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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>
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<tbody>
<tr>
<td>&lt;50m</td>
<td>1. High Side (&amp; Keeper) wear</td>
<td>1. Harder steel grades offering greater resistance to wear and corrugation</td>
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<td></td>
<td>2. Vertical wear</td>
<td>2. Weld restoration for side &amp; keeper wear</td>
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<td>3. Corrugation</td>
<td>3. Rail grinding to remove corrugation</td>
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<td></td>
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<td>4. Track or vehicle mounted lubrication/friction management to reduce wear</td>
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<tr>
<td></td>
<td></td>
<td>5. Optimisation of WR contact conditions to reduce wear</td>
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<tr>
<td>&gt;50 to &lt;250m</td>
<td>1. Side (&amp; Keeper) wear</td>
<td>1. Harder steel grades offering greater resistance to wear and corrugation</td>
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<td>2. Vertical wear</td>
<td>2. Rail grinding to remove corrugation</td>
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<tr>
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<td>3. Corrugation</td>
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<td>&gt;250 to &lt;1000m</td>
<td>1. Limited side wear</td>
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<td>2. Vertical wear</td>
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<td>3. Corrugation</td>
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<tr>
<td>&gt;1000m</td>
<td>1. Vertical wear</td>
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</tr>
<tr>
<td></td>
<td>2. Corrugation</td>
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</table>
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
<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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</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

21-23 October, 2015 • Derby, UK
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>
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<td></td>
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<td>Head Height</td>
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<td>B</td>
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<td>42.47</td>
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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

21-23 October, 2015 • Derby, UK
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