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Katedra za strojne elemente
in razvojna vrednotenja

LABORATORIJ ZA VREDNOTENJE KONSTRUKCIJ

LABORATORIJ ZA STROJNE ELEMENTE

Traction force balance and vehicle drive

assist. prof. Simon Oman

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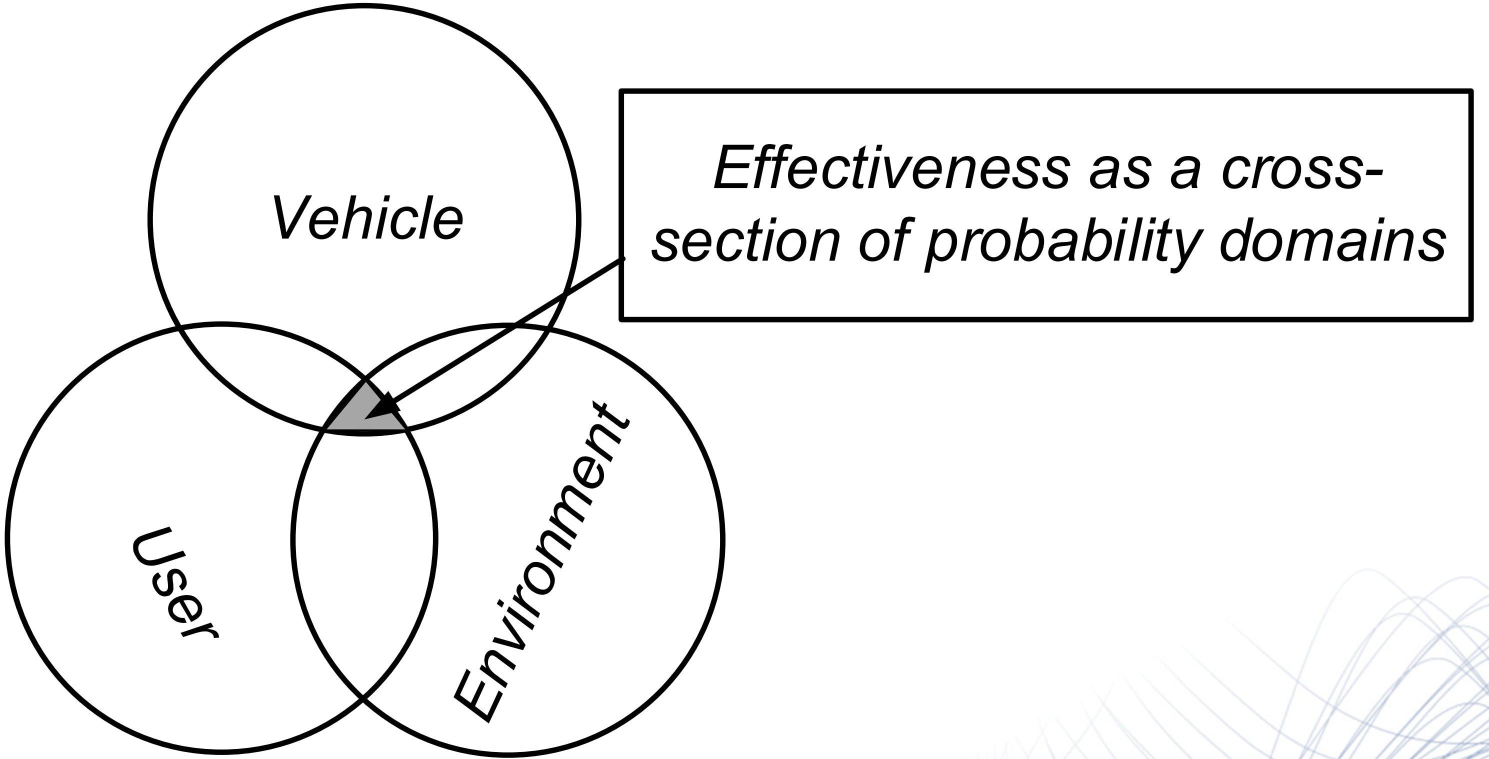
Vehicle – interactions and effectiveness



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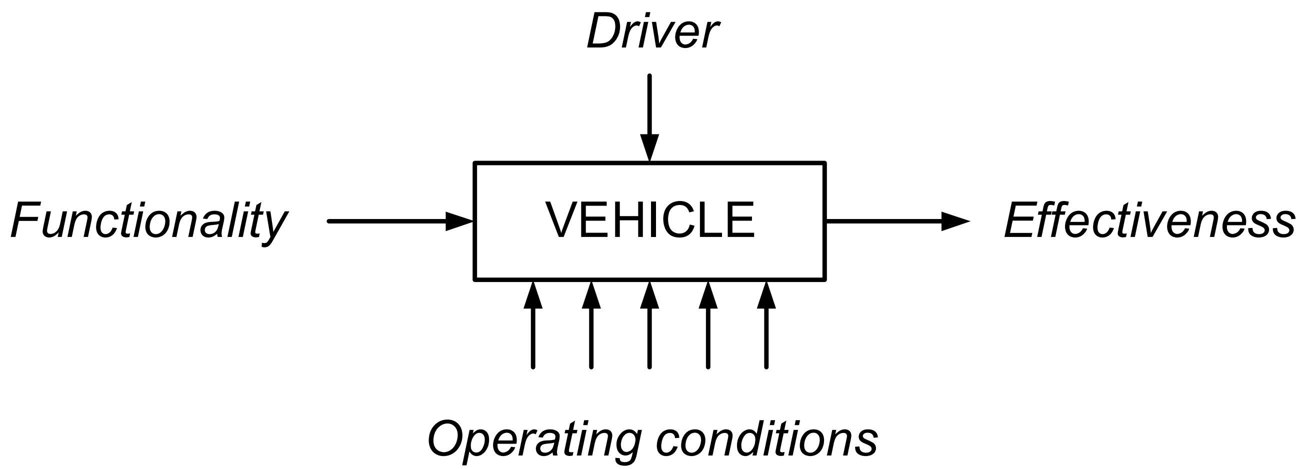
Vehicle – interactions and effectiveness



A vehicle effectiveness is a probability that the vehicle fulfils its requirements on operation readiness, availability and characteristics for the given operating conditions, maintenance conditions and environmental influence.

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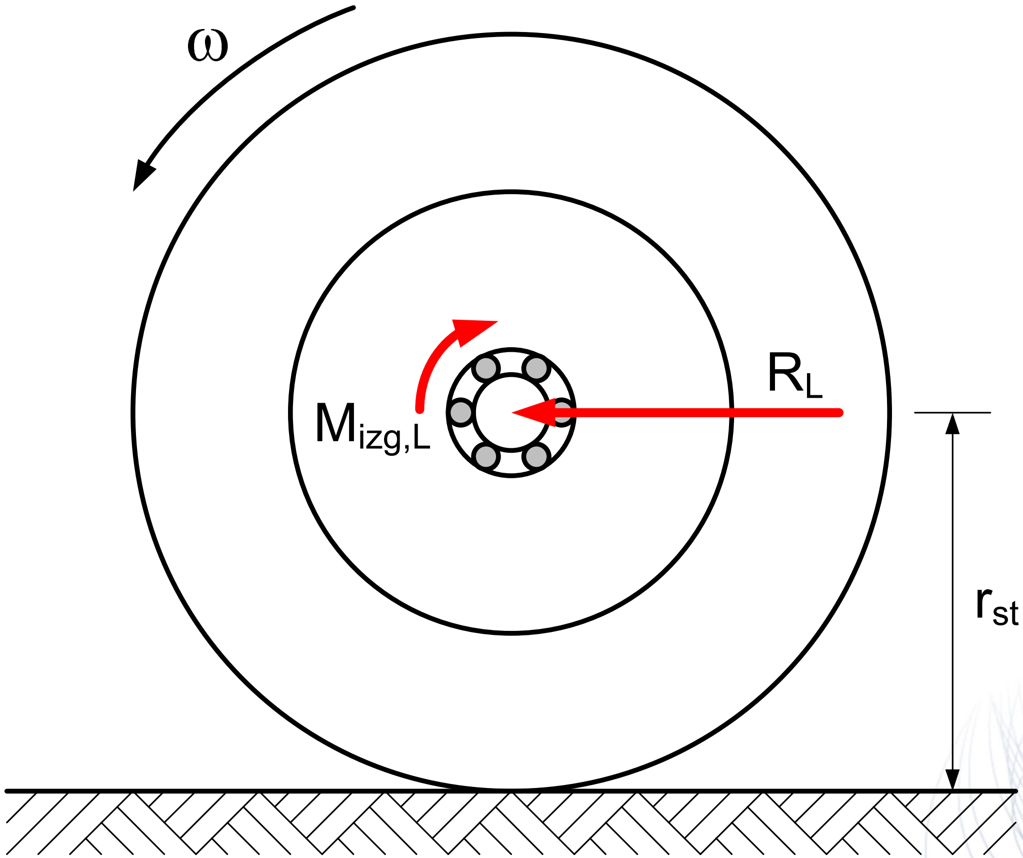
Driving resistances

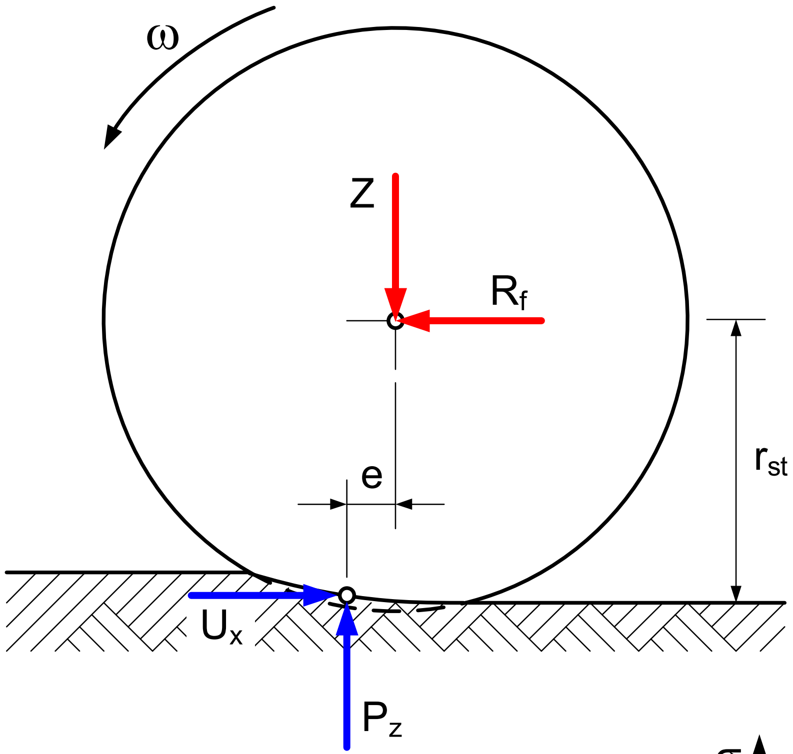
- *Resistance of bearings*
- *Rolling resistance*
- *Aerodynamic resistance (Drag resistance)*
- *Resistance of a hill*
- *Trailer resistance*

Resistance of bearings



$$R_L = \frac{M_{izg,L}}{r_{st}}$$

Rolling resistance



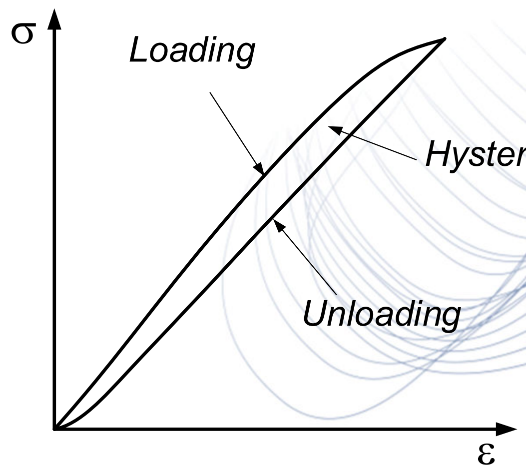
$$P_z = Z$$

$$U_x = R_f$$

$$\sum M = 0$$

$$Z \cdot e - R_f \cdot r_{st} = 0$$

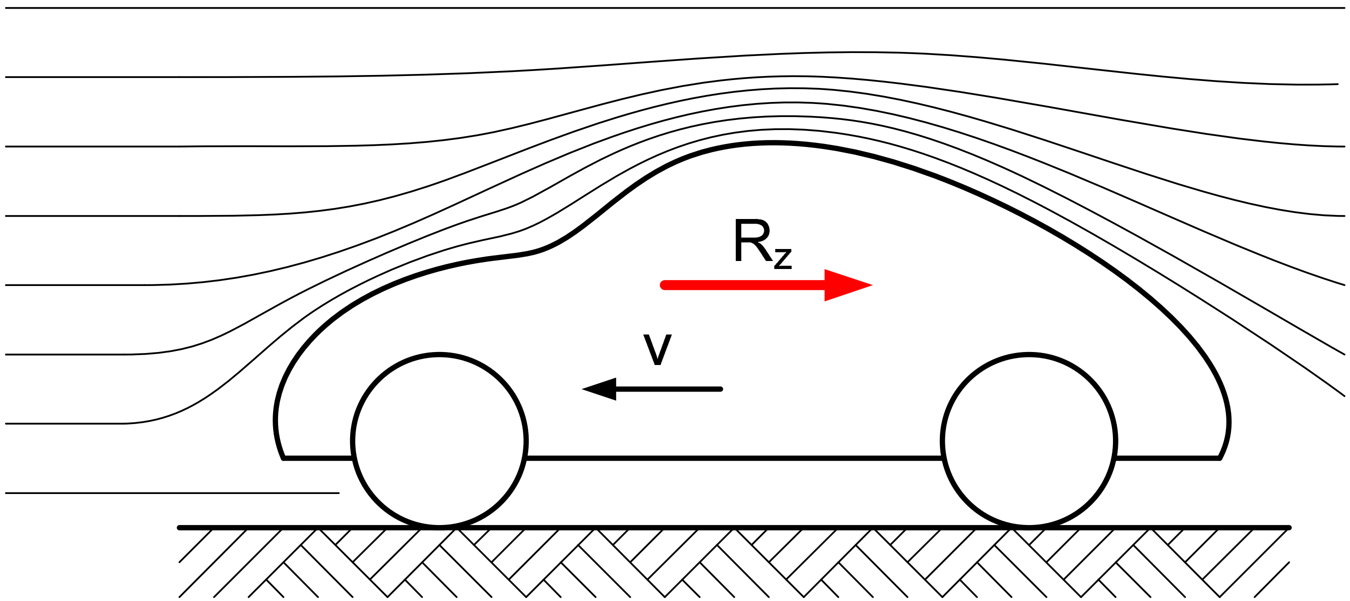
$$R_f = Z \cdot \left(\frac{e}{r_{st}} \right) = Z \cdot f$$

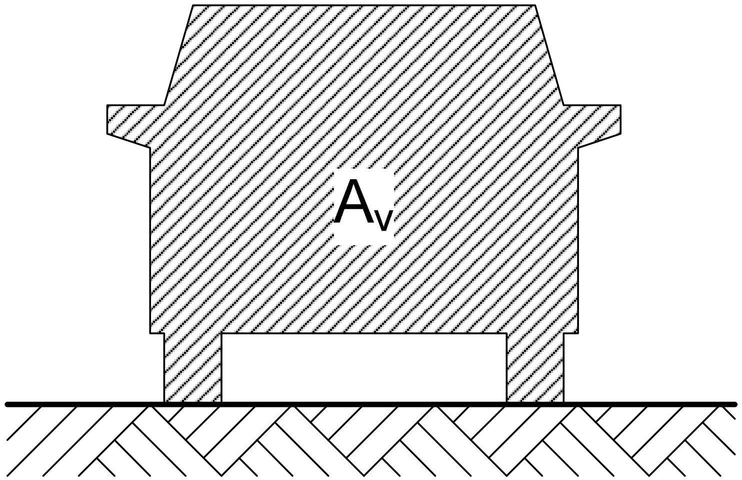


Rolling resistance

- *Typical values of the rolling resistance for a road vehicle with rubber tires:*
  - *f = 0,01 – 0,015 (a tire on asphalt or concrete)*
  - *f = 0,035 (a tire on a macadam road)*
  - *f = 0,3 (a tire on a dry and non-compacted sand)*
- *A typical value of the rolling resistance for a railway vehicle:*
  - *f = 0,001*

Aerodynamic (Drag) resistance





$$R_z = c^* \cdot A_v \cdot \rho_z \cdot \frac{v_v^2}{2}$$

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Aerodynamic (Drag) resistance

- *An augmented aerodynamic-resistance coefficient c* includes the following influences:*
  - *An aerodynamic resistance of the air flow around the vehicle;*
  - *A friction between the air and the vehicle (can be neglected);*
  - *A resistance of the air flow through the vehicle (e.g. ventilation losses).*

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Aerodynamic (Drag) resistance

- *Typical values of the augmented aerodynamic-resistance coefficient* c* *are the following:*
  - *c* = 0,3 … a car*
  - *c* = 0,6 … a bus*
  - *c* = 0,9 … a truck*
  - *c* = 0,98 … a truck with a trailer / train*

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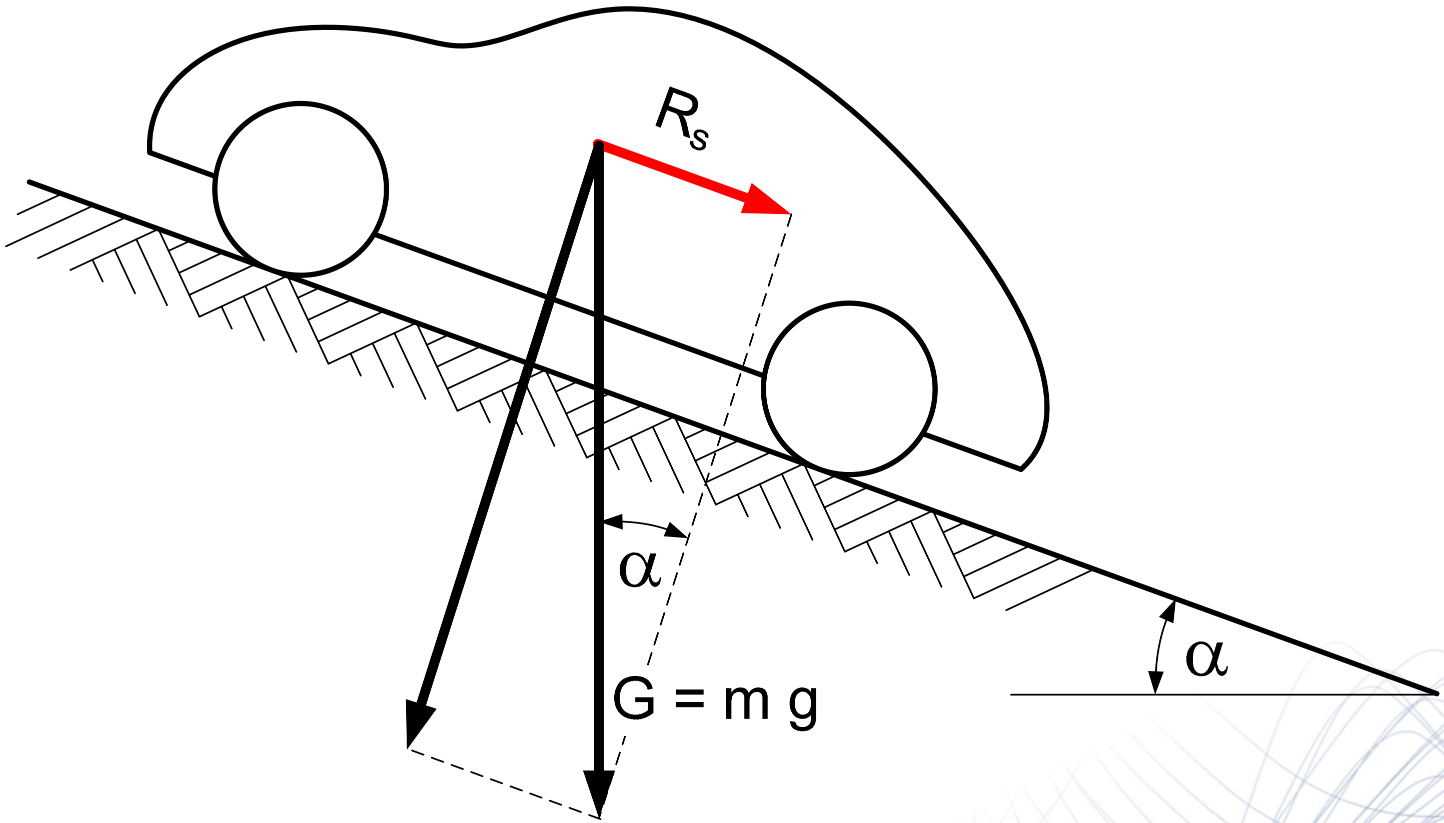
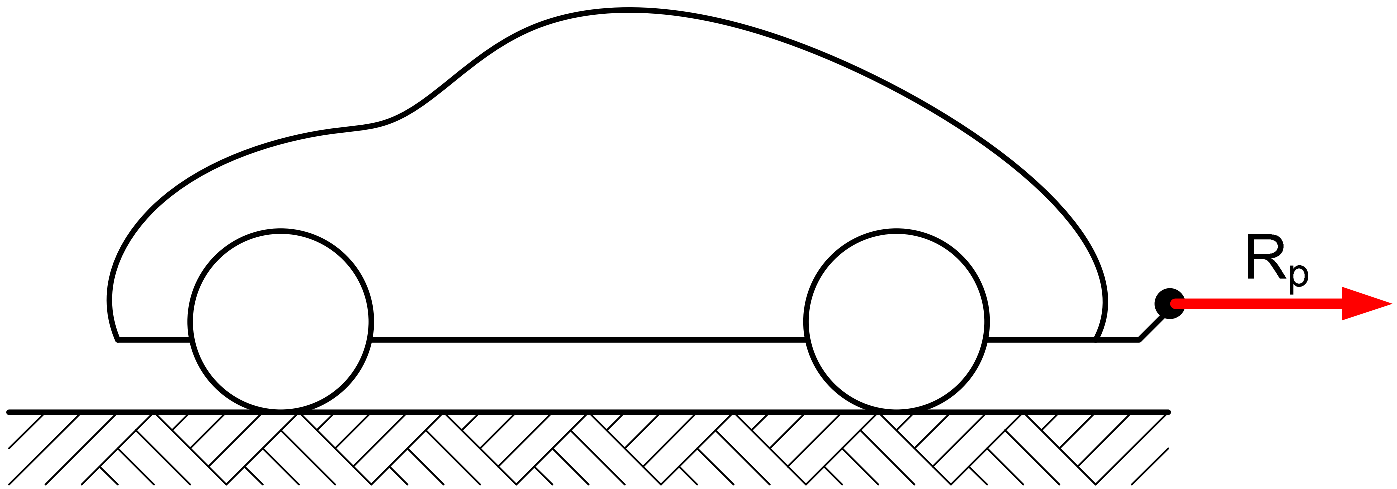
Resistance of a hill



$$R_s = G \cdot \sin\alpha = m \cdot g \cdot \sin\alpha$$

Trailer resistance



$$R_p = \sum (R_L + R_f + R_z + R_s)_{prikolica\_trailer}$$

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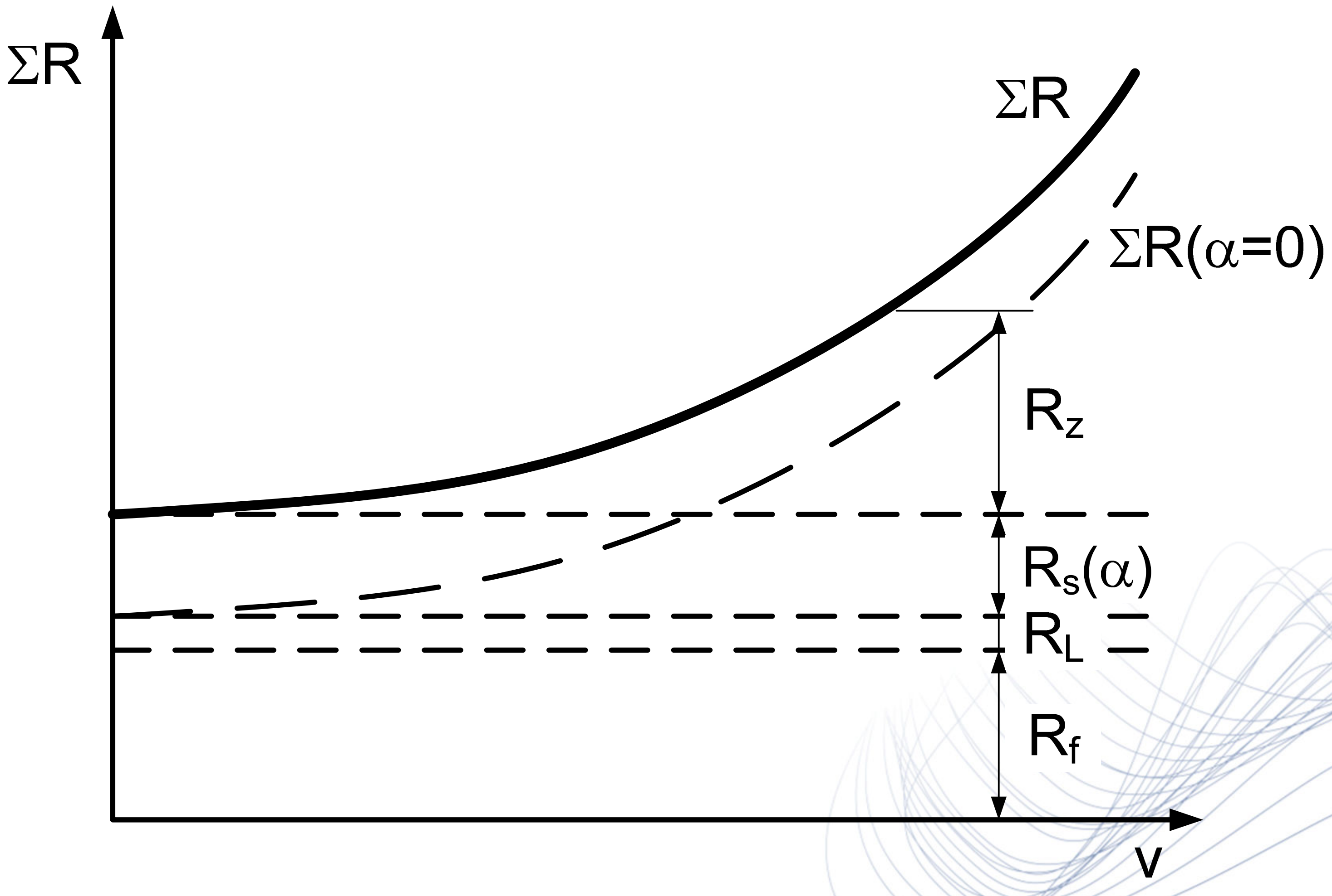
A sum of driving resistances



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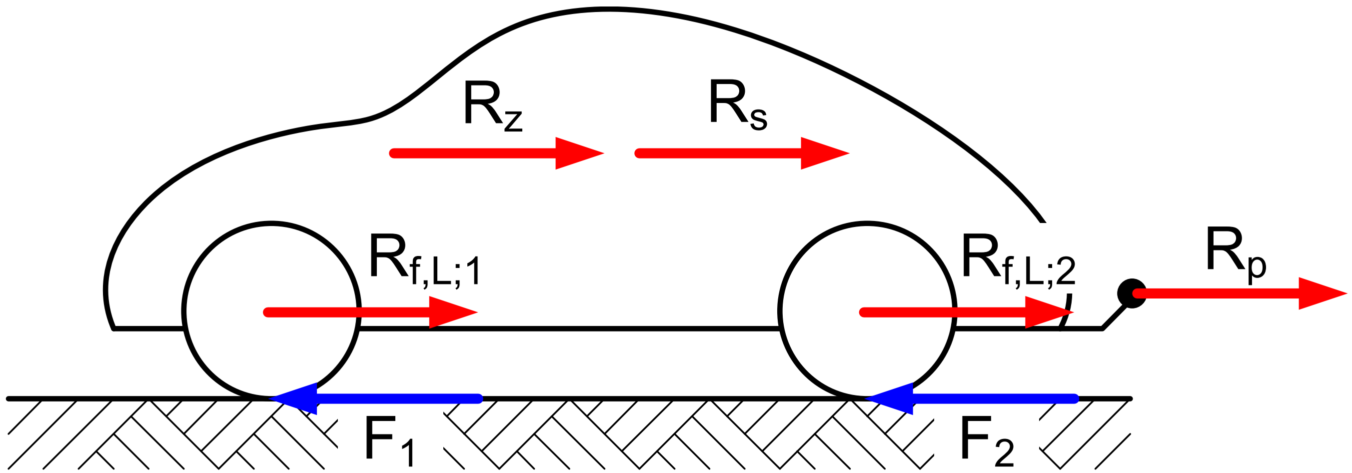
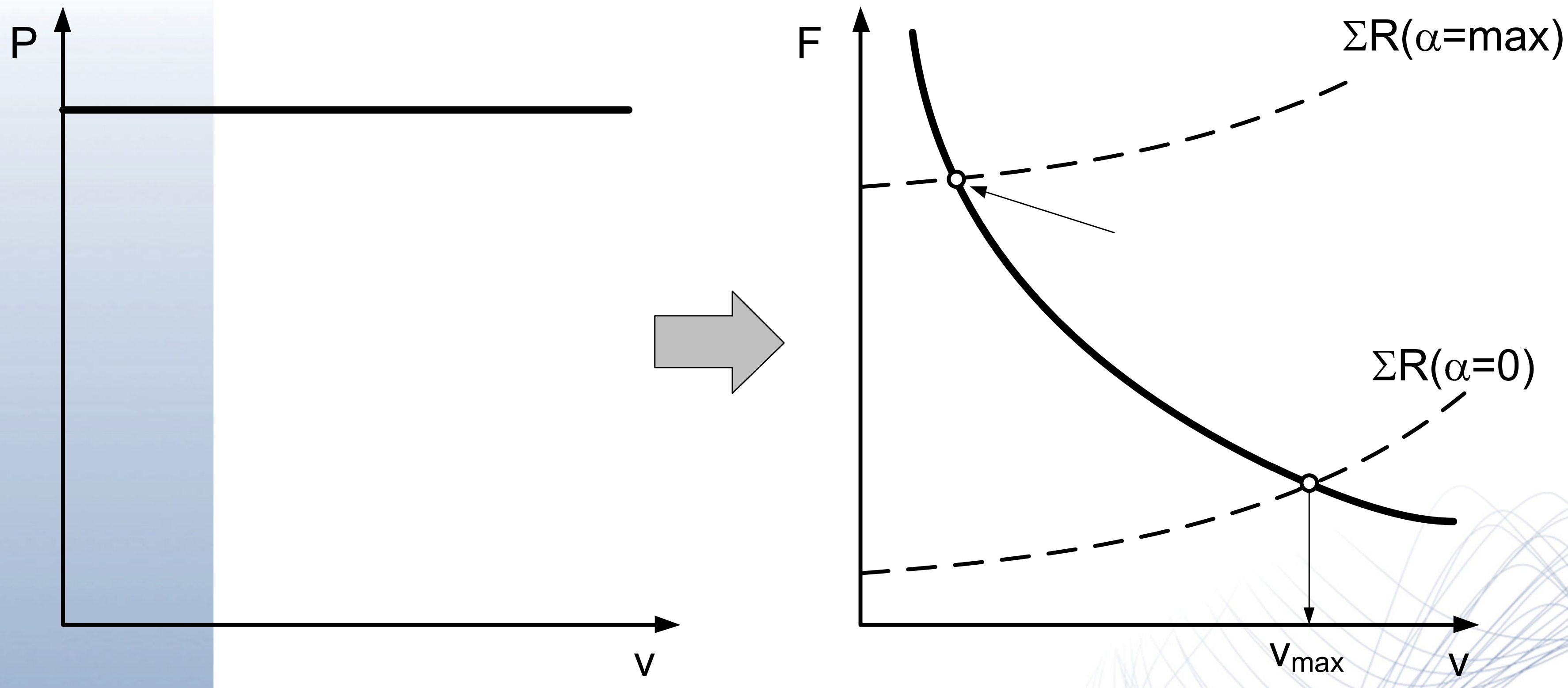
A sum of driving resistances

- DO TU



- *A sum of driving resistances is equal to the sum of the resistance of bearings, the rolling resistance, the aerodynamic resistance, the resistance of a hill and the trailer resistance.*
- *During vehicle movement the tangential forces between the wheels and driving surface ($F_{1,2}$) must overcome the sum of the driving resistances (and the inertial forces at accelera-ting/braking if applicable).*
- *The tangential forces acting on the wheels $F_{1,2}$ result from the transformed torque of the driving engine or brakes.*

Ideal characteristics of a driving engine



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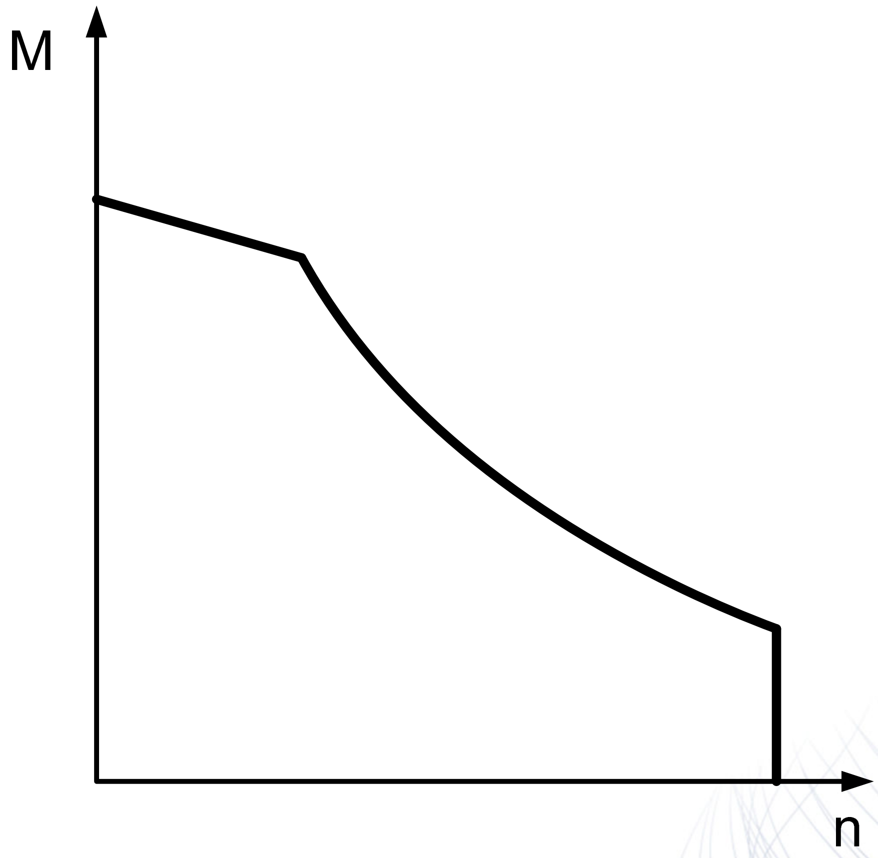
Characteristics of an electric motor



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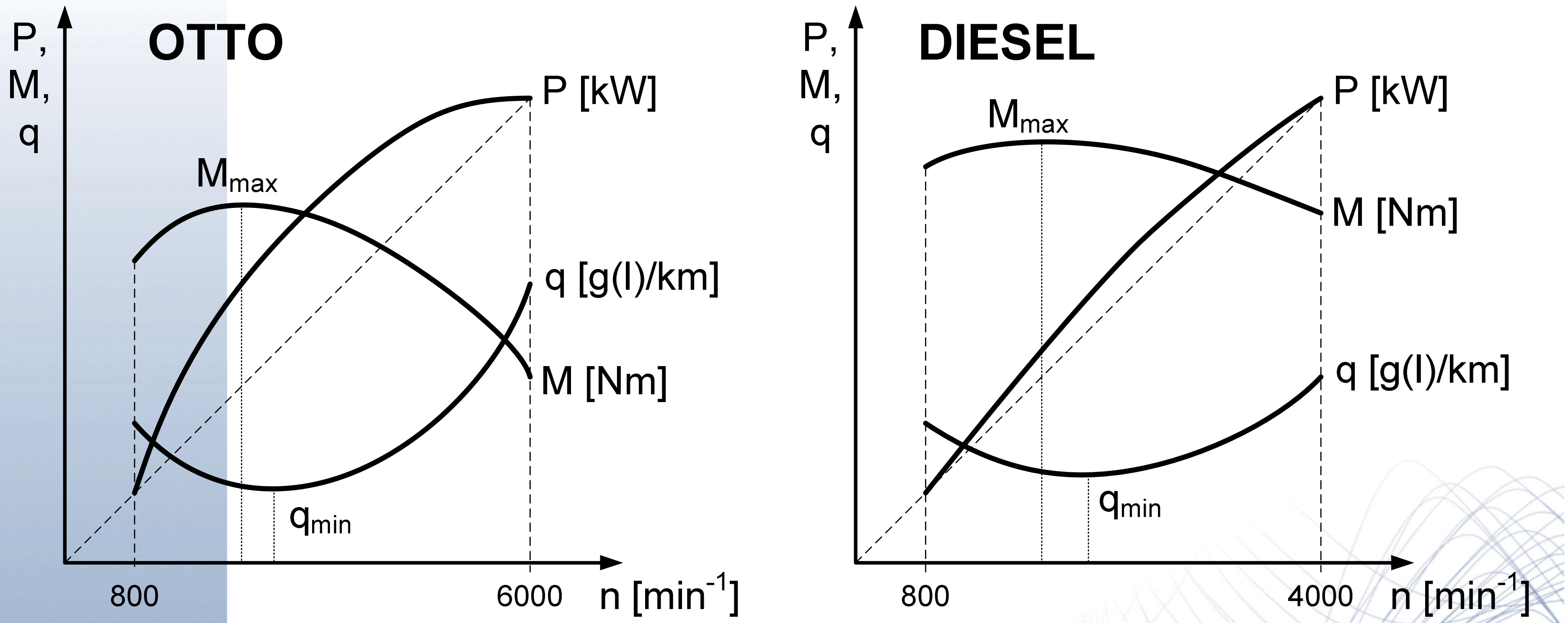
ICE characteristics



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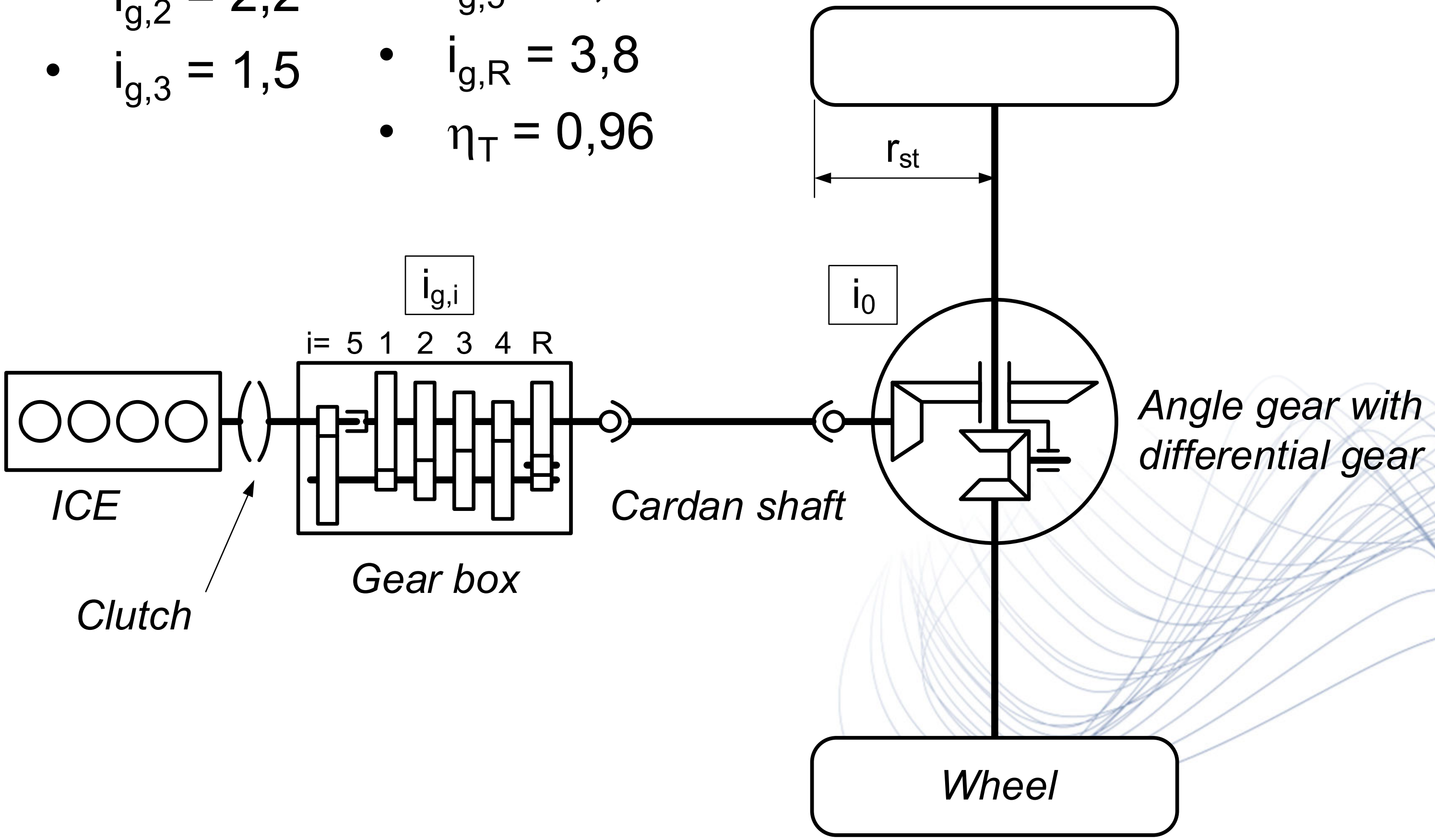
Multiple gear mechanical transmission

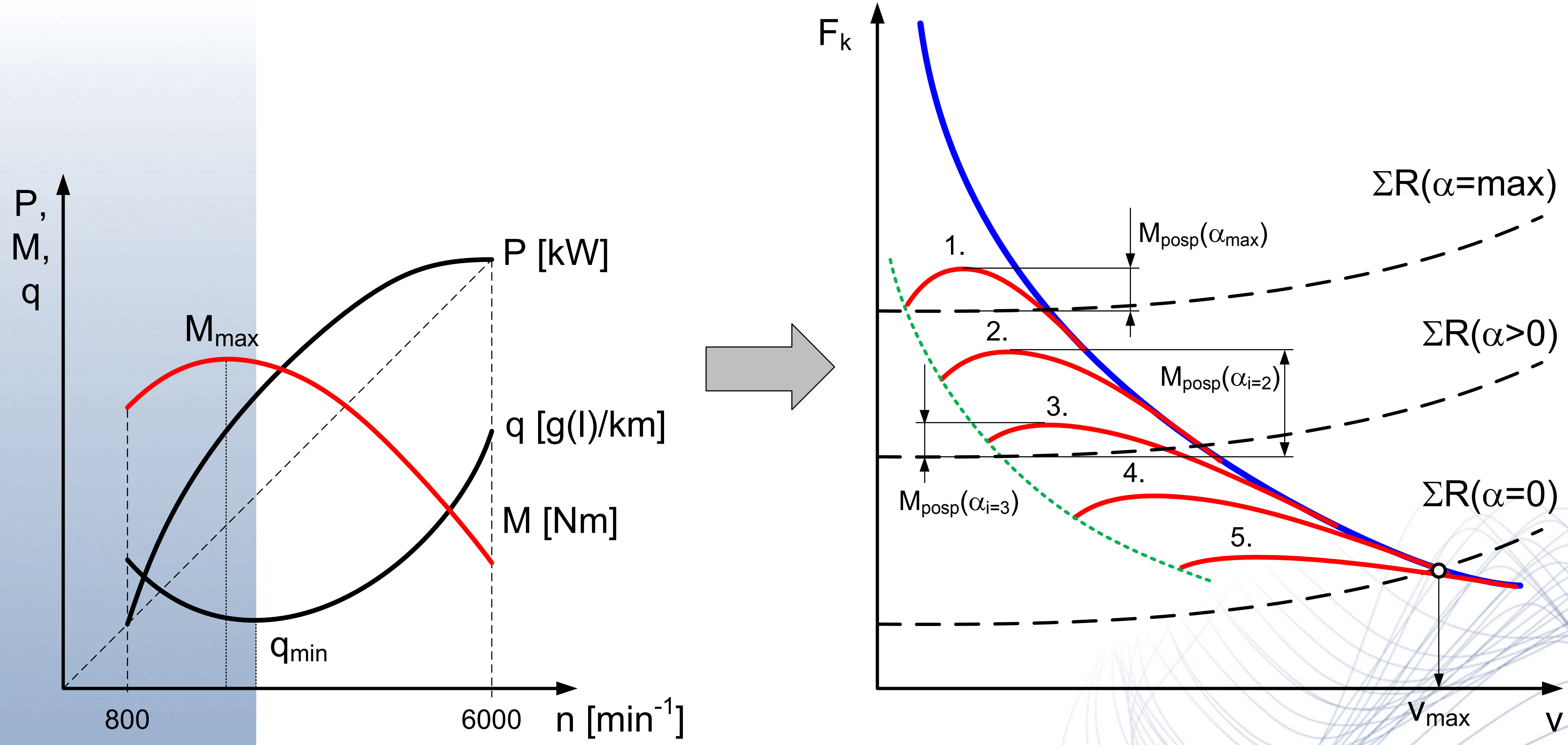
Typical gear ratios:

- $i_0 = 3{,}7$
- $i_{g,1} = 3{,}9$
- $i_{g,2} = 2{,}2$
- $i_{g,3} = 1{,}5$
- $i_{g,4} = 1{,}2$
- $i_{g,5} = 1{,}0$
- $i_{g,R} = 3{,}8$
- $\eta_T = 0{,}96$

$$F_k = \frac{M_m \cdot i_{g,i} \cdot i_0 \cdot \eta_T}{r_{st}}$$



ICE elasticity and gear influence



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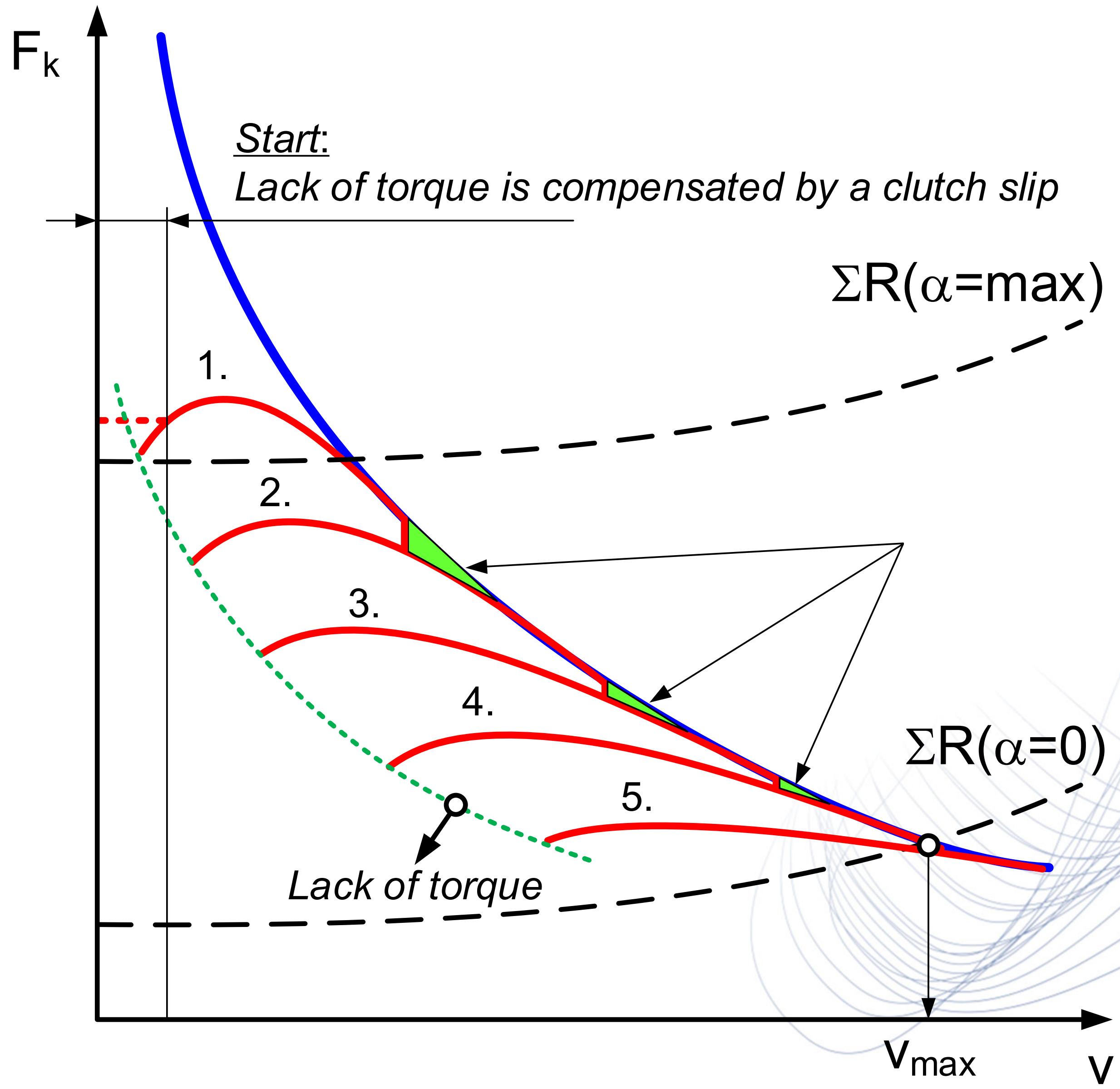
ICE elasticity and gear influence



Dynamic coefficient of a vehicle

$$F_k \geq R_L + R_f + R_z + R_s \qquad / \cdot 1/G$$

$$\frac{F_k}{G} = \frac{R_L + R_f + R_z + R_s}{G}$$

$$\frac{F_k - R_z}{G} = D = \frac{R_L + R_f + R_s}{G}$$

Dynamic coefficient D *is a specific traction force relative to a vehicle's weight that is available for accelerating the vehicle and surpassing the rolling resistance, resistance of bearings and resistance of the hill.*

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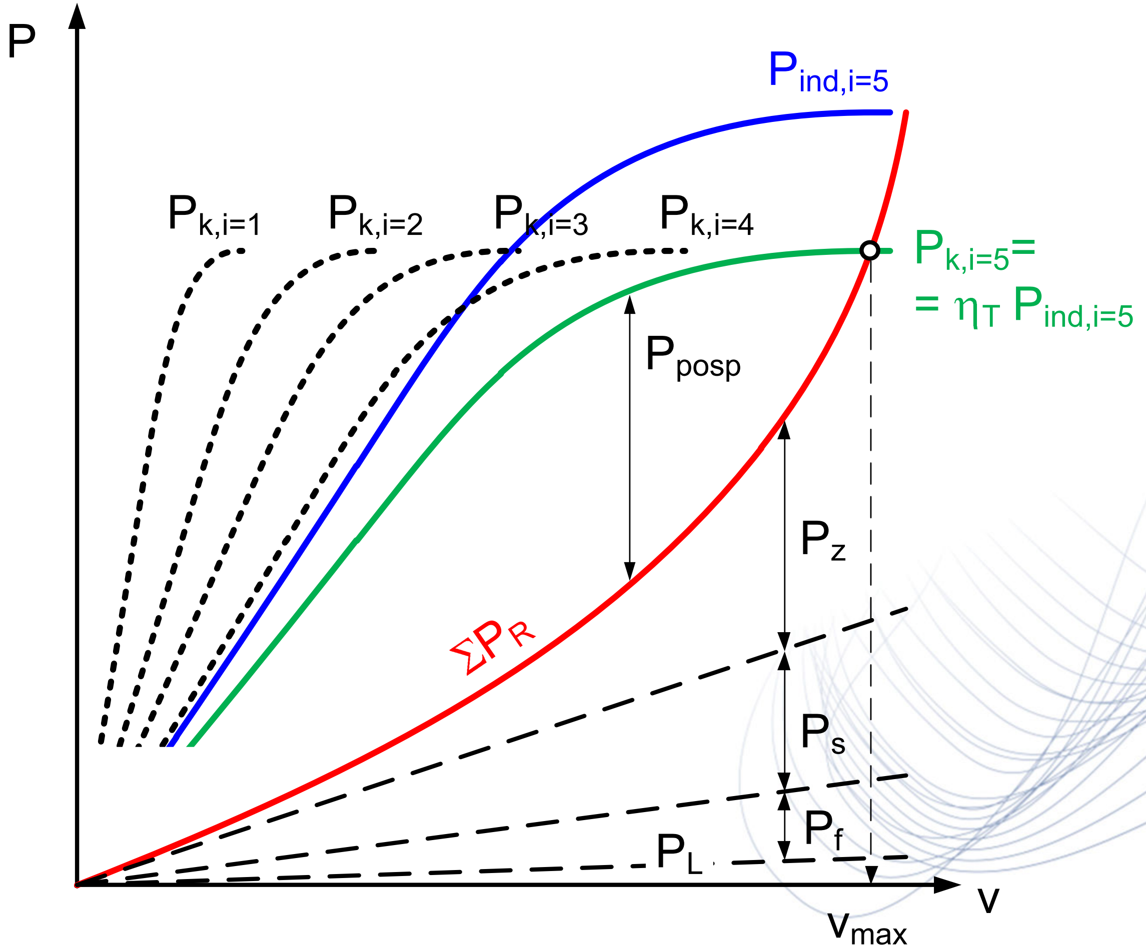
Vehicle power balance

$$F_k \cdot v = R_L \cdot v + R_f \cdot v + R_z \cdot v + R_s \cdot v \Rightarrow$$

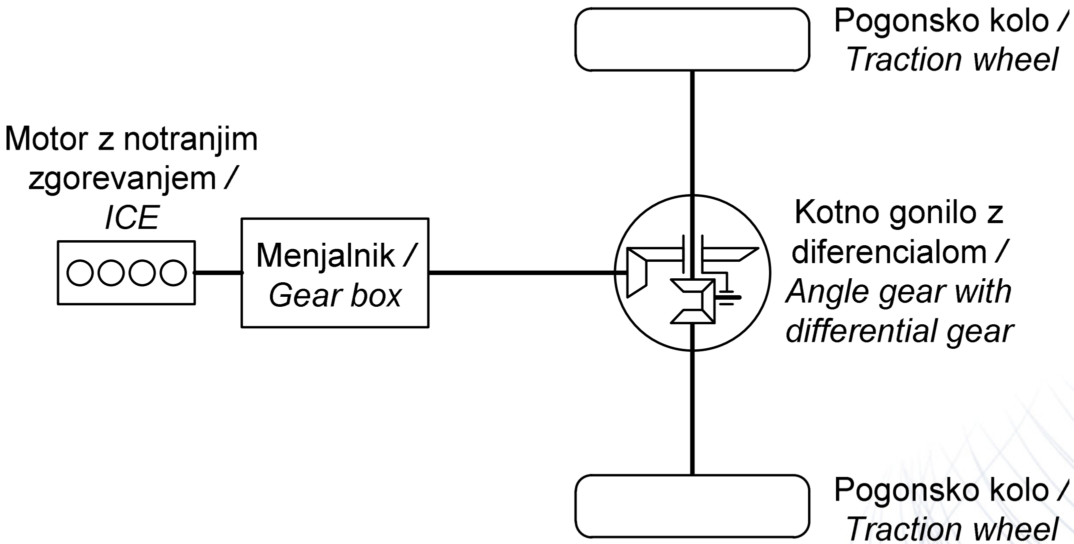
$$\Rightarrow P_k = P_L + P_f + P_z + P_s$$



Hybrid vehicles (HV)

<u>DEFINITION of a HV:</u> in the hybrid road vehicle a propulsion energy is available from two or more sources and/or energy storage devices and/or energy converter devices [1].

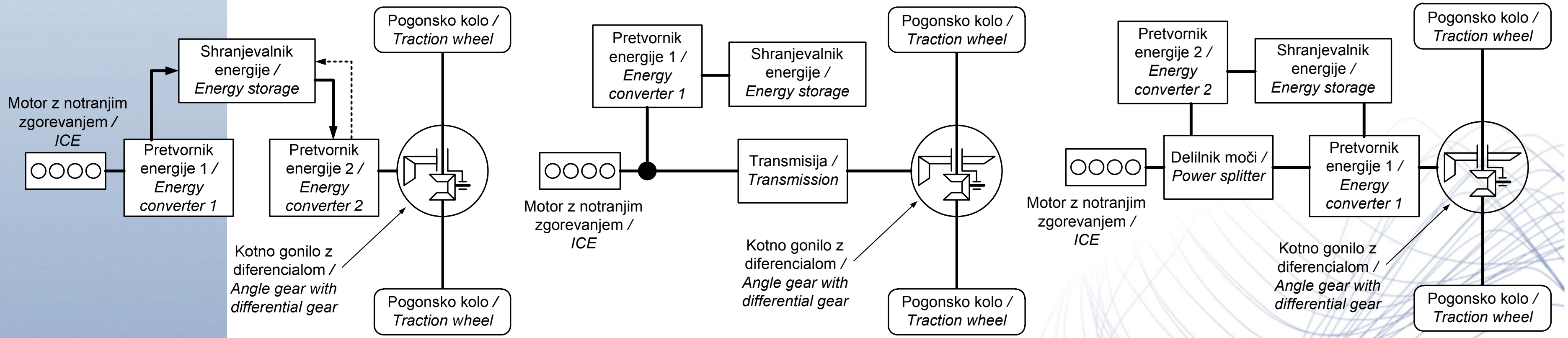
A scheme of a conventional vehicle with the ICE:



Hybrid vehicles (HV)

Assembly of a hybrid drive:

- Internal combustion engine (ICE);
- Energy storage and/or converter device;
- Power splitter (planetary or CVT/RVT gear), dependent on the HV type (serial, parallel or combined hybrid).



Schemes of three HV types (left - serial hybrid, middle – parallel hybrid, right – combined hybrid)

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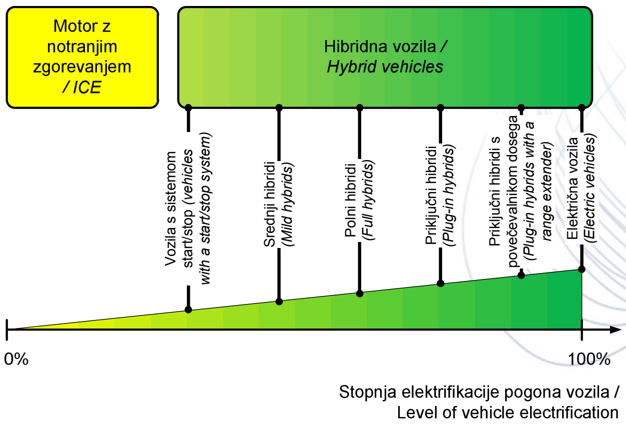
HV types

- *Hybrid electric vehicles (HEV)*
  - *Electric charge is stored in batteries.*
  - *Electric motor as a support or main drive.*
- *Hybrid hydraulics vehicles (HHV)*
  - *Hydro-pneumatic accumulators store the energy from the transmission and return the energy back into transmission.*
- *Mechanical hybrid vehicles (MHV)*
  - *A flywheel is used for energy storage.*
- *Electro-mechanical hybrid vehicles (EMHV):*
  - *A combination of an electric motor/generator and electro-mechanical flywheel is used for energy storage and return.*

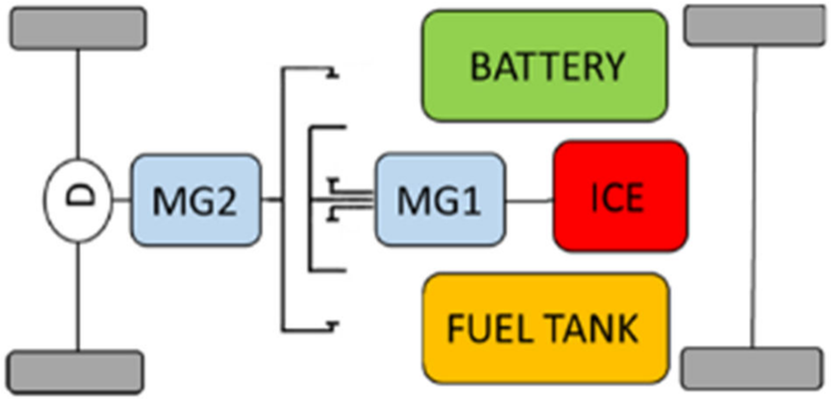
Hybrid electric vehicle (HEV)

- *HEV combines propulsion power from an ICE and a battery driven electric motor.*
- *The electric motor supports or replaces a power flow from ICE.*
- *A transmission efficiency influences a fuel economy and reduces pollutant emissions.*
- *The fuel economy and vehicle performances strongly depend on the vehicle mass.*
- *A lack of charge storage in batteries significantly reduces the range applicability of the electric vehicles.*
- *A vehicle-electrification levels are as follows:*

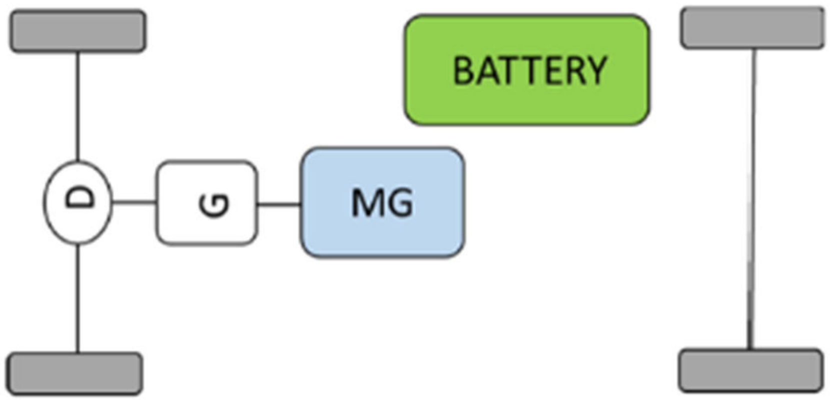


Hybrid electric vehicle (HEV)

An example of a (plug-in) parallel hybrid power train [1]:



An example of a full electric vehicle [1]:



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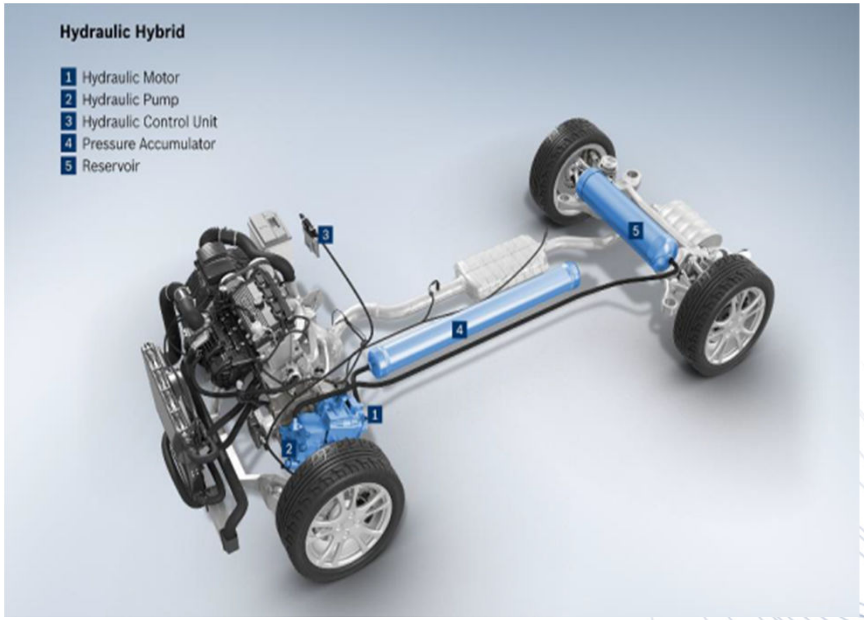
Hybrid hydraulic vehicle (HHV)

- *A kinetic energy during braking is stored into hydraulic-pneumatic accumulators. During the acceleration phase the energy (reduced for the energy losses) is returned into a transmission system.*
- *Hybrid hydraulic vehicles (HHV) concepts can be designed in a serial (S-HHV) or a parallel configuration (P-HHV).*



Gas (N_2) and hydraulic fluid system of a manufacturer Bosch [2]

Serial hydraulic hybrid (S-HHV)

- *ICE is not mechanically linked to the wheels.*
- *Hydraulic pump/motor in a drive mode uses high-pressure fluid from the hydraulic accumulator for the vehicle propulsion.*
- *Three main operation modes of the S-HHV vehicle are:*
  - *mild acceleration / short cruising;*
  - *Extended cruising / strong acceleration;*
  - *regenerative braking.*

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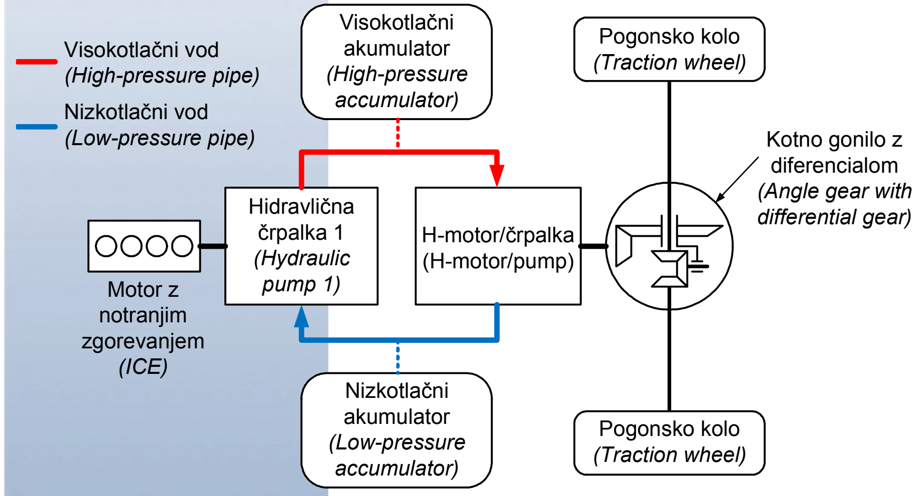
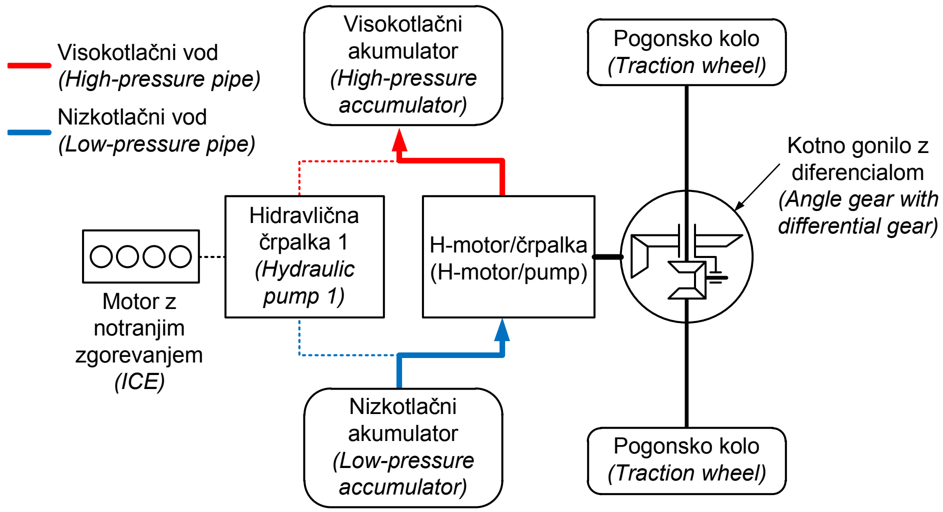
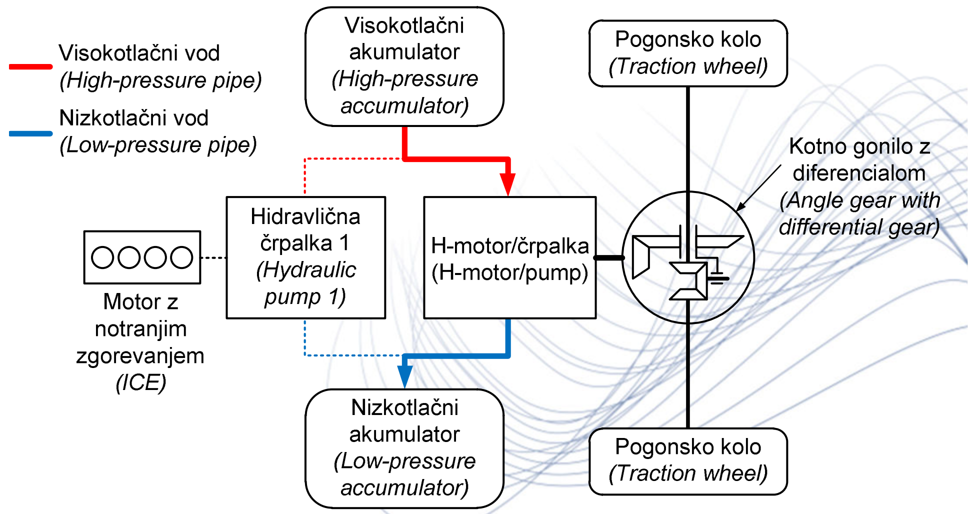
Serial hydraulic hybrid (S-HHV)



Extended cruising / strong acceleration [2]



Regenerative braking [2]



Mild acceleration / short cruising [2]

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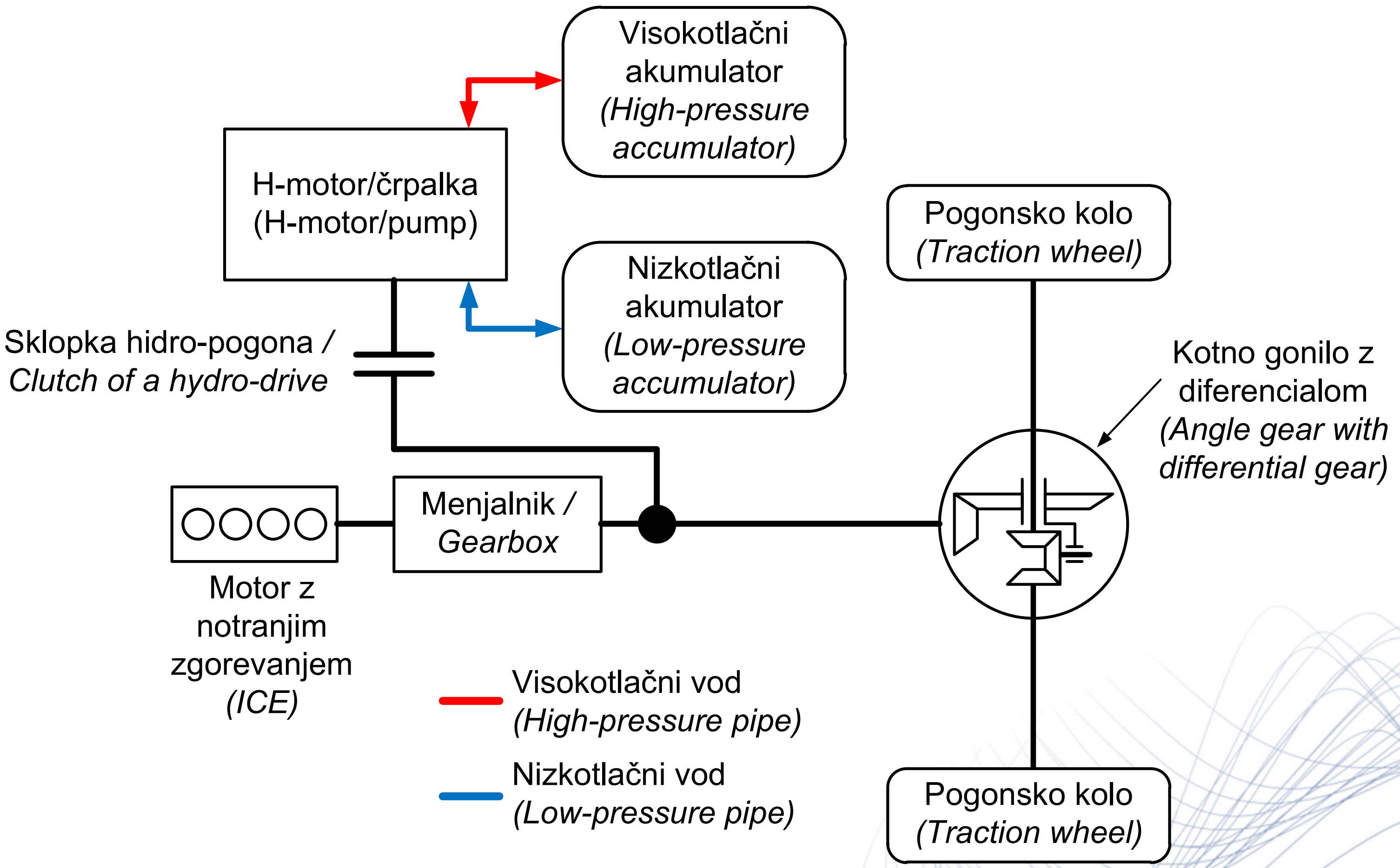
Parallel hydraulic hybrid (P-HHV)

- *ICE, standard powertrain transmission and hybrid hydraulic technology are linked to a main propulsion shaft.*
- *ICE supplies the power to the traction wheels through the standard powertrain transmission.*
- *Hydraulic components that support the powertrain during braking and accelerating are linked to the main propulsion shaft.*

Parallel hydraulic hybrid (P-HHV)



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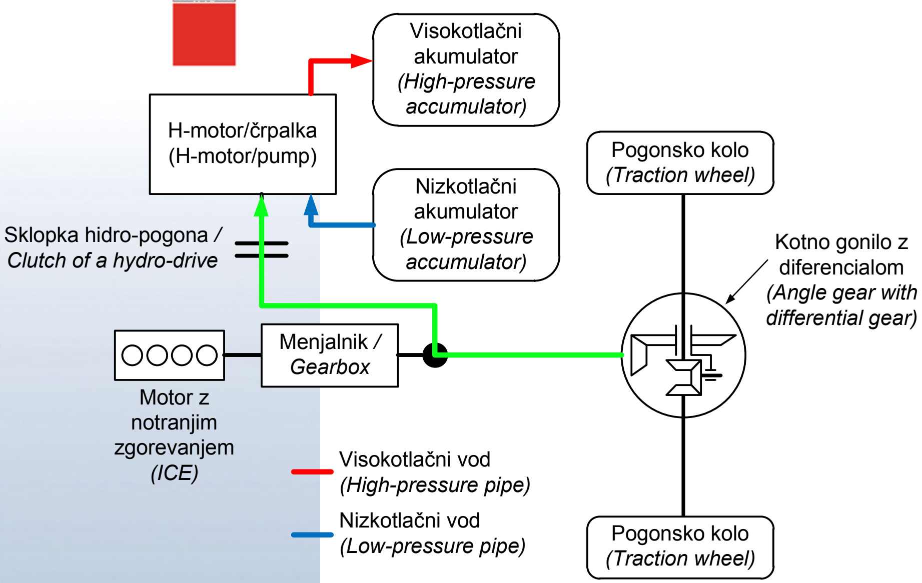
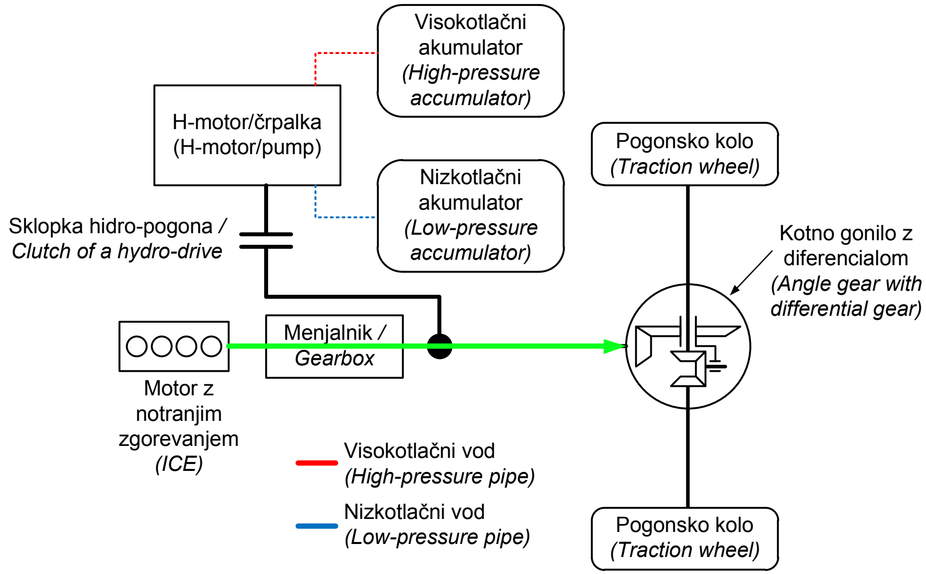
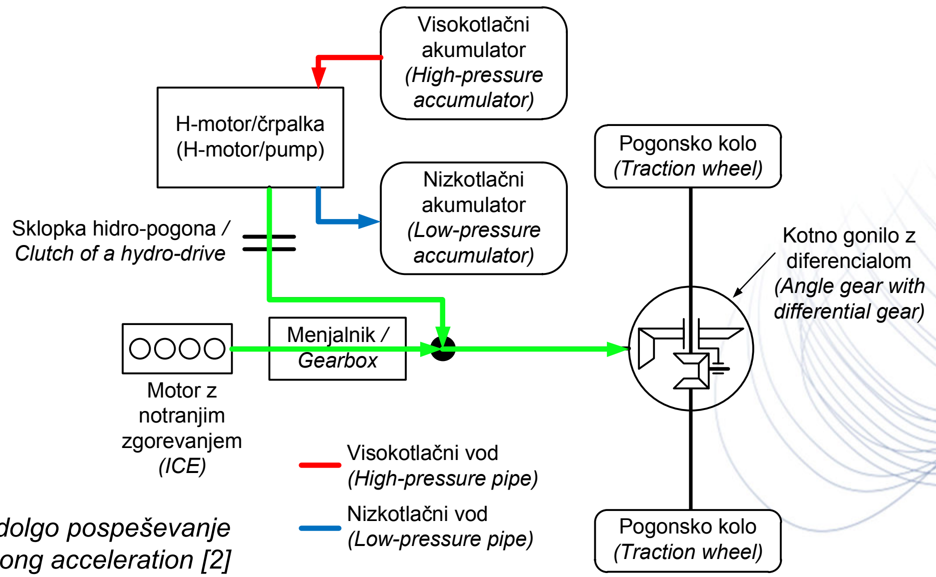
Vzporedni hidravlični hibrid / *Parallel hydraulic hybrid (P-HHV)*



Regenerativno zaviranje
Regenerative braking [2]



Zmerno pospeševanje / križarjenje
Mild acceleration / Cruising [2]



Močno/dolgo pospeševanje
Strong/long acceleration [2]

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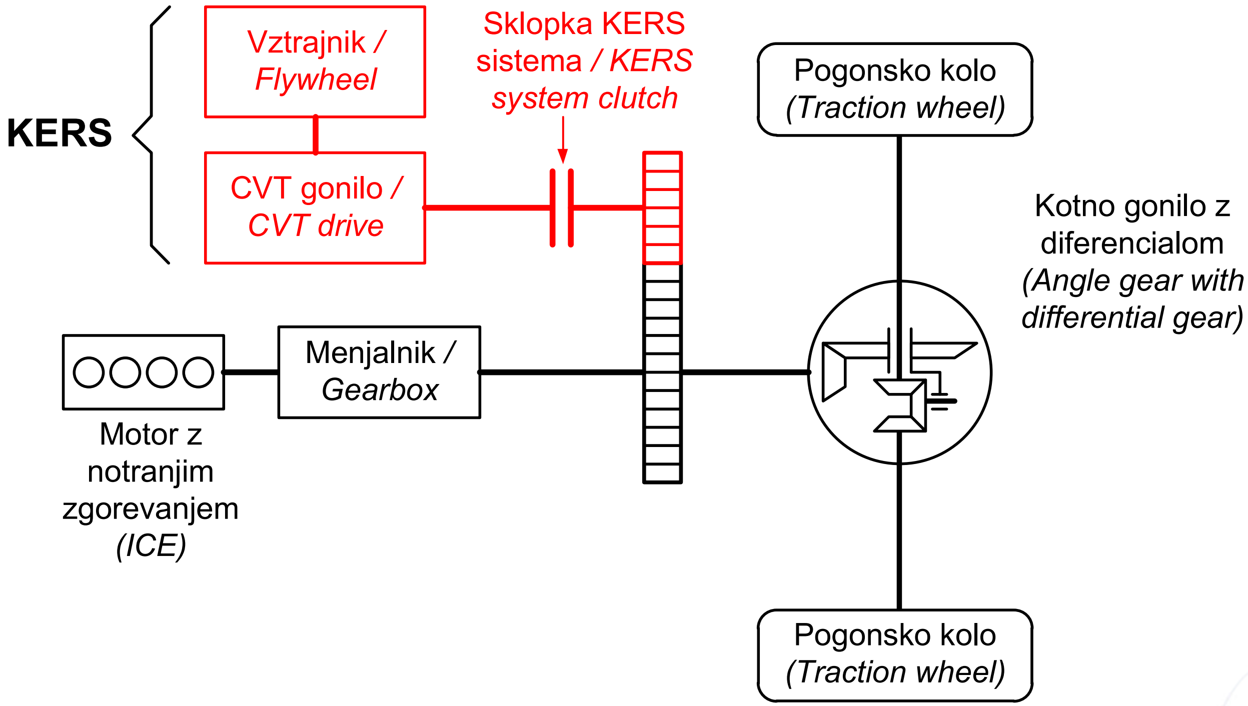
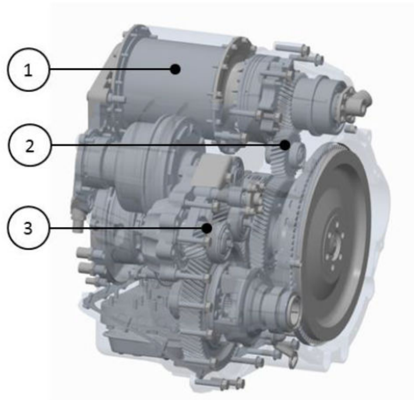
Mechanical hybrid vehicle (MHV)

- *A high-voltage high-current electronics and batteries are not applied for energy storage.*
- *The principle of operation is KERS – Kinetic Energy Recovery System.*
- *These hybrid-drive systems should fit in to the market niche by lowering fuel consumption at lowest possible cost.*
- *Simulations at different driving cycles show a reduction in fuel consumption between 15% and 25%.*

Mechanical hybrid vehicle (MHV)





Main mechanical changes over standard CVT:

1) Flywheel unit,
2) Geared connection to CVT input shaft,
3) DNR on secondary lay-shaft.

3D model of the KERS [3]

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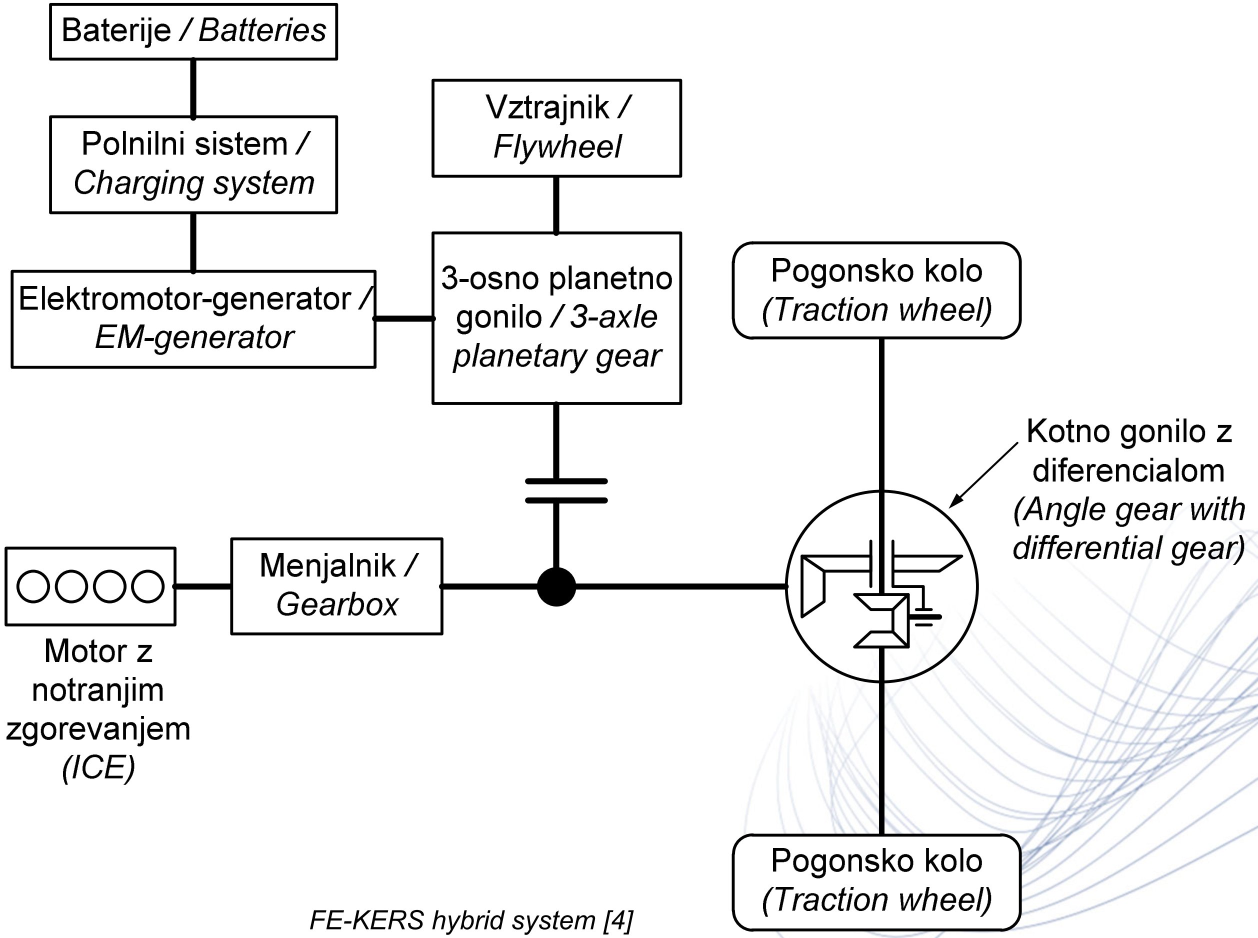
Electro-mechanic hybrid vehicle (EMHV)

- *This is a cost-effective 48V hybrid technology that can be mounted on the front or rear axles of the existing vehicle platforms.*
- *Planetary gear and electric system are joint into a continuously variable transmission gear between the flywheel and the rest of the vehicle's powertrain.*
- *Flywheel is applied to boost performance of the electric motor.*

Electro-mechanic hybrid vehicle (EMHV)

- *Flywheel can boost peak power of a combined system up to five times the electric-motor power.*



FE-KERS hybrid system [4]

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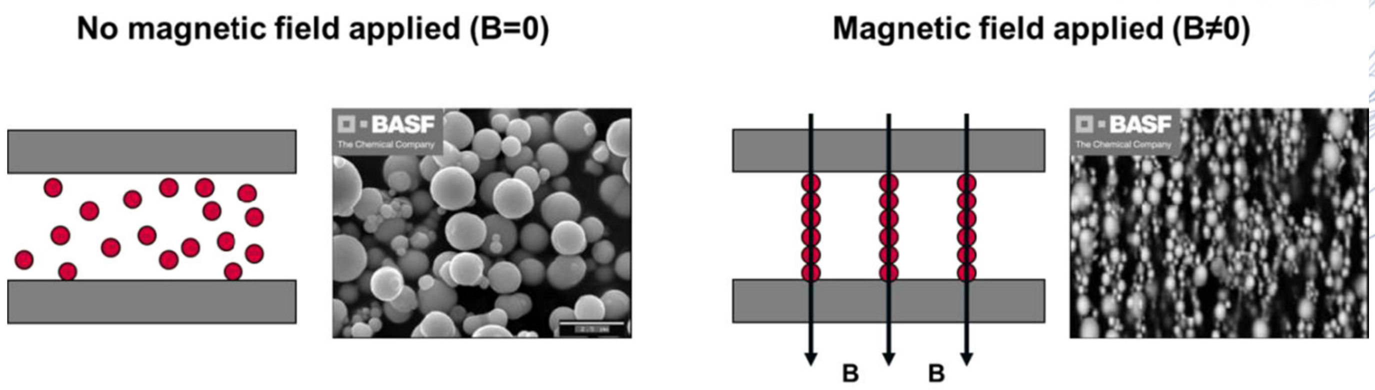
Transmission and power division

- *In a hybrid powertrain a torque and power from ICE is combined with the torque and power from the energy storage and converter device.*
- *The main cause for power-train losses and increased fuel consumption is a friction in powertrain elements.*
- *Continuously-variable transmission elements are one of the most effective and environmentally friendly technologies for reduction of the fuel consumption in conventional vehicles.*
- *Applied transmission elements:*
  - *Planetary gears.*
  - *Continuously-variable transmission elements (CVT).*
  - *Reversible transmission elements with continuously variable transmission ratios (RVT).*
  - *Clutch elements using magneto-rheological fluid.*

Clutch with magneto-rheological fluid (MRF)

- *Magneto-rheological fluids (MRF) are so called „smart fluids“ with their viscosity that is significantly changed in the presence of an external magnetic field.*
- *This effect is achieved using a suspension of spherical magnetic particles of micro-meter size (carbonyl-ferrous powder with particle diameters of 5-10 µm) in the fluid, which is usually a lubricant oil.*
- *Under the action of the magnetic field these particles are aligned in the form of chains in the direction of the magnetic field forces. Consequently, a shear yield stress of the MRF fluid is changed as a function of the magnetic field density.*

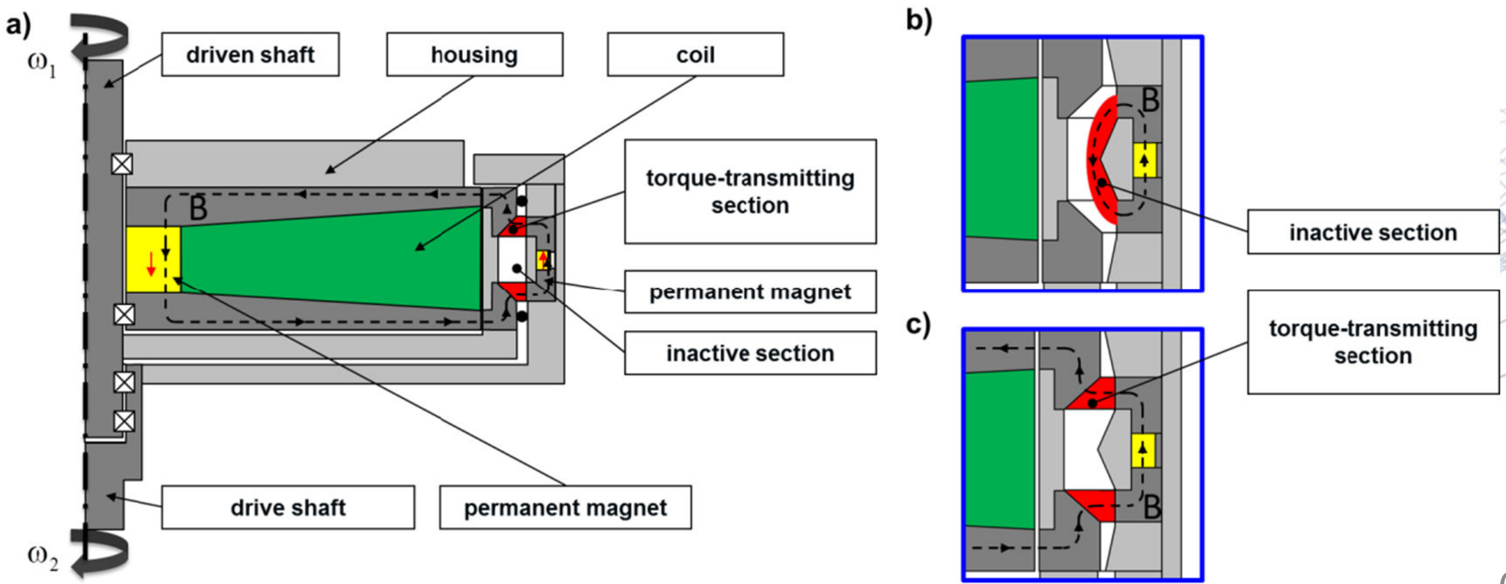


A scheme of the MRF fluid in the absence (left) and action (right) of the magnetic field [5]

Clutch with magneto-rheological fluid (MRF)

- *MRF fluids are suitable for application in mechanical systems as brakes and clutches in which a generated/transmitted torque should be proportionally controlled.*

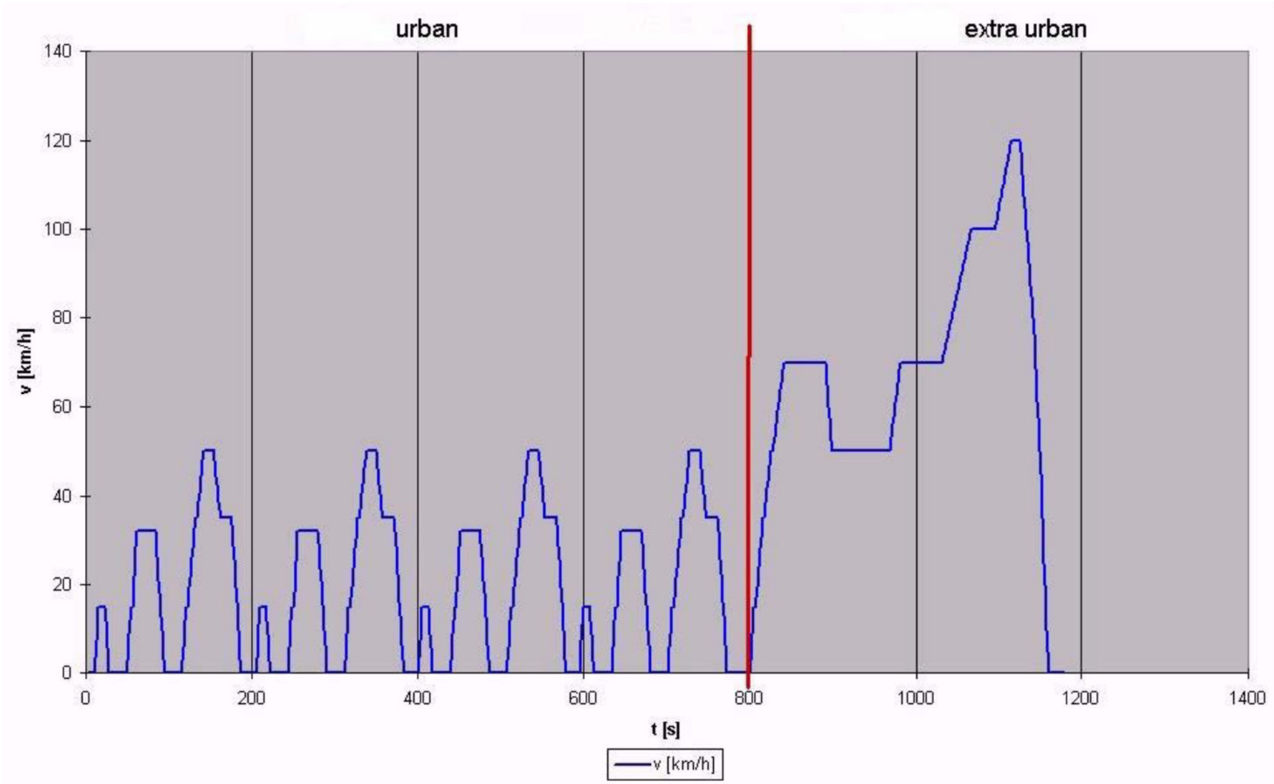
- *A dissipated energy and a peak thermal load in the MRF fluid are less important when compared to the conventional friction systems (brakes, clutches) due to larger volume of the heated MRF fluid (a bulk of the MRF fluid instead of a thin contact surface).*



Clutch with magneto-rheological fluid [5]

New European Driving Cycle (NEDC)

- *NEDC forms a basis for a vehicle homologation.*
- *Vehicle emissions are measured for NEDC according to a 98/69/EC directive.*
- *NEDC is composed of two parts: urban and extra-urban driving cycle.*

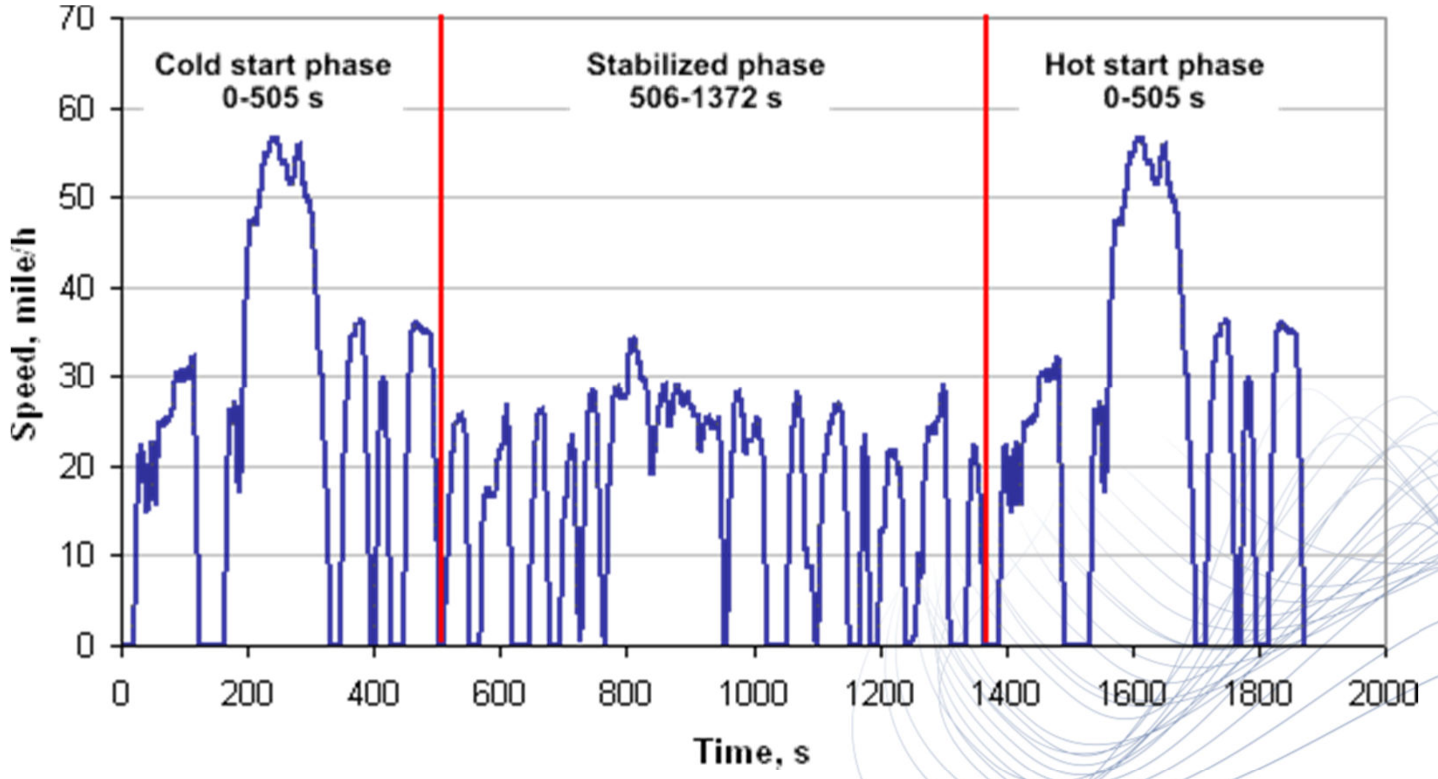


New European Driving Cycle (NEDC)

- *There exist two different NEDC tests.*
- *NEDC cold test that is applied for evaluation of:*
  - *Pollutant emissions;*
  - *CO_2 emissions;*
  - *Fuel consumption;*
  - *Engine temperature before start should be 22° C±2° C. Engine down-time for this test should be at least 6 hours and maximum 30 hours. This test is used for a vehicle-state examination.*
- *NEDC warm test that is applied for evaluation of:*
  - *CO_2 emissions;*
  - *Fuel consumption;*
  - *Engine temperature before start should be approximately 90° C. This test is used for a replication of driver‘s habits.*

Testing cycle of USA: US FTP-75

- *Testing cycle FTP-75 (Federal Test Procedure) is applied for certification of emissions and economy testing of light vehicles in USA.*



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Testing cycle of USA: US FTP-75

- *The complete FTP-75 cycle is composed of the following segments[12]:*
  - *Cold-start transient phase (temp. 20-30° C), 0-505 s;*
  - *Stabilised phase, 506-1372 s;*
  - *Warm stop (min. 540 s, max. 660 s);*
  - *Warm-start transient phase, 0-505 s;*
  - *Travelled distance: 11.04 miles (17.77 km);*
  - *Average velocity: 21.2 mph (34.1 km/h);*
  - *Duration: 1874s.*

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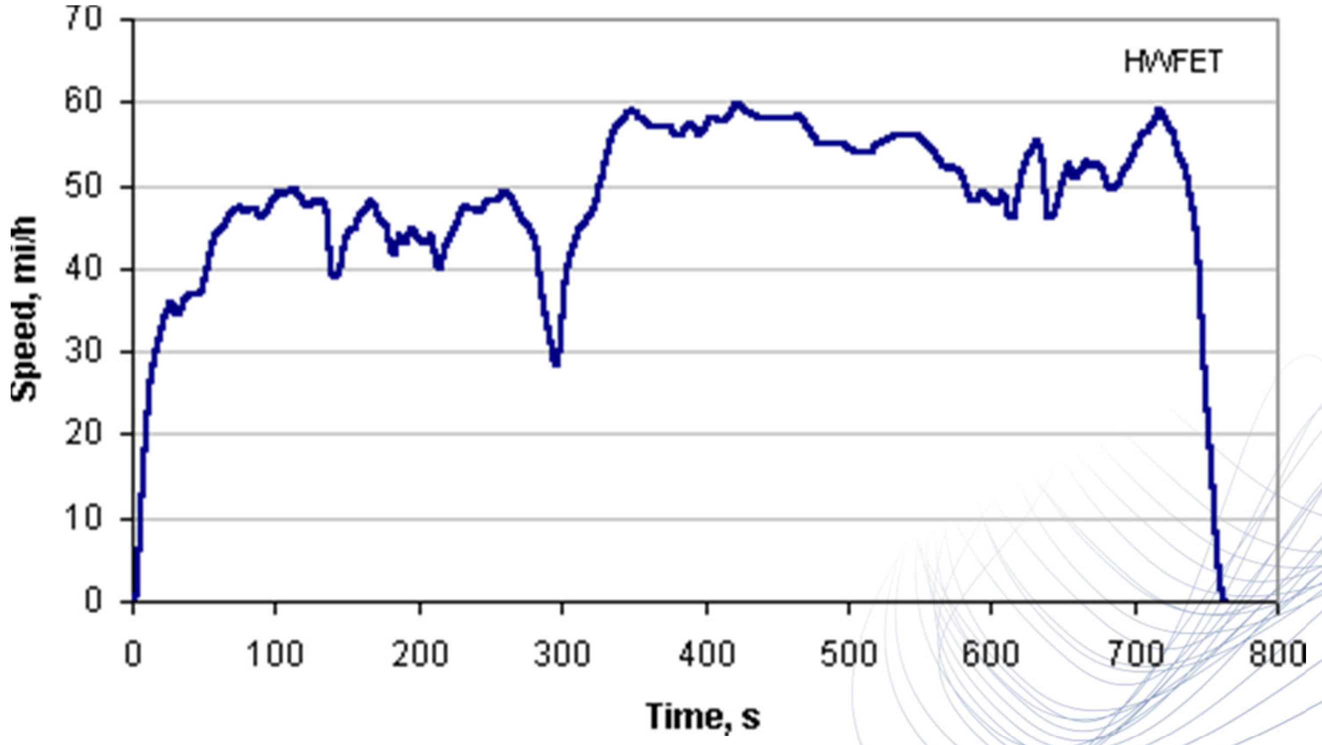
Testing cycle of USA: US HWFET

- *Testing cycle HWFET (The Highway Fuel Economy Cycle) represents a driving schedule that was developed by the US EPA organization for estimating an economy of light vehicles [40 CFR part 600, subpart B].*



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Testing cycle of USA: US HWFET

- *Testing cycle HWFET is applied for classifying vehicles according to their driving economy on the highway.*
- *Testing-cycle parameters are as follows:*
  - *Duration: 765 s;*
  - *Travelled distance: 10.26 miles (16.45 km);*
  - *Average velocity: 48.3 mph (77.7 km/h).*

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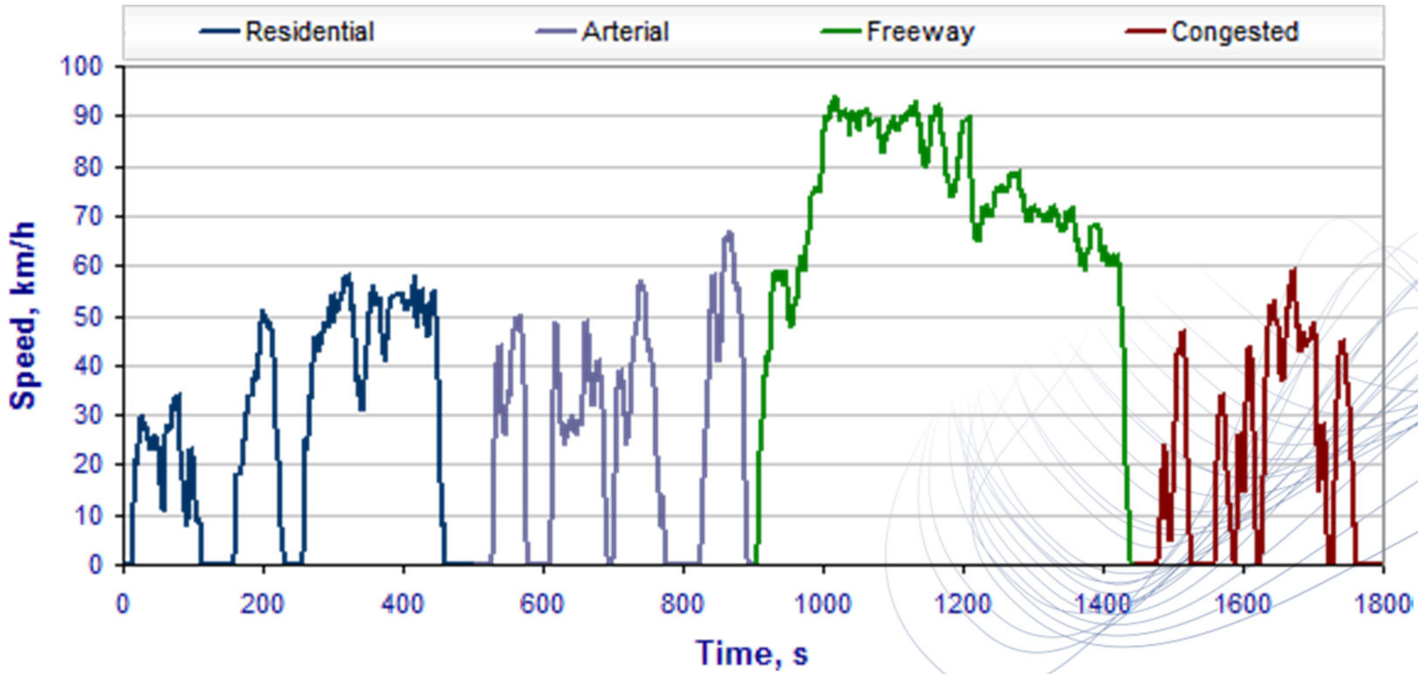
Australian testing cycle: AUDC

- *Testing cycles AUDC (Australian Urban Drive Cycle) and CUEDC (Composite Urban Emissions Drive Cycle) were developed for light gasoline-driven vehicles.*
- *Testing cycle CUEDC represents a real Australian driving in an urban area. It is composed of four segments: residential area, arterial link, freeway and traffic congestion.*



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Energy-management strategy for HEV

- *HEV is efficient only, if the stored electric energy is larger than the losses in an electric system together with an electric motor/generator, a battery management system and a battery.*
- *Energy-management strategy (EMS) supports the optimization of HEV.*
- *EMS is an algorithm that divides positive requirements on energy between the ICE and battery for the biggest possible regenerative-braking effort.*
- *HEV economy depends heavily on the applied EMS as well as on the capability of the system for storage/ return of the energy.*
- *Problems of the optimal-EMS determination were solved with different optimization algorithms.*

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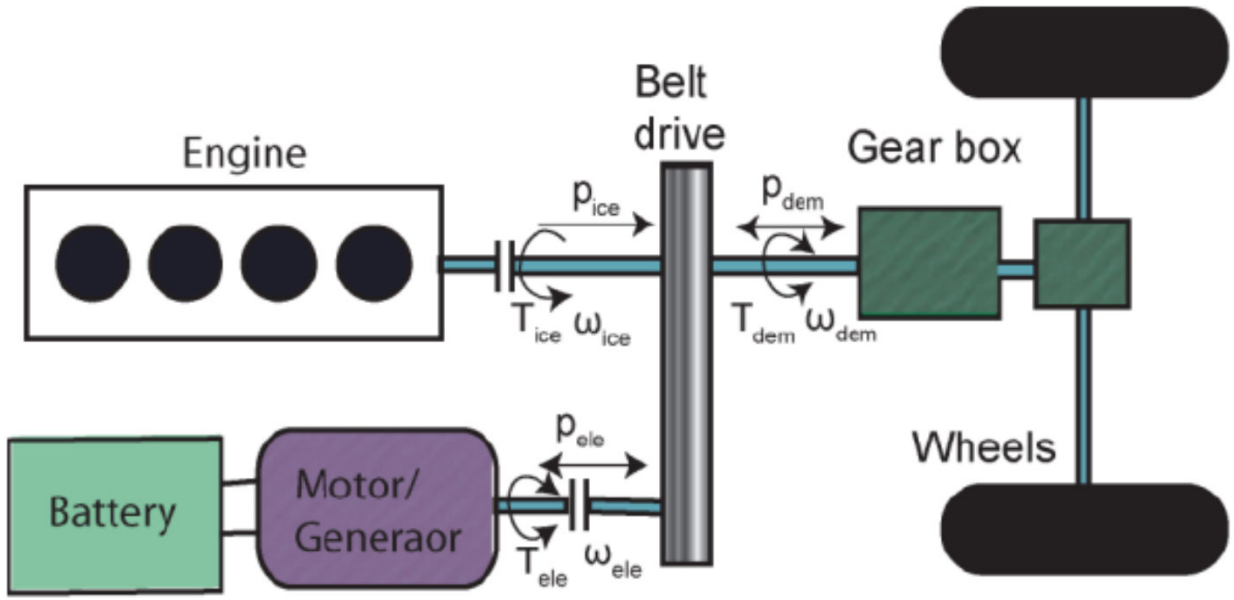
Energy-management strategy for HEV

- *Case1: parallel HEV for different testing cycles (US FTP-75, NEDC, AUDC and US HWFET).*
- *Optimal EMS were determined by applying the following methods: dynamic programming (DP), equivalent-fuel-consumption minimization strategy (ECMS) and heuristic methods (HCEMS).*

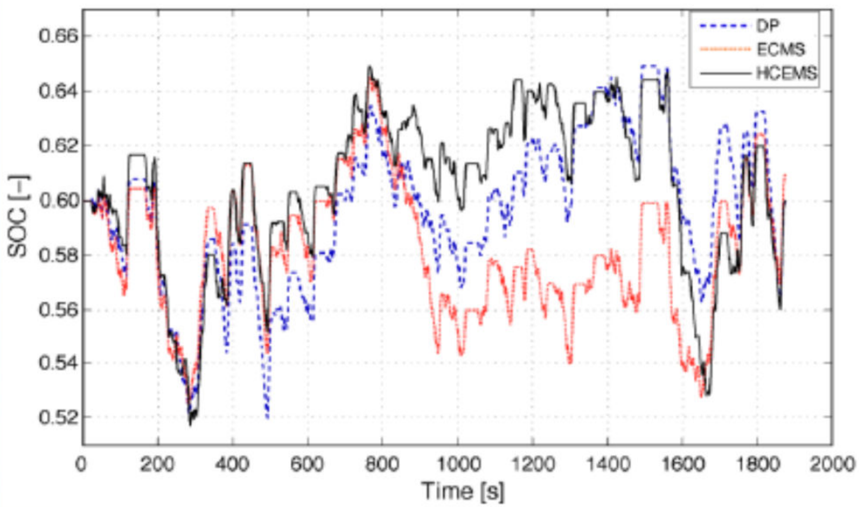


A schema of a parallel HEV [13]

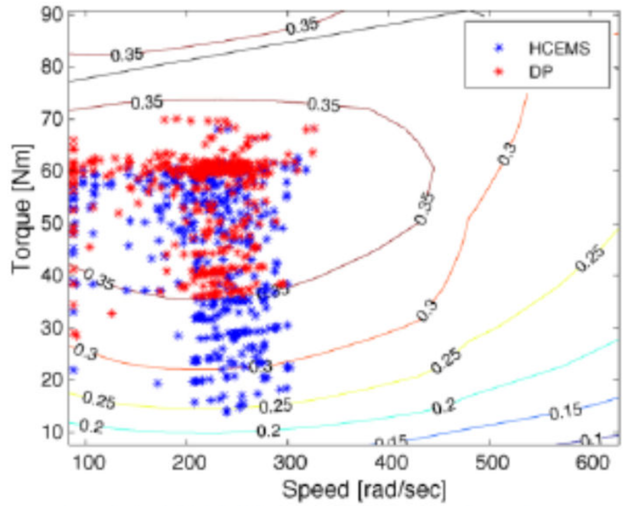
Energy-management strategy for HEV

Fuel consumption (L/100 km), difference between the starting and final electric charge (SOC) (%) and processing time for different optimization methods [13]

Drive Cycle	Fuel Consumption (L/100km)				SOC Deviation (%)			Computational Time (s)		
	DP	ECMS	HCEMS	Conv.	DP	ECMS	HCEMS	DP	ECMS	HCEMS
NEDC	**3.90**	3.93	3.90	6.36	0	+1.0	0	72092	285	2142
FTP_75	**3.65**	3.69	3.66	6.23	0	-1.8	0	103797	312	3140
AUDC	**3.64**	3.68	3.65	6.32	0	-4.5	0	84827	304	2512
HWFET	**3.85**	4.02	3.98	4.90	0	-3.8	0	74846	268	2028



SOC variation [13]



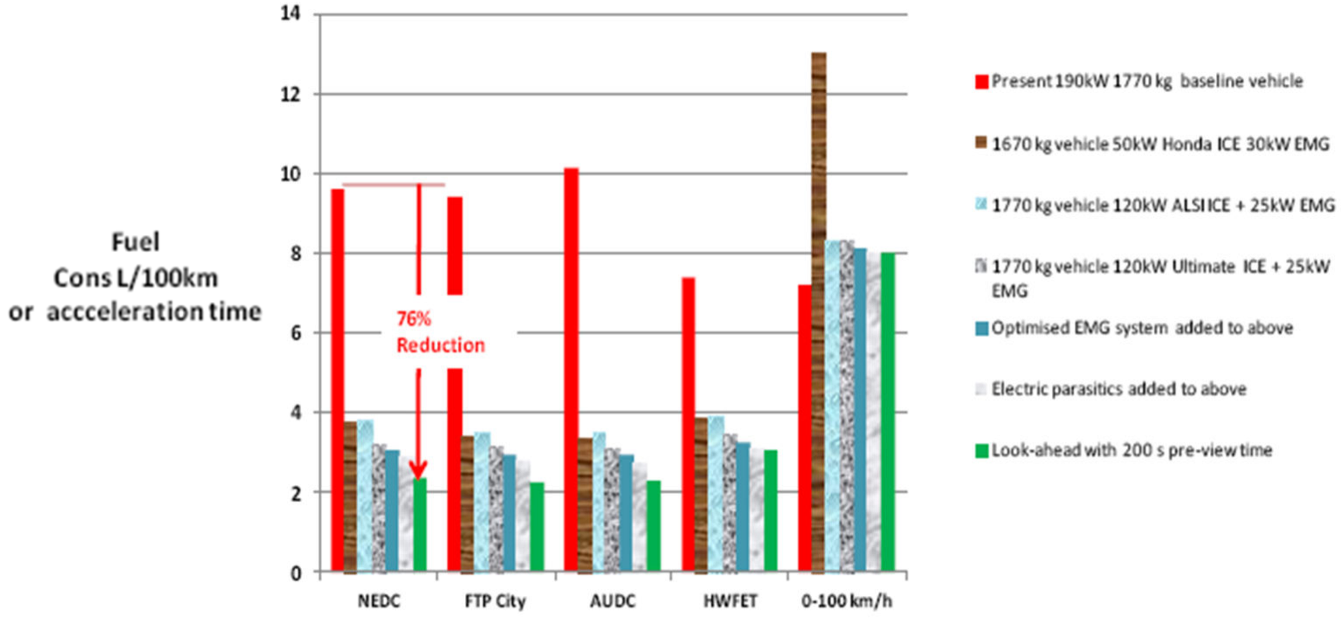
Operating points of ICE for the HCEMS and DP methods for US FTP-75 [13]

Energy-management strategy for HEV

- *Primer 2 final evaluation of a system.*
- *Optimal ES according to DP, ECMS in HCEMS methods were tested on the optimised model of the parallel HEV by considering energy losses for the driving cycles: US FTP-75, NEDC, AUDC in US HWFET [13].*

Drive Cycle	Present 190kW 1770 kg baseline vehicle	1670 kg vehicle 50kW Honda ICE 30kW EMG	1770 kg vehicle 120kW ALSI ICE + 25kW EMG	1770 kg vehicle 120kW Ultimate ICE + 25kW EMG	Optimised EMG system added to above	Electric parasitics added to above	Look-ahead with 200 s pre-view time	Look ahead reduction from baseline
	Fuel Consumption L/100 km							%
NEDC	9.60	3.73	3.77	3.23	3.05	2.88	2.37	75.4
FTP City	9.40	3.39	3.51	3.13	2.95	2.79	2.24	76.2
AUDC	10.16	3.36	3.52	3.11	2.93	2.77	2.29	77.4
HWFET	7.39	3.87	3.9	3.46	3.26	3.08	3.04	58.9
0-100 km/h	7.2	13.0	8.3	8.3	8.1	8.0	8.0	

Energy-management strategy for HEV



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