# Squeal noise mitigation in urban rail surface transport

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## Introduction

This paper presents some of the results from the research carried out under the EC Research Project "*Squeal noise reduction in urban transport by rail treatment*" and is updated with results obtained in results from the EC Research Project "Quiet City Transport". A mathematical model for squeal noise calculations is presented, as well as solutions at the track level and a vehicle based solution.

## Tram squeal noise model including a suitable model for the roll-slip excitation of the wheel and rail

### The Lumped parameter model with non-linear friction element

For tram systems, the most important cause for curve squeal noise generation is the crabbing of the wheel across the top of the rail: lateral stick-slip (rolling slip). The radiated sound power by the wheel during squeal can be calculated with a lumped parameter model.

The lumped parameter model includes two damped single-degree-of-freedom systems (representing wheel and rail) on each side of a non-linear friction element. The system is driven to self-sustained vibrations by pulling the wheel end of the system with a constant velocity similar to the constant crabbing velocity occurring when a two-axle bogie with fixed axles is passing through a curved track. The model includes one mode of the wheel (shown to the left of the friction element) and one mode of the rail (shown to the right of the friction element).

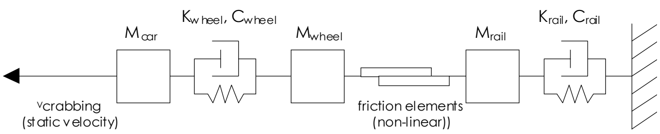


**Figure 1 - Conceptual sketch of the lumped parameter model for prediction of wheel/rail squeal noise**

A typical non-linear friction characteristic of the contact between the wheel and the rail is stored as a (numerical) function in a finite element model and is based on measurements of actual wheel/rail friction. A standard wheel/rail configuration with actual data leads to a predicted vibration velocity in the wheel. As can be seen, the system is squealing nicely at a frequency determined by the resonance (mode) of the wheel.

### Parametric study

A special non-linear friction element has been introduced within the finite element software in order to be able to carry out a parametric study.

#### Base case

The reference case is based on actual STIB (Brussels Tram) data. A vehicle is considered with a 2 m bogie axle spacing, velocity of 7 m/s and 100 m radius curve. The wheel squeal mode is represented by following equivalent one degree of freedom parameters: m = 24 kg; k = 2.85*$10^8$N/m and c = 330 Ns/m (550 Hz mode). The lateral rail dynamic behaviour is represented by following equivalent parameters: m = 10 kg; k = 63*$10^6$N/m; c = 10 000 NS/m.

Figure 2 clearly shows the wheel squealing (top picture) and the rail vibration (bottom picture) for this base case (left pictures).

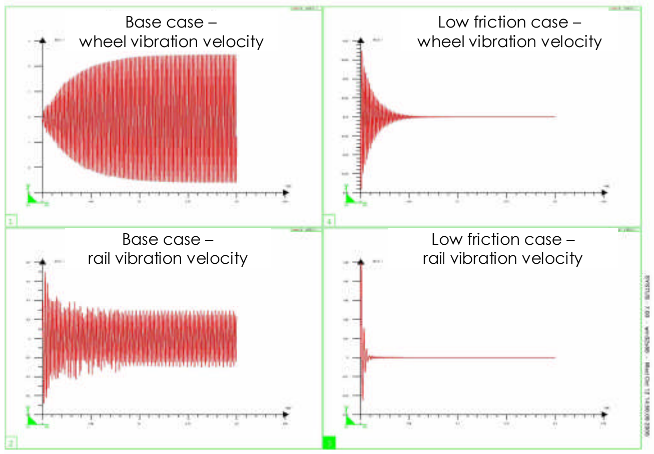


**Figure 2**

#### Low friction

Carrying out the calculation with a reduced friction curve (friction-creep curve amplitude divided by a factor 3) yields results given in the right part of figure 2: wheel and rail vibrations are reduced significantly and no squeal is occurring.

#### Laterally resilient rail

Carrying out the squeal calculation with a laterally resilient low damped rail system yields results given in figure 3: the wheel is squealing during 0.4 s but is then damped out; the rail is squealing at its low resonance frequency (not audible).

Following equivalent rail parameters have been considered for the lateral rail dynamics: m = 120 kg; k = 14*$10^6$N/M; c = 250 Ns/m.

It is observed that as soon as the rail squeal vibration velocity reaches the wheel squeal vibration velocity, the wheel vibration is damped out to a very small value: no wheel squeal is occurring any more.

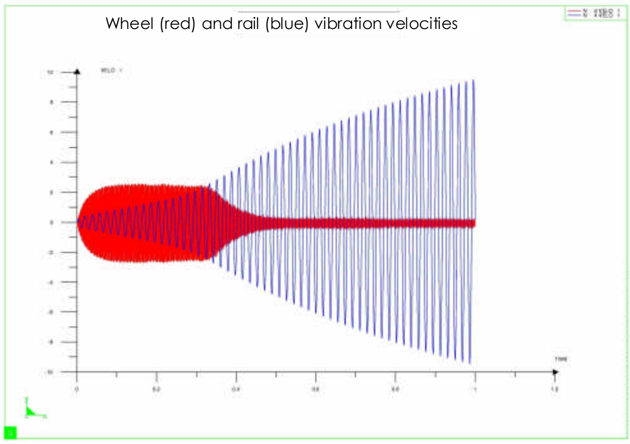


**Figure 3**

## Conclusions

The conclusions from the parametric study are as follows:

- Control of wheel/rail friction behaviour can avoid/reduce squeal noise. Squeal will be reduced when the coefficient of friction is reduced.
- Reduction of the rail mechanical impedance at the squeal frequency to a value below the wheel mechanical impedance will reduce squeal noise as long as the rail damping is low enough.

# Wayside Rail Lubrication

A wayside lubrication system from Lionoil was installed at the entrance of a tram depot designed to lubricate two tracks where trams enter the depot and at two tracks where trams leave the depot. As explained above, we measured the squeal noise at two representative locations for different modes of application of the lubricant:

- no lubrication: carried out at the beginning and the end of the campaign;
- lubrication once a day, one day out of two;
- lubrication once a day, every day.

We carried out measurements without lubrication in the beginning and at the end of the campaign to check if the noise levels were identical before and after.

Measurements were carried out at least a week after each change of mode (or after cleaning of the site by Lion Oil in the case of modes without lubrication) and as soon as dry weather conditions permitted.

All measurements were carried out between 6 am and 9 am.

The location of the measurement points is presented in figure 4. Figure 5 shows that the peak of the squeal noise is between 500 and 1000 Hz. The lubrication significantly reduces or even eliminates the squeal frequency peak from the noise spectrum.

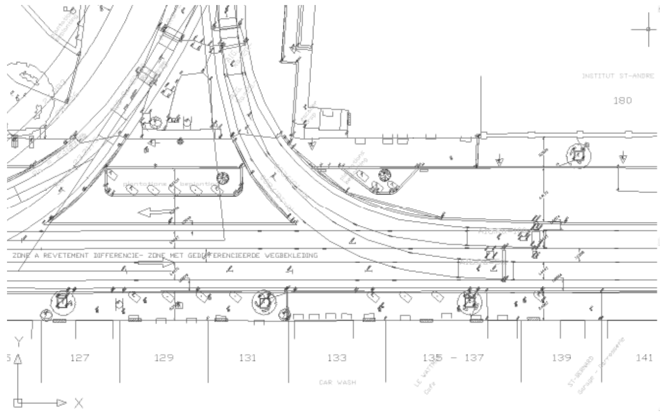

**Figure 4**

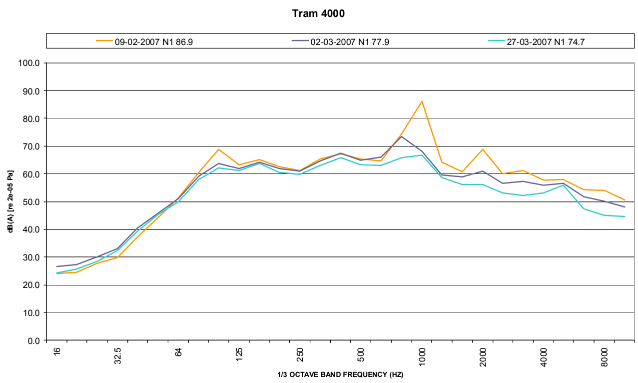


**Figure 5**

The noise amplitude reduction in dB(A) brought by the various modes of lubrication at the squealing frequency in comparison with the situation where no lubrication is applied, are shown in the following table:

| mode of lubrication | T2000: N1 | T2000: N2 | T3000: N1 | T3000: N2 | T4000: N1 | T4000: N2 |
|---|---|---|---|---|---|---|
| 1 application every 2 days | 7.9 | 7.1 | 22.4 | 18.1 | 18 | 14.8 |
| 1 application every day | 18.4 | 16.3 | 23.7 | 19.9 | 19.4 | 16.2 |

**Table 1**

One sees in this table that the Tram 3000 and Tram 4000 types are very sensitive to lubrication even with the first limited mode of lubrication, while the Tram 2000 has an important squeal reduction only with the second mode of lubrication (once a day).

# On-board Lubrication

Figure 6 shows the on-board lubrication system that has been installed at De Lijn in Antwerp (Siemens Hermelijn Tram). Its performance has been measured.

The system from manufacturer Baier + Köppel aims at:

- minimization curve noise;
- wear reduction (rail and wheel);
- no negative effect on breaking distance;
- no pollution;
- low life-cycle cost.

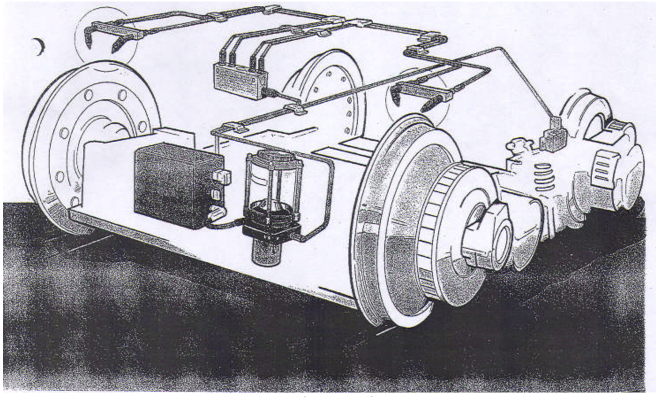

**Figure 6**

Figure 7 shows the maximum noise level during pass by with indication of the state of the track and the direction of riding (IN or OUT).

It is clear to see that after the first lubrication the maximum noise level during pass by reduces more than 16 dB, e.g. from 102 dB(A) to 85 dB(A). The peak at 1250 Hz is eliminated completely.

This level stays low at least after 8 passages without further lubrication.

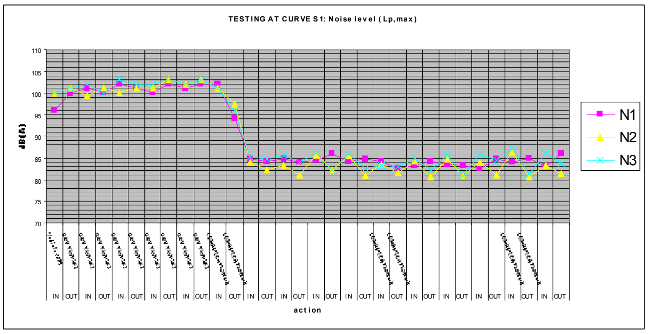


**Figure 7**

## Laterally resilient rail fasteners (according to result 2)

A low rail impedance in lateral direction (with low modal damping of first modes) can be obtained with a special fastener concept yielding dynamic stiffness below 10 kN/mm. A typical rail fastener is shown in figure 8.

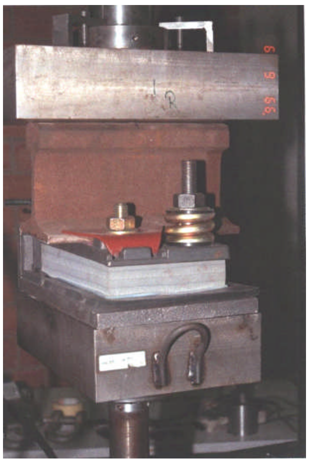

**Figure 8**

This solution has been installed in a curve in the Antwerp tramway system (keerlus Melsele): with laterally resilient rail fasteners squeal is minimal (audible during very short periods and then disappearing). In another identical curve with classical ballasted track (keerlus Zwijndrecht), squeal is present and continuous at a much higher amplitude, see figures hereafter (same vehicles at same speeds, same curve radii, same rails).

A comparison of the curve in Melsele with the lateral fasteners with an identical curve in Zwijndrecht on classical ballasted track show a reduction in $L_{Aeq}$ values from 81.9 dB(A) to 55.5 dB(A).

## Conclusions

Effective measures for squeal noise control in curves have been presented. The final selection of a solution type depends on the local network conditions.

Lateral rail damping is very effective to control squeal noise.

Both lubrication methods (on board and wayside) are very effective at eliminating the squeal noise.

The on-board lubrication is:

- relatively low cost (investment less than 3000€ per vehicle);
- limited maintenance in the depot;
- limited use of lubrication fluid.
- installed in maximum one out of eight vehicles running on the specific tramline.
- flexible: only the curves with a diameter below an adjustable value are lubricated.
- the vehicles only need a compressor unit.

The wayside system is more expensive (at least 5000€ per installation + cost of embedding):

- its maintenance can be problematic;
- each curve has to be treated;
- refilling of lubrication fluid maintenance have to be done on site;
- electric power has to be available on site.

For all the above reasons, we strongly recommend the use of an on board lubrication system for solving the squeal noise problem.