Towards railway wheel performance prediction by simulation

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Outline

- Background
- Wheel-rail interface performance
- Emerging prediction methods
  - Wear prediction
  - Rolling contact fatigue assessment
- SIMPACK implementation
- Applications
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  - Rolling contact fatigue
  - Accumulated fatigue damage
- Wheel-rail contact issues
- Conclusions
Market requirements

- **Increased performance requirements on wheels**
  - Higher axle loads
  - Higher braking and traction forces
  - Higher dynamic loads due higher speeds
  - Smaller wheels

- **Increased focus on maintenance costs**
  - Wheel deterioration is in the top 10 of maintenance cost drivers

- **Track access charges being differentiated towards track damage dependency**

- **Increased interoperability between different track systems with different rail standards**
Modes of deterioration

- **Rolling contact fatigue (RCF)**
  - Shelling, spalling, head checking, fracture

- **Adhesive or abrasive wear**
  - Material loss, altered profile geometry

- **Plastic deformation**
  - Material relocation, ratchetting

- **Phase transformation**
  - Altered material properties, martensite

- **Mode interactions**
  - Out-of-roundness, corrugation
Emerging technologies

- **Wheel profile wear prediction procedure based on Archard’s wear model**
  (Royal Institute of Technology, Sweden)

- **Empirical RCF risk assessment method including influence of wear**
  (Delta Rail for RSSB, UK)

- **Engineering model for RCF risk assessment based on shake down properties**
  (Chamers Technical University, Sweden)
Wheel wear simulation procedure

Initial wheel profile

Contact data generation

Transient simulations

Wear calculation

Scaling to step limit

Wheel profile updating

Wear step limits
Max wear depth
Running distance

no

yes

Finished

Rail profiles

Simulation set

Wear map

Archard wear model

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

Desired mileage

Enblom, KTH Rail Vehicles: On Simulation Of Uniform Wear And Profile Evolution In The Wheel-rail Contact.
Map of wear coefficients

- Seizure
- Mild wear (oxide)
- Severe wear (metallic)
- Mild wear (high oxidation rate)

Issues:
- Lubrication
- Climate
- Calibration

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

Pressure [GPa]

Slip velocity [m/s]

- \( k_1 = 300 - 400 \)
- \( k_2 = 1 - 10 \)
- \( k_3 = 30 - 40 \)
- \( k_4 = 1 - 10 \)
Empirical RCF damage model

Combined fatigue/wear damage related to energy dissipation

Issues:
- Fatigue life
- Calibration
- Contact pressure

Burstow, Delta Rail (for RSSB):
*Whole Life Rail Model Application and Development for RSSB – Continued Development of an RCF Damage Parameter*
Engineering criterion for surface fatigue

Risk criterion:
$F_{I_{surf}} = \mu - \frac{p_0}{k} < 0$

$\mu = $ traction coefficient  
$p_0 = $ contact pressure  
$k = $ yield strength in shear

Issues:
Fatigue life  
Crack depth  
Creep

Ekberg, Kabo, Chalmers Applied Mechanics :  
An Engineering Criterion for Prediction of Surface Initiated Rolling Contact Fatigue.
SIMPACK implementation

- **SIMPACK development (public parts)**
  - Internal profile and wear data handling
  - User routine interface for wear model implementation
    - Krause & Poll wear model
    - Wear accumulation and profile updating
  - Extension of the parameter variation facility to handle the wear simulation set and loop control
SIMPACK implementation

- **BT development (proprietary parts)**
  - Implementation of wear model as proprietary user functions
    - Contact patch discretisation and local contact condition calculation
    - Archard’s wear model
    - Automatic wear step control
    - Running distance calculation
  - Implementation of RCF criteria as proprietary user functions
    - Shake down model
    - RSSB damage function
  - Software procedure testing
  - Quantitative validation with reference operations
Representation in SIMPACK Virtual Test Lab

- Simulation set in the innermost loop
  - Controlled by ParVar steering files
  - Selecting predefined database tracks
  - Selecting track irregularity files
  - Further parameters to be varied in parallel, for instance speed, weighting factors, simulation time, number of output points, …
  - Varying of rail profiles
  - Variation of any substitution variable

- Profile variation in the outer loop
  - Dummy parameter to define number of profile updates
Application – Hollow wear

- 14 simulations per step (164000 km, 364 steps)
  - Curves and tangent
  - Tractive forces

- Calibration of wear map
  - Ambient conditions
  - Contact modelling

- Corrective actions
  - Improved yaw dampers
  - Monitoring of profile shapes

EMU radial wear, 164000 km

Wear depth [mm]

Profile co-ordinate [mm]
Application – Rolling contact fatigue

- Three vehicles with different occurrence of RCF
- Evaluation of fatigue indices against reality
  - Significance of wheel profile
  - Significance of wear
- Quasi-static curving
  - Curve radii 300 – 1000 m
Application – Rolling contact fatigue

- Both indices have pros and cons
- An attempt to classify RCF risk
- Calibration needed
Application – Fatigue accumulation

- High speed train during curve negotiation
  - Accumulated wear indices

![Curve-outer wheel](image1)

![Curve-inner wheel](image2)

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SIMPACK contact modelling

- **Classic contact modelling experience**
  - One-point contact with quasi-elastic model works well
  - Standard multi-point contact may cause problems due to the rigid flange contact approach (difficulties to find the correct contact location on wearing profiles)
  - The all-elastic s-variable contact approach is more stable for multi-point cases
  - The contact position and wear depth at the flange may be sensitive to the quasi-elastic regularisation setting (EPSREG)

- **New wheel / rail contact model being tested**
  - Variable number and arbitrary location of contact points
  - Expected to ease the difficulties experienced so far

- **Non-elliptic / conformal contact not available**
Conclusions

- The effort to implement academic results in engineering should not be underestimated
- Experienced methods have been helpful in gaining understanding of the deterioration processes
- Wear models reasonably well calibrated for normal operating conditions
- RCF models indicate risk for appearance
- Improvements needed
  - Contact model
  - Wear maps for extended range of contact conditions
  - Fatigue life model