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German Aerospace Center (DLR)

The Foundation of the DLR RailwayDynamics Library: The Wheel-Rail Contact

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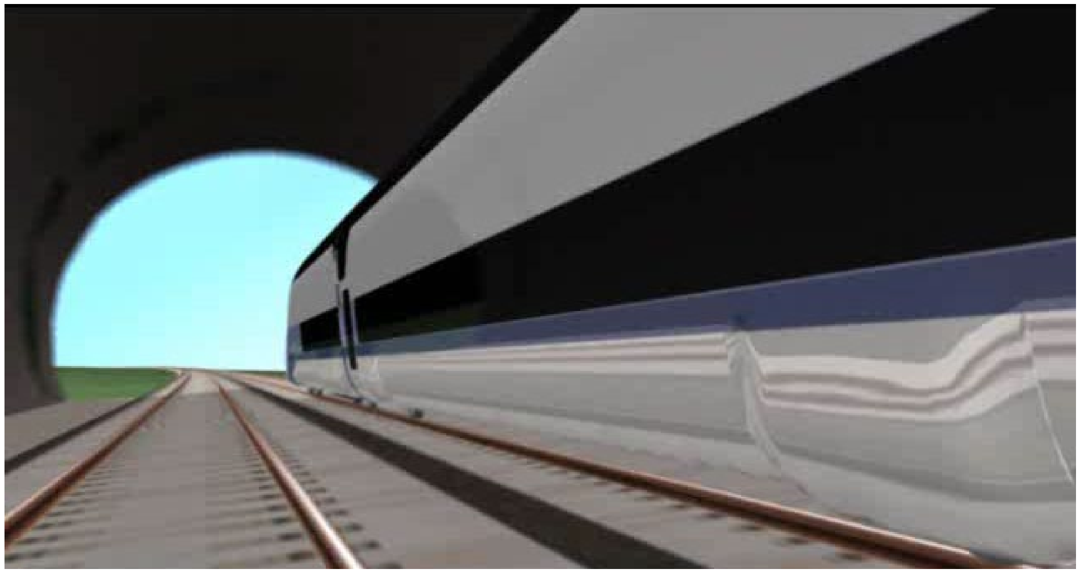
Content

Motivation: DLR‘s Next Generation Train Project

- 10 DLR institutes contribute to the NGT project.

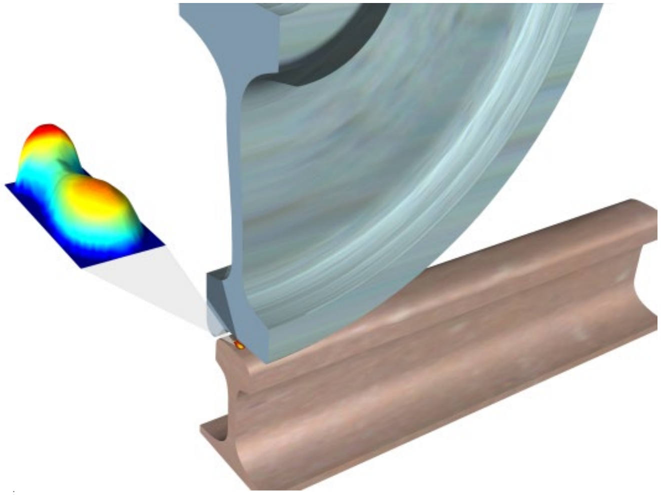


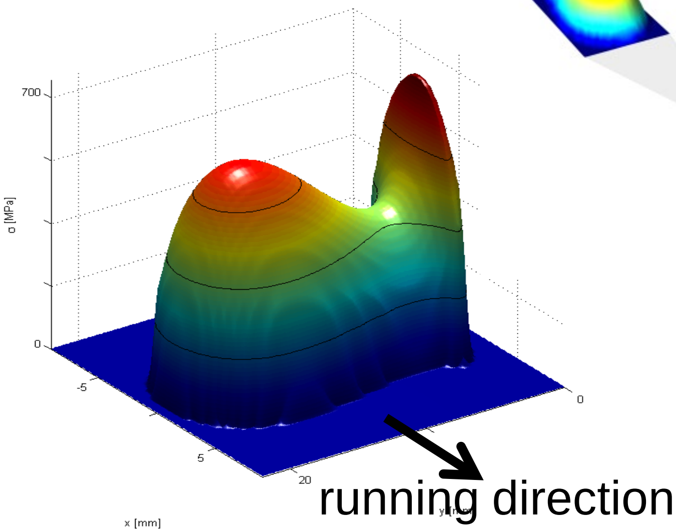
Multi-Body Simulation
animated by Autodesk® Maya

- Very high speed train in double deck configuration and lightweight design
- New type of running gear with active control
- Nonlinear Modelica Models for
  - Observer (see Brembeck et al. : Nonlinear State Estimation with Extended FMI 2.0 Co-Simulation Interface, Modelica 2014)
  - Control

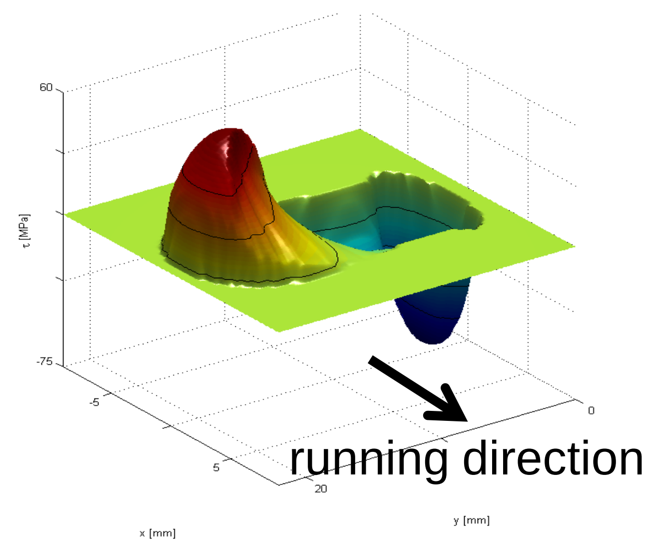
The Reference: The Nonlinear Rolling Contact [Kalker 1982]

- Highly elaborated but much too expensive for vehicle dynamics simulations
- Several assumptions allow to tackle the problem in sequential steps.



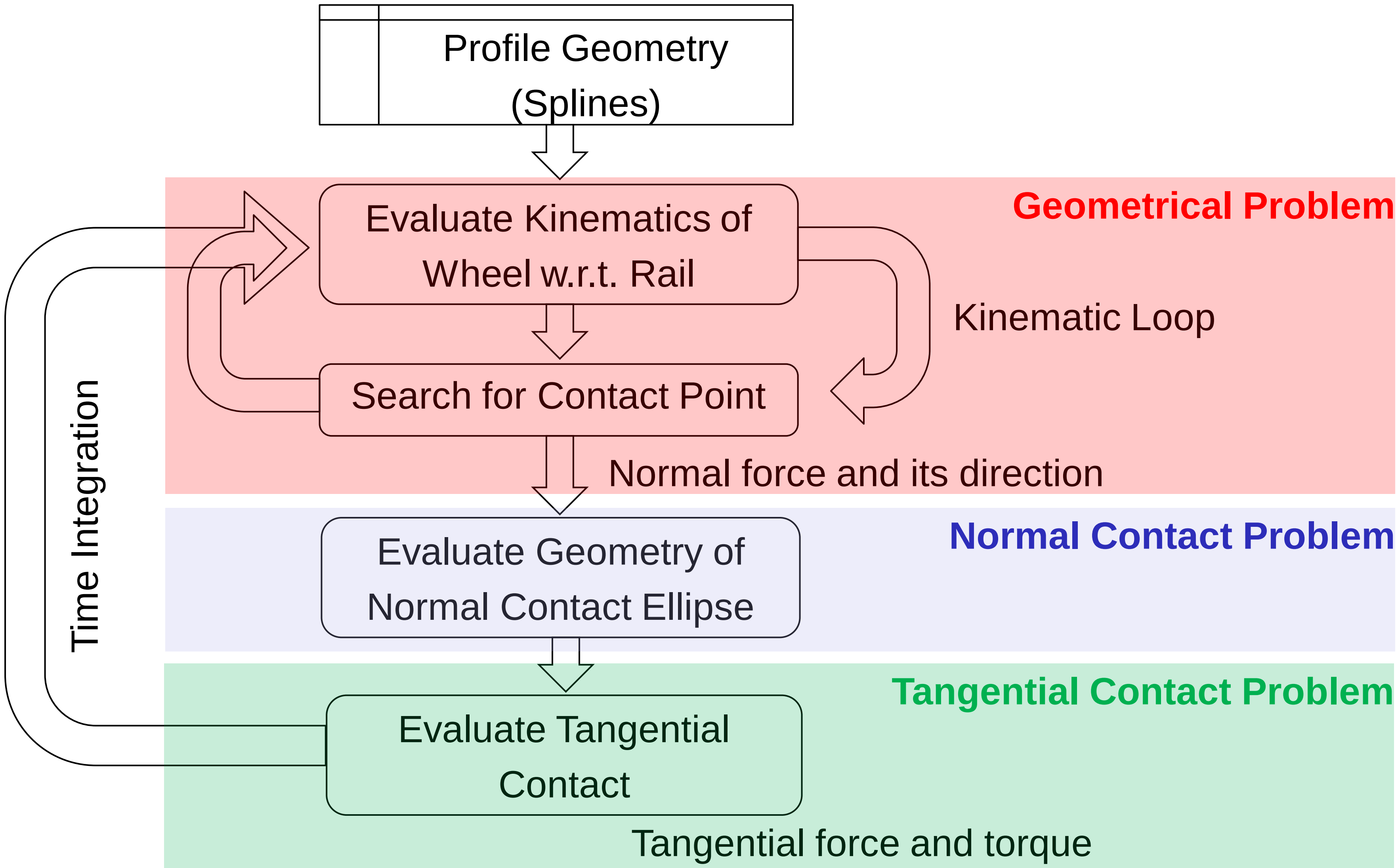


Exemplary normal stresses



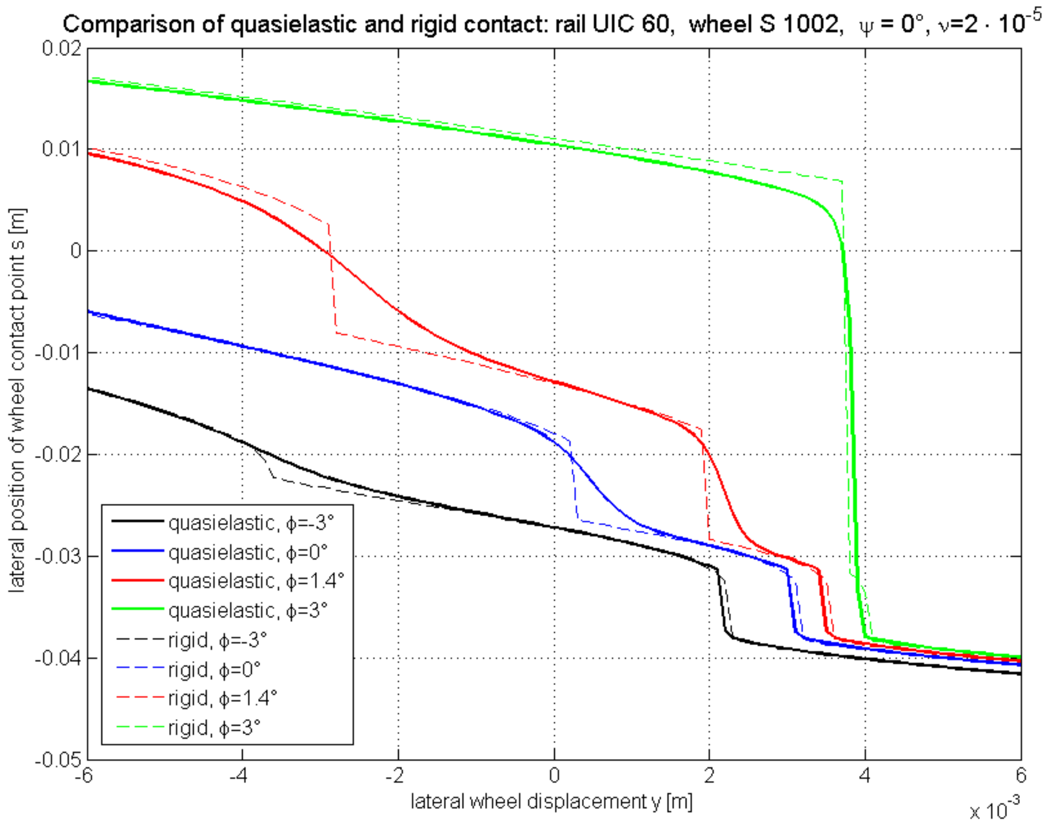
Exemplary shear stresses

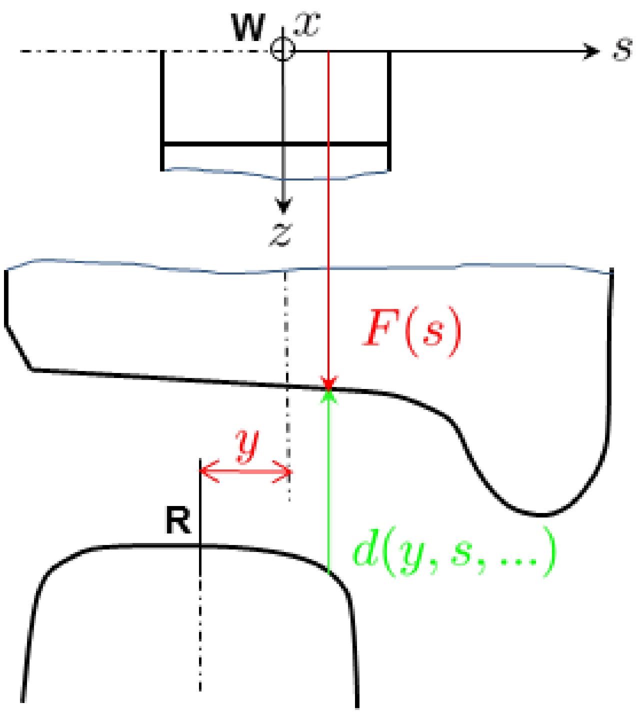
Evaluation Scheme Implemented in Modelica



Theory: The Geometrical Problem I

- Contact formulated as kinematical constraint $g = \max_s d(y, s, \varphi, \psi) = 0$



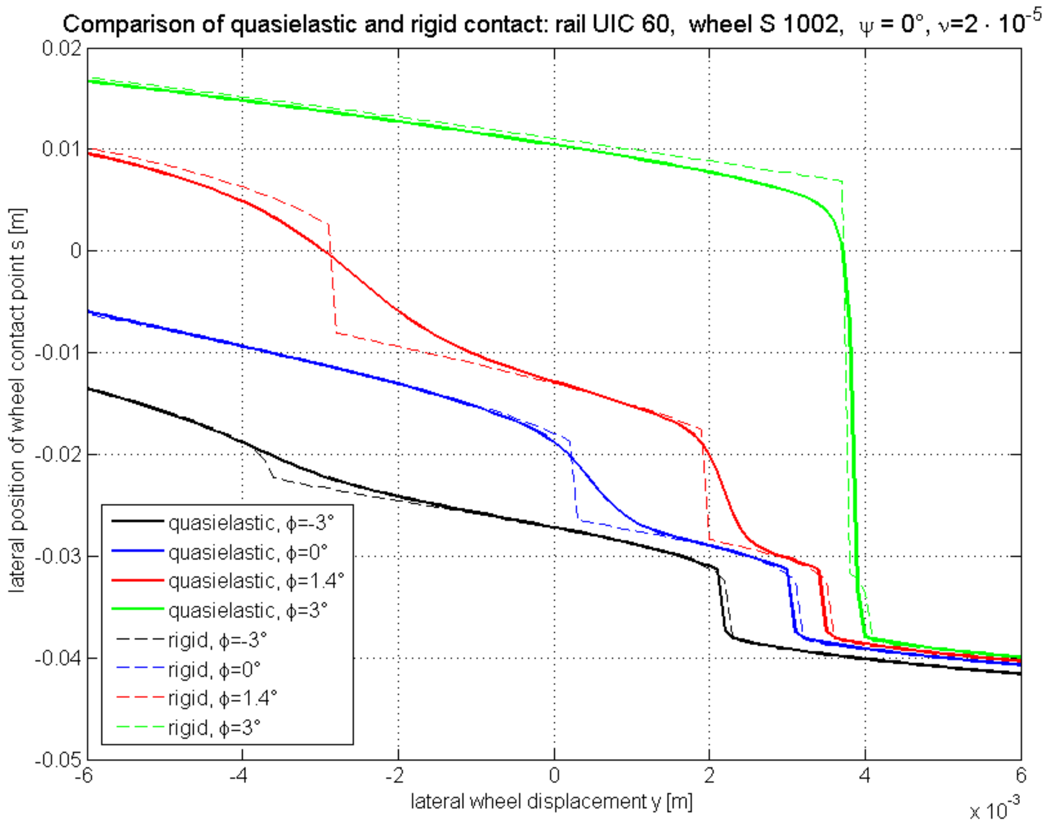


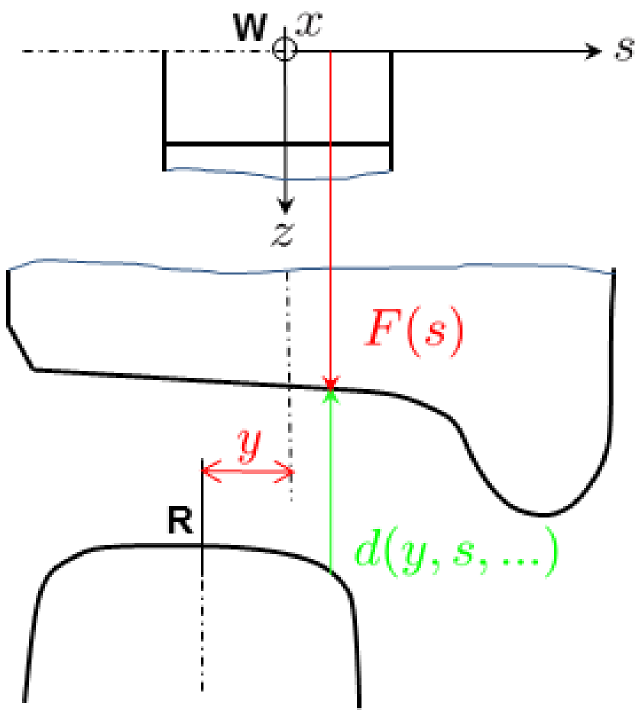
Theory: The Geometrical Problem: II

- Quasielastic formulation: [Arnold, Netter 96]:

$$g = \epsilon \ln \frac{\int e^{\frac{d(y,s,\varphi,\psi)}{\epsilon}} \mathrm{d}s}{\int \mathrm{d}s} = 0$$

$$\epsilon = 1 \ldots 5 \cdot 10^{-5}$$



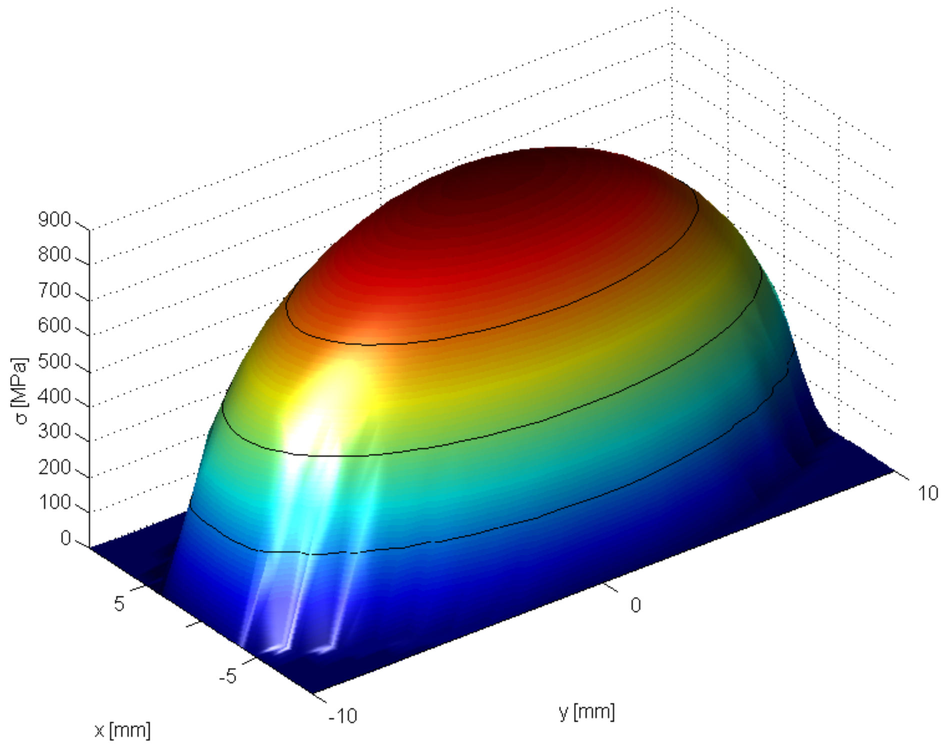


Theory: The Normal Contact Problem

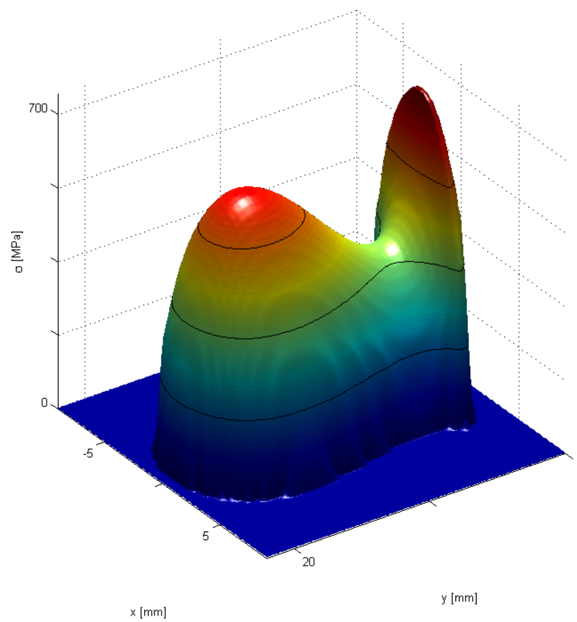
- The Hertz assumption
  - Geometry of contacting surfaces ≈ elliptic paraboloids

  ⇒ contact patch is a plain ellipse

Normal pressure according to Hertz: a=5 mm, b=10 mm, F=100 kN

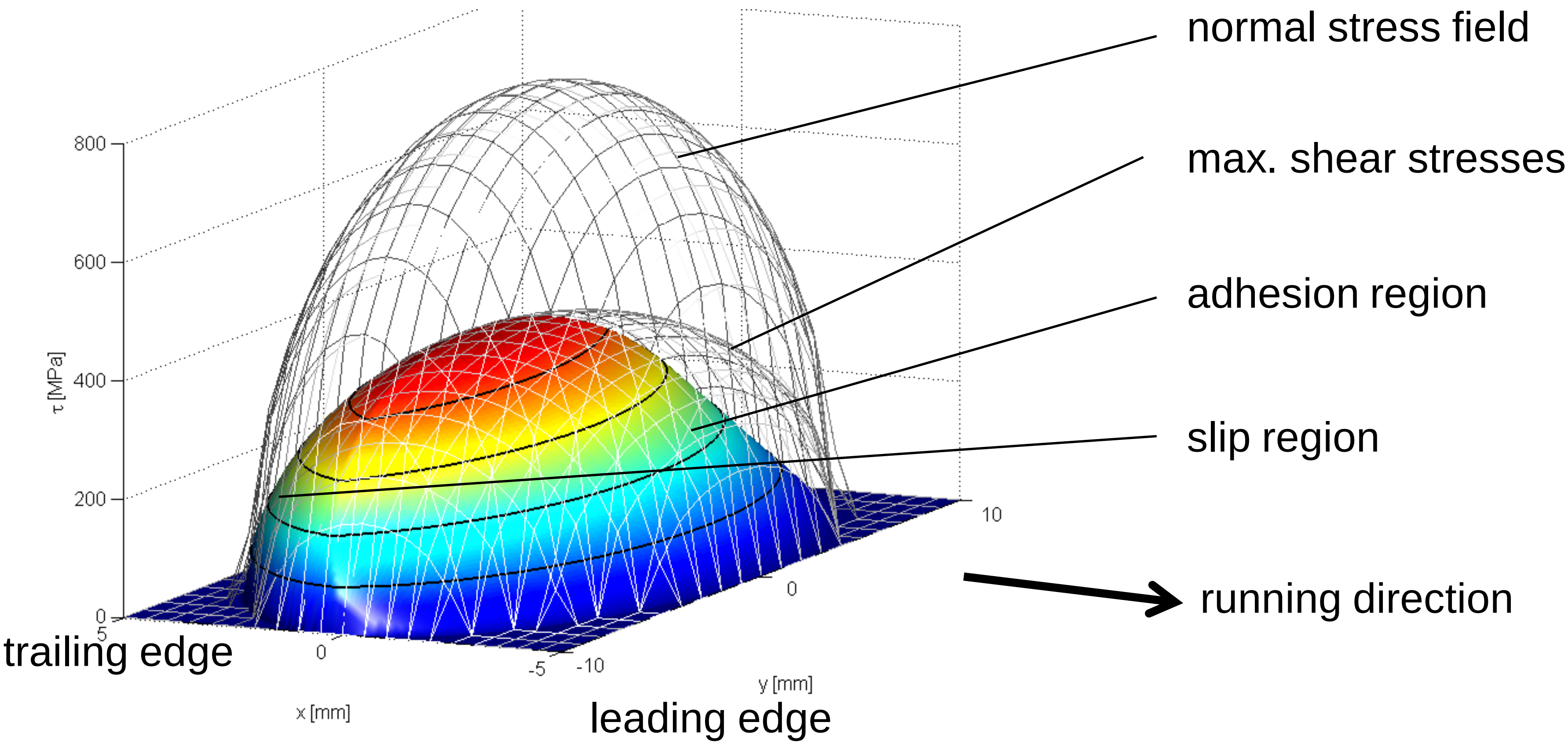


For comparison:
Kalker‘s nonelliptical contact

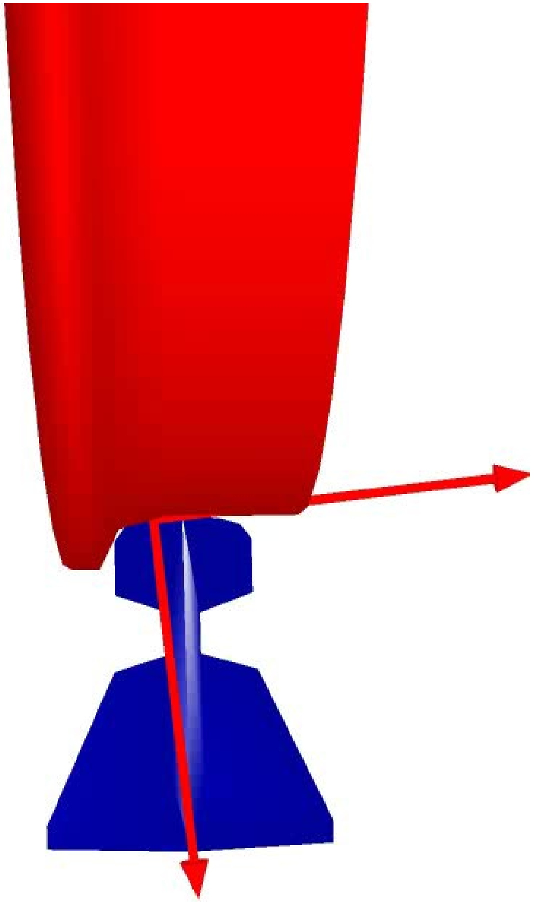


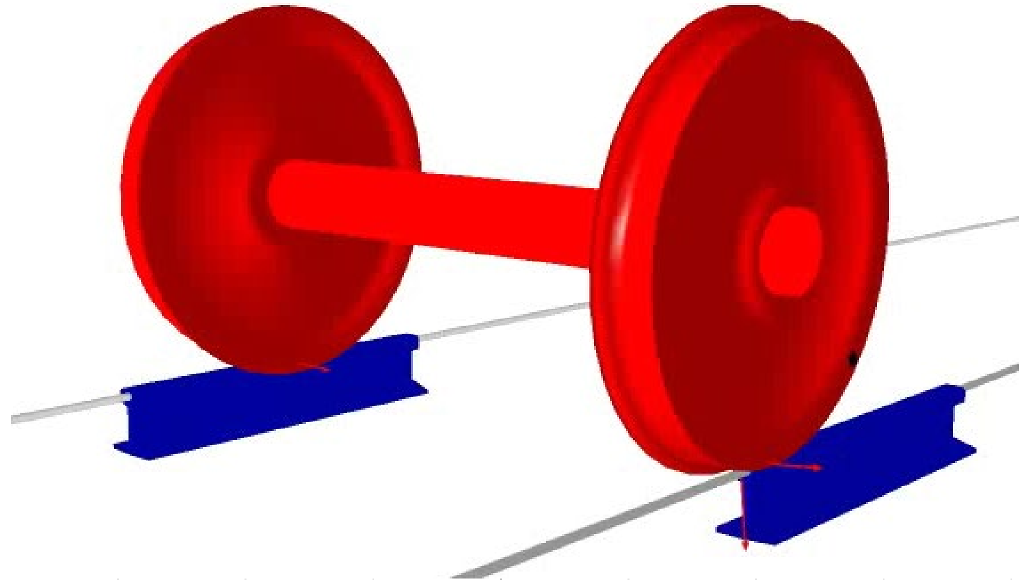
Theory: The Tangential Contact Problem

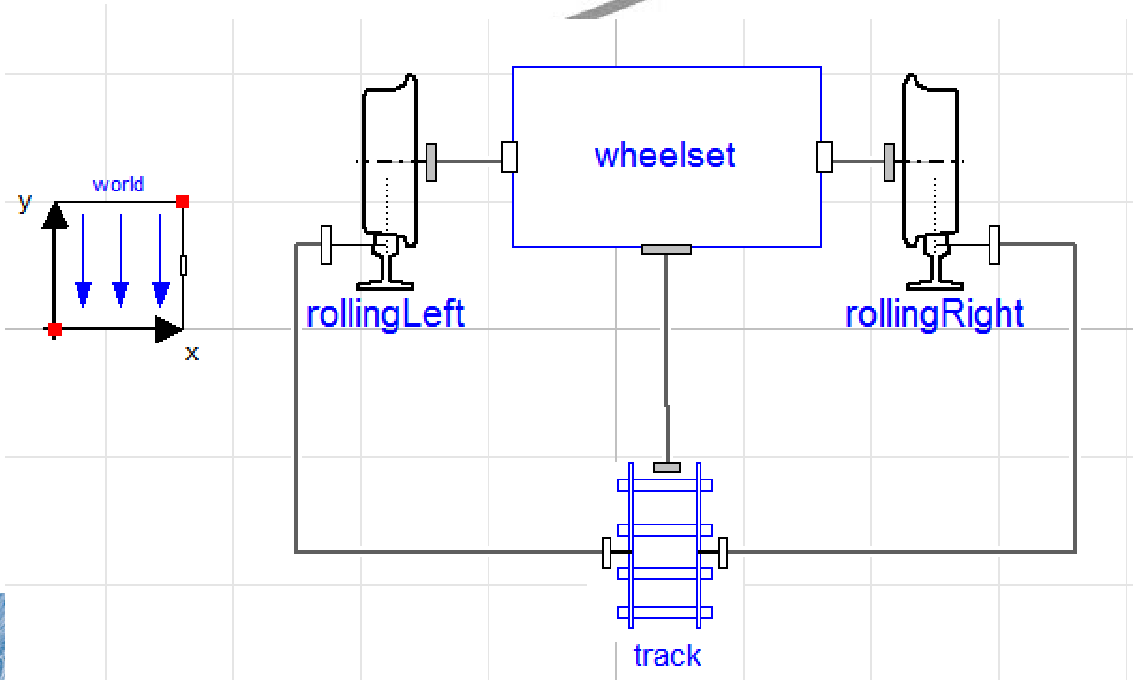
- Nonlinear analytical formulation [Polach 2000]:
  - Converges against Kalker‘s linear theory for vanishing slip
  - Is in particular tailored for high traction forces



Application: The free Wheelset

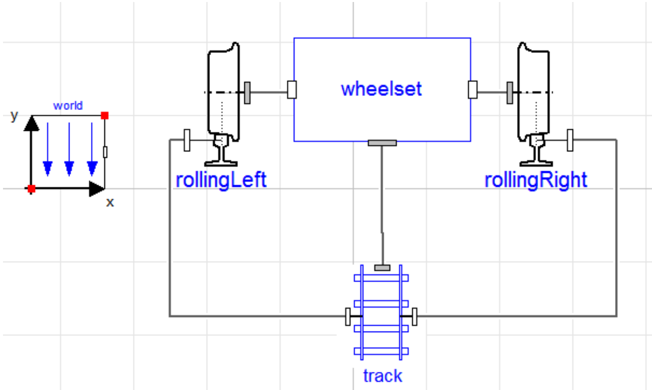


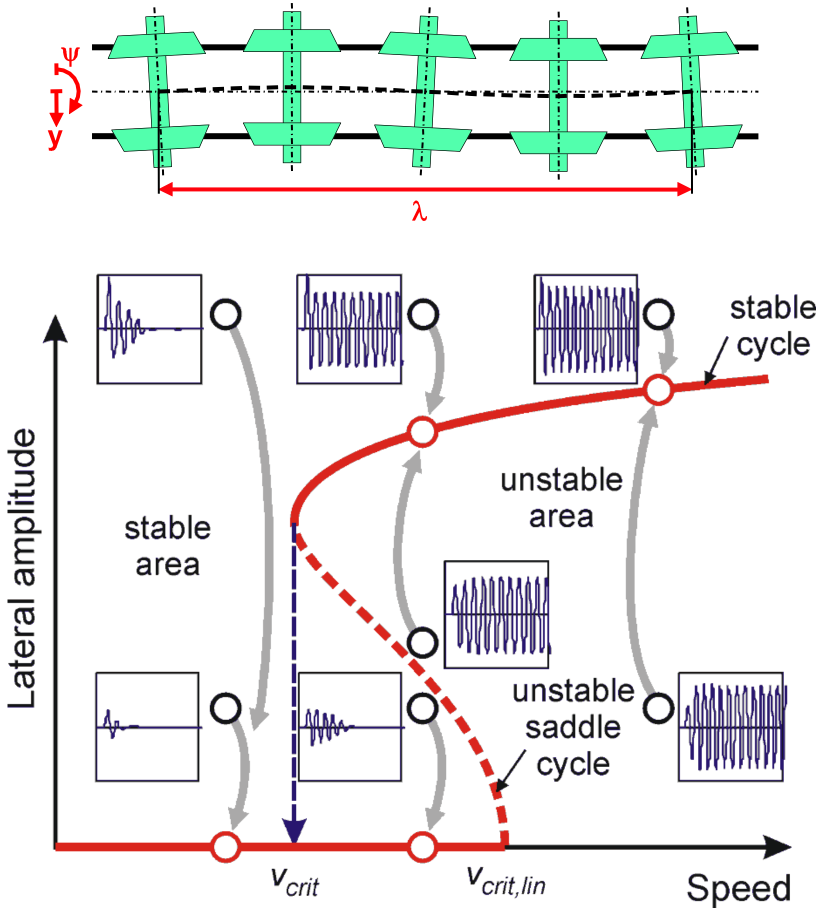




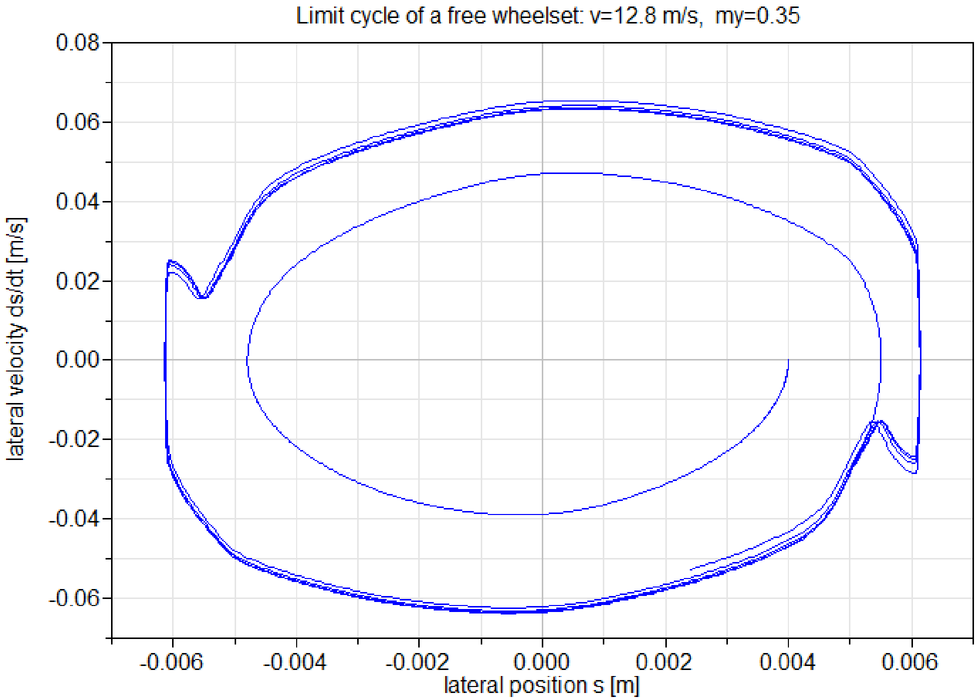
Application: the free Wheelset

- Beyond critical speed: limit cycle behavior



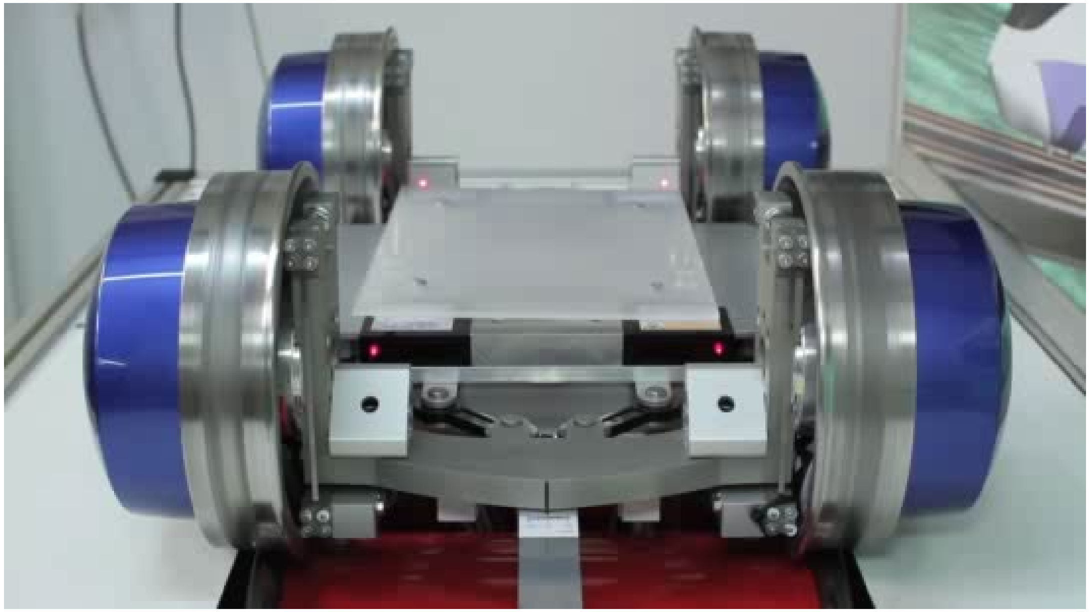


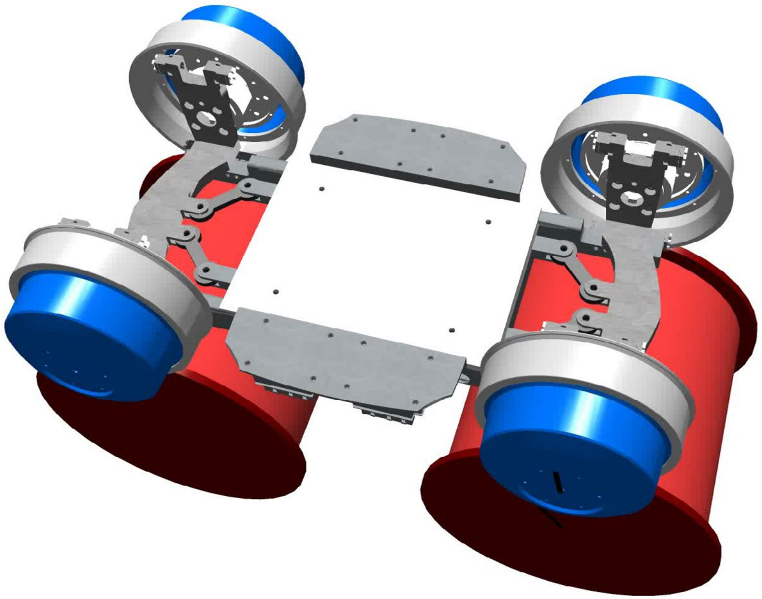
[Polach 2010]



Application: the scaled roller rig

- Experimental environment for validation and research on control
- Actual wheel-rail profile in use here is comparable simple.
- Assembled with force / torque – sensors
- Modelica simulation is approx. 2 times faster than real time.

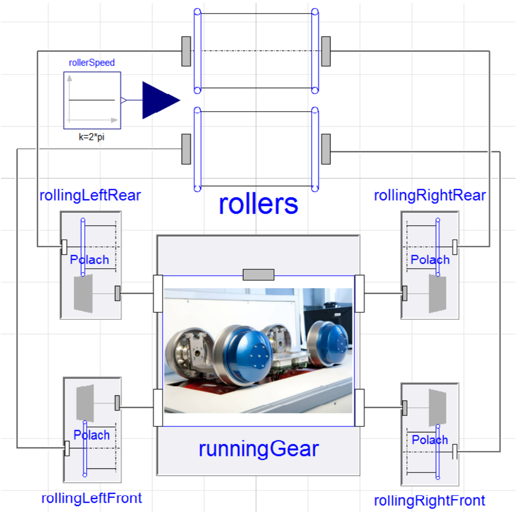




see youtube-video

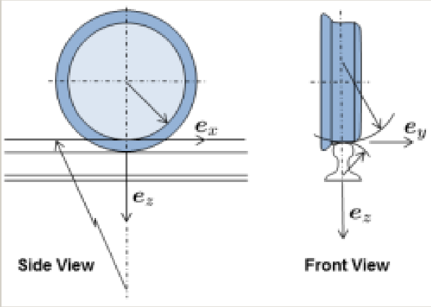
animated by DLR Visualization Library

Application: the scaled roller rig



Geometry

wheelRadius	wheelRadius	m	Wheel radius
rollerRadius	rollerRadius	m	Roller radius
conusAngle	-1*conusAngle	deg	cone angle
r_Rail_SideView	rollerRadius	m	radius of the rail in side-view
r_Rail_FrontView	0.06	m	radius of the rail in front-view
r_Wheel_SideView	wheelRadius	m	radius of the wheel in side-view
r_Wheel_FrontView	1e12	m	radius of the wheel in front-view

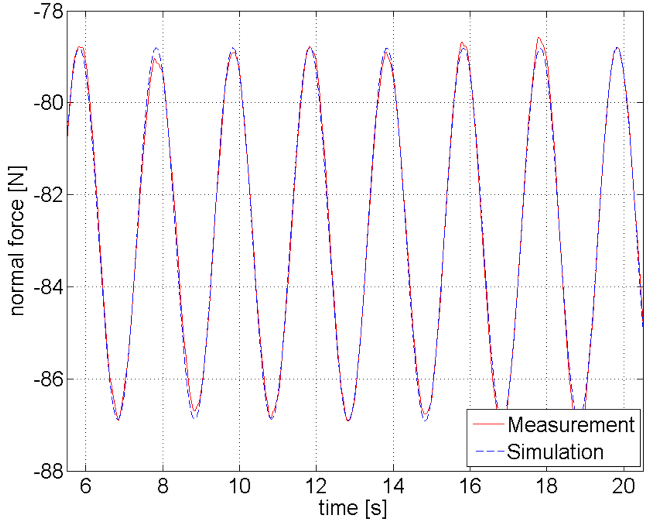


Physics

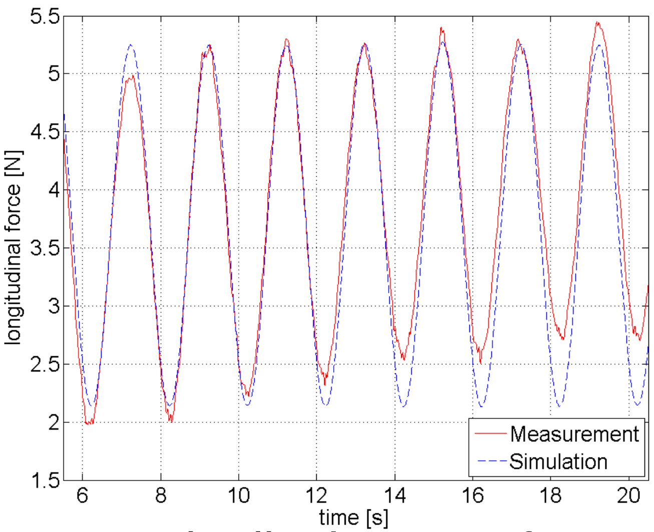
mue_0	0.3	1	maximum friction coefficient at zero slip velocity
B	0.6	s/m	coefficient of expotential frcition decrease
A	0.4		ratio of frcition coefficients my0/my_infinity
k_S	0.4		<= 1 friction reduction in slip area
k_A	1		<= 1 friction reduction (in adhesion area)
nue	0.3	1	Poisson number
E	2.1e11	Pa	Young's modulus

Application: the scaled roller rig

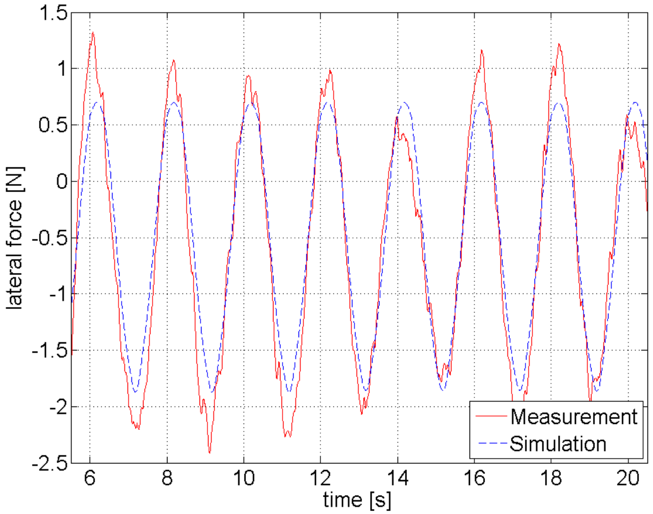
- Measurements versus simulation



Normal contact forces



Longitudinal contact forces



Lateral contact forces

Conclusions and Outlook

- The wheel-rail contact for several geometries has been implemented.
- The final goals are
  - observer development
  - feed-forward control
  - feed-back control

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