Reducing Wheel-Rail Noise on the Johnsonville Line

Rhys Hayward
JVL curve noise problem:

“Number one priority” to fix squealing Johnsonville trains, says Fran Wilde

March 18, 2013

6:34 am on 21 March 2013

Residents of a Wellington suburb have vented their frustrations over squealing trains on the local rail line at a public meeting.

Johnsonville trains have been in use for about a year on the line since then some people living nearby have complained of noise.

Greater Wellington Regional Council and Kiwirail will be meeting at Ngaio Town Hall on Wednesday.

Fresh batch of trains hopefully squeal-free

MICHAEL FORBES

(Full story here)

The Wellingtonian | News | Upper Hutt Leader | Kapiti News | Kapiti Observer

Johnsonville trains still screeching

Barry JOWHAN

(Journalist)
Wheel-Rail Noise on JVL

The Johnsonville Line (JVL)

- Steep grades 1:39
- Tight curves <200m
- Houses close to track
Matangi EMU

Introduced 2011 replacing English Electric sets which had been running since JVL electrification in 1938

- 2-car (motor-trailer)
- Flange lubrication
- M1 (2011) and M2 (2015)
Curving noise

**Squeal:** Generated by lateral slip-stick oscillation between wheel tread and rail head. Occurs where insufficient lateral force to steer axle around curve. Slip-stick generates vibration with wheels resonating and radiating noise. Tonal noise 1-5kHz.

**Flanging:** Metal-on-metal contact of wheel flange and gauge face of rail. Broadband or multi-tonal noise 5-10kHz.
Flange Lubrication

Flanging noise has always been an issue on JVL:

- In 2010 Kiwirail undertook a trialled an electronic Gauge Face (GF) lubrication machine on a 200m radius curve.
  - Eleven-fold reduction in side wear
  - Subsequently four electronic GF lubricators installed

- 20% of the Matangi I & II fleets are equipped with flange lubricators on leading axles
  - Activated by an inclination sensor
  - Spray lubricant onto rotating wheel flange
Analysis of Squeal factors *(Interfleet 2011)*

- Dynamic modelling using Vampire software
- Variations from base case:

<table>
<thead>
<tr>
<th>Track Design</th>
<th>Operation</th>
<th>Vehicle</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rail shape: New vs worn</td>
<td>• Speed: 40±10 km/h</td>
<td>• Motor vs Trailer</td>
<td>• Wheel-rail friction coefficient</td>
</tr>
<tr>
<td>• Cant: ± 50% of installed cant</td>
<td>• Braking: +5%g deceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Track gauge: 1068 to 1074mm</td>
<td>• Traction: +5%g acceleration</td>
<td>• Suspension parameters: 1. Primary yaw stiffness 2. Primary lateral stiffness 3. Secondary yaw +100/-50%</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Wheel profile: NZ TRA-1 vs “Auckland”, S1002 (Europe), LW3 (QLD)</td>
</tr>
</tbody>
</table>
Analysis of Squeal Factors
(Interfleet 2011)

- Flange contact below 1315m radius
- Squeal below 420m
- Only wheel-rail friction level had significant influence over curving performance
- Recommended “Friction Modifier”

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th>Wheelset 1</th>
<th>Wheelset 2</th>
<th>Wheelset 3</th>
<th>Wheelset 4</th>
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<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>IN</td>
<td>OUT</td>
<td>IN</td>
<td>OUT</td>
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<tr>
<td>µ=0.1</td>
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<td>-</td>
<td>265</td>
<td>405</td>
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<td>-</td>
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<tr>
<td>µ=0.3</td>
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<td>-</td>
<td>-</td>
<td>400</td>
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<tr>
<td>µ=0.5</td>
<td>280</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>265</td>
<td>-</td>
</tr>
</tbody>
</table>

Curve radius for wheel tread creep saturation under different adhesion scenarios.
IN = Inner wheel, OUT = Outer wheel
Top-Of-Rail Friction Modifier

- Gel applied to rail head
- Proprietary formulation designed to maintain adhesion of $\mu = 0.3-0.4$
- Claimed success in Australia, Europe and North America

- Preliminary trial in 2012 was inconclusive but suggested a reduction in squeal noise
- Follow-up trial in May 2013 indicated squeal noise had been eliminated!
Top-Of-Rail Friction Modifier

- Track-based TOR-FM machines were installed in 2014
- The subsequent study was inconclusive but residents reported some improvement
- Instances of wheel slip and slide logged by the train increased

Crust of TOR-FM which forms on the trains underframe
Wheel Dampers

**Constrained Layer Dampers** (CLD’s) are devices that are typically attached to the wheel web that combine metallic sheets with polymeric layers. CLD’s damp the wheel modes due to the dissipation of energy into heat that occurs through the shear deformation of the polymer.

**Ring dampers** are steel rings that snap into grooves machined in the wheel rim, usually one on each side of the tread. The rings, which are free to move, absorb vibration energy through friction between wheel and rings (coulomb damping).
Wheel Vibration Modes

Vibration of the wheels are one of the component sources of wheel-rail noise.

Wheel modes can be classified as axial (or bending) modes and radial modes.

- **Squeal** noise generally originates from the self-excited vibration of the wheel which corresponds to Axial modes of the wheel.

- **Flanging** noise mainly corresponds to Radial modes of the wheel.
FE Modal Analysis

Bonatrans undertook Finite Element (FE) analysis of a non-damped Matangi wheel in the frequency range from 0 to 10 kHz.

Calculation of natural frequencies and mode shapes confirmed the assumption that squeal noise is caused by axial modes.
Experimental modal Analysis

Tested undamped, Ring damped and CLD’s by measuring the response of a suspended wheelset to mechanical excitation by impact hammer and modal exciter.

Results:

- Ring dampers reduce axial mode shapes much more significantly than CLD’s.
- Ring dampers can make a significant reduction of squeal noise in peaks of 1500 Hz and higher and an overall noise reduction of about 5 to 10 dBA.
- GWRC opted to include ring dampers on the wheels of the second batch of Matangi EMU’s (M2)

<table>
<thead>
<tr>
<th>Mode shape</th>
<th>Non-damped $f_0$ [Hz]</th>
<th>Non-damped br</th>
<th>Ring damper br</th>
<th>CLD’s br</th>
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</thead>
<tbody>
<tr>
<td>Ax2</td>
<td>451</td>
<td>0.012</td>
<td>0.03</td>
<td>0.03</td>
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<tr>
<td>Ax3</td>
<td>1151</td>
<td>0.011</td>
<td>0.08</td>
<td>0.03</td>
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<td>2054</td>
<td>0.007</td>
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<td>Ax5</td>
<td>3070</td>
<td>0.007</td>
<td>0.46</td>
<td>0.03</td>
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<tr>
<td>Ax6</td>
<td>4146</td>
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<td>6364</td>
<td>0.010</td>
<td>0.25</td>
<td>0.02</td>
</tr>
<tr>
<td>Ax9</td>
<td>7467</td>
<td>0.009</td>
<td>0.40</td>
<td>0.01</td>
</tr>
<tr>
<td>Ax10</td>
<td>8547</td>
<td>0.008</td>
<td>0.41</td>
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<td>R5</td>
<td>3866</td>
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<td>0.23</td>
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<td>R6</td>
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<td>R7</td>
<td>6050</td>
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<td>0.10</td>
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<td>R8</td>
<td>7223</td>
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<td>R9</td>
<td>8426</td>
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<td>R10</td>
<td>9649</td>
<td>0.011</td>
<td>0.41</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Noise and Weather Measurement

An automatic track-side noise monitoring station was commissioned in November 2015 to measure the effect of the various noise mitigations.

- train speed and direction
- high quality audio recordings
- weather (temp, humidity, rain, wind)

Data uploaded to a remote server where the noise recording is analysed using the Cooperative Research Centre for Rail Innovation (CRC) algorithm to determine flange, squeal and rolling noise components.

Web based interface which displays noise and weather measurements as well as spectral data
Noise Data Analysis

The first stage of data analysis involved matching the various data sources in Excel:

- Noise data from monitoring station
- Weather data from monitoring station
- Vehicle identification from the Rail Performance Monitoring System (RPMS)

Comparison of the noise spectra showed a marked difference in noise profile between M1 and M2 fleets:

- M2 units rarely squealed compared to M1 units. Flanging noise levels were also attenuated.
- It was believed that the wheel ring dampers fitted to the M2 units had virtually eliminated squeal.
Noise Data Analysis

Despite squeal having been virtually eliminated some residents continued to complain about the noise so attention turned to Flanging noise.

It was noted that Flanging occurs predominantly during the middle of the day corresponding with low Relative Humidity and high track temperatures.

[Graph showing Flanging noise, Flanging LAeq (dBA), Humidity (%), and Temperature (C) over a range of dates]

Wheel-Rail Noise on JVL
Noise Data Analysis

2-D histograms were prepared to further understand the relationship between wheel-rail noise and meteorological conditions on JVL.

Moisture reduces the coefficient of friction between wheel and rail track and therefore reduces the incidence and level of flanging. The level of moisture on the rail is dependent on relative humidity (%RH) and the temperature of the track.

Incidence of squeal was similarly plotted against RH% and time of day but showed no obvious relationship with meteorological conditions.
Noise Data Analysis

Problem with GF grease migrating onto the railhead causing adhesion issues.

No tangent track on JVL so lubricators placed at curve transitions. One rail had better pick-up than the other resulting in an accumulation of grease on the other rail or insufficient grease output.

One way to eliminate this problem is to separately dose each rail

- Optimum grease output
- Can be installed on curves
- Extra machines needed
Noise Data Analysis

The noise monitoring data showed no correlation between squeal or flange noise from:

a. **Train direction.** Note in the uphill direction the unit is likely to be powering, and in the downhill direction is likely to be braking.

b. **Consist size.** 1 x 2-car and 2 x 2-car sets – squeal and flanging noise incidence and severity is proportional to number of axles.

c. **Pass-by speed.**

d. **Vehicles equipped with Flange lubrication.**

The effect of TOR-FM treatment on both squeal noise and flanging noise was unclear so the machines were turned off to establish baseline measurements.

Flanging noise incidence and severity was unchanged and continued to exhibit the same diurnal pattern relating to dryness of the rails.
Noise Data Analysis

During the trial with TOR-FM turned off occurrence of squeal gradually increased

The machines were turned back on but squeal occurrence continued to increase!
Noise Data Analysis

Squeal and flange occurrence data was matched with vehicle ID to compare incidence of squeal for each unit.

- Oldest vehicles in the M2 fleet exhibited the highest occurrence of wheel squeal
- Flange noise occurrence follows seasonal conditions rather than age.

Two mechanisms were considered for the increased squeal as vehicles age:

- Wheel tread roughness – smooth worn wheels versus machining ridges on new wheels
- That the ring-dampers were not working.
Ring dampers stopped working

Percussion tests were performed in the depot to compare the response of an undamped M1, a ring-damped M2 which had been in-service for 2-years (5010) and a new ring-damped wheelset.

The percussion test indicated a similar response between the used M1 and M2 wheelsets which was significantly different to the new M2 wheelset.

<table>
<thead>
<tr>
<th>Axial Mode Shape</th>
<th>Non-damped $f_0$ [Hz]</th>
<th>Non-damped br</th>
<th>New Ring damper br</th>
<th>Used Ring damper br</th>
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Modal analysis of noise recordings by wheel manufacturer Bonatrans confirmed that the M2 ring-dampers are not working effectively.
Conclusions

• Analysis of noise and meteorological measurements has shown that squeal and flanging noise are influenced by different factors.
• Flanging noise correlates strongly with humidity; generally the flanging noise is highest when the track is dry.
• Squeal noise was temporarily eliminated with the introduction of the ring-damped M2 fleet but has since returned. Over time the damping rings have seized in place inhibiting their ability to dampen wheel vibration. Tests to restore the ring-dampers effectiveness are ongoing.
• It was found that TOR-FM has not been effective at reducing squeal in this situation and has caused adhesion issues.