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Curve Squeal: Causes, Treatments and Results

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ABSTRACT

Curve squeal is a major impact from rail operations on tight curves through residential areas. TfNSW has embarked on an intensive study into curve squeal and this paper presents an overview of that study. We have taken a holistic approach by considering each of the key contributors to wheel squeal: rolling stock, the wheel/rail interface, and the trackform. This paper will report on the results of trials, measurements and research into each of these areas, including (1) measurement and analysis methods for identifying/classifying curve squeal. This includes how squeal is identified from wayside noise measurements, a means of determining which wheel is squealing and which wheel/rail contact area is involved. (2) Which rolling stock is causing squeal and why. This includes a discussion of wagon steering behaviour based on measurements from wayside systems, the difference in performance between wagon classes and designs, and what this means for squeal noise generation. (3) Management of the wheel/rail interface for mitigating curve squeal. This includes a discussion of the importance of rail profile and friction management and provides results from on-track testing.

Keywords: Wheel squeal, curve noise, railway noise I-INCE Classification of Subjects Number(s): 13.4.1, 52.4

1. INTRODUCTION

Curve squeal is the very loud, tonal noise emitted by the wheels of some rail vehicles negotiating tight radius curves. It is one of the most significant environmental impacts from rail operations in populated areas and potentially impacts the railway's social license to operate.

Much has been written on the theory and physics behind curve squeal (see e.g. (1) which provides an excellent summary). This paper however, approaches the mitigation of curve squeal from a practitioner's perspective, that is, how to identify and treat squeal in the field. It discusses Transport for New South Wales's (TfNSW) practical experience with squeal on the RailCorp network around Sydney and identifies straight-forward methods that can be applied both quickly and with little expense by other practitioners.

The work described in this paper is part of TfNSW's Strategic Noise Action Program which provides a systematic approach to the management of rail freight noise in NSW.

2. WHEEL SQUEAL MEASUREMENT AND ANALYSIS

2.1 What is Wheel Squeal?

We make the distinction in this work between "squeal" and "flanging". By our definition, "squeal" is dominated by a single frequency, generally above 1.5kHz, which is typically more than 20dB above the rolling noise level. "Flanging" is the multi-modal rubbing noise generated by contact between the flange of the wheel and the gauge face of the rail. It is often well above the rolling noise level too, but in our experience is not nearly as loud as squeal and hence is less annoying for residents near rail lines. While all noise is a concern, our approach has been to tackle the greatest sources of impact first, hence our focus has been on mitigating squeal.

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2.2 Which Wheel is Squealing?

Squeal is often described as a random phenomenon. It is generally not possible to predict whether or not a particular wheel will squeal in any given train pass due to the interplay of many variables. Great insight has been provided by statistical analyses however, and the core of these analyses has been our ability to identify which wheel is squealing in any given train pass and to match this to other physical properties that we can measure independently (more on this later). Our approach to identifying which wheel is squealing is simple but effective; a) measure the noise very close to the track so that the noise from each individual wheel can be discriminated – 2.5m has provided a good compromise between proximity and remaining clear of the structure gauge, b) identify squeal from the measured noise by its unique frequency content (2), and c) match the noise records to individual wheels by simultaneously measuring the voltage trace from a wheel sensor installed in line with the microphone. This measurement and analysis can be easily automated and has been implemented using off-the-shelf and relatively inexpensive components.

This basic approach can be further developed by the addition of an accelerometer mounted on the underside of each rail. By comparing the vibration levels from each squealing wheel, a difference of at least 10dB has proven a reliable differentiator, the rail on which squeal is occurring can be identified. This simple addition has highlighted stark differences between the squeal “mechanism” at different sites on the network, with the full spectrum from almost all squeal occurring on the LOW rail side to almost all squeal occurring on the HIGH rail side, being observed at different sites.

This measurement system is shown in Figure 1.

Figure 1 – Measurement system to identify which wheel is squealing – microphone (A), optical switch used as a wheel sensor (B) and rail mounted accelerometers (C)

A word of caution regarding the accelerometers. On electrified lines, it is important to isolate the accelerometers from the rails – standard accelerometer case isolation is typically not sufficient as break-down voltages of >1kV are often required. A disk of 3mm Perspex between the accelerometer and the rail will do the job. In addition, the selection of accelerometers must consider the extreme rail accelerations that can occur under squealing wheels. We have measured (briefly) accelerations in excess of 1500g at frequencies >10kHz which caused the demise of accelerometers. This can be mitigated through mechanical filtering (such as a thin rubber element between the accelerometer and the rail, or a magnet mount) or preferably by selecting accelerometers with an appropriate shock rating.

In summary then, it is possible to quickly establish a significant database identifying which particular wheels are squealing from a simple four channel data acquisition system, standard sensors such as a microphone, two accelerometers and a wheel sensor, and some clever but simple signal processing. The use of this data is discussed in more detail in subsequent sections.

3. The Causes of Wheel Squeal and Mitigation Measures

The TfNSW approach to squeal mitigation has been to consider the influence of each of the three main systems – the rolling stock, the trackform, and the wheel/rail interface that sits between them. Each of these systems is discussed below.

3.1 Management of the Wheel / Rail Interface

In 2012, RailCorp (the precursor to TfNSW) undertook an extensive study into the effectiveness of gauge face lubrication and top-of-rail-friction-modification for the purposes of noise mitigation. These trials involved in-service measurements of noise and vibration over more than six months at three locations around a 300m radius curve. Treatments were applied in between the first and second measurement location. The test and results are described in detail in (3), and summarized in Figure 2. The trial concluded that gauge face lubrication when applied to both rails delivered the greatest mitigation in squeal noise. The study further identified squeal noise being generated under four distinct wheel/rail interaction conditions – top of the HIGH rail and LOW rail, which were the traditionally accepted mechanisms for squeal as found in the literature, but also at the gauge corner of the HIGH rail and LOW rail, which was counter to accepted wisdom. Indeed, the majority of squeal at this curve occurred under gauge corner contact conditions on the HIGH rail, and hence was effectively mitigated by lubricating this section of the rail.

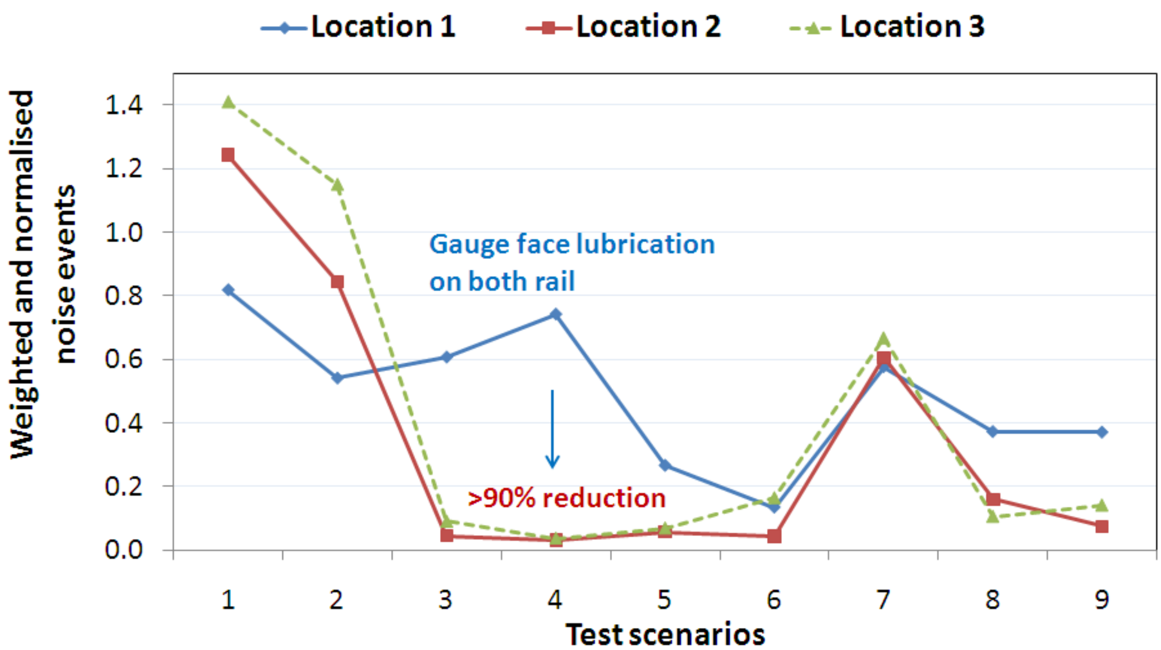

Figure 2 – Summary of the results of the 2012 friction management trial at Beecroft

Sroba et al (4) have established a strategy for effective friction management at the wheel/rail interface which has delivered savings in terms of maintenance, wear and fuel consumption. This strategy includes modern electronic lubricators positioned in tangent track with purpose designed rail greases to deliver friction levels at the gauge corner of less than 0.25. Local trials of similar approaches have replicated these results (5).

TfNSW has successfully implemented best practice rail lubrication at a number of sites which have experienced high levels of squeal. This involved a) installing modern, electronic lubricators, as shown in Figure 3, in place of the unreliable and ineffective mechanical lubricators, and b) using modern, purpose designed rail greases. This combination provided effective grease coverage of the gauge corner of the rail throughout each track section. The lubricators have operated relatively maintenance free with near 100% reliability, significantly reducing maintenance costs. Another advantage of the modern electronic lubricators is that servicing can be conducted outside the danger zone, eliminating the risk of being struck by trains that is associated with servicing mechanical lubricators. The incidence of severe wheel squeal was reduced at the lubricated sites, but severe squeal was not eliminated. Effective lubrication is seen as a key component of effective squeal mitigation (as well as a necessary component of proper maintenance of the rail asset), which works in parallel with measures targeting the rolling stock and track, which are discussed below.

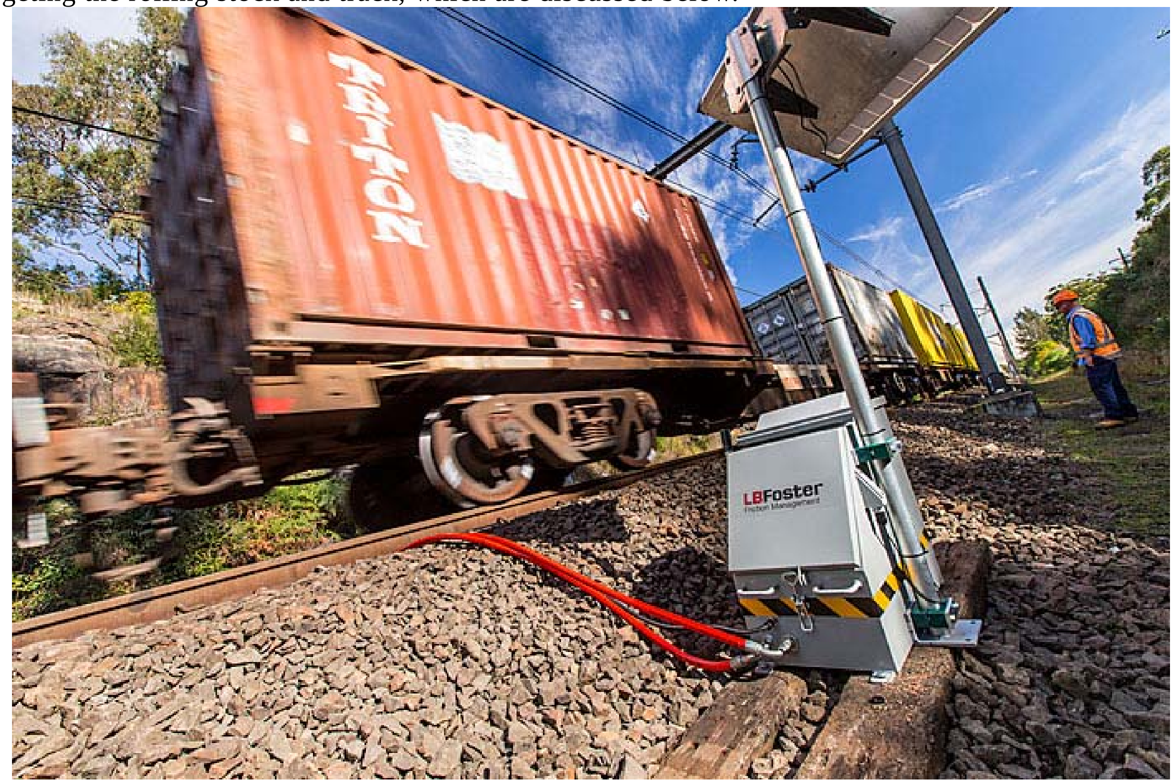

Figure 3 – TfNSW installed modern electronic lubricators at several curve noise sites

Another important aspect of wheel/rail interaction is profile, i.e. the cross sectional shape of the wheels and rails. The rail profile is managed through rail grinding whereby purpose designed machines with large numbers of grinding stones remove metal from the rail so as to impart a carefully designed cross sectional shape. When the wheel and rail profiles are properly managed, the contact is spread and hence the contact stresses are reduced. Under these conditions, rail grease can effectively lubricate the gauge corner contact area and thereby reduce wear and noise. Unfortunately, poorly executed rail grinding can lead to severe two point contact between the wheel and rail in tight curves which can increase contact stresses and undermine the effectiveness of the grease. This can lead to increases in curve noise, as shown in Figure 4, which shows the incidence of squeal before and after grinding at a curve in Sydney. The incidence of squeal has reduced over time as the rail has worn to a more conformal shape, but has still not returned to the pre-grinding levels nearly twelve months after the rail was ground.

3.2 Rolling Stock Curving Performance

It is frequently observed by residents near tight curves that only a small percentage of passing wagons cause squeal. In Sydney, severe squeal is associated with only around 5% of wagons… so what makes these wagons different from the majority which generally don’t squeal?

As the wheels on a bogie negotiate a tight curve, the leading wheelset typically presents an Angle-of-Attack (AoA) to the rail whereas the trailing wheelset aligns to the curve tangent with zero AoA. The AoA of a leading wheelset with good steering performance can be calculated from

$$AoA = \frac{wheelbase}{curve\_radius} \quad (1)$$

The AoA of each passing wheel is monitored on a 300m radius curve in Sydney using a purpose designed wayside measurement system (6). On this curve, a typical freight bogie with good steering presents an AoA of around 7mrad at the leading wheelset, but some wheelsets have been measured with AoA of more than 50mrad. Analysis of AoA data by TfNSW has shown that high AoA is a pre-requisite for squeal. TfNSW have also developed algorithms to process AoA data and determine the curving performance of passing bogies. Our analysis of this data has shown that the cause of squeal from freight wagons is typically associated with warping of three piece bogies due to an inability of the bogie bolster to rotate to negotiate the curve (7). This adverse curving behavior is typically associated with classes of wagons, rather than individual wagons within a class, and is therefore suspected to be associated with the design of these particular wagons and bogies. This is an important discovery in that it has allowed the focus to shift from the symptoms associated with squeal (high AoA) to the cause (poor rotation at the centre plate and high levels of bogie warp) and hence to identify possible solutions. Rotation can be improved by reducing the friction at the centre plate, either through lubrication or a wear liner (8). A more effective strategy is to eliminate warping of three piece bogies altogether through the use of cross bracing or steering arms (9), and many wagons operating on the NSW network already include these features. TfNSW are currently working with freight operators to evaluate mitigation strategies.

Wayside measurement systems for recording AoA can be expensive. A quick indication of bogie steering can be obtained however from inspection of the rails in a tight curve. On a wagon with good steering performance, the leading wheelsets on both the leading and trailing bogies will attack the HIGH rail. We have shown that, by contrast, a consequence of poor rotation and bogie warp is that both wheelsets on the leading bogie will attack the HIGH rail and both wheelsets on the trailing bogie will attack the LOW rail. Hence, if there is clear evidence of wear on the gauge corner/face of the LOW rail, such as that shown in Figure 5, then it is likely that some wagons using the track are experiencing poor rotation.

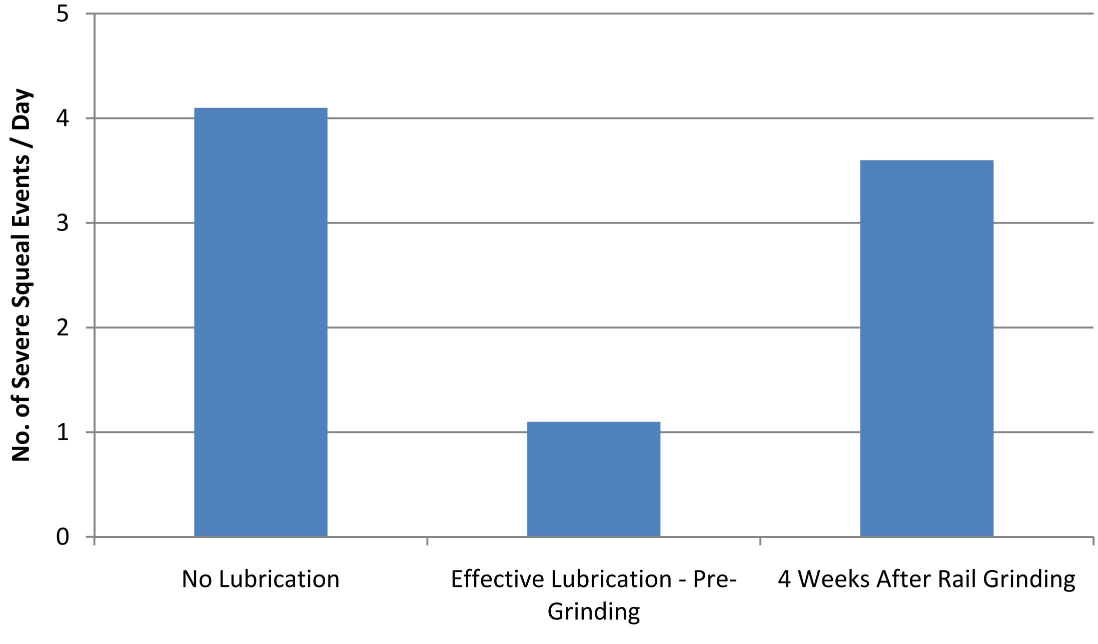

Figure 4 – Effect of poorly executed rail grinding on the incidence of squeal

3.3 Design of the Track Form

Squeal has been an issue at some locations on networks in Australia for many years. In recent times however, the issue appears to have expanded greatly, often in conjunction with upgrades to the track wherein timber sleepers are replaced with concrete sleepers (10). In 2012, RailCorp undertook a study to try to determine what was changing during such upgrades that led to squeal noise increasing. This study is described in (11), and it identified two main differences between the dynamic properties of timber and concrete sleeper tracks; 1) the dynamic gauge of timber sleeper tracks was an order of magnitude greater (approximately 3mm compared to 0.3mm), and 2) the track decay rate in the squeal frequency region was much higher on timber sleeper tracks, than on concrete sleeper tracks.

Figure 5 – The LOW rail on a tight curve showing a clear running band on the gauge corner. The gauge corner and face would be rusty in the absence of wheel contact.

Using these insights, TfNSW is implementing a follow-up study in which we aim to replicate these dynamic properties on a concrete sleeper track and to quantify their effect on squeal. It is planned to increase the dynamic gauge, i.e. the spread of the rails under passing wheels, by using soft, studded rubber rail pads that will allow the rails to both deflect and roll slightly. We propose to increase the track decay rate by installing rail dampers which are designed to target the squeal frequency region above 1.5kHz. This study is planned for late 2014.

4. A Classic Noise Control Approach

The various bodies of work described above can be understood in terms of a classic noise control approach, as summarized in Figure 6.

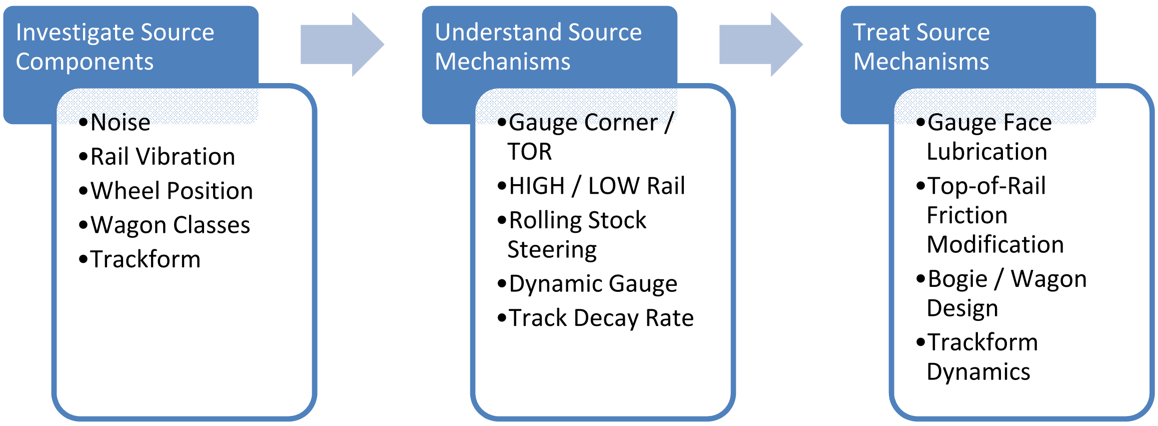

Figure 6 - Curve noise mitigation as a classic noise control problem

The first stage of this approach is to understand the noise source components, as described in Section 2, and to assess their impacts. This includes quantifying the squeal noise issue, separating wheel squeal from other noise sources, identifying which wheels are squealing and the contributions from the HIGH and LOW rail.

Based on this information, especially when a large data set is available to support statistical analyses and trending, an understanding of the source mechanisms may emerge. In our case, the data identified the rolling stock steering of particular wagon classes, and the HIGH rail gauge corner, as key components in the generation of squeal.

Finally, solutions can be targeted at the specific source mechanisms. This has included implementing effective lubrication and working with rail operators to improve rolling stock curving performance.

5. CONCLUSIONS

This paper has presented TfNSW's experience of working to mitigate wheel squeal on the NSW rail network. We have considered the three main systems that interact to cause squeal – the rolling stock, track form, and the interface between the two, and identified ways in which each contributes to squeal generation.

During the course of this work we have come to appreciate that wheel squeal is a symptom of the deterioration in some aspect of the proper maintenance or operation of the railway. Insufficient lubrication at the wheel/rail interface will generate wear as well as noise. Poor rail profiles can lead to high rail stresses that can cause defects to occur. Poorly steering rolling stock will increase wear, fuel consumption and emissions, as well as causing squeal.

Often, noise emissions can be seen as a separate issue to be resolved "out of the way" of running the railway. By recognizing the common interest of noise control engineers and managers of rail and rolling stock assets, however, a potential win-win opportunity is presented. By improving the efficiency of rail maintenance and the performance of rolling stock, not only can squeal noise be addressed, but the costs of maintaining and operating the railway can be reduced. To seize this opportunity however, requires that noise control engineers engage directly in the maintenance and operation of the railway, and that asset owners facilitate and encourage this engagement.

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