Simulation Modeling of Vehicle-Track Interaction in Swedish Heavy Axle Load Iron Ore Wagons

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KTH Railway Group

Key activities:

- Research, graduate and postgraduate education
- Courses for professional engineers
- Seminars
- Consulting
Traffic and Logistics

Electric Energy Conversion

Cost effective bridges

soil-steel composite railway bridges.

Structural Engineering and Bridges

Rail Vehicles (Light and with good dynamic and acoustic comfort)

Machine design

KTH Railway Group
Graduate education

- Vehicle System Technology, 8 credits
- Rail Vehicle Technology, 7.5 credits
- Rail Vehicle Dynamics, 8 credits
- Railway Traffic - Market and Planning, Basic Course, 7.5 credits
- Railway Traffic - Market and Planning, Advanced Course, 7.5 credits
- Railway Signalling System, 7.5 credits
- Railway Signalling System – Reliability, 7.5 credits
- Railway Signalling System - Project Planning, 7.5 credits
- Train Traffic Simulation, 7.5 credits
- Road and Railway Track Engineering, 7.5 credits
- Operation and maintenance of Railways, 7.5 credits
- Electric Traction, 6 credits
Simulation Modeling of Vehicle-Track Interaction in Swedish Heavy-Axle-Load Iron Ore Wagons

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Background to the project

• Reduce frequency of Rolling Contact Fatigue
• Optimize whel and rail profiles to minimize maintenance cost
• Further increase of axle load to 35 ton
• Increase vehicle speed to increase line capacity

→ Build a Multibody simulation model (GENSYS)
• The Iron Ore Line (Swedish: Malmbanan) is around 500 km.
• The bogie type is Amsted motion control M976 with load sensitive friction damping.
• Wagons are so called Fanoo:
  • Axle load: 30 tons
  • Vehicle speed:
    • Loaded: 60 Km/h
    • Empty: 70 km/h
• Number of wheel injuries (RCF) rises dramatically in winter time
We have modelled many freight cars before

Double-link

Y25  TF25

TF25SA

Unitrack

G70
Assumptions

- Bodies (car body, bolster, side frames, wheelset, wheels) are stiff bodies,
- Side bearers has always contact with car body,
- Wedges – massless elements,
- Contact between bolster and wedge – one dimensional friction block,
- Contact between wedge and side frame – two dimensional friction block,
- Adapter Plus – rubber elements with high stiffness in vertical direction,
- Clearances between elements are implemented in model (bolster-side frame, axel-side frame, etc,...)
The three-piece bogie

• ASF M975 Motion control

- Bolster – Side Frame
  7 outer – D5
  5 inner – D5

- Wedge – Side Frame
  Outer - 5062
  Inner - 5063
Simulation model of iron ore wagon with three piece bogie
Modelling friction damping

One dimensional friction block  Saint Venant element
Saint Venant element

Force – deflection curve

\[ F_0 = \mu N \]
Warping stiffness

- Variable rail profiles
- Stiffer Vehicle by adding a yaw damper in the secondary suspension (simulating the warping stiffness)
Model validation

Empty Vehicle (Carbody centre of gravity-acceleration)

Lateral Direction

Vertical Direction

Longitudinal position on the track [Km]

Measurement

Simulation

Measurement

Simulation
Model validation

Frequency domain- Q forces PSD

- PSD of Q111r, [kN²/(Hz)]
- PSD of Q111l, [kN²/(Hz)]
- PSD of Q112r, [kN²/(Hz)]
- PSD of Q112l, [kN²/(Hz)]
Model validation

Time domain - Y forces
Getting to the roots of RCR

• Concrete sleepers compared to wooden sleepers
• The wheel-rail coefficient of friction
• New and worn wheel profiles
• Seasonal variations of the track stiffness

• Track gauge → High normal stress
• Low conicity and speed → Resonance between the carbody and the hunting frequency
• Sleeper distance of 65 cm → Resonance between the bolster and the sleeper passing frequency
• Plastic shake down (Low Cycle Fatigue)
  For fatigue lives shorter than $10^4$ cycles. The LCF life is normally preedicted by the magnitude of the strain amplitude.
• Ratcheting
  The plastic deformation will remain unstable and there will be an incremental strain growth at each load cycle.
Surface initiated fatigue

Due to the longitudinal direction of the creep forces, the fluid can get entrapped in a crack on the *inner wheels* and on the *outer rail* in a curve. The creep force causes the crack to open and therefore the fluid can get in.
Concrete sleepers compared to wooden sleepers

![Graphs and Track Model Diagram]

- Wooden sleeper track measurement
- Concrete sleeper track measurement
- Simulated track
Concrete sleepers compared to wooden sleepers

- 20 Hz Low pass filtered
- Curve radius 476 m.
- Friction coefficient 0.4.
Seasonal variation of track stiffness

The vertical rail-track stiffness \((K_{zrt})\) and viscous damping \((C_{zrt})\) are reduced and increased by a factor of ten.

No significant difference is observed regarding RCF and the wear number. Moreover, there has not been any study showing that the frequency of the forces affects the RCF of the wheels.
Influence of wheel profile (WP4)
Wheel-rail coefficient of friction

Depends on:

- Rail Temperature
- Passing axle number
- Humidity
- Tribological surface condition: roughness, hardness,...
Wheel-rail coefficient of friction

Dependency of the longitudinal creep forces on the wheel-rail friction coefficient

\[ \mu = \frac{F_T}{F_z} = \frac{\sqrt{F_x^2 + F_y^2}}{F_z} \]

Dependency of the lateral creep forces on the wheel-rail friction coefficient

Curve radius
- 300 m
- 376 m
- 476 m
- 693 m
- 998 m
Wheel-rail coefficient of friction

Curve radius = 300 - 400 m
Wheel-rail coefficient of friction

Curve radius = 300 - 400 m

RCF Probability [%] vs Friction Coefficient
Track gauge

Track gauge distribution in Sweden and Norway

Sweden

Norway

Track Gauge [mm]
Track gauge

Utilized Friction Coefficient vs. Normalized vertical load for track gauge 1435 mm and 1450 mm.
Track gauge

R = 376 m
V = 60 km/h
μ = 0.5
Track gauge

$R = 376\text{m}$
$V = 60\text{km/h}$
$\mu = 0.5$
Track gauge

R = 376m
V = 60 km/h
μ = 0.5
Track gauge

\[ R = 376 \text{m} \]
\[ V = 60 \text{km/h} \]
\[ \mu = 0.5 \]
Track gauge

\[ R = 376 \text{m} \]
\[ V = 60 \text{km/h} \]
\[ \mu = 0.5 \]
Conclusions

• The effect of both concrete and wooden sleeper track on the wear number and RCF probability is studied and it does not show any significant difference.

• The new wheel profile is more vulnerable regarding RCF.

• A parametric study applied on the wheel-rail friction coefficient shows its significant impact on the RCF. This dependency is even more pronounced with larger track irregularities.

• The effect of seasonal variations of track stiffness is investigated, and it cannot be concluded that it is the main reason for severe RCF during winter.

• RCF will happen on the tread of the inner wheels while negotiating curves below approximately 450 m radius.
Increased speed

Measurement, 65 km/h
Increased speed

Simulation, 70 km/h
Thank you very much for your attention

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