Sustainable rail condition management by top of rail friction control: technical and economic aspects

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Overview

- Corrugation Background
- Friction Control for Top of Rail
- Effects of Friction Modifiers on corrugation growth – technical aspects
- Economic aspects of corrugation mitigation
- Conclusions
BACKGROUND ON CORRUGATION
Corrugation Examples

- Commonly found on transit systems
- Multiple types and appearances
- On all types of track
Corrugation Impacts

- Noise and vibration
  - Inside and outside of vehicles
- Potential track and vehicle damage
- Reduced rail life
- Costs to control:
  - Grinding
  - Premature rail replacement
  - Track and vehicle damage
# Transit Specific Corrugation Types

<table>
<thead>
<tr>
<th>Pinned-Pinned</th>
<th>P2 Resonance</th>
<th>Rutting</th>
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<tbody>
<tr>
<td>Rail oscillation pinned by ties (nodes)</td>
<td>Second oscillation of unsprung mass of vehicle. <em>(Vehicle &quot;bouncing&quot; on track)</em></td>
<td>Roll–slip oscillation associated with differential tangential force between low and high rail wheels</td>
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<tr>
<td>400-1200 Hz</td>
<td>50-100 Hz</td>
<td>250-400 Hz</td>
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\[ \lambda = \frac{v}{f} \]

- **Train Speed**
- **Corrugation frequency**

Corrugation frequency will indicate the underlying mechanism.
Components of Corrugation Formation

- Wear
  - Plastic flow
  - Contact Fatigue

(Dr. S. Grassie, Dr. J. Kalousek)

FRICTION CONTROL FOR TOP OF RAIL
The Proper Material for the Proper Surface

- **Lubrication reduces** friction to a **minimum** level

- **TOR Friction Control reduces** friction to a **controlled** level
KELTRACK®

Top of Rail Friction Modifier

**Required Properties**

- Top of Rail Friction control at intermediate level (~0.35)
  - based on inherent friction modifier material properties
- Positive friction at the wheel rail interface

**Achieved in Practice via:**

- Water based suspension of dry solids, no liquid oil or grease components – environmentally benign
- Modifying rheology of existing third body layer (iron oxides)
Friction Modifier: Positive Friction

Brittle “High Hardness” Wear Particles (Fe₃O₄)

Pliable “Soft” FM Particles

“dry” rail-wheel contact

Stick (roll) - slip oscillations

Dry film FM treated

negative friction characteristics

positive friction characteristics

Traction (T/N)

Creepage %
Influence of Friction Modifier on Corrugation

• **Reduced absolute friction levels** on the rail head *(without compromising traction / braking)* expected to reduce wear component of corrugation mechanism

• **Positive friction characteristics of interfacial layer** - reduction of roll-slip oscillations associated with wavelength fixing / initiation component of rutting corrugation mechanism
WHEEL RAIL APPROACHES TO CORRUGATION GROWTH
Corrugation Control

- Grinding / wheel rail profiles
- Hard rails
- Friction Management
Grinding and Corrugation

- Will remove corrugation if applied correctly
- Adjust profiles and improve steering
- Will primarily treat the symptoms
Premium Rails and Corrugation

- With increasing rail hardness reduced formation of corrugation - wear resistance
- Rails cannot address the stick-slip oscillation mechanism
- Rail exchange only feasible when existing rail close to end of life

Friction Modifier and Corrugation

- Grading

Initial profile

Profile change

Wavelength fixing mechanism

Damage mechanism

Stick – slip feedback loop

Dynamic loads

Traction, creep, friction

Wear

- Plastic flow
- Contact fatigue

Rail grade

(Dr. S. Grassie, Dr. J. Kalousek)
KELTRACK® Application Systems

- Wayside Application
- Onboard Application
Track Test Example

- Commuter Rail
- Curve radius: 227m, curve length: 480m
- Ballast / concrete sleepers
- 3% gradient
Results

Commuter Rail System - Track 1

![Graph showing amplitude (average) in mm over time with measurement dates from 25-Nov-03 to 17-Jul-05. The x-axis represents measurement dates and the y-axis represents amplitude (average) in mm. Two distinct phases are highlighted: Grinding and start of reference phase and Grinding and start of FM phase (KELTRACK® application). Two zones, Zone 4 and Zone 5, are indicated on the graph with corresponding data points.]
Corrugation comparison

Improvement factor of 27
(based on corrugation growth per 30 days)

Reference phase – 30 days after grinding

FM phase – 280 days after grinding
Overview over All KELTRACK® Track Tests

- Average corrugation improvement factor: 11
- Variability: complete suppression to factor 4
ECONOMIC ASPECTS
Economic Factors

• Noise and Vibration
• Damage of track components
• Grinding
• Friction Management
Noise and Vibration

- Difficult to indicate direct cost impact
- Legislative noise regulations
- Upset residents in neighbourhood
  - Local politician in the neighbourhood?
  - Lawsuits?
  - Health Impact?
- Vibration might cause some track / vehicle damage
- Impact on highly vibration sensitive public buildings
Damage of Track Components

• Vibration
  – Ballast degradation
  – Sleeper damage
  – Clip breakage

• Replacement Costs
  – Material costs
  – Labour costs
  – Track closure costs
Grinding Costs

- Machine availability
- Machine costs per shift
- Available operating windows
- Related maintenance activities
  - Removal and installation of track equipment
- Safety considerations / restrictions
- Track closures
Friction Management

• Installation costs
• Consumables costs
• Maintenance (filling, repair)
  – In house
  – Service contract
Hypothetical Case: Assumptions

• Corrugation Trial at Transit A showed an improvement factor of 10 by FM application.
• Grinding interval of 6 months (contracted)
  – 2 grinding campaigns per year
Hypothetical Case: Maintenance Window

• No Operation between 1am and 5am
• Grinding Window 1:30am – 4:30 am
• Full time operational between Saturday 5am and Monday 1am
  – No maintenance on the week-ends
• 5 shifts per week each 3h maximum
Hypothetical Case: Further Assumptions

- x% of track have corrugation problems
- 20 grinding shifts to treat these x% per campaign
  - Costs per shift include everything
- 20 FM applicators to effectively treat these x%
- Typical application settings, typical axle count
- Conservative numbers for costs
  - Grinding costs on lower end
  - Consumable costs factor in maintenance (percentage)
Hypothetical Case: Cost development

- Based on assumptions for example case

![Graph showing costs over months with a trend line labeled 'Grinding without FM']
Hypothetical Case: Cost development

- Cost saving with TOR-FM possible

![Graph showing costs over months with different scenarios: Friction Modifier (FM), Grinding without FM, and Grinding (FM).]
Simplified Payback Calculation

• $C_{GR}$: Grinding Cost per year [1/year]
  – Grinding cost per shift $\times$ No. shifts $\times$ No. of campaigns per year
Simplified Payback Calculation

- $C_{GR}$: Grinding Cost (without FM) [1/year]
- $C_{CAP}$: Investment Cost for FM equipment
Simplified Payback Calculation

- $C_{GR}$: Grinding Cost (without FM) [1/year]
- $C_{CAP}$: Investment Cost for FM equipment
- $C_{FM}$: Friction Management Costs [1/year]
  - Consumables Cost + Grinding cost with FM
  - Consumables Costs:
    - $No. \, FM \, units \times application \, settings \, in \, gal / axle \times No. \, axles \, per \, year \times FM \, costs \, per \, gal \, (incl. \, maintenance)$
  - Grinding cost per year for FM:
    - $C_{GR} / Improvement \, Factor \, by \, FM$
Simplified Payback Calculation

- \( C_{GR} \): Grinding Cost (without FM) \([1/\text{year}]\)
- \( C_{CAP} \): Investment Cost for FM equipment
- \( C_{FM} \): Friction Management Costs \([1/\text{year}]\)

- \( R \): \( \frac{C_{GR}}{C_{FM}} \) ... Cost Ratio grinding vs. FM
- \( P \): \( \frac{C_{CAP}}{(C_{GR} - C_{FM})} \) ... Payback \([\text{years}]\)
Example Case: Payback Diagram

- Payback in [years] over cost ratio for given improvement factor by FM

![Diagram showing simplified payback information with a starting point for Example Case: R = 3.15]
Example Case: Payback Diagram

- Excellent payback time also for lower improvement factors possible

Simplified Payback Information

Payback [years]

R [Cost Grinding / Cost FM]

- > 1 year payback time
Conclusions

• KELTRACK® Friction Modifier can successfully mitigate rutting corrugation development by impacting both relevant development factors

• Short pitch corrugation growth rate can be reduced on average by factor 11 by TOR-FM

• Clear economic benefits
  – Payback within a year or less even for low reduction factors for the assumed case
Thank You for Your Attention

Source: P.T. Torstensson, Charmec, Sweden