International Collaborative Research Initiative Workshop

Wheel Damage Research

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Overview

• Background
• Damage mechanisms
• Quantifying surface damage
• Modelling wheel tread damage
  – Profile shape (wear)
  – Rolling contact fatigue
• Material challenges
• Gaps and potential collaboration
Background

- Wheelsets are expensive:
  - Manufacturing
  - Reprofiling
  - Inspections
  - Renewal
  - Environmental impact
  - Costs of trains out of service

- Strong demand to reduce the rate of wheel damage
  - Extend wheel re-profiling intervals
  - Better wheelset life
  - Lower costs
Damage Mechanisms

Wheel wear and damage

Transversal profile change
- Flange wear
- Tread wear

Circumferential profile change
- Discrete tread defect
  - Tread shelling
  - Tread spalling
  - Tread flats

Wheel wear and damage

Uniform wear

Out-of-roundness
- Non-uniform wear

Circular irregularity

Rolling contact fatigue

Wheel polygonalization
- Long wavelengths
  - Big amplitude
- Short wavelengths
  - Small amplitude

Stochastic irregularity
- Various wavelengths
Damage Mechanisms

Profile wear prediction:
- Energy method
- Archard model

Damage prediction:
- Energy method
- Shakedown (Ekberg...)

Prediction models:
- Johansson (2005)
- Morys (1999)

- Damage classification
- Quantifying damage severity
- Validation data
MRX’s Surface Crack Measurement (SCM) technology has been in use on rails for 8 years+

Technology adapted to measure surface and sub-surface cracking in wheels

Funding awarded by RSSB to further develop and validate the wheel SCM device

Wheel SCM device reports the depth of the deepest artifact in the entire wheel scan
  - Reported depth is the amount of material to remove from the wheel to eliminate the measured damage

Quantifying Surface Damage (2)

- Replacing visual inspection during routine maintenance exams
- Optimise wheel lathe cut depths
- Trending to understand RCF development and growth rates
- Supporting specific case studies

- Wheelset life tracked based on observed average wear rates and cut depths (with and without use of HHU)
- Increase in wheel life by 2 additional turning activities (~370kmi) and saving in wheelset costs of ~25%
Wheel Sectioning and Examination

Graph Showing the Relationship Between Confirmed Depth and Predicted Depth for Disc Braked Vehicles

Wheel 2
Wheel 5
Wheel 9
Linear (1 to 1)
Linear (+/- 0.5 mm)

Crack parallel to running surface

Hardness in running band Region D

Vickers hardness scale

Wheel hardness (macro 30 kg or micro 1 kg)

Radial depth below surface (mm)

Predicted Depth (mm)

Confirmed Depth (mm)
Classification of Damage

- Categorisation of wheel damage mechanisms to improve identification and selection of appropriate mitigation

Profile Wear Prediction

- Utilises the wear iteration procedure developed by KTH (Sweden) and applied to GB rolling stock by MMU/UoH
- Wear calculation based on Archard wear model
  - Volume of material removed predicted based on the normal force, tangential forces, creepages and material properties

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

- \( V_w \) = Volume of wear
- \( s \) = Sliding distance
- \( N \) = Normal force
- \( H \) = Hardness
- \( k \) = Wear coefficient
Example Applications

- Development of P12 (anti-RCF) wheel profile
- Assessment of economic tyre turning
- Modified P8 wheel profile
- Wheel profile wear limits (GM/RT2466)

Areas of Development

- Most fleets operate on a wide range of routes with large total mileage and varying conditions (e.g. curve radii, cant deficiency, rail profile, traction/braking forces and lubrication)

- Two modelling approaches developed:
  1. **Route-based** – running an analysis over long distances including the full range of conditions can take considerable time
  2. **Vehicle duty-cycle** – routines developed to represent the duty-cycle of the vehicle with a series of much shorter simulations

- What are the most influential factors and how detailed do the simulations need to be to capture these differences?

- Applicability of current wear coefficients:
  - Representative of the range of conditions seen by the wheel?
  - Representative of different route characteristics and environmental conditions?

- Influence of wheel-rail contact model
• Contact stress vs. Slip velocity
Wear Coefficients (2)

- **Contact stress vs. Slip velocity**
  - Shallow radius curves
  - Single-point contact tread
  - Medium radius curves
  - Two-point contact
  - Small radius curves
  - Single-point flange contact
Wear Coefficients (3)

- Contact stress vs. Slip velocity
**W-R Contact Modelling**

- FASTSIM incorporated in wear modelling

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**High Rail Tread & Flange**

- Vampire
  - $R = 250\text{m}$
  - $R = 450\text{m}$
  - $R = 800\text{m}$
  - $R = 1000\text{m}$
  - $R = 2000\text{m}$
  - $R = 4000\text{m}$
RCF Cracks in Wheels (1)

- Railway wheels operate in a demanding environment
  - High normal contact forces
  - Significant tangential forces (traction, braking, curving)
  - Contaminants (water, sand, leaves etc)
- Stresses exceed yield stress of the as-manufactured material
  - Plastic flow, wear and fatigue damage
- Rolling contact fatigue is a dominant damage mechanism
  - Many fleets have their wheels turned on a preventive distance-interval
  - ‘State of the art’ modelling of RCF in railway wheels has not achieved a deterministic model owing to the complexity of the conditions
• Many factors influence RCF crack growth rates in wheels:
  – Material properties
  – Train/wheelset type
  – Operating/environmental conditions
  – Position of wheelset on train
  – Distance run since last tyre turning

• RCF growth rate is higher as the wheels near the end of their life
  – Approaching the minimum diameter before the wheelset is renewed
Wheel RCF Prediction

- Methodology:
  - Read outputs from vehicle dynamics simulations
  - Scale $T_\gamma$ based on the direction of the longitudinal force (RCF damage only occurs when the wheel is the driven surface)
  - Calculate crack damage using scaled $T_\gamma$ and wear damage using un-scaled $T_\gamma$
  - Calculate total damage (crack + wear damage)
  - Distribute damage elliptically over the width of the contact patch
  - Accumulate damage and weight to represent vehicle operating conditions

Bevan, A., Molyneux-Berry, P., Eickhoff, B. and Burstow, M. (2013) 'Development and Validation of a Wheel Wear and Rolling Contact Fatigue Damage Model' Wear, 307 (1-2), pp. 100-111. ISSN 0043-1648
• Clear pattern of predicted forces:
  - Wide variety of input conditions
  - Damaging $T_T$ values are clustered in distinct areas

• Two groups of observed cracks:
  - Field side cracks $90^\circ < |\psi| < 120^\circ$
  - Flange root cracks $|\psi| \approx 45^\circ$
  - Cracks plotted on all wheels of the bogie - locations mirrored as observed

Molyneux-Berry, P. and Bevan, A. (2012) ‘Wheel surface damage: relating the position and angle of forces to the observed damage patterns’ Vehicle System Dynamics, 50 (S1), pp. 335-347. ISSN 0042-3114
Comparison of observations and predictions:

- Crack position and angle correlate with damaging forces on leading wheelset.
- Trailing wheelset forces are lower, no match to crack position or angle.
- Cracks correlate with the areas of higher forces (75 < Ty < 175)
Accumulated RCF Damage

- Linear regression fitted to both the observed and predicted crack lengths and damage rates determined.

Generally a good agreement between predicted and observed damage rates is obtained.

Relative damage rates between different vehicle types/axles also predicted.
Example Applications

- Incorporated into the Wheelset Management Model (part of the VTISM software tool)
- Optimisation of wheelset maintenance
- Assessment of economic tyre turning and modified P8 wheel profile

Areas of Development

- Further validation of predicted RCF damage using measured crack depths (using NDT techniques)
  - Previous validation based on material removal at wheel lathe
- Incorporate alternative wheel-rail contact models
- Comparison with other damage models
- Influence of material properties on damage modelling
Materials Challenges

- Novel wheel steels which are more resistant to wear, damage and noise (e.g. comparison R8T vs. RS8T)
- Advanced (or additive) manufacturing techniques
- Smart materials for condition monitoring
- Reduction in wheel size and mass (unsprung mass)
Gaps in Knowledge

• Improve fundamental understanding of wheel damage mechanisms
  – Root causes and mitigation measures

• Harmonised classification of wheel damage and maintenance statistics
  – Some work has been done in UK to improve the classification of different types of damage
  – Further work is required to quantifying the severity of damage and therefore the corrective action which should be taken

• Develop improved engineering models to aid design and optimisations

• Guidance on future design criteria and troubleshooting to reduce wheel damage related problems

• Intelligent wheelset maintenance
  – Use of data from current RCM tools (e.g. WILD, HABD….)
  – Fault diagnosis and predictive maintenance
  – Improved maintenance scheduling and planning
Damage Modelling

Expert2 Analysis
Wheel Observations and Profiles
Fleet Wheel Data

Where the train has been?
Wheel profiles

Vampire Modelling
Contact forces & positions

Contact Modelling
Stress etc for locations in wheel rim cross-section
Wheel profiles

Wear Predictions
RCF Predictions
Plastic Flow Predictions

Damage Predictions
Validation

Discussion

Review of Damage Models
Wheel profiles

Residual Stress Analysis
Selected Damage Models
Wheel profiles

Material Analysis
Residual Stress Field
Hardness & Fraction Deformation

Out-of-Course Events

RCF Predictions
Plastic Flow Predictions
Full Scale Testing
Thank You