Univerza *v Ljubljani*
Fakulteta *za strojništvo*

Katedra za strojne elemente
in razvojna vrednotenja

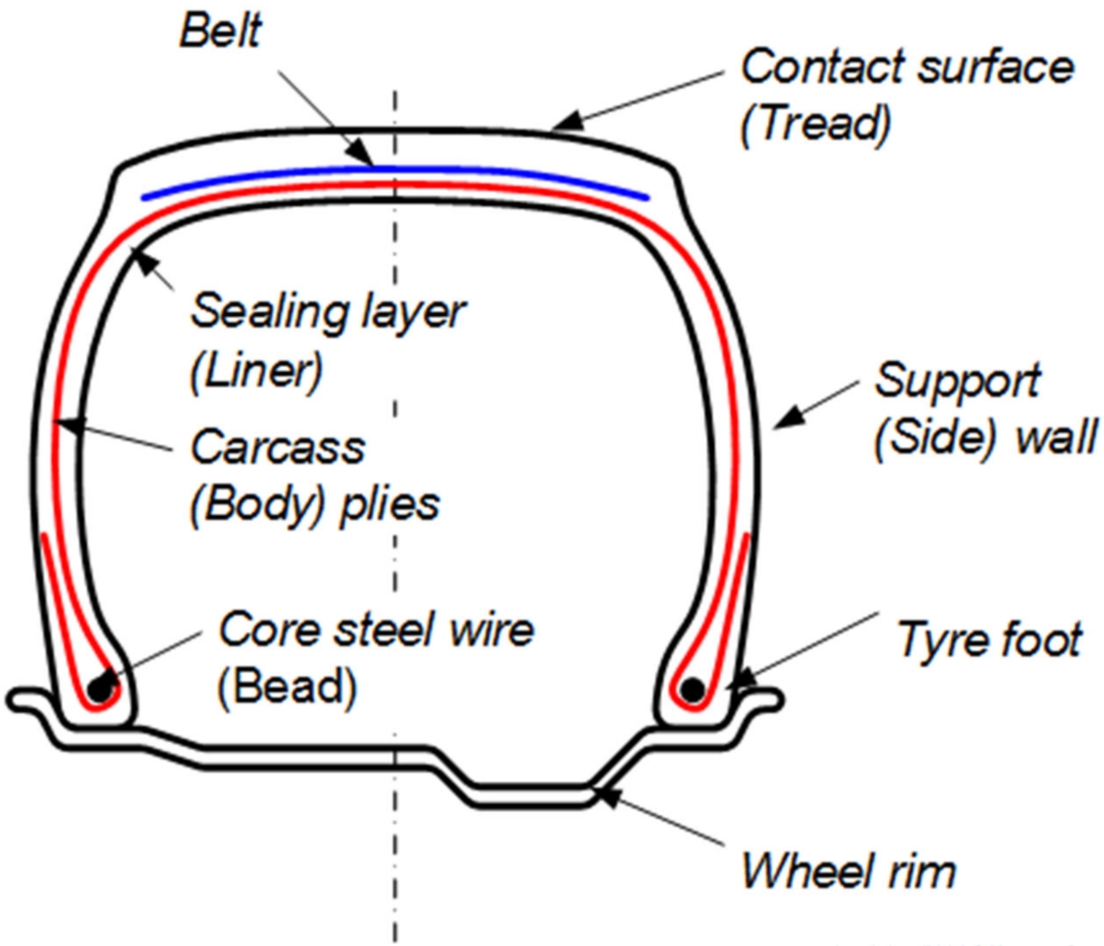
LAVEK
LABORATORIJ ZA VREDNOTENJE KONSTRUKCIJ

LASEM
LABORATORIJ ZA STROJNE ELEMENTE

Tires and differential gear

Asist. Prof. dr. Simon Oman

Composition of a radial-ply tire



Univerza v Ljubljani
Fakulteta za strojništvo

Tire labeling

- *265/50 R 14 101 V:*
  - *Radial-ply tire (R)*
  - *Tire width: 265 mm*
  - *Wheel-rim diameter : 14”*
  - *Tire-wall height : 0,50 * 265 mm*
  - *Load index: 101*
  - *Velocity index: V (maximum velocity = 240 km/h)*

- *6,40-13/6 PR:*
  - *Bias-ply tire*
  - *Tire width: 6,40”*
  - *Wheel-rim diameter: 13”*
  - *Tire-wall height: 0,95 (super balloon for D) * 6,40”*
  - *Loading index: PR6*
  - *Velocity index: no index (maximum velocity = 150 km/h)*

Univerza v Ljubljani
Fakulteta za strojništvo

Tire labeling

- *Production date*: DOT xxyy
  - xx => *week*;
  - yy => *year*.

- *Tire load index*:

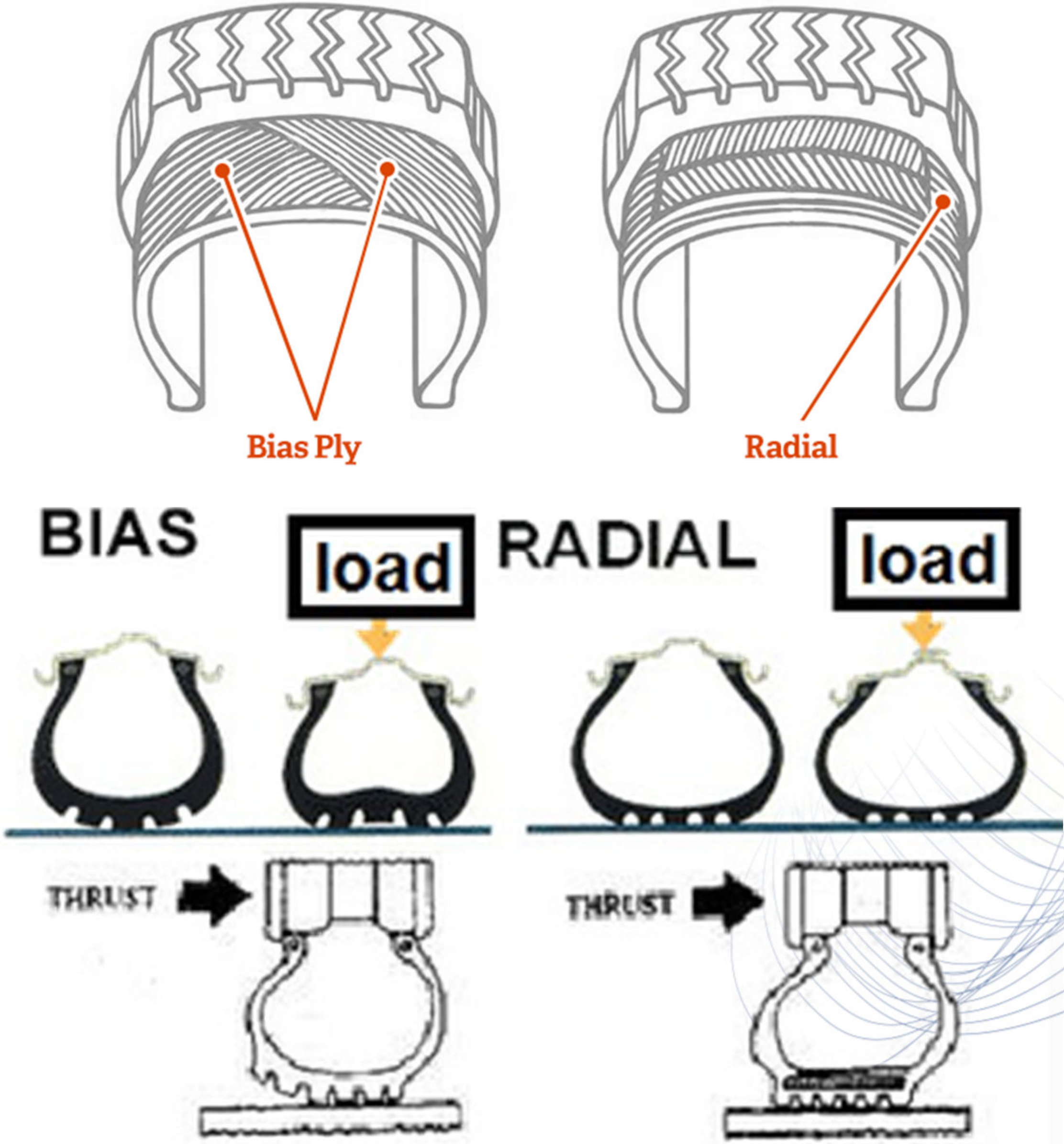
Load index	Load in Kg per tyre	Load index	Load in Kg per tyre	Load index	Load in Kg per tyre	Load index	Load in Kg per tyre	Load index	Load in Kg per tyre
62	265	75	387	88	560	101	825	114	1180
63	272	76	400	89	580	102	850	115	1215
64	280	77	412	90	600	103	875	116	1250
65	290	78	425	91	615	104	900	117	1285
66	300	79	437	92	630	105	925	118	1320
67	307	80	450	93	650	106	950	119	1360
68	315	81	462	94	670	107	975	120	1400
69	325	82	475	95	690	108	1000	121	1450
70	335	83	487	96	710	109	1030	122	1500
71	345	84	500	97	730	110	1060	123	1550
72	355	85	515	98	750	111	1090	124	1600
73	365	86	530	99	775	112	1120	125	1650
74	375	87	545	100	800	113	1150	126	1700

Tire labeling

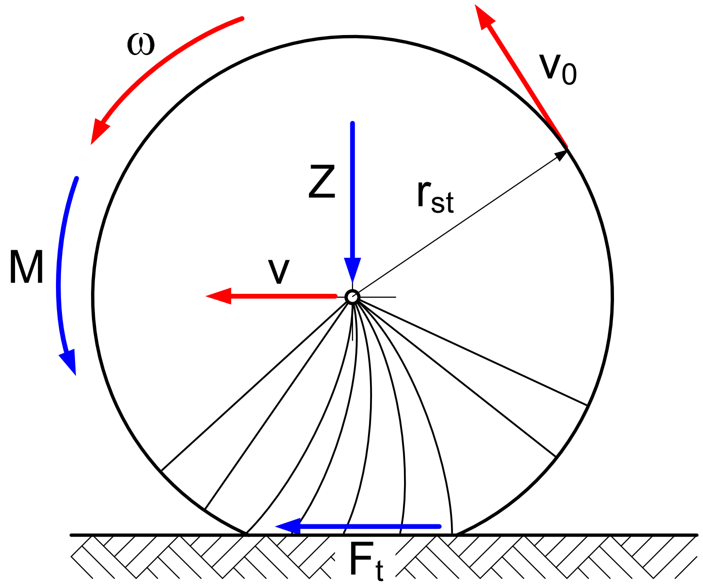
- *Tire velocity index:*
  - *P => 150 km/h*
  - *Q => 160 km/h*
  - *S => 180 km/h*
  - *T => 190 km/h*
  - *H => 210 km/h*
  - *V => 240 km/h*
  - *W => 270 km/h*
  - *Y => 300 km/h*
  - *VR => above 210 km/h*
  - *ZR=> above 240 km/h*

Univerza v Ljubljani
Fakulteta za strojništvo

Difference between radial and bias tire

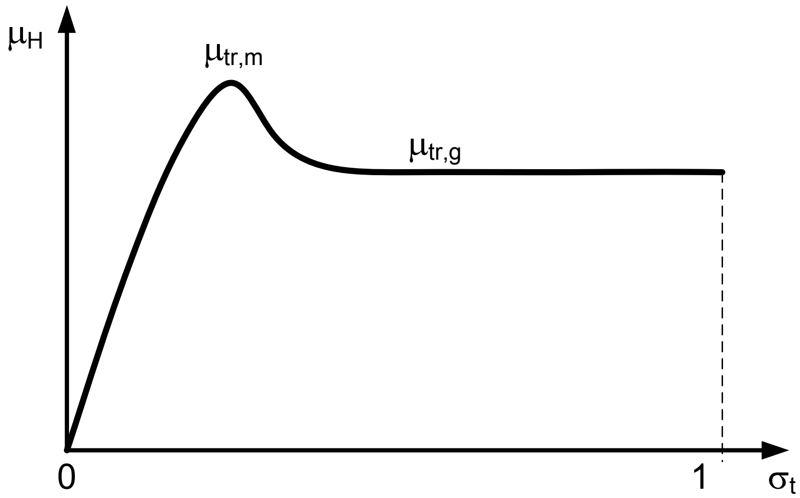


Tire as a friction wheel - acceleration



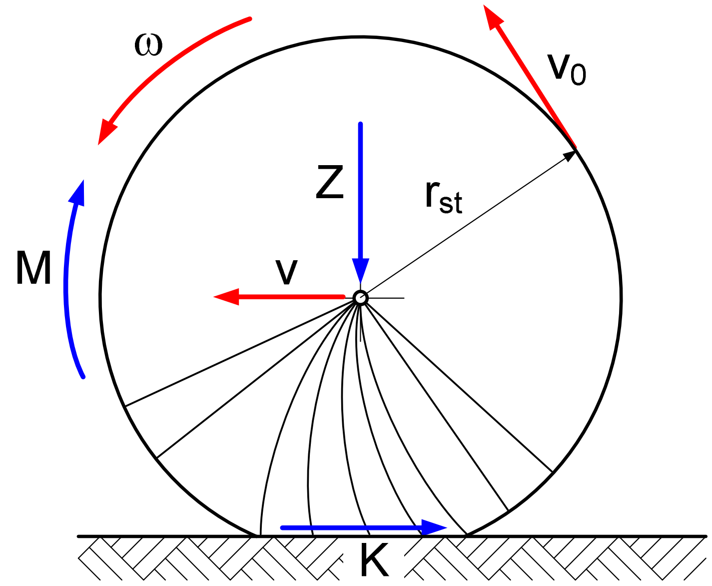
$$\mu_h = \frac{F_k}{Z}$$

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



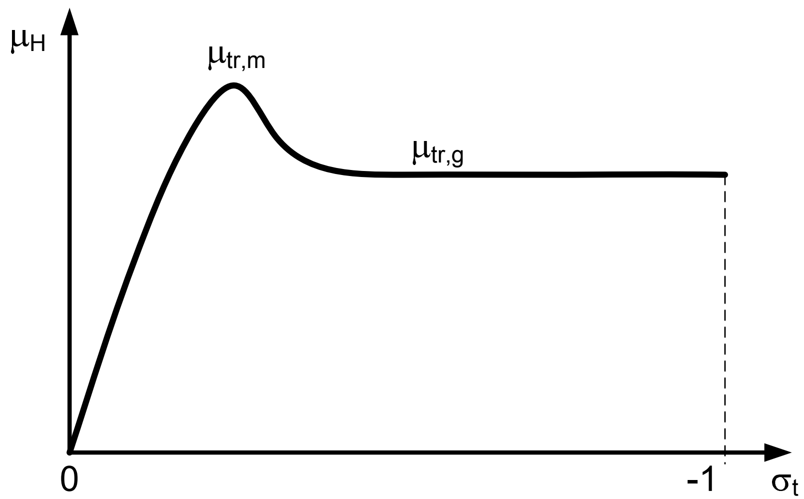
$$M = \mu_H \cdot Z \cdot r_{st} = \mu_H \cdot konst$$

Tire as a friction wheel - braking



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

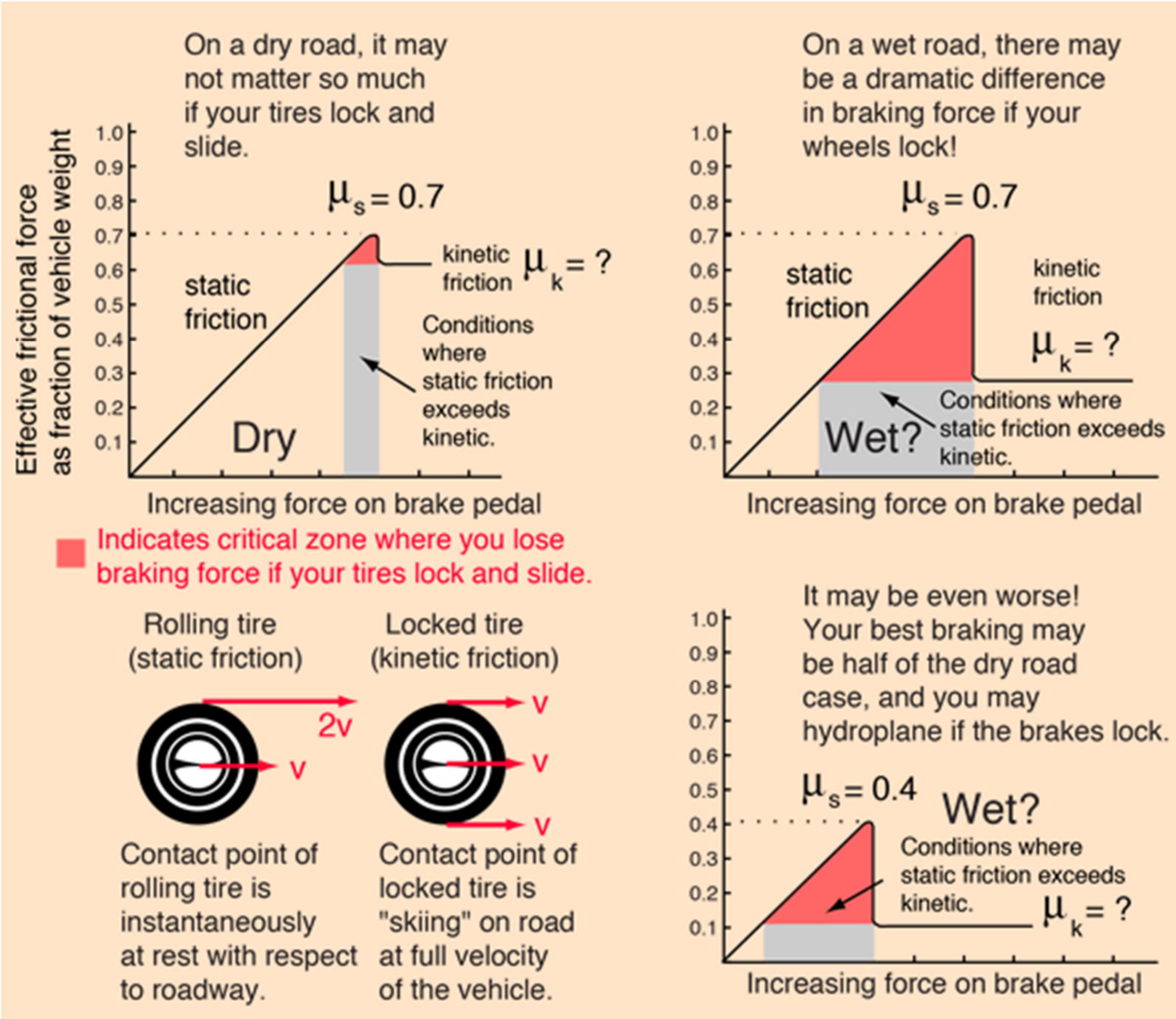
$$\sigma_t = \frac{v_0 - v}{v}$$



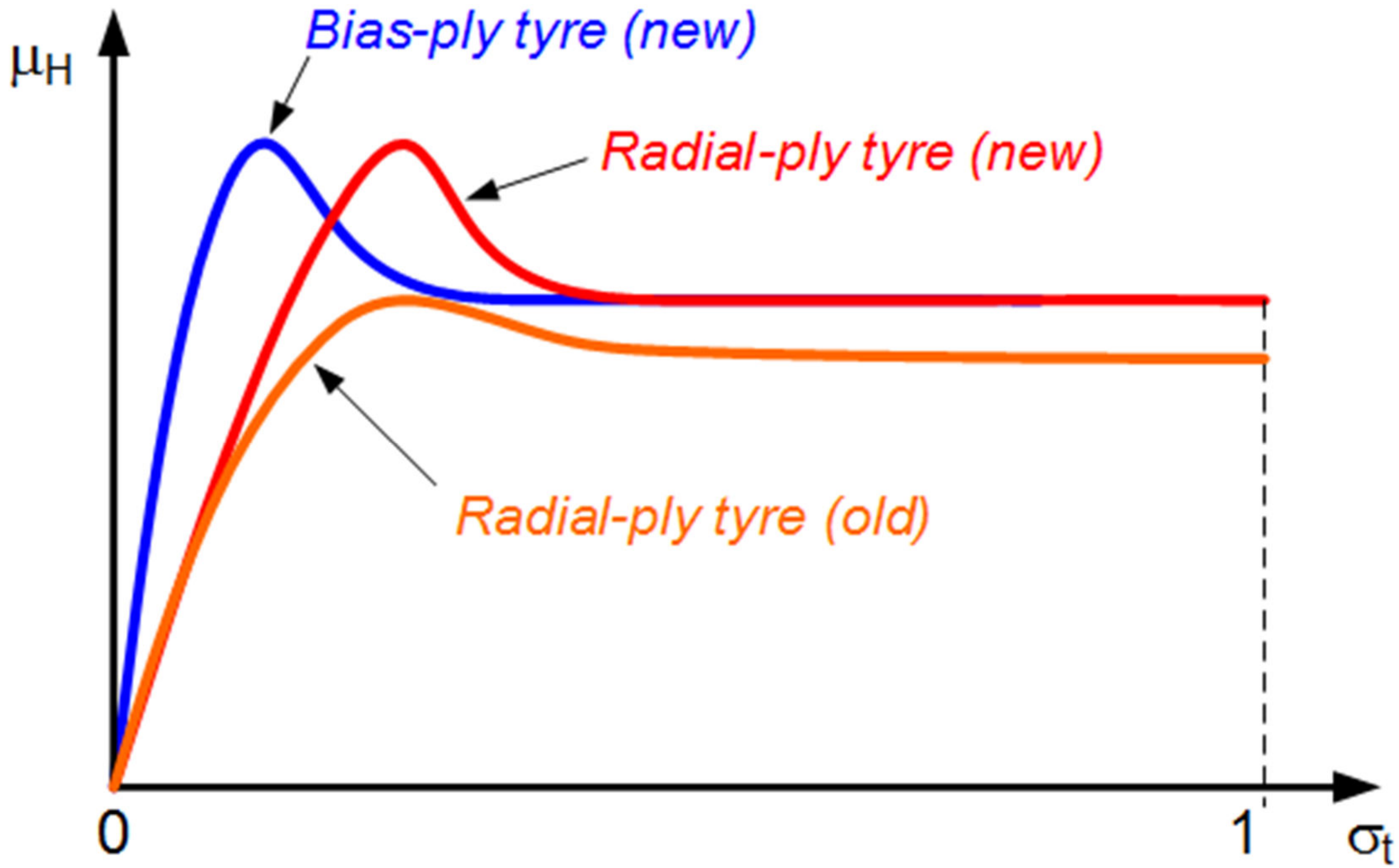
$$M = \mu_H \cdot Z \cdot r_{st} = \mu_H \cdot konst$$

Univerza v Ljubljani
Fakulteta za strojništvo

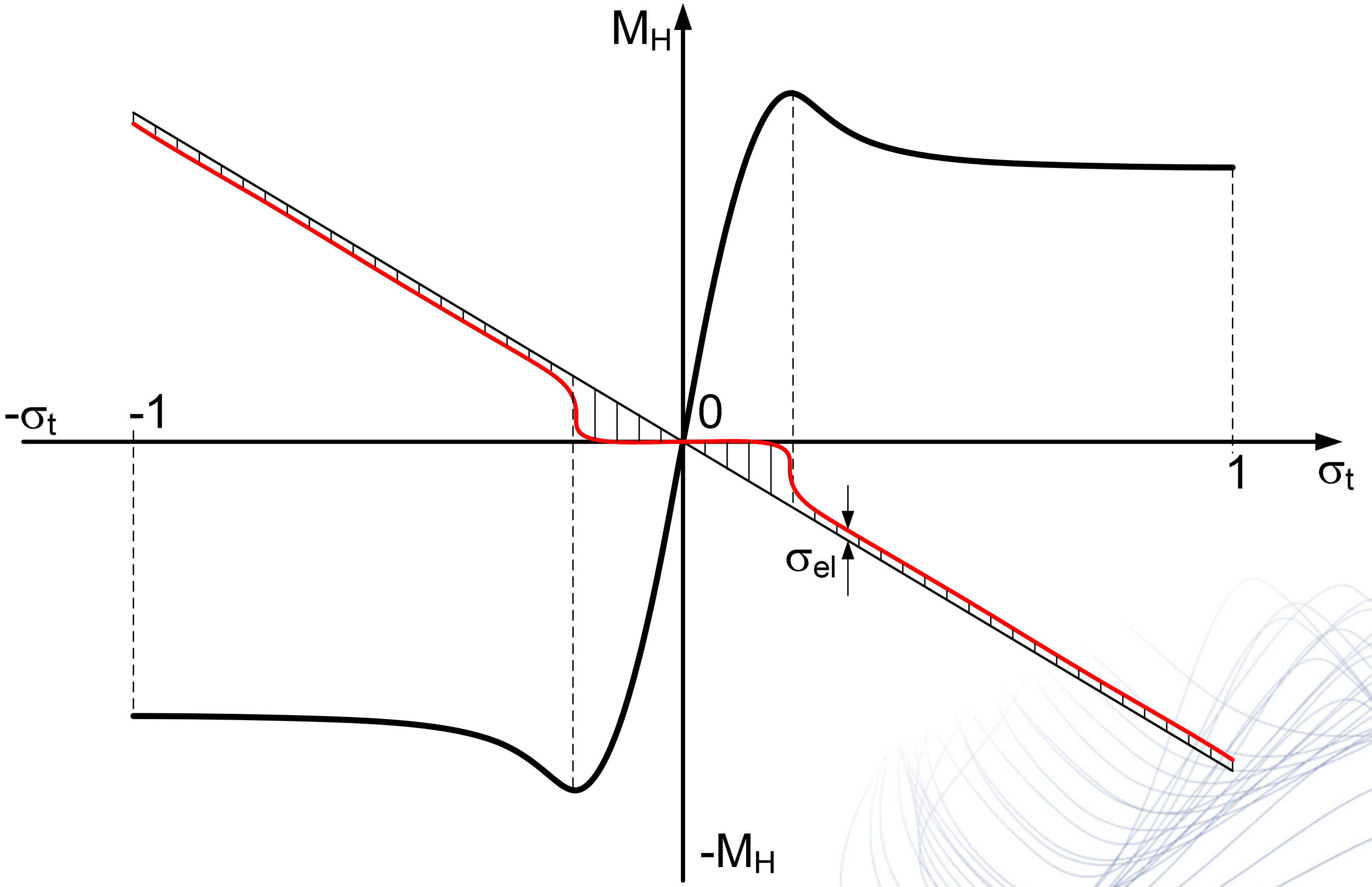
Difference between rolling and sliding



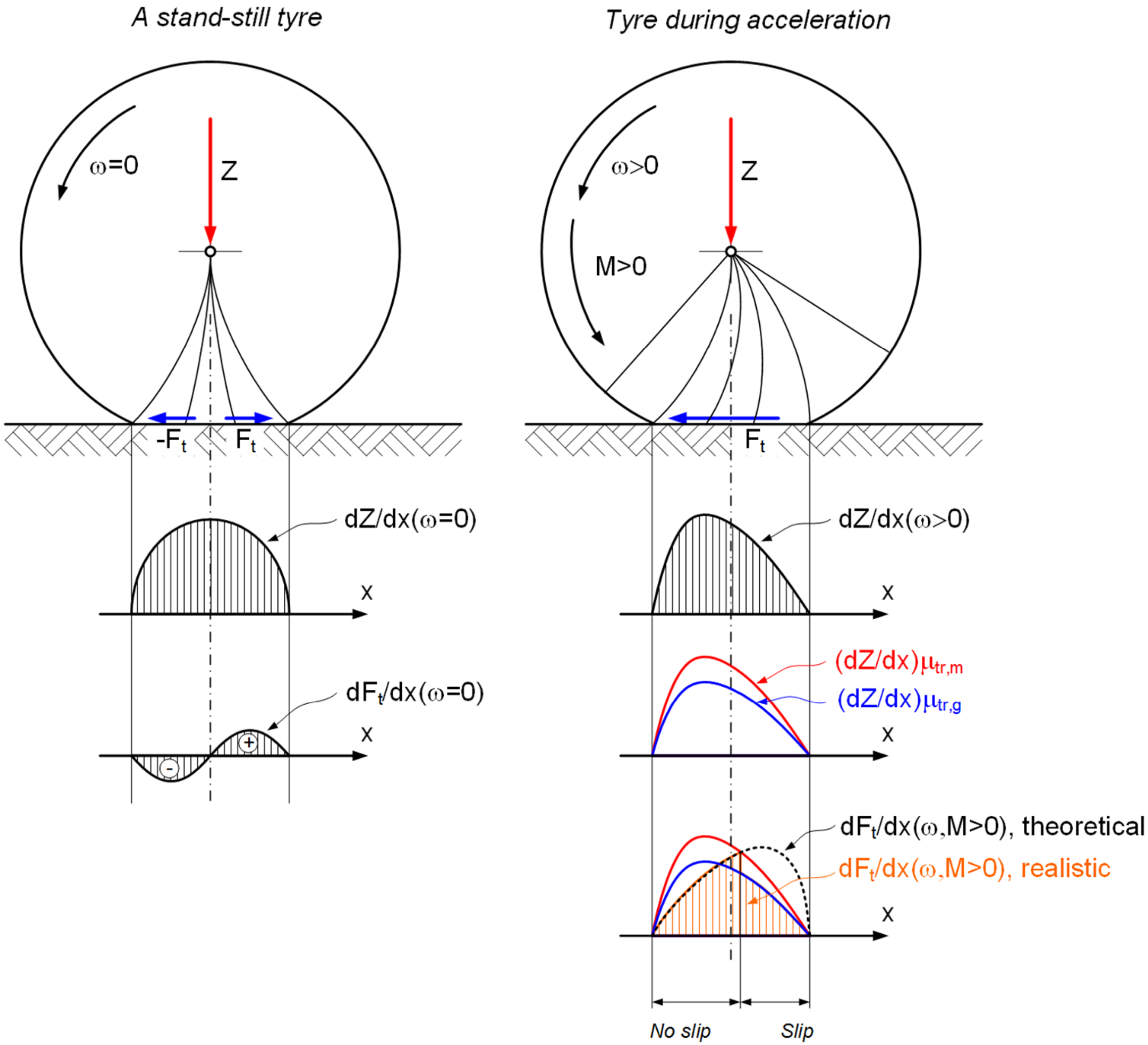
Traction diagram for radial-ply tires and bias-ply tires



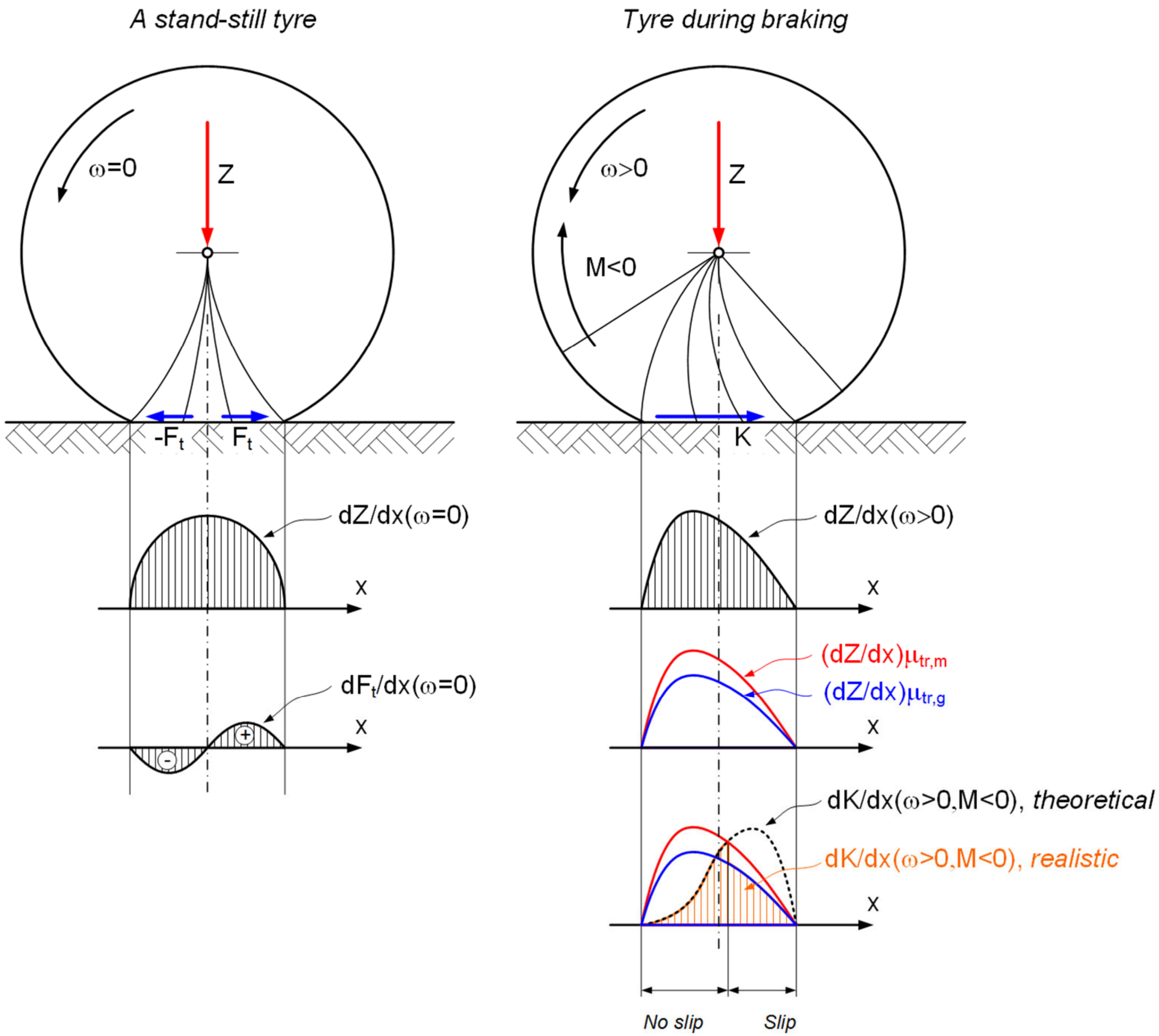
Traction diagram for accelerating and braking



Micro-contact between tire and driving surface during acceleration

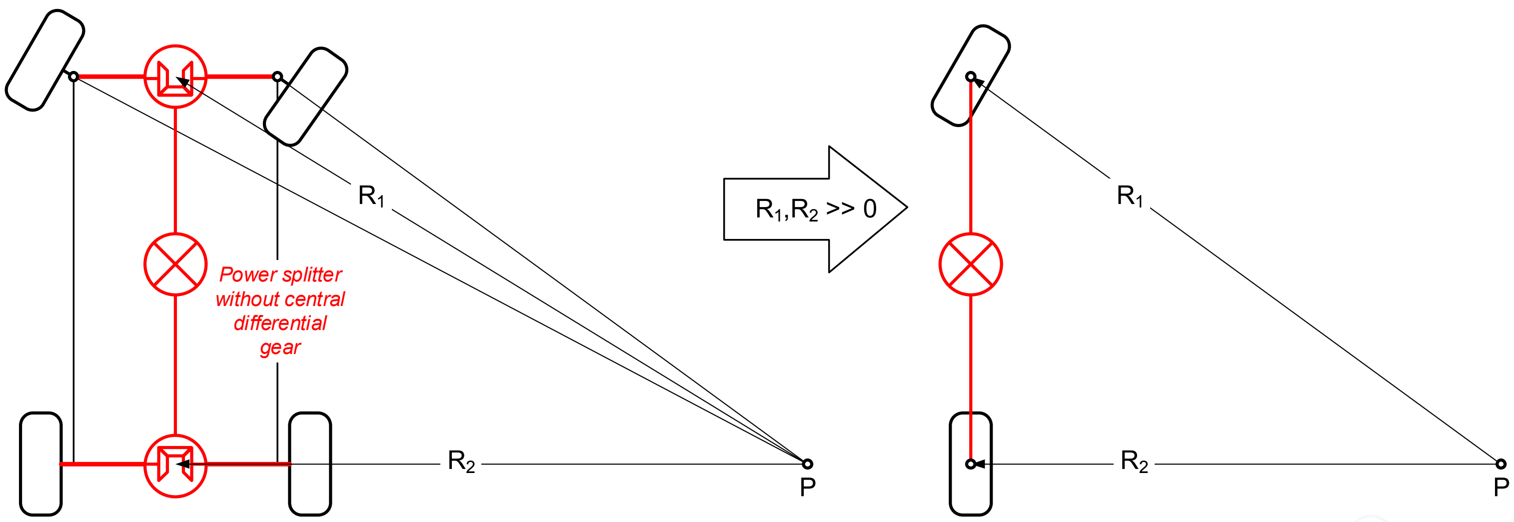


Micro-contact between tyre and driving surface during braking



4x4 wheel drive

- *Central power splitter without differential gear on a hard surface:*



- *Theoretical tangential velocities:*

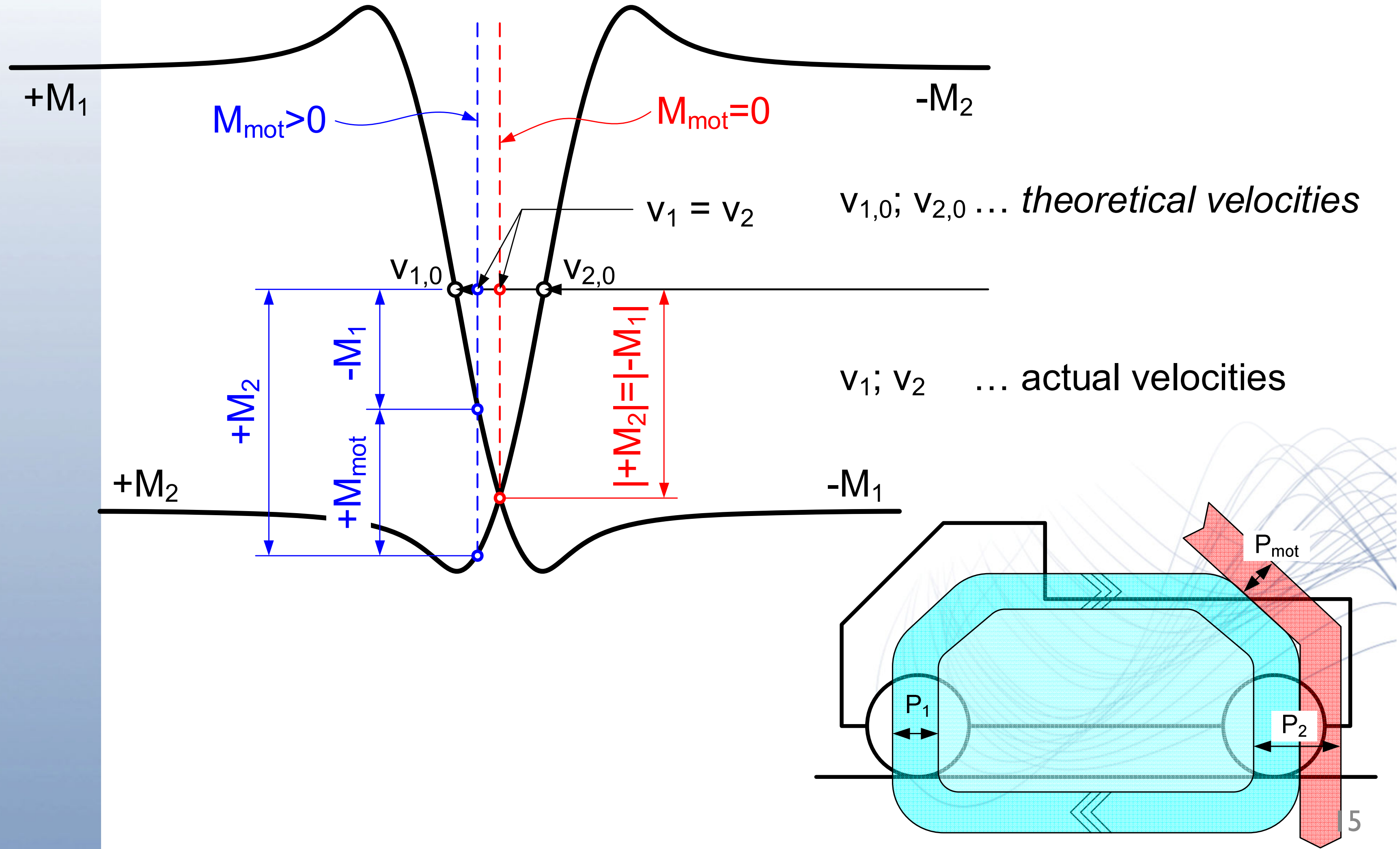
$$v_{1,0} = \omega_{1,0} \cdot r_{st} \propto R_1 > v_{2,0} = \omega_{2,0} \cdot r_{st} \propto R_2$$

- *Actual tangential velocities:*

$$v_1 = v_2 \;\; ; \;\; M_1 \neq M_2$$

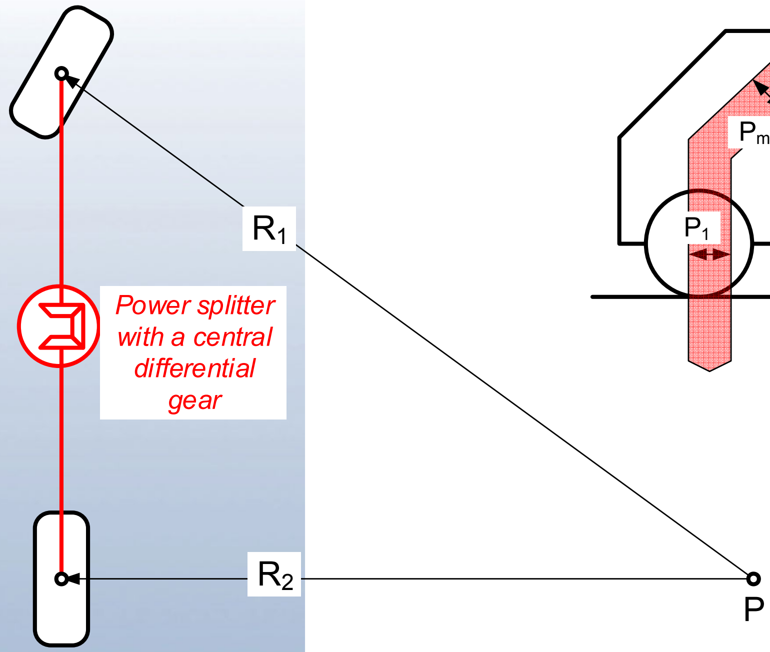
4x4 wheel drive

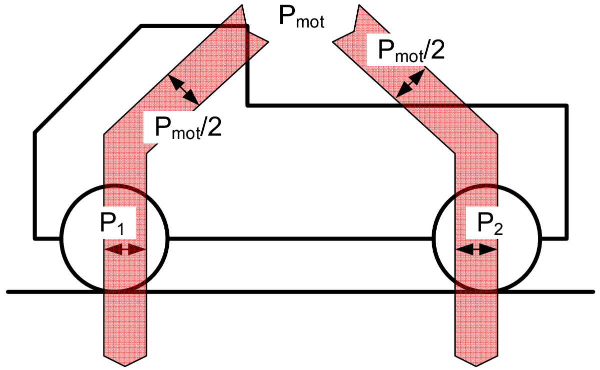
- *Central power splitter without differential gear on a hard surface:*

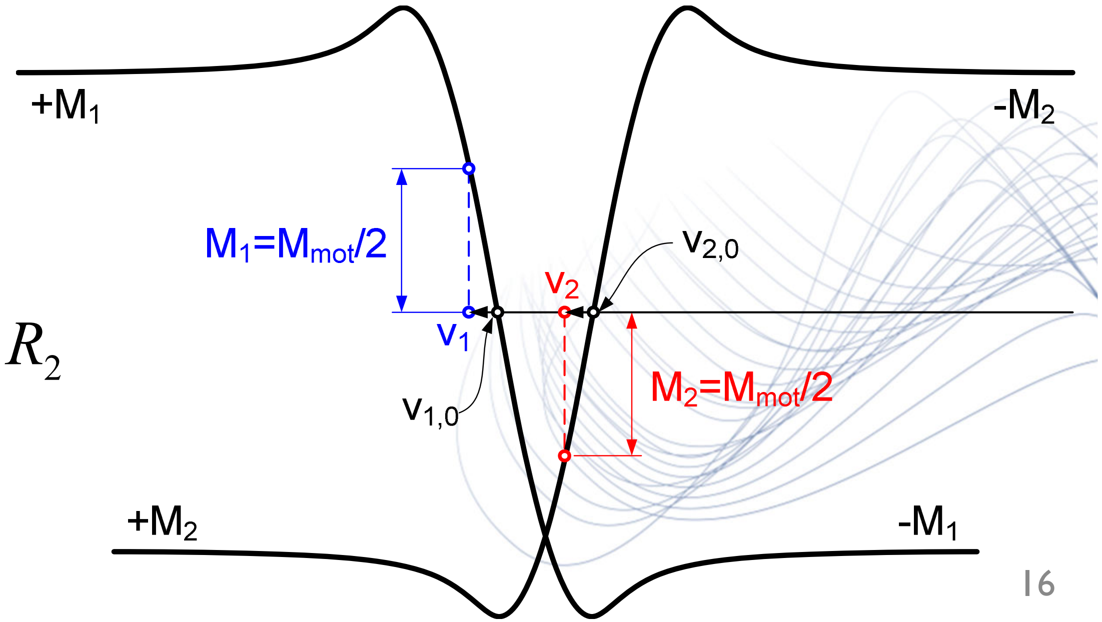


4x4 wheel drive

- *Central power splitter with a differential gear on a hard surface:*





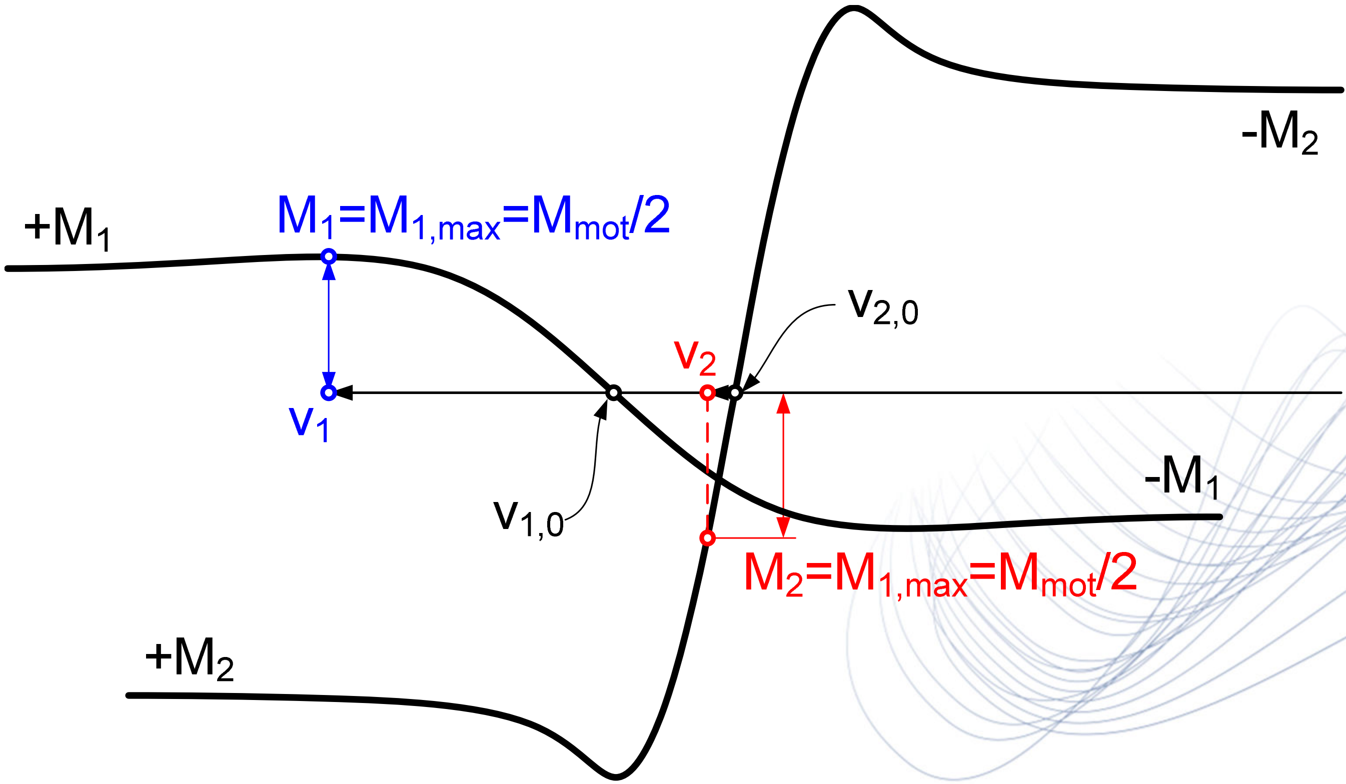


$$v_1 = \omega_1 \cdot r_{st} \propto R_1 > v_2 = \omega_2 \cdot r_{st} \propto R_2$$

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

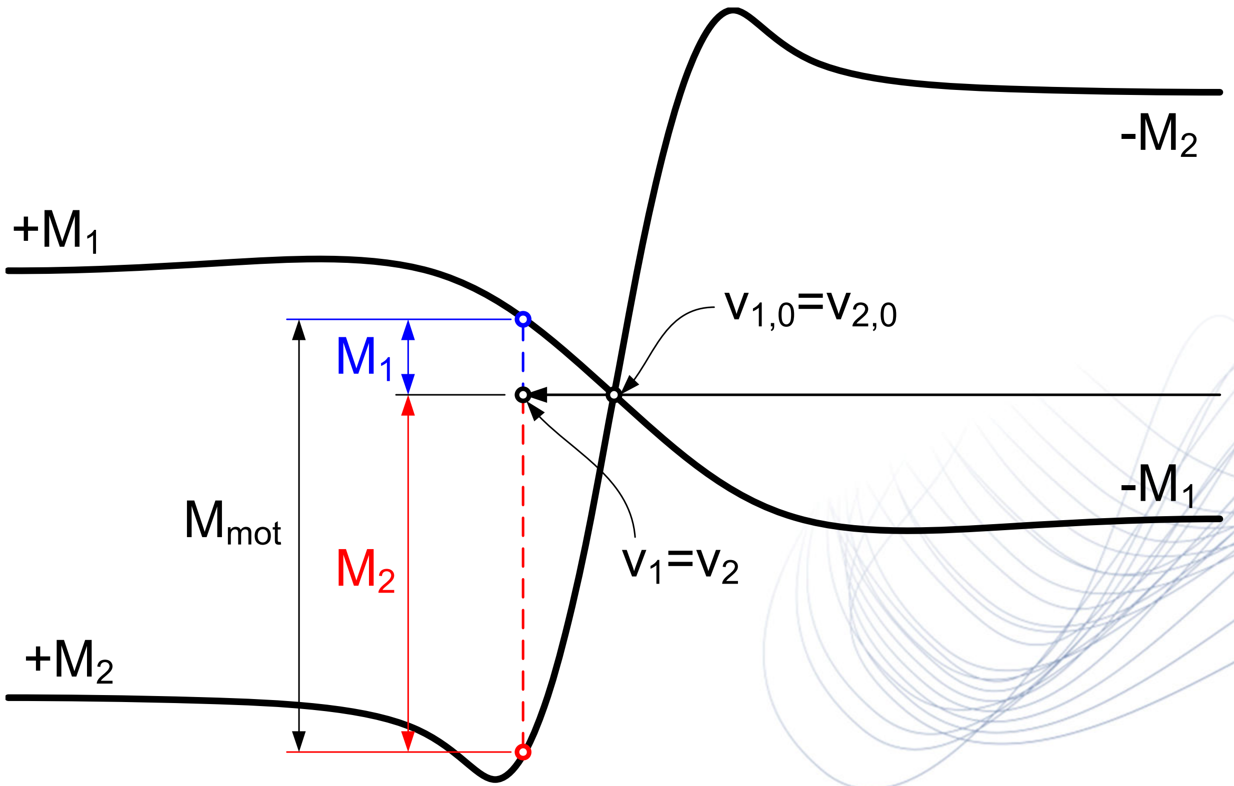
4x4 wheel drive

- *Central power splitter with a differential gear – hard surface under the rear axle, soft surface under the front axle, straight driving:*

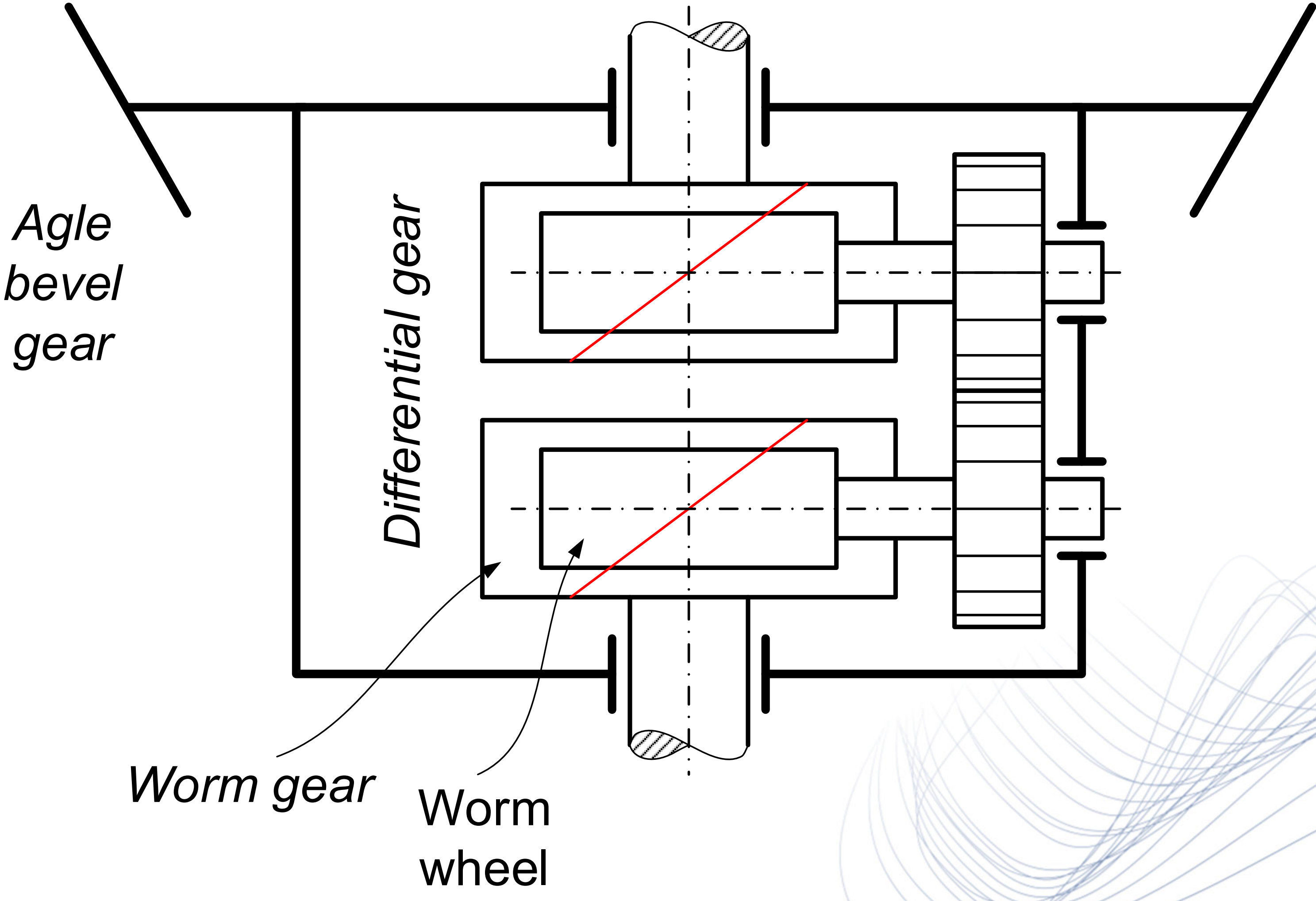


4x4 wheel drive

- *Central power splitter without differential gear – hard surface under the rear axle, soft surface under the front axle, straight driving:*



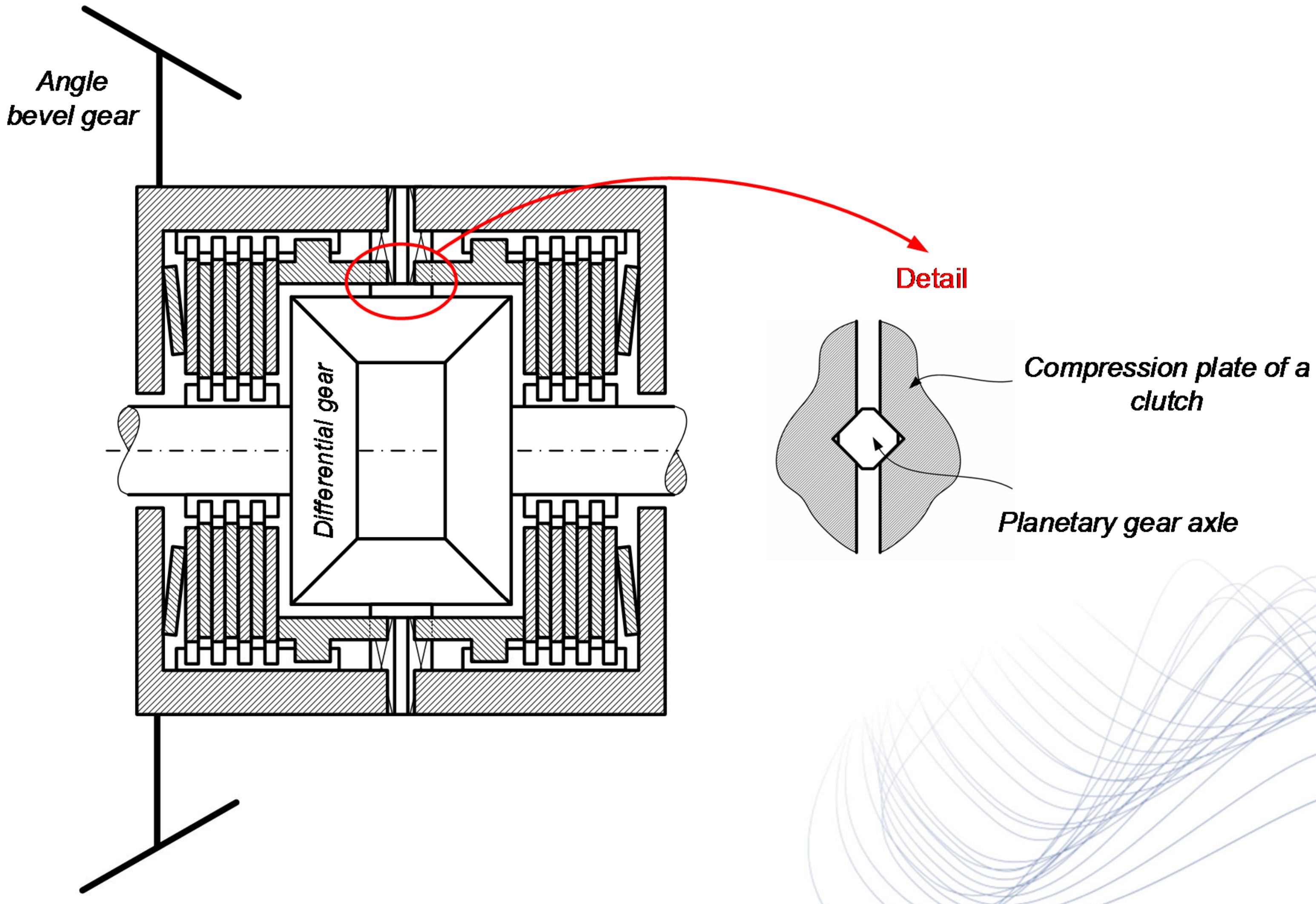
TORSEN differential gear



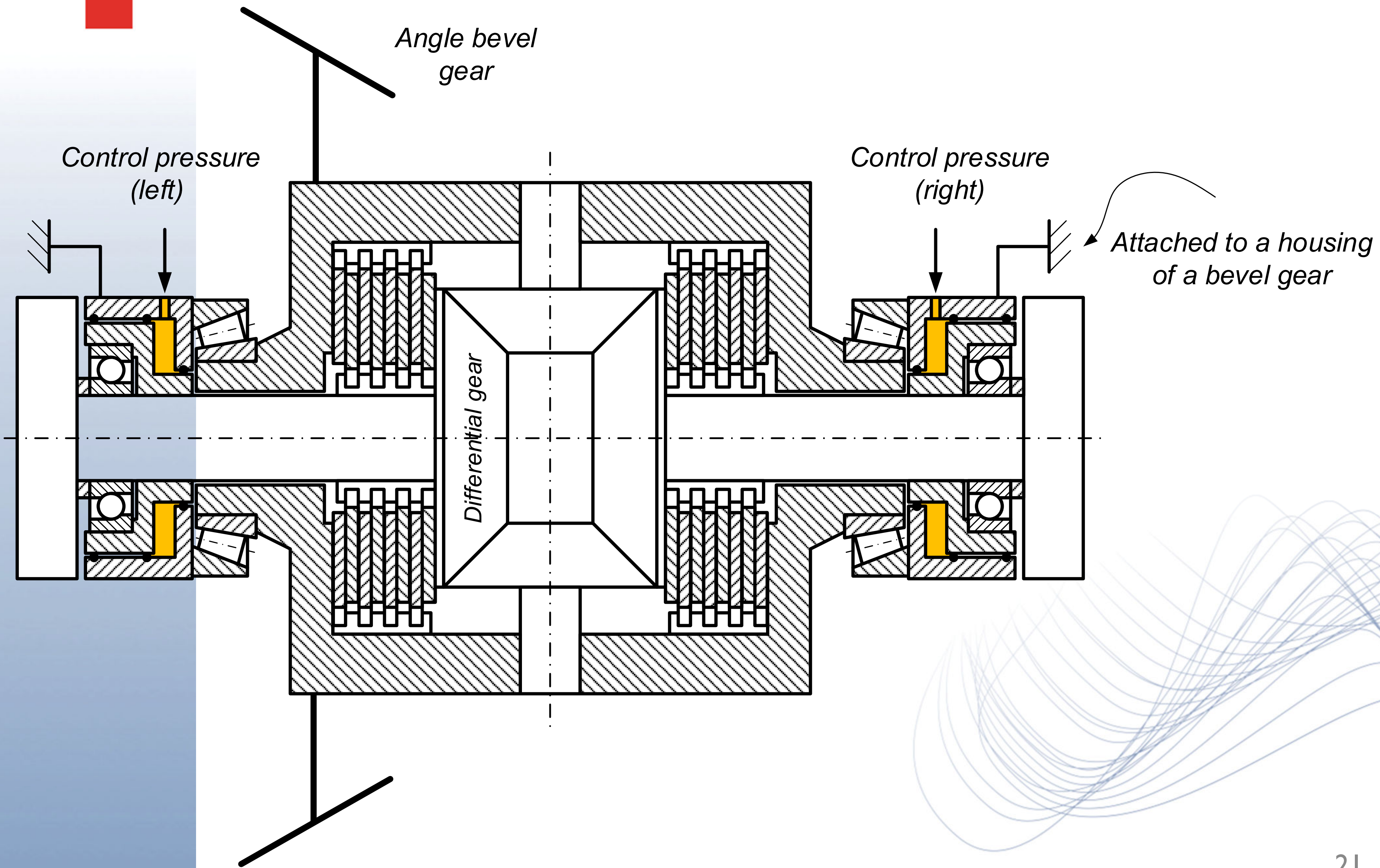
[Animation]

Univerza v Ljubljani
Fakulteta za strojništvo

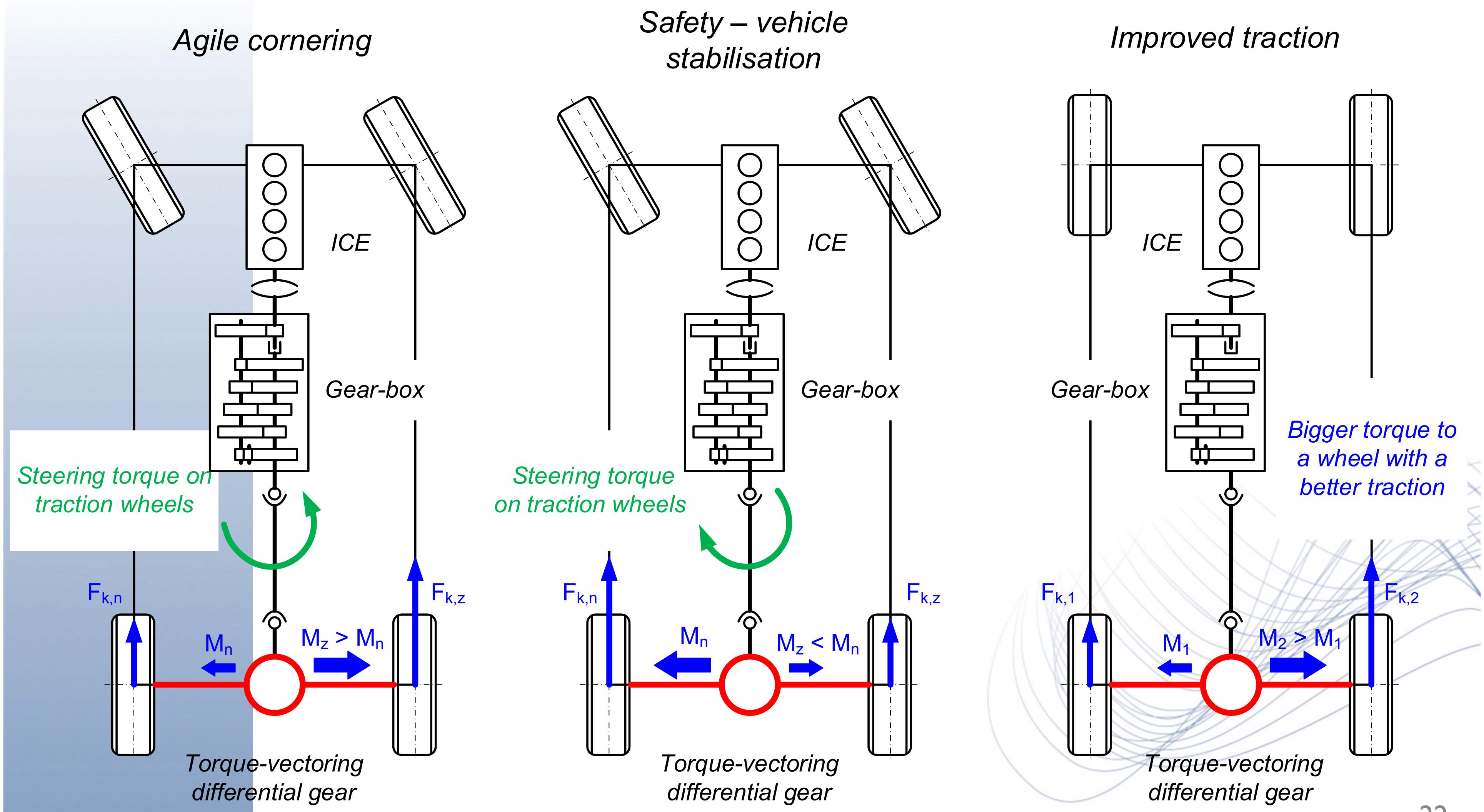
Mechanical self-locking differential gear with lamellas



Automatic self-locking differential gear - ASD



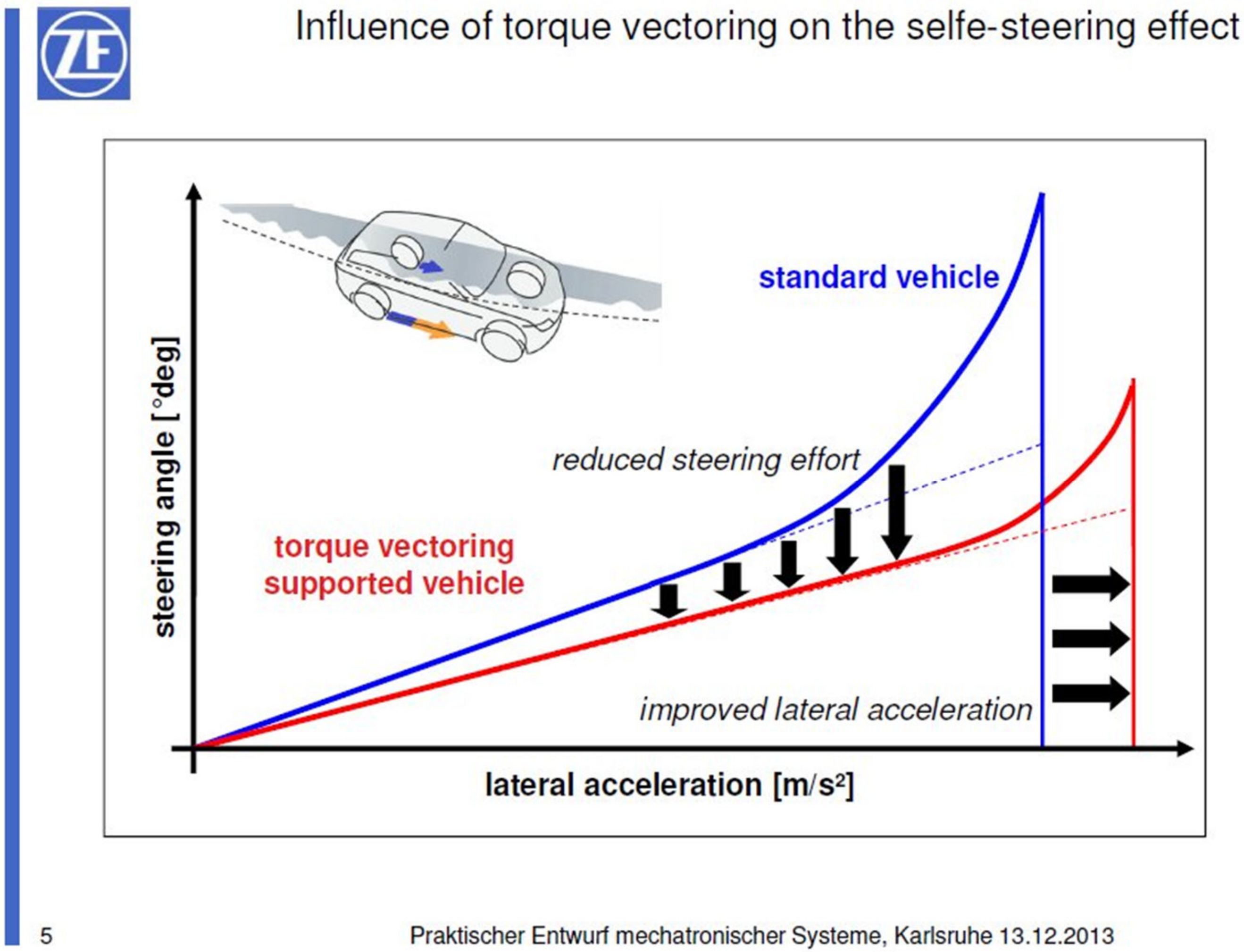
Torque vectoring differential



Univerza v Ljubljani
Fakulteta za strojništvo

Torque vectoring differential

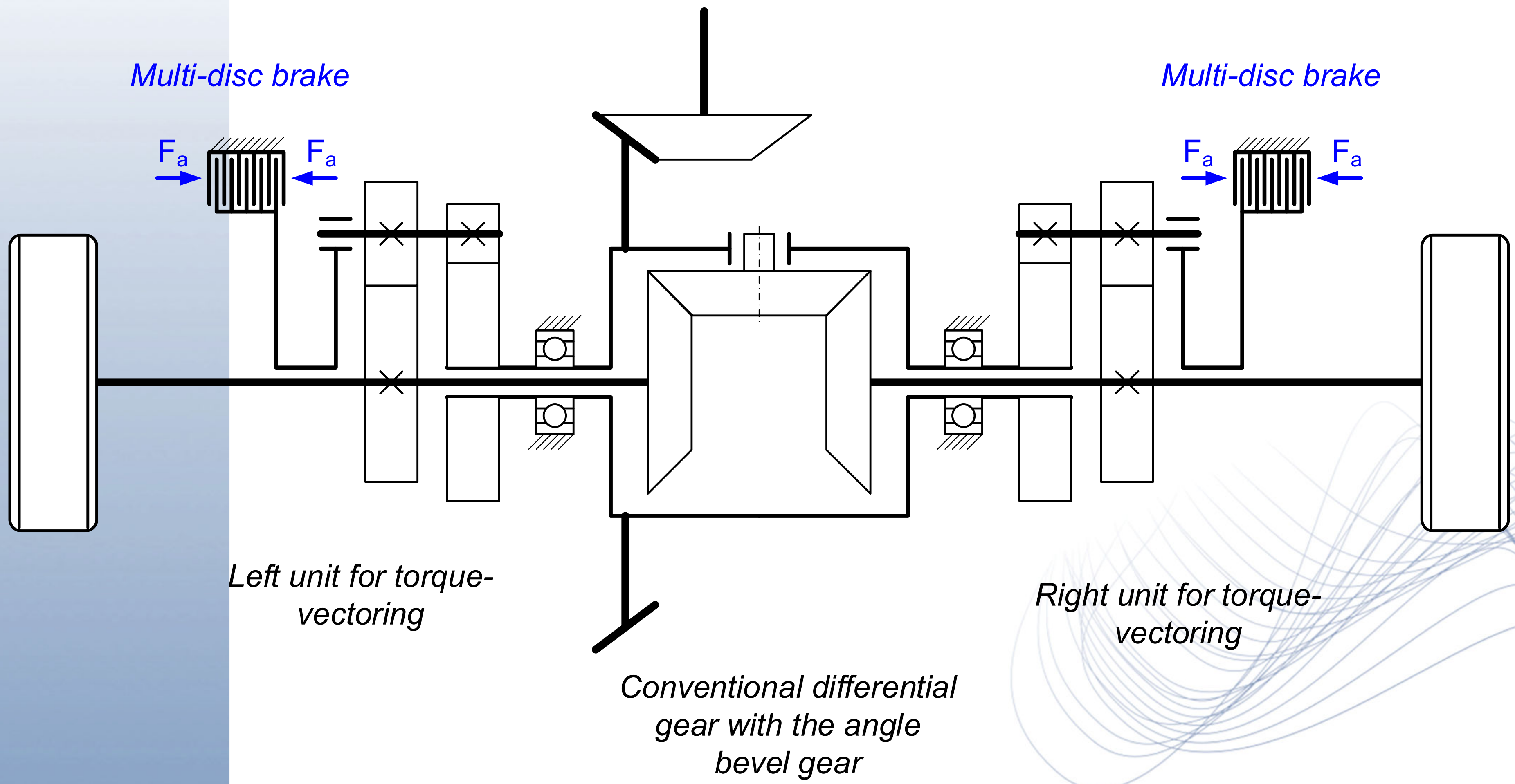
- *Operation during cornering:*



Granzow 2013, str. 5.

Torque vectoring differential

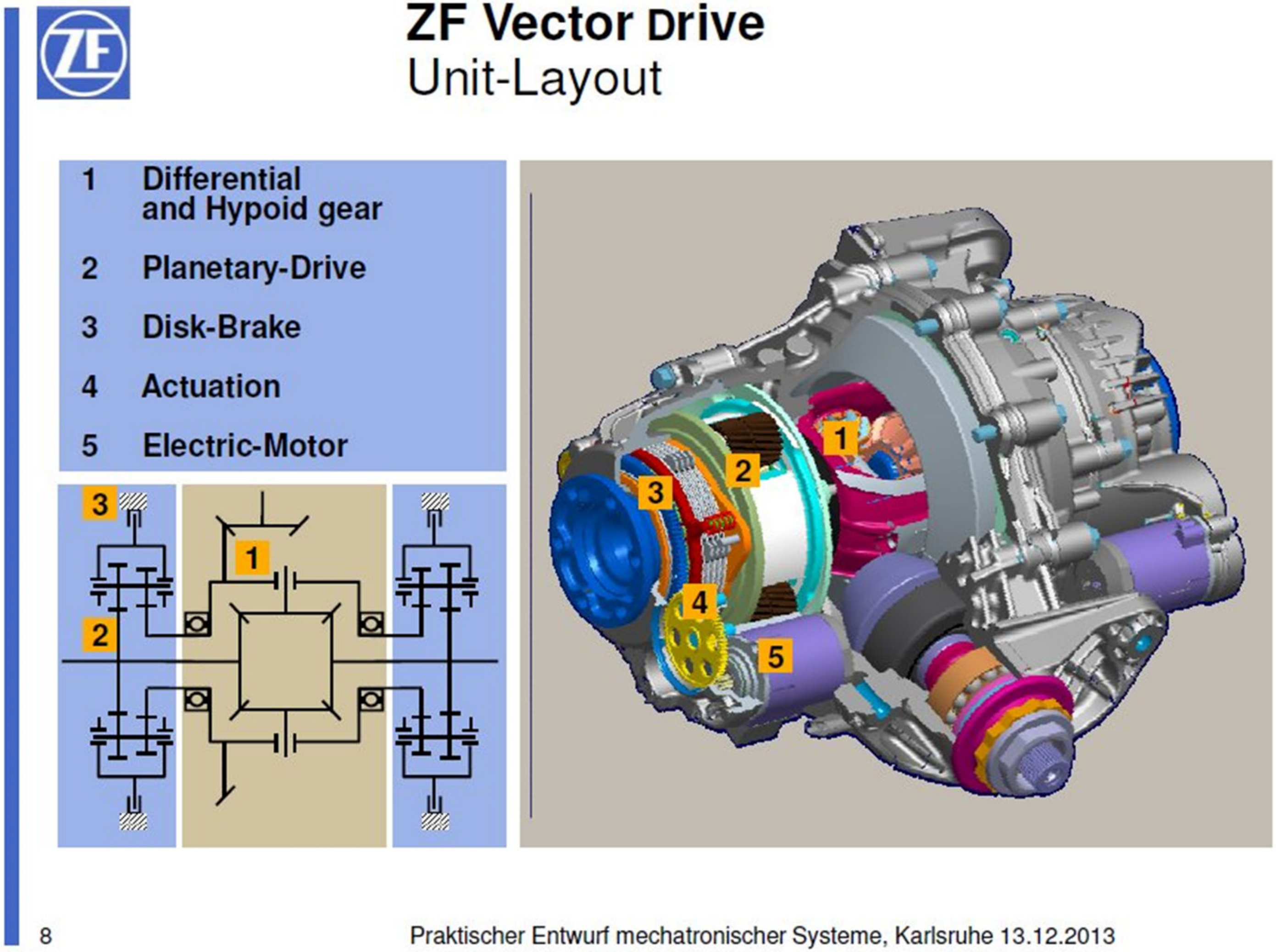
- *Functional assembly of a **ZF Vector drive** differential gear:*



Torque vectoring differential

Univerza v Ljubljani
Fakulteta za strojništvo

- *System assembly:*

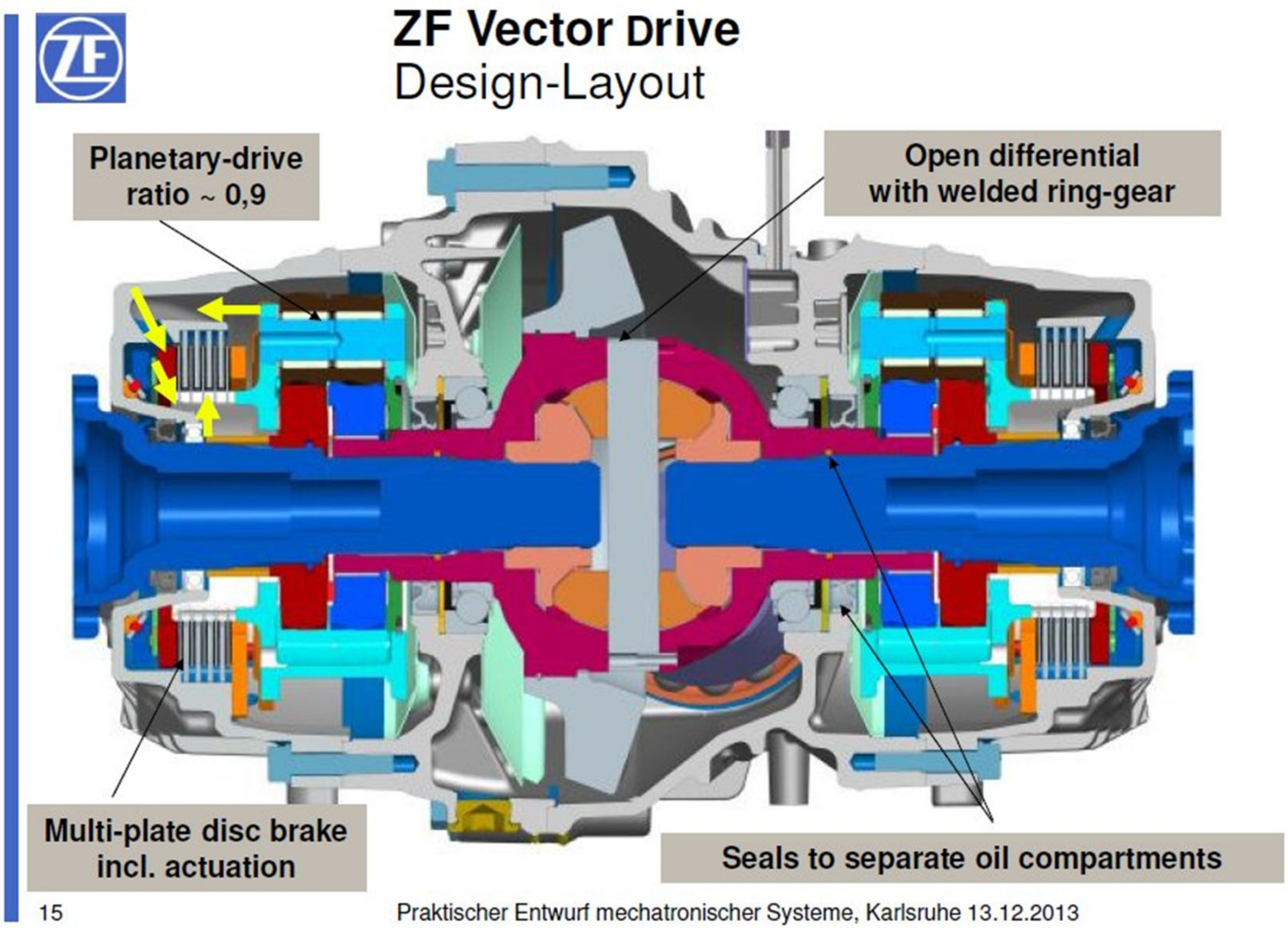


Granzow 2013, str. 8.

Torque vectoring differential

Univerza *v Ljubljani*
Fakulteta *za strojništvo*

- *Assembly cross-section:*

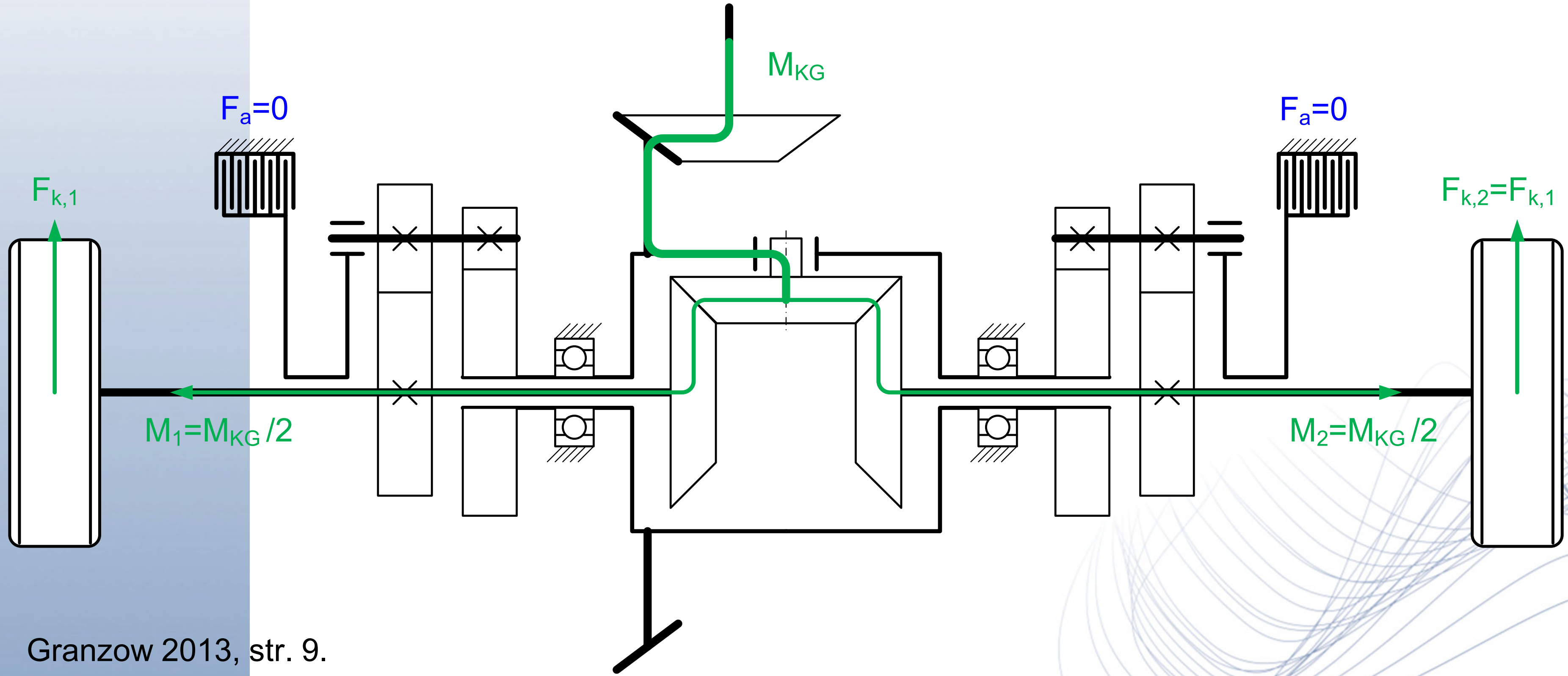


Granzow 2013, str. 15.

Torque vectoring differential

Univerza *v Ljubljani*
Fakulteta *za strojništvo*

- *Principle of operation without torque-vectoring function:*

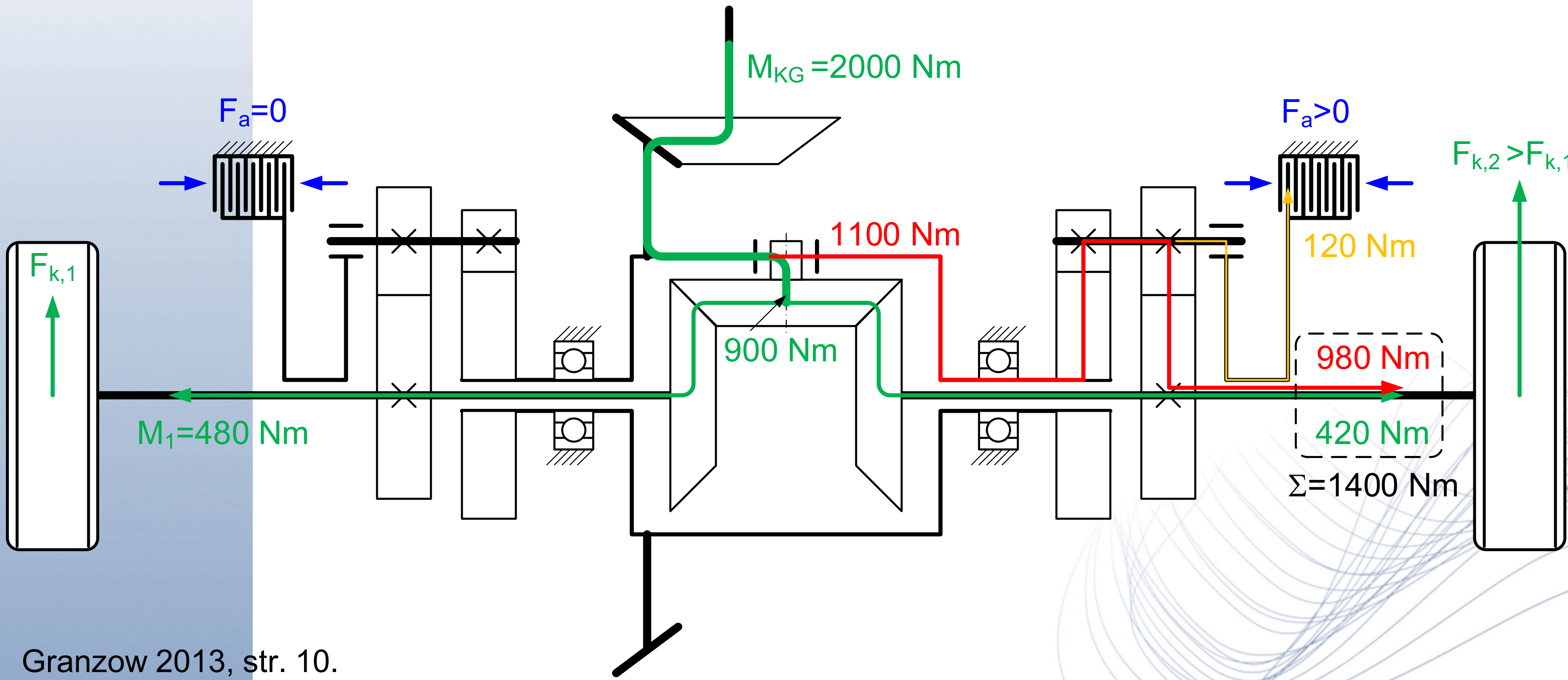


Granzow 2013, str. 9.

Univerza v Ljubljani
Fakulteta za strojništvo

Torque vectoring differential

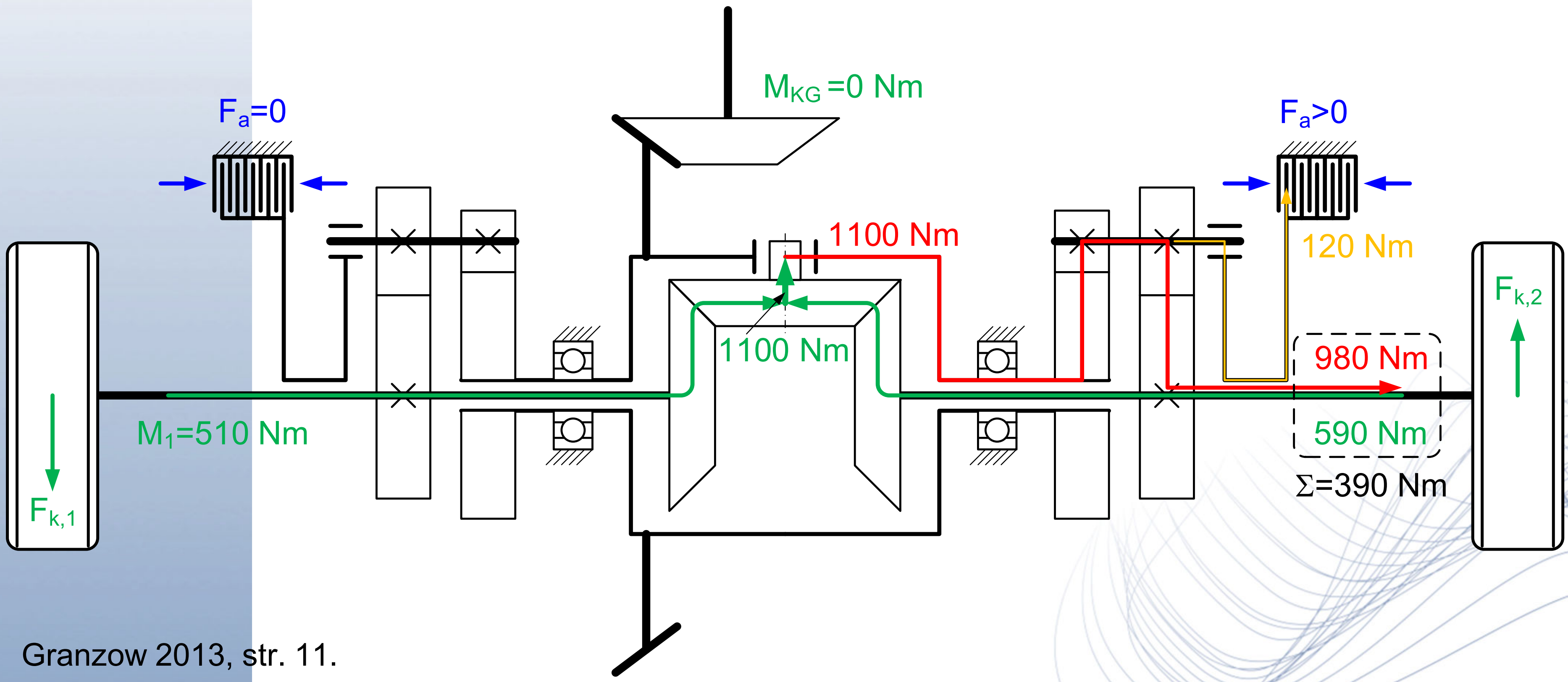
- *Principle of operation by applying the torque-vectoring function:*



Granzow 2013, str. 10.

Torque vectoring differential

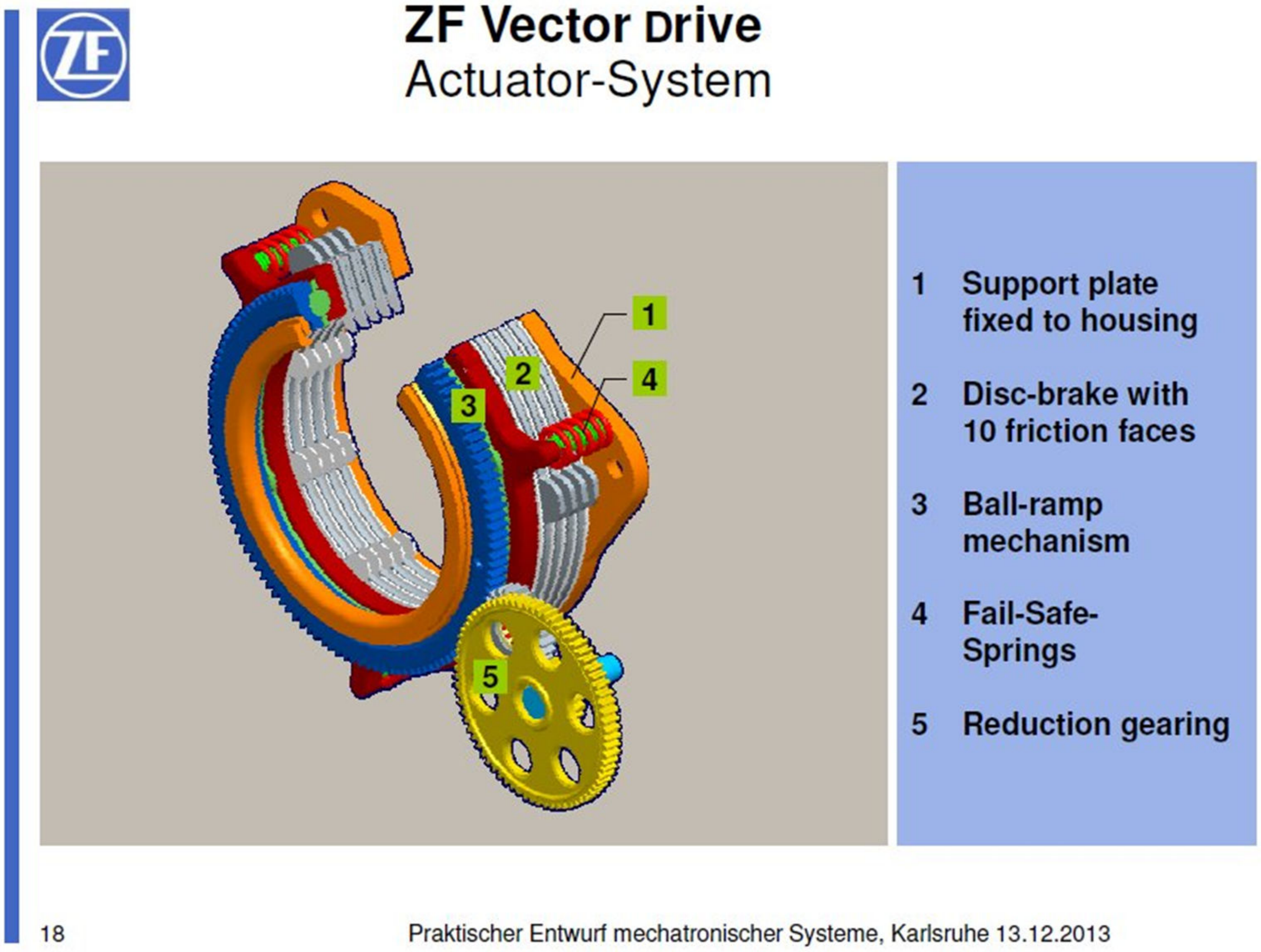
- *Principle of operation by applying the torque-vectoring function:*



Granzow 2013, str. 11.

Torque vectoring differential

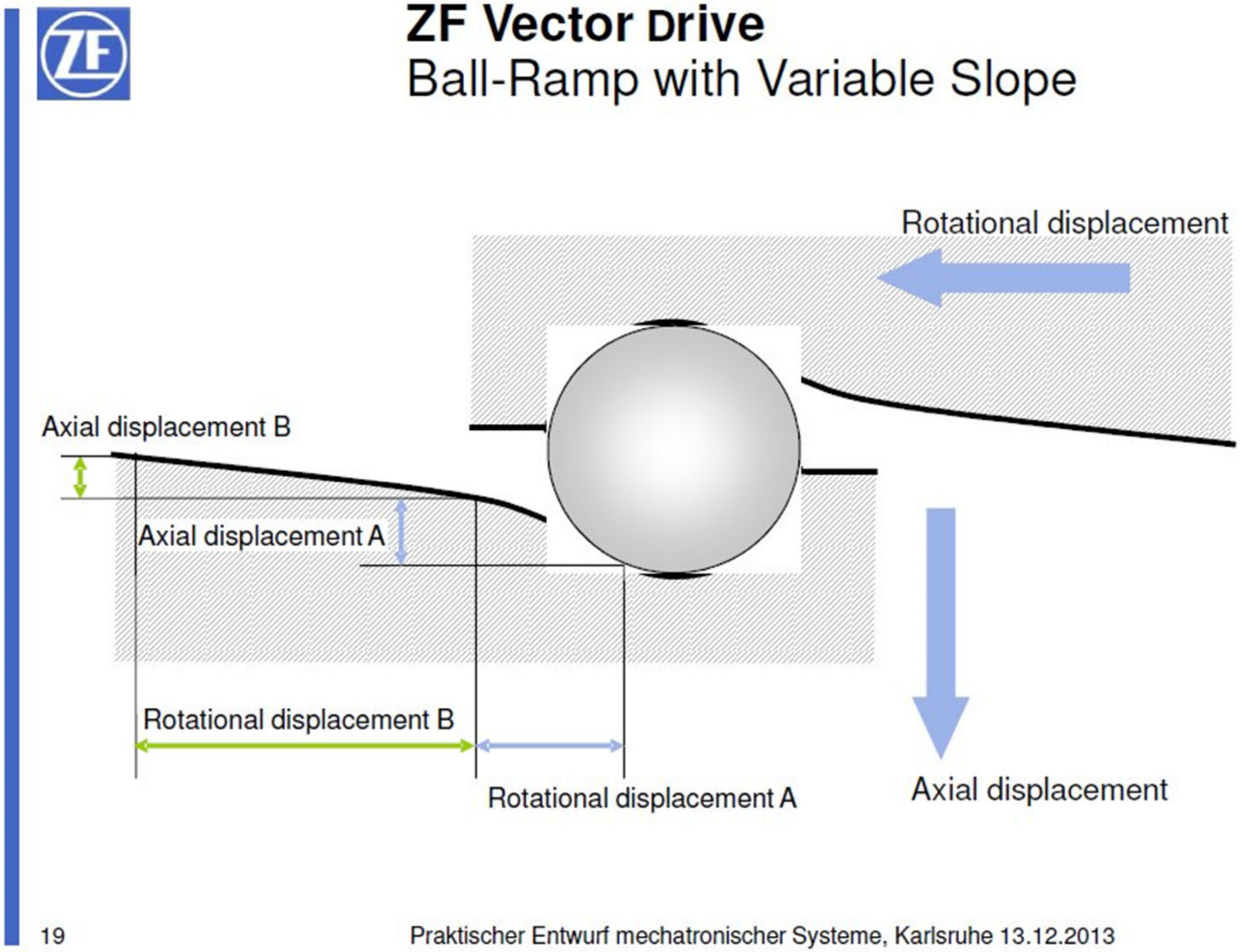
- *Activation of a multi-disc brake of a planetary shaft:*



Granzow 2013, str. 18.

Torque vectoring differential

- *Activation of a multi-disc brake of a planetary shaft:*

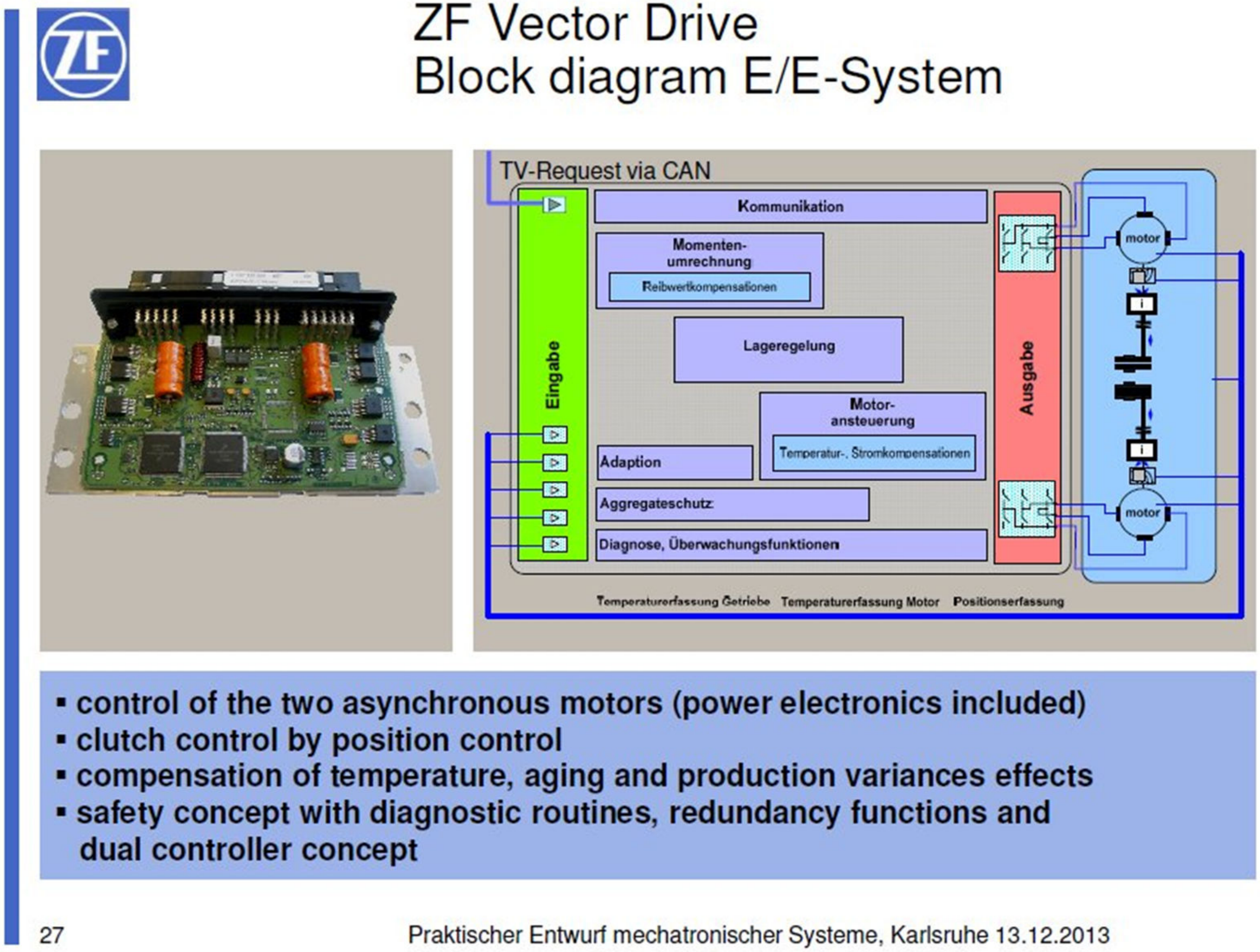


Granzow 2013, str. 19.

Torque vectoring differential

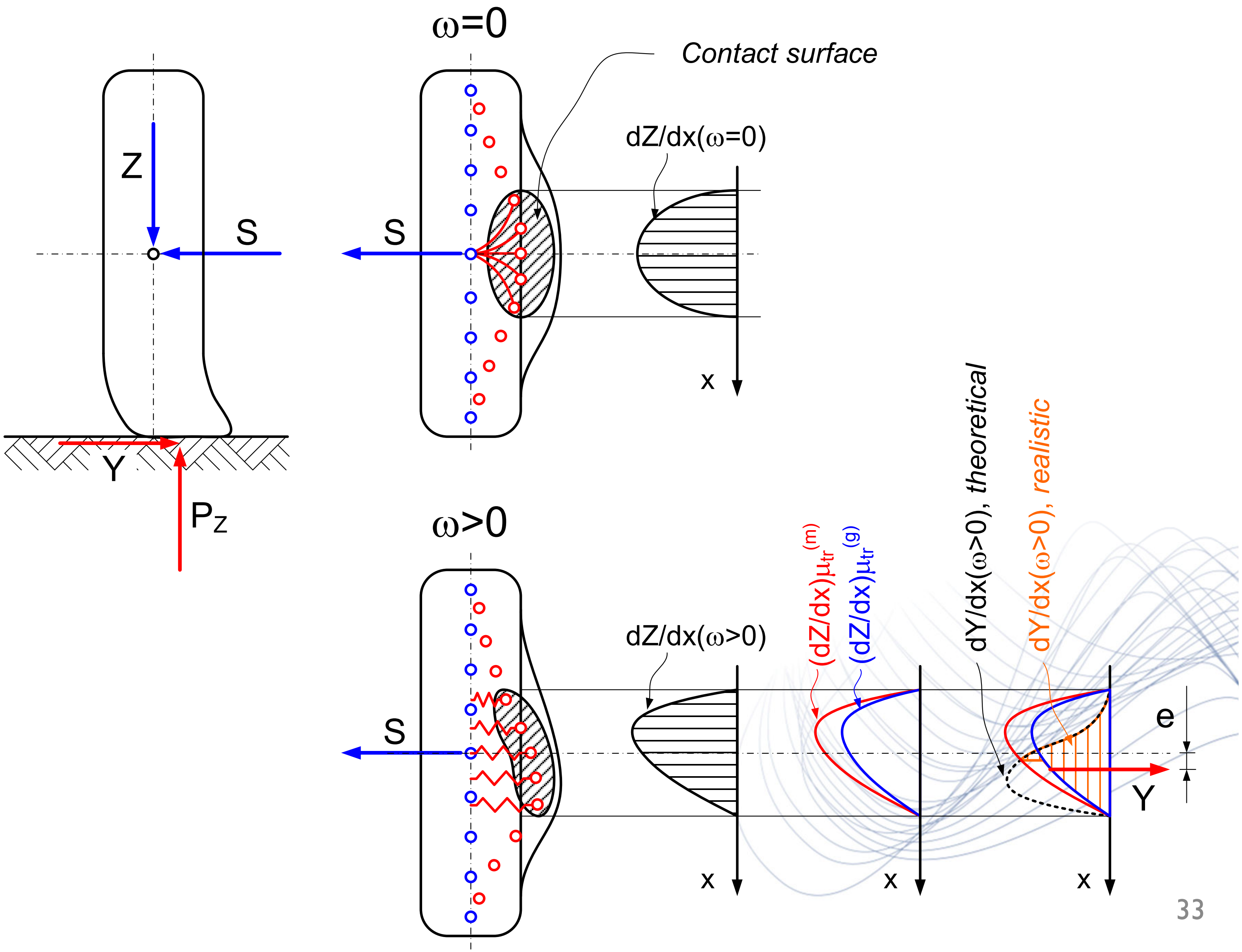
Univerza v Ljubljani
Fakulteta za strojništvo

- *The torque-vectoring differential is a mechatronic system:*



Granzow 2013, str. 27.

Cornering stifness of a tire



Lateral traction coefficient and side-slip angle

$$M_s = Y \cdot e$$

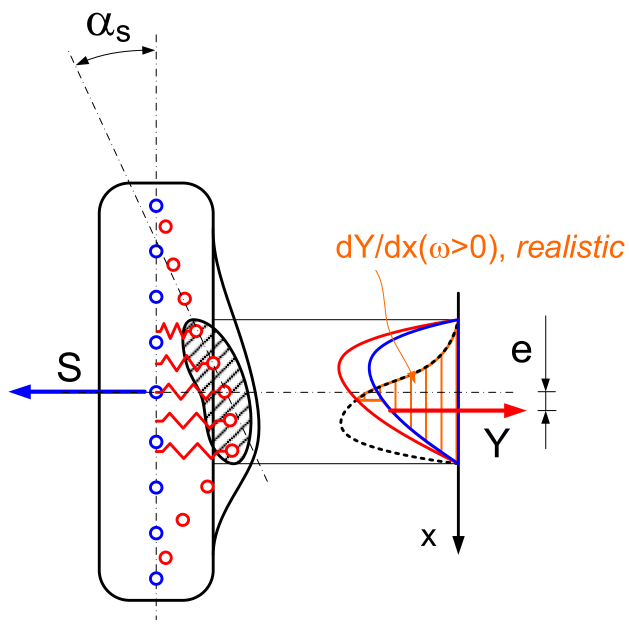
α_s ... *side-slip angle*

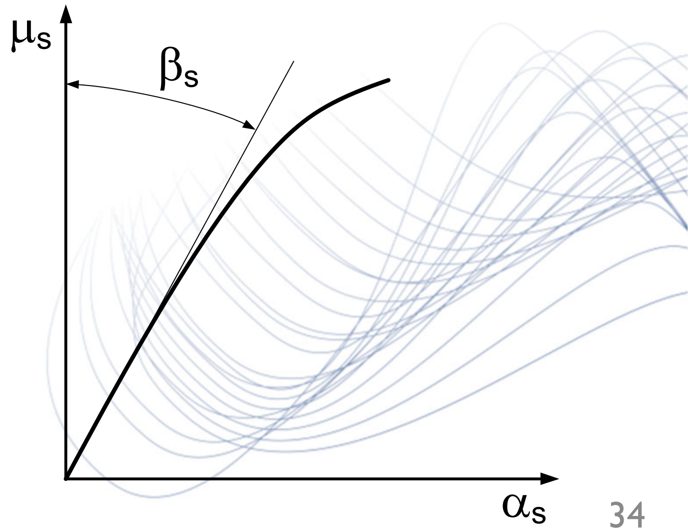
$$\mu_s = \frac{S}{Z}$$

μ_s ... *lateral traction coefficient*

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

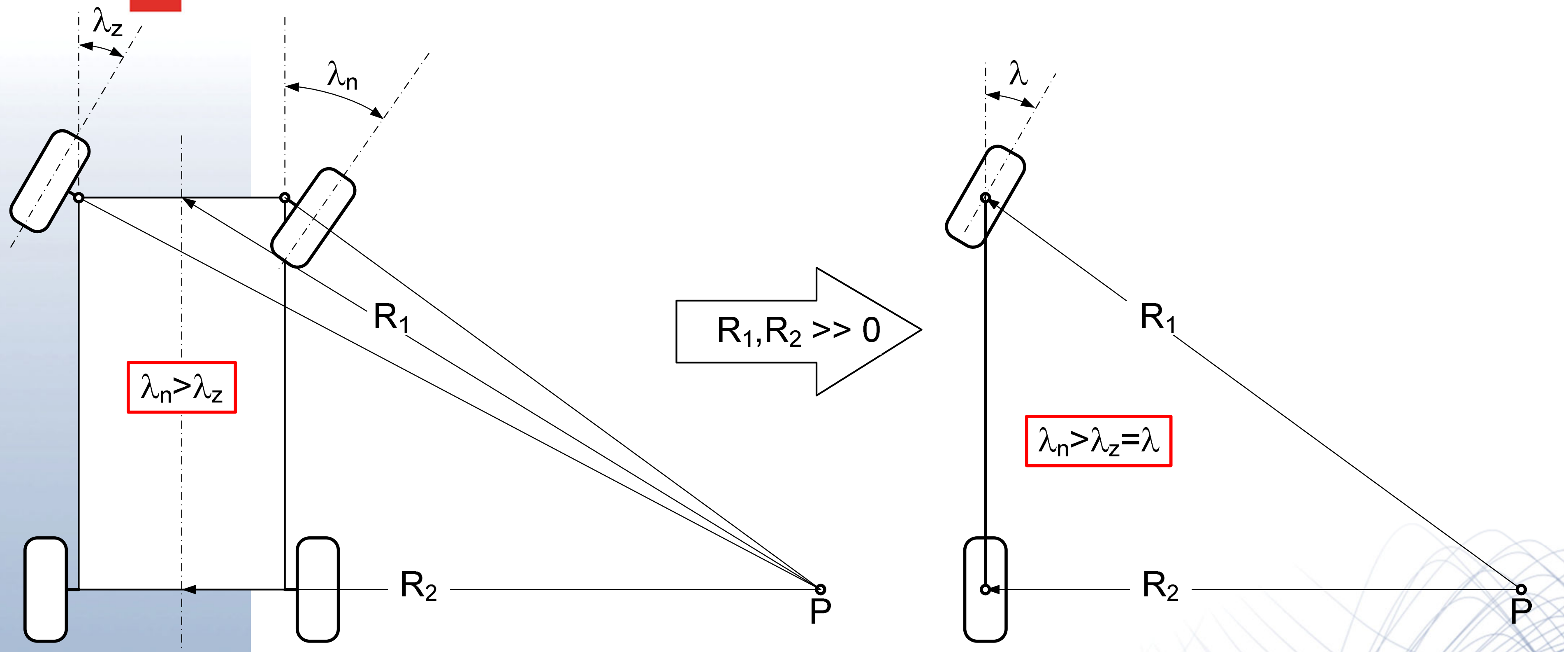
c_s ... *cornering stiffness of a tire*





Univerza v Ljubljani
Fakulteta za strojništvo

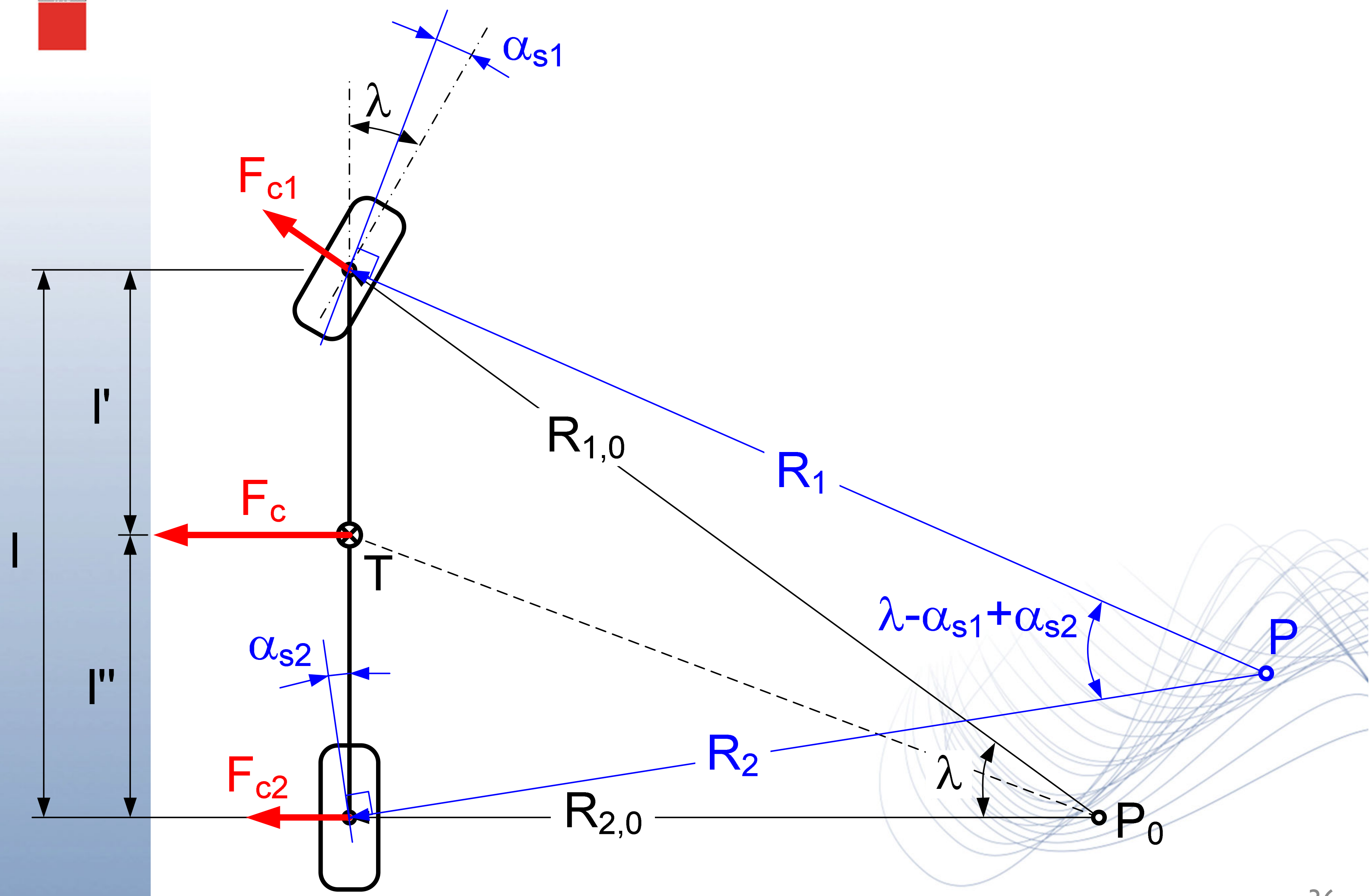
Steering angle during cornering



λ ... *steering angle*

$$\lambda = f(R)$$

Influence of side-slip rolling during cornering



Influence of side-slip rolling during cornering

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

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

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

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

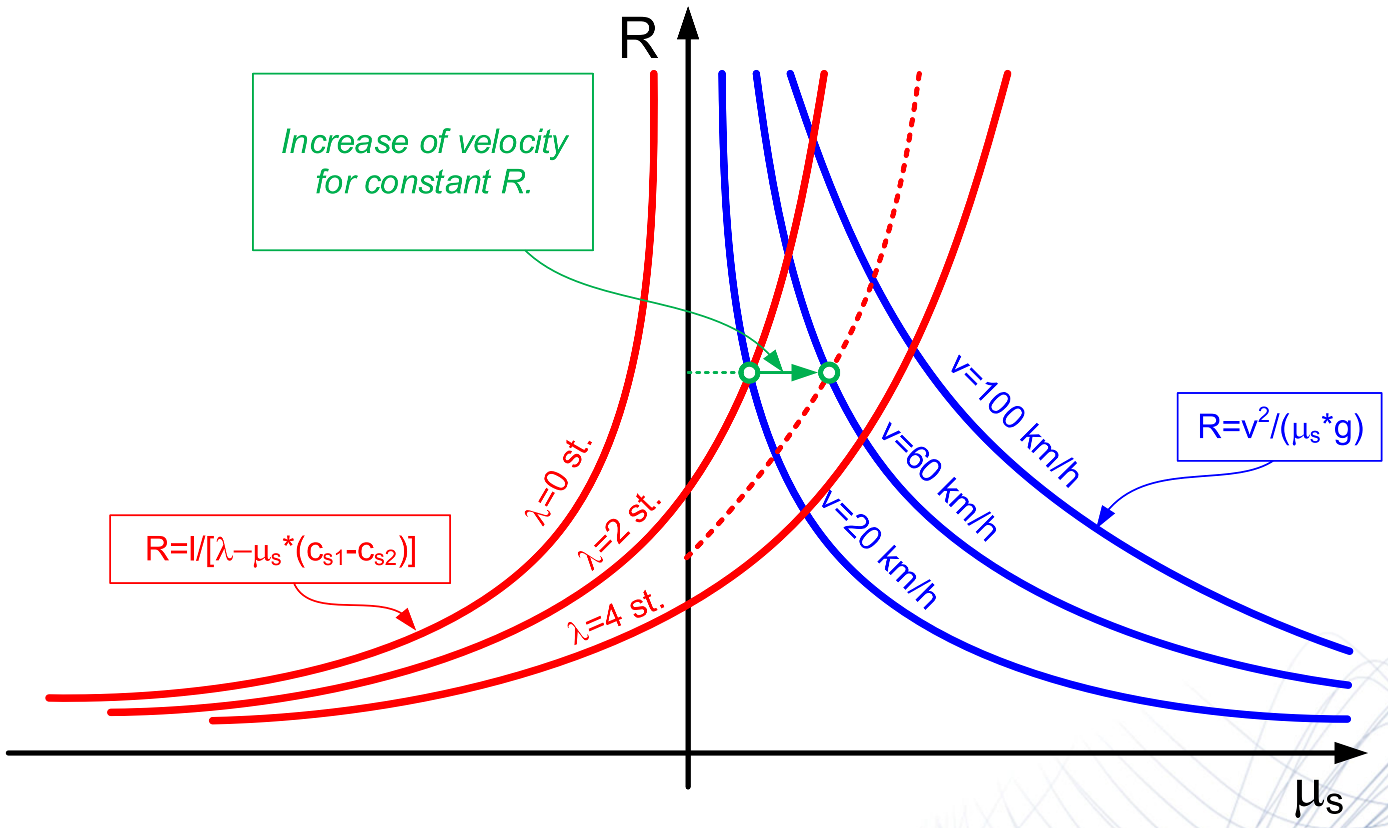
$$\alpha_{s1} = c_{s1} \cdot \mu_s$$

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

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

Univerza v Ljubljani
Fakulteta za strojništvo

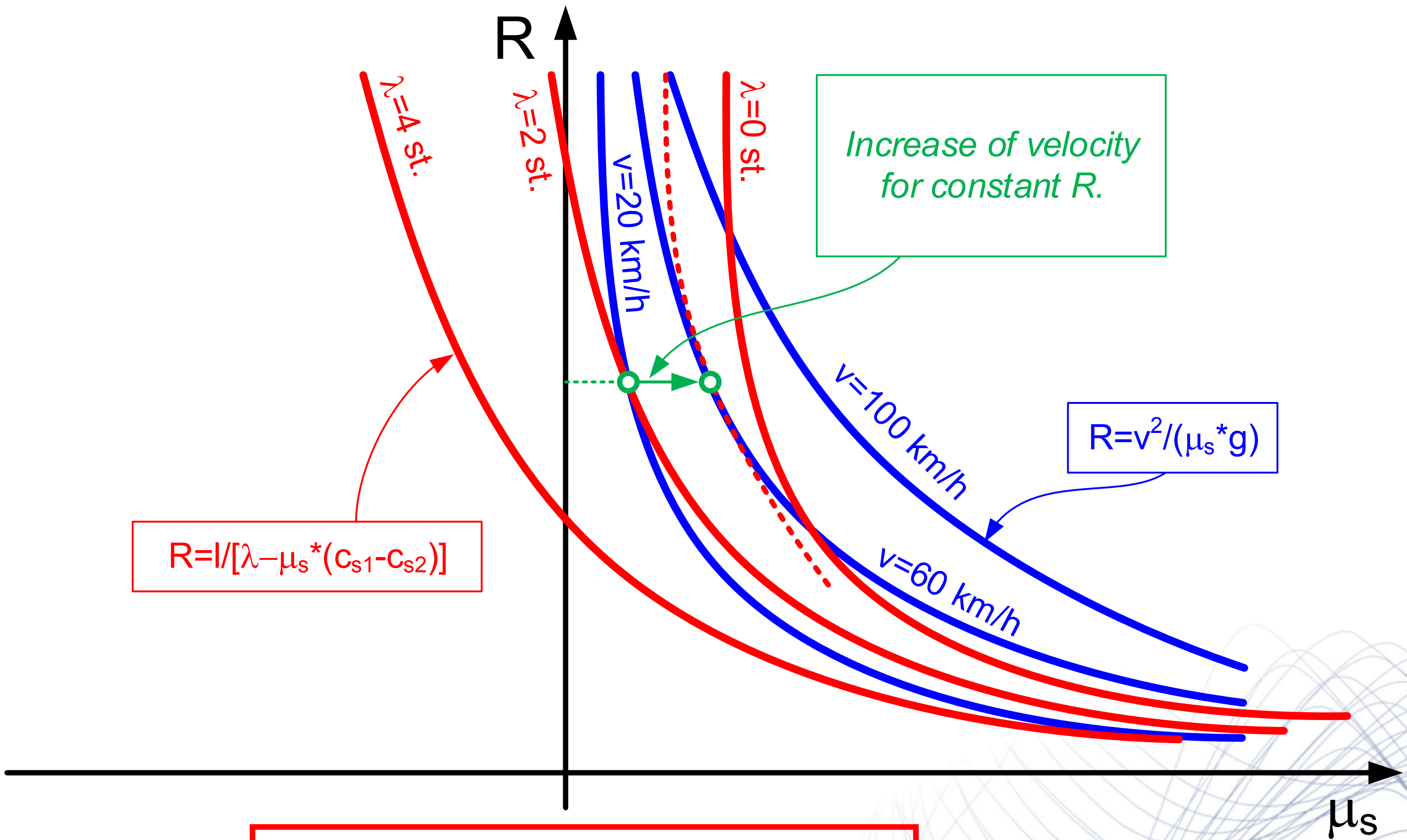
Under-steered vehicle: $c_{s1} > c_{s2}$



If a vehicle's velocity is increased during cornering, the steering angle λ should be increased.

Univerza v Ljubljani
Fakulteta za strojništvo

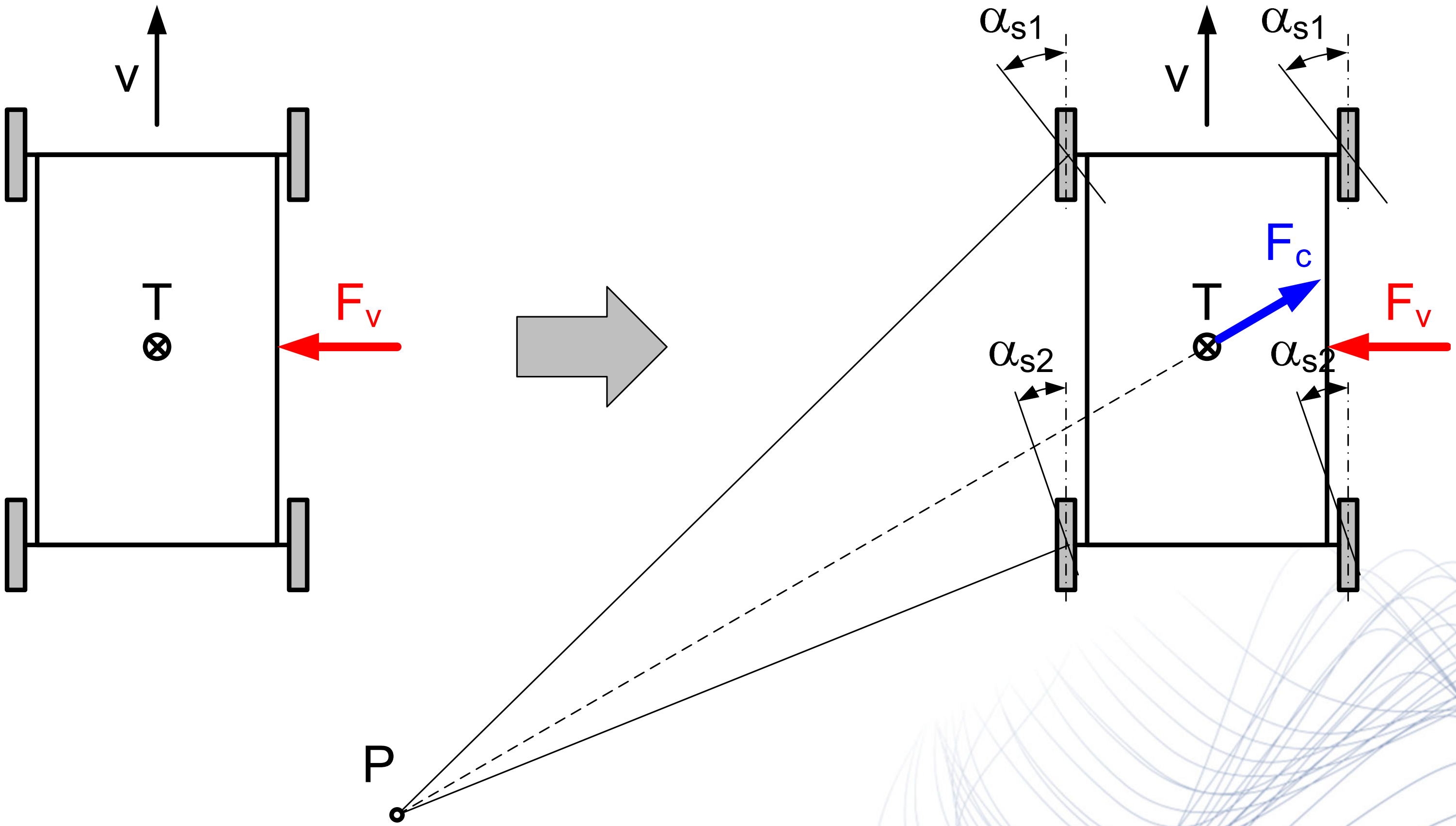
Over-steered vehicle: $c_{s1}<c_{s2}$



If a vehicle's velocity is increased during cornering, the steering angle λ should be reduced.

Influence of a side wind

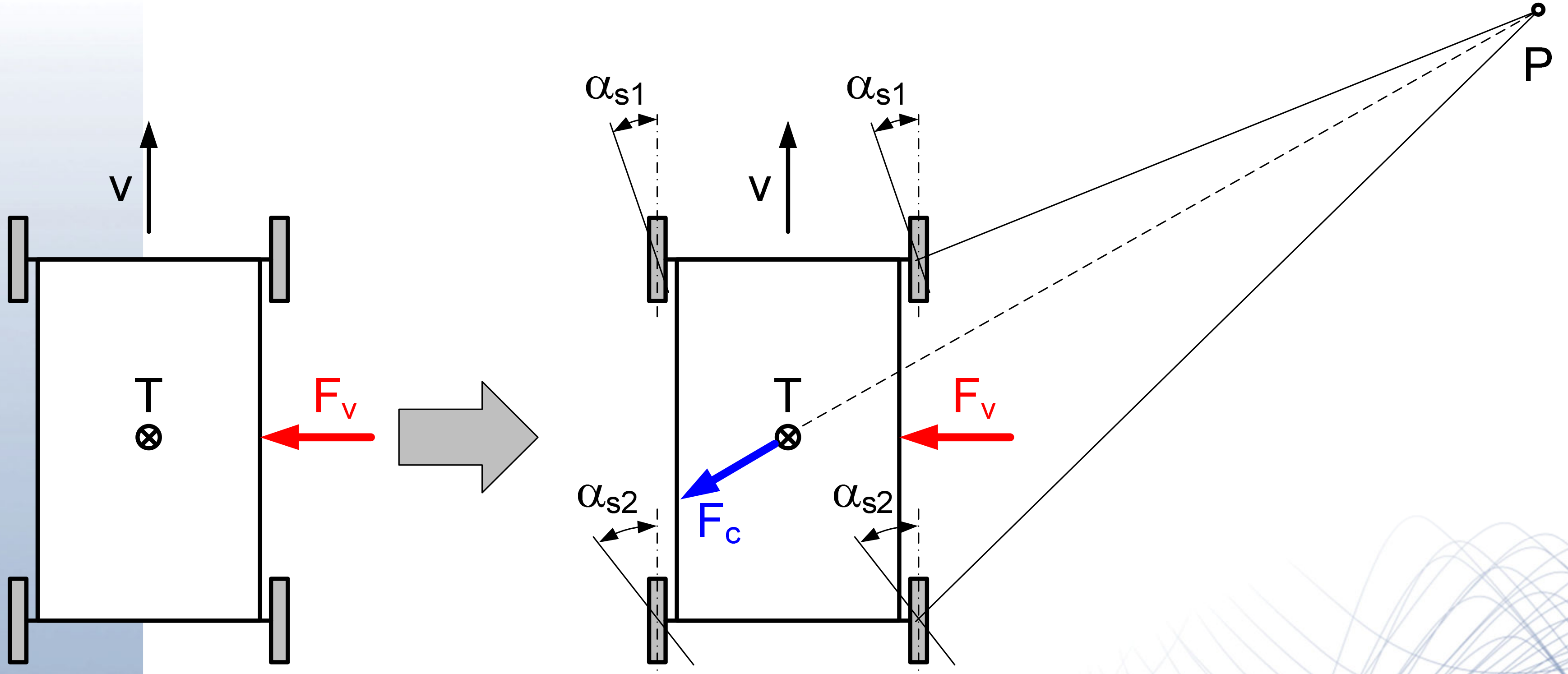
- *Under-steered vehicle* ($c_{s1}>c_{s2}$):



The centrifugal force stabilizes the wind force.

Influence of a side wind

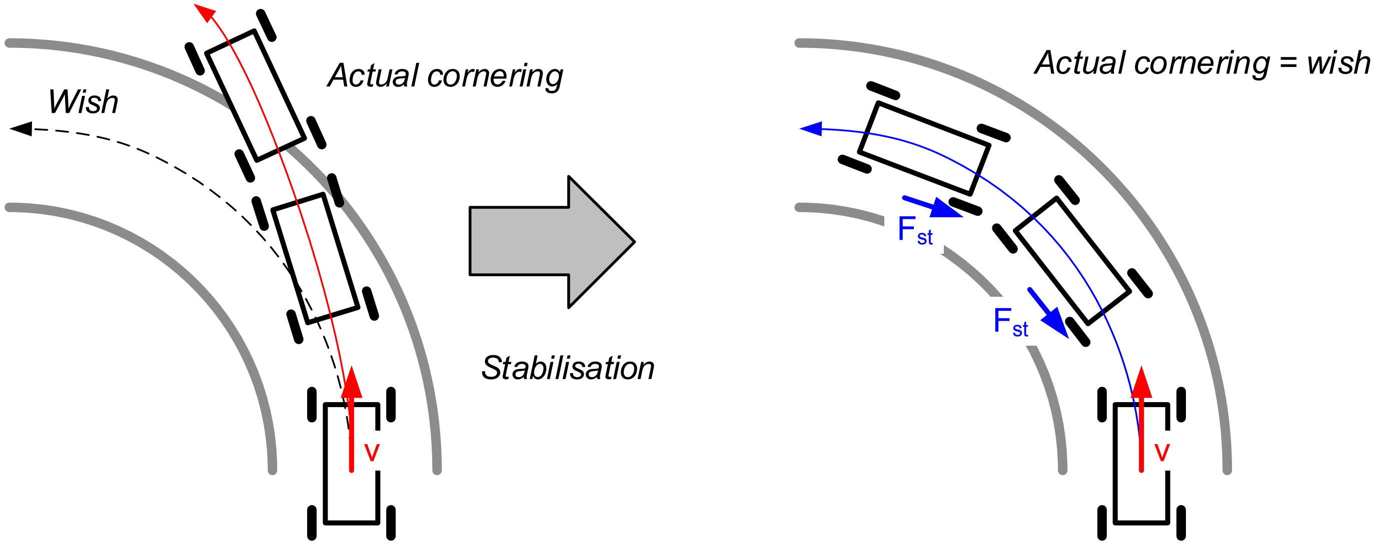
- *Over-steered vehicle* ($c_{s1}<c_{s2}$):



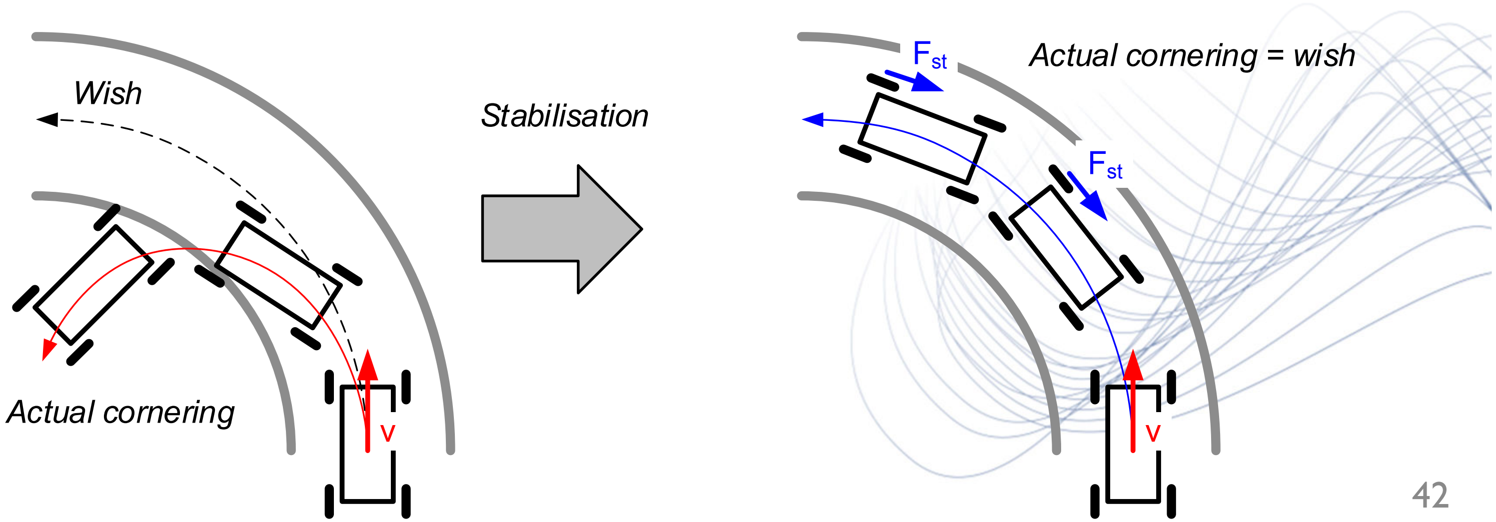
The centrifugal force de-stabilizes the wind force.

Vehicle stabilization during cornering

- *Under-steered vehicle*:



- *Over-steered vehicle*:



Univerza v Ljubljani
Fakulteta za strojništvo

Critical velocity of over-steered vehicle

- *A critical velocity of the over-steered vehicle is the velocity at which the vehicle can negotiate curves with a zero steering angle, if subjected to a lateral disturbance (e.g. wind blow):*

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

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

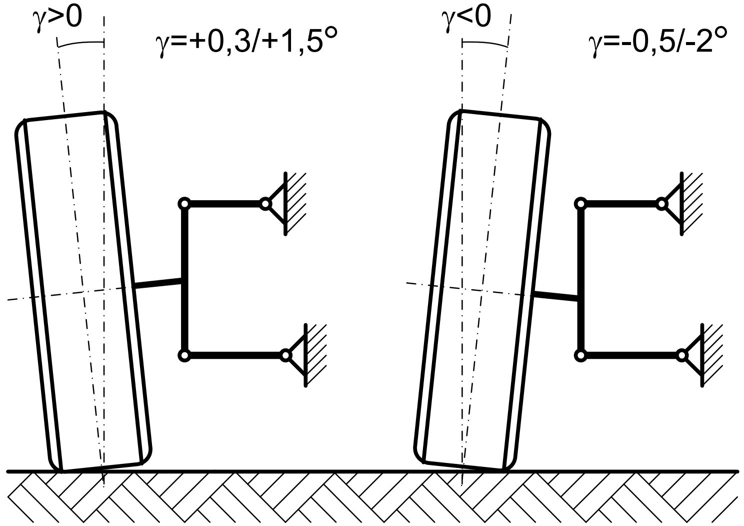
$$\mu_s = \frac{1}{g} \cdot \frac{v^2}{R} \Rightarrow R = \frac{1}{g} \cdot \frac{v^2}{\mu_s}$$

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

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

Position of steered wheels

- *Camber angle:*

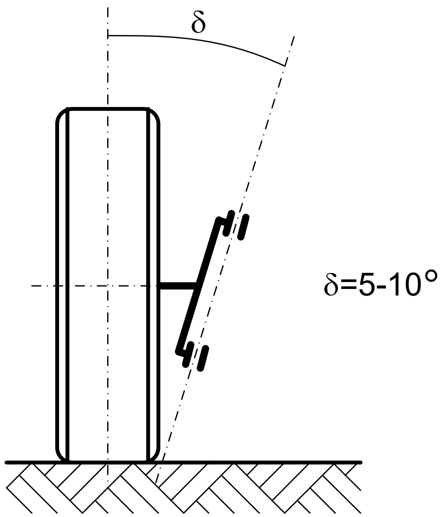


  - *Nullifies bearing clearance.*
  - *Positive camber angle reduces lateral forces during cornering.*
  - *Negative camber angle increased grip during heavy cornering.*

Univerza v Ljubljani
Fakulteta za strojništvo

Position of steered wheels

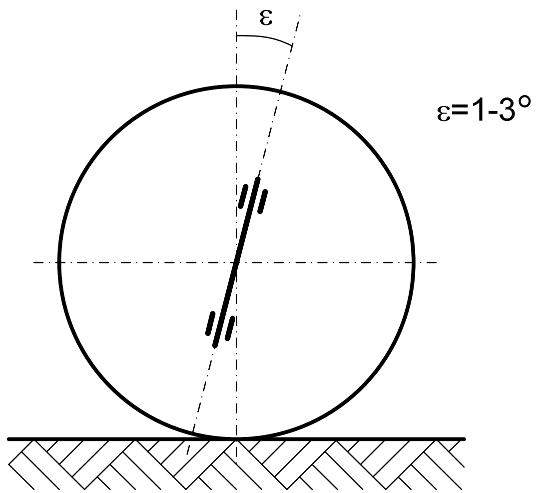
- *Lateral slope of a pivot line:*



  - *It causes a raise of the vehicle's front part during a steering maneuver.*
  - *A consequence is self-alignment of the steering wheels if a driver releases a steering wheel.*

Position of steered wheels

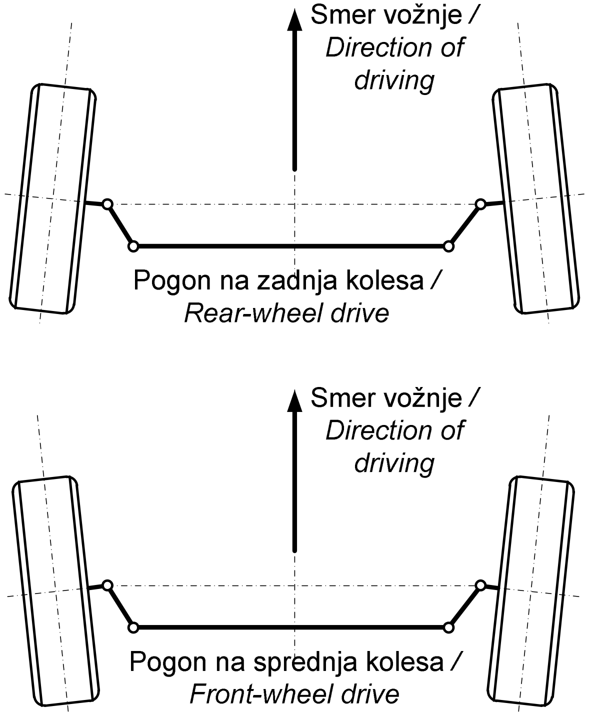
- *Caster angle:*



  - *Positive caster will make the vehicle more stable at high speeds, and will increase tire lean when cornering.*

Position of steered wheels

- *Toe angle:*



  - *The angle derived from pointing the tires inward or outward from a top view.*
  - *The steering mechanism is pre-stressed to nullify clearance.*
  - *Reduces lateral wheel twisting.*

Univerza v Ljubljani
Fakulteta za strojništvo

List of references

- 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.