Simulation of Railway Wheel Profile Evolution due to Wear

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Outline

- **Scientific foundation**
  - Basic methodology
  - Method validation
  - Further applications

- **Simpack implementation structure**
  - Wear model interface
  - New result element
  - Parameter variation functionality

- **Test examples**
  - Contact modelling issues
  - Elementary cases
  - Reference case
Wheel/rail contact research at Royal Institute of Technology (KTH), Stockholm

- Research programme initiated 1995
- Divisions of Rail Vehicles and Machine Elements

Material testing with partner universities
Contact modelling and wear
Wheel - rail wear prediction
System level wear simulation

Sponsored by most bodies of the Swedish railway community
System simulation objective

- **Project goals**
  - Quantitative prediction of wheel and rail profile evolution to a resolution sufficient for dynamic simulations
  - Proposed system improvements for wear reduction

- **Project means**
  - Systematic selection of simulations adequately representing the actual operation
  - Numerical simulation of the vehicle/track interaction by MBS formalism
  - Relevant contact and material loss models
  - Validation through full scale measurements
Wear simulation cornerstones

- **Simulation set:** A discretisation of the network to be considered, represented by an adequate selection of simulation cases
- **Dynamic model:** MBS model of the vehicle to be investigated
- **Wear model:** Relation between contact quantities (stresses, slip) and material removal
- **Profile updating:** Influence of material removal on the profile geometry considering actual contact positions
Wear simulation approach

- Simulation set design
  - Main discretisation parameter is the radius in the circular part of each curve
  - For each defined curve radius interval a type-curve is calculated
  - The wear distribution is weighted by the total curve length in the interval
  - Other parameters are speed, friction, rail profiles, track alignment

![Graph showing wear simulation approach](image)
Wear simulation approach

1. Initial wheel profile
2. Contact data generation
3. Transient simulations
4. Wear calculation
5. Scaling to step limit
6. Wheel profile updating

Wear step limits
0.1 mm max depth
1500 km running

Rail profiles
Simulation set
Wear map
Desired mileage

no
?
yes
Wear simulation approach

- Wear model - Archard’s wear equation

\[ V_w = k \cdot \frac{N \cdot s}{H} \]

Locally applied:

\[ \Delta z = k \cdot \frac{p_z \cdot \Delta s}{H} \]

- \( V_w \) = volume of wear \([m^3]\)
- \( s \) = sliding distance \([m]\)
- \( N \) = normal force \([N]\)
- \( H \) = hardness \([Pa]\)
- \( k \) = wear coefficient \([-]\)
Wear simulation approach

- Wear model – Map of wear coefficients

![Wear model diagram showing wear coefficients](image-url)

- Wear coefficient, $k$ (dry) [$10^4$]

- Pressure [GPa]

- Slip velocity [m/s]

- Seizure
- Mild wear (oxide)
- Severe wear (metallic)
- Mild wear (high oxidation rate)
KTH wear simulation validation
Reference case Stockholm commuter

- Radial wheel wear comparison
  - 200 km network with curve radii 300 – 2000 m
  - Simulated braking and elastic surface deformation
  - Running distance 200 000 km

![Radial wheel wear comparison](image)

![Graph: Radial wear depth vs Lateral profile co-ordinate](graph)
Further application by KTH/Bombardier
Swedish tilting train X2000

- Wheel profile comparison
  - Running distance 292 000 km
Further application by KTH/Bombardier
Swedish tilting train X2000

- Scalar wear measures
UK application by Manchester Metropolitan University
Three different vehicles

- Investigation of the anti RCF profile WRISA2
  - Shape evolution due to wear
  - Running distance with maintained RCF properties

- Shown: Calibration run with P8 profile
  - Mark 4 coach
  - Running distance 228 000 km
  - East coast mainline (Kings Cross – York)

- WRISA2 RCF-relief duration approximately 100 000 km
Industrial implementation objectives

- Bombardier concluded the method to be sufficiently mature for industrial implementation
- Joint effort by Intec and Bombardier to integrate the KTH wheel wear simulation approach into Simpack aiming at:
  - Accuracy of profile evolution prediction to be sufficient for use in MBS transient simulations
  - Possibility to estimate required reprofiling intervals with respect to wear when running on a defined network
  - Both profile shape and standard scalar wear measures to be calculated
Simpack wear module structure

- **Wear model**
  - Simpack standard wear model, preliminary Krause & Poll
  - User routine interface for wear model implementation

- **Profile updating**
  - Internal wear and profile data handling
  - Wear result element for wear accumulation and profile updating
  - The (general) result element new feature in version 8800

- **Simulation set execution**
  - Simulation set variations in the ParVar innermost loop
  - Wear step control with updated profiles in the middle ParVar loop

- **Result output**
  - Standard features of the plot module via the .sbr file
Typical result layout

- Single wheelset in S-curve
- Simpack standard wear model: Krause - Poll
Joint implementation work packages

- **Bombardier: Initial development of Simpack interface**
  - Implementation of the wear model as a wheel/rail friction user function
  - Realisation of a temporary Matlab loop control routine for testing and initial validation
  - Temporary external automated profile updating

- **Intec: Simpack integration**
  - Internal profile and wear data handling
  - Wear accumulation and profile updating
  - Wear user routine interface
  - Extension of the parameter variation facility to handle the wear simulation set and loop control
Structure of temporary solution

MATLAB
- Simulation mgmt
  Updated .sys file
  Automatic execution
- Profile mgmt
  Accumul patch wear
  Profile update

SIMPACK
- Contact conditions
  Force and creep
  Contact patch size
- Friction and wear
  Creep forces
  Patch wear

USER ROUTINE
- FASTSIM
  + slip velocity
  + wear depth distribution

User Meeting March 2006, Roger Enblom
Elementary testing

- **Compatibility with Simpack contact models**
  - Elastic contact with on-line contact data calculation preferable
  - Problems with the rigid flange contact calculation in case of two-point contact
  - The s-var rail profile methodology necessary for multi-point contact conditions
  - Results sensitive to regularisation parameter setting in the quasi-elastic contact data generation

- **Profile updating**
  - Shaping of the wear distribution critical due to possible interference with the profile approximation
  - Simulation time sensitive to the profile quality
Difference between s-variable and s-constant profiles

s-Variable Profiles

Contacts may act anywhere on profile

- Constraint or elastic contact
- Back of the wheel: Only elastic contact
- Quasi-elastic contact data generation on-line

s-Constant Profiles

Contacts act only in their designated profile sections

- Constraint or elastic contact
- Tread: Quasi-elastic or rigid contact data by table
- Flange: Rigid contact data generation on-line
Contact patch condition examples

Max sliding velocity in patch
Radius 432 m curve passing

<table>
<thead>
<tr>
<th>Leading outer wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>force output SF_RW_Friction_Left_of_wtl_tr1_1.Max sliding velocity in cont</td>
</tr>
<tr>
<td>force output SP_RW_Friction_FlangeLeft_of_wtl_tr1_1.Max sliding velocity in c</td>
</tr>
</tbody>
</table>

Severe wear

Max contact pressure in patch
Radius 432 m curve passing

<table>
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<tr>
<th>Leading outer wheel</th>
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<tbody>
<tr>
<td>force output SF_RW_Friction_Left_of_wtl_tr1_1.p_max max. Hertz pr</td>
</tr>
<tr>
<td>force output SP_RW_Friction_FlangeLeft_of_wtl_tr1_1.p_max max. Hertz pr</td>
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</tbody>
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Seizure

Tread contact

Flange contact
Emerging validation

- Wear rate in comparison to the KTH reference case
  - Tread wear comparable
  - Flange wear excessive due to critical contact stress (seizure)
Reference case example

- **Flange wear distribution per rolled distance**
  - Reduced simulation set (8 simulations/step)
  - Based on 10 steps, 14 km
  - Straight cone profile, 1:20 tread, 60° flange, two-point contact

![Radial wear distribution per km, flange](image1)

![Wheel profile, wear after 10 steps](image2)
Reference case example

- Flange wear distribution per rolled distance
  - Reduced simulation set (8 simulations/step)
  - Based on 10 steps, 5677 km
  - S1002 initial profile

![Radial wear distribution pr km](image1)

![Wheel profile, wear after 10 steps](image2)
Conclusions

- **Wear simulation concept works**
- **Flange wear rate high**
  - Sliding velocities comparable
  - Contact pressure critical with respect to seizure
  - Re-evaluate contact mechanics and wear model settings
- **Simulation time long**
  - Short wear steps due to distorted profile geometry
  - S-variable rail profiles necessary for multi-point contact cases
  - Use local smoothing of worn geometry
- **New wheel/rail contact element essential**
  - Multi-point contact consistency and efficiency
  - EPSREG setting not critical