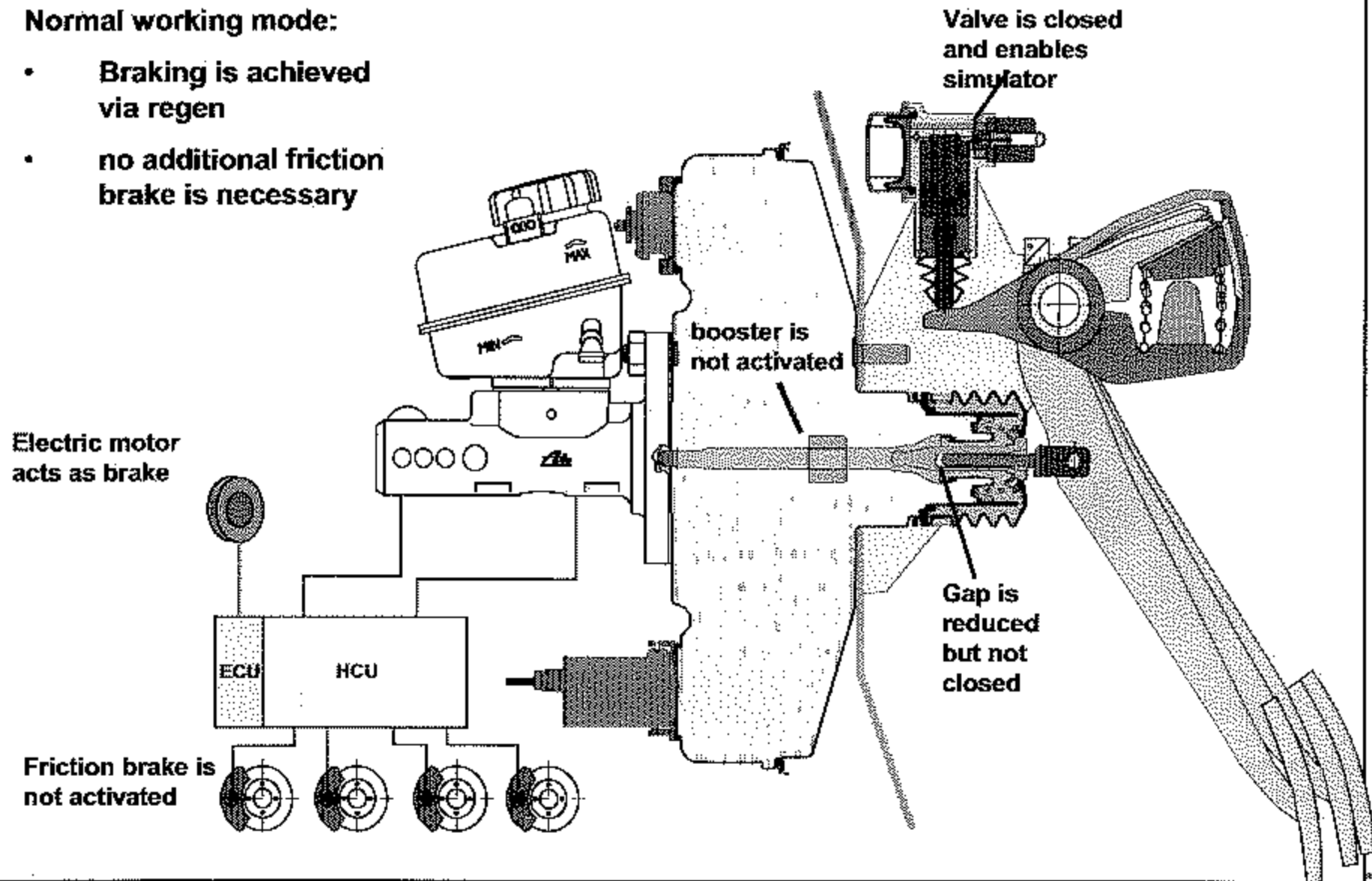
- Conventional hydraulic brake system
 - Vacuum or hydraulic booster
 - Amount of boost varied
-





Normal working mode:

- Braking is achieved via regen
- no additional friction brake is necessary

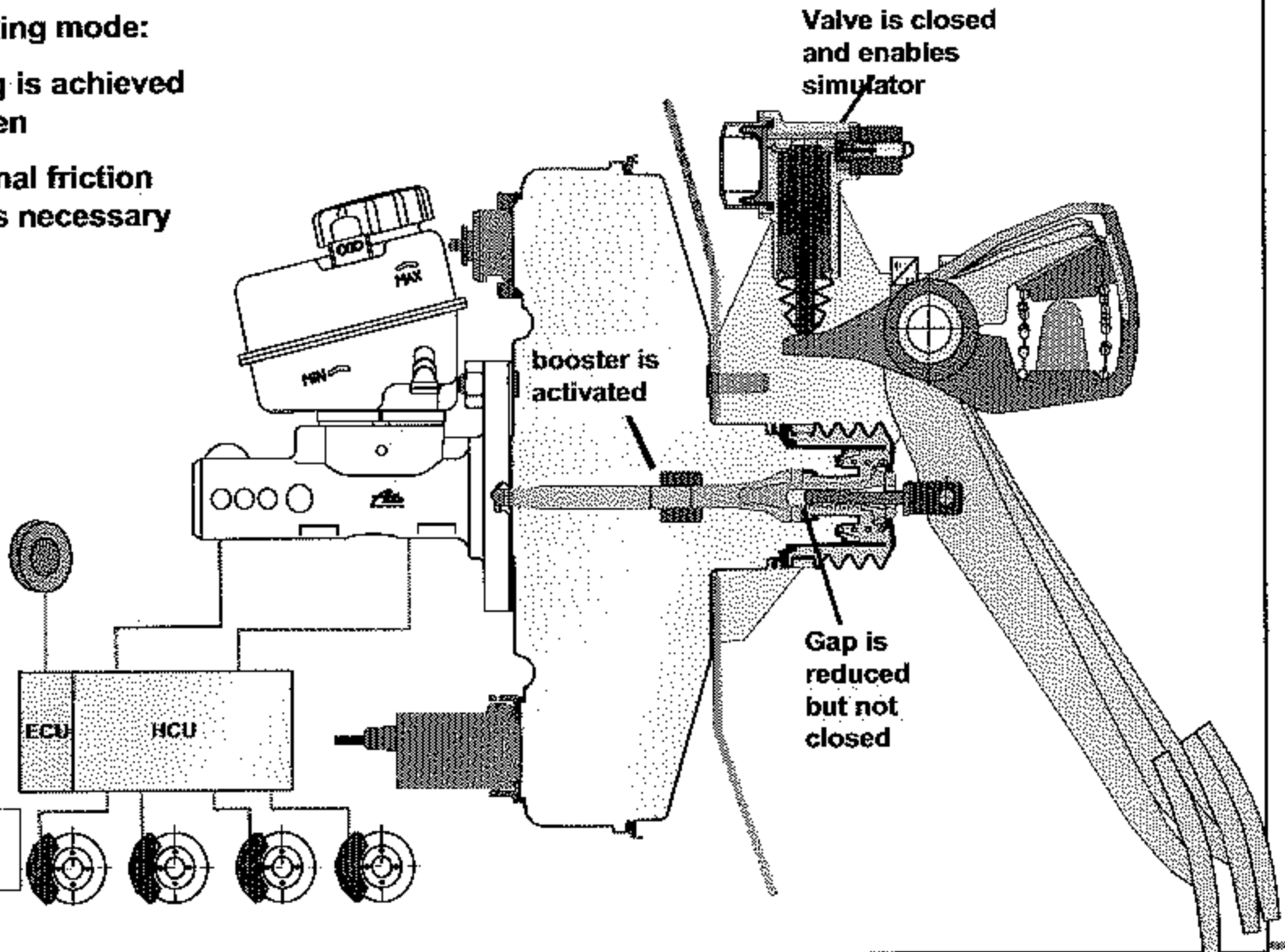


Normal working mode:

- Braking is achieved via regen
- additional friction brake is necessary

Electric motor acts as brake

Friction brake is activated

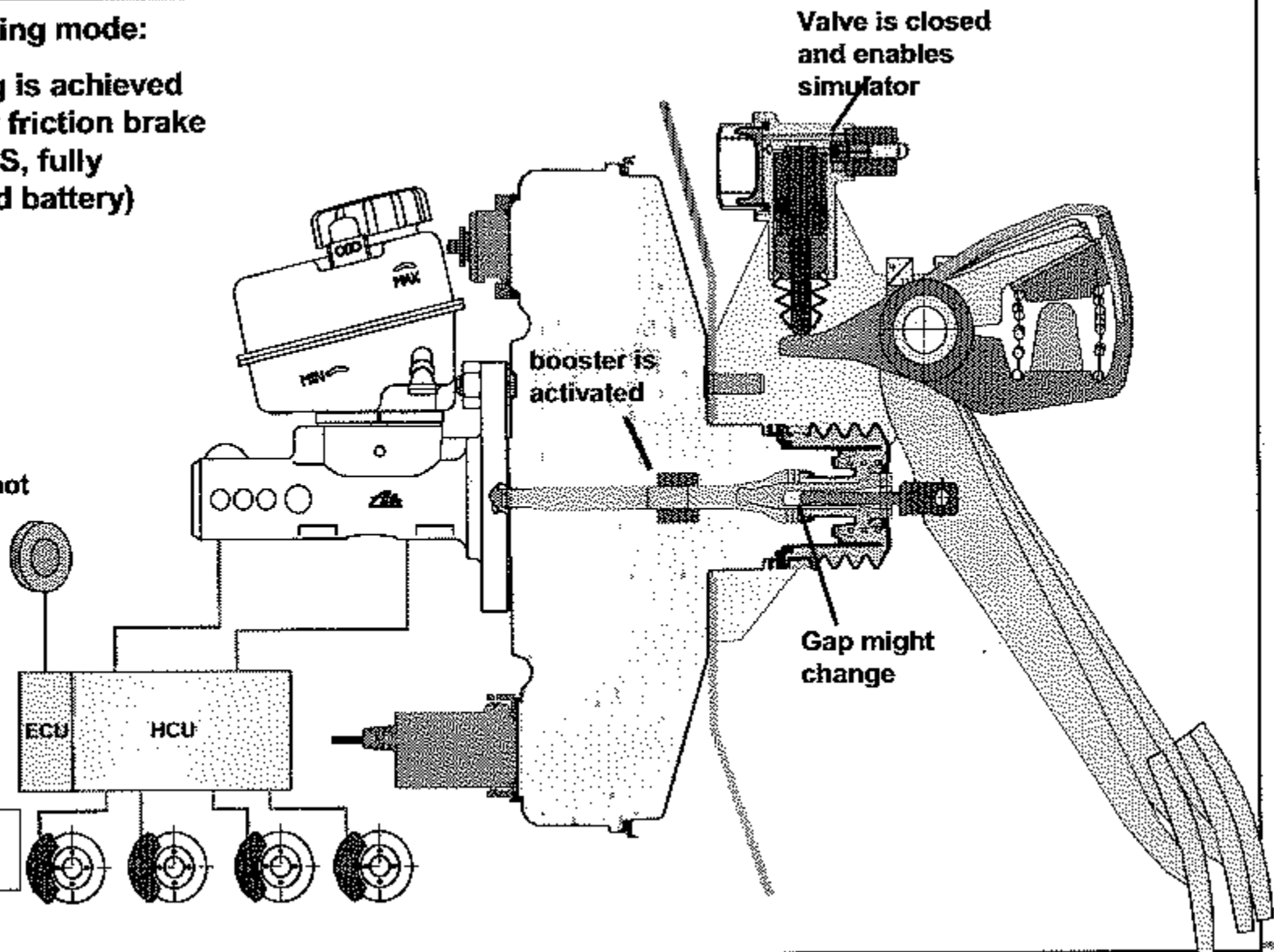


Normal working mode:

- Braking is achieved only by friction brake (eg. ABS, fully charged battery)

Electric motor not braking

Friction brake is activated

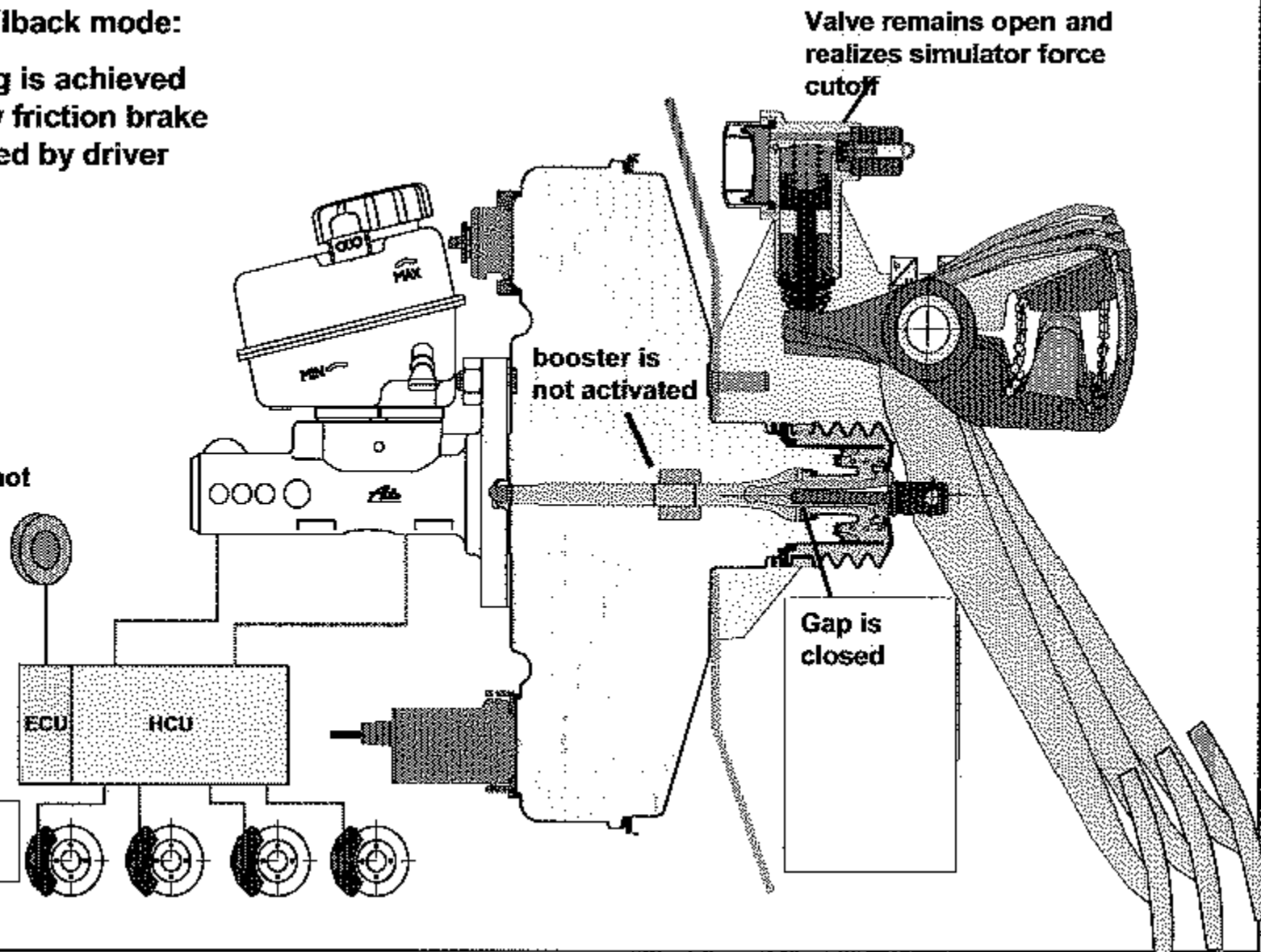


Hydraulic fallback mode:

- Braking is achieved only by friction brake activated by driver

Electric motor not braking

Friction brake is activated



Series Braking Systems Solutions

□ Electro Hydraulic brakes

- Brake pedal sensor
 - Pump controlled to generate pressure
 - Standard hydraulic conventional brakes
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