University of Huddersfield Repository

Bevan, Adam

Effective Management of the Wheel-Rail Interface on Light-rail Networks

Original Citation


This version is available at http://eprints.hud.ac.uk/26345/

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

http://eprints.hud.ac.uk/
Effective Management of the Wheel-Rail Interface on Light-rail Networks

Dr Adam Bevan
Institute of Railway Research
University of Huddersfield
Overview

• Characteristics and maintenance challenges
• Key degradation mechanisms and mitigation measures
• Optimising the WRI:
  – Wheel-rail profiles
  – Rail wear limits
  – Rail steel grades
• Conclusions
Characteristics of Light-rail

• On-street (embedded) and ballasted track operation
• Very sharp curves (≈18 m in radius)
• Steeper gradients
• Lighter axle loads
• Smaller wheel diameters
• Low-moderate speeds (50-70kph)
• Frequent stop / start
Maintenance Challenges

- Very arduous operating environment
- Large variation on operating conditions between different networks
- Lack of relevant standards and guidance
- Short maintenance window (track and rolling stock)
- Location of utility works
- Additional cost of replacing embedded or underground track
# Key Degradation Mechanisms

<table>
<thead>
<tr>
<th>Track Radius Range</th>
<th>Key degradation Mechanisms</th>
<th>Available Mitigation Measures</th>
</tr>
</thead>
</table>
| <50m               | 1. High Side (& Keeper) wear  
2. Vertical wear  
3. Corrugation          | 1. Harder steel grades offering greater resistance to wear and corrugation |
| >50 to <250m       | 1. Side (& Keeper) wear  
2. Vertical wear  
3. Corrugation          | 2. Weld restoration for side & keeper wear  
3. Rail grinding to remove corrugation  
4. Track or vehicle mounted lubrication/friction management to reduce wear  
5. Optimisation of WR contact conditions to reduce wear |
| >250 to <1000m     | 1. Limited side wear  
2. Vertical wear  
3. Corrugation          | 1. Harder steel grades offering greater resistance to wear and corrugation |
| >1000m             | 1. Vertical wear  
2. Corrugation          | 2. Rail grinding to remove corrugation |
Wheel-Rail Interface Management

• Requirements for effective WRI:
  – Maintain safety and reduce derailment risk
  – Minimise damage to vehicle/track
  – Ensure good vehicle dynamic performance (curving, ride...)
  – Increase asset life and reduce whole life costs
Wheel-Rail Profiles

- Large variation in wheel and rail profiles used on light-rail systems
- Profiles must be geometrically compatible, with respect to:
  - Wheelset fit (e.g. track gauge, groove width, depth)
  - Compromise between steering and vehicle lateral stability
  - Minimise wear rates, contact stress, squeal noise and derailment risk
- Contact conditions generated by chosen wheel-rail profiles can be checked to ensure they do not produce excessive contact stress and wear
- Vehicle dynamics simulations can be used to select optimal profile combinations
  - Optimise conicity for a given system
**Rail Profiles**

<table>
<thead>
<tr>
<th>Rail Section</th>
<th>Cross-section Area (mm²)</th>
<th>Weight (kg)</th>
<th>Iₓₓ (cm⁴)</th>
<th>Rail Height (mm)</th>
<th>Groove Depth (mm)</th>
<th>Groove Width (mm)</th>
<th>Keeper Thickness (mm)</th>
<th>Gauge Corner Radii (mm)</th>
<th>Crown Radii (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grooved Rails</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55G1 (35GP)</td>
<td>69.78</td>
<td>54.77</td>
<td>2075.6</td>
<td>152.50</td>
<td>45.9</td>
<td>35.94</td>
<td>19.65</td>
<td>10.0</td>
<td>225</td>
</tr>
<tr>
<td>55G2 (41GP)</td>
<td>70.53</td>
<td>55.37</td>
<td>2081.6</td>
<td>152.50</td>
<td>45.9</td>
<td>40.94</td>
<td>19.73</td>
<td>10.0</td>
<td>225</td>
</tr>
<tr>
<td>59R1 (Ri59-R10)</td>
<td>75.12</td>
<td>58.97</td>
<td>3266.8</td>
<td>180.00</td>
<td>47.0</td>
<td>42.00</td>
<td>15.00</td>
<td>10.0</td>
<td>225</td>
</tr>
<tr>
<td>59R2 (Ri59-R13)</td>
<td>74.13</td>
<td>58.20</td>
<td>3213.8</td>
<td>180.00</td>
<td>47.0</td>
<td>42.36</td>
<td>14.82</td>
<td>13.0</td>
<td>300</td>
</tr>
<tr>
<td>60R1 (Ri60-R10)</td>
<td>77.19</td>
<td>60.59</td>
<td>3352.9</td>
<td>180.00</td>
<td>47.0</td>
<td>36.00</td>
<td>21.00</td>
<td>10.0</td>
<td>225</td>
</tr>
<tr>
<td>60R2 (Ri60-R13)</td>
<td>76.11</td>
<td>59.75</td>
<td>3298.1</td>
<td>180.00</td>
<td>47.0</td>
<td>55.83</td>
<td>20.82</td>
<td>13.0</td>
<td>300</td>
</tr>
<tr>
<td>Flat-bottom Rails</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39E1 (BS80A)</td>
<td>50.66</td>
<td>39.77</td>
<td>1204.9</td>
<td>133.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11.1</td>
<td>305</td>
</tr>
<tr>
<td>49E1 (S49)</td>
<td>62.92</td>
<td>49.39</td>
<td>1816.0</td>
<td>149.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>13.0</td>
<td>300</td>
</tr>
<tr>
<td>56E1 (BR113A)</td>
<td>71.69</td>
<td>56.30</td>
<td>2321.0</td>
<td>158.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12.7</td>
<td>305</td>
</tr>
</tbody>
</table>
Wheel Profiles (1)

• Selection UK / European Wheel Profiles
Wheel Profiles (2)

• Selection of North American Wheel Profiles
Wheel-Rail Profile Selection

• Light-rail engineers face particular problems:
  – Insufficient consideration given to profile selection at design stage
  – Varying rail profiles (street and ballasted track, S&C etc.)
  – Low speed / very tight curves on street running (flange contact), higher speeds / heavy rail alignments elsewhere
  – Varying bogie types (conventional and IRW)
  – Steep gradients, grooved rail etc.
  – Shared running

• But...also have some advantages:
  – Closed, geographically small systems running a single vehicle type
  – Lighter axle loads
  – Predictable and stable wear conditions
  – Control both vehicles and track conditions
Variation in Conicity

- Large variation in equivalent conicity:
  - Increasing conicity:
    - Increases steering (flange free curving)
    - Reduces critical speed
    - May increase tread wear / gauge shoulder wear
    - Will increase forces, contact stresses
  - Reducing conicity:
    - Reduces steering (flange contact at larger curve radii)
    - Increases critical speed
    - Will increase flange / side wear
Wheel Profile Design

- Example 1: Wheel and rail shapes very different (1)

- Tread slope, flat rail and large flange root radius gives large RR difference
- Single point contact
- Excellent steering in sharp curves with low flange wear
- High contact stresses even in metro applications
- Potential stability problems
Wheel Profile Design

- Example 2: Wheel and rail shapes different (2)

- No contact gauge shoulder / flange root = very low conicity
- Two point contact
- Little steering except in shallow curves
- Potential for high flange wear
- Relatively insensitive to rail inclination
- Potential stability problems
Wheel Profile Design

- Example 3: Wheel and rail shapes closely conformal

- Moderate RR difference with good distribution of contact (even wear)
- Mostly single point contact
- Good steering in moderate curves with controlled flange wear
- Suitability will depend on characteristics of system
- Sensitive to changes in rail inclination
Rail Steel Grade Selection

- Primary cause of rail replacement on light-rail systems is wear (particularly in tight curves)
- To maximise rail life appropriate steel grades should be selected
  - Based on track conditions and degradation mechanisms experienced in service
- Selection of steel grade which offer high resistance to wear and corrugation, but also ability to weld restore rail side wear in-situ (in very tight curves)

*Courtesy of Tata Steel*
Maintenance Limits

• Large variation in wear limits adopted by light-rail systems
  – Selected based on experience or heavy rail standards

• Lack of relevant standards or guidance for selection of optimum wear limits and asset management

• Conflicting requirements:
  – To maintain safe operation
  – To prolong rail and wheel life
Rail Wear Limits

• To ensure safe operation and to prolong asset life it is important that appropriate rail wear limits are specified
  – Limits which are overly conservative can result in premature rail replacement and therefore increased renewal/maintenance costs
  – Limits which are too lax can compromise the operational safety of the system
Comparison of Rail Wear Limits

- Significant variation in the maintenance limits for both grooved and vignole rail

<table>
<thead>
<tr>
<th>System</th>
<th>Wheelset</th>
<th>Rail Section</th>
<th>Rail Section Dimensions (mm)</th>
<th>Rail Wear Limits (mm)</th>
<th>% of Head Height</th>
<th>% of Keeper Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flange Height (mm)</td>
<td>Flange Thickness (mm)</td>
<td>Back-to-Back (mm)</td>
<td>Head</td>
<td>Groove</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>26.3 (~29.3)</td>
<td>22 (~19)</td>
<td>1362</td>
<td>59R1, 35G, 56E1</td>
<td>41.15</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>25.5 (~29.8)</td>
<td>23.2 (~20.2)</td>
<td>1380</td>
<td>59R1, 59R2, 56E1</td>
<td>41.15</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>24.0</td>
<td>23 (~19)</td>
<td>1379</td>
<td>35G, 56G1, 39E1 (CPF)</td>
<td>40.50</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>24 (~20)</td>
<td>23 (~19)</td>
<td>1379</td>
<td>60R1, 60R2</td>
<td>41.15</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>24.2 (~21.2)</td>
<td>22.2 (~18.2)</td>
<td>1379</td>
<td>59R2, 59G1, 39E1</td>
<td>42.47</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>25.5</td>
<td>22.2</td>
<td>1379</td>
<td>51R1, 49E1</td>
<td>41.15</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>25.5</td>
<td>21.2 (~18.5)</td>
<td>1384</td>
<td>59R2, 49E1</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>30.1 (~31.5)</td>
<td>27.6 (~25)</td>
<td>1362</td>
<td>390.00, 42.47</td>
<td>-</td>
</tr>
</tbody>
</table>

Network Rail (NR/L2/TRK/001)

- 56E1 (tangent track) | - | - | 13.75 | - | - |
- 56E1 (curved) | - | - | 9.25 | 9 | - | - |
Comparison of Rail Wear Limits

- Significant variation in the maintenance limits defined both grooved and vignole rail
Optimised Rail Wear Limits

• Following variables play a key role:
  – Structural integrity of the rail and keeper due to a loss in cross-section
  – Reduction in clearance to vehicle and lineside equipment, structures and road surface
  – Maintaining track gauge, ride quality and derailment protection
  – Interaction of side wear scar and new/worn wheel profile shape
Vertical Rail Wear

• Excessive levels of vertical rail wear can lead to safety and operational issues when the available groove depth becomes limited
  – Resulting in wheels running on the tip of the wheel flange for prolonged periods
  – Critical for Tram-Train schemes where a full flange wheel profiles are often required for S&C compatibility
Geometric Compatibility

• Reduction in clearance between wheel and track components
  – Risk of striking fishplates and other track components
  – Clearance reduced due to rail vertical and side wear and wheel tread wear
Side and Keeper Rail Wear (1)

- New Rail Section
- Worn Rail Section

Wear due to Leading Wheelset Flangeback
Wear due to Trailing Wheelset Flangeback
Wear due to Leading Wheelset Flange

‘Low’ Rail
‘High’ Rail

Wheelset Positions and Forces in a Tight Curve
Side and Keeper Rail Wear (2)

- Excessive wear to keeper rail should be avoided:
  - Wear of keeper rails could eventually lead to failure, increasing the risk of derailment, as wheel flange strikes broken keeper
  - Controlling rail side wear, wheel flange wear and dynamic gauge spreading (through application of tie bars) will help to reduce keeper rail contact
- The permissible levels of rail side and keeper wear can be effectively determined using a combination of wheelset fit and geometric assessment
Grooved Rail Structural Integrity

- Structural integrity of new and worn rail sections assessed under typical loads using finite element analysis
- Wheel-rail contact conditions and forces derived from vehicle dynamics simulation
Vertical and Side Rail Wear

Von Mises Stress versus Rail Height

Contact point

Von Mises Stress versus Rail Height

Contact point

Maximum Von Mises stress against Head & Side wear

- LC01 = 5.7 tons
- LC02 = 6.3 tons
- LC03 = 6.8 tons

21-23 October, 2015 • Derby, UK
Keeper Rail Wear

- Initial results suggest that structural integrity of the keeper is maintained until thickness reduces to <8mm
- To be confirmed through experimental testing

![Graph showing Von Mises Stress versus Rail Height and Maximum Von Mises stress against Keeper thickness]
Wheelset Maintenance

• Worn wheel profile shapes may be designed to reduce initial wear rates, but further savings can be made through effective management of wheelset maintenance.

• Optimisation of wheel reprofiling interval, through assessment of maintenance/inspection records can significantly improve wheelset life.

• Mileage-based reprofiling tends to be undertaken more frequently, but resulting in less material removal on the lathe and more consistent contact conditions.
Economic Drivers

• Previous studies have shown that effective management of the WRI can provide significant benefits and cost savings for light-rail systems
  – Improved planning of future maintenance and renewals
  – Reduction in disruption to passenger service
  – Maximising the life of the rail section (reduction in premature rail replacement) and wheelset
  – Reduction in carbon footprint
Wear Limits on Rail Life

- EU project *PM’n’IDEA* demonstrated the financial impact of a change in vertical wear limit on various segments of a UK light-rail network (≈ €90M over 30 years)
- Justification for establishing optimum limits for rail wear
Conclusions

• Significant variation in design conditions and maintenance limits adopted on light-rail networks
  – Lack of detailed guidance
• Opportunities exist to optimise the WRI on light-rail networks through selection of optimal:
  – Wheel-rail profiles
  – Rail steel grades
  – Maintenance limits and practices
• Tools to assist in management of the WRI, which combine vehicle-track degradation data and prediction models, are currently under development as part of UKTram ‘Low Impact Light Rail’ project
Thank-you