Quantifying Rail Surface Damage

Daniel Szablewski, Metallurgist
Automotive and Surface Transportation
National Research Council of Canada
Overview

• Current approach to RCF analysis
• Fe-C metallurgy
• Effect of rail position in curve
• Quantitative RCF assessment
  • NDT evaluation: Rohmann, MRX, Sperry
  • Other NDT methods: DP & MP
  • Microstructural analysis of RCF: depth & angle
• Qualitative RCF assessment
• Cataloguing RCF: Atlas, Matrix
RCF – Current Approach

Inspection Methods
- Visual surface assessment
- Non-destructive:
  - Dye penetrant
  - Magnetic particle
  - Walking stick (Rohmann, MRX, Sperry)
- Destructive:
  - Cutting
  - Milling
  - Metallography
    - LOM, SEM

Factors to Consider
- Rail type
- Position in curve
- Track curvature
- Lubrication
- Traffic:
  - Axle load
  - MGT accumulation
  - Frequency
- Maintenance practices
  - Grinding/Milling
    - Frequency
    - Amount

Outcomes to Evaluate
- RCF location:
  - TOR vs. GF
- RCF severity:
  - Mild vs. Severe
  - Depth of spalling
- RCF crack morphology:
  - Length, depth, angle to rail surface, density & distribution, amount of branching
  - Propagation in rail microstructure
    - Trans-granular vs. inter-granular
    - Assisted by inclusions (rail cleanliness)
Increasing carbon content in rail increases rail hardness and improves wear resistance.

- Microstructure needs to be fully-pearlitic to achieve best mechanical and wear performance.
- Only one carbon composition (approx. 0.83%C) gives fully-pearlitic structure.
  - < 0.83%C we get ferrite at grain boundaries.
  - > 0.83%C we get cementite at grain boundaries.

Reference: Fe-Fe₃C Phase Diagram
Rail Metallurgy – Decarburization Layer

- Solid State Diffusion (SSD) of Carbon
  - Fick’s First Law (i.e. Carbon migration down a concentration gradient)
  - Takes place at rail rolling surface
  - Temperature activated process (during rail production)
- Results in Carbon-poor (i.e. decarburized) phase (ferrite) at the grain boundaries

Typical Decarburized Pearlitic Rail Microstructure

Decarburized Layer (ferrite)
Pearlitic Grain

100μm
Decarburization is only an issue with new rails

Decarburized rail microstructure is less uniform (less homogenous) below W/R contact zone

It is softer than surrounding pearlite matrix structure:
- Easier to plastically deform the decarburized layer
- Rolling Contact Fatigue (RCF) cracks form more easily in the decarburized zone

Decarburized Layer (ferrite)  
**Approx. 80HB**

Pearlitic Grain (300-400HB)
Rail Metallurgy – Decarburization Layer

• Typical intermediate rail type

T – Transverse section
TL – Transverse Longitudinal section
TG – Transverse Gage section
Rail Metallurgy – Decarburization Layer

- 5 microstructure locations:
  - Decarburized layer present in all 3 cross-sections
  - Average decarburized layer thickness: $0.16 \pm 0.03\text{mm}$ (~0.006in)
Quantifying Rail Surface Damage
Effect of Rail Position in Curve

TOR

GF
Quantifying Rail Surface Damage
Non-Destructive Evaluation Methods

Three Electro-Magnetic Based Techniques were Evaluated by NRC Under the FRA Program:
- Eddy Current (Rohmann)
- Magnetic Flux Leakage (MRX)
- ACFM (Sperry)

Rohmann Drasine® trolley (eddy current)
MRX RSCM (magnetic flux leakage)
Sperry Surface Crack Detection + Walking Stick
Quantifying Rail Surface Damage
Rohmann Technology

- Provides RCF crack depth vs. rail distance travelled
- A walking unit with 4 eddy current probes
- Staggered design, each probe covers a portion of the rail head
- Voltage output is converted to crack length, which combined with crack angle yields crack depth
- RCF measurements made by Rohmann at CSX, CN and NS
## Quantifying Rail Surface Damage
### Rohmann Technology

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
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<tr>
<td>Technology</td>
<td>Eddy current</td>
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<tr>
<td>Measures</td>
<td>Crack length.</td>
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<tr>
<td>In dense cracks</td>
<td>Max. crack length per 5 mm of rail head</td>
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<tr>
<td>Range</td>
<td>Length to 12 mm</td>
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<tr>
<td># of probes</td>
<td>4 individually adjustable</td>
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<tr>
<td>Probe Spot size</td>
<td>6 mm for each probe</td>
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<tr>
<td>Operating speed</td>
<td>0 up to jogging speed</td>
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Typical Draisine® Output

Table from: FRA, 2016, Eric Magel, “Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems”
Quantifying Rail Surface Damage
Rohmann Technology

- Also used to detect defects in track
- Gage corner shear crack
  - Pre-grind measurements showed depth > 5mm
  - Approximately 3mm of railhead was taken off in grinding
  - Post-grind measurements still indicated max depth > 5mm
- Rail was taken out of service
Quantifying Rail Surface Damage
Eddy Current for Shelling Detection?
Quantifying Rail Surface Damage
MRX Technology

- Magnetic Flux – Magnetic field floods the rail. Cracks disrupt the field at the surface. Disruptions detected by sensors.
  - Provides crack depth vs. rail distance travelled
  - An operator propelled unit (OPU) with 19 sensors
  - Lateral positioning accuracy better than 5mm
  - Disruption to magnetic field is seen as a volume of damage, which is converted to depth
  - RCF measurements made by Loram at CSX
Quantifying Rail Surface Damage
MRX Technology

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<td>Technology</td>
<td>Magnetic flux leakage</td>
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<td>Measures</td>
<td>Damage depth</td>
</tr>
<tr>
<td>In dense cracks</td>
<td>Deepest crack every 0.25 m</td>
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<tr>
<td>Range</td>
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<tr>
<td># of probes</td>
<td>19</td>
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<td>Probe Spot size</td>
<td>5 mm</td>
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<tr>
<td>Operating speed</td>
<td>2-5 km/hr</td>
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</tbody>
</table>

Table from: FRA, 2016, Eric Magel, “Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems”
Quantifying Rail Surface Damage
MRX Technology

- Ongoing testing at CSX Fitzgerald and Jessup sites in Georgia
- Progress of damage as measured with the MRX RSCM
  - Depth and extent of cracking is observed to grow with time
Quantifying Rail Surface Damage
Dye Penetrant and Magnetic Particle NDT

Dye Penetrant NDT
• The rail is coated by a dye formulated to penetrate cracks. After cleaning dye from the surface, a white developer powder is sprayed that draws dye from within the cracks.

Magnetic Particle NDT
• A magnetic field is applied across the field of view and then iron powder is sprayed to the surface. Particles congregate around disruptions to the magnetic field, highlighting surface cracks.
Quantifying Rail Surface Damage
Combining NDT Methods

MRX - CSX Tangent site
Pre-Grind  April 27, 2016

Post-Grind  Sep 22, 2016
Quantifying Rail Surface Damage
Combining NDT Methods

Jan 2016

Sept 2016

RCF reduction

RCF reduction

RCF reduction

RCF reduction
Quantifying Rail Surface Damage: Rail Milling

Rail from BNSF line
Quantifying Rail Surface Damage: Rail Milling

Electromagnetic Measurements
Sperry: 5 mm
Rohmann: 5 mm
MRX: 7 mm

Rail from BNSF line
Quantifying Rail Surface Damage
Comparison of RCF measurements

Graph from: FRA, 2016, Eric Magel, “Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems”
Quantifying Rail Surface Damage
Metallography of Crack Morphology

• Typical micrographs at location X in each rail type

<table>
<thead>
<tr>
<th>Premium Rail 1</th>
<th>Premium Rail 2</th>
<th>Premium Rail 3</th>
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<tbody>
<tr>
<td>(1.01wt.% C)</td>
<td>(0.93wt.% C)</td>
<td>(0.83wt.% C)</td>
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</tbody>
</table>

Hyper-eutectoid
Eutectoid

Reference: 2013 TTCI Annual Review
Quantifying Rail Surface Damage
Metallography of Crack Morphology

- Typical micrographs at location Y in each rail type

<table>
<thead>
<tr>
<th>Rail Type</th>
<th>Carbon Content</th>
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<tbody>
<tr>
<td>Premium Rail 1</td>
<td>1.01 wt.% C</td>
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<tr>
<td>Premium Rail 2</td>
<td>0.93 wt.% C</td>
</tr>
<tr>
<td>Premium Rail 3</td>
<td>0.83 wt.% C</td>
</tr>
</tbody>
</table>

Hyper-eutectoid

Eutectoid

Reference: 2013 TTCI Annual Review
Quantifying Rail Surface Damage
Metallography of Crack Morphology

- High rail quantitative RCF assessment
- RCF crack depth & angle analyzed in three rail types with varying Carbon content

Reference: 2013 TTCI Annual Review
Quantifying Rail Surface Damage

Metallography of Crack Morphology

Steep Angle

Shallow Angle
Quantifying Rail Surface Damage
Metallography of Crack Morphology

• Other crack features should be analyzed as well:
  • Length, branching, density
• In addition, crack path in the microstructure should be considered
  • Inter-granular vs. trans-granular cracking
Quantifying Rail Surface Damage – Rating Scale

• One method applied utilizes visual rating of RCF cracks
  • Qualitative, user dependent (subjective to some extent)
  • Used to rate RCF in premium rails tested at TTCI

Mild: Scale 1  Heavy: Scale 2  Severe: Scale 3

Reference: 2016 TTCI Annual Review Poster
Another method utilizes a Machine Vision System to rate the crack surface appearance. Not user dependent (more objective)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Barely perceptible, but clearly regular pattern (preventive grinding &lt; 0.5mm)</td>
</tr>
<tr>
<td>2</td>
<td>Clear, well-defined, distinct individual cracks – but no pitting &gt; 1.5mm (maintenance, depth &lt; 1.0 mm)</td>
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<tr>
<td>3</td>
<td>Clear cracking, pits up to 4 mm diameter (corrective grinding 1.5-2.5 mm deep)</td>
</tr>
<tr>
<td>4</td>
<td>Pitting greater than 4mm &lt; 10 mm (preventive gradual, up to 3.5 mm deep), or “heavy” cracks with clear lifting of metal or separation of crack faces</td>
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<tr>
<td>5</td>
<td>Isolated pitting/shelling/spalling &gt; 10, diameter (up to 5 mm deep)</td>
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<tr>
<td>6</td>
<td>Shelling/spalling: regular pitting, &gt;10mm diameter (near impossible to catch up on)</td>
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<tr>
<td>7</td>
<td>Shelling/spalling: any defect &gt; 16 mm diameter, &gt;20mm length</td>
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</table>

Note: Machine Vision System was developed with KLD Laboratories
# Quantifying Rail Surface Damage – RCF Atlas

<table>
<thead>
<tr>
<th>High Low Tangent S&amp;C</th>
<th>Railroad: BNSF Subdivision: Staples MP: 200.69 Curvature: 2 degree Lubricated: No</th>
<th>Date: Removed from track November 2014 Sample: C8</th>
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<tbody>
<tr>
<td>Metallurgy: 13GRE VT</td>
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**Cross-Section**

<table>
<thead>
<tr>
<th>Surface Crack Length</th>
<th>approx. 25 mm</th>
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<tr>
<td>Start/End Position</td>
<td>approx. 5 - 55 mm</td>
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<tr>
<td>Surface Angle (to Longitudinal Direction)</td>
<td>approx. 70 degrees</td>
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<tr>
<td>Crack Depth (Milling)</td>
<td>3.9 mm</td>
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<td>Spacing Avg. =</td>
<td>approx. 2 mm</td>
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<td>Comment: SSC – through crossing</td>
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**HEAVY HAUL SEMINAR • JUNE 7-8, 2017**

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**Canada**

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**WRI 2017**
# Quantifying Rail Surface Damage – RCF Matrix

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<tr>
<th>Curvature</th>
<th>MGT 0 - 49</th>
<th>MGT 50 - 99</th>
<th>MGT 100 - 149</th>
<th>MGT 150 - 199</th>
<th>MGT 200 - 299</th>
<th>MGT 300 - 399</th>
<th>MGT 400 - 499</th>
<th>MGT 500 - 599</th>
<th>MGT 600 - 699</th>
<th>MGT 700 - 799</th>
<th>MGT 800 - 899</th>
<th>MGT 900 - 999</th>
<th>MGT &gt; 1000</th>
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**Example:**
- 40 rails placed in the matrix:
- **Additional layers:**
  - standard, intermediate, premium rails (variable Carbon content)
  - High/Low rail locations
  - crack assessment:
    - Depth, length, angle, branching, density
Summary

• RCF is a complex problem with a multitude of contributing factors
  • Track curvature, rail position in curve, rail type, lubrication, traffic, others
  • Different inspection methods yield different results:
    • **Quantitative methods** are more objective
      • Rohmann and MRX overestimate crack depth
      • Rail milling/metallography: most accurate way to assess RCF
      • Metallography is important to map out crack morphology as a function of position on the railhead
    • **Qualitative methods**
      • Provide only surface information
  • RCF results need to be:
    • RCF Atlas & Matrix (a more systematic approach to mapping RCF)
Acknowledgements

• Special thanks to Rohmann, MRX, Sperry, KLD Laboratories, CSX, CN, NS, BNSF and TTCI for reference materials

• FRA for funding of study to validate crack measuring systems

• Eric Magel (NRC) for guidance on work at CSX and CN

• Ali Roghani (NRC) for MRX assessment of CSX data
Thank You