Design and Calculation of „Fast-Running“ Shunting Locomotives

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SIMPACK User Meeting 2011
Shunting Locomotive Ee 922 - Introduction

• 2007: Swiss Federal Railways (SBB) called for tenders for a 2-axle electric shunting locomotive

• Operating conditions: shunting of coaches in main stations with maximum operating speed of 40km/h

• Main vehicle data:
  - weight 40 – 45t
  - axle distance 4 – 4.5m

• Soft axle guidance desired (wear reduction)

• Maximum speed for transfer vehicle between stations and maintenance site: 100 km/h

⇒ Investigation of the hunting behavior necessary
Shunting Locomotive Ee 922 – Design Stage

- Building a SIMPACK model from design picture and sketch
Shunting Locomotive Ee 922 – SIMPACK Model

- Model with 9 bodies
  - wheelsets
  - axle boxes
  - motor/gear unit
  - carbody

- Standard force elements for
  - primary springs
  - primary dampers
  - traction rods
  - bump stops
Shunting Locomotive Ee 922 – Stability Chart

- Calculation of critical speed with parameter variation
- Stability chart for basis model ⇒ insufficient stability

Critical speed

<table>
<thead>
<tr>
<th>Conicity λ</th>
<th>v.crit [km/h]</th>
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<tbody>
<tr>
<td>0.00</td>
<td>200</td>
</tr>
<tr>
<td>0.05</td>
<td>190</td>
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<tr>
<td>0.10</td>
<td>180</td>
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<tr>
<td>0.15</td>
<td>170</td>
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<td>0.20</td>
<td>160</td>
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<td>0.30</td>
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<td>110</td>
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<td>0.50</td>
<td>100</td>
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<td>0.55</td>
<td>90</td>
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<tr>
<td>0.60</td>
<td>80</td>
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<tr>
<td>0.65</td>
<td>70</td>
</tr>
<tr>
<td>0.70</td>
<td>60</td>
</tr>
<tr>
<td>0.75</td>
<td>50</td>
</tr>
<tr>
<td>0.80</td>
<td>40</td>
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</tbody>
</table>

- Limit value
- Basis Model 2007
Shunting Locomotive Ee 922 – Time Integration

• Non linear wheel/rail contact with worn profiles
• Investigation of sum of lateral forces (stability criterion)
Shunting Locomotive Ee 922 – Stability Chart

- Parameter variation: axle distance

Critical speed

- Limit value
- $2a = 4.0\,\text{m}$
- $2a = 4.5\,\text{m}$
- $2a = 5.0\,\text{m}$

Axle distance increasing
Shunting Locomotive Ee 922 – Stability Chart

- Parameter variation: stiffness of axle guidance

Critical speed

- Guiding stiffness increasing
Shunting Locomotive Ee 922 – Stability Chart

- Parameter variation: carbody moment of inertia about z
Shunting Locomotive Ee 922 – SIMPACK Model

- Significant amount of vehicle mass is additional mass (needed for traction reasons)
- Modification of SIMPACK model
- 2 separate bodies positioned at the end of the carbody
- Suspended with springs
- Low spring stiffness in lateral direction
- Used as “tuned mass damper”
Shunting Locomotive Ee 922 – Stability Chart

- Parameter variation: lateral stiffness of absorber mass spring

![Stability Chart](chart.png)

**Critical speed**

- Limit value
- A.Mass Stiffness Var1
- A.Mass Stiffness Var2
- A.Mass Stiffness Var3
- A.Mass Stiffness Var4

Stiffness increasing

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Shunting Locomotive Ee 922 – Root Locii

- Parameter variation: lateral stiffness of absorber mass spring
- Eigenvalue calculation for constant conicity ($\lambda=0.7$) and different velocities (10 .. 150 km/h)

lateral stiffness increasing
Shunting Locomotive Ee 922 – Eigenmodes

• Eigenmode 1.5 – 2.5Hz
• Carbody yawing and mass lateral movement in phase

• Eigenmode 4 – 5Hz
• Carbody yawing and mass lateral movement in antiphase
Shunting Locomotive Ee 922 – Parameter Optimization

- Refinement of SIMPACK model
- Definition of axle distance 4.0m
- Optimization of parameters:
  - Soft primary spring and axle guiding
  - Definition of mass spring and damper
  - Definition of primary dampers
Shunting Locomotive Ee 922 – Stability Verification

- Simulation of stability behavior
- Verification of behavior during type tests
Shunting Locomotive Ee 922 – On Track
Shunting Locomotive Eem 923 – Next Project

- 2-frequency – Hybrid – Locomotive BUTLER with Electric- and Dieselpower
- Ordered by SBB Cargo for Cargo- and Shunting-Services
- Maximum speed 100km/h (designed for 120km/h)
Shunting Locomotive Eem 923 – SIMPACK Model

- Model of Ee 922
- Adjusted parameters:
  - axle distance
  - mass properties of carbody
  - mass properties of absorber
- Evaluation of influence of
  - axle distance change
  - absorber mass
  - center of gravity of absorber mass (asymmetry)
- Is it possible to use mass of components (diesel engine, converter) as absorber mass?
Shunting Locomotive Eem 923 – Simulations

- SIMPACK parameter variation on eigenfrequency:
  - Calculation of eigenvalues: constant vehicle velocity, variation of conicity
  - Fast overview over large array of conicities and velocities

- Selective simulations in time domain to determine forces, distances and velocities of force element
Shunting Locomotive Eem 923 – Root Locii

- Calculation of eigenvalues

- $v = 100 \text{ km/h}$

- $v = 140 \text{ km/h}$

E.g. absorber mass: shifting of center of gravity in $x$ toward vehicle center has to be avoided.
Shunting Locomotive Eem 923 – Results

• Conclusions from simulation results (eigenvalue calculation and time integration):
  – Possibility to reduce absorber mass compared to Ee 922
  – Possibility to use mass of components as absorber mass
  – Only little changes of suspension parameters compared to Ee 922

• Additional simulations: safety against derailment, swaying behavior running behavior in curves and turnouts
Shunting Locomotive Eem 923 – Turnouts

- Simulation of runs through turnouts
- Evaluation of sum of Y-forces
- Comparison with limit value for switches (according to Swiss regulation)

\[
(\Sigma Y)_{\text{max,2m}} = 0.85 \left( 10 + \frac{2Q_0}{3} \right) + \frac{2Q_0}{3}
\]

Interpolation

\[\text{Interpolation}\]

25 + \frac{2Q_0}{3}

\[
\text{Summe Y [kN]}
\]

\[
\text{Weg s [m]}
\]
Shunting Locomotive Eem 923 – Turnouts

- Simulation
  Turnout S-curves

- Two locos connected with sophisticated buffer model
  - hysteresis elements
  - contact elements

- Leading loco $v=$const.
  trailing loco with max. traction force
Shunting Locomotive Eem 923 – On Track soon