RAIL WHEEL SQUEAL – SOME CAUSES AND A CASE STUDY OF FREIGHT-CAR WHEEL SQUEAL REDUCTION

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Abstract

Rail wheel squeal on curves in rail track is a source of potential noise annoyance to residents adjacent to rail lines. For one private rail freight operator, wheel squeal was causing repeated complaints from neighbours. Wheel squeal can be caused by the wheel-tyre to rail-top interaction and the wheel flange interaction with the gauge face of the rail (more like a screech). This paper describes some of the main causes of wheel squeal and the alternative approaches taken by various rail operators to reduce the generation of wheel squeal. The approaches taken by the operator in one study to successfully reduce wheel squeal are described. The source of wheel squeal in that case was identified as being related to the steering and suspension of the bogies on the rail car. Different bogies have different suspension systems and the methods to reduce wheel squeal may differ for bogie types. Rail vehicle maintenance regimes may also need to consider wheel squeal issues to reduce the potential for noise annoyance.

Introduction

This paper is based around a case study of approaches by a private rail operator to reduce environmental noise emissions from rail operations in a methodical manner. Wheel-squeal was the first noise source tackled. As this was treated and reduced or eliminated, subsequent noise sources were tackled to achieve ongoing improvements in management of rail noise emissions. Wheel squeal was the initial and major source of the noise emission which was of concern to neighbours. After significant reduction of the wheel squeal noise, subsequent noise sources treated were dynamic-regenerative brakes and brake shudder.

This paper is not intended to be a definitive work on wheel squeal but a case study. The findings may be indicative of potential solutions to wheel squeal for similar rail car suspension systems, and could be of relevance to others.

What is Wheel Squeal?

There are several publications that describe the source of noise from rail transit vehicles. The US FTA's Transit Noise and Vibration Impact Assessment Report of 1995 provides a good description of how to assess noise from rail projects [1].

Rail wheel-squeal is described in detail in the TCRP report Wheel/Rail Noise Control Manual of 1997[2].

The different types of wheel/rail noise include rolling noise, corrugation noise, impact noise at joints, imperfections or from flat wheels, curving noise and wheel/rail howl. Curving noise is the main cause of wheel squeal, and includes two main types of wheel squeal – flange noise, longitudinal stick-slip and lateral slip or what I will term as wheel/rail-top squeal to indicate where it arises.

Longitudinal stick-slip is caused by the different translation velocities between the inner and outer rails. The WRNCM advises that wheel taper is usually sufficient to compensate for differential slip at curves in excess of 600m radius, though shorter radii may be accommodated by profile grinding of the rail head.

Flange rubbing noise is where the flange of the rail wheel strikes the gauge-face (the inner side) of the rail. For Figure 1 shown below, as the train negotiates a bend, the wheel on the inner or low rail moves away from the rail while the wheel on the outer or high rail moves closer to the rail. Wheels and rails have the shape they do to allow curves to be negotiated – if there was less clearance between the rails and the wheels, they would constantly be rubbing and making flange strike the gauge face, causing the high pitch noise and excessive wear on wheels and rails.

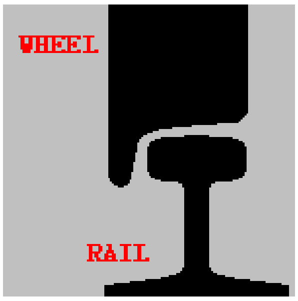

Figure 1: Schematic of Wheel/Rail Interface [5]

Flange noise is a common feature that will be known to many rail commuters. Many rail systems use grease pots to lubricate rails at curves to minimise wear and noise. Flange rubbing noise appears to occur mainly around 1400 to 1600 Hz, depending on wheel geometry.

Figure 2 below shows examples of the profiles of actual rails, where the repetitive wheel movement on a curve has resulted in wearing of the rail-head.

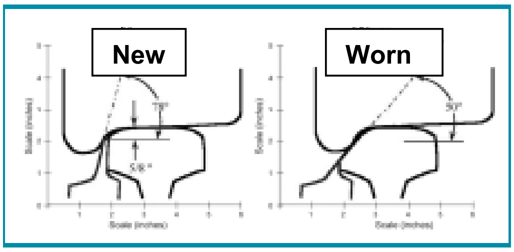

Figure 2: Actual Wheel & Rail Profiles [3]

Lateral slip of the tread running surface of the wheel across the rail-head is the most probable cause of wheel squeal and was identified as the major source in the case study. What happens is that the wheel tread moves in a crab-walk manner across the rail-head in a curve.

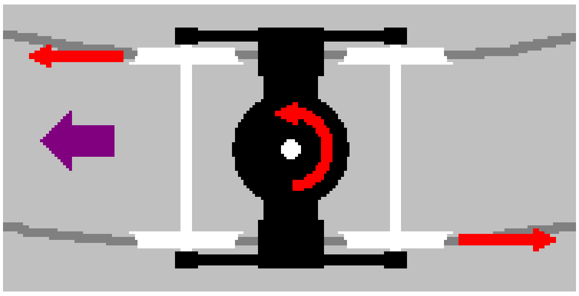
Figure 3: Schematic of a Rail bogie in a curve [5]

The WRNCM provides detailed acoustic theory about the causes of the stick-slip mechanism, which will not be in this paper. You can imagine that with a tight radius curve, there will be many stick-slip actions of the wheels across the rail. Higher noise tends to come from the wheels in opposite positions on the bogie, shown in Figure 3 above.

Some rail operators have tried rail-head “lubrication” with friction modifiers in curves to reduce friction on the wheel-rail interface so that the wheel slides instead of the stick-slip approach. However the effectiveness of this approach is variable and depends on the circumstances of the location and operations occurring. On very tight curves in light-rail systems in some Canadian cities, such as at street intersections, water sprays are used to provide the lubrication (personal communication). On the NSW City Rail Sydney North-Shore line, a spray friction-modifier with an automatic actuator is used on some curves to reduce wheel squeal noise. In other Australian and European operations, the lubricant is mounted on the locomotive or lead car and applied on each curve (Lubricant supplier advice).

One reason that wheel squeal is emitted as a significant sound level is that the stick-slip induces vibration in the wheel hub, providing a large diaphragm to radiate the noise, so the train, in effect, becomes a series of loudspeakers traveling along the track emitting the high pitch of the wheel squeal. Wheel squeal occurs at frequencies of 3000 to 4000 Hz, is very tonal and quite an intense noise when experienced.

Case study: BlueScope Steel - Rail Operations, Kemira Valley Railway

BlueScope Steel operated the Kemira Valley rail line between Kemira Valley, near Mount Kembla Village, and Port Kembla, near Wollongong, NSW. Originally, the railway transported coal from the coal storage bins at the Kemira Valley Coal Receival Facility to the BlueScope Steel steelworks at Port Kembla. This system of railway avoids the need to transport the coal by trucks through a large urban area. At the steelworks, the coal is used in the coke making process. From 2004, the rail line has been operated by Pacific National. They haul coal for BHP Billiton from the Dendrobium Coal Mine’s 150,000 tonne coal stockpile in Kemira Valley, to the BlueScope Steel plant at Port Kembla.

In late 2000 and 2001, as the Dendrobium Coal Project was being planned and environmental studies for approval were being scoped, there were several noise complaints from residents in the village of Mount Kembla and the area of Cordeaux Heights, living along the line, regarding wheel squeal. Hatch were requested to assist BlueScope Steel in assessing the scope of the environmental noise problem and advise on options for reduction of environmental noise. Experts in rail track conditions from the BHP Rail Research Institute at Monash University were also involved in consulting to the activity.

Over the period January to June 2001, specialists in railway operations and environmental noise assessment and control from BlueScope Steel, BHP Billiton and Hatch worked together in a study team to progress the assessment and control activities.

The main environmental noise issue assessed by the study team and raised by the community was wheel squeal from the coal wagons on the curves from the Central Road rail crossing to the foot of the Mount Kembla Village. These had a feature of high frequency or pitch and high sound level, considered to be potentially very annoying. So the main considerations of the team were to address wheel squeal. Once this was addressed, other noise sources could be addressed.

The activities of the team included:

- Engineering improvements in the operation of the coal wagons being considered, trialled and then implemented through the whole Kemira Valley rail fleet.
- Track lubrication alternatives were assessed, trialled and additional flange lubrication installed
- Track alignment, super-elevation (the height difference between rails on curves), wheel and rail profile and rail grinding regime were considered and modifications to rail grinding activities proposed. Wheel profile changes were also being considered.

Following implementation of the improvements to the coal wagons, wheel squeal noise appears to have been almost completely eliminated. This resulted in a significant improvement in environmental noise amenity by removal of high levels of tonal noise and improved community response (through residents' comments).

Further noise emission assessment and control options were also considered and trialled or implemented over the subsequent 3 years, including:

- engineering controls on the wagon braking system to reduce "brake shudder" noise and changed brake-block compounds;
- the effects of operation of dynamic braking systems on locomotives;
- the effects of number of wagons in a train set (or "rake"); and,
- administrative controls on the use of dynamic brakes in the locomotives and speed of operation of the trains.

Track Details: The rail track between Central Road Crossing at Cordeaux Heights and the base of Bushell's Hill contains seven curves, some with relatively tight radii, the smallest being 145.4m. This large number of curves in the relatively short track and the tight radii cause the speed of the train to be limited to a maximum of about 40km/hr on the uphill-empty trip. The speeds on the return trip are lower to allow safe braking distances within visibility ranges from the driver's compartment of the locomotive. At the time of the study, the line operated 24-hours per day, and it was the late night operations with wheel-squeal which caused the most complaint.

All of the improvement or trial activities were accompanied by noise measurements, both attended for level variation and frequency content over the train bypass, and unattended for statistical assessment and comparison with objectives over several weeks.

Figure 4 below shows spectra of the train movements at the start of the study. Note the tonal components at frequencies close to 3000 and 4000 Hz. These were from the wheel-squeal caused by lateral stick-slip movement of the wheels on the rails. Measurements were at ~100m.

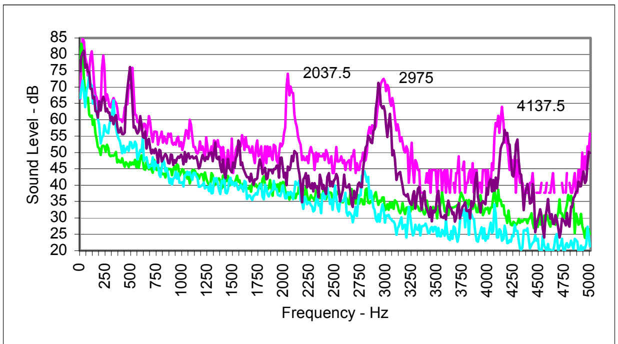

Figure 4: Kemira Valley – 5kHz Spectra Midnight Trains Before Conversion Up & Down Trains 9 Feb 2001

Lubrication with friction a modifier was the initial method tried to reduce wheel-squeal noise, with hand application to the track sections ahead of the curves. This was done on each morning prior to the commencement of operations over a three-week period. A proprietary emulsion-based 'lubricant' was tried. No measurements were taken and assessment was subjective, on the frequency of occurrence of squealing. No reduction in the occurrence was noted. Lubrication was considered as a stop-gap measure for implementation while the actual cause of the wheel-squeal noise was identified and potential treatment sourced. Based on the international reports of water sprays being used on light-rail tracks for minimization of wheel squeal, lubrication by water sprays had been considered as a possibility for this track because a water pipeline followed the rail easement. However any form of water lubrication was likely to be difficult from an operations aspect because it reduced friction, and in the steeper sections of the track, locomotives were experiencing loss of traction. When this occurred, a second locomotive was called to push the train up the hill, adding to the noise.

One factor which was reported as common to the frequency of occurrence of the wheel-squeal noise for this line, was that it was worse on a Monday and after a line outage. Rust on the rail-head was considered as a possible source of squeal, or part of its generation mechanism. The theory was that as the period of time between train movements increased, such as over a weekend or several days of no operations, rust would build-up and this may somehow be a cause of the squeal. If this was so, then any form of water lubrication would also add to the noise generation problem.

Where was the wheel-squeal noise occurring? Eventually, careful listening during the attended noise measurements identified that the wheel squeal was occurring not just on the curves, but also on the straight sections between the curves. As the train proceeded up the hill, we could hear it coming. The low-frequency noise of the locomotive was relatively constant as it started coming under load moving up the hill, then the wheel-squeal would be heard on the first curve, and continue after the train was on the straight section of track between the curves.

Not all wagons would squeal, and some had a higher sound level than others. Squealing would also rarely occur, if ever, on the downhill journey, when the wagons were loaded with coal. It was assumed that the higher axle loads damped out the squeal, or changed the wheel/rail interaction such that squeal could not occur. Another factor in the puzzle was that when a service train of only 6 wagons (which were rarely used) came up the track, the squeal levels were significantly higher than had been measured previously, and were at painful levels at locations adjacent to the track (within 20m).

One of the team members from the rail operations team then had an idea that the noise could be related to the bogie suspension system used in the coal wagons. He arranged for a train of flat cars with a different suspension arrangement to travel along the line while noise measurements were being taken. Four passes were made at one of the tightest curves and no squeal occurred, in either direction. Although there was a difference in the mass of the wagons, it was thought that the different suspension arrangement could be a key factor in the generation of the wheel squeal.

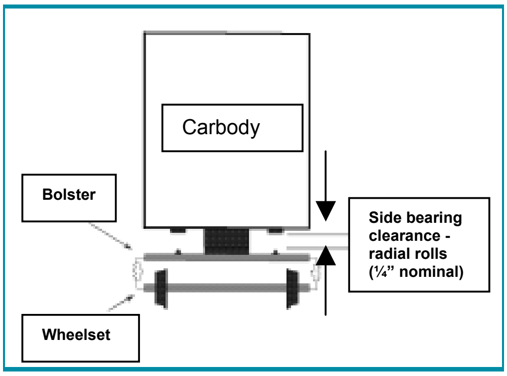

Figure 5: Schematic of Rail Wagon suspension [3]

The general suspension arrangement for a rail wagon is shown in Figure 5. The main body of the wagon is connected to the bogie by a king-pin (large cylinder) fitting into a recess (centreplate) in the bolster.

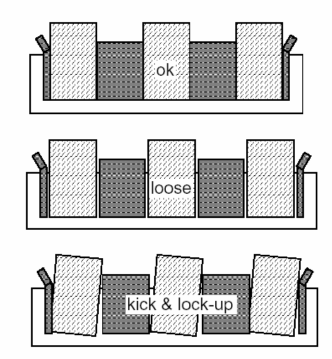

Figure 6: Stucki Constant Contact sidebearer arrangement and effects of sticking [4]

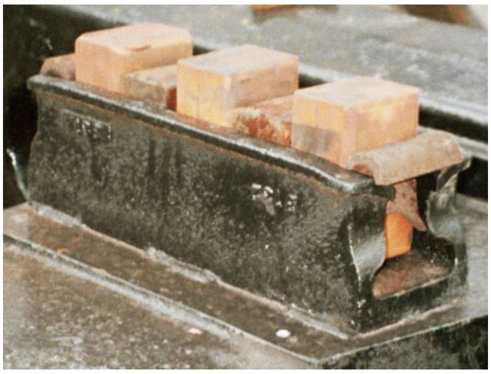

Figure 7: Stucki blocks in position

The coal wagons were fitted with Stucki type constant contact side bearers, shown in Figures 6 and 7. These are a group of three polymer blocks separated by steel blocks, which are located on either side of the king-pin and are designed to stop the wagons swaying from side to side. They were originally intended for use on long-distance straight runs at speeds of 60 to 80 km/h, where a build-up of swaying could cause instability.

The rail wagons had originally been delivered (in the 1950's) with a different suspension system, known as radial rollers. These were two steel rolls within a box which would roll on a contact plate on the bottom of the wagon, shown in Figure 8.

Figure 8: Radial Rolls in retaining box

As the wagon travels around a curve, the rolls act like a roller bearing. These were the style of suspension in the flat cars which had been trialled on the track without the wheal squealing occurring. This flat-car trial, though limited, was enough of an incentive to try the different suspension on some coal cars.

Since the boxes holding the CCSB blocks were the same as those into which the radial rolls fitted, a decision was made to fit a half-rake (8 wagons) with radial rolls and compare their noise emission. This while relatively simple, still required sourcing of replacement rolls and a crane to lift the wagons in the workshop and replace the blocks with the rolls and took a few weeks. Trials with the "new" rolls were successful, in that no wheel-squeals occurred over several weeks of operations, and operations with this arrangement were reviewed as not reducing safety. Given that there were no long straight runs and the speed limit was between to 20 and 40 km/h in the 11 km of track, it was decided to fit the whole fleet with the radial rolls after the trial.

Why were the CCSB Blocks Noisy? The reason for the wheel-squeal occurring with the CCSB block suspension was determined by the BHP Rail Research Institute team members [4]. As shown in the lower section of Figure 6, the blocks were becoming locked up and sticking. This meant that the bogies on affected wagons were not steering correctly. Bogies need to turn beneath cars when entering and exiting curves and at any time the track geometry requires bogies to steer correct tracking. The rotational resistance at the centreplate in combination with that created by the CCSB elements has the ability to increase/decrease flanging forces. The effect depends on their direction that differs for curve entry/exit and leading/trailing bogies.

A high rotational resistance promotes bogie crabbing at curve exit with flanging extending into tangent (straight) track. Essentially the bogies were not steering correctly, moving slightly off-centre along the track. Inspection of the bogies removed from wagons showed some elements were loose and consequently kicked/rotated leading to two wear surfaces. This can lead to lock-up and increased rotational resistance. In shallow curves with small bogie rotations the unit is likely to recover position when entering tangent track. However, in sharper curves the elements are more likely to kick and stick in the opposite direction, and resist a realignment of the bogie. As well as changing the blocks to standard radial rolls, lubrication of the centreplate was also recommended to control the rotational resistance.

This explanation would also account for the higher incidence after a break of operations. Some of the blocks would seize-up after a prolonged period of non-use and the longer the break the higher the radial resistance, as evidenced by the service rake with the very high wheel-squeal noise levels

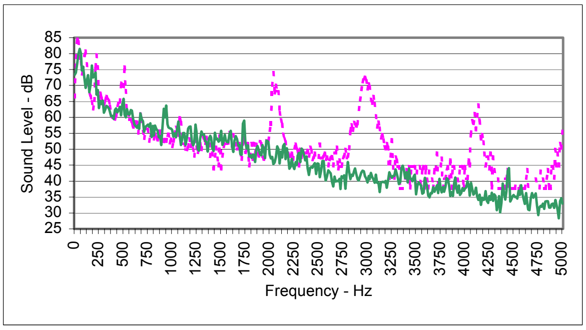

Figure 9: Comparison of Before & After Spectra
Pink (dotted) curve 9/2/2001; Green curve 8/5/2001

Figure 9 shows a comparison of spectra for similar train movements before and after treatment with the radial rolls. The peaks in the spectrum in the "before" measurement, which were up to 25 dB above adjacent spectral levels, were not seen in the after measurements.

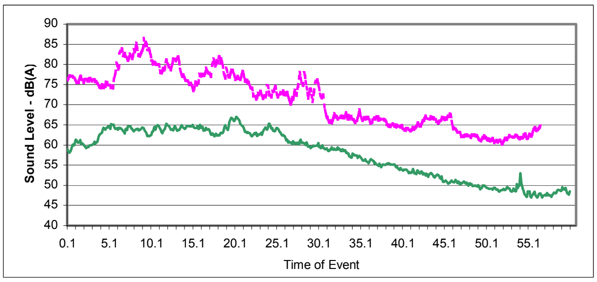

Figure 10: Time history comparison of before & after

Figure 10 shows the comparison of the total sound levels as a time history over the passage of a train. The top curve is for the train before treatment, the lower curve shows the after treatment.

Residents noted the difference and advised the team that the trains sounded like a normal railway again. They then asked about programs for reduction of other noise – locomotive noise, dynamic brakes and shuddering brakes. These were attended to over some years – the additional time taken because the line was taken out of service while the Dendrobium project was developed.

Locomotive noise at night was reduced by reducing operating speeds from 40 to 20 km/h, without any effect on productivity. Dynamic brake operation noise was managed by training drivers in better operational use. Brake shudder was initially looked at by fitting a spacer into the brake bar, but this was ineffective. Alternative brake block compounds were trialled and found to reduce the incidence of brake shudder. Track realignment and repair was included with the new development, to provide optimum rail conditions for the operation.

Application to Other Operations

Wheel-squeal from rail freight and transit operations is a common occurrence on many rail lines with tight curves. Personal experience in Sydney indicates that flange rubbing noise is (subjectively) common on even almost straight track on urban track, especially the city sections. Yet it is not every train or every carriage which exhibits the emission, and the level of emission and frequency of occurrence varies. This presents a potential comparison between the case study and these other similar occurrences.

The experience of the case study was that the noise emission arose from bogies/wagon suspension or steering systems which are not tracking correctly. Whilst there are many different types of wagon suspension systems in rail operations in Australia, it is possible that a similar maintenance-type of problem (rather than CCSB block sticking) is the cause of wheel-squeal in many other problem locations.

Rail-wagon noise cameras have been developed to identify specific rail wagons which are emitting wheel squeal, or have flat wheels or other high noise emission. These have been implemented in the Adelaide Hills in South Australia, in response to public complaints about rail noise. These have the objective of identifying noisy wagons so that they can be taken out of service and repaired or properly maintained. Identification of noisy wagons should include a review of the causes of their noisiness, to allow some understanding of the main causes of high noise emission. Improved maintenance and attention to those issues which are related to high noise emission, will hopefully, eventually lead to reduced occurrence of wheel squeal and thereby, reduced noise emission from the rail fleet.

In Europe, the STAIRRS Project [6] has considered the contributions to railway noise emissions from various mechanisms on a train. The project separated out vehicle and track contributions to total noise. The study found that in nearly all cases, a change in wheel surface quality caused the major change to pass-by noise. The roughness of the wheel and rail surfaces is the main contributor to an increase in noise level – increases of 10 to 15 dB caused by roughness were found. Prevention and removal of roughness on wheels (and rails) are closely linked to whether a vehicle conforms to noise emission criteria or not. The report noted:

Wheel surface condition was found to be influenced by wheel steel quality, the axle load, the adhesion coefficient, the surface treatment after reprofiling, and braking principle (dynamic brake or disc brake or block *brake). This means that the surface condition is dependent on the vehicle design and the operating conditions* (and presumably, the maintenance regime). *It should therefore be seriously considered whether periodic checks – like used for road traffic vehicles – are reasonable and sufficient to ensure conformity* [6].

Such findings are considered to be related to the findings of this case study – it is the maintenance condition of the rail vehicle (wheel roughness, brake system set-up and bogie suspension-tracking operation), which determines whether the noise emission will be of concern and cause high noise levels.

Conclusions

The major causes of wheel-squeal from railway freight operations have been identified as flange noise, longitudinal stick-slip and lateral stick-slip.

The frequency and sound level of lateral stick-slip wheel-squeal, along with its frequency of occurrence, is considered to make it the major mechanism of wheel-squeal noise of concern for environmental noise.

In the case study of a rail freight operation on a relatively short and curved track, lateral stick-slip was also the major source of wheel squeal noise emission, and was of concern to adjoining residents. Identification of the source mechanism showed it to be the sticking of the bogie, which provided rotational resistance in and out of curves. Modification of the bogie/wagon suspension system returned the rotational resistance to a minimal level, in-line with rail safety requirements. This resulted in the wheel-squeal from this source being virtually eliminated on this line.

Further reductions of noise emission were achieved through administrative changes of speed at night-time and dynamic brake operation. Material changes of changing brake-block compounds reduced the occurrence of brake shudder.

Wheel-squeal on other rail operating systems may also be related to maintenance issues. Identification of specific high-noise emitting rail cars through such technology as the noise camera, will provide an opportunity to identify the major mechanisms for wheel-squeal from maintenance or engineering problems.

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