Enhancing Software Tools for Vehicle Dynamics and the Validation for Rail Vehicle Engineering

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- Equivalent elastic contact model
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- Articulated train

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- Contact positions for a single wheelset
- Nonlinear stability for a passenger coach
- Articulated train running through a curve

### Conclusions
History of major development steps

1994  Nonlinear kinematics

2000  Flexible body simulation

2007  New SIMPACK Rail
In a nutshell: Why a new SIMPACK Rail?

Easy to use:
- Input parameters: only geometric and material data
- Arbitrary number and position of contact patches, automatically handled
- Compatible with substitution variables and substructures
- Open kinematic tree structure
- Detailed outputs for vehicle dynamics and rail-wheel contact specialists
  “What you see is what you get”

Open for the future:
- State-of-the-art: equivalent elastic contact – „close to the reality“
- In preparation: non-elliptic contact patches – realistic wear/RCF simulation
- Modern data structure
- Modular programming
Modeling methods

- Position
- Velocity
- Rotation angle
- Angular velocity

Profile geometry
- Profile approximation (splines)
- Calculation of the contact points

Normal contact
- Normal force calculation
- Positions of the contact points

Tangential contact
- Calculation of the creep forces
- Contact area
- Normal stress distribution

- linear
- Johnson/Vermeulen
- ... (discrete)
- FASTSIM
- non-elliptic (discrete)

- rigid
- quasi elastic
- equivalent elastic
- discrete elastic

See workshop!
Two different approaches: elastic or constraint model

Wheel-rail contact

Normal contact force

\[ F_N = f(p) \]

Spring (+ damper)

Contact search: equivalent elastic / discrete elastic (non-elliptic)

Tangential contact forces

\[ F_N = \lambda \]

Constraint

Contact search: quasi elastic
Contact methods compared here

Classic SIMPACK Rail:
- *Quasi elastic* contact point search (onepoint / multipoint)
- *Constraint* normal force
- FASTSIM tangential forces

New SIMPACK Rail:
- *Equivalent elastic* contact point search (always multipoint)
- *Hertzian* normal force
- FASTSIM tangential forces

Additionally, for non-elliptic contact:
- *Discrete elastic* contact point search (always multipoint)
- *Discrete elastic* normal force
- *Discrete* tangential forces
Verification process

- Module tests
- Plausibility tests
- Comparison with classic SIMPACK wheel-rail contact
- LD Benchmark (normal forces)
- Comparison with original ArgeCare contact module
- Single wheelset, synthetic passenger coach (with INTEC)
- Articulated train
- Manchester Benchmark etc.
- Further vehicles
Verification models: single wheelset

Verification:  *Basic* rail-wheel contact behavior

Model: Single wheelset guided by springs and dampers (derived from IAVSD Benchmark, 1991)

Scenarios: *Non-linear:*
- limit cycles and critical speed
- quasistatic flanging by lateral force and yaw torque
- deterministic irregularities in tangent track
- braking

*Linear:*
- root loci and critical speed
Verification models: synthetic passenger coach

Verification: Influence of rail-wheel contact upon the full vehicle

Model: Simplified passenger coach with basic damping

Scenarios: Non-linear:
- quasistatic flanging in curves
- deterministic and stochastic irregularities
- narrow curve, S-curve
- limit cycles and critical speed
- braking

Linear:
- root loci and critical speed
- frequency response, comfort
Verification models: articulated train

Verification: Behavior of a realistic vehicle

Model: Articulated train:
- 96 degrees of freedom
- 175 force elements
- 2 bogies with wheelsets
- 2 bogies with independent wheels
- 1 suspended car body

Scenarios: Non-linear:
- low-speed narrow curve with twist
- high-speed curve with unbalanced lateral acceleration
- tangent track with stochastic irregularities
- S-curve
Single wheelset – quasistatic flanging

**Why:**
Most basic behavior of a wheelset but of crucial importance for curving

**How:**
- tangent track
- constant lateral force
- constant yaw torque

**Results:**
- contact point positions (lateral, longitudinal)
- number of contacts
- wheelset lateral position
- wheelset yaw angle
- Y forces

**Wheelset y Deviation**

- New SIMPACK Rail (equivalent elastic)
- Classic SIMPACK Rail (quasi elastic, constraint, multipoint)

**Good agreement**
Single wheelset – quasistatic flanging

Wheelset Yaw Angle

-0.5
-0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0 2 4 6 8 10 12 14 16

Time (s)

Psi (deg)

- New SIMPACK Rail (equivalent elastic)
- Classic SIMPACK Rail (quasi elastic, constraint, multipoint))

Good agreement
Single wheelset – quasistatic flanging

Flange contact positions are slightly different (elastic/constraint).
Single wheelset – quasistatic flanging

Flange contact positions are slightly different (elastic/constraint).
Single wheelset – quasistatic flanging

Y forces are slightly different (elastic/constraint).
Synthetic passenger coach – limit cycle, critical speed

Why:  $v_{\text{crit}}$ is very sensitive against differences in modeling and methods

How:  
- tangent track
- initial excitation
- several increasing velocities
- re-use end states for new run
- non-linear simulation

Results:  Amplitudes of the wheelset after 6 s
Synthetic passenger coach – limit cycle, critical speed

164 km/h: y Position Wheelset

- New SIMPACK Rail (equivalent elastic)
- Reference (quasi elastic, constraint)
Synthetic passenger coach – limit cycle, critical speed

Limit Cycle Amplitudes $y$ Position Wheelset

- New SIMPACK Rail (equivalent elastic)
- Reference (quasi elastic, constraint)

Good agreement
Articulated train – narrow curve with twist

Why: Important for derailment behavior, crucial for light rail vehicles

How:  
- narrow curve ($R \ 20 \ m$) with entry and exit
- large superelevation with entry/exit ramps
- low speed (quasistatic)
- large $\mu = 0.4$

Results:  
- contact point positions
- number of contacts
- $Y/Q$ derailment safety indicator

Good agreement in $Y/Q$
Articulated train – narrow curve with twist

Additional contact patches are found on flange and tread.
Articulated train – narrow curve with twist

**Y/Q Independent Wheel Axle 3 L**

- Classic SIMPACK Rail (quasi elastic, onepoint, constraint)
- New SIMPACK Rail (equivalent elastic)

**Good agreement in Y/Q**
Articulated train – narrow curve with twist

Additional contact patches are found on flange and tread.
Articulated train – large unbalanced lateral acceleration

Why: Important for derailment behavior and wheel-rail forces

How:
- curve entry and exit
- $a_q = 1.4 \text{ m/s}^2$
- $\mu = 0.1$

Results:
- contact point positions
- $Y/Q$ derailment safety indicator

Good agreement in $Y/Q$. Peak at curve entry is different.
Articulated train – large unbalanced lateral acceleration

yw Wheelset 1 L

- Classic SIMPACK Rail (quasi elastic, one point, constraint)
- New SIMPACK Rail (equivalent elastic) – 1st CONTACT
- 2nd CONTACT

Additional contact patches are found.
Articulated train – large unbalanced lateral acceleration

<table>
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<tr>
<th>Y/Q Independent Wheel Axle 3 L</th>
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Good agreement in Y/Q. Peak at curve entry is different.
Articulated train – large unbalanced lateral acceleration

Additional contact patches are found.
Conclusions and Outlook

Following a long history of software verification also the New SIMPACK Rail will be verified by INTEC and Siemens TS.

Several verification procedures are used:
- INTEC internal procedures
- Collaboration INTEC / Siemens TS
- Siemens TS internal procedures

Results with equivalent elastic contact show good agreement so far.
- A more realistic contact patch search for multipoint contact has been reached.

Tests will be continued both at INTEC and Siemens TS.
- Fully non-elliptic contact is available but needs further effort.