Overview of the DLR RailwayDynamics Library

A. Heckmann, M. Ehret, G. Grether, A. Keck, D. Lüdicke, C. Schwarz
DLR German Aerospace Center
Institute of System Dynamics and Control
Oberpfaffenhofen, Germany
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Background and Motivation

- DLR‘s historical background in multibody and railway dynamics
- DLR‘s Next Generation Train Project
  - Running gear development for an ultra high-speed train in double deck configuration and lightweight design, see video
- Several precursor papers

  - 2012: Energy Flows in Networks
  - 2014: Wheel-Rail Contact
  - 2015: Scaled Running Gear
  - 2017: Crosswind Stability
  - 2018: Brake Pneumatics
  - 2019: Railway Dynamics Library

- Objectives
  - Gathering, reorganizing and publishing given models
  - framework for future multidomain engineering tasks
Library, Model and Data Structure (I)

- General subpackage
  - 3D multi-purpose models
    - traction, comfort, safety, roller rigs, ...
- 3 specialized subpackages
  - Vertical ⇒ comfort
  - Longitudinal ⇒ traction
  - Crosswind ⇒ simplified crosswind assessment
- Vehicle template
  - Railroad base, running gears, carbody
Library, Model and Data Structure (II)

- General subpackage
  - 3D multi-purpose models traction, comfort, safety, roller rigs, …
- 3 specialized subpackages
  - Vertical ➞ comfort
  - Longitudinal ➞ traction
  - Crosswind ➞ simplified crosswind assessment
- Vehicle template
  - Railroad base, running gears, carbody
- Data Structure
  - Replaceable encapsulated records
Railway Modeling Particularities

Overview

- Track (inner/outer)
  - 3D curve $\vec{r} = \vec{r}(s)$, collateral frame
  - rail position and orientation
  - irregularities
- Track joint
  - Longitudinal degree of freedom
  - 2 states: $s, v$
- Track panel
  - accompanying mass-spring-damper system
  - 2 rail stubs and sleeper
- Wheelset
  - 5 degrees of freedom
  - Inertia properties
- Wheel-Rail contact
  - UIC60 and S 1002 predefined
  - Linear and Polach model predefined
Railway Modeling Particularities (I)
Track: some details

File format from the early 90's
Railway Modeling Particularities (II)

- Wheel reference frame
- Tape circle
- Taper line distance
- Rail tread
- Rail reference frame
- Rail gauge

- Gauge: 1.435 m
- Gauge offset: 0.072 m
- Inclination: 1/40
Railway Modeling Particularities (III)

Track:

```
```

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>redeclare verticalIrregularity</td>
<td></td>
</tr>
<tr>
<td>Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_min</td>
<td>1e-3</td>
<td>minimal distance frequency to consider</td>
</tr>
<tr>
<td>f_max</td>
<td>10</td>
<td>maximum distance frequency to consider</td>
</tr>
<tr>
<td>n_f</td>
<td>1024</td>
<td>sampling of spectrum w.r.t frequencies</td>
</tr>
<tr>
<td>samplingMethod</td>
<td>linear</td>
<td>method of frequency sampling</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td>time constant to smooth onset</td>
</tr>
<tr>
<td>onset</td>
<td></td>
<td>initial onset of excitation</td>
</tr>
<tr>
<td>globalSeed</td>
<td>97215</td>
<td>Global seed to initialize random phase generator</td>
</tr>
<tr>
<td>localSeed</td>
<td>104976</td>
<td>Local seed to initialize random phase generator</td>
</tr>
<tr>
<td>b</td>
<td>7.343623e-7</td>
<td>numerator of the polynomial that specifies PSD</td>
</tr>
<tr>
<td>a</td>
<td>0.00028855,0.6803895,0.1</td>
<td>denominator of the polynomial that specifies PSD</td>
</tr>
<tr>
<td>scale</td>
<td>1</td>
<td>map specification units to SI</td>
</tr>
<tr>
<td>angular</td>
<td>true</td>
<td>polynomial specification w.r.t. angular frequency</td>
</tr>
</tbody>
</table>

```
redeclare Excitation.Irregularities.Lateral.Default lateralIrregularity
```
Railway Modeling Particularities (I)
Contact: some details
Railway Modeling Particularities (II)

Contact: some details
Railway Modeling Particularities (III)
Contact: some details

- **Name**: rollingRight
- **Comment**:

**Model**
- **Path**: RailwayDynamic
- **Comment**: elastic contact

**General**
- **Tangential Contact**
- **Normal Contact**
- **Add modifiers**
- **Attributes**

**nonLinearTangentialContact**: false, true

- **mue_0**: 0.36
- **A**: 0.38
- **B**: 0.2
- **k_A**: 0.9
- **k_S**: 0.5

**eval_NonLinearTangentialContact**: Polach Cor

Maximum friction coefficient at zero slip velocity
Ratio of friction coefficient
Coefficient of expotential friction decrease
Friction reduction in adhesion area
Friction reduction in slip area
Applications: Traction

• Estimate longitudinal forces & oscillations during braking and accelerating
  ➢ Use reduced models: simulate large systems (e.g. freight train with 50 cars)

<table>
<thead>
<tr>
<th>Example: Train with 5 cars</th>
<th>CPU-s/s</th>
<th>Number of states</th>
</tr>
</thead>
<tbody>
<tr>
<td>General models only</td>
<td>69.5</td>
<td>605</td>
</tr>
<tr>
<td>Mixed: 1 car 3D + 4 cars 1D</td>
<td>6.65</td>
<td>157</td>
</tr>
<tr>
<td>Longitudinal models only</td>
<td>0.08</td>
<td>51</td>
</tr>
</tbody>
</table>

➢ Peaks of coupler forces occur at beginning of brake and acceleration phases
➢ Simulation results of different models coincide
Applications: Comfort

\[ S(\Omega) = \frac{b_0 + b_1 \Omega^2}{a_0 + a_2 \Omega^2 + a_4 \Omega^4 + a_6 \Omega^6} \]

\[ f = \frac{\Omega}{2\pi} \left[ \frac{1}{m} \right] \]

<table>
<thead>
<tr>
<th></th>
<th>CPU-s/s</th>
<th>( N_{\text{MVZ}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter vehicle</td>
<td>1.58</td>
<td>0.63</td>
</tr>
<tr>
<td>Full vehicle</td>
<td>9.08</td>
<td>0.43 ... 0.83</td>
</tr>
</tbody>
</table>
Applications: Roller Rig (I)

Knorr Bremse, Munich

Luccini

wheel radius [m]: 0.46
roller radius [m]: 1.5
initial velocity [m/s]: 33

lateralLoad
riseTime=2

primarySuspension

wheelset

roller

railway

fixedRotation
Applications: Roller Rig (II)
Multidomain Modeling
VehicleInterfaces Library reloaded
Multidomain Modeling
Alternative Proposal
Conclusions

• The DLR RailwayDynamics Library covers railway dynamics.
• Different levels of details up to realtime capability: SiL, HiL
• Synthesis of advanced observer and controller lay-outs
• Multidomain modeling in one consistent environment
  • Pneumatics: brakes, air suspensions
  • Power trains: electric, Diesel-hydraulic, Diesel-electric
  • Regeneration of electric energy
  • Adhesion and interaction of traction and power-train
  • Auxiliary systems
  • ....