Creep Forces in Simulations of Traction Vehicles Running on Adhesion Limit

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Creep Force Models in Vehicle Dynamics and Drive Dynamics => Demand of one Common Model

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

- Necessary for drive dynamics (large creep - slip)
- Usually used only for longitudinal direction
- Function of slip velocity
Demand for Creep Force Model Suitable for Simulations of Traction Vehicles Running on Adhesion Limit

Difference dry - wet rail:
- Reduced initial slope
- Adhesion optimum at large creep on wet or polluted rail

State-of-the-art:
- Modells with decreasing section published
- Agreement only for dry and clean contact conditions
- No simple model to simulate real wet and/or polluted conditions
Calculation of Creep Forces in Vehicle Dynamics

Wheel-rail forces are functions of at least four independent variables (multi-dimensional problem):

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

- creepages
- shape of the contact area

The calculation is repeated many times for each wheel in each integration step

\[ \rightarrow \text{the calculation time is very important} \]
A Time-Saving Method for Calculation of Creep Forces in Multi-body Simulations

- Compromise between calculation time and necessary accuracy
- Magnitude of the resultant creep force as integration of the shear stress distribution
- Effect of spin included - based on integration of tangential stress distribution caused by pure spin and on Kalker’s results
- Simple algorithm - no discretisation or iteration loops necessary
- Calculation time comparable with saturation functions or look-up tables
- Accuracy comparable with FASTSIM
- Method available in ADAMS/Rail, SIMPACK, GENSYS and used in other tools as well
Friction Coefficient Dependent on Slip (Creep) Velocity

- Friction coefficient decreasing with slip velocity
- Reduction of Kalker's factor
  - Kalker's factor = 1
  - Kalker's factor < 1
Limitations of the Model with Decreasing Friction Coefficient

- Disagreement mainly for bad adhesion conditions (contaminated or wet rail)
Principle of the Extended Model for Large Creep

- Decrease of shear stiffness with increasing creep
- Modelled by two reduction factors

![Graph showing the decrease of shear stiffness with increasing creep](image)

- **$k_1$**
- **$k_2$**
Extended Model for Large Creep Applications

- Different reduction factors $k_A$ in the area of adhesion and $k_S$ in the area of slip
Parameter Identification from Measurements

- Measurements with GM Locomotive SD 45X
  (Logston-Itami, USA, 1980)
Parameter Identification from Measurements

- Measurements with Bombardier Locomotive SBB 460, watered rails (Switzerland, 1992)
Parameter Identification from Measurements

- Measurement with Siemens Locomotive Eurosprinter (DB 127), dry rails
  (Engel - Beck-Alders, Germany, 1998)

![Graph showing parameter identification from measurements.](image)
Typical Parameters for Real Wheel-Rail Contact

- Three additional parameters:

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>dry</th>
<th>wet</th>
</tr>
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<tbody>
<tr>
<td>$k_A$</td>
<td>1.00</td>
<td>0.30</td>
</tr>
<tr>
<td>$k_S$</td>
<td>0.40</td>
<td>0.10</td>
</tr>
<tr>
<td>$\mu_0$</td>
<td>0.55</td>
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</tr>
<tr>
<td>$A$</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>$B$ (s/m)</td>
<td>0.60</td>
<td>0.20</td>
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</table>
Extended Model for Large Creep Applications

- Influence of longitudinal, lateral, spin creepages and the shape of the contact ellipse considered

$$\omega_B = 0 \text{ rad/m}$$
$$a/b = 1$$
Extended Model for Large Creep Applications (2)

- Influence of longitudinal, lateral, spin creepages and the shape of the contact ellipse considered

\[ \omega_B = 10 \text{ rad/m} \]
\[ a/b = 3.5 \]
Extended Model for Large Creep Applications (3)

- Influence of vehicle speed
Influence of Tractive Force on the Self-Steering Model of Locomotive SBB 460 (ADAMS/Rail)

Mechanism of Wheelset Coupling:
- Wheelset
- Linkage
- Coupling shaft
- Axle box

294 Degrees of Freedom
Simulation of Adhesion Test with Locomotive SBB 460

- Output time plots - leading bogie

- Curve: $R = 400$ m
- Vehicle speed: $V = 70$ km/h
- Rail conditions: wet
Co-Simulation of Vehicle Dynamics and Traction Control

Traction Controller
(MATLAB-SIMULINK)

Vehicle Model
(SIMPACK)

\[ \omega_{R3}, \omega_{R4}, V, M_{R3}, M_{R4} \]
Vehicle Model: Test Locomotive DB 128 (12X)

- Extended multi-body model
  - Vehicle model
  - Traction chain with torsionally elastic wheelset
Parameter Identification of Creep Force Model from Measured Creepforce-Creep-Functions

- One parameter set considers the influence of:
  - Vehicle speed
  - Longitudinal creep
  - Lateral creep
  - Spin
  - Contact geometry
  - Normal force
Reaction of Traction Control on Sudden Worsening of Adhesion Conditions

- Starting on straight track
- Sudden decrease of friction coefficient
Comparison Calculation - Measurement

- Starting and acceleration of a test composition on curved sloping track (Kanderviadukt, Switzerland, August 2001)

**Longitudinal guiding force**
(Difference left - right)

- Measurement wheelset 3
- Measurement wheelset 4
- Calculation wheelset 3
- Calculation wheelset 4

<table>
<thead>
<tr>
<th>Distance [m]</th>
<th>Force [kN]</th>
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<tbody>
<tr>
<td>0</td>
<td>-20</td>
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<tr>
<td>100</td>
<td>-15</td>
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<tr>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>700</td>
<td>15</td>
</tr>
</tbody>
</table>

- Right curve 300 m
- Left curve 385 m
- Right curve 290 m
Conclusions

- The proposed method enables computer simulations of complex vehicle system dynamics including running and traction dynamics.
- Influence of speed, shape of the contact ellipse, longitudinal, lateral and spin creep is considered using one parameter set.
- The method can be used to model the creep forces based on the measured creepforce-creep-functions.
- If no measurements are available, the parameters recommended for typical wheel-rail contact conditions can be used in engineering applications.
- The method was used in complex simulations and validated by comparisons with measurements.