AN ACOUSTICIAN'S GUIDE TO RAILWAY TERMINOLOGY AND COMMON PITFALLS WITH ACOUSTIC TERMINOLOGY WHEN APPLIED TO RAIL

Dave Anderson

Acoustic Engineering Specialist, RailCorp (previously Rail Infrastructure Corporation), Sydney, Australia

Abstract

This paper provides an explanation of key railway terms that may not be familiar to acoustic engineers and also suggests some standardisation of acoustic terms used in rail noise and vibration projects. It highlights some aspects of railway noise and vibration that are challenging, either because of the constraints imposed by the rail environment or because of the complexity of the issues involved. The aim of the paper is to prompt debate on these issues rather than to provide definitive answers.

Introduction

The rail environment can be a confusing place for the uninitiated, both because of the unfamiliar terminology and because of the complexity of railway operational constraints, many of which are steeped in history.

Acoustic engineers are often criticised by clients and the community for speaking in jargon and using a multitude of units and indices. Whether intentionally or not, they often reinforce the perception that acoustics is a 'black science'.

It follows that when these two fields overlap, namely in the delivery of railway noise and vibration expertise, confusion is common and errors sometimes result.

This paper aims to:

- Prompt debate about these issues,
- provide explanations of some railway terminology familiar to the author, highlighting aspects that are significant for the acoustic engineer,
- suggest a basis for consistent communication of noise and vibration terminology in rail projects, and
- highlight some potential pitfalls by way of examples.

The paper also describes the complexities involved in some aspects of rail noise and vibration and highlights the risks of addressing these without a good understanding of the issues. This forms a cautionary note, both for consultants considering working in the field and for rail sector clients considering which consultant to engage.

Acoustic Terminology in Rail

This section addresses a number of noise and vibration terms that are used predominantly, if not exclusively, in relation to rail. In many cases there are several variants of each term and, in some cases, several meanings of a given term.

Groundborne Noise and Vibration

'Groundborne noise' is a term that has been used widely, particularly in Europe and North America, to describe noise that is caused by railways, transmitted as vibration through the ground and into structures, and radiated as low frequency 'rumble' noise. Other terms in common use are 'structureborne noise', 're-radiated noise', 'solidborne noise', 'secondary noise' and (in Australia) 'regenerated noise'. Each of these terms has advantages and disadvantages. Regenerated noise, for example, is the term commonly used to describe noise generated by turbulent flow in air-conditioning ducts and also has connotations of a link with regenerative braking. The term 're-radiated noise' is misleading because its manifestation in a building is the first time it has been radiated (not the second). 'Groundborne noise' is suggested as the preferred term because it is adopted in many overseas guidelines and in a draft International Standard [1]. 'Structureborne' is suggested when the transmission path involves propagation via a structure but not via the ground (such as in an air-rights building over a railway).

The obvious corollary to the above is the term ***'groundborne vibration'.*** Other terms in common use for this are 'tactile vibration', 'perceptible vibration' and 'tangible vibration'. Again, 'groundborne' is preferred as it is consistent with other guidelines and is more general (ie it may or may not be at a level that is perceptible).

Although not strictly related to terminology, it is also notable that consent conditions for several recent rail projects have adopted groundborne noise criteria defined in terms of $L_{Amax,F}$ (ie 'FAST' response). This ignores the fact that applicable criteria developed over the last 20 years or so pre-dated sound level meters giving 'FAST' response readings and were based on an eye-average of an analogue sound level reading, more equivalent to 'SLOW' response. This can make a difference of between 1 and 5 dB depending on the nature of the groundborne noise signal.

Some other terms that deserve mention in the context of groundborne noise and vibration are:

- ***'structure-radiated noise'***, being the noise radiated by a vibrating structure such as a railway bridge, and
- ***'airborne noise induced vibration'***, being the low frequency vibration sometimes found in lightweight structures and resulting from airborne rather than groundborne railway noise.

Airborne Noise

Again, there are a plethora of terms. Notable are:

- ***'roar'***, usually used to describe wheel/rail noise arising from rough or corrugated rail
- ***'stretching'*** and '***bunching'***, describing the noise that occurs when the couplings between wagons on a train (usually freight) undergo force reversals during acceleration and deceleration
- ***'booming'*** describing a low frequency noise generated by some types of bulk product wagons when empty and subject to impact forces.

Airborne noise generated by trains negotiating curves deserves particular attention. ***'Flanging'*** noise seems to be in common use in Australia, but for some reason not overseas where it is more commonly called 'flange squeal'. It is a distinctive screeching metal on metal scraping noise generated when a wheel flange makes contact with the gauge face of the rail (although some researchers suggest that it may also arise as a result of a wheel tread / rail surface interaction [2]).

'*Flanging noise*' is often intermittent on curves and is sometimes described as a buzzing, hissing or 'schring schring' sound. However, it may also be continuous over a length of curved track and may reach high sound levels, perhaps more akin to 'curve screech', as it is sometimes also termed. Lubrication is normally applied, either to the gauge face of the rail or to the flange of the wheel, to reduce wheel and rail wear resulting from flange contact. This generally dramatically reduces flanging noise.

'Wheel squeal' (sometimes called 'curve squeal') is also associated with curves, but differs from flanging in respect of the cause and (in most cases) the audible nature of the noise. It is a high-pitched tonal noise radiated by resonant excitation of wheels caused by 'stick-slip' motion of the wheel tread on the rail running surface of the rail [3].

The term 'curving noise' is gaining favour as a term covering all noise sources associated with a curving rail vehicle (including wheel squeal and flanging). In the meantime, confusion between flanging and wheel squeal noise arises frequently. This can lead to problems given that the causes and treatments for these effects are very different. Particular care is required when discussing complaints about curving noise as affected communities often use words such as 'screech' and 'squeal' interchangeably to describe what they hear. The author is also aware of several examples of specialist noise consultants failing to correctly differentiate between the two effects. There are also numerous examples of railway engineers misinterpreting published results, again because of confusing terminology used for the two effects.

The potential for confusion is compounded by three facts:

- firstly, the fact that railway engineers often use the term 'flange squeal' to differentiate it from 'wheel squeal';
- secondly that the term 'flanging noise' is not widely adopted overseas;
- and finally, flanging noise is often remedied by operation of 'track lubricators' while squeal noise may be treated by 'friction modifiers'. The former involves the application of a low friction product (grease) to the gauge face of the rail while the latter involves a medium friction product on the running surface of the rail. The two systems are not interchangeable in either acoustic or railway terms. Despite these significant differences, rail engineers often use the term 'lubricator' to refer to the track-side devices used for both treatments.

In one recent study it appears that the overall confusion resulted in the specialist consultant and the railway field maintenance staff talking at cross purposes about flanging (versus squeal) and lubrication (versus friction modification) for the duration of the project. Needless to say, the results were somewhat inconclusive!

Railway Terminology

The glossary attached at the rear of this paper lists some of the common railway terms encountered by an acoustic engineer. It does not provide a comprehensive list, but forms a suitable beginning for discussion purposes.

A number of terms are of particular relevance to noise and vibration and warrant separate discussion, as follows.

Wheel/rail interaction is a specialist field in itself. Wheel treads have a conical or *tapered* profile so that, on *tangent track*, forces arise to promote stable running. This profile also assists on large curves allowing different rolling radii to compensate for a fixed axle. The exact tread profile is carefully chosen based on parameters such a rail profile to prevent the wheels from hunting (oscillating from one gauge face to the other), to ensure optimum traction and to manage wear at the wheel / rail interface. The taper (also referred to as '*conicity'*) will vary as the wheel wears, with consequent changes to wheel rail interaction on both tangent and curved track.

Most heavy rail rolling stock comprises solid axles arranged in pairs (on bogies). On curves, the leading axle tends to track towards the tangent to the curve and the outer wheels tend to climb towards the gauge face of the high rail to equalize the travel distance around the curve. On sharper curves, this can lead to:

- flange contact at the gauge face of the high rail (and the potential for flanging noise)

- lateral creep (or slip) of the wheel tread across the running surface of the rail (and the potential for wheel squeal when this occurs as 'stick-slip' motion).

'Angle of attack' describes the angle (usually quoted in milli-radians) of the wheel to the tangent to the curve. These effects are also influenced by rail profile. Rail profiles vary according to the requirements of a particular rail system (and also with wear), but generally amount to a compromise between competing requirements of various rolling stock and consideration of energy efficiency, steering and noise control. Where rolling stock on a network does not have a common wheel profile, wearing of the rail profile to a non-ideal shape somewhere between the wheel profiles can occur. This is not ideal from a maintenance or noise and vibration point of view.

Wheel and rail defects often generate elevated levels of wheel rail noise. The most common forms of wheel defect are *skid flats* (also called '*wheel flats'*) and *spalling*. Corresponding rail defects of relevance to noise are:

- *wheel burns* (indentations and roughness in the running surface caused by wheel spin under high traction)

- *corrugation*, including '*short pitch'* corrugation (postulated by some to be due to stick-slip vibration at the wheel/rail interface) and '*long pitch'* corrugation (postulated to be due to plastic flow of the rail surface under dynamic loading from train/track resonance effects). It should be noted that the causes of corrugation are the subject of ongoing research and remain rather unclear.

- *Dipped joints or welds*, whereby plated or welded joints progressively wear into an uneven running surface, significantly increasing noise and vibration from a rail joint. In the case of a welded joint, resulting noise can be similar in level and character to a conventional rail joint.

Special track features (points, cross-overs and turn-outs) generally increased noise as a result of the need for a gap in the rail to allow wheels to pass from one track to another. Worn crossing components can result in substantial increases in way-side noise.

Rail grinding is a technique increasingly used to achieve longer rail life on heavy rail systems. As the name suggests, it involves grinding some material from the head of the rail to remove defects and/or reinstate the preferred profile. Preventative grinding generally involves the removal of a small amount of material so as to remove small cracks and imperfections before they degenerate into larger defects. Corrective grinding involves the removal of larger quantities of material so as to eradicate significant defects such as head checking, corrugation or wheel burns. Grinding generally results in some improvements in wheel/rail noise. However, this is not always the case and care must be taken if noise is a significant factor. Residual grinding marks can actually lead to a prolonged increase in noise, sometimes of a tonal character. Also, some components of wheel/rail noise can only be improved if the grinding is designed to tackle the appropriate wavelengths of surface condition. In Europe grinding is now routinely applied as a noise management measure and is referred to as '*acoustic grinding'* or '*rail polishing'*.

Rolling Stock Terms

There are, of course, many aspects of rolling stock design and operation of relevance to noise and vibration. *Unsprung mass*, the mass of the axles and other components of the bogie (such as gearbox etc) below the primary suspension, is a key parameter in rail vibration. A higher unsprung mass generally leads to higher vibration levels, but also facilitates a higher track deflection (and therefore, at certain frequencies, higher insertion loss) from a given resilient track support system.

Tread brakes cause wheel roughness (and hence increased noise relative to smooth wheels) due to heating and distortion of the wheel tread. Conventional cast iron tread brake blocks can be upgraded to composite brake blocks for some improvement in tread condition. A major UIC program is underway in Europe to retrofit 'K-blocks' to existing freight wagons for noise reduction [4].

A 'multiple unit' is a series of passenger cars or freight wagons permanently coupled together. A Diesel Multiple Unit (DMU), for example, comprises two or more passenger cars amongst which is one or more 'motor' cars equipped with diesel traction. Similarly EMU for Electric Multiple Unit.

In the context of freight, a 'multi-pack' may comprise two or more permanently coupled wagons, a 'five-pack' being five wagons. Often these units 'share' bogies, such that a five-pack may have six bogies, rather than ten.

Locomotive throttle settings are referred to in terms of the '*notch setting'*; typically notch 1 is the lowest power setting and notch 8 is the highest. Dynamic braking is also a source of locomotive noise, being the use of the motor and generator to assist braking by generating electrical power.

Complexity and Constraints

Working in the operating rail environment brings with it many complexities and constraints that are not found on traditional construction or operational sites. The first striking feature of construction and maintenance in the operating rail environment is the difficulty of site access (called ‘track possession’). Construction projects that would normally take 3 months may instead take 3 years or more, with all site activity compressed into a 7 day ‘closedown’ each Christmas and 3 or 4 weekend ‘possessions’ each year.

It follows that, during these brief periods of site access, 24-hour working is common and there is unlikely to be the flexibility to allow programming of ‘noisy works’ during the daytime rather than the night. Often the only practical means of mitigation are:

- Selection of the quietest available methods, plant and equipment for the task;
- Informing the community about the nature of the works and the expected impacts.

The use of *noise barriers* in the rail environment warrants specific mention. Most members of the community immediately think of noise barriers when the subject of noise arises. Indeed, noise barriers can be used successfully to mitigate operational railway noise, particularly on electrified passenger lines (where wheel / rail noise dominates). Barriers are also a visible representation to the community that noise levels have been reduced (compared to ‘invisible’ treatments such as minimising wheel and rail roughness). However, there are numerous detriments of noise barriers in the rail environment, as described below.

Firstly, there are a number of issues that communities often complain about, such as:

- Visual impact
- Loss of views
- Loss of breezes
- Over-shadowing
- Reflected heat
- Graffiti
- Reflection of noise (usually other than rail noise)
- Security issues

Barriers also have potential impacts on rail operation and maintenance, such as:

- Disruption to signal sighting
- Disruption to train sighting (by track inspection staff on patrol)
- Reflected heat (which may affect track stability)
- Maintenance access (usually alongside the track)
- Vegetation control (which may now be split between track side and community side of a barrier)

There are also acoustic design issues to be resolved where barrier insertion losses are predicted to be high (as can be the case with a barrier located close to the wheel/rail noise source).

In addition to all of the above, barriers are fundamentally difficult to construct in a rail environment and are a cost-inefficient way to achieve noise control [5].

Finally, ***groundborne noise and vibration*** is perhaps the most complex aspect of rail noise and vibration. Even professionals with decades of experience in the field have observed unexpected effects and large uncertainties in prediction [6, 7]. To attempt to tackle the issues as if they were simply an extension of airborne noise generation, propagation and transmission is doomed to failure, and yet is common amongst acoustic consultants starting out in the field. Pitfalls of particular note are:

- Track dynamics and ‘track isolation’, which can result in very different outcomes from systems that appear, on the face of it, to be similar [8].
- Ground response (rail operations on soft soils may generate substantial levels of low frequency vibration) [7].
- Ground propagation, which can vary substantially horizontally and vertically and can exhibit significant variations at interfaces between soil layers or buried structures [6].
- Building response, which may include significant amplification of structural components as well as (at low frequencies) amplification vertically from lower to upper floors [9].
- Low frequency noise perception, which is not well described by the A-weighting filter [10].

Concluding Remarks

This paper has attempted to highlight some of the pitfalls of terminology and technical complexity in the field of railway noise and vibration, and to provide some clarity and suggestions aimed at promoting debate and agreement on a more consistent basis for our work in the field.

The author is grateful for the time and advice given by many colleagues in discussions about this paper, notably Andrew Wearne, Kym Burgemeister and Richard Greer.

References

[1] ISO/DIS 14837-1.2 Mechanical vibration – ground-borne noise and vibration arising from rail systems – Part 1: General guidance.

[2] Nelson, JT “Wheel/Rail Noise Control Manual”, Transport Cooperative Research Program report 23, 1997

[3] Kerr M, Kalousek J, Elliot G, Mau F and Anderson D, "Squeal Appeal: Addressing Noise at the Wheel / Rail Interface," proceedings of the Conference on Railway Engineering, Rockhampton, 1998.

[4] Hubner P, "The Action Programme of UIC, CER and UIP: Abatement of Railway Noise Emissions on Goods Trains", Journal of Sound and Vibration (2000) 231(3), 511-517.
[5] Oertli J, "The STAIRRS project, work package 1: a cost-effectiveness analysis of railway noise reduction on a European scale", Journal of Sound and Vibration 267 (2003), 431 – 437.
[6] Nelson JT "Comparison of Measured and Theoretical Responses of Layered Soils for Rail Transportation Systems", proceedings of 8th International Workshop on Railway Noise, September 2004.
[7] Saurenman H, and Phillips J, "In-service Tests of the Effectiveness of Vibration Control Measures on the BART Rail Transit System", proceedings of 8th International Workshop on Railway Noise, September 2004.
[8] Burgemeister K, "Using Insertion Gains To Evaluate Railway Vibration Isolation Systems", Proceedings of the Annual Australian Acoustical Society meeting, November 2004 (preprint).
[9] Anderson D, "Engineering Prediction of Railway Vibration Transmission in Buildings", Proceedings of Euronoise 1992.
[10] Harris, Miller, Miller, Hanson, "Transit Noise and Vibration Impact Assessment", 1995, US Federal Transit Agency.

Glossary

Toe load, The downward force exerted by a single resilient clip on the foot of the rail
Clip, A device to clamp the rail in place in the *fastening assembly* to facilitate vertical, longitudinal and lateral restraint.
Resilient rail clip, as above, but for use with rail pads to reduce impact forces and wear, and to better control longitudinal forces.
Rail fastening, the system used to hold the rail in place while allowing longitudinal movement for expansion and contraction of the rail.
Rail baseplate, provides bearing support for the rail and load distribution from the rail into the sleeper or support structures. Base plates may also incorporate ***shoulders*** that provide lateral restraint to the rail and anchorage and positioning for the ***resilient clips***.
Spike (or dog-spike), a steel fastener used on timber sleepers to hold the rail foot.
Sleeper, 'tie' in US, timber, concrete or steel member used to fix rails at set gauge.
Block, a half sleeper used in some slab track systems.
Ballast, crushed rock used to form the track bed in conventional 'ballasted' track. Ballast depth, the nominal depth of ballast below bottom of sleeper, may affect the dynamic track response (as may ballast grading and any ballast attrition or contamination).
Slab track, track constructed using a concrete slab as the track bed instead of ballast (also 'ballast-less track').
Jointed rail, rail in discrete lengths, joined by fish-plates.
Continuously welded rail, rail with joints welded rather than plated.
Glued insulated joint, a joint containing an insulator, used to separate adjacent track circuits (for signalling purposes).
Bearer, in Australia, a type of sleeper used under points and crossing track structures. Bearers are generally larger in dimension than standard sleepers to provide support for both tracks as well as the increased loading experienced under such track structures. In the UK, longitudinal 'beams' under the rail (with ties) to provide consistent rail support in areas where the foundation is other wise inconsistent (e.g. transitions, bridges etc) .

Track support
Attenuation, the percentage reduction in peak strain on a sleeper (relative to a stiff reference pad) under impact test load (**not** to be confused with vibration/acoustic attenuation)
'Soft' rail pad, less than 80MN/m.
Resilient rail fastening, A fastening that provides a degree of elasticity between the sleeper/slab/plinth and rail with the aim of avoiding the loosening of the fastening due to vibration, as well as enhancing the ability of the fastening system to resist longitudinal creep forces and buckling forces associated with continuously welded rail (CWR).
Fastener passage frequency, the frequency at which individual axles pass over track fasteners (leading to a corresponding peak in the frequency spectrum of groundborne vibration)
Continuous rail support, self-explanatory. Examples include continuous rail pads and embedded rail.
Resilient baseplate, a rail baseplate assembly comprising resilient components to achieve a lower dynamic stiffness than standard products.
Resilient rail chair, an assembly that achieves resilient rail support (either partly or wholly) via the web of the rail.
Under-sleeper pad (or sleeper soffit pad), a resilient component inserted between the sleeper and the ballast.
Ballast mat (or under ballast mat), a resilient mat inserted between the ballast and the track slab or formation.
Floated slab track (FST), (sometimes Floated Track Slab, FTS), a track slab supported on resilient bearings.

Track Maintenance
Tamping, the process of compacting loose ballast
Dynamic stabilisation, the process of dynamic excitation of track to accelerate settling in (eg with freshly laid ballast)
Ballast cleaning, the process of excavation of ballast, screening to remove debris and small particles, then replacement and replenishment with fresh ballast