Influence of Locomotive Tractive Effort on the Forces between Wheel and Rail

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Contents

- Calculation of wheel-rail forces in railway vehicle dynamics
- Differences in the calculation of wheel-rail forces in vehicle dynamics and in drive dynamics
- Model of wheel-rail forces suitable for computer simulation of vehicle and drive dynamics interaction
- Influence of tractive effort on the wheel-rail forces during curving
- Co-simulation of vehicle dynamics and traction control
- Conclusions
Wheel-rail forces are functions of at least four independent variables (multi-dimensional problem):

\[ F_x, F_y = f(s_x, s_y, \omega, a/b, Q, f) \]

- The calculation is repeated many times for each wheel in each integration step
  - the calculation time is very important
A Time Saving Method of Wheel-Rail Forces Calculation

- Compromise between calculation time and necessary accuracy
- Spin taken into account
- Calculation time comparable with saturation functions or look-up tables
- Pre-calculation superfluous
- Accuracy comparable with FASTSIM or look-up tables
- Principle and computer code published at the 16th IAVSD Symposium, Pretoria 1999
Comparison of Simulation and Measurement
ADAMS/Rail Model of Locomotive SBB 460

Vehicle Model:
- 51 rigid bodies
- 84 bushings
- 4 bump-stops
- 24 dampers

Mechanism of Wheelset Coupling:
- Wheelset
- Axle box
- Linkage
- Coupling shaft
Comparison of Simulation and Measurement Results

Derailment quotient

Wheelset

Wheelset

Calculation time

\[ a_{\text{lat}} = -0.3 \text{ m/s}^2 \]

\[ a_{\text{lat}} = 1.1 \text{ m/s}^2 \]

R = 300 m

\[ L = 1.1 \text{ m/s}^2 \]

\[ R = 300 \text{ m} \]

\[ \text{FASTSIM} \]

\[ \text{Calculation time} \]

\[ \text{proposed} \]

\[ \text{measurement} \]

\[ \text{FASTSIM} \]

\[ \text{proposed} \]

\[ \text{measurement} \]
Differences of Creep-Force Functions in Vehicle Dynamics and Drive Dynamics

Vehicle Dynamics
- Possible for use in vehicle dynamics (small creep)
- Used for longitudinal and lateral directions
- Function of creep

Drive Dynamics
- Necessary for drive dynamics (large creep - slip)
- Usually used only for longitudinal direction
- Function of slip velocity
Wheel-Rail Model for Computer Simulation of Vehicle and Drive Dynamics

- Friction coefficient decreasing with slip velocity
- Reduction of Kalker's factor

Friction coefficient vs. Slip velocity

Adhesion coefficient vs. Creep

Kalker's factor = 1
Kalker's factor < 1

Creep
Wheel-Rail Model for Computer Simulation of Vehicle and Drive Dynamics

- Modelling of measured creep-force functions (Measurement on locomotive SBB 460)

V = 40 km/h, wet
Average curve of 7 measurements

V = 20 km/h

Calculation
Wheel-Rail Model for Computer Simulation of Vehicle and Drive Dynamics

- Influence of vehicle speed
Simulation of Vehicle and Drive Dynamics
Model of Loco SBB 460 Including Drive System

Drive System:
- Wheelset
- Motor
- Pinion
- Idler
- Hollow shaft
- Large gear wheel

Vehicle Model:
294 Degrees of Freedom
Influence of Locomotive Tractive Effort on the Wheel-Rail Forces in a Curve

Tractive force:
- $Z = 0 \text{kN}$
- $Z = 100 \text{kN}$
- $Z = 200 \text{kN}$

Forces between wheel and rail

R = 300 m, $a_{\text{lat}} = 1 \text{ m/s}^2$

wet condition, friction coefficient function of slip velocity

Steering angle

$\beta$ [mrad]
Test composition
Simulation of the Adhesion Test

- Time plots of the values on the leading bogie

  - Curve: R = 400 m
  - Vehicle speed: V = 70 km/h
  - Rail conditions: wet

  Rotation torque
  
  Longitudinal force in steering linkages
  
  Lateral displacement of wheelset relative to track
  
  Steering angle between the wheelsets

  Wheelset 1
  
  Wheelset 2
  
  Wheelset 1
  
  Wheelset 2
Co-Simulation of Vehicle Dynamics and Traction Control

- Adhesion Controller (MATLAB-SIMULINK)
- Mechanics (ADAMS/Rail)
Co-Simulation of Vehicle Dynamics and Traction Control
Co-Simulation Results of the Interaction of Vehicle Dynamics and Traction Control

Track design: straight, curve R = 300 m, straight, curve R = 385 m

Rail conditions: wet

Vehicle speed

Longitudinal force of wheelset 1

Rotor torque

Lateral force of wheelset 1

Traction rod force

Steering angle between the wheelsets

Rail conditions: wet

Track design: straight, curve R = 300 m, straight, curve R = 385 m
Conclusions

- The method of wheel-rail forces calculation developed by the author is suitable for computation of full non-linear wheel-rail forces; it takes spin into account and saves calculation time.

- The presented extension of the proposed method allows a parallel simulation of vehicle and drive dynamics.

- The proposed method was verified by measurements and is suitable for investigations of interaction of traction dynamics, traction control and vehicle behaviour.