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

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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  
                          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 |
| >50 to <250m       | 1. Side (& Keeper) wear  
                          2. Vertical wear  
                          3. Corrugation  |                              |
| >250 to <1000m     | 1. Limited side wear  
                          2. Vertical wear  
                          3. Corrugation  | 1. Harder steel grades offering greater resistance to wear and corrugation  
                          2. Rail grinding to remove corrugation |
| >1000m             | 1. Vertical wear  
                          2. 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>
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<tbody>
<tr>
<td>Grooved Rails</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<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>
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<td>59R2 (RI59-R13)</td>
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<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>
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<td>47.0</td>
<td>36.00</td>
<td>21.00</td>
<td>10.0</td>
<td>225</td>
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<td>60R2 (RI60-R13)</td>
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<td>180.00</td>
<td>47.0</td>
<td>55.83</td>
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<td>300</td>
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<td>Flat-bottom Rails</td>
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<tr>
<td>39E1 (BS80A)</td>
<td>50.66</td>
<td>39.77</td>
<td>1204.9</td>
<td>133.25</td>
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<td>-</td>
<td>-</td>
<td>11.1</td>
<td>305</td>
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<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>
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<td>300</td>
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<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

- BR P8 (worn)
- Sheffield Supertram (1:40)
- Manchester Metrolink (1:20)
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>A</td>
<td>26.3 (~29.3) 22 (~19) 1362</td>
<td>59R1, 35G, 56E1</td>
<td>Flange Height (mm) Flange Thickness (mm) Back-to-Back (mm)</td>
<td>Head Height Groove Depth Groove Width Keeper Thickness</td>
<td>15 (20)</td>
<td>2 (5)</td>
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<tr>
<td>B</td>
<td>25.5 (~29.8) 23.2 (~20.2) 1380</td>
<td>59R1, 59R2, 60R1, 60R2, 56E1, 49E1</td>
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<td>41.15 41.15 41.15 41.15 49.21</td>
<td>47.00 47.00 47.00 47.00 47.00</td>
<td>40.40 42.17 34.40 36.00 36.00</td>
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<tr>
<td>C</td>
<td>24.0 23 (~19) 1379</td>
<td>35G, 35G1, 39E1 (CWR), 39E1 (FP)</td>
<td>42.47</td>
<td>42.47</td>
<td>40.50 40.50</td>
<td>40.00 45.90</td>
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<tr>
<td>D</td>
<td>62R1, 60R2</td>
<td>41.15 41.15</td>
<td>41.00 41.00</td>
<td>32.83 36.00</td>
<td>26.23 20.57</td>
<td>22.00 18.00</td>
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<tr>
<td>E</td>
<td>60R1, 60R2</td>
<td>41.15 41.15</td>
<td>41.00 41.00</td>
<td>32.83 36.00</td>
<td>26.23 20.57</td>
<td>22.00 18.00</td>
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<td>F</td>
<td>24 (~20) 23 (~19) 1379</td>
<td>59R2, 59G1, 39E2</td>
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<td>42.47</td>
<td>40.50 40.50</td>
<td>45.90 45.90</td>
</tr>
<tr>
<td>G</td>
<td>25.5 22.2 1379</td>
<td>51R1, 49E1</td>
<td>41.15</td>
<td>41.15</td>
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<td>42.17 42.17</td>
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<tr>
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<td>10 (20) 10 (20)</td>
<td>24% 24%</td>
<td>- - - - - - -</td>
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<tr>
<td>I</td>
<td>30.1 (31.5) 27.6 (25) 1362</td>
<td>390.00, 390.00</td>
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<td>42.47</td>
<td>42.47</td>
<td>42.47</td>
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</tbody>
</table>

Network Rail (NR/L2/TRK/001): 56E1 (tangent track) 56E1 (curved)
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 sidewear, 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

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
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