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Katedra za strojne elemente
in razvojna vrednotenja

LABORATORIJ ZA VREDNOTENJE KONSTRUKCIJ

LABORATORIJ ZA STROJNE ELEMENTE

Bilanca vlečnih sil in pogon vozila

Traction force balance and vehicle drive

Prof. dr. Jernej Klemenc

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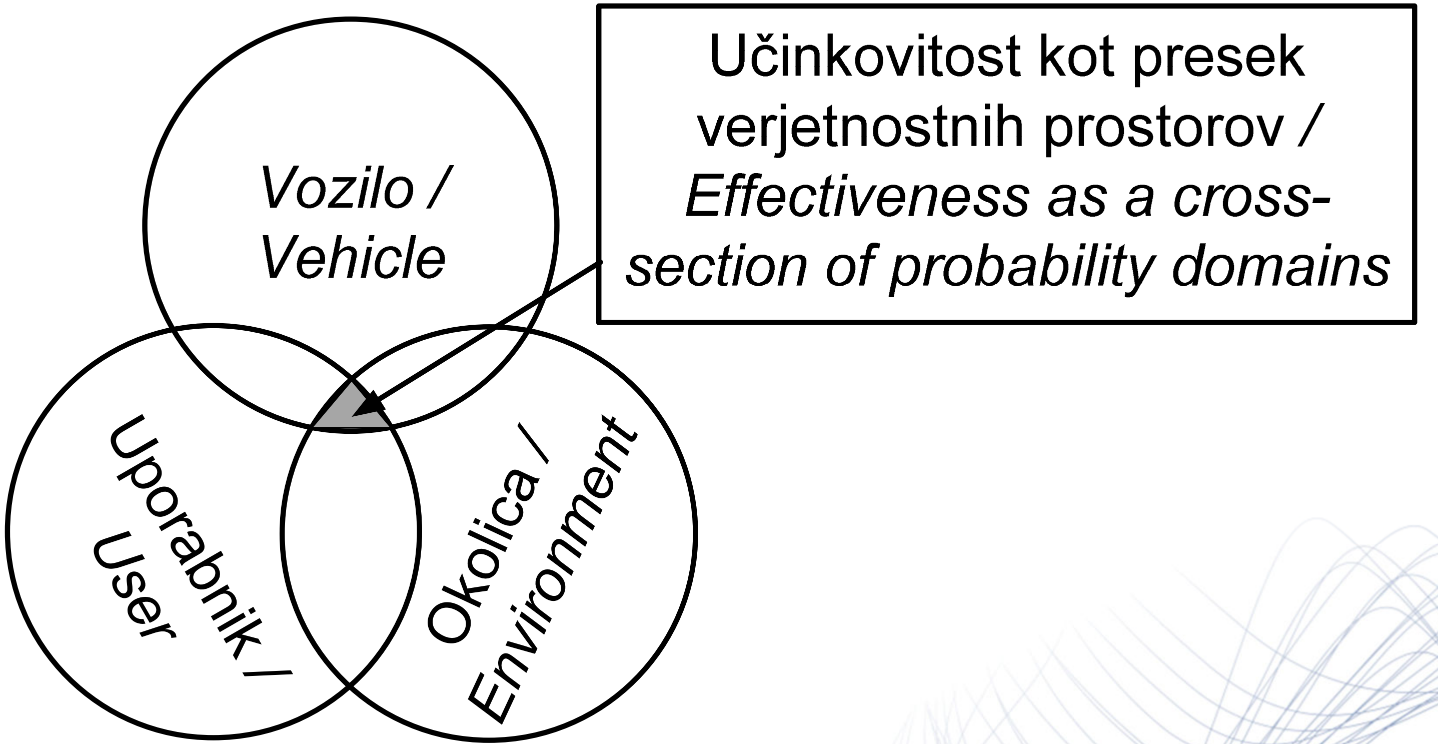
Vozilo – interakcije in učinkovitost / *Vehicle – interactions and effectiveness*



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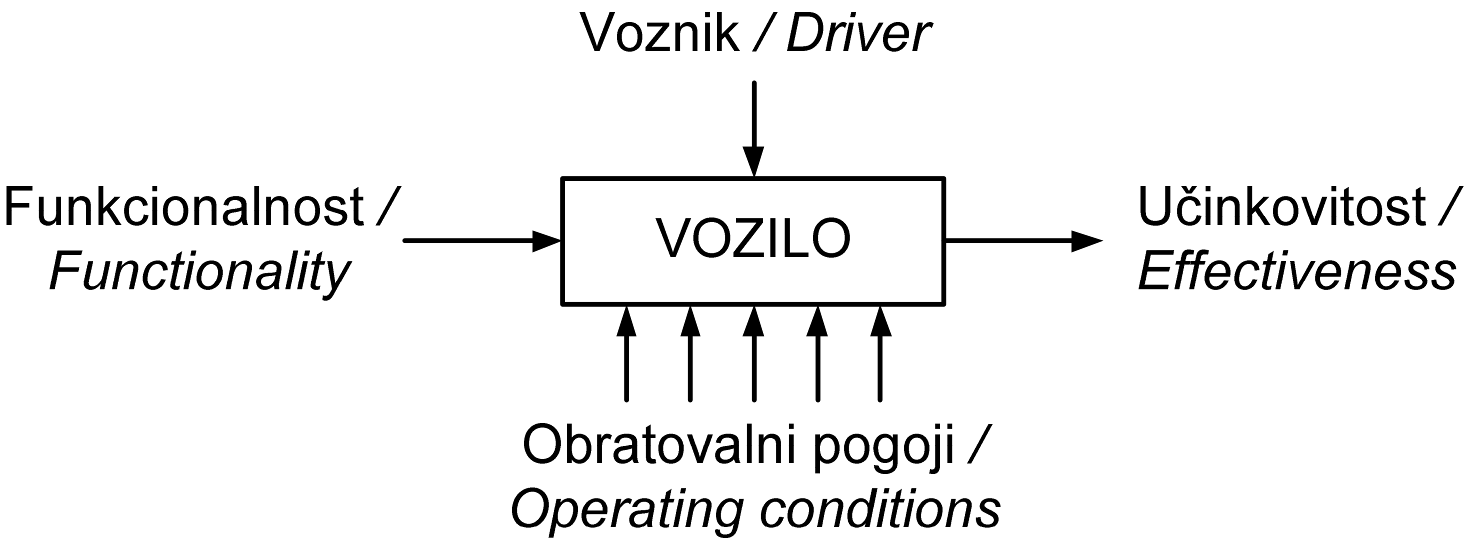
Vozilo – interakcije in učinkovitost / *Vehicle – interactions and effectiveness*



Učinkovitost vozila je verjetnost, da bo vozilo pri določenih pogojih uporabe, pogojih okolja in pogojih vzdrževanja dosegalo zahteve glede na pripravlje-nost na obratovanje, razpoložljivost in zmogljivost.

A vehicle effectiveness is a probability that the vehicle fulfills its requirements on operation readyness, availability and characteri-stics for the given operating conditions, maintenance conditions and environmental influence.

Vozni upori / *Driving resistances*

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- Upor ležajev
- Kotalni upor
- Zračni upor
- Upor strmine
- Upor priklopnega vozila

- *Resistance of bearings*
- *Rolling resistance*
- *Aerodynamic resistance*
- *Resistance of hill*
- *Trailer resistance*

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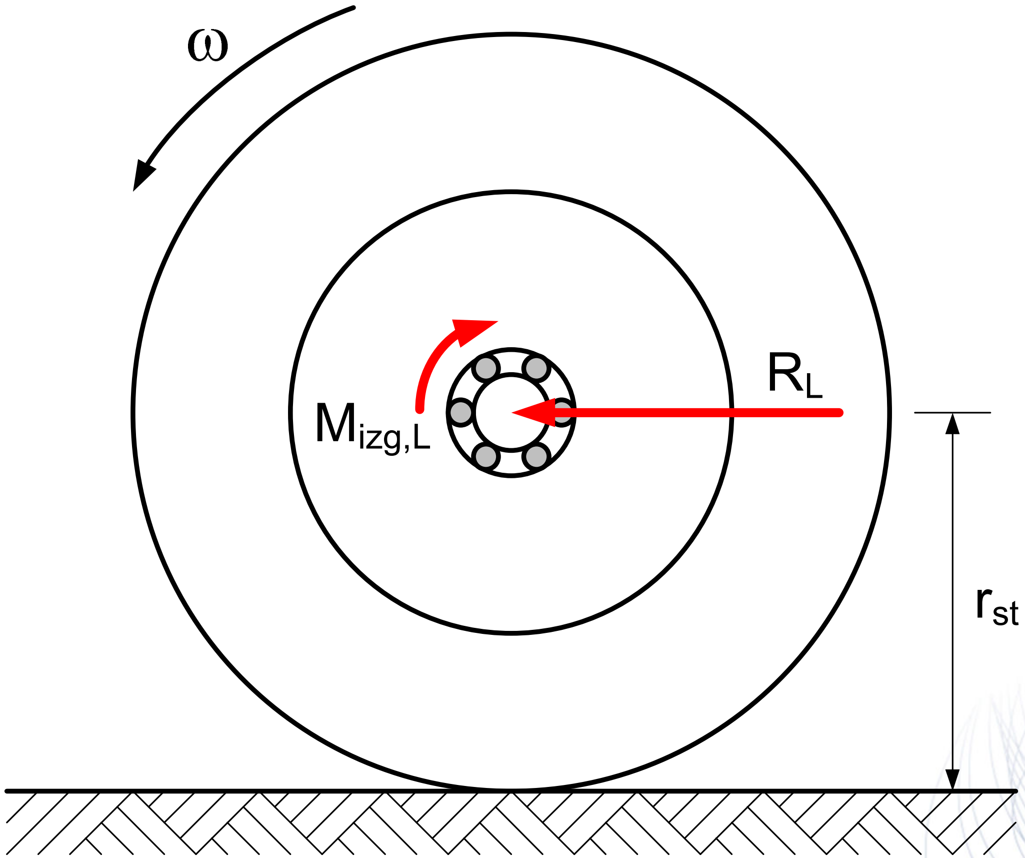
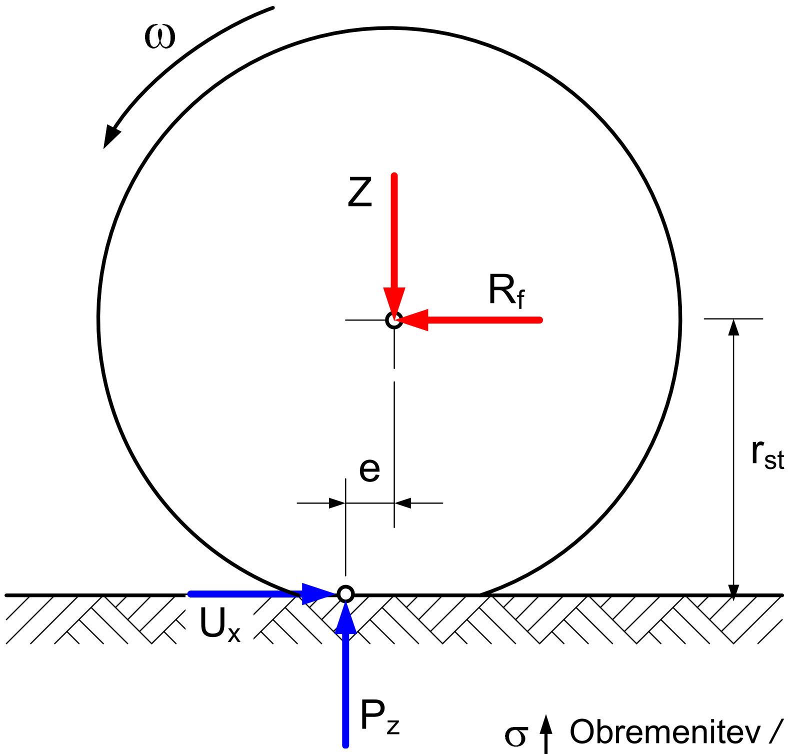
Upor ležajev / *Resistance of bearings*



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

Kotalni upor / *Rolling resistance*



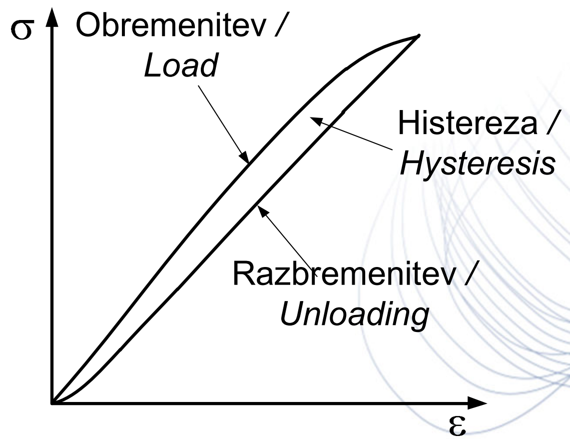
$$P_z = Z$$

$$U_x = R_f$$

$$\sum M = 0$$

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

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



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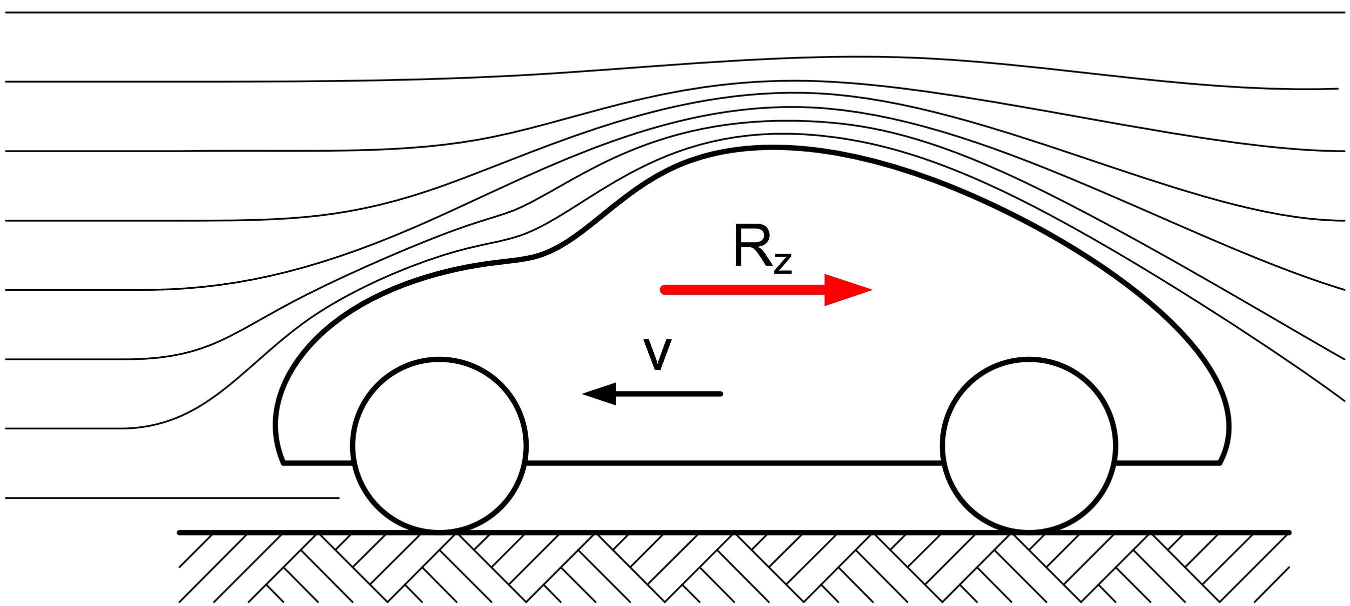
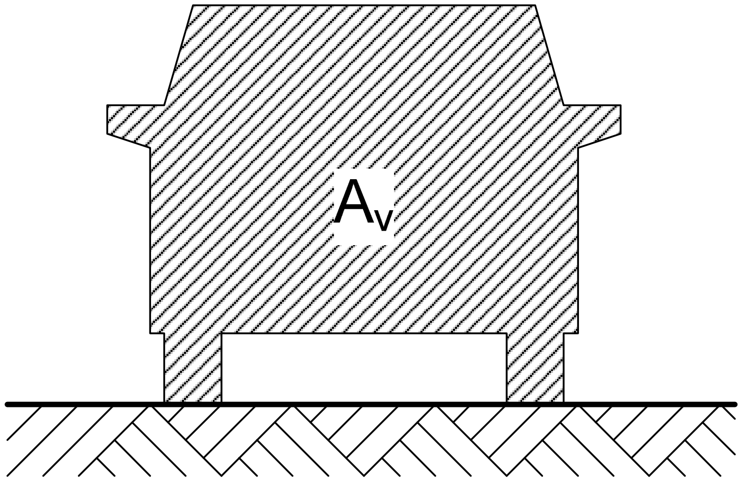
Kotalni upor / *Rolling resistance*

- Tipične vrednosti kotalnih uporov za cestno vozilo s pnevmatikami:
  - f = 0,01 – 0<,015 (pnevmatika na asfaltu ali betonu)
  - f = 0,035 (pnevmatika na makadamski cesti)
  - f = 0,3 (pnevmatika na sipkem pesku)
- Tipična vrednost kotalnega upora za železniško vozilo:
  - f = 0,001

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

Zračni upor / *Aerodynamic resistance*





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

Zračni upor / *Aerodynamic resistance*

- Korigirani koeficient zračnega upora c* vsebuje naslednje vplive:
  - Dinamični upor zaradi zračnega toka ob vozilu;
  - Trenje zraka ob vozilo (zanemarljivo);
  - Vpliv uporov zaradi pretoka zraka skozi vozilo.

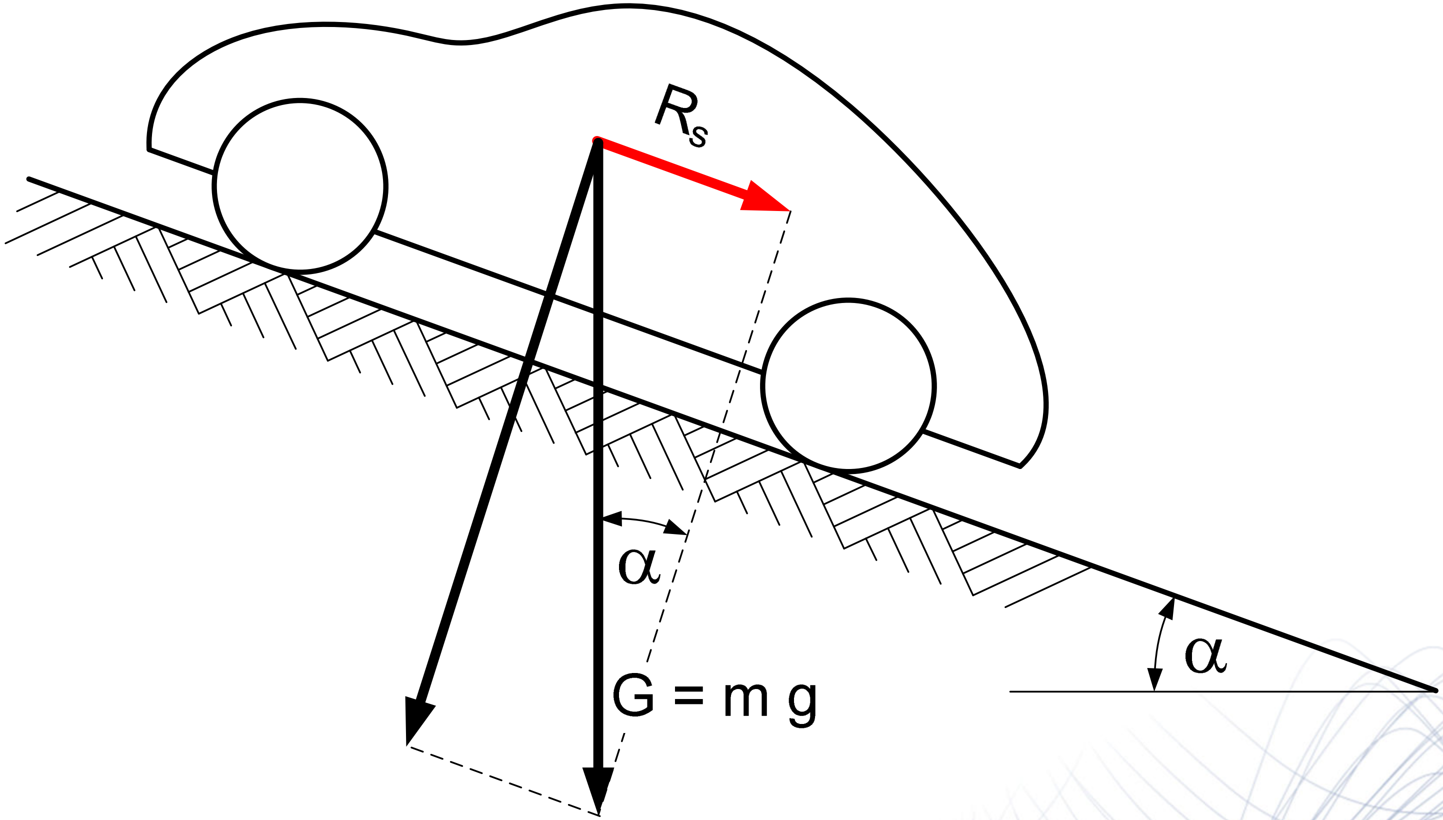
- *An augmented aerodynamic-resistance coefficient c* includes the following influences:*
  - *An aerodynamic resistance of the air flow around the vehicle;*
  - *A friction between the air and the vehicle (can be neglected);*
  - *A resistance of the air flow through the vehicle (e.g. ventilation losses).*

Zračni upor / *Aerodynamic resistance*

- Tipične vrednosti korigiranega koeficienta zračnega upora c*:
  - c* = 0,3 … osebno vozilo
  - c* = 0,6 … avtobus
  - c* = 0,9 … tovornjak
  - c* = 0,98 … tovornjak s priklopnikom ali vlak

- *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*

Upor strmine / *Resistance of a hill*



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

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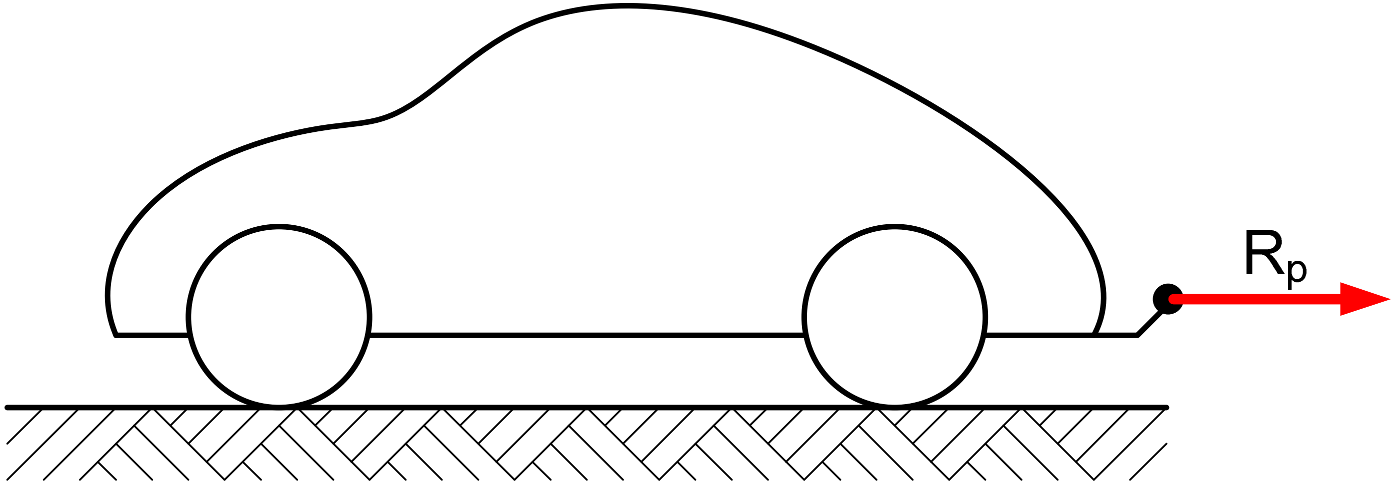
Upor priklopnika / *Trailer resistance*



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

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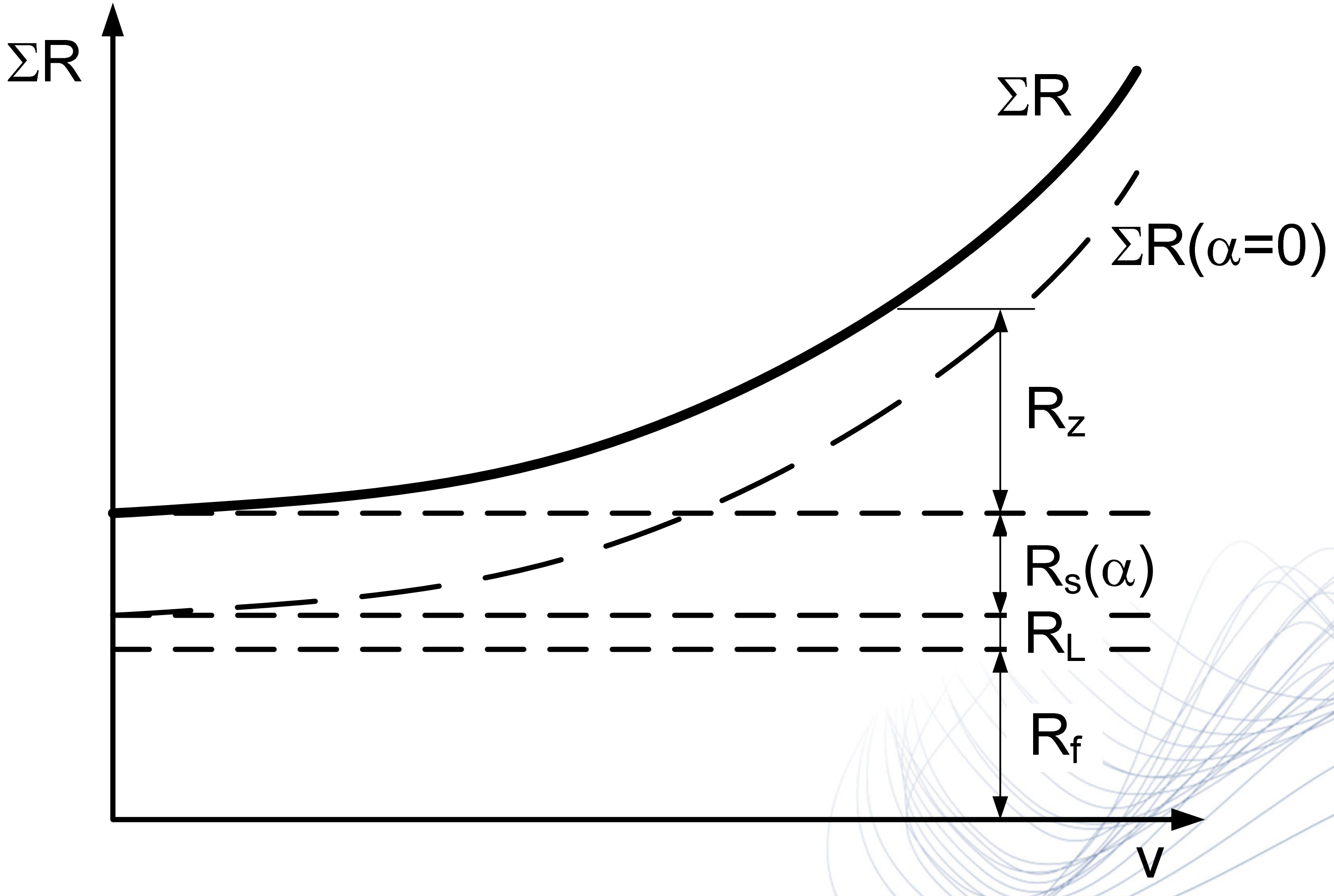
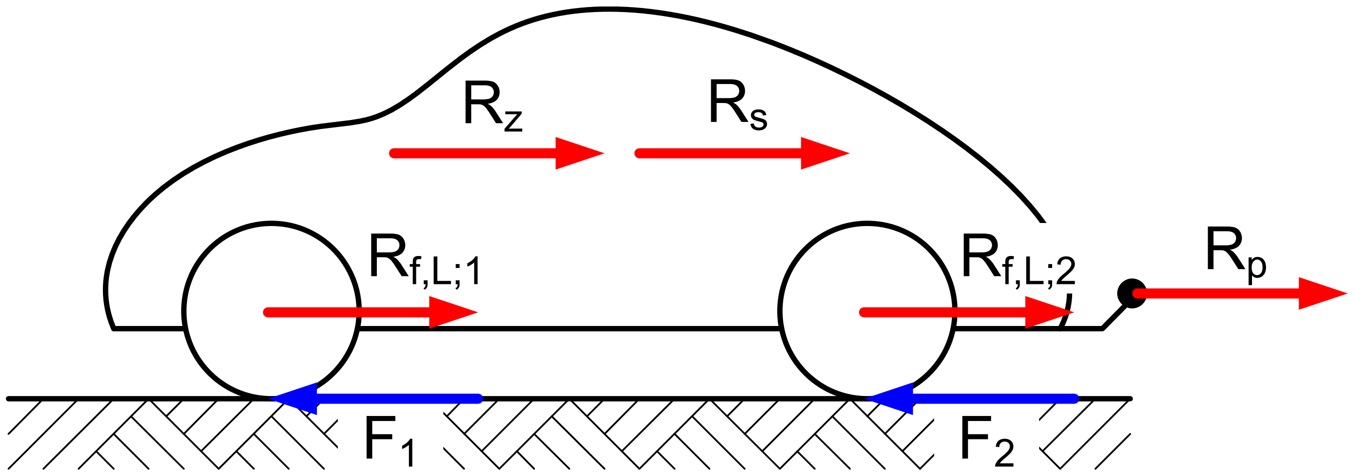
Vsota voznih uporov / *A sum of driving resistances*



Vsota voznih uporov / *A sum of driving resistances*



- Vsota uporov na vozilu je enaka vsoti uporov ležajev, kotalnih uporov, upora zraka, upora strmine in upora priklopnika.

- *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.*

Vsota voznih uporov / *A sum of driving resistances*

- Pri premikanju vozila morajo obodne sile med kolesom in podlago ($F_{1,2}$) premagovati vse vozne upore (in eventuelno še vztrajnost vozila pri pospeševanju/zaviranju).
- Obodne sile na kolesih $F_{1,2}$ so posledica transformiranega vrtilnega momenta motorja ali zavor.

- *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 accelerating/braking if applicable).*
- *The tangential forces acting on the wheels $F_{1,2}$ result from the transformed torque of the driving engine or brakes.*

Idealna karakteristika pogonskega stroja / *Ideal characteristics of a driving engine*

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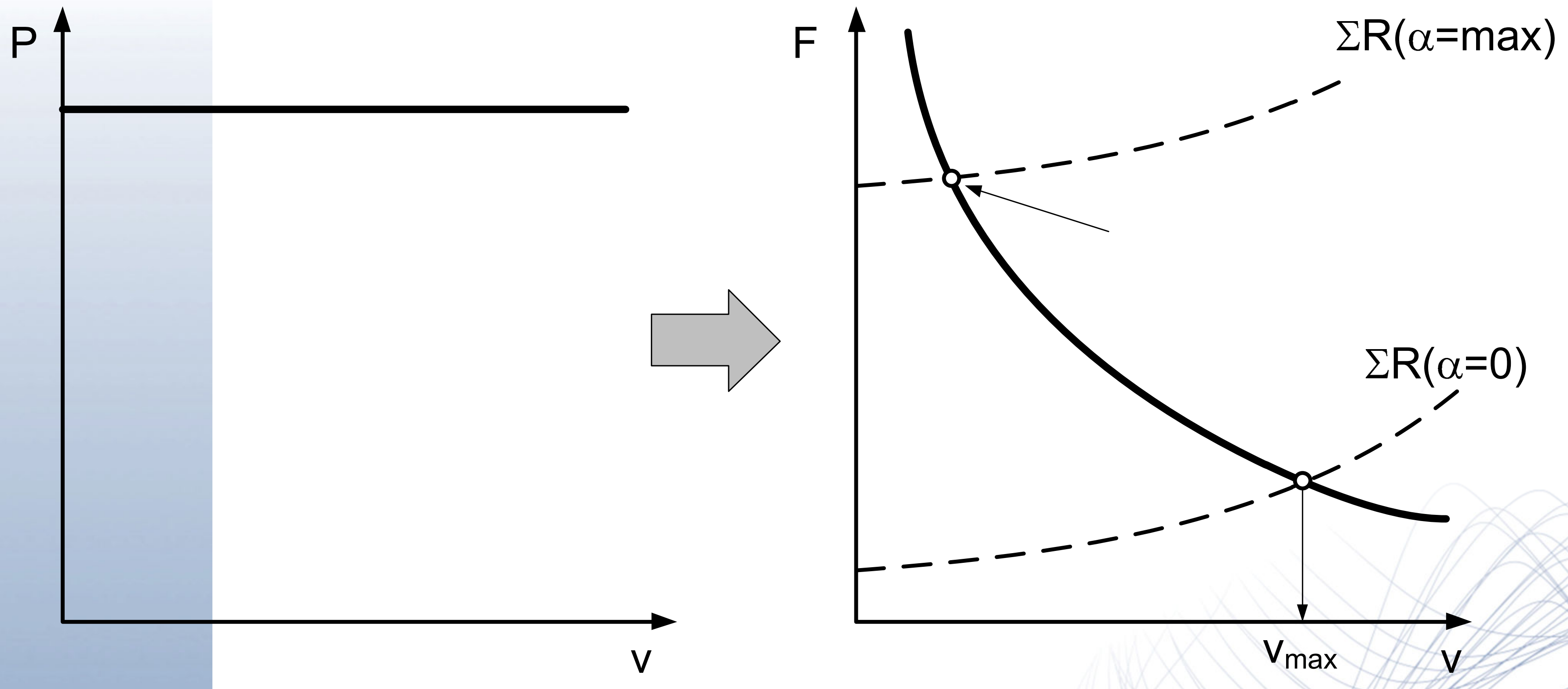
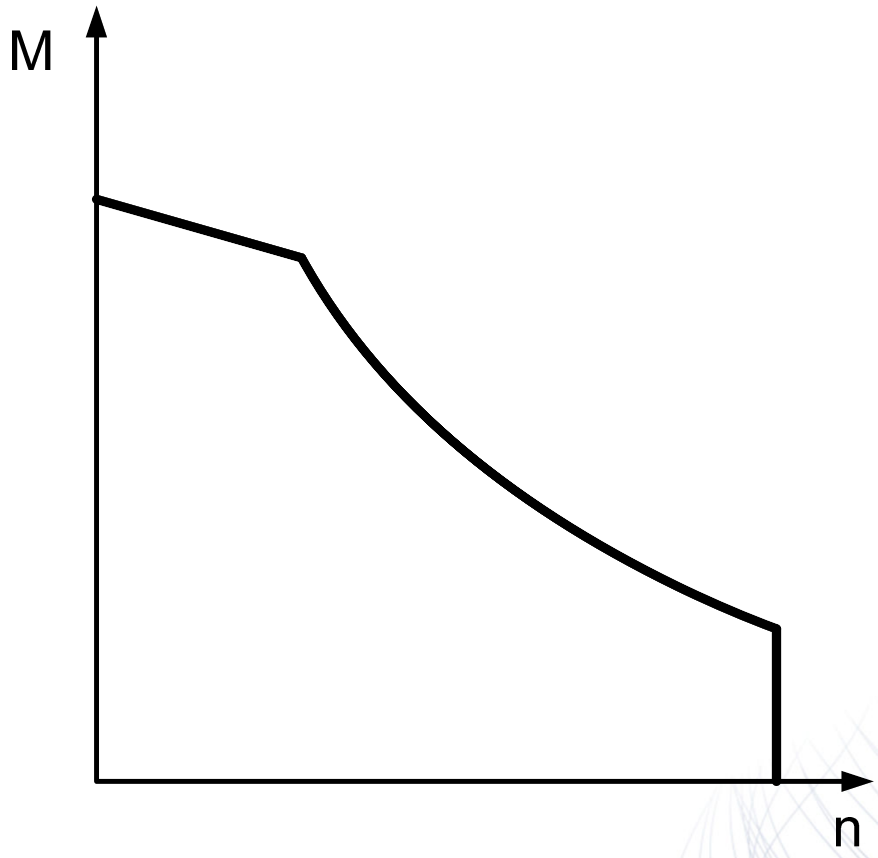


Karakteristika elektromotorja / *Characteristics of an electric motor*



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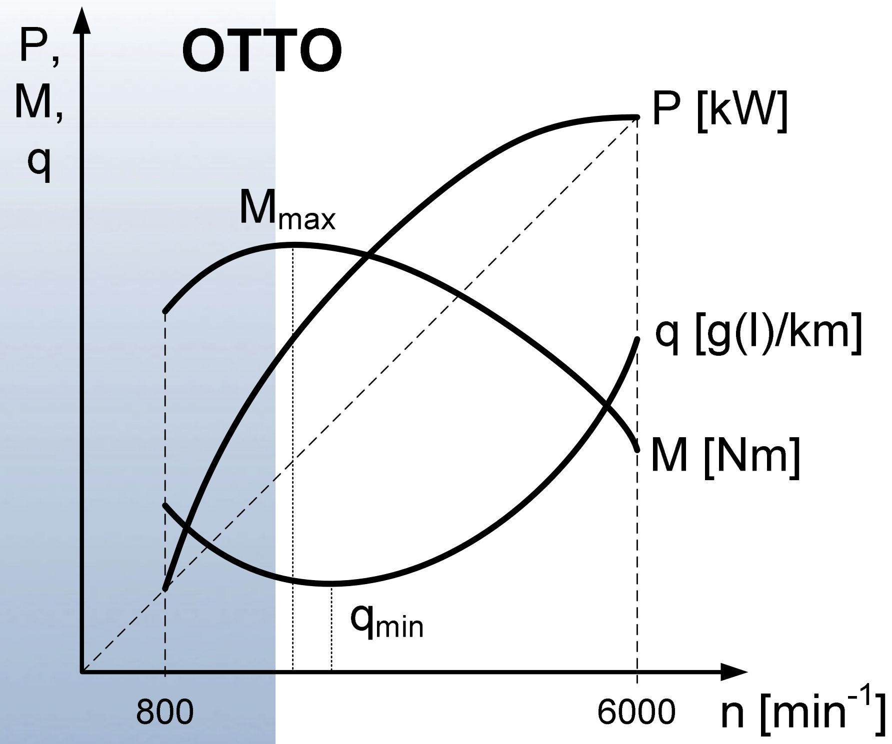
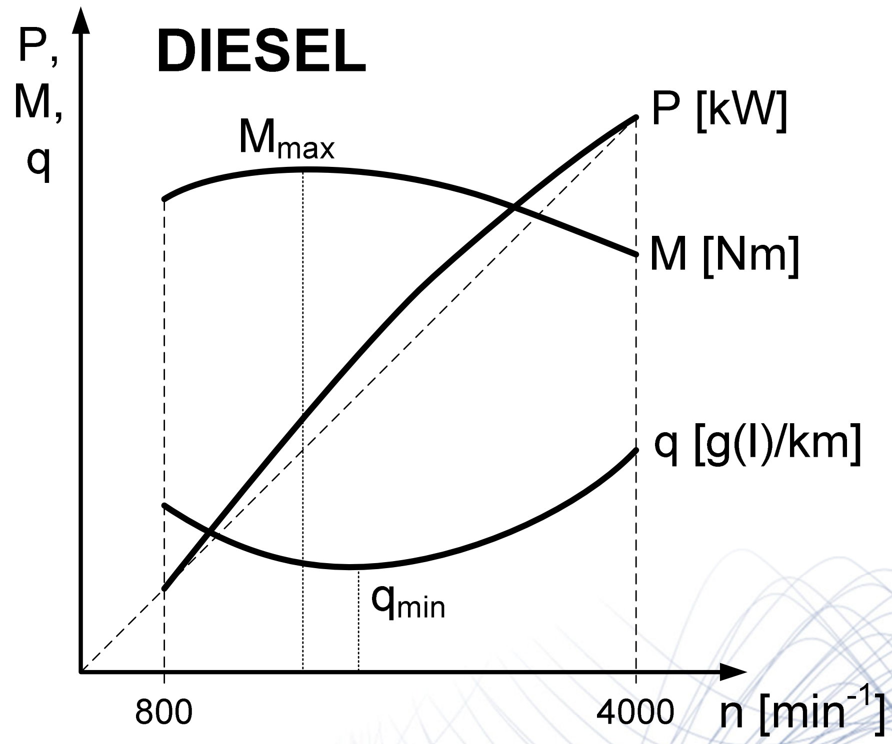
Karakteristika motorjev z notranjim zgorevanjem / *ICE characteristics*



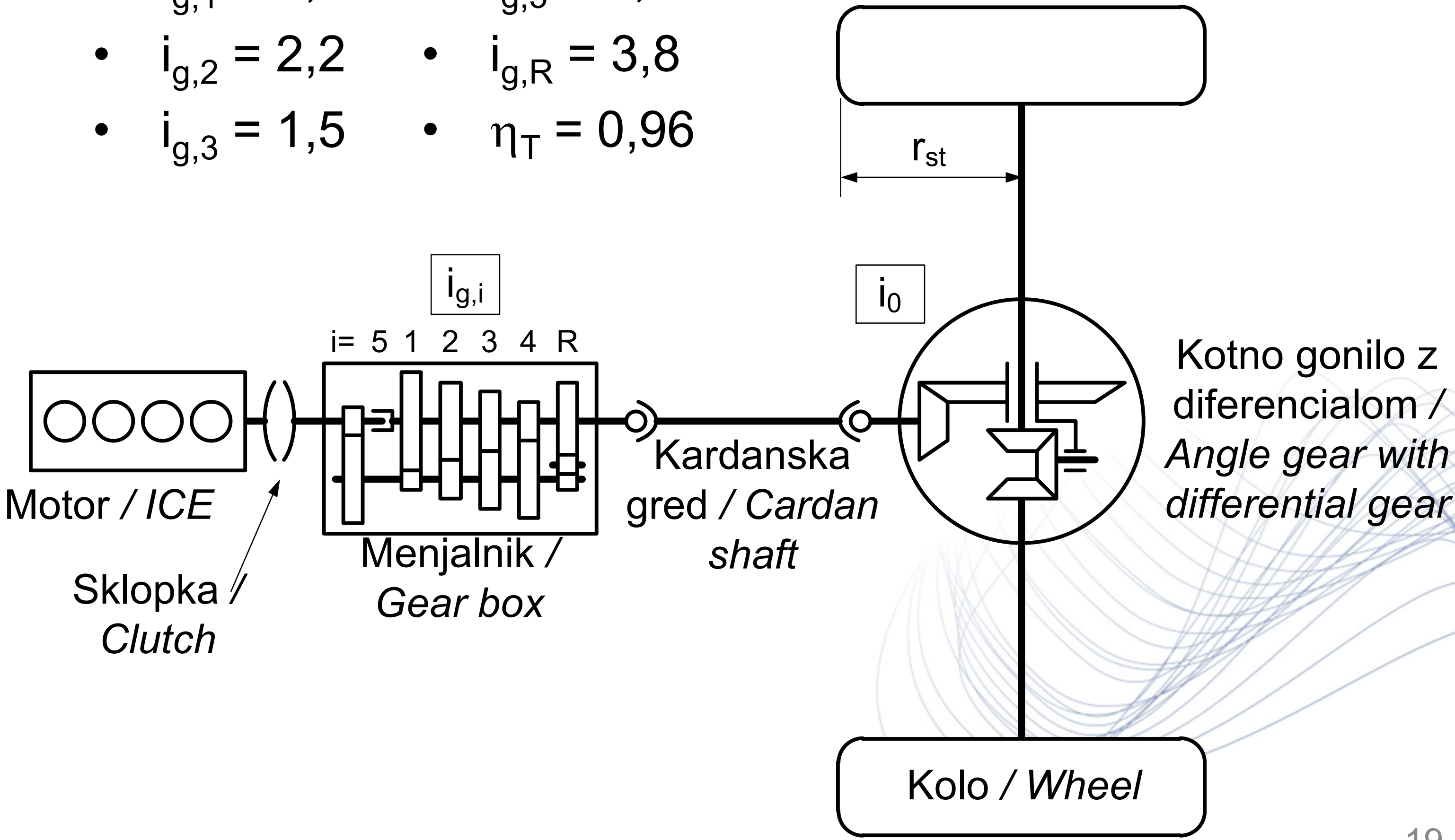


Mehanska transmisija z več prestavami / *Multiple gear mechanical transmission*

Tipična prestavna razmerja / *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
- η_T = 0,96

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



Elastičnost motorja in vpliv prestavnih razmerij / *ICE elasticity and gear influence*

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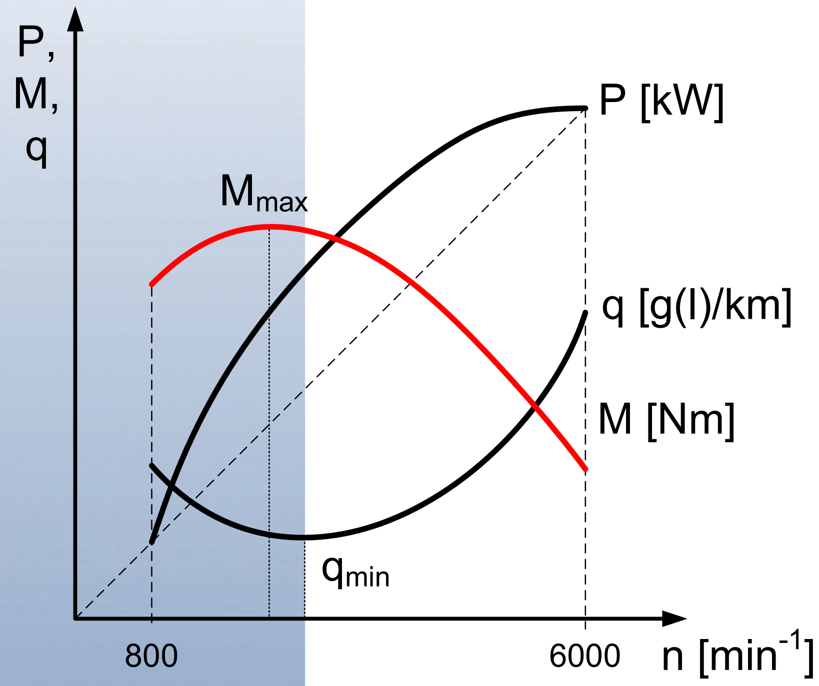

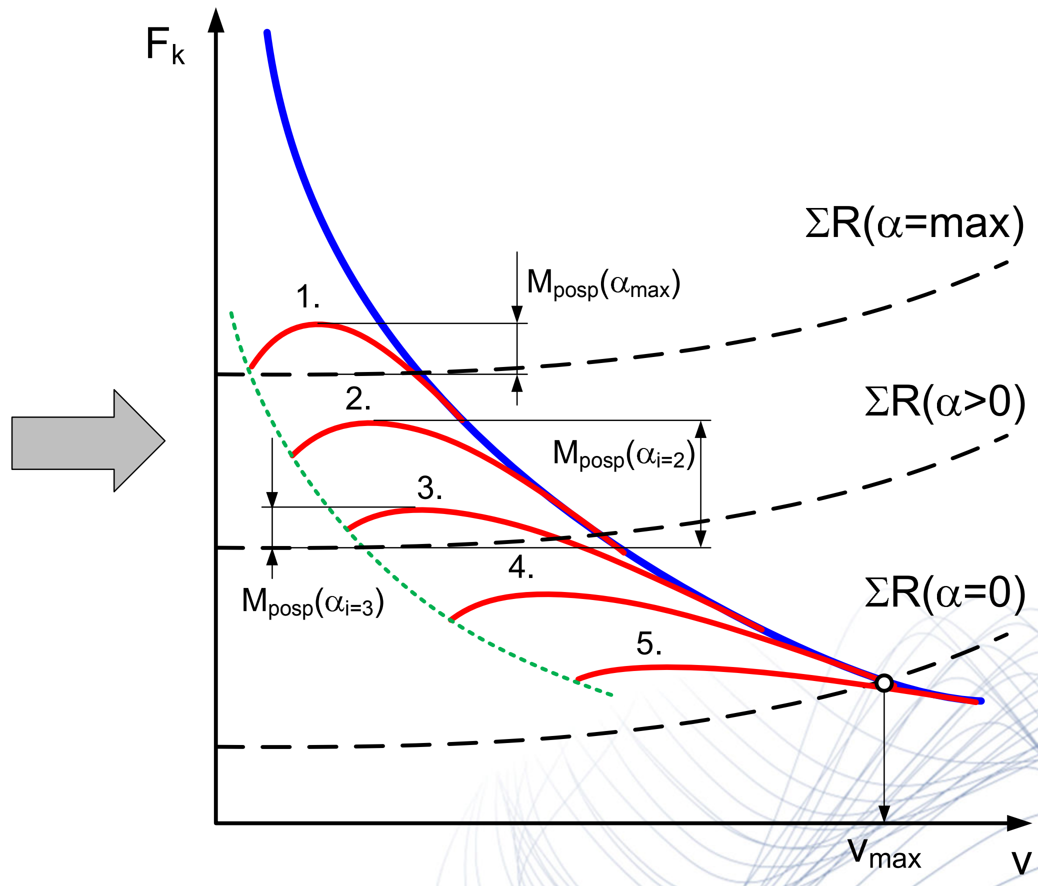

Elastičnost motorja in vpliv prestavnih razmerij / *ICE elasticity and gear influence*

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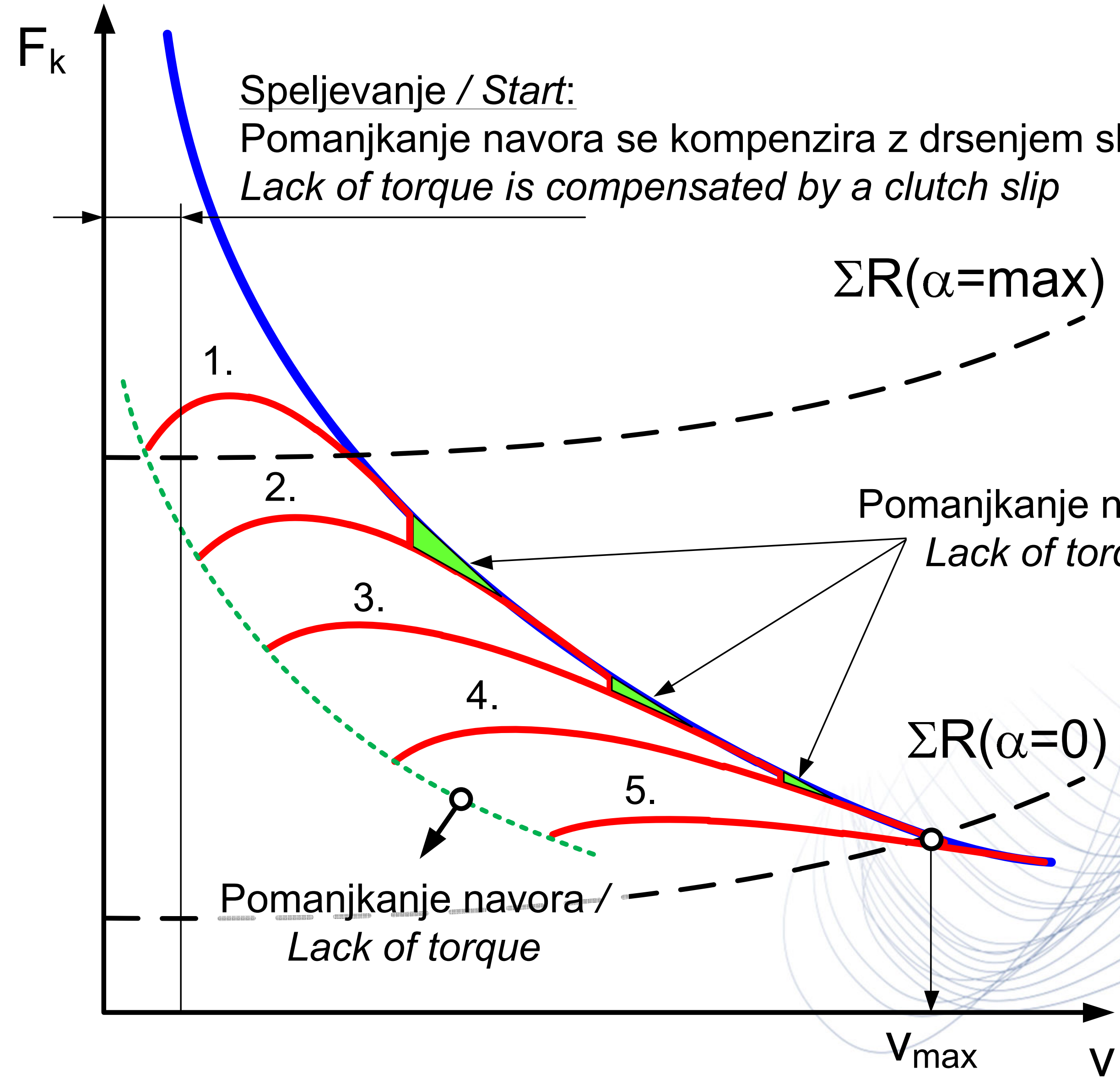


Dinamični faktor vozila / *Dynamic coefficient of a vehicle*

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

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

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

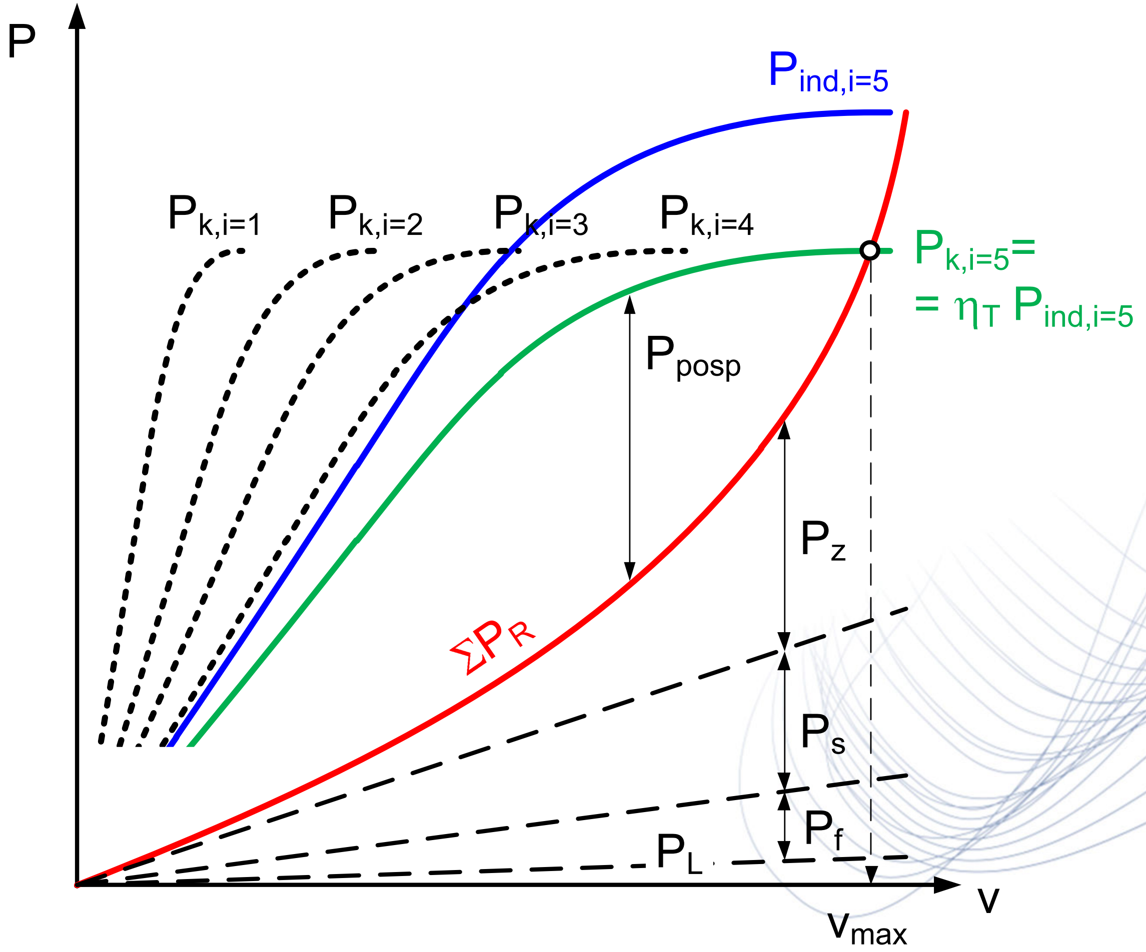
Dinamični faktor *D* je razpoložljiva specifična sila glede na težo vozila, ki je na voljo za pospeševanje vozila in premagovanje uporov v ležajih, kotalnih uporov ter uporov strmine.

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.*

Bilanca moči vozila / *Vehicle power balance*

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

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

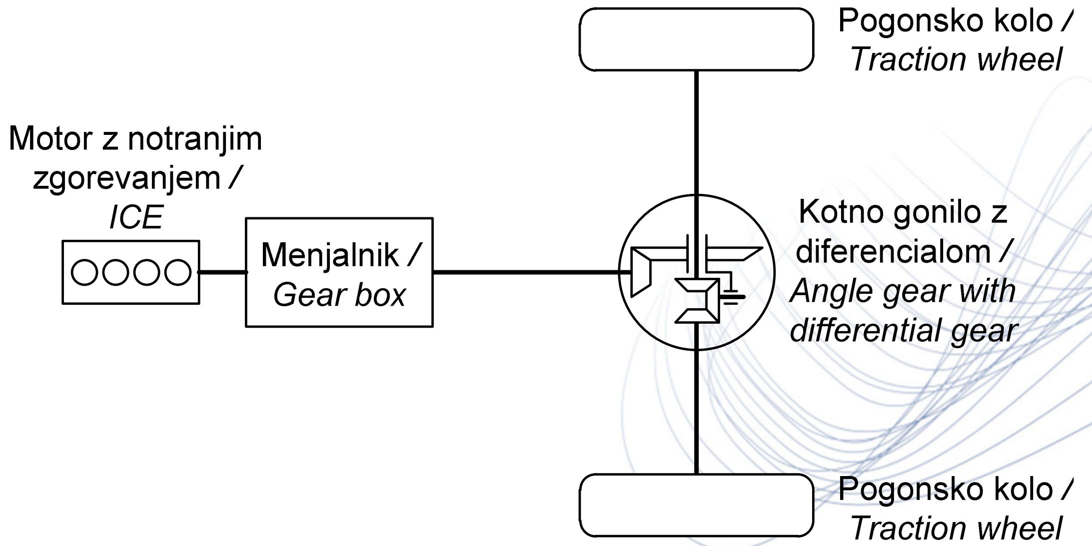


Hibridna vozila / *Hybrid vehicles (HV)*

DEFINICIJA HV: Hibridno cestno vozilo je tisto, pri katerem je energija za pogon na voljo iz dveh ali več vrst energije ali načinov shranjevanja energije ali pretvornikov energije [1].

DEFINITION of a HV: 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].

Shema konvencionalnega vozila z notranjim zgorevanjem /
A scheme of a conventional vehicle with the ICE:



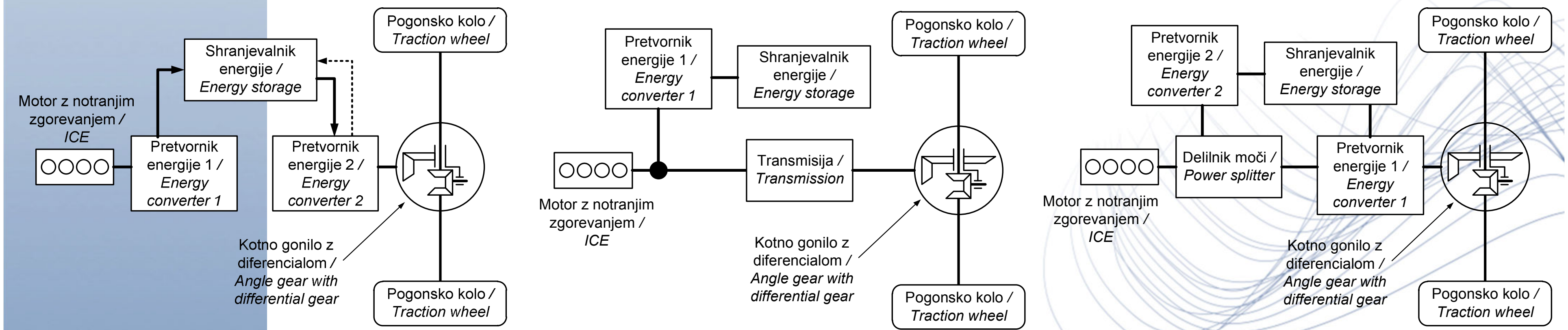
Hibridna vozila / *Hybrid vehicles (HV)*

Sestav hibridnega pogona:

- Motor z notranjim zgorevanjem;
- Pretvornik in/ali hranilnik energije;
- Delilnik moči (planetno ali CVT/RVT gonilo), odvisen od tipa HV (zaporedni, vzporedni ali kombinirani hibrid).

Assembly of a hybrid drive:

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



Sheme treh tipov HV (levo - zaporedni hibrid, sredina – vzporedni hibrid, desno– skombinirani hibrid) / Schemes of three HV types (left - serial hybrid, middle – parallel hybrid, right – combined hybrid)

Tipi HV / *HV types*

- Hibridna električna vozila (HEV)
  - Shranjevanje električne energije v baterijah.
  - Elektromotor za podporo ali nadomestek pogona.
- Hibridna hidravlična vozila (HHV)
  - Hidro-pnevmatski akumulatorji shranjujejo iz- in vračajo energijo v transmisijo(e).

- *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.*

Tipi HV / *HV types*

- Mehanska hibridna vozila (MHV)
  - Uporaba vztrajnikov za shranjevanje energije.
- Elektro-mehanska hibridna vozila (EMHV):
  - Uporaba elektro-motorja/generatorja in elektro-mehanskega vztrajnika.

- *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.*

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Hibridno električno vozilo / *Hybrid electric vehicle (HEV)*

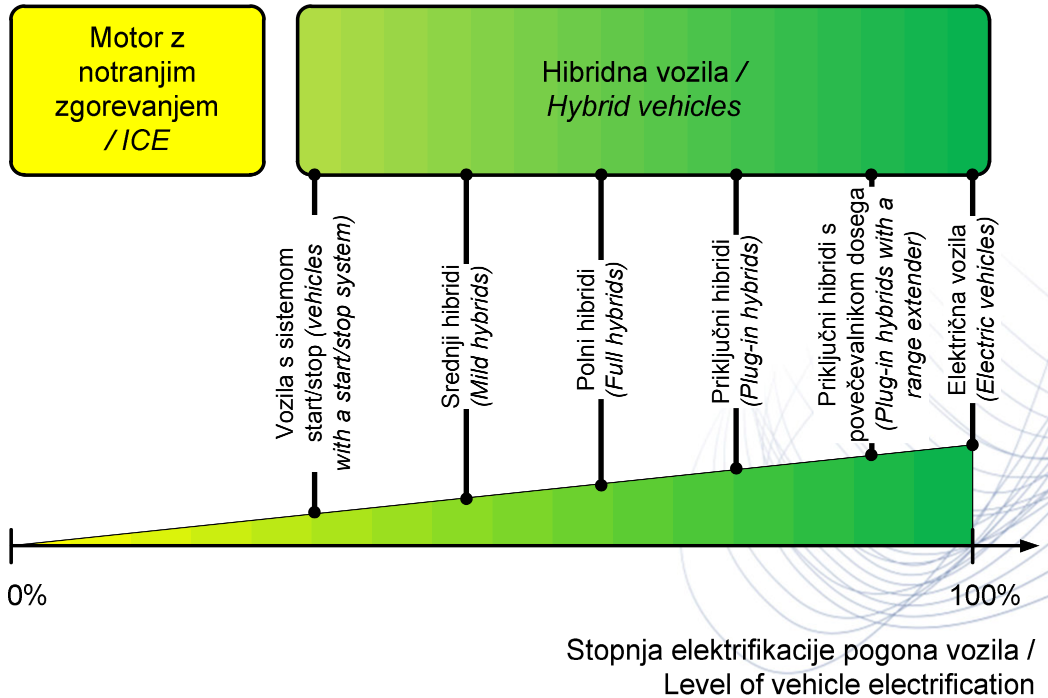
- Kombinacija pogonske moči iz motorja z notranjim zgorevanjem in električne energije iz baterije.
- Elektromotor podpira ali zamenjuje motor z notranjim zgorevanjem.
- Izkoristek vpliva na ekonomičnost porabe goriva in hkrati zmanjšuje onesnaževanje ozračja.
- Ekonomičnost porabe goriva in zmogljivosti vozila so močno odvisne od mase vozila.

- *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.*

Hibridno električno vozilo / *Hybrid electric vehicle (HEV)*

- Pomanjkanje kapacitete za shranjevanje energije zmanjšuje doseg in uporabnost električnih vozil.
- Stopnje elektrifikacije električnih vozil so prikazane spodaj:

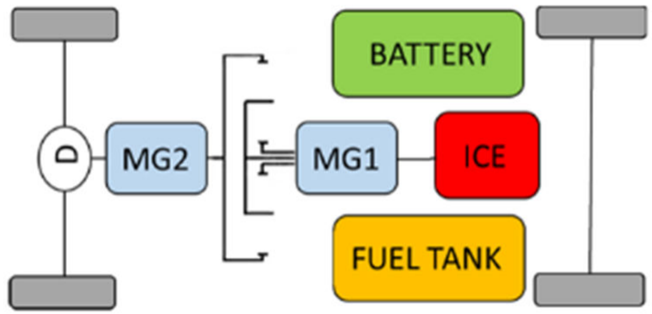
- *A lack of charge storage in batteries significantly reduces the range apllicability of the electric vehicles.*
- *A vehicle-electrification levels are as follows:*



Hibridno električno vozilo / *Hybrid electric vehicle (HEV)*

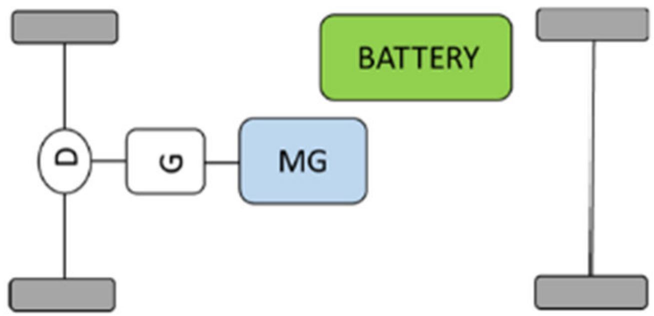
Primer (priključnega) vzporednega hibridnega pogona [1]:

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



Primer popolnoma električnega vozila [1]:

An example of a full electric vehicle [1]:



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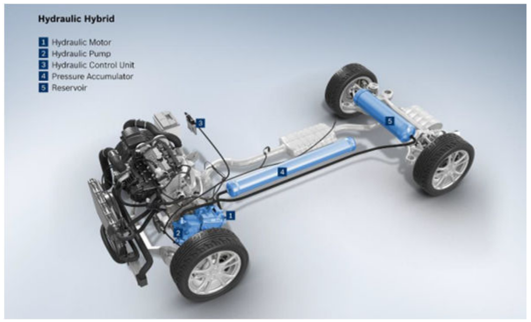
Hibridno hidravlično vozilo / *Hybrid hydraulic vehicle (HHV)*

- Kinetična energija se med zaviranjem shranjuje v hidro-pnevmatske akumulatorje. Med pospeševanjem se v transmisijo vrača energija zmanjšana za izgube zaradi polnitve, shranjevanja in izpraznitve akumulatorjev.
- Hibridna hidravlična vozila (HHV) so zasnovana v zaporedni (S-HHV) in vzporedni konfiguraciji (P-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).*



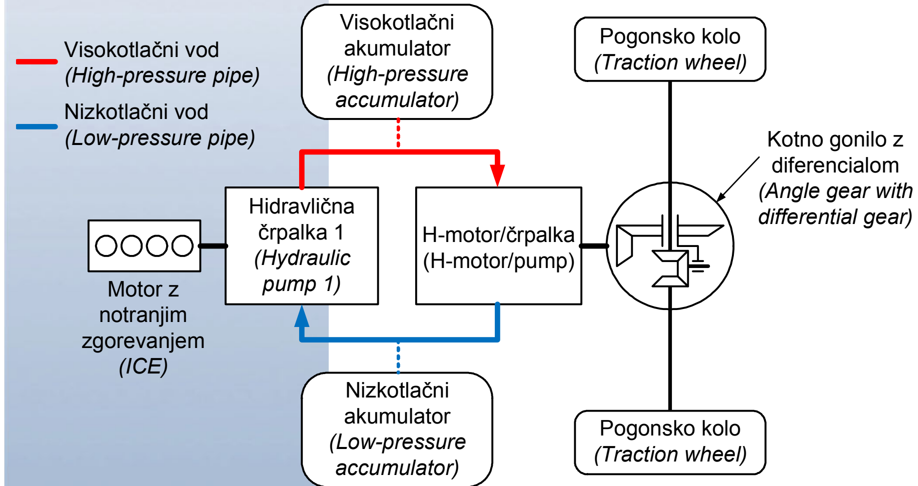
Plinski (N_2) in hidravlični fluidni sistem proizvajalca Bosch / Gas (N_2) and hydraulic fluid system of a manufacturer Bosch [2]

Zaporedni hidravlični hibrid / *Serial hydraulic hybrid (S-HHV)*

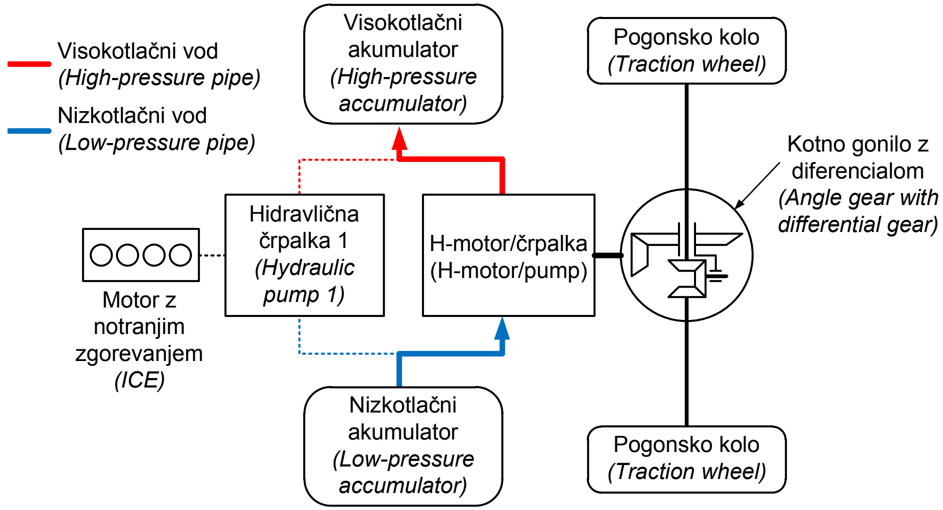
- Motor ni direktno priključen na kolesa.
- Hidravlična črpalka/motor v motorskem načinu delovanja uporablja visokotlačni fluid iz hidravličnega akumulatorja za pogon vozila.
- Trije glavni načini delovanja S-HHV vozila so:
  - zmerno pospeševanje / kratko križarjenje;
  - podaljšano križarjenje / močno pospeševanje;
  - regenerativno zaviranje.

- *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.*

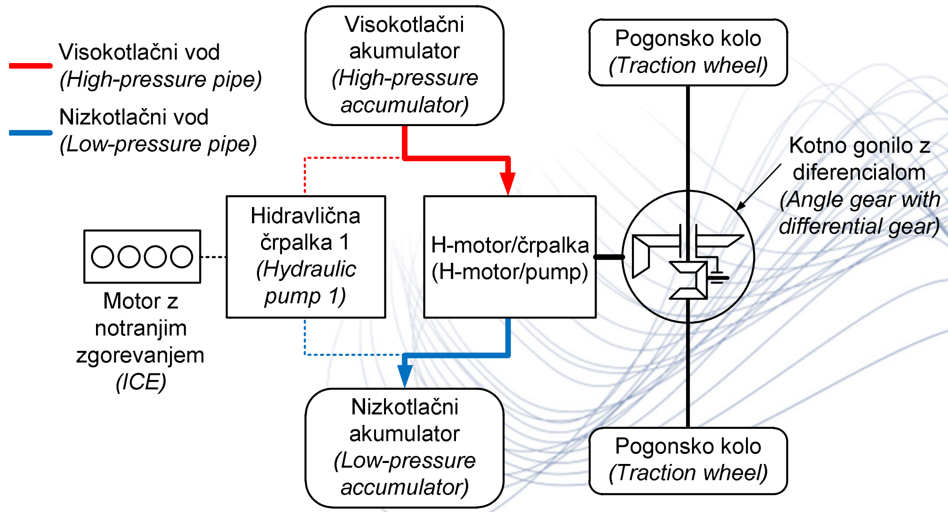
Zaporedni hidravlični hibrid / *Serial hydraulic hybrid (S-HHV)*



Podaljšano križarjenje / močno pospeševanje
Extended cruising / strong acceleration [2]



Regenerativno zaviranje / Regenerative braking [2]



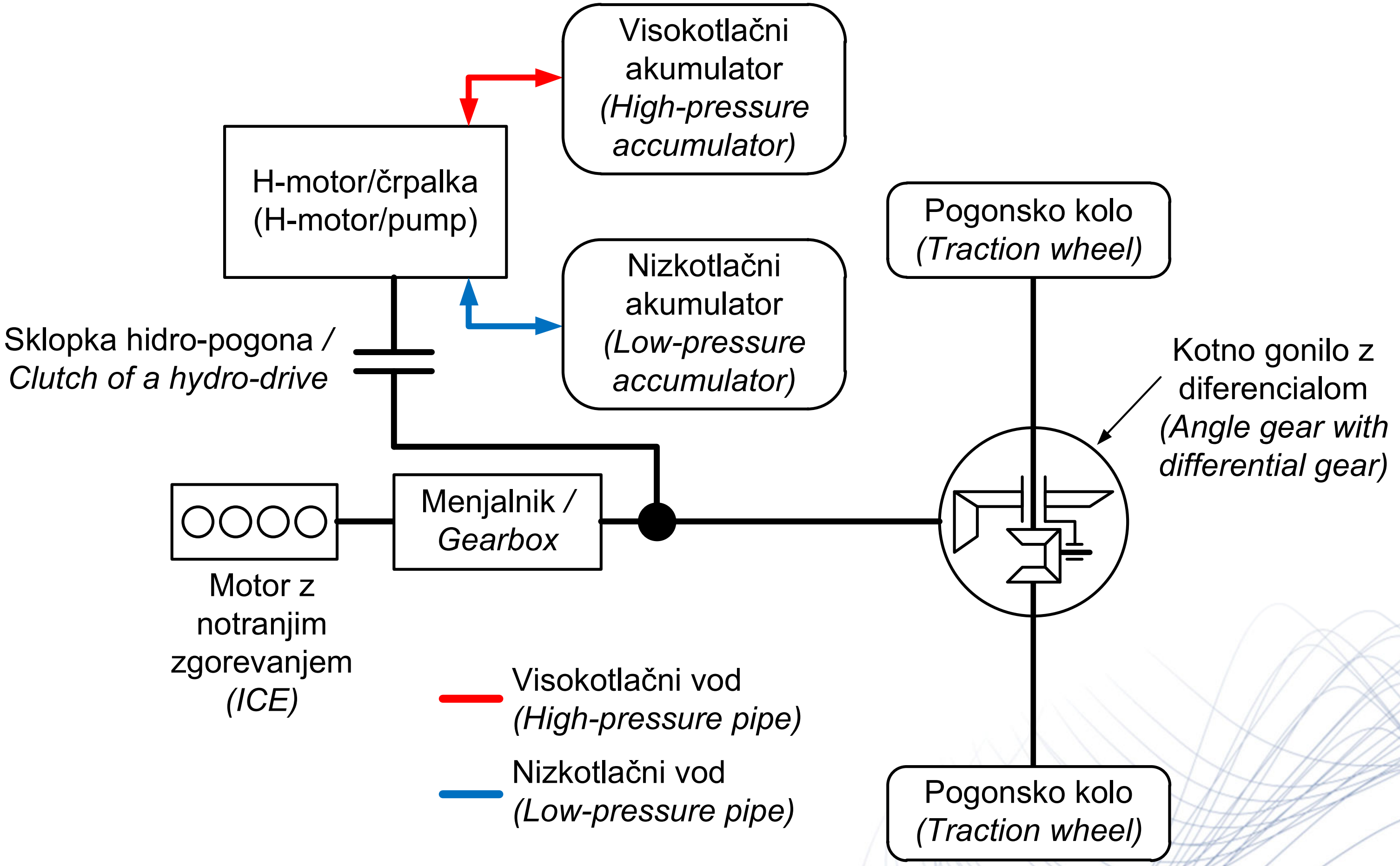
Zmerno pospeševanje / kratko križarjenje
Mild acceleration / short cruising [2]

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

- Motor z notranjim zgorevanjem, standardna transmisija in hidravlična hibridna tehnologija so povezani na pogonsko gred.
- Motor dovaja energijo kolesom preko standardne transmisije.
- Na pogonsko gred povezane hidravlične komponente pomagajo pogonu pri zaustavljanju in pospeševanju.

- *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.*

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



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

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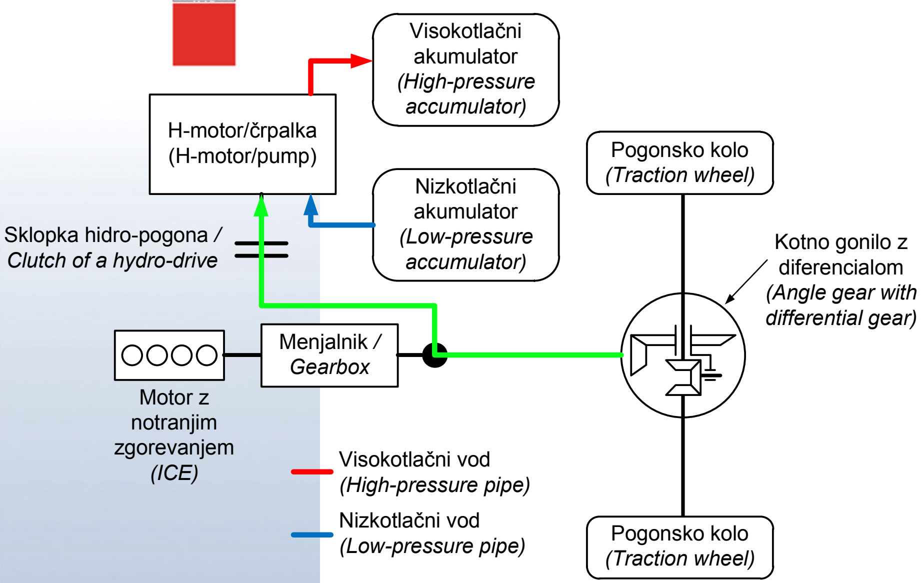
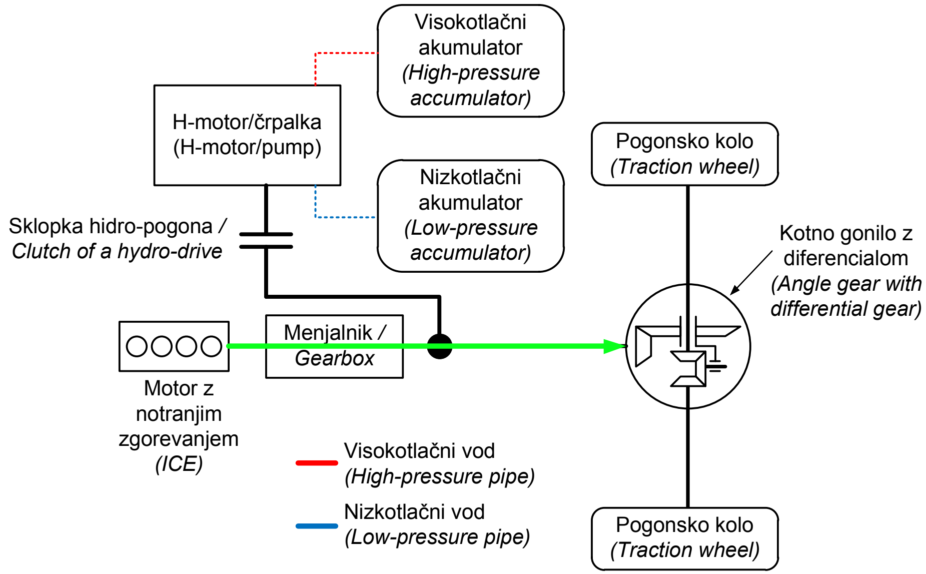
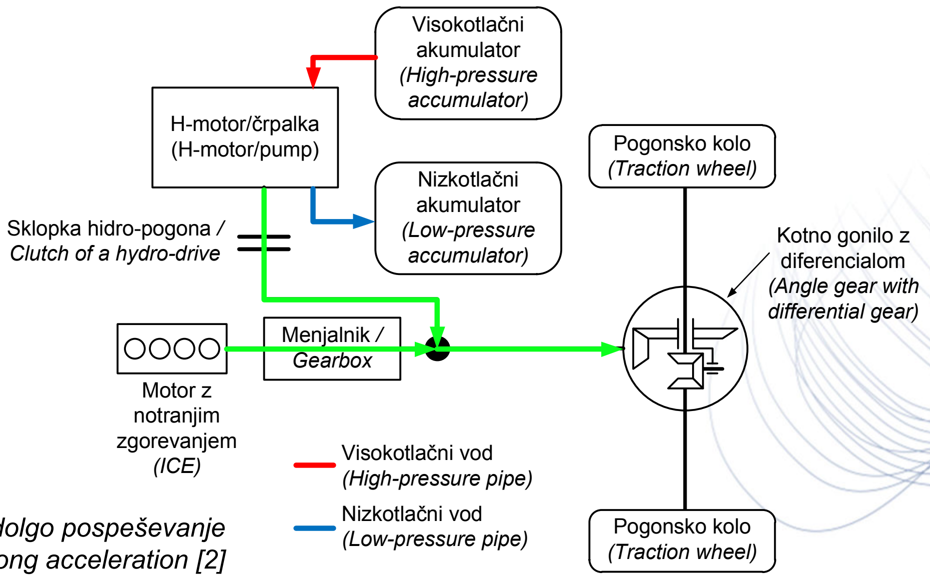


Regenerativno zaviranje
Regenerative braking [2]



Zmerno pospeševanje / križarjenje
Mild acceleration / Cruising [2]



Močno/dolgo pospeševanje
Strong/long acceleration [2]

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Mehansko hibridno vozilo / *Mechanical hybrid vehicle (MHV)*

- Ne uporablja močnostne elektronike in baterij za shranjevanje energije.
- Delujejo na principu shranjevanja kinetične energije vozila med zaviranjem.
- Cilj je ponuditi trgu hibridni pogonski sistem, ki močno zniža porabo goriva ob najnižjih možnih stroških.
- Simulacije pri različnih voznih ciklih obljubljajo prihranke pri porabi goriva med 15% in 25%.

- *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 lovering fuel consuption at lowest possible cost.*
- *Simulations at different driving cycles show a reduction in fuel consuption between 15% and 25%.*

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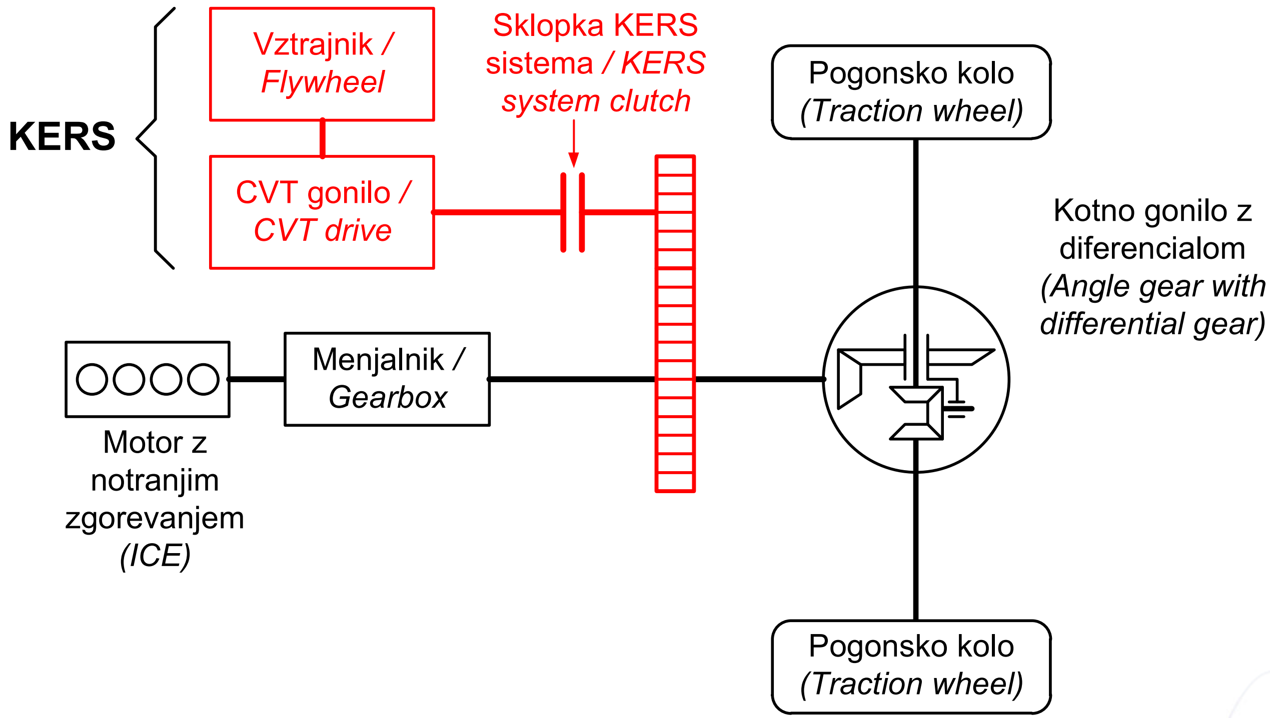
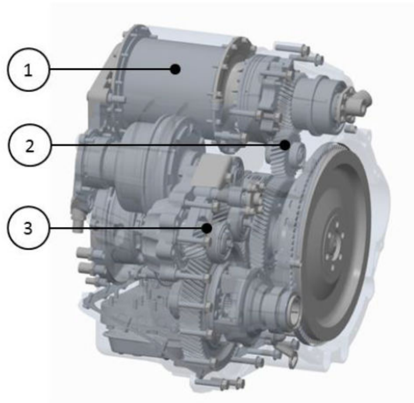
Mehansko hibridno vozilo /
Mechanical hybrid vehicle (MHV)





Main mechanical changes over standard CVT:

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

3D model mehanskega hibrida z vztrajnikom
3D model of the KERS [3]

Elektro-mehansko hibridno vozilo / *Electro-mechanic hybrid vehicle (EMHV)*

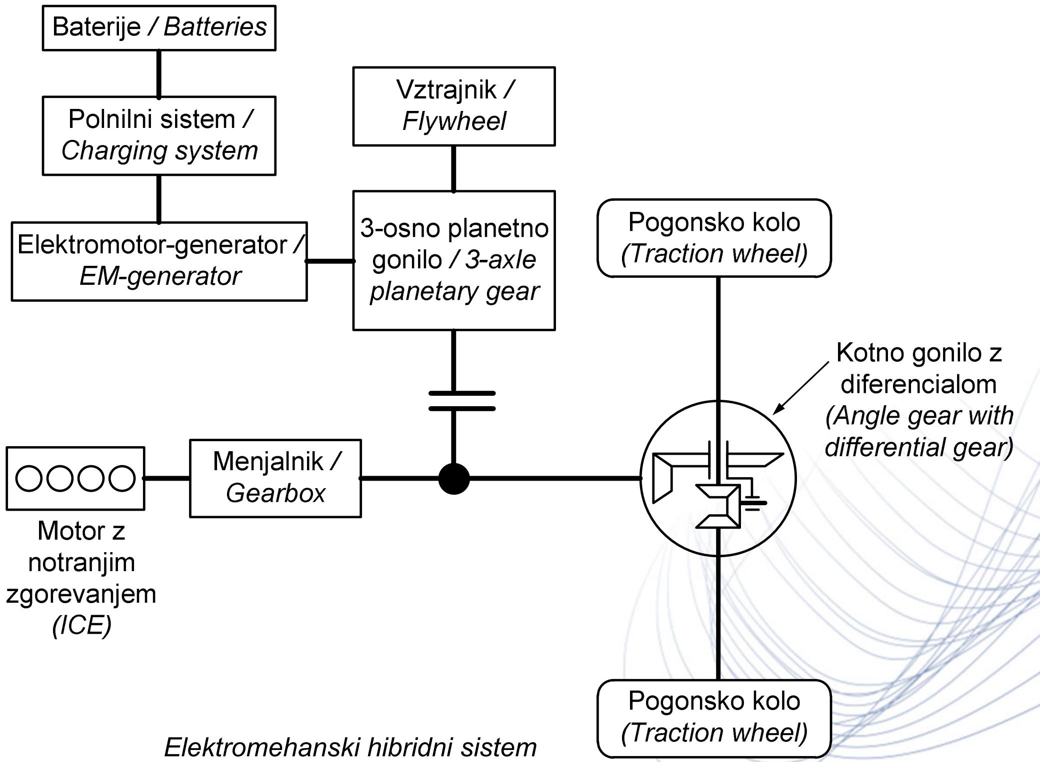
- Stroškovno učinkovit hibrid na temelju 48 V tehnologije, ki je lahko prilagodljivo vgrajen na sprednjo ali zadnjo premo obstoječih platform vozil.
- Planetno gonilo in električni sistem skupaj delujeta kot gonilo z zvezno spremenljivim prestavnim razmerjem med vztrajnikom in preostalo transmisijo vozila.
- Vztrajnik se uporablja za povečanje učinka elektromotorja.

- *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 en electric system are joint into a continously variable transmission gear between the flywheel and the rest of the vehicle's powertrain.*
- *Flywheel is applied to boost performance of the electric motor.*

Elektro-mehansko hibridno vozilo (EMHV)

- Vztrajnik lahko poveča vršno moč skupnega sistema do petkratnika nazivne moči elektromotorja.

- *Flywheel can boost peak power of a combined sistem five-folds of the electric-motor power.*



Elektromehanski hibridni sistem
FE-KERS hybrid system [4]

Transmisija in delilniki moči

- V transmisiji hibridnega vozila se kombinirata in navor in moč iz motorja z notranjim zgorevanjem ter pretvornika energije/shranje-valnika energije.
- Glavni razlog za izgube v transmisiji in povečane porabe goriva predstavlja trenje v transmisiji.
- Gonila z zvezno spreme-nljivimi prestavnimi razmerji predstavljajo eno izmed okoljsko učinkovitih tehnologij za zmanjšanje porabe goriva v konvencionalnih vozilih.

- *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 consuption is a friction in powertrain elements.*
- *Continously-variable transmision elements are one of the most effective and environmentally friendly technologies for reduction of the fuel consumption in conventional vehicles.*

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Transmisija in delilniki moči

- Uporabljeni tipi transmisijskih elementov:
  - Planetna gonila.
  - Gonila z zvezno spremenljivimi prestavnimi razmerji (CVT).
  - Reverzibilna gonila z zvezno spremenljivimi prestavnimi razmerji (RVT).
  - Sklopke na osnovi magnetno-reoloških fluidov.

- *Applied transmission elements:*
  - *Planetary gears.*
  - *Continuously-variable transmission elements (CVT).*
  - *Reversible transmission elements with continuously variable transmission ratios (RVT).*
  - *Clutch elements using magneto-rheologic fluid.*

Sklopka z magnetno-reološkim fluidom / *Clutch with magneto-rheologic fluid (MRF)*

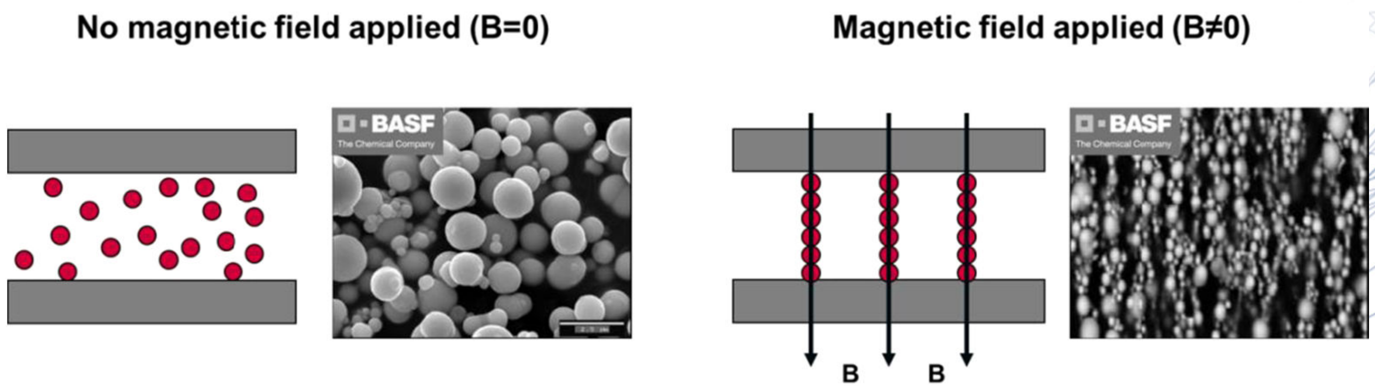
- Magnetno-reološki fluidi (MRF) so t.i. „pametni fluidi“, katerim se značilno spremeni viskoznost v prisotnosti zunanjega magnetnega polja.
- Ta učinek se doseže s suspenzijo mikro-metrskih sferičnih magnetnih delcev (carbonyl-železni prah s premerom 5-10 μm) v nosilnem fluidu, ki je navadno olje.

- *Magneto-rheologic 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.*

Sklopka z magnetno-reološkim fluidom / *Clutch with magneto-rheologic fluid (MRF)*

- Pod vplivom magnetnega polja se ti delci formirajo v verige v smeri delovanja magnetnega polja. S tem se spremeni strižna meja tečenja MRF fluida v odvisnosti od gostote magnetnega toka.

- *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.*



Shema MRF fluida ob odsotnosti (levo) in prisotnosti (desno) magnetnega polja
A scheme of the MRF fluid in the absence (left) and action (right) of the magnetic field [5]

Sklopka z magnetno-reološkim fluidom / *Clutch with magneto-rheologic fluid (MRF)*

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- MRF fluidi so primerni za uporabo v mehanskih sistemih, kot so zavore in sklopke, kjer mora biti gneneriran/prenesen navor zvezno nastavljiv.
- Dissipirana energija in vršna termična obremenitev v MRF fluidu sta manj pomembni, kakor v primeru klasičnih tornih drsnih sistemov (zavora, sklopka) zaradi večjega volumna toplotno obremenjenega materiala (MRF fluid namesto trde tanke kontaktne površine).

- *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).*

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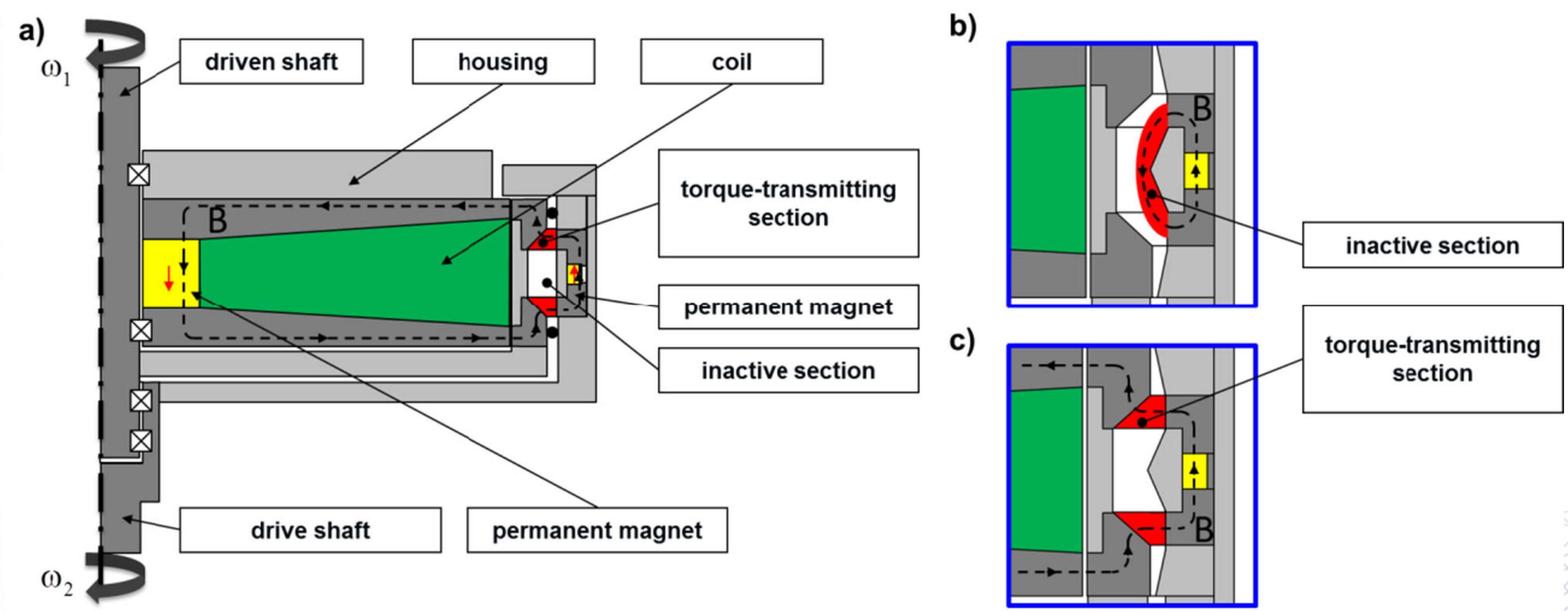
Sklopka z magnetno-reološkim fluidom / *Clutch with magneto-rheologic fluid (MRF)*



Sklopka na osnovi MRF fluida
Clutch with magneto-rheologic fluid [5]

Novi evropski vozni cikel / *New European Driving Cycle (NEDC)*

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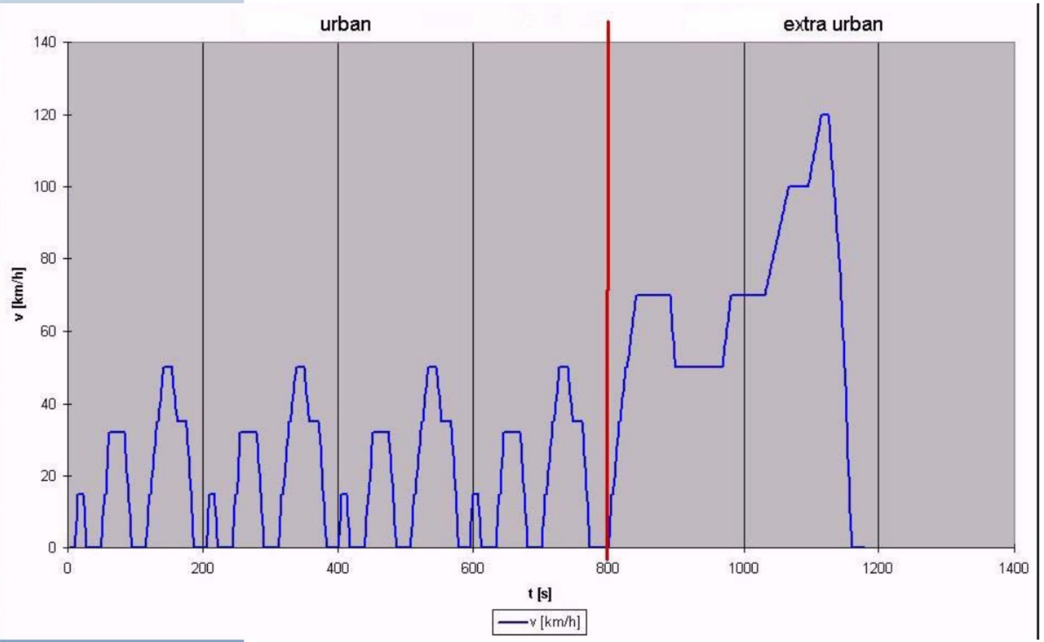
- NEDC je osnova za homologacijo vozil
- Izpusti vozil se merijo med NEDC po direktivi 98/69/EC
- NEDC je sestavljen iz dveh delov: urbana in izven-urbana vožnja.



- *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.*

Novi evropski vozni cikel / *New European Driving Cycle (NEDC)*

- Obstajata dva različna NEDC preskusa.
- NEDC hladni preskus, ki se ga uporablja za ovrednotenje:
  - Izpustov polutantov;
  - CO_2 izpustov;
  - Porabe goriva;
  - Temperatura motorja pred zagonom mora biti 22°C±2°C. Čas zaustavitve motorja za ta preskus mora biti najmanj 6 ur in naveč 30 ur. Ta preskus se uporablja za kontrolo stanja vozila.

- *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.*

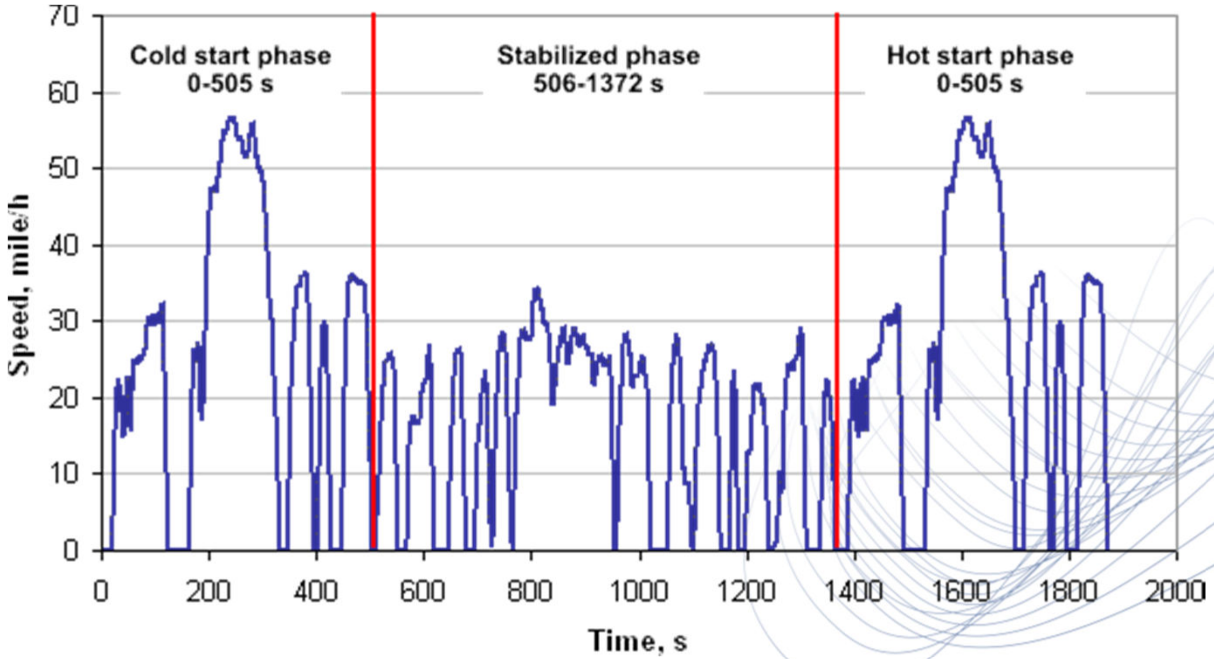
Novi evropski vozni cikel / *New European Driving Cycle (NEDC)*

- <u>NEDC topli preskus</u>, ki se ga uporablja za ovrednotenje:
  - CO_2 izpustov
  - Porabe goriva
  - Temperatura olja v vozilu pred zagonom mora biti približno 90°C. Ta preskus se uporablja za replikacijo uporabnikovih navad.

- *<u>NEDC warm test</u> 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.*

Testni cikel ZDA / *Testing cycle of USA: US FTP-75*

- Testni cikel FTP-75 se uporablja za certificiranje emisij in preskus ekonomičnosti lahkih vozil v ZDA.
- *Testing cycle FTP-75 (Federal Test Procedure) is applied for cerfication of emissions and economy testing of light vehicles in USA.*



Testni cikel ZDA / *Testing cycle of USA: US FTP-75*

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- Celoten FTP-75 cikel je sestavljen iz naslednjih segmentov [12]:
  - Tranzientna faza hladnega zagona (temp. 20-30° C), 0-505 s;
  - Stabilizirana faza, 506-1372 s;
  - Topla zaustavitev (min. 540 s, max. 660 s);
  - Tranzientna faza toplega zagona, 0-505 s;
  - Prepotovana razdalja: 11.04 milj (17.77 km);
  - Povprečna hitrost: 21.2 mph (34.1 km/h);
  - Trajanje: 1874s.

- *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 milj (17.77 km);*
  - *Average velocity: 21.2 mph (34.1 km/h);*
  - *Duration: 1874s.*

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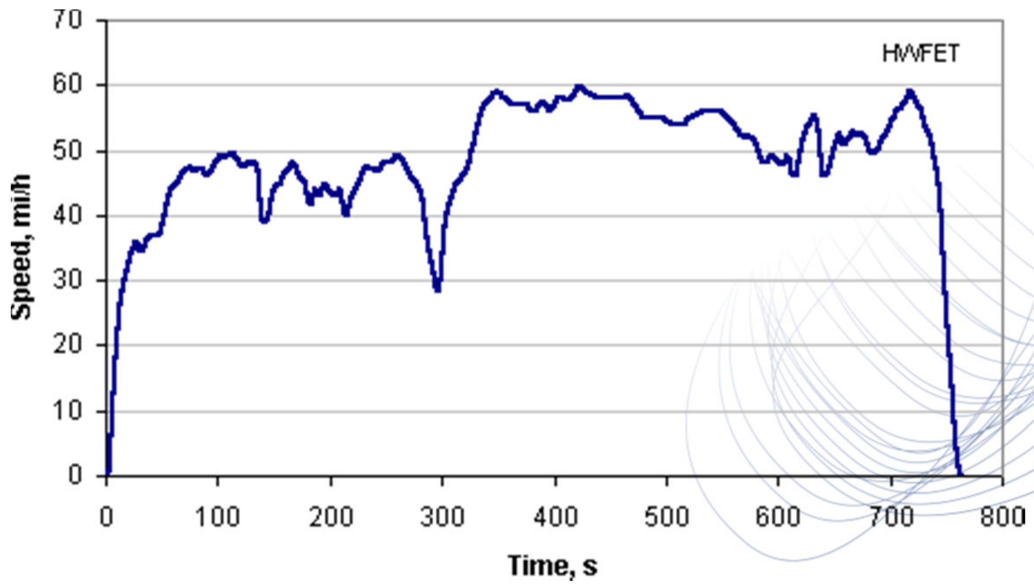
Testni cikel ZDA / *Testing cycle of USA: US HWFET*

- Testni cikel HWFET predstavlja urnik vožnje, ki ga je razvila organizacija US EPA za determiniranje ekonomičnosti lahkih vozil [40 CFR part 600, subpart B].

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



Testni cikel ZDA / *Testing cycle of USA: US HWFET*

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- Testni cikel HWFET se uporablja za razvrščanje vozil glede ekonomičnosti vožnje na avtocesti.
- Testni parametri cikla so naslednji:
  - Trajanje: 765 s;
  - Prepotovana razdalja: 10.26 milj (16.45 km);
  - Povprečna hitrost: 48.3 mph (77.7 km/h).

- *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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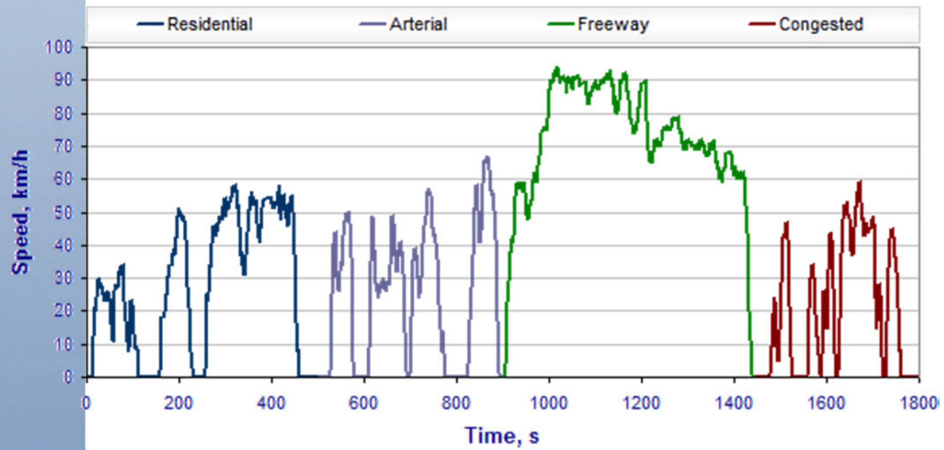
Avstralski testni cikel / *Australian testing cycle: AUDC*

- Testna cikla AUDC in CUEDC sta bila razvita za lahka bencinska vozila.
- Testni cikel CUEDC predstavlja realno avstralsko vožnjo v urbanem okolju. Vsebuje štiri segmente: bivalno sosesko, dovodno povezavo, prosto cesto in gnečo.



- *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.*

Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*

- HEV je učinkovito le takrat, ko je shranjena električna energija večja od izgub v električnem sistemu, vključno z električnim motorjem/generatorjem, nadzornim sistemom in baterijo.
- Strategija ravnanja z energijo (SRE) pripomore k optimizaciji HEV.
- SRE je algoritem, ki razčleni pozitivne zahteve po energiji med motor z notranjim zgorevanjem in baterijo, pri največji možni sposobnosti regenerati-vnega zaviranja.

- *HEV is efficient only, if the stored electric energy is larger than the losses in an electric system together with an electric motor/gene-rator, a battery managment system and a battery.*
- *Energy-management strategy (EMS) supports the oprimisation of HEV.*
- *EMS is an algorithm that divides positive requirements on enery between the ICE and battery for the biggest possible regenerative-braking effort.*

Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*

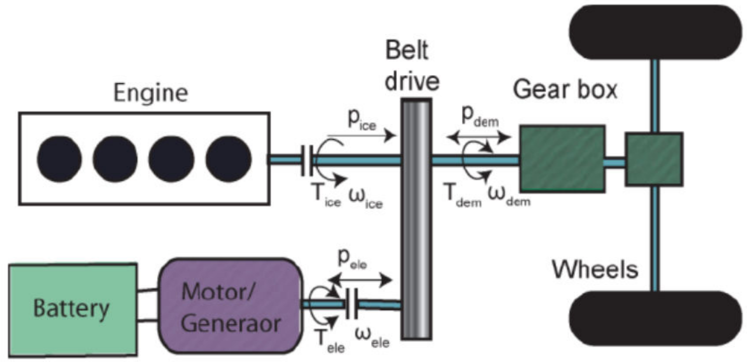
- Ekonomičnost HEV je močno odvisna od uporabljene SRE, kakor tudi od sposobnosti sistema za shranjevanje/vračanje energije.
- Problemi določanja optimalne SRE so bili reševani z različnimi optimizacijskimi algoritmi.

- *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 oprimal-EMS determination were solved with different optimisation algorithms.*

Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*

- Primer 1: vzporedno HEV pri različnih testnih ciklih (US FTP-75, NEDC, AUDC in US HWFET).
- Za določitev optimalne SRE so bile uporabljene naslednje metode: dinamično programiranje (DP), strategija minimizacije ekvivalentne porabe goriva (ECMS) in hevristične metode (HCEMS).

- *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 minimisation strategy (ECMS) and heuristic methods (HCEMS).*

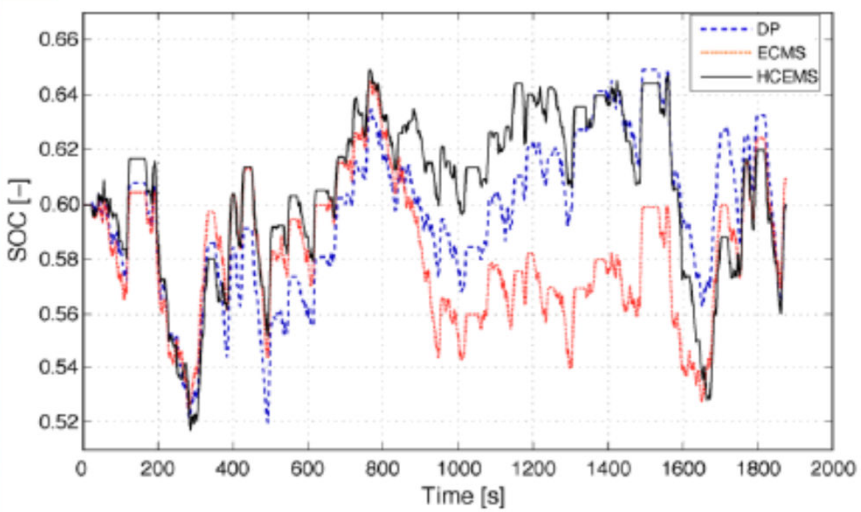


Shema modela vzporednega HEV / A schema of a parallel HEV [13]

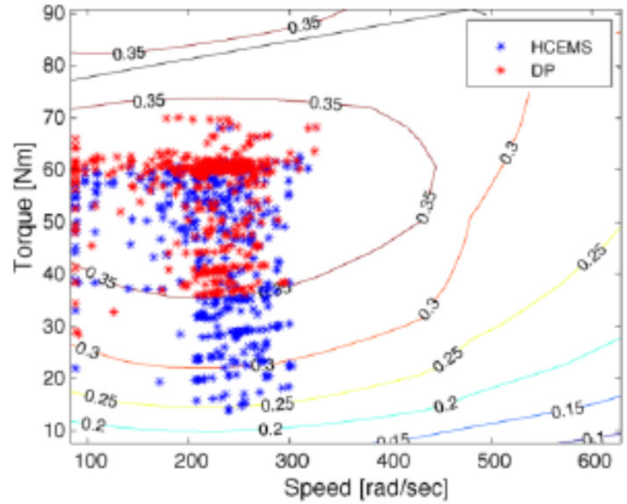
Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*

Poraba goriva (L/100km), deviacija končnega stanja električnega naboja od začetnega (SOC) (%) in računski časi za optimizacijske metode / *Fuel consumption (L/100 km), difference between the starting and final electric charge (SOC) (%) and processing time for different optimisation 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



Variacija SOC / SOC variation [13]



Delovne točke motorja z notranjim zgorevanjem pri metodah HCEMS in DP po US FTP-75 / Operating points of ICE for the HCEMS and DP methods for US FTP-75 [13]

Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*

- Primer 2: končna evalvacija sistema.
- Optimalne SRE po DP, ECMS in HCEMS metodah so bile preskušene na optimiranem modelu paralelnega HEV z upoštevanjem električnih izgub za testne cikle: US FTP-75, NEDC, AUDC in US HWFET [13].

- *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	

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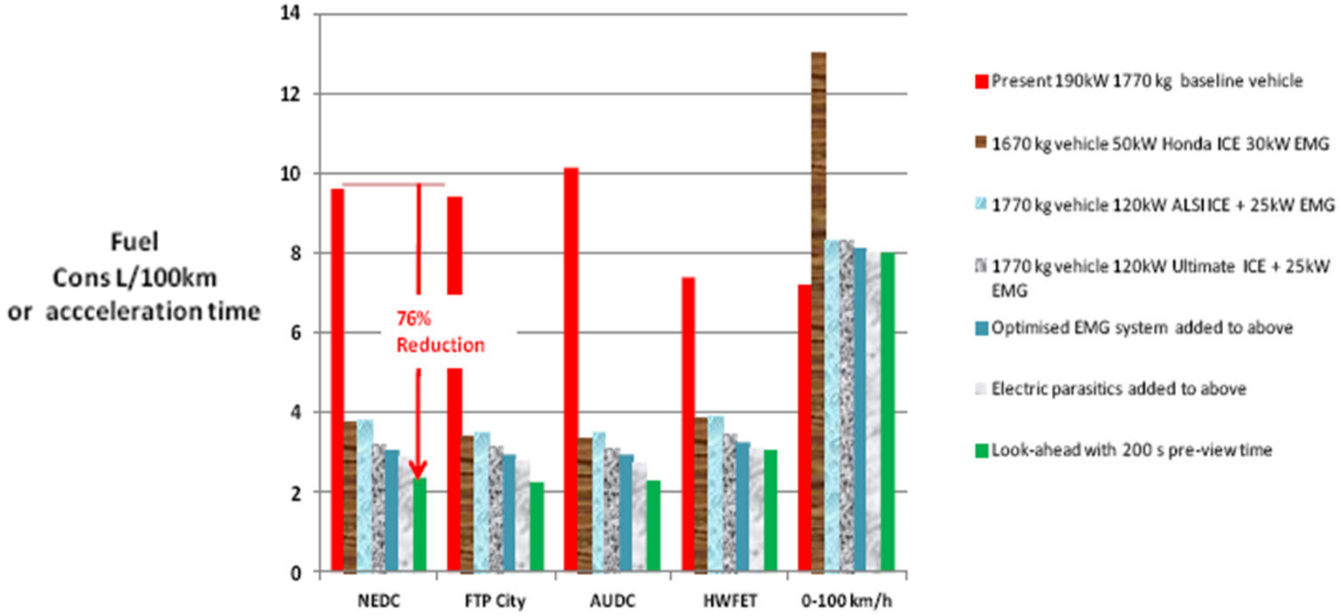
Strategija ravnanja z energijo pri HEV / *Energy-management strategy for HEV*



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