Fatigue Strength and Fatigue Life of Railway Axles

BAM - Federal Institute for Materials Research and Testing, Berlin, 11-12 October 2010

A S Watson: Implications of Impact Damage on the Structural Integrity of Axles
How might Cracking Initiate in an Axle?

• “Classical” fatigue (stress-life) process
  – Extremely unlikely at the stress levels found in a correctly designed axle

• Corrosion fatigue (Hoddinott cracking)
  – Significant source of crack initiation – to be discussed in detail at a future conference

• Geometric flaws (stress concentration effects)
  – Could be due to corrosion pits
  – Could be due to mechanical damage (such as impact by debris)

• This presentation concentrates on the implications of geometric flaws
Depth of Corrosion Pits - Overview

• Historic British Rail Research work suggested typical depth of about 0.3 mm (corroded wagon axles)
• Detailed measurements carried out in RSSB Project T728
  - TWI examined six ex-service axles in detail to determine distributions of sizes of corrosion pits
  - Politecnico di Milano carried out Extreme Value Analysis to estimate maximum pit size for an axle or fleet of axles
• Test axles divided into three groups:
  - Axles 1-3, from Class 313 EMU: relatively well protected against corrosion
  - Axles 4 & 5, from MK3 coach and wagon: corrosion may be regarded as typical or a little more severe than typical
  - Axle 6, from wagon carrying corrosive freight: significantly more severe than typical
### Depth of Corrosion Pits - Findings

<table>
<thead>
<tr>
<th>Case</th>
<th>Maximum corrosion pit depth (mm)</th>
<th>Estimated maximum (one axle)</th>
<th>Estimated maximum (whole fleet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axles 1-3 (protected)</td>
<td>0.043</td>
<td>0.1</td>
<td>0.13</td>
</tr>
<tr>
<td>Axles 4 &amp; 5 (typical)</td>
<td>0.076</td>
<td>0.24</td>
<td>0.35</td>
</tr>
<tr>
<td>Axle 6 (severe)</td>
<td>0.346</td>
<td>0.82</td>
<td>1.02</td>
</tr>
</tbody>
</table>

- Note agreement with previously measured typical depth of 0.3 mm for typical corroded axles
Depth of Impact Craters – Sources of Data

• Six corroded axles examined in RSSB T728 did not include representative impact damage
  – Only two craters found, neither look like typical impact from debris

• Impact damage has been studied in a number of previous projects
  – Sometimes measured width or depth but very rarely both
  – Width can be estimated from photographs but not depth
  – Therefore only limited depth data available – Is there any more?
Depth of Impact Craters – Comparison with Corrosion Pits

- Distribution of impact craters best described by Weibull-type distribution
  - But can be approximated by a log-normal distribution
  - Depth does not appear to depend on vehicle type
  - Mean depth about 0.8 mm, 95% upper bound about 2 mm, (i.e. upper bound approximates to depth often assumed previously)
  - Impact craters significantly deeper than typical corrosion pits
Probability of Impact Damage

- Probability is a function of vehicle type
  - High speed vehicles subject to harder impacts, more likely to damage axle
  - Aerodynamic effects may make impact from debris more likely for high speed vehicles

- Probability of impact damage derived mainly from examination of high speed trains and RSSB T728 depot visits
  - Examination of three rakes of high speed trains suggested that 30% of axles had impact damage
  - Significant numbers of impact-damaged high speed axles in depots
  - Very few impacts seen or recorded for multiple unit or wagon axles
  - Assume 30% of high speed axles subject to impact, 5% of other axle types
Simulation of Impact in Crack Growth Calculations

• Calculate base level crack growth curve (cracking caused by corrosion fatigue)

• Impact is probabilistic in nature
  – Only occurs for a proportion of axles (5% or 30%)
  – Crater depth is a variable
  – May occur early or late in axle overhaul cycle

• Create set of modified crack growth curves, e.g:

![Graph showing crack depth vs. elapsed miles with impact and no impact curves].

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Implications of Impact on Axle Failure: Influence of Impact Probability

- Sensitivity study carried out for high-stressed and low-stressed axles
  - Increase in failure probability linearly related to probability of impact
  - Low stressed axles more sensitive to impact
Implications of Impact on Axle Failure: Estimated Effects for Actual Axles (1)

- Calculated failure probabilities over axle overhaul interval for a range of real axles with and without impact
- Results for high speed vehicles (30% probability of impact)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>periodicity (miles)</th>
<th>failure probability</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>overhaul</td>
<td>UAT</td>
<td>no impact</td>
<td>impact</td>
</tr>
<tr>
<td>Mk3 coach (current)</td>
<td>600,000</td>
<td>200,000</td>
<td>9.03E-12</td>
<td>2.59E-07</td>
</tr>
<tr>
<td>Mk3 coach (current)</td>
<td>1,200,000</td>
<td>200,000</td>
<td>1.86E-06</td>
<td>3.34E-06</td>
</tr>
<tr>
<td>Mk3 DVT</td>
<td>615,000</td>
<td>308,000</td>
<td>8.36E-05</td>
<td>1.22E-04</td>
</tr>
<tr>
<td>Mk3 DVT</td>
<td>1,230,000</td>
<td>410,000</td>
<td>2.34E-03</td>
<td>3.05E-03</td>
</tr>
<tr>
<td>Mk3 coach (original tapered)</td>
<td>600,000</td>
<td>200,000</td>
<td>5.54E-03</td>
<td>6.57E-03</td>
</tr>
<tr>
<td>Mk3 coach (original skimmed)</td>
<td>600,000</td>
<td>200,000</td>
<td>2.86E-02</td>
<td>3.36E-02</td>
</tr>
</tbody>
</table>

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Implications of Impact on Axle Failure: Estimated Effects for Actual Axles (2)

- Results for lower speed vehicles (5% probability of impact)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>periodicity (miles)</th>
<th>failure probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>overhaul</td>
<td>UAT</td>
</tr>
<tr>
<td>Class 313 EMU power (FCC)</td>
<td>600,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Class 313 EMU power (Silverlink)</td>
<td>600,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Class 47 locomotive</td>
<td>500,000</td>
<td>125,000</td>
</tr>
<tr>
<td>Class 332 EMU power</td>
<td>600,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Class 153 DMU trailer</td>
<td>320,000</td>
<td>160,000</td>
</tr>
<tr>
<td>Y25 wagon</td>
<td>250,000</td>
<td>125,000</td>
</tr>
<tr>
<td>Class 87 locomotive</td>
<td>620,000</td>
<td>124,000</td>
</tr>
<tr>
<td>Class 86 locomotive</td>
<td>600,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Class 175 DMU trailer</td>
<td>1,000,000</td>
<td>143,000</td>
</tr>
<tr>
<td>Class 323 EMU power</td>
<td>640,000</td>
<td>128,000</td>
</tr>
<tr>
<td>Class 175 DMU power</td>
<td>750,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Class 14x DMU power</td>
<td>260,000</td>
<td>130,000</td>
</tr>
<tr>
<td>Class 168 DMU power</td>
<td>700,000</td>
<td>78,000</td>
</tr>
<tr>
<td>Class 67 locomotive</td>
<td>600,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Class 170 DMU power</td>
<td>715,000</td>
<td>80,000</td>
</tr>
</tbody>
</table>
Implications of Impact on Axle Failure: Estimated Effects for Actual Axles (3)

- Overall trends from actual axle calculations
  - Confirms larger effect for 30% impact probability
  - Confirms larger effect for low stress / low failure probability
Conclusions

- Geometric flaws from impact damage are in general significantly deeper than corrosion pits
  - Upper bound close to 2 mm depth assumed in previous studies
- Size of impact damage craters does not appear to depend on vehicle type
- Probability of impact damage higher for high speed vehicles
- Impact damage can significantly increase failure probability
  - Effect more marked for low-stressed axles with low failure probability