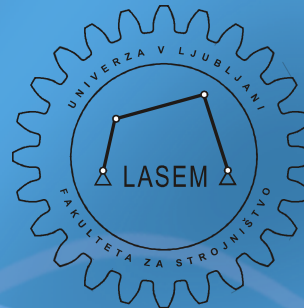


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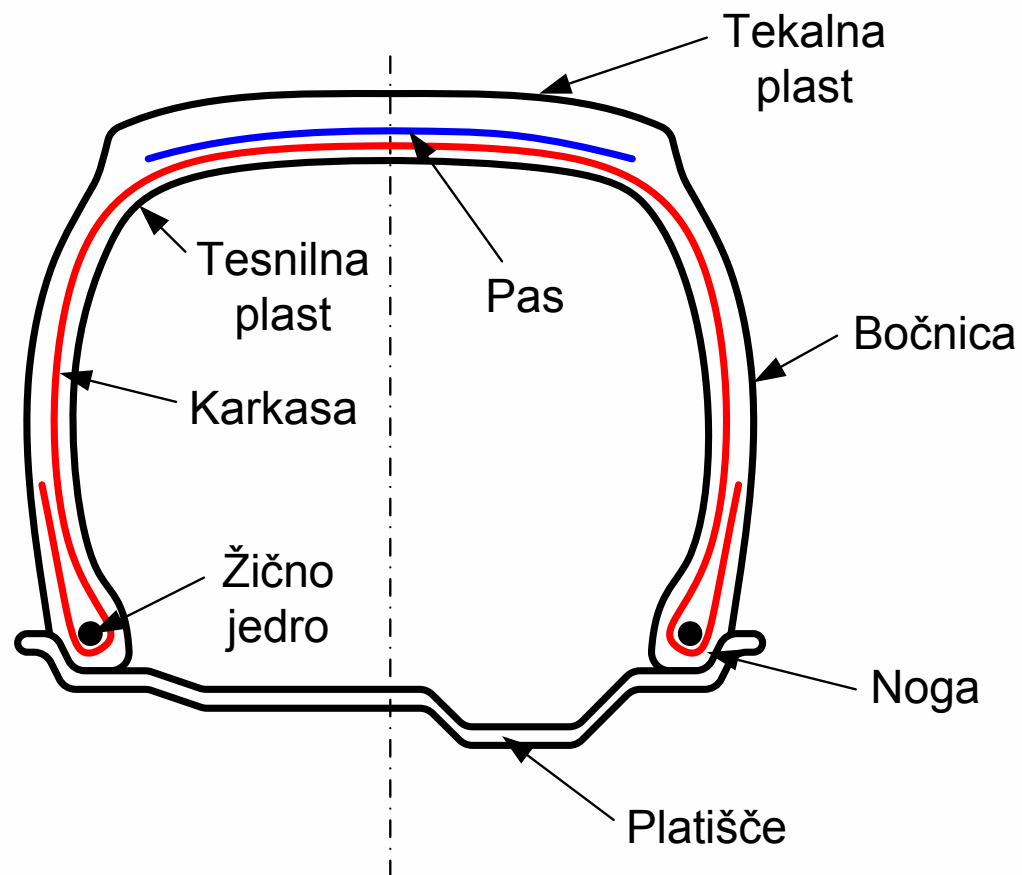
Katedra za strojne elemente in razvojna vrednotenja



TRANSMISIJE VOZIL – Pnevmatike in diferencial

Izr. prof. dr. Jernej Klemenc

Konstrukcija radialne pnevmatike



Označevanje pnevmatik

- 6,40-13/6 PR:
 - Diagonalna pnevmatika
 - Širina pnevmatike: 6,40"
 - Premer platišča: 13"
 - Višina pnevmatike: $0,95$ (superbalon za D) * 6,40"
 - Indeks nosilnosti: PR6
 - Simbol hitrosti: - (najvišja hitrost = 150 km/h)
- 265/50 R 14 101 V:
 - Radialna (R) pnevmatika
 - Širina pnevmatike: 265 mm
 - Premer platišča: 14"
 - Višina pnevmatike: $0,50$ * 265 mm
 - Indeks nosilnosti: 101
 - Simbol hitrosti: V (najvišja hitrost = 240 km/h)



Označevanje pnevmatik

■ Simboli hitrosti za pnevmatike:

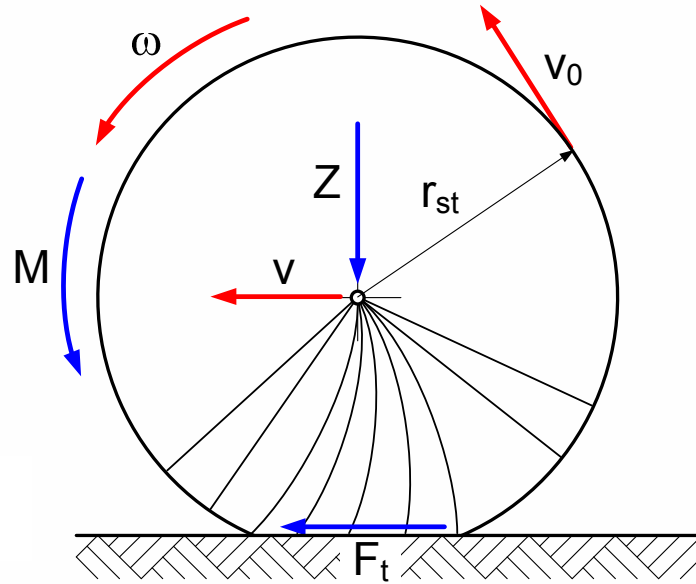
- P => 150 km/h
- Q => 160 km/h
- S => 180 km/h
- T => 190 km/h
- H => 210 km/h
- V => 240 km/h
- W => 270 km/h
- ZR=> nad 270 km/h

■ Indeks nosilnosti za pnevmatike:

- 76 => 400 kg
- 77 – 83 => 400 kg + i * 12,5 kg (i = število indeksov nad 76)
- 84 => 500 kg
- >84 => 500 kg + i * 15 kg (i = število indeksov nad 84)



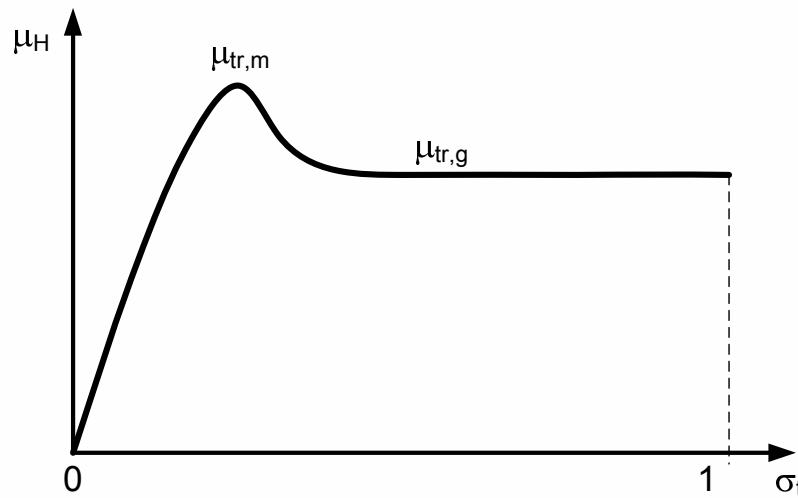
Pnevmatika kot torno gonilo - pospeševanje



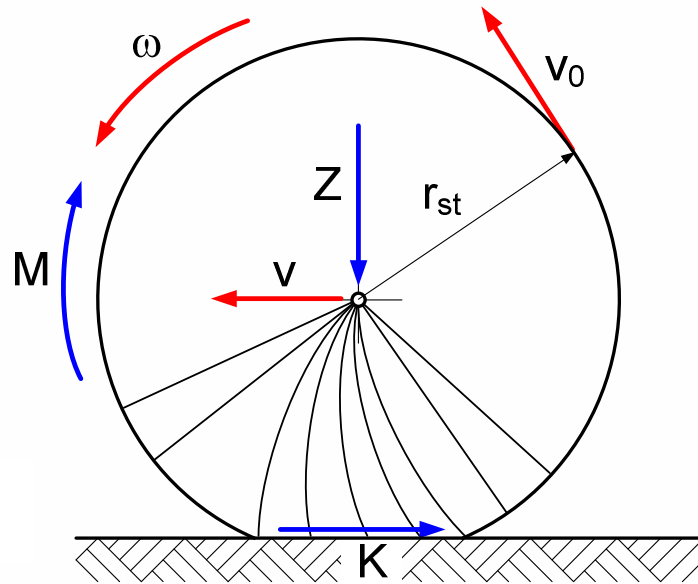
$$\mu_h = \frac{F_k}{Z}$$

$$\sigma_t = \frac{v_0 - v}{v_0}$$

$$M = \mu_H \cdot Z \cdot r_{st} = \mu_H \cdot konst$$



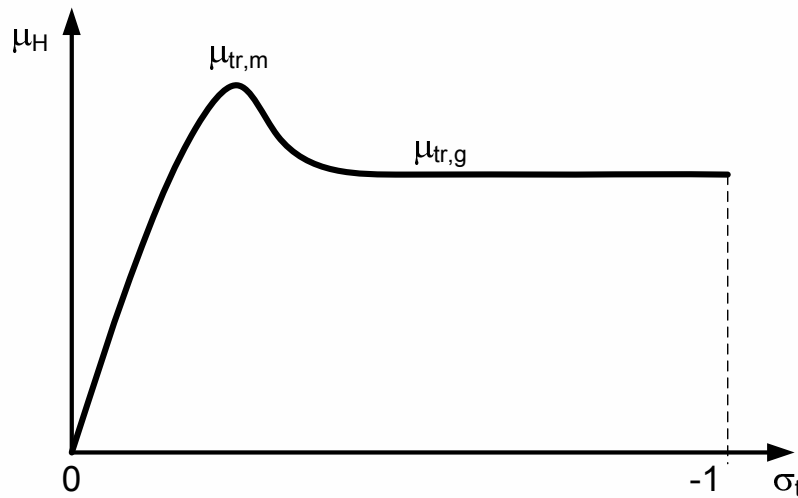
Pnevmatika kot torni gonilo - zaviranje



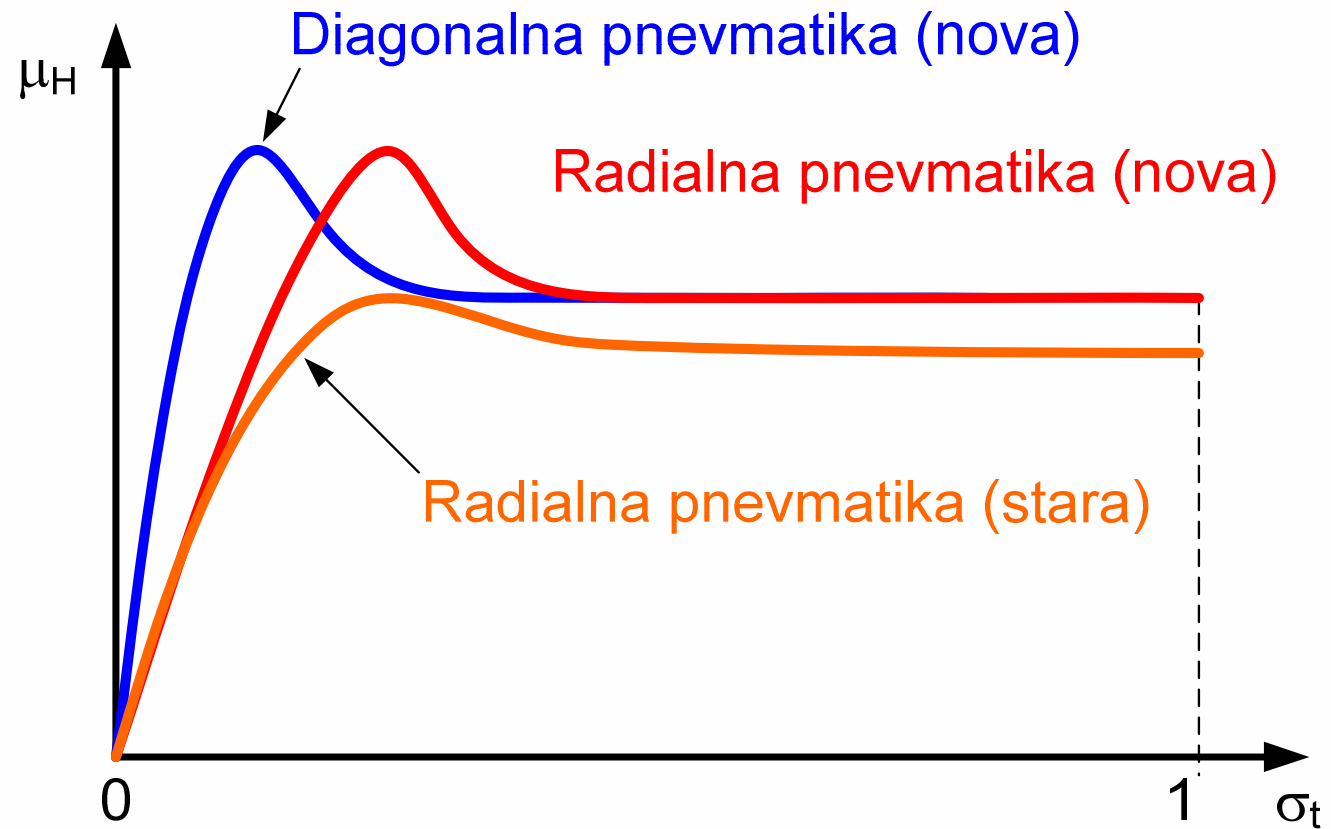
$$\mu_h = \frac{K}{Z}$$

$$\sigma_t = \frac{v_0 - v}{v_0}$$

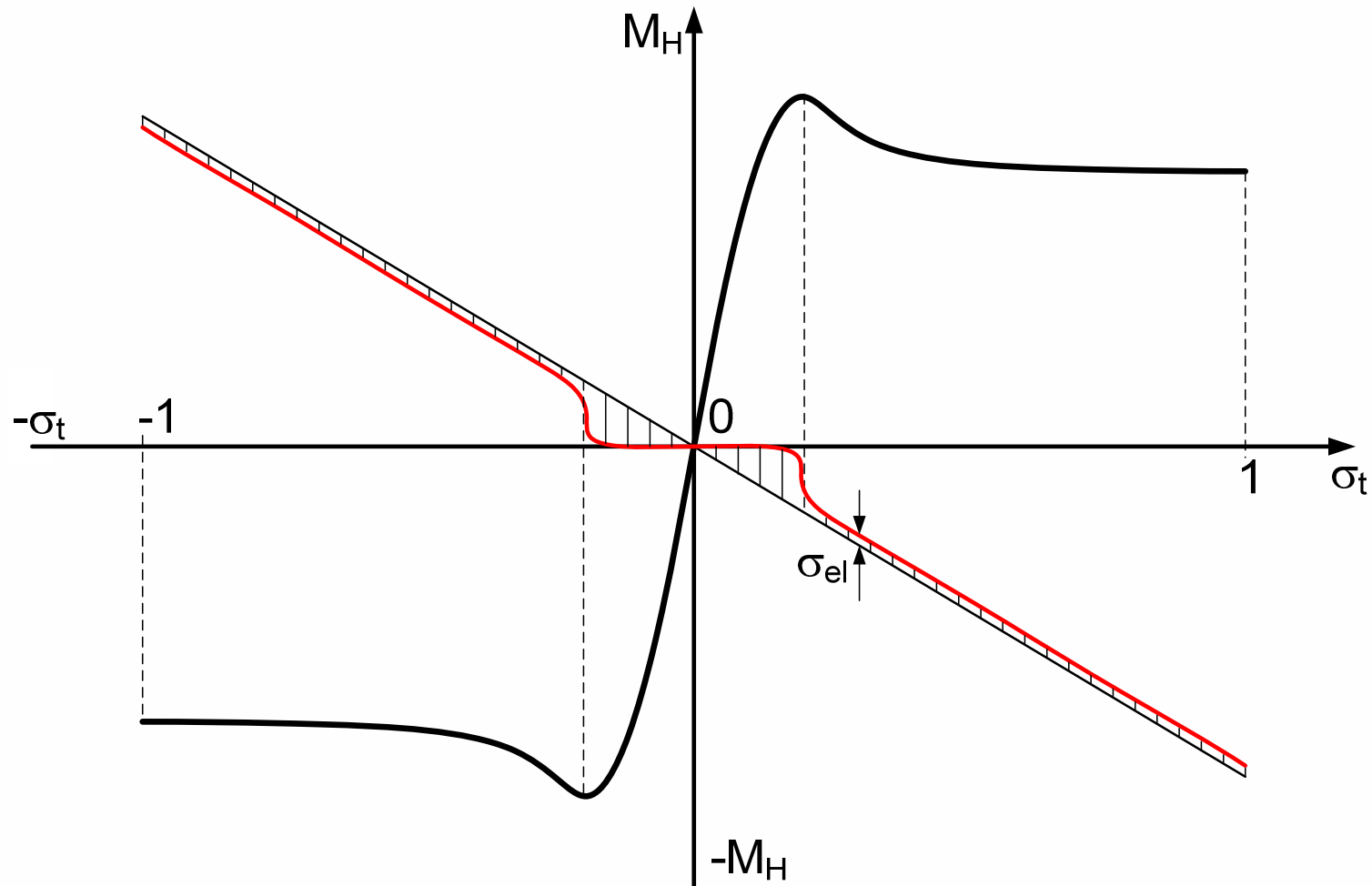
$$M = \mu_H \cdot Z \cdot r_{st} = \mu_H \cdot konst$$



Sojemalni diagram za radialne in diagonalne pnevmatike

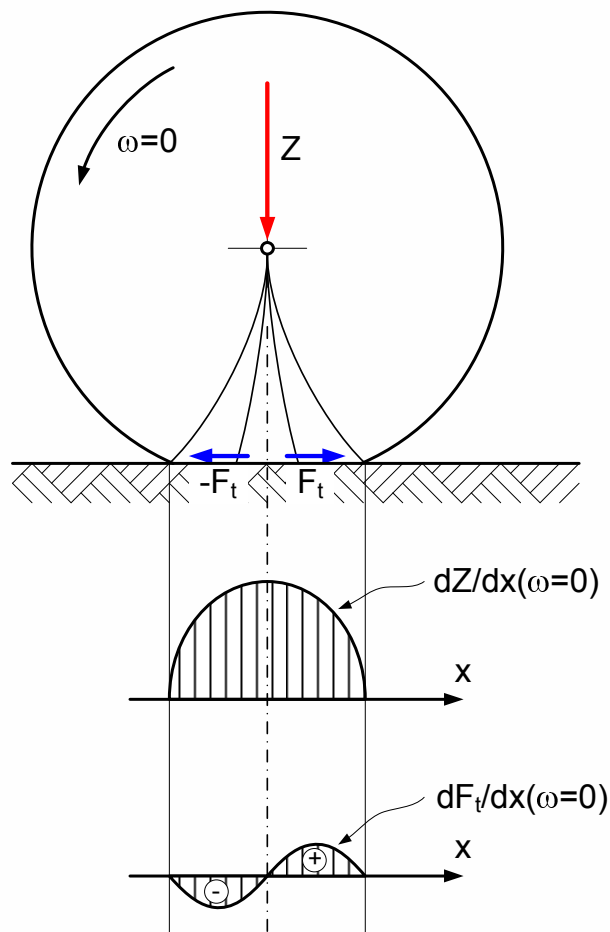


Sojemalni diagram za pospeševanje in zaviranje

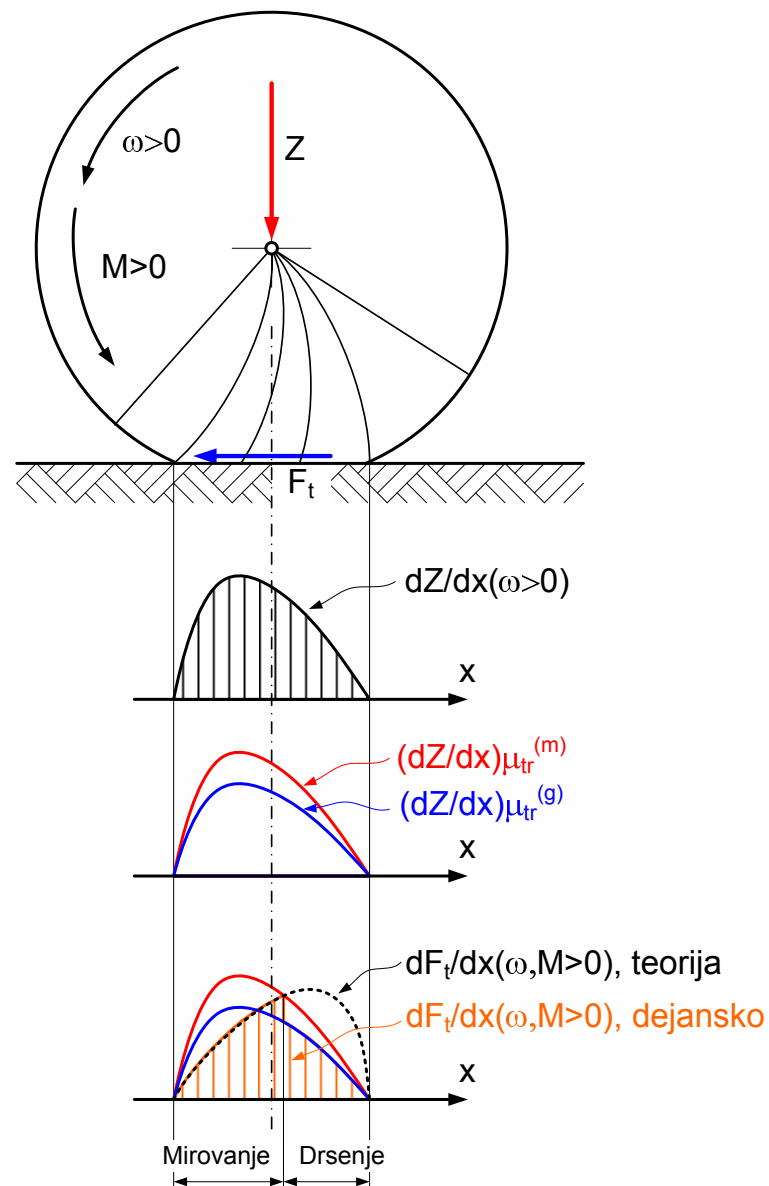


Mikro-kontakt pnevmatike in vozne površine - pospeševanje

Pnevmatika v stanju mirovanja

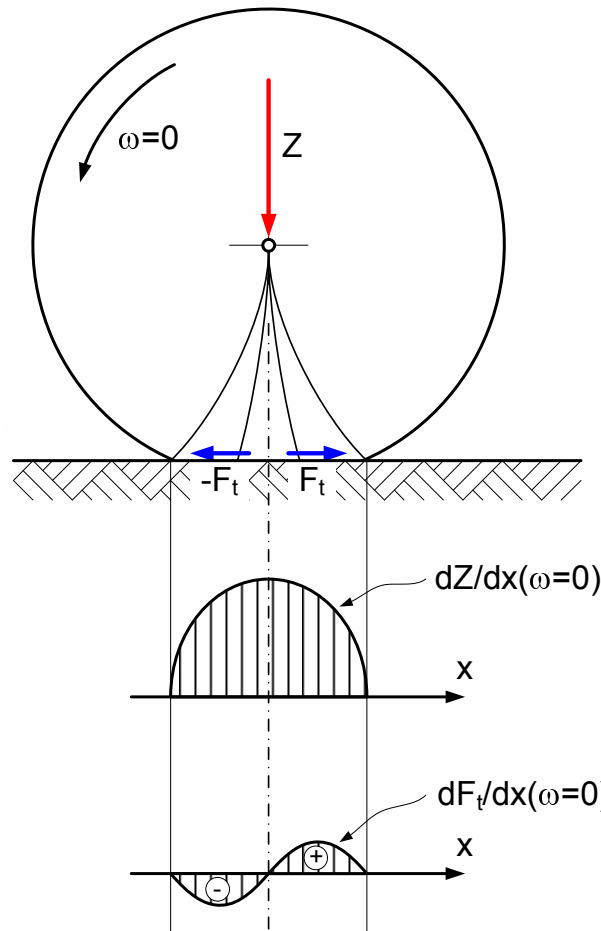


Pnevmatika med pospeševanjem

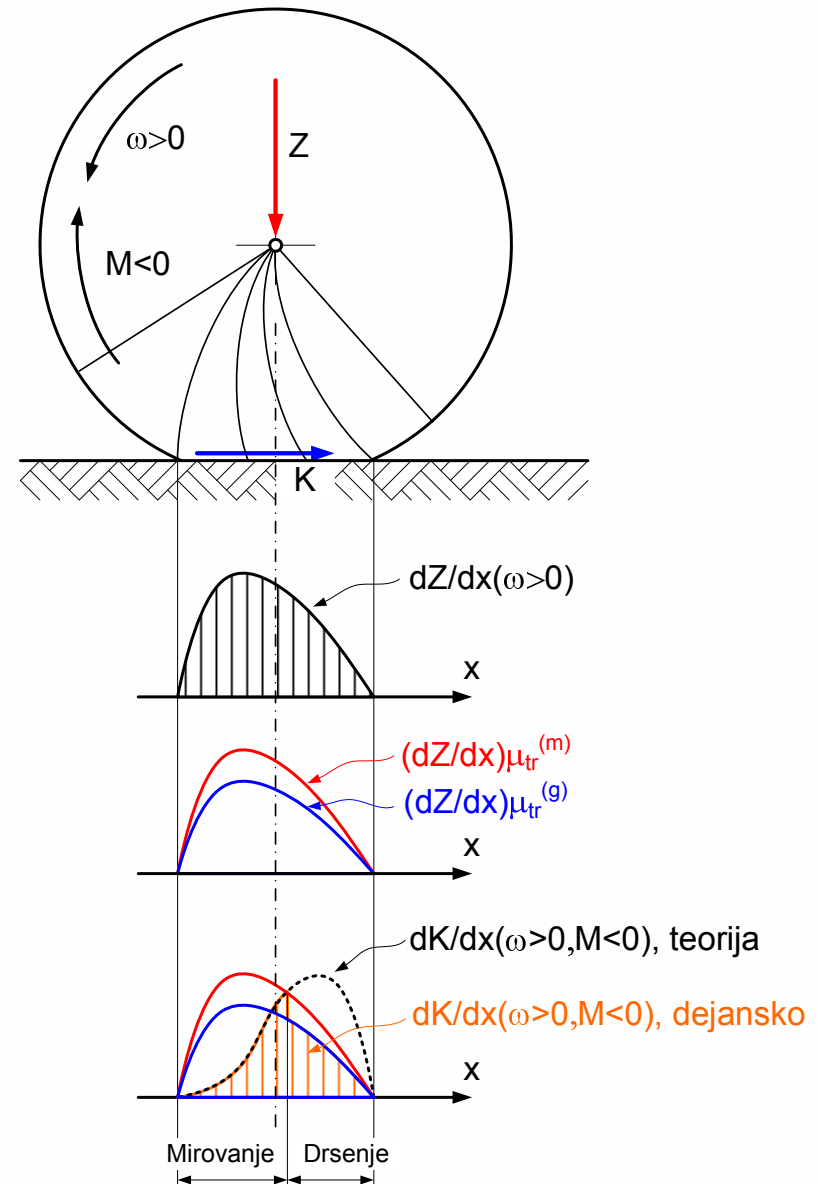


Mikro-kontakt pnevmatike in vozne površine - zaviranje

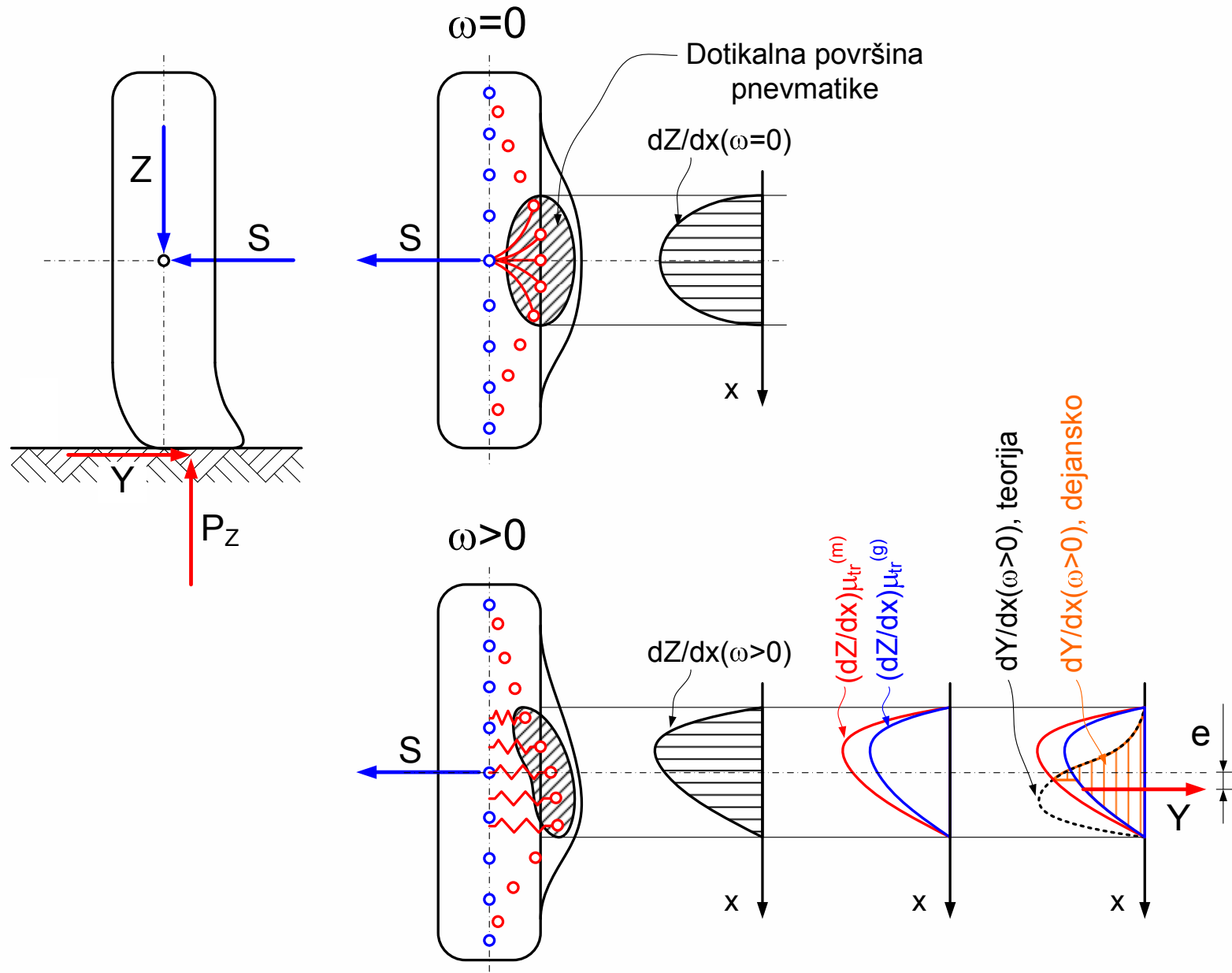
Pnevmatika v stanju mirovanja



Pnevmatika med zaviranjem



Bočna elastičnost pnevmatike



Koeficient sojemanja za prečno silo in kot poševnega nakotaljevanja

$$M_s = Y \cdot e$$

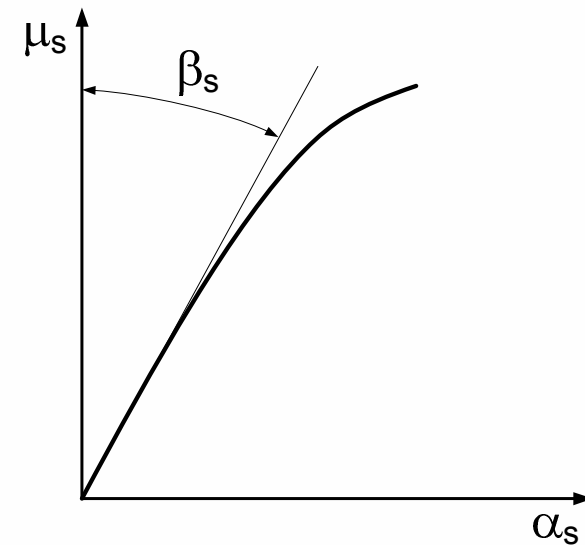
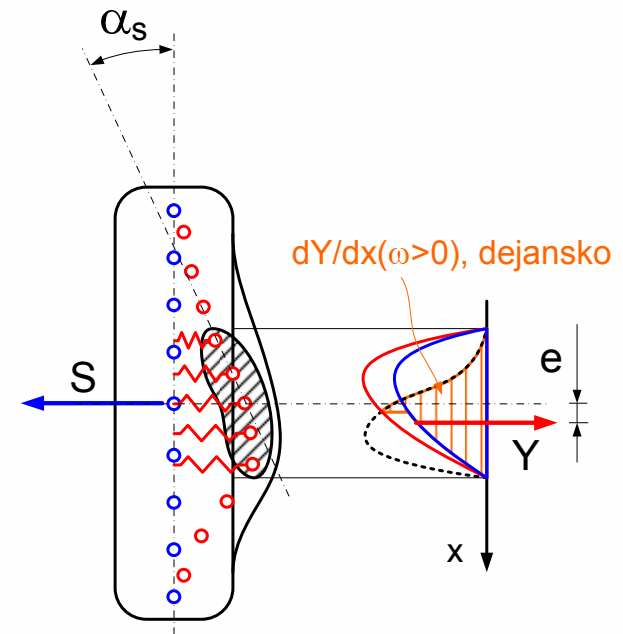
α_s ...kot poševnega nakotaljevanja

$$\mu_s = \frac{S}{Z}$$

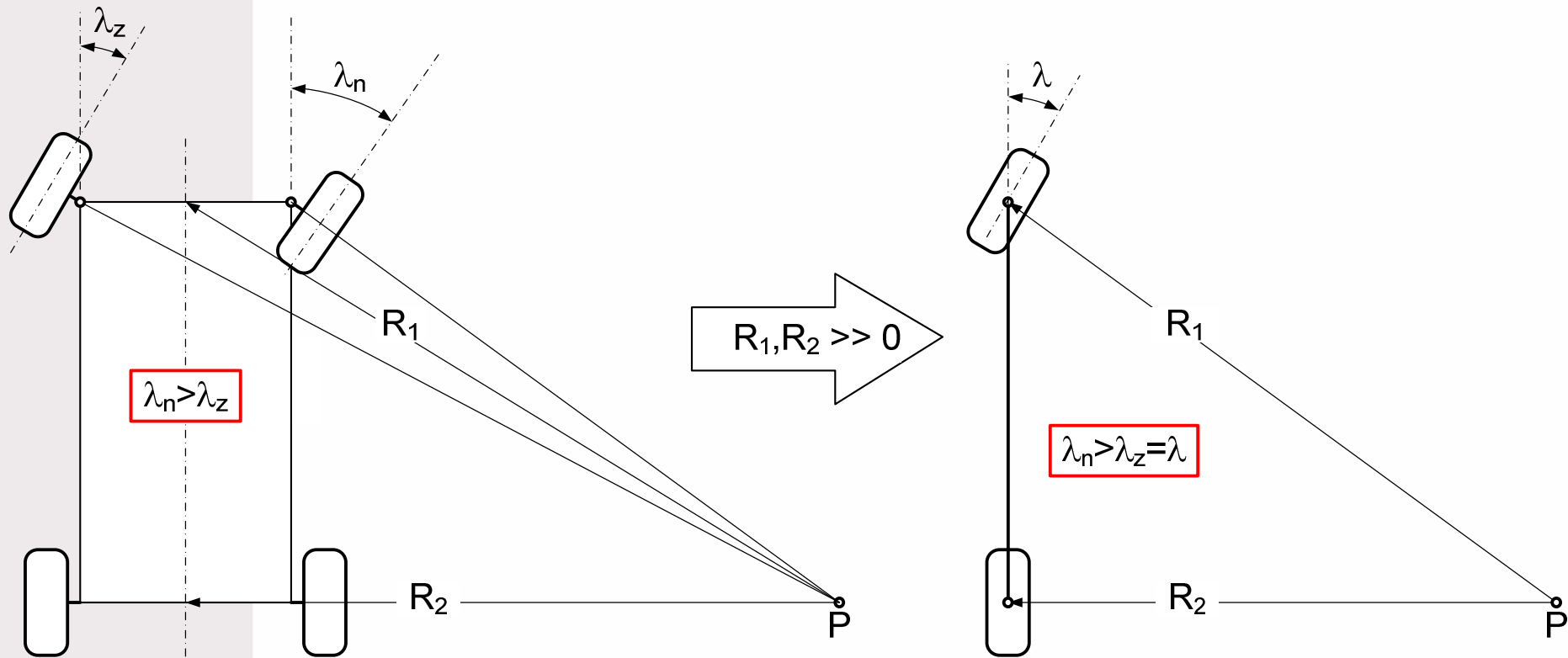
μ_s ...bočni koeficient sojemanja

$$c_s = \operatorname{tg} \beta_s = \frac{\alpha_s}{\mu_s}$$

c_s ...bočna elastičnost pnevmatike



Kot zasuka krmilnih koles pri vožnji v ovinek



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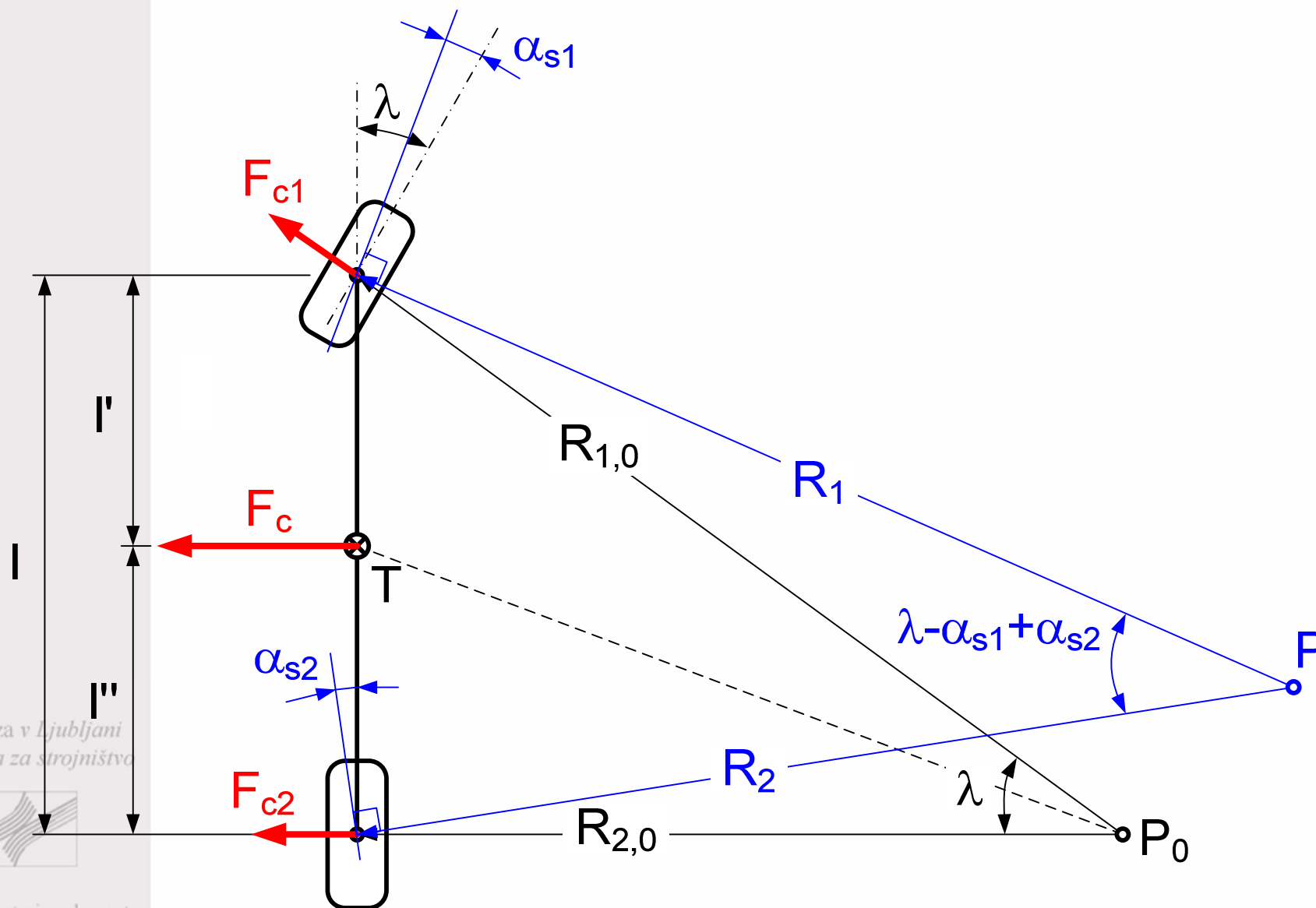


Katedra za strojne elemente
in razvojna vrednotenja

λ ... krmilni kot

$$\lambda = f(R)$$

Vpliv poševnega nakotaljevanja pri vožnji v ovinek



Vpliv poševnega nakotaljevanja pri vožnji v ovinek

$$R_1, R_2 \gg 0 \Rightarrow R_1 \approx R_2 \approx R \Rightarrow F_{c1} \approx F_c \cdot \frac{l''}{l}; F_{c2} \approx F_c \cdot \frac{l'}{l}$$

$$F_c = m_v \cdot \frac{v^2}{R} = \frac{G}{g} \cdot \frac{v^2}{R}$$

$$\mu_s = \frac{F_c}{G} = \frac{1}{g} \cdot \frac{v^2}{R}$$

$$\mu_{s1} \approx \mu_{s2} \approx \mu_s$$

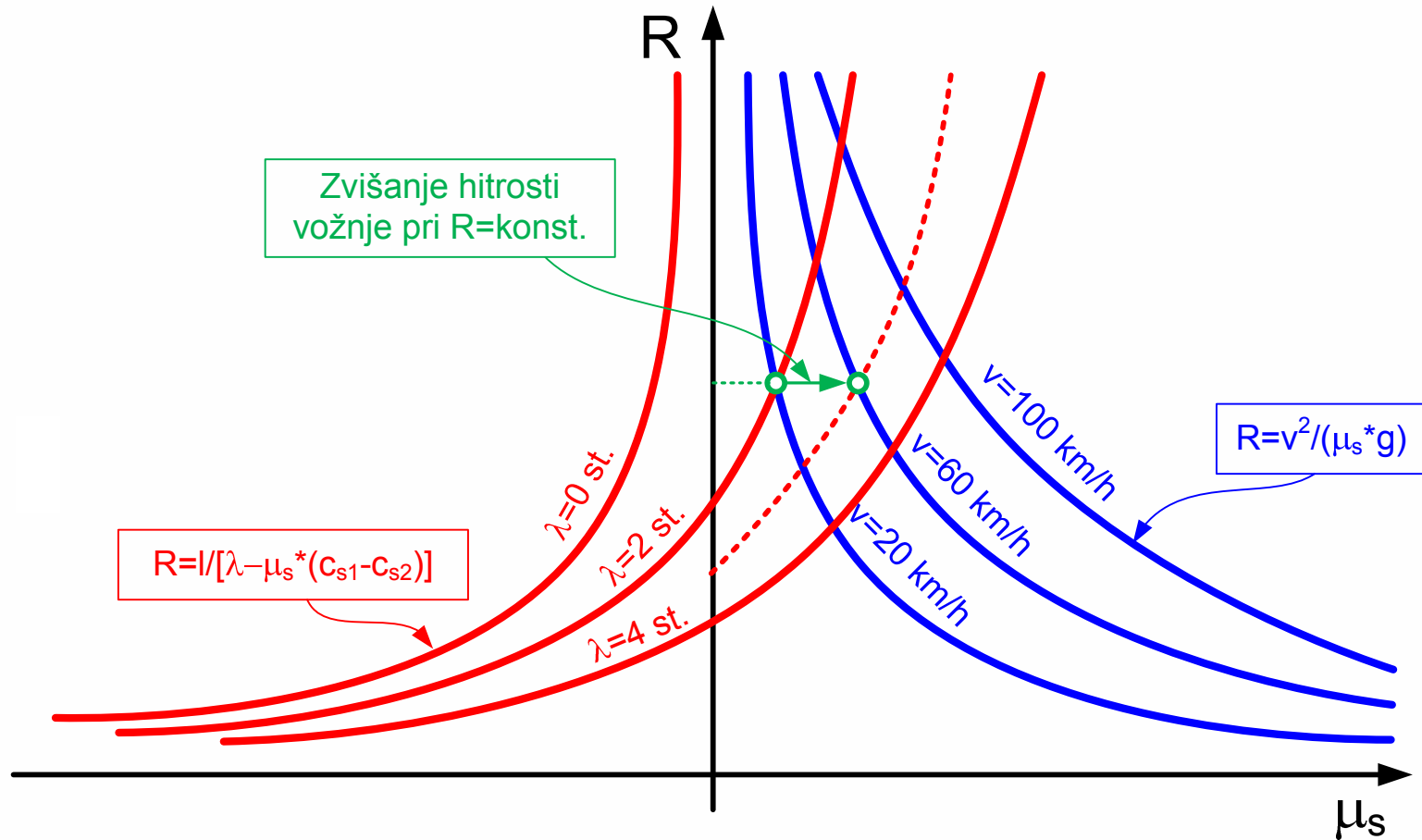
$$\alpha_{s1} = c_{s1} \cdot \mu_s$$

$$\alpha_{s2} = c_{s2} \cdot \mu_s$$

$$l = [\lambda - (\alpha_{s1} - \alpha_{s2})] \cdot R \Rightarrow R = \frac{l}{\lambda - \mu_s \cdot (c_{s1} - c_{s2})}$$



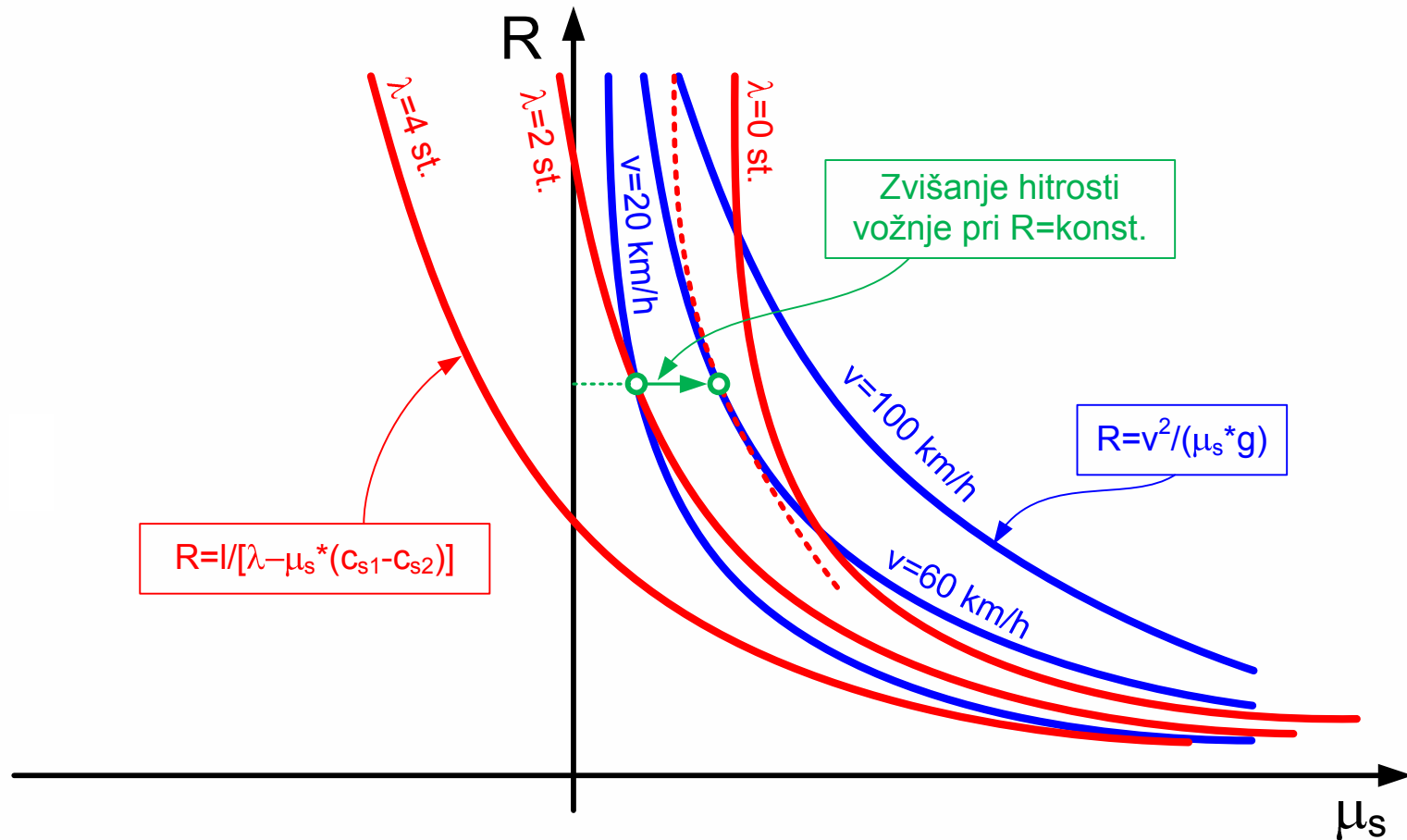
Podkrmarjeno vozilo – $c_{s1} > c_{s2}$



Če se poveča hitrost vožnje v ovinek, je treba povečati krmilni kot λ .



Prekrmarjeno vozilo – $c_{s1} < c_{s2}$



Če se poveča hitrost vožnje v ovinek, je treba zmanjšati krmilni kot λ .



Kritična hitrost prekrmarjenega vozila

- Kritična hitrost prekrmarjenega vozila je tista hitrost, pri kateri je vozilo ob minimalni bočni motnji (npr. sunek vetra) sposobno voziti v ovinek brez zasuka krmilnih koles:

$$c_{s2} > c_{s1}$$

$$\lambda = 0; R > 0$$

$$\mu_s = \frac{1}{g} \cdot \frac{v^2}{R} \Rightarrow R = \frac{1}{g} \cdot \frac{v^2}{\mu_s}$$

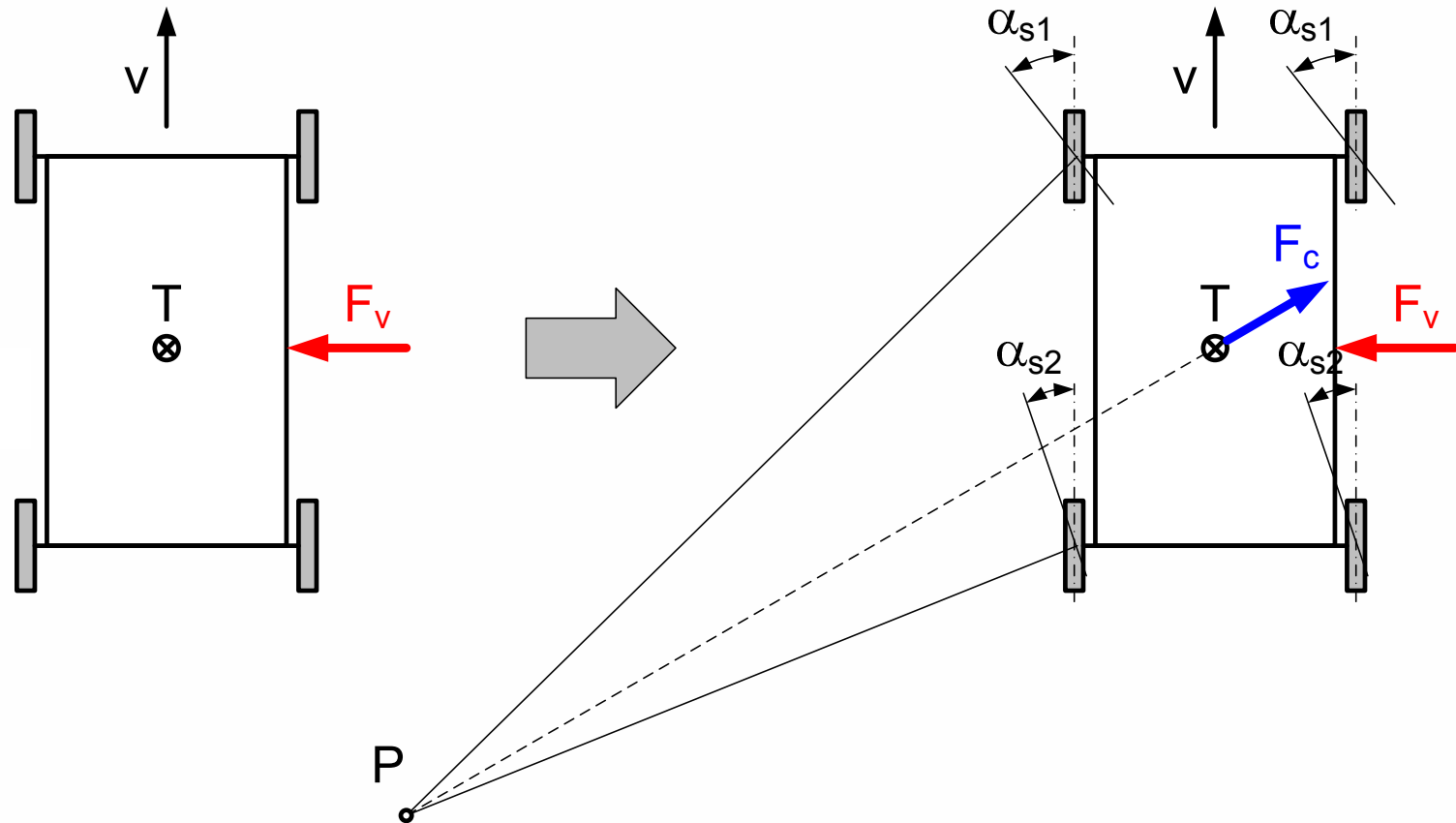
$$R = \frac{1}{g} \cdot \frac{v_{krit}^2}{\mu_s} = \frac{l}{-\mu_s \cdot (c_{s1} - c_{s2})}$$

$$v_{krit} = \sqrt{\frac{l \cdot g}{(c_{s2} - c_{s1})}}$$



Vpliv bočnega vetra

- Podkrmarjeno vozilo ($c_{s1} > c_{s2}$):

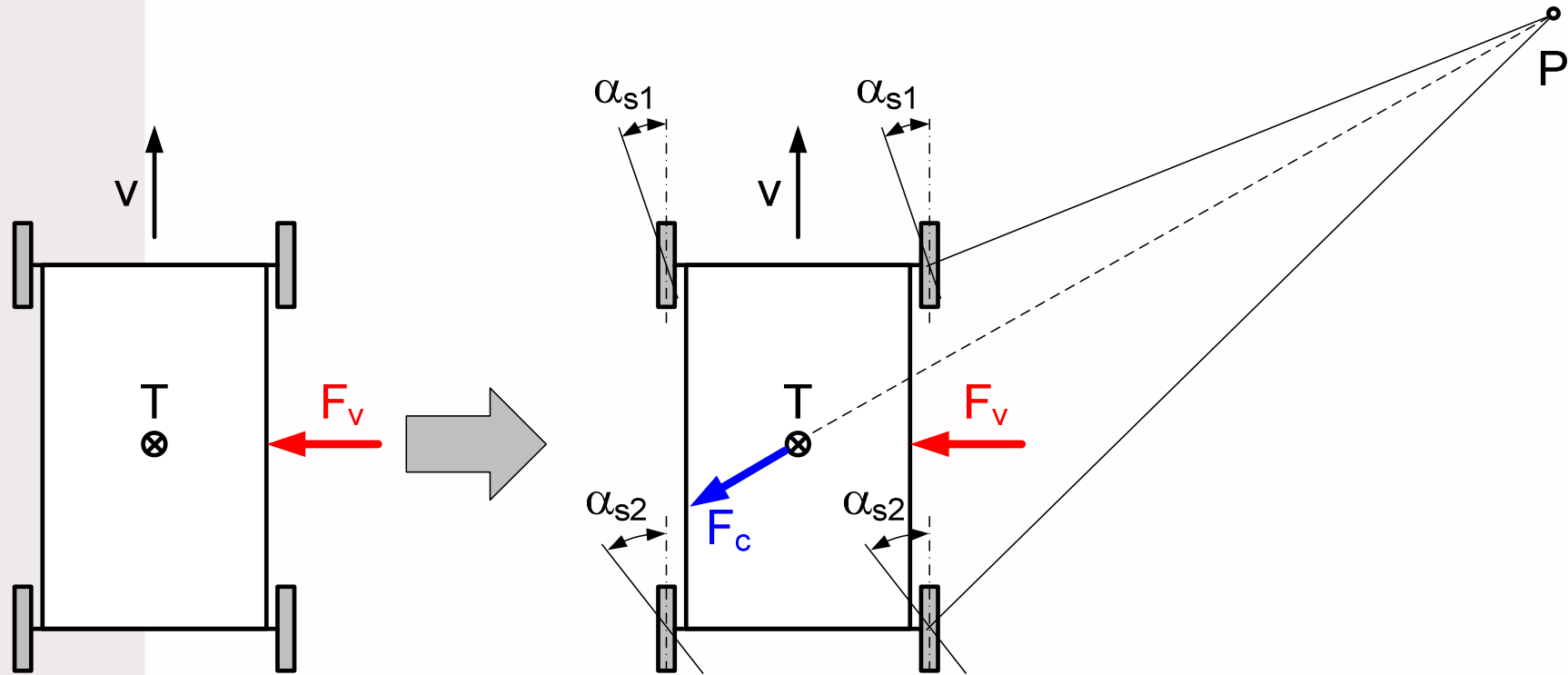


Centrifugalna sila stabilizira silo vetra.



Vpliv bočnega vetra

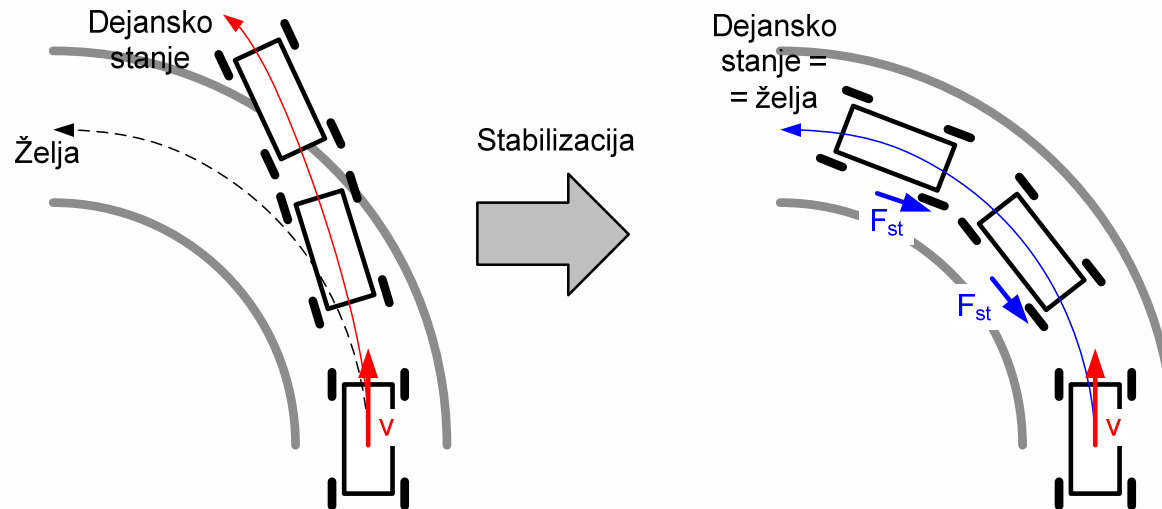
- Prekrmarjeno vozilo ($c_{s1} < c_{s2}$):



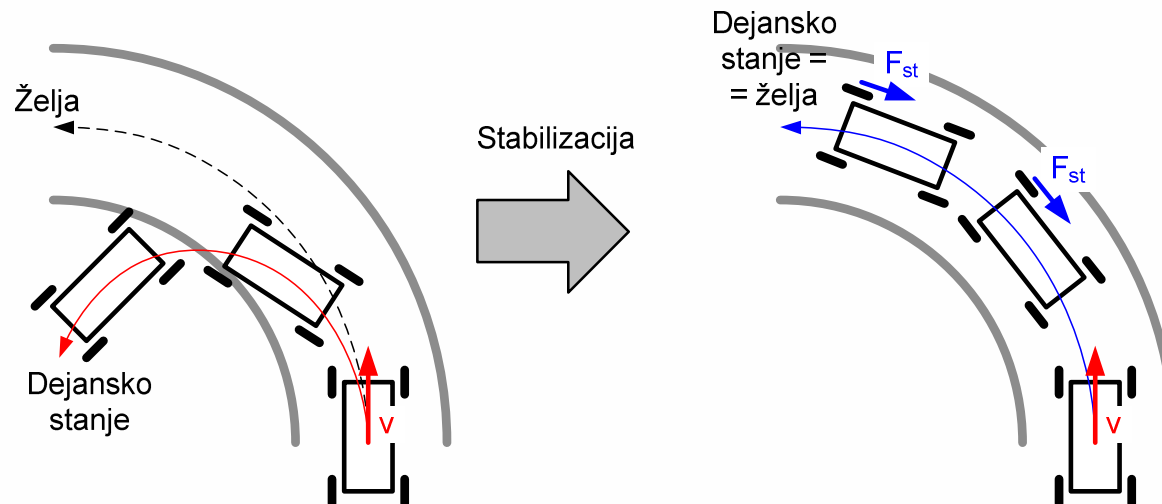
Centrifugalna sila destabilizira silo vetra.

Stabilizacija vozila pri vožnji v ovinek z veliko hitrostjo

■ Podkrmarjeno vozilo:



■ Prekrmarjeno vozilo:



Kritična hitrost prekrmarjenega vozila

- Kritična hitrost prekrmarjenega vozila je tista hitrost, pri kateri je vozilo ob minimalni bočni motnji (npr. sunek vetra) sposobno voziti v ovinek brez zasuka krmilnih koles:

$$c_{s2} > c_{s1}$$

$$\lambda = 0; R > 0$$

$$\mu_s = \frac{1}{g} \cdot \frac{v^2}{R} \Rightarrow R = \frac{1}{g} \cdot \frac{v^2}{\mu_s}$$

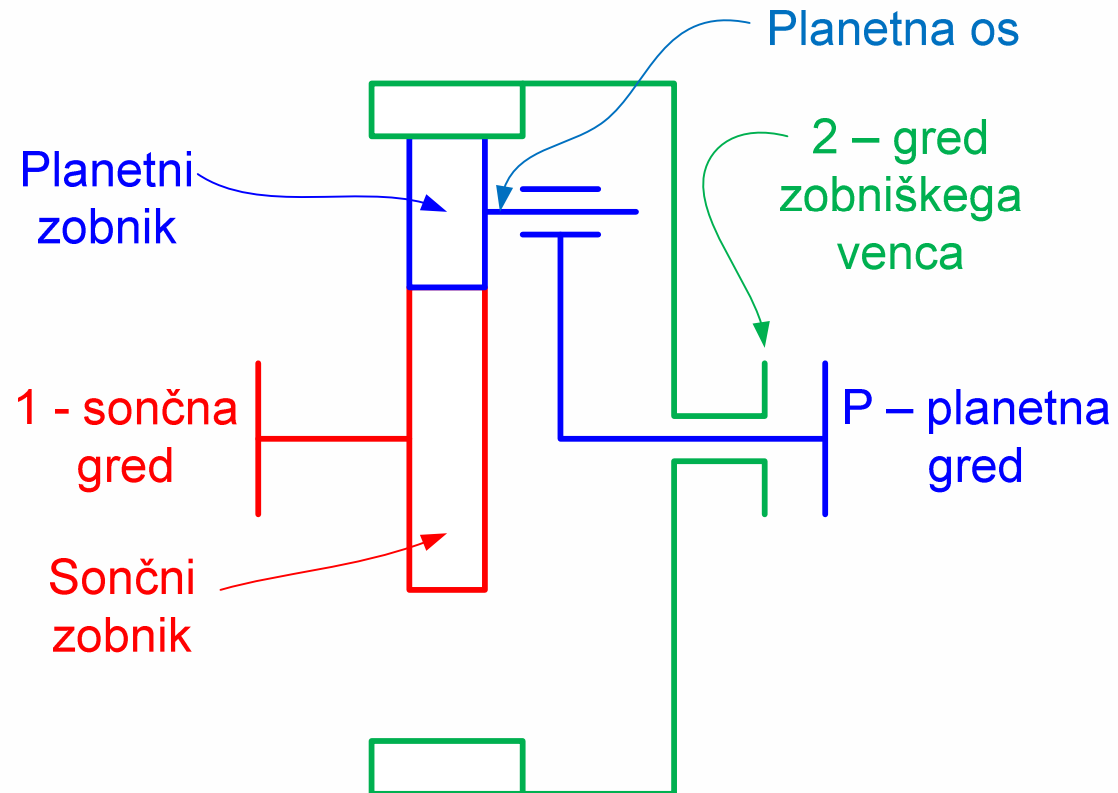
$$R = \frac{1}{g} \cdot \frac{v_{krit}^2}{\mu_s} = \frac{l}{-\mu_s \cdot (c_{s1} - c_{s2})}$$

$$v_{krit} = \sqrt{\frac{l \cdot g}{(c_{s2} - c_{s1})}}$$



Planetna gonila

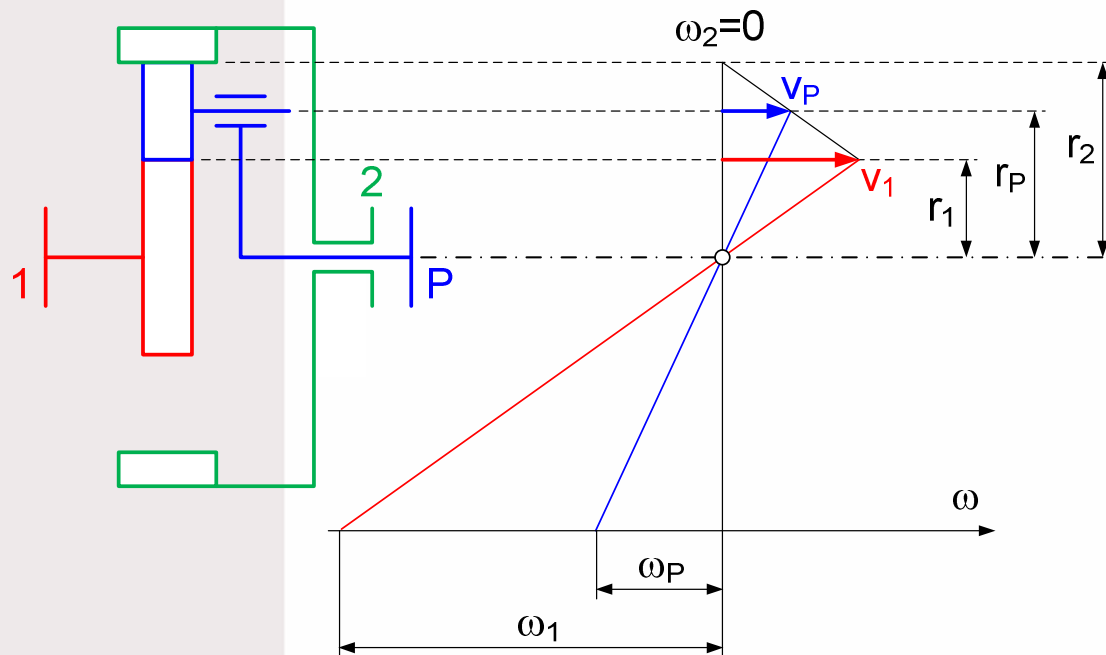
- Triosno planetno gonilo:



Planetna gonila

- Prestave triosnega planetnega gonila:

- Notranja prestava 1-P (gred 2 je blokirana, gred 1 je poganjana):



$$v_1 = \omega_1 \cdot r_1$$

$$v_P = \frac{v_1}{2}$$

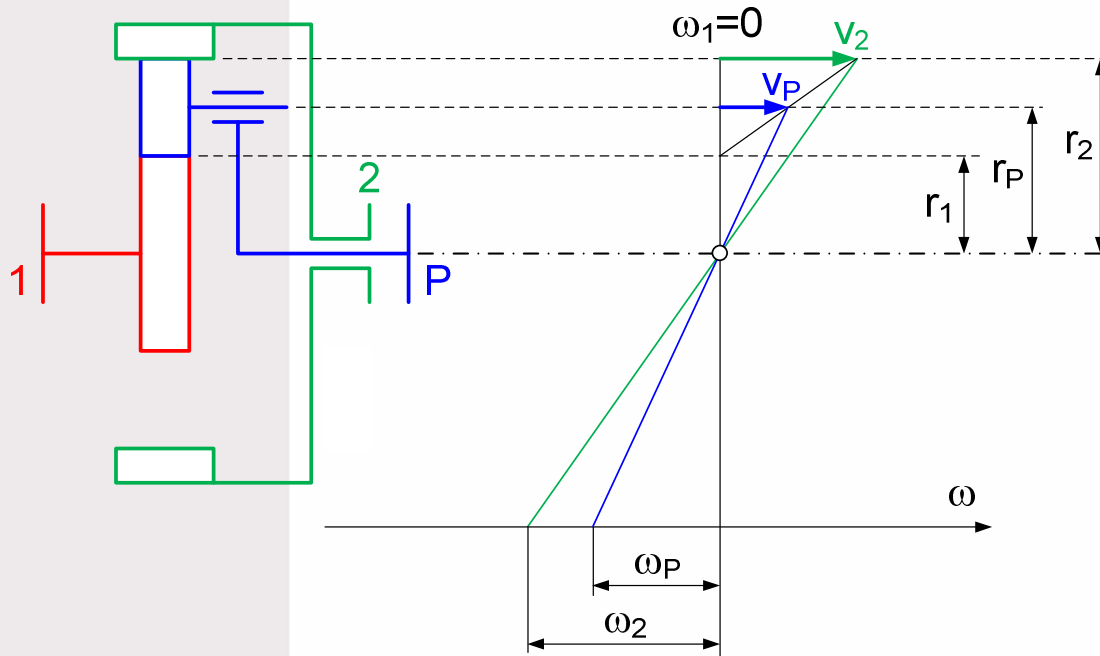
$$\omega_P = \frac{v_P}{r_P} = \frac{v_1}{2 \cdot r_P} = \omega_1 \cdot \frac{r_1}{2 \cdot r_P}$$

$$i_{1P} = \frac{\omega_1}{\omega_P} = \frac{2 \cdot (Z_1 + Z_P)}{Z_1}$$



Planetna gonila

- Notranja prestava 2-P (gred 1 je blokirana, gred 2 je poganjana):



$$v_2 = \omega_2 \cdot r_2$$

$$v_P = \frac{v_2}{2}$$

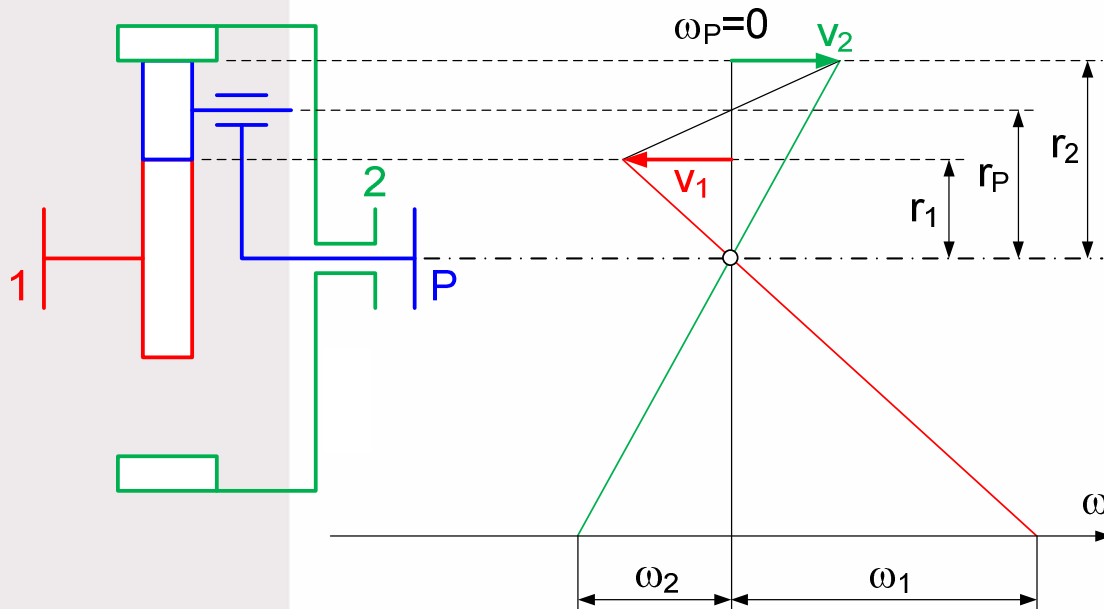
$$\omega_P = \frac{v_P}{r_P} = \frac{v_2}{2 \cdot r_P} = \omega_2 \cdot \frac{r_2}{2 \cdot r_P}$$

$$i_{2P} = \frac{\omega_2}{\omega_P} = \frac{2 \cdot (Z_1 + Z_P)}{Z_2}$$



Planetna gonila

- Notranja prestava 1-2 (gred P je blokirana, gred 1 je poganjana):



$$v_1 = \omega_1 \cdot r_1$$

$$v_2 = -v_1$$

$$\omega_2 = \frac{v_2}{r_2} = \frac{-v_1}{r_2} = \omega_1 \cdot \left(-\frac{r_1}{r_2} \right)$$

$$i_{12} = -\frac{\omega_1}{\omega_2} = -\frac{Z_2}{Z_1}$$



Planetna gonila

- Zveze med posameznimi notranjimi prestavami:

$$i_{12} = -\frac{\omega_1}{\omega_2} = -\frac{Z_2}{Z_1}$$

$$i_{1P} = \frac{\omega_1}{\omega_P} = \frac{2 \cdot (Z_1 + Z_P)}{Z_1} = \frac{2 \cdot \left(Z_1 + \frac{Z_2 - Z_1}{2} \right)}{Z_1} = 1 - i_{12}$$

$$i_{2P} = \frac{\omega_2}{\omega_P} = \frac{2 \cdot (Z_1 + Z_P)}{Z_2} = \frac{2 \cdot \left(Z_1 + \frac{Z_2 - Z_1}{2} \right)}{Z_2} = 1 - \frac{1}{i_{12}}$$



Planetna gonila

- Zveze med navori na posameznih gredeh:

$$M_{t,1} + M_{t,2} + M_{t,P} = 0$$

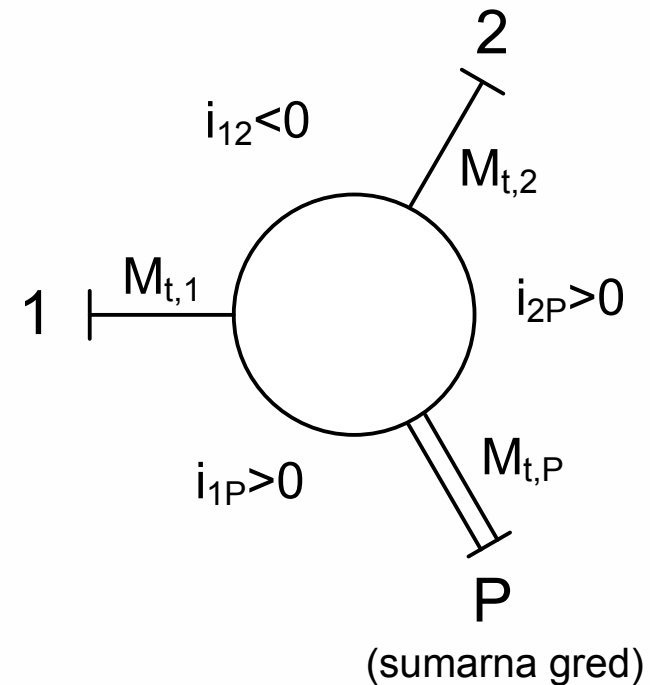
$$1 + \frac{M_{t,2}}{M_{t,1}} + \frac{M_{t,P}}{M_{t,1}} = 0$$

$$\frac{M_{t,2}}{M_{t,1}} = -i_{12}$$

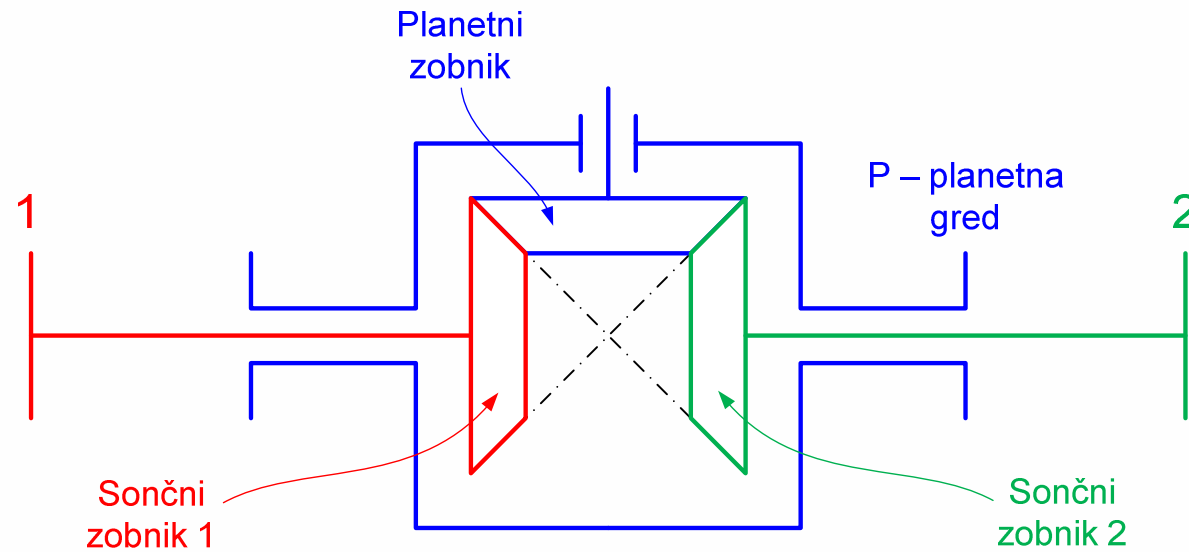
$$\frac{M_{t,P}}{M_{t,1}} = -(1 - i_{12})$$

$$\frac{M_{t,P}}{M_{t,2}} = \frac{1 - i_{12}}{i_{12}}$$

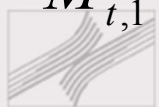
Wolfova shema:



Diferencial je planetno gonilo

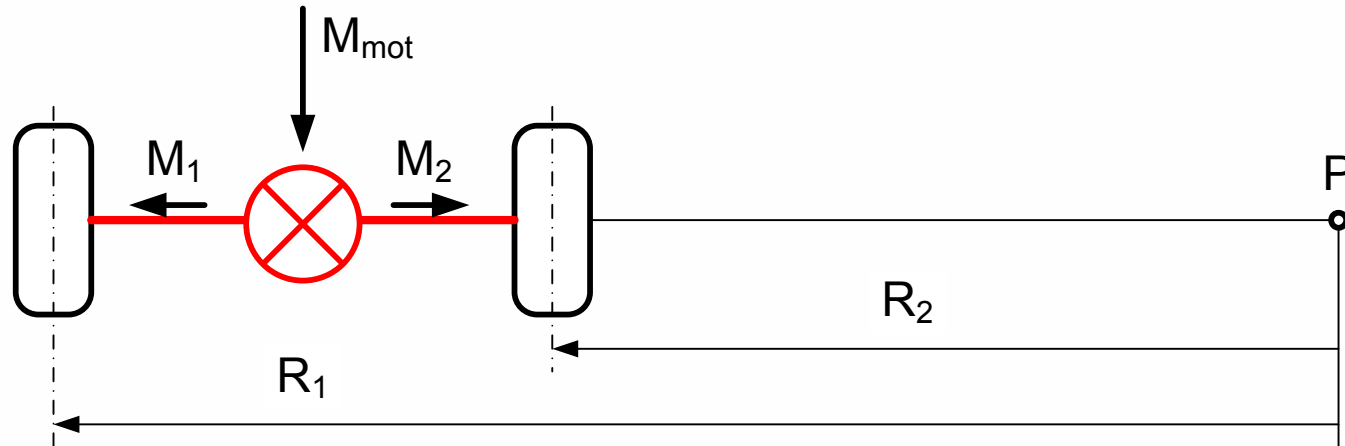


$$\left. \begin{aligned} i_{12} = -\frac{\omega_1}{\omega_2} = -\frac{Z_2}{Z_1} = -1 \\ M_{t,1} + M_{t,2} = -M_{t,P} \end{aligned} \right\} \Rightarrow \begin{cases} \frac{M_{t,2}}{M_{t,1}} = -i_{12} = 1 \Rightarrow M_{t,1} = M_{t,2} \\ \frac{M_{t,P}}{M_{t,1}} = -(1 - i_{12}) = -2 \Rightarrow M_{t,1} = -\frac{M_{t,P}}{2} \end{cases}$$



Pogonska prema brez diferenciala

- Pogonska prema brez diferenciala na trdi podlagi:



- Teoretične obodne hitrosti koles pri vožnji v ovinek:

$$v_{1,0} = \omega_{1,0} \cdot r_{st} \propto R_1 > v_{2,0} = \omega_{2,0} \cdot r_{st} \propto R_2$$

- Dejanske obodne hitrosti koles in vrtilni momenti:

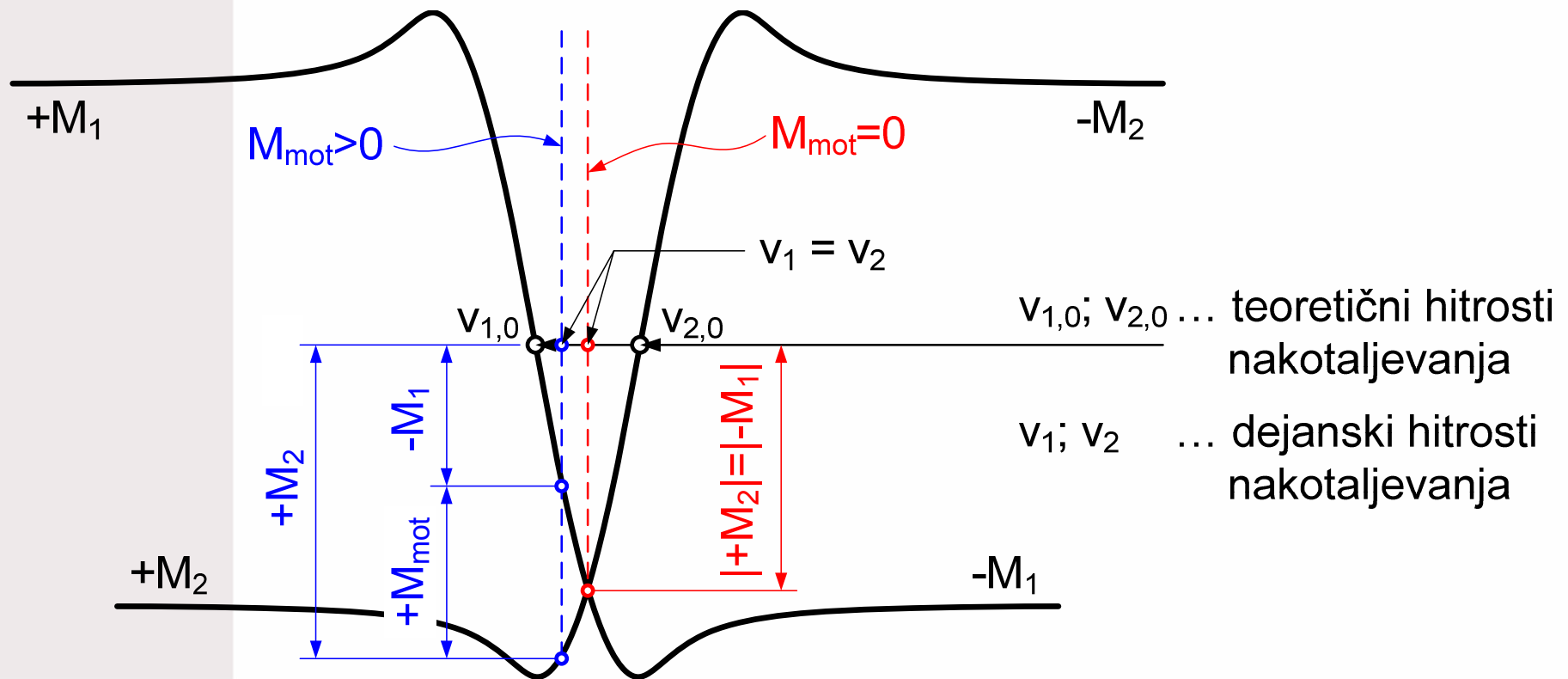
$$v_1 = v_2$$

$$M_1 \neq M_2$$



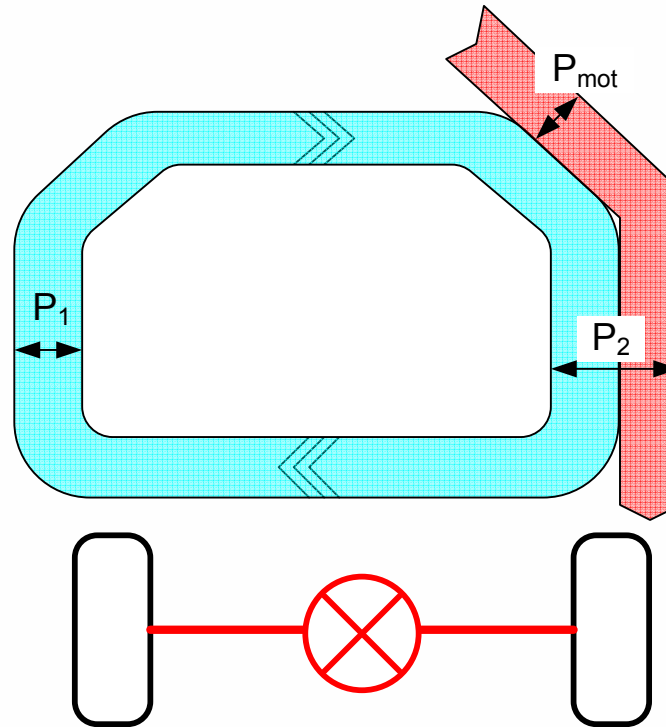
Pogonska prema brez diferenciala

- Pogonska prema brez diferenciala na trdi podlagi:



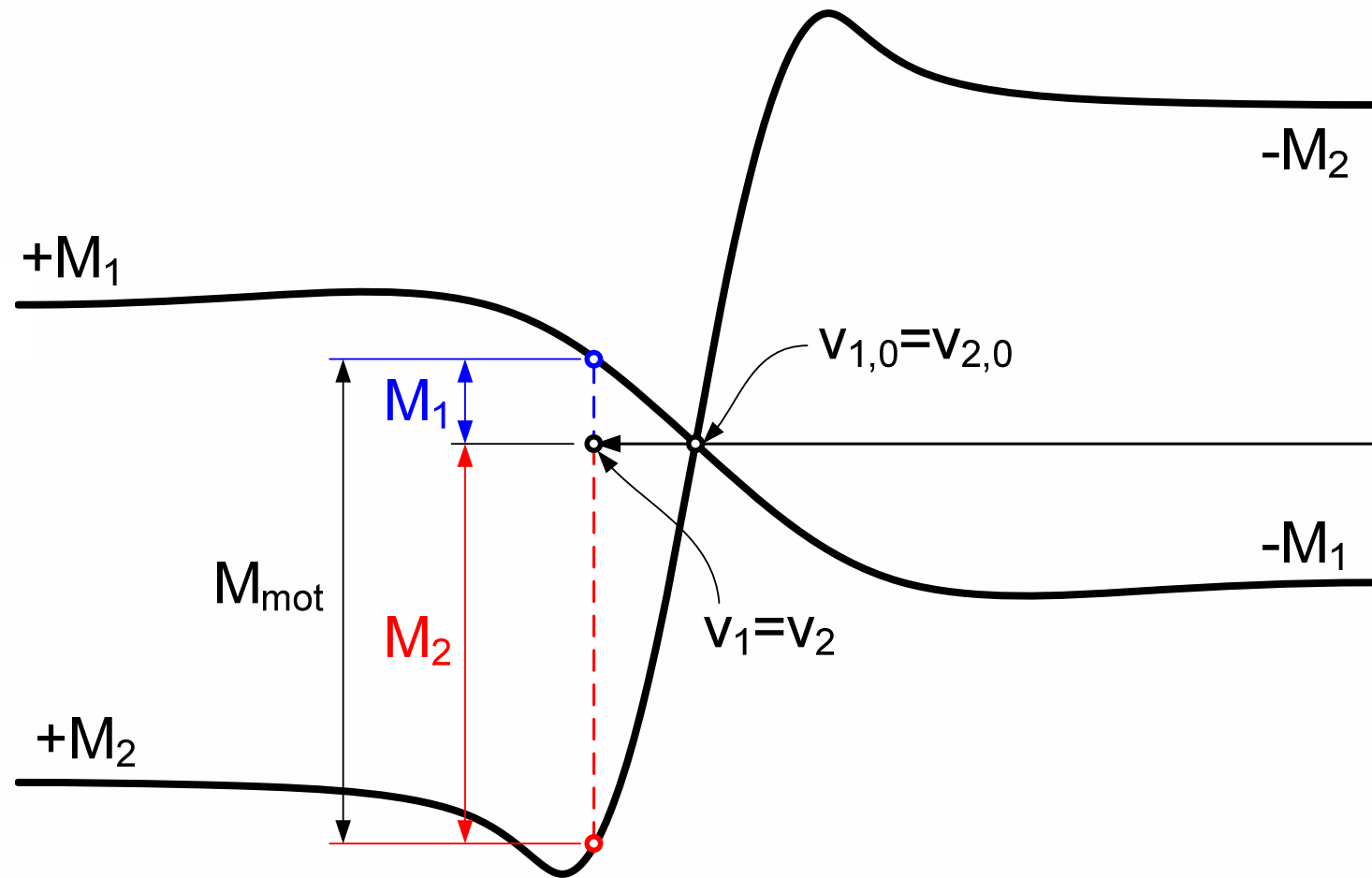
Pogonska prema brez diferenciala

- Pogonska prema brez diferenciala na trdi podlagi:



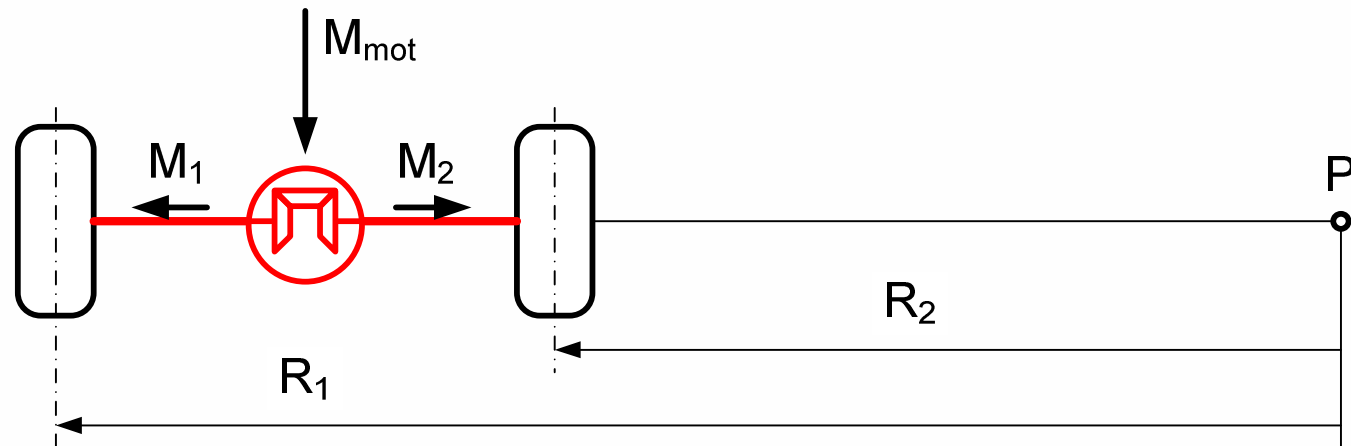
Pogonska prema brez diferenciala

- Pogonska prema brez diferenciala – trda podlaga pod levim kolesom, mehka podlaga pod desnim kolesom, vožnja naravnost:



Pogonska prema z diferencialom

- Pogonska prema z diferencialom na trdi podlagi:



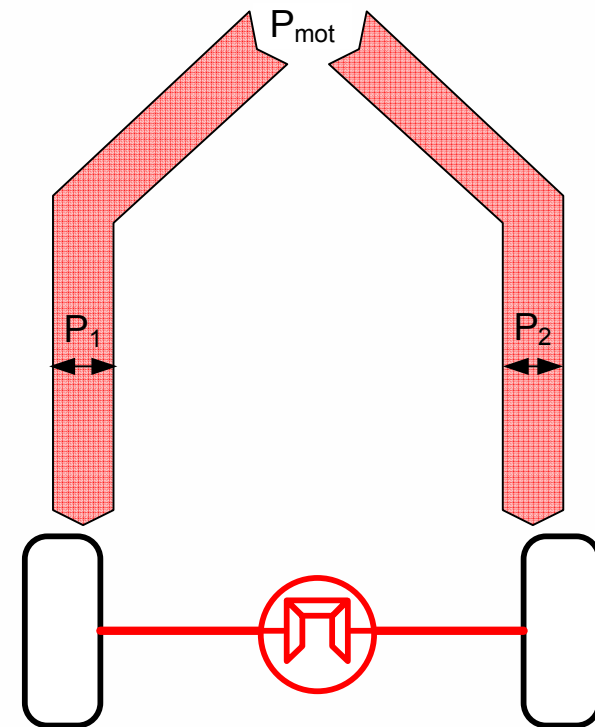
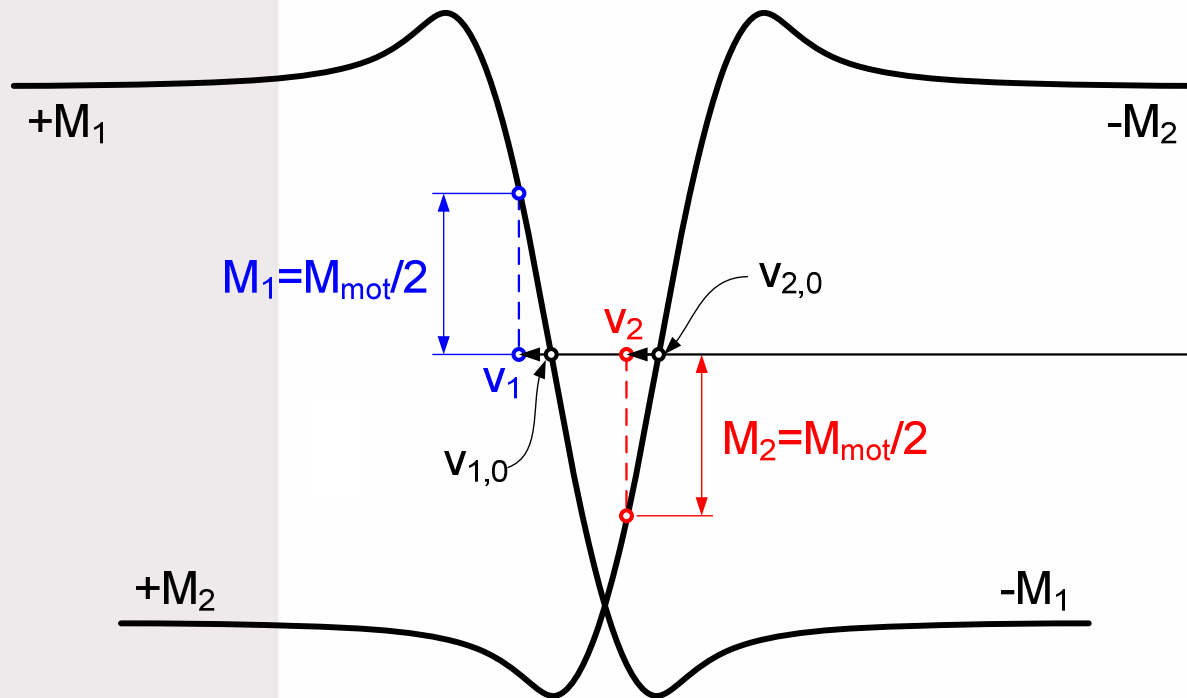
$$v_1 = \omega_1 \cdot r_{st} \propto R_1 > v_2 = \omega_2 \cdot r_{st} \propto R_2$$

$$M_1 = M_2 = \frac{M_{mot}}{2}$$



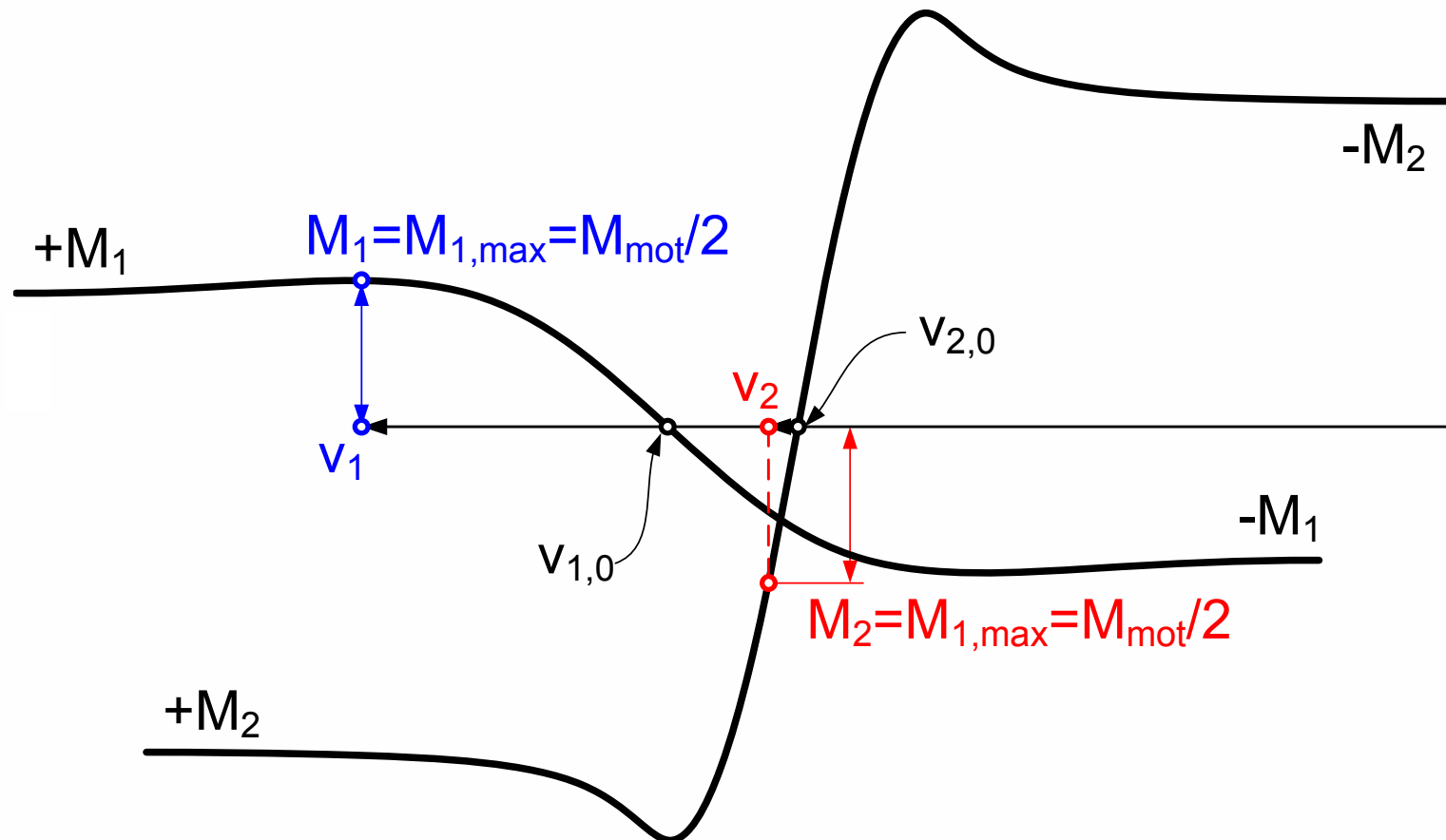
Pogonska prema z diferencialom

- Pogonska prema z diferencialom na trdi podlagi:

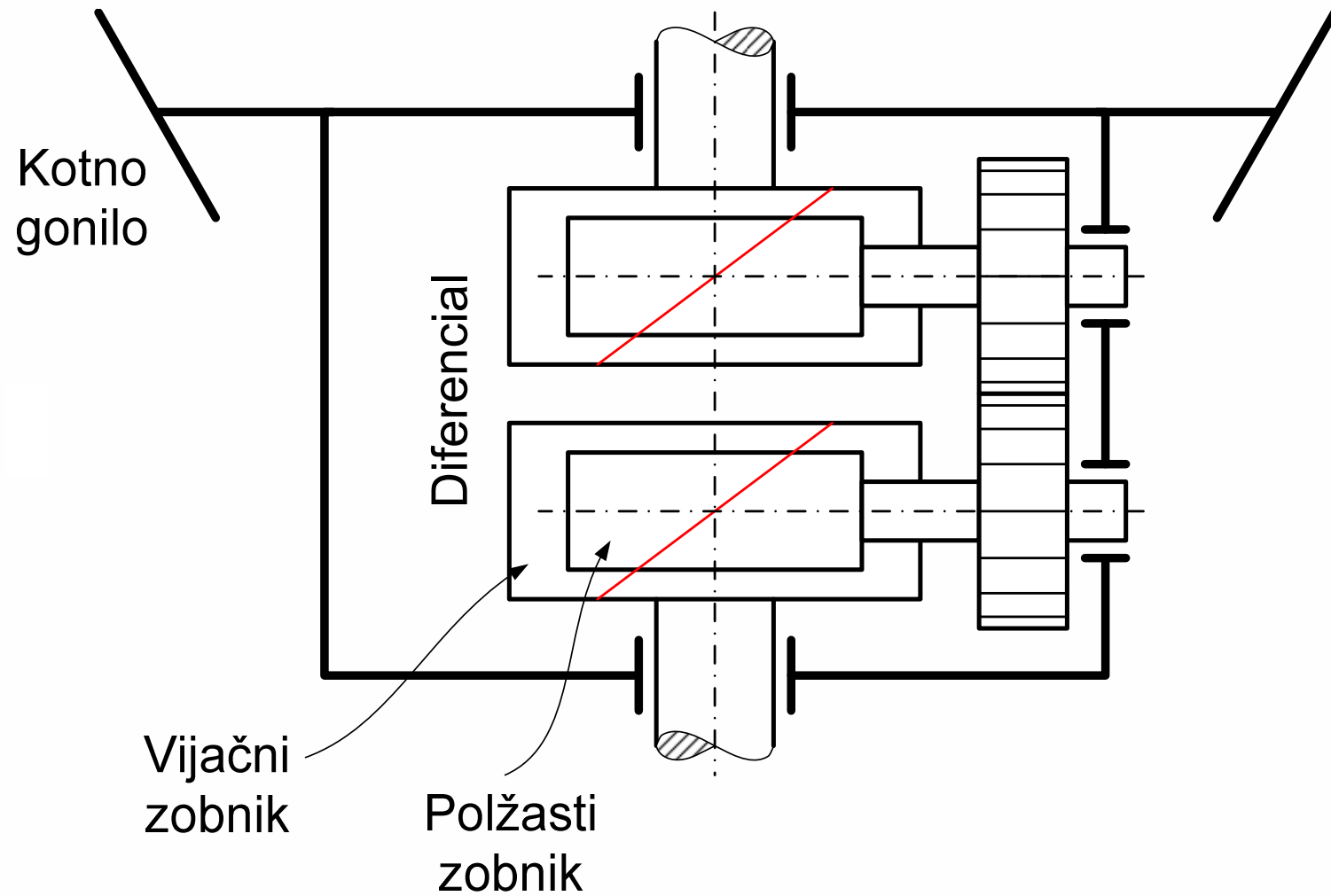


Pogonska prema z diferencialom

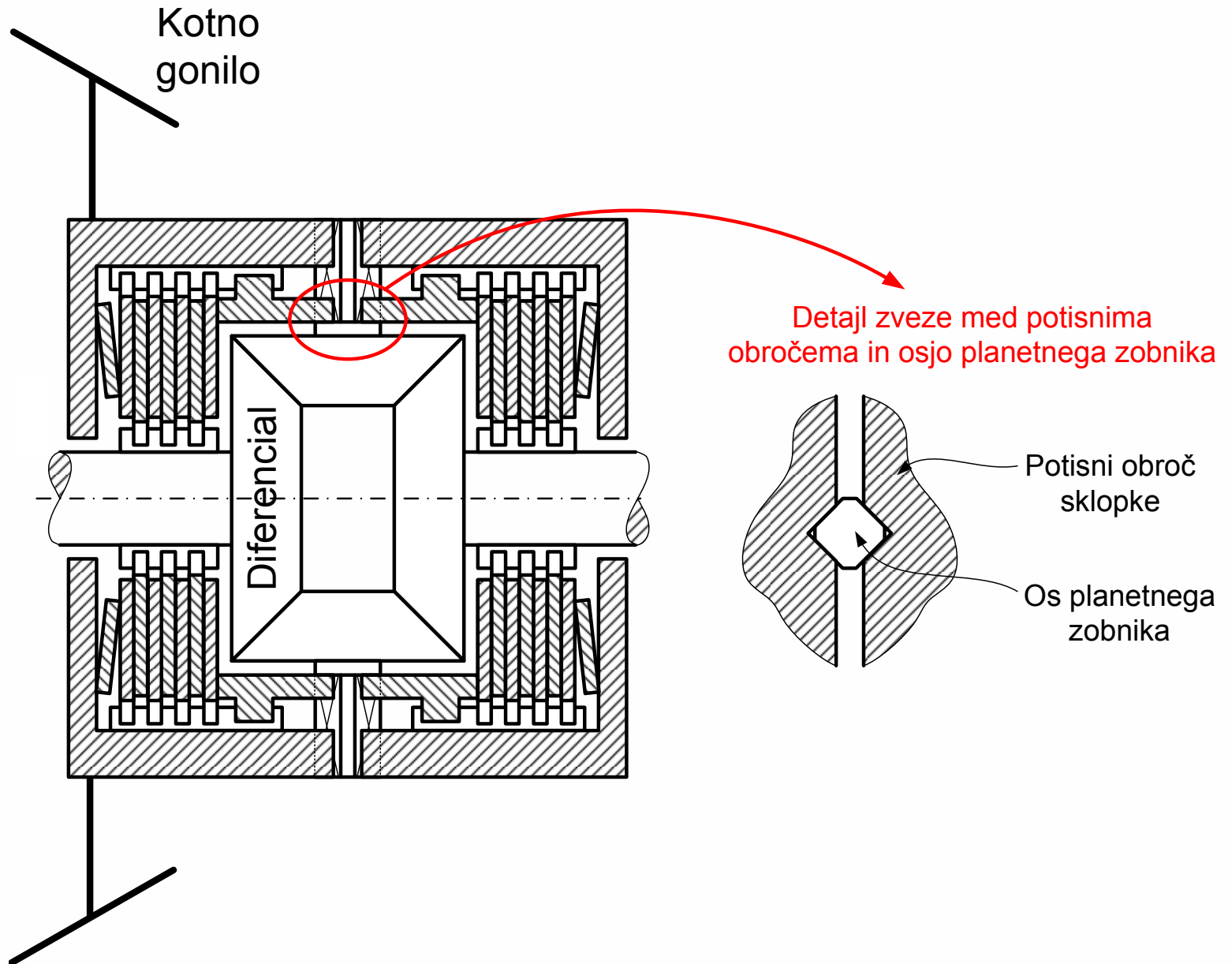
- Pogonska prema z diferencialom – trda podlaga na notranji strani ovinka, mehka podlaga na zunanji strani ovinka:



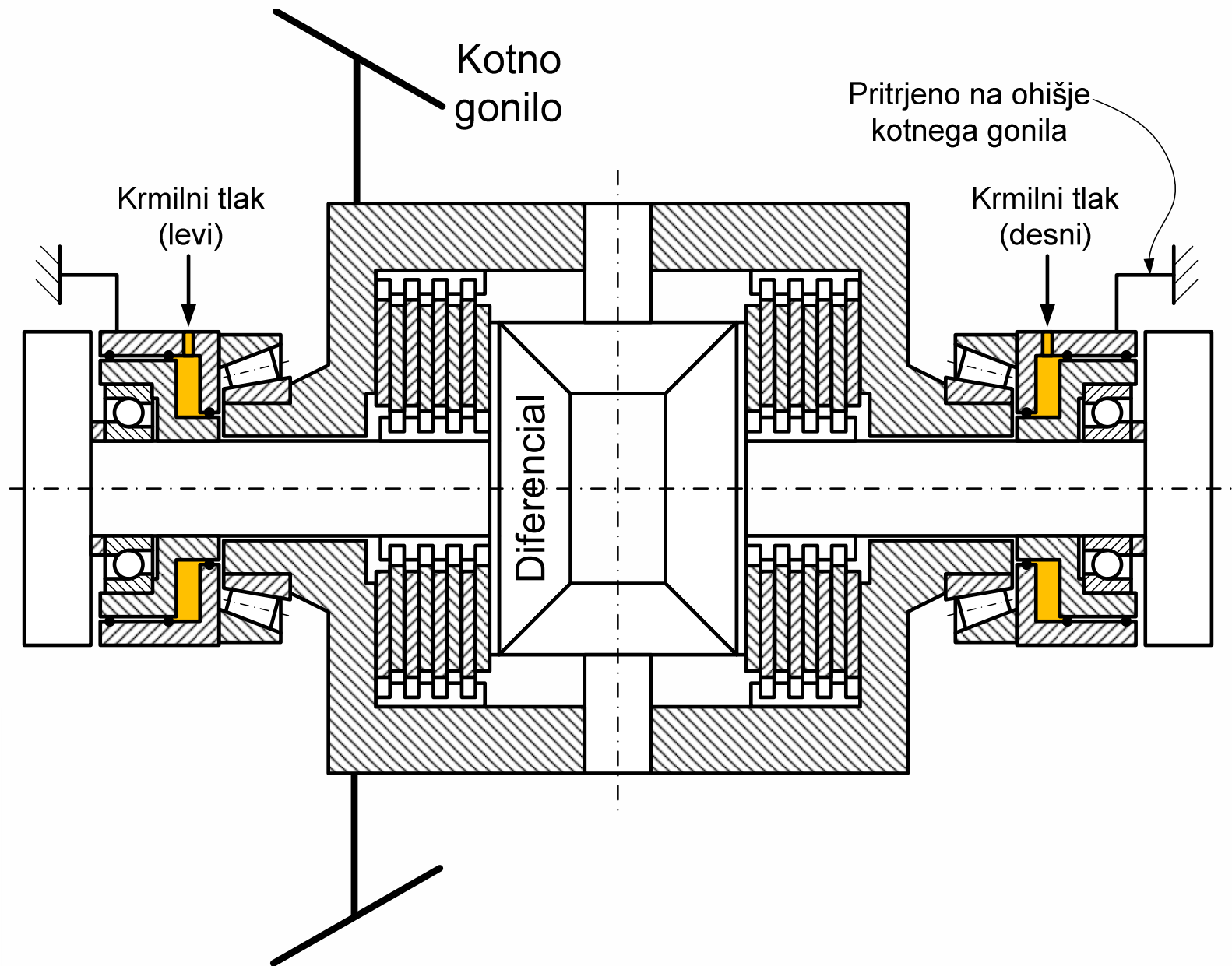
TORSEN diferencial



Mehanski samozaporni diferencial z lamelami



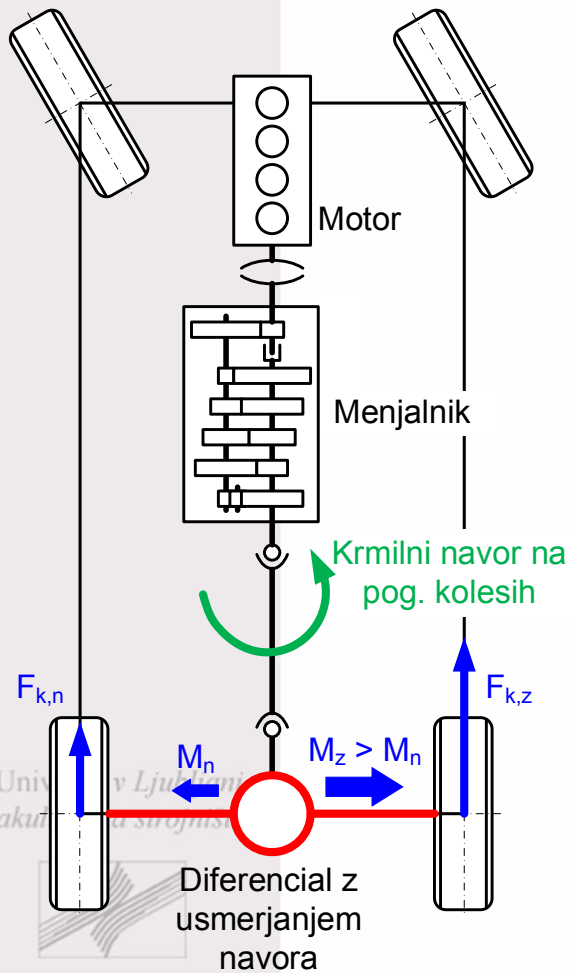
Avtomatski samozaporni diferencial z lamelami - ASD



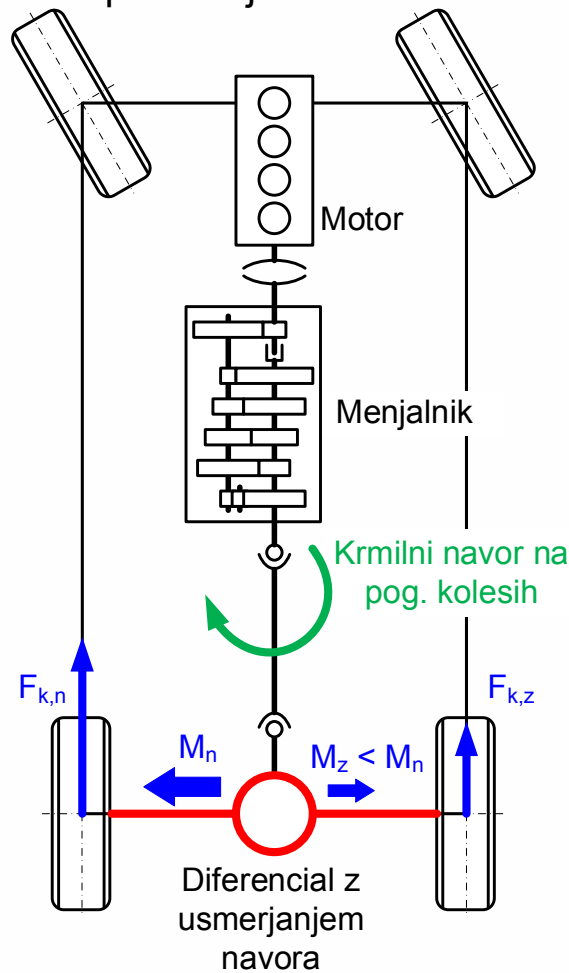
Diferencial z usmerjanjem navora (Torque vectoring differential)

■ Namen:

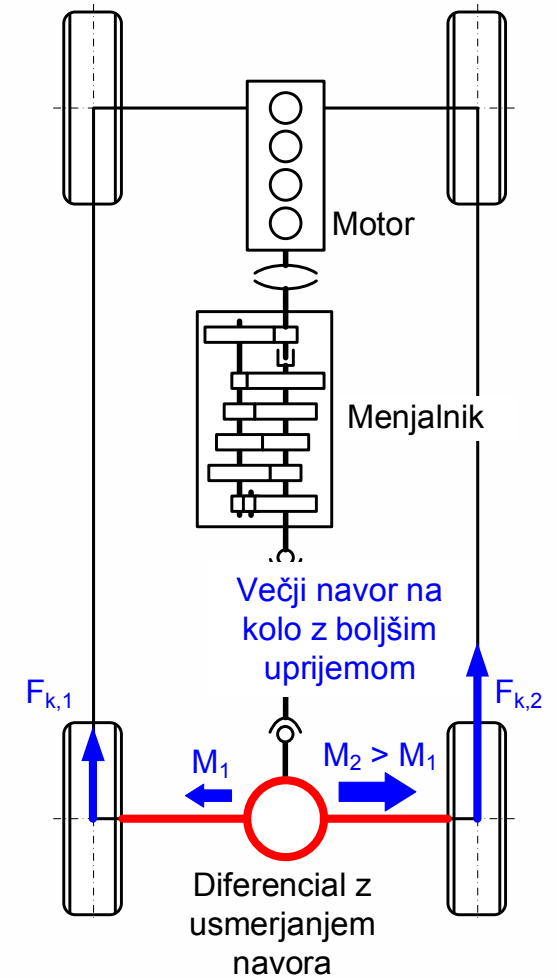
Agilna vožnja v ovinek



Varnost – stabilizacija pri vožnji v ovinek



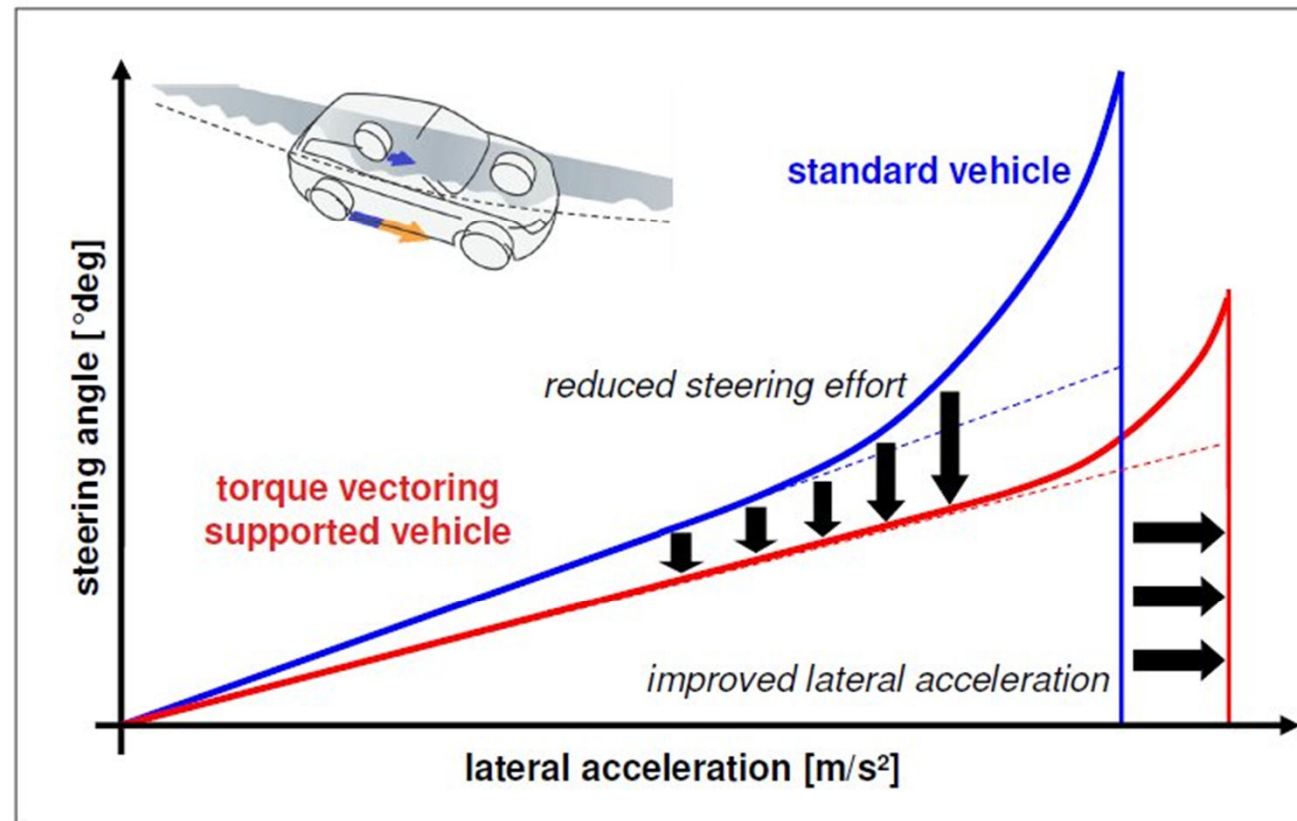
Izboljšanje uprijema



Diferencial z usmerjanjem navora

■ Učinek na vožnjo v ovinek:

Influence of torque vectoring on the self-steering effect

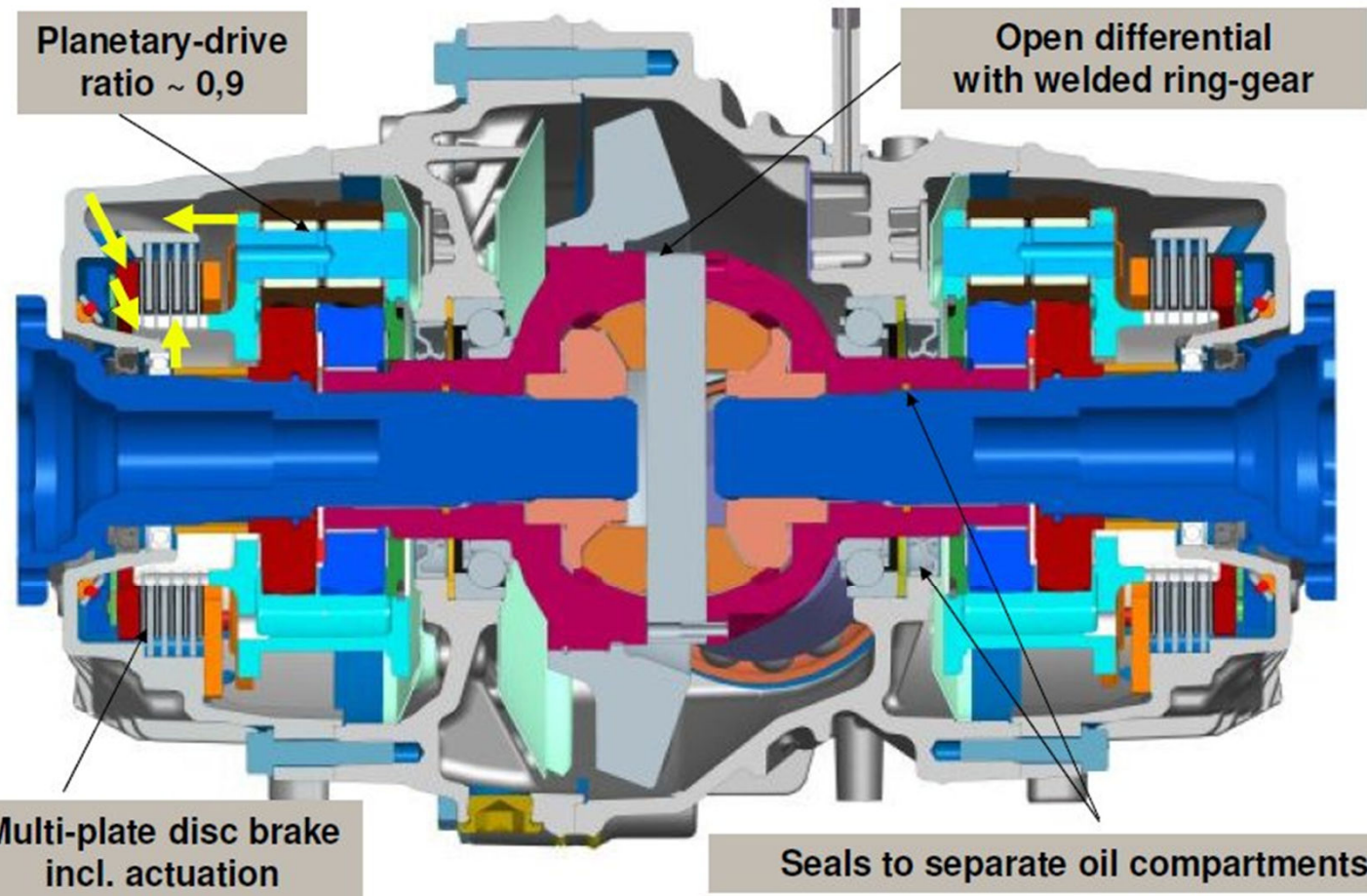


Diferencial z usmerjanjem navora

- Prerez sestava:



ZF Vector Drive Design-Layout



15

Praktischer Entwurf mechatronischer Systeme, Karlsruhe 13.12.2013

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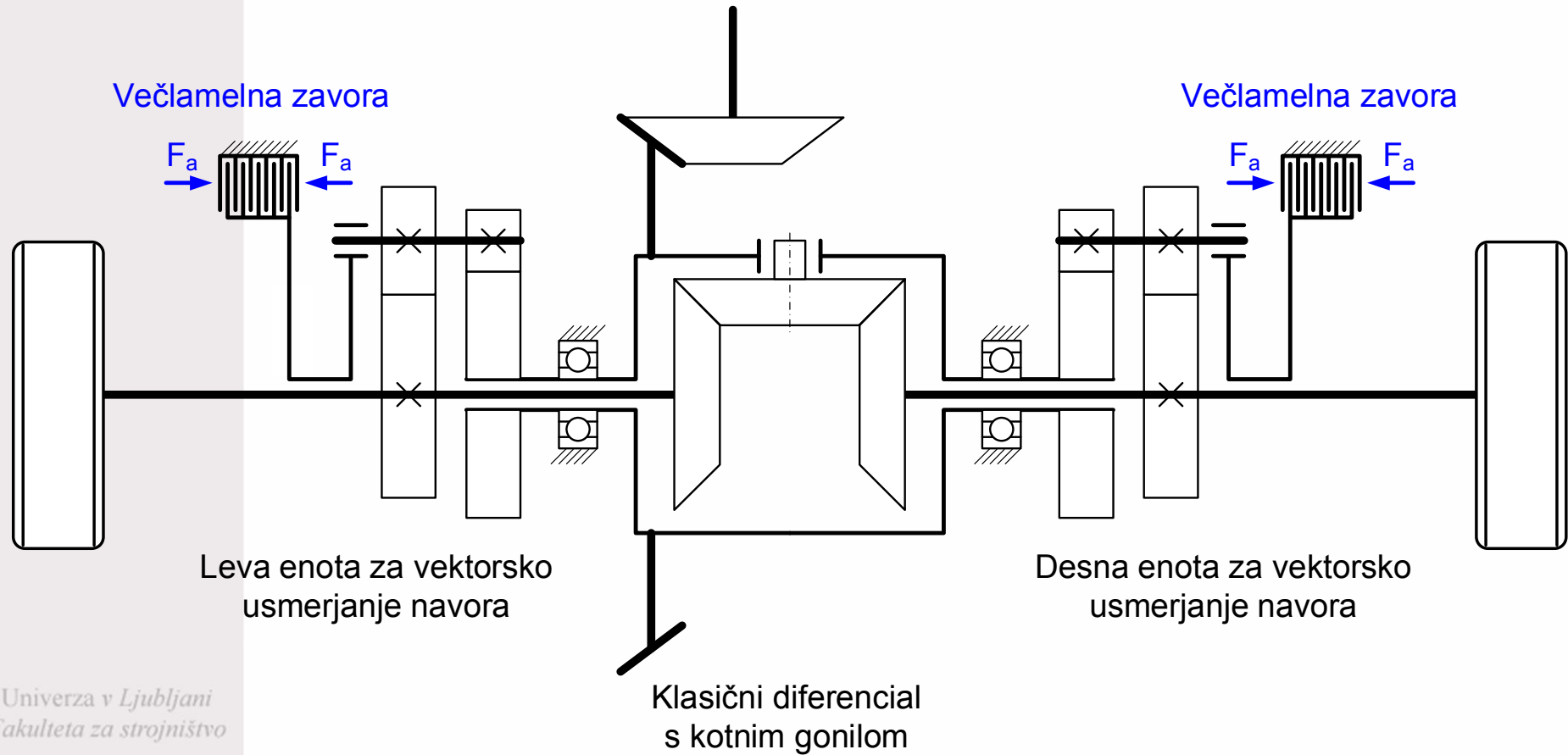


Katedra za strojne elemente
in razvojna vrednotenja

Granzow 2013, str. 15.

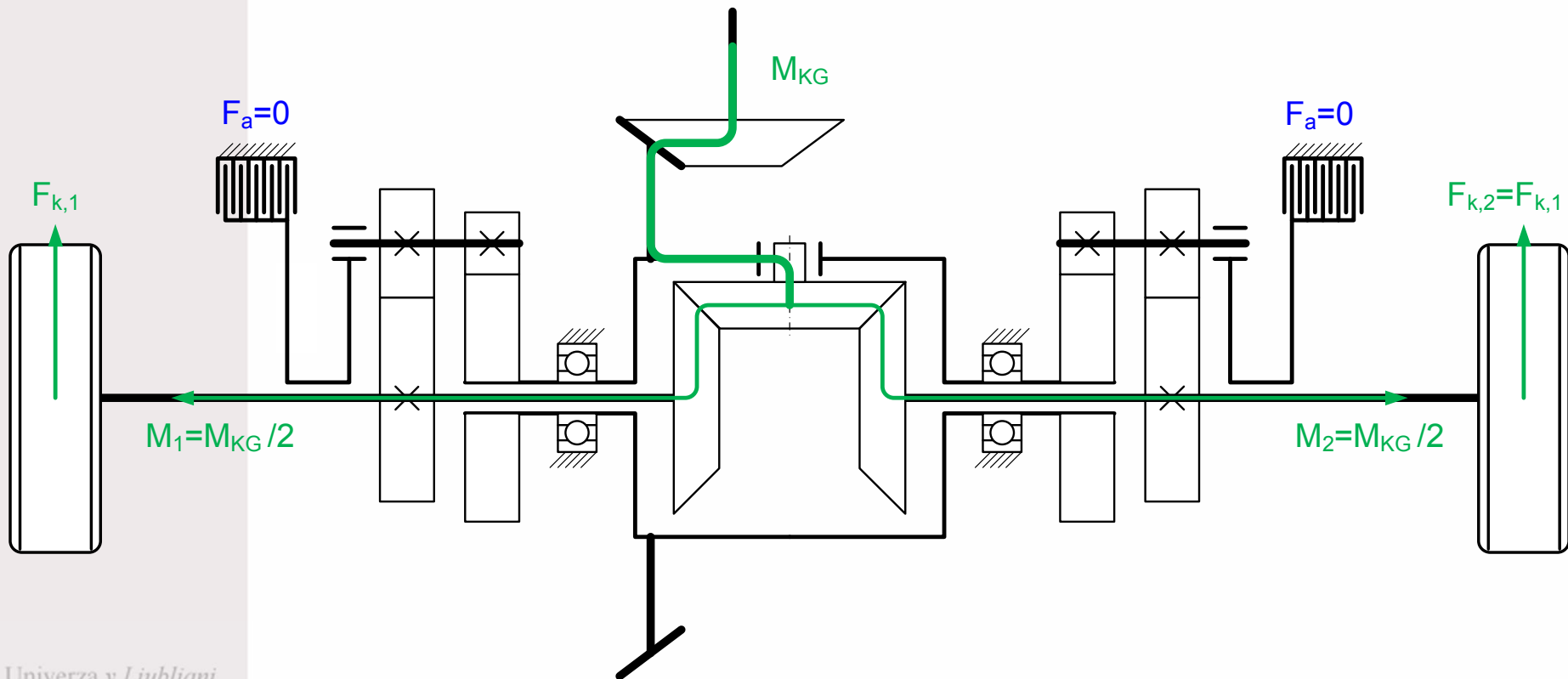
Diferencial z usmerjanjem navora

- Funkcionalni sestav diferenciala **ZF Vector drive**:



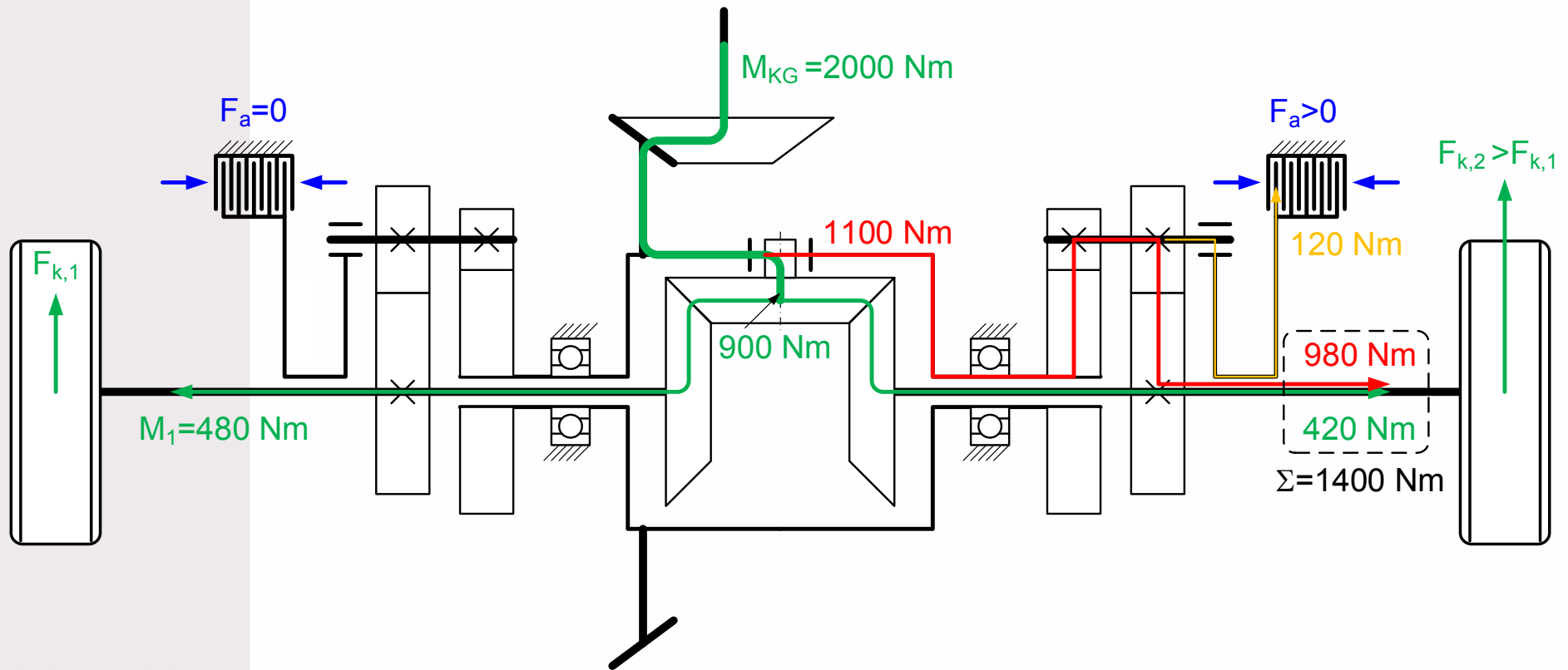
Diferencial z usmerjanjem navora

- Princip delovanja brez vektorskega usmerjanja navora:



Diferencial z usmerjanjem navora

- Princip delovanja z vektorskim usmerjanjem navora:

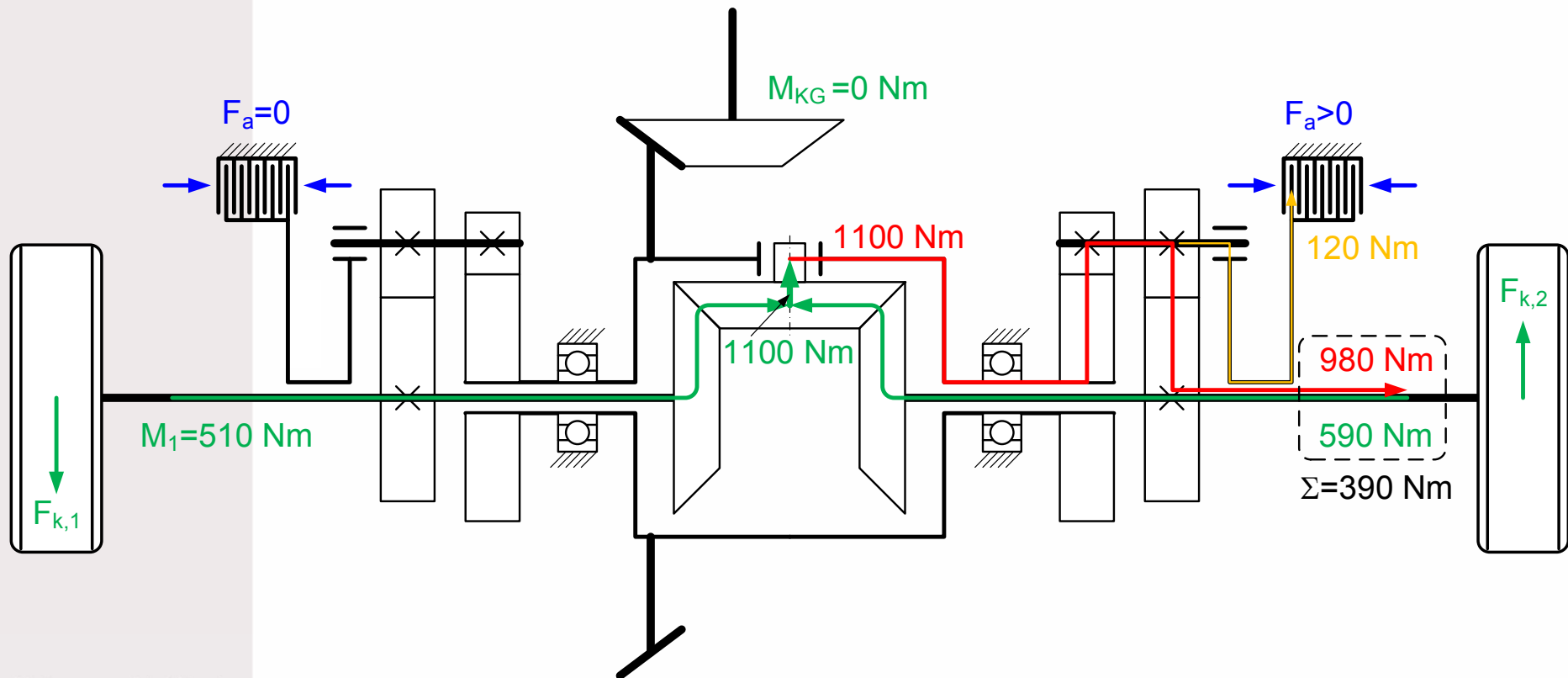


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Granzow 2013, str. 10.



Diferencial z usmerjanjem navora

- Princip delovanja z vektorskim usmerjanjem navora:



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Granzow 2013, str. 11.



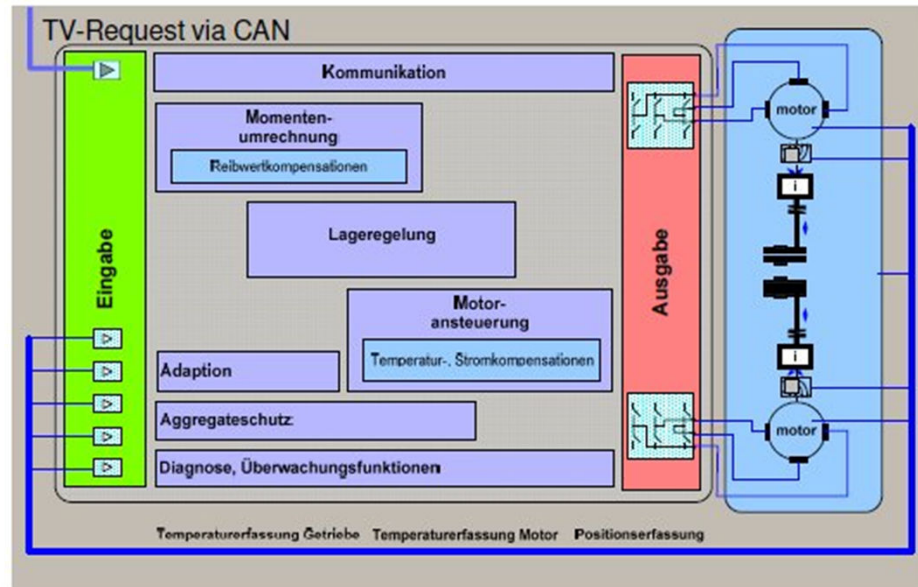
Katedra za strojne elemente
in razvojna vrednotenja

Diferencial z usmerjanjem navora

- Diferencial z usmerjanjem navora je mehatronski sistem:



ZF Vector Drive Block diagram E/E-System

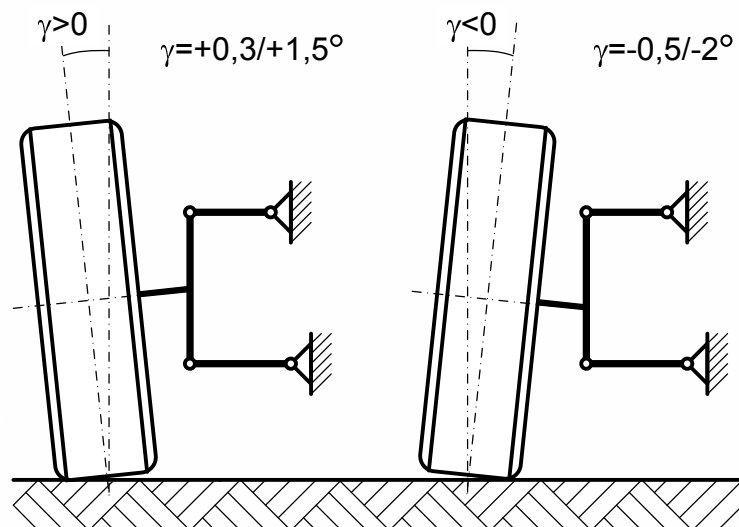


- control of the two asynchronous motors (power electronics included)
- clutch control by position control
- compensation of temperature, aging and production variances effects
- safety concept with diagnostic routines, redundancy functions and dual controller concept



Postavitev vodilnih koles vozila

■ Previs kolesa:

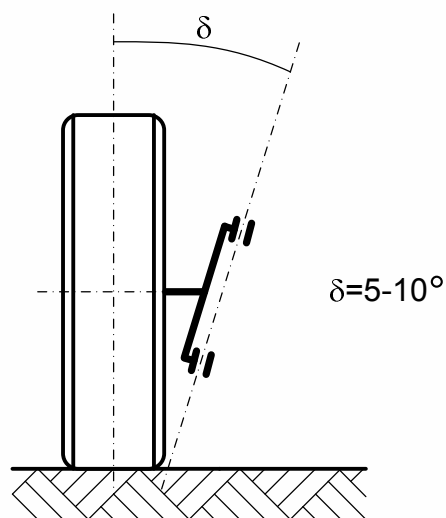


■ Izniči zračnost v ležajih.

■ Pozitivni previs zmanjšuje stranske vodilne sile pri vožnji v ovinek.

■ Negativni previs izboljšuje stransko vodenje pri vožnji v ovinek.

■ Prečni nagib premnega sornika:



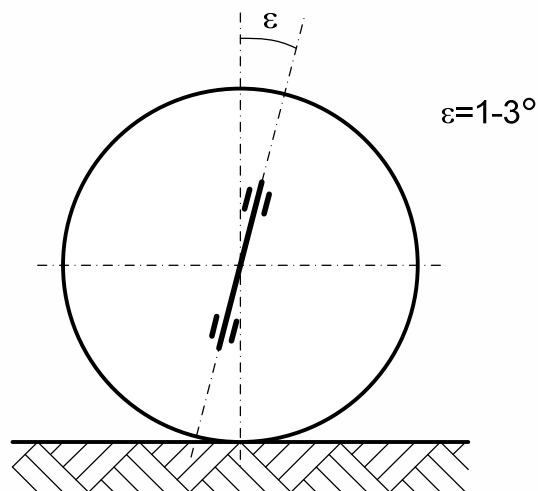
■ Povzroči dviganje prednjega dela vozila pri zasuku vodilnih koles.

■ Posledica je samodejno vzpostavljanje položaja koles za vožnjo naravnost, če voznik izpusti volan.



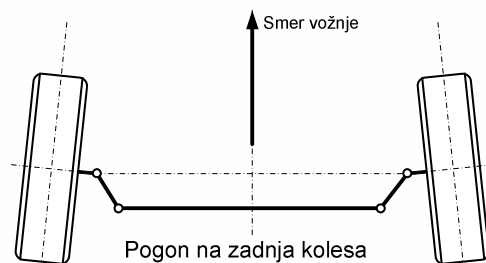
Postavitev vodilnih koles vozila

- Vzdolžni nagib premnega sornika (kot zaostajanja):

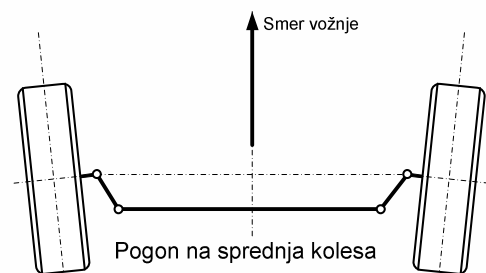


- Kot zaostajanja kolesa usmeri tako, da dosežemo stabilnost zasukanih koles.

- Stekanje/raztekanje koles:



- Napenja pnevmatike in drogovje krmilnega mehanizma.



- Zmanjšuje opletanje koles.



Seznam literature

- Granzow C.: ZF Vector Drive – better driving dynamics and driving safety through Torque Vectoring. Praktischer Entwurf mechatronischer Systeme, Karlsruhe 13.12.2013.
- Lewis R., Olofsson U. (editors): Wheel-rail interface handbook. Boca Raton: Woodhead Publishing in Mechanical Engineering, 2009.
- Wong J.Y.: Theory of Ground Vehicles, 3rd edition. New York: John Willey & Sons, 2001.
- Simić D.: Motorna vozila. Beograd: Naučna knjiga, 1988.
- Janičijević N., Janković D., Todorović J.: Konstrukcija motornih vozila. Beograd: Mašinski fakultet, 1979.
- Goljar M.: Motorna vozila, osnove konstruiranja. Ljubljana: Fakulteta za strojništvo, 1977.

