Proceedings of the Institute of Acoustics

WHEEL-RAIL NOISE: CAUSES, EFFECTS AND REMEDIES

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1.0 INTRODUCTION

The most important noise source from fast trains is that from the wheels rolling over the rails, although other noises such as the diesel locomotive noise of slowly moving trains, may be significant occasionally.

Wheel-rail noise always arises due to the motion of a train over its rails. With lines which are laid in the open, this is the familiar "train noise" which is easily recogniseable and which is now the source of anxiety among potentially affected people in Kent. However, this same noise is in part responsible for the background noise which is heard by passengers within the train.

For traffic which is confined to tunnel, the noise experienced by the passengers in the train will be due almost completely to the wheel-rail source. The external noise field within the tunnel is incident upon the outside of the vehicle structure, and to a greater or lesser extent passes through it to generate the internal noise field.

The critical features which contribute to the noise heard outside as the train passes, or to the acoustic environment of those within the train are therefore:-

- the amount of noise generated by the wheels rolling over the rails (assuming that the traction and auxilliary noise sources are negligible.)

- the transmission loss which occurs between this source and the people (wayside dwellers or passengers) who will hear it.

When trains are in tunnel, the effect of wheel-rail noise becomes particularly far-reaching. The higher the noise level inside the tunnel, the greater the transmission loss which needs to be built into the vehicle structure in order to achieve a given degree of acoustic comfort. To provide a higher degree of acoustic isolation for passengers requires a heavier vehicle, leading to greater traction power requirements and greater braking effort to achieve a desired train performance. Alternatively, if the maximum vehicle weight or axle load is the governing factor, a lower payload would have to be accepted.

The acoustic isolation needs are more difficult for the tunnel-bound vehicle than for one which runs mostly in the open. On open line, the surface noise level around the vehicle decreases rapidly with height above rail level. For vehicles which run in tunnel, the input in much more nearly uniform over the whole of the outer surface of the vehicle. The noise input to the structure through the upper sidewalls and the roof assumes great significance compared with open line.

There is thus a strong incentive in both cases to reduce to a minimum the wheel-rail noise of the train.

2.0 THE CAUSE OF WHEEL-RAIL NOISE

Figure 1 illustrates the skeleton of the well-known Remington model (ref. 1) for wheel-rail noise generation. It assumes (and there is strong evidence that the assumption is valid) that the fundamental cause of wheel-rail noise is some function of the combined roughness of wheel and rail. Passage of the wheel over the rail at speed causes a force input equally into the wheel and rail which in its turn causes the wheel and rail to vibrate. The vibrations generated by the dynamic excitation result in radiated noise respectively from wheel and rail which combine to produce the familiar phenomenon of wheel-rail noise.

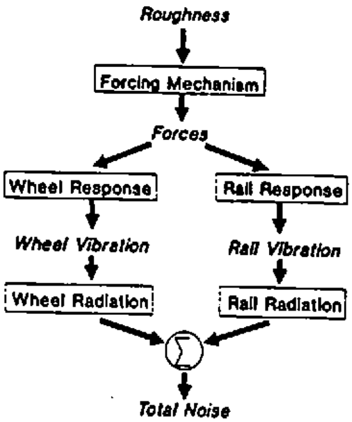

FIG.1 Block diagram of Remington model for wheel-rail noise

One of the features of the model is the incorporation of a "contact patch" filter in the forcing process. This is the effect exerted on the generation mechanism by the finite size of the contact between wheel and rail - there is an area of intimate contact about 10 mm long. Roughness components shorter in "wavelength" than this patch are subject to strong mechanical filtering, and do not contribute significantly to the wheel vibration or radiated noise spectra. The effect for a 200km/h train is that there is little noise above 4 kHz. The way in which the level and spectrum of wheel-rail noise is influenced by roughness of the constituent components is sketched in figure 2. This limited range of frequencies over which wheel-rail noise can be excited may turn out to have important consequences in the further limitation of wheel-rail noise.

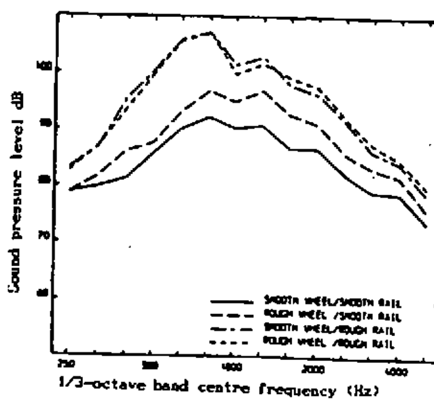

FIG.2 Noise spectra at 2m from near rail: various roughnesses; 120 km/h

The effect of train speed on the level and spectrum of wheel-rail noise is shewn in figure 3. Both of these figures 2 & 3 are based on measurements made of wayside noise in the open: the effect of tunnel running would be simply to raise the levels due to either parameter as a consequence of the reverberation in the tunnel.

Research at British Rail into the way in which the normal rolling noise of trains is generated shews that at present normal

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traffic speeds the wayside noise (and hence also the enhanced noise within a tunnel) is radiated about equally from wheel and from rail, although the balance varies slowly with speed. This is an unfortunate conclusion, because it implies that both members of the system need to be treated if a significant reduction in radiated noise is to be achieved beyond the current best practice. Complete removal of either wheel noise or rail noise alone would reduce the wayside noise by only some 3 dB, a barely perceptible amount.

This localisation of the principal noise source to the immediate vicinity of the wheel-rail system is of course useful in calculation of the propagation of train noise.

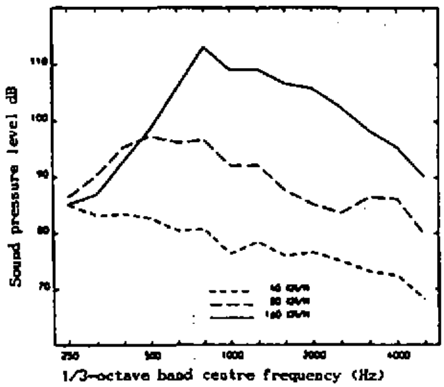

FIG.3 Noise spectra at 2m from near rail: various speeds for rough wheel/rough rail

3.0 CONTROL OF WHEEL-RAIL NOISE

3.1 Effect of train speed

It is clear that there is apparently infinite scope to reduce the generated wheel-rail noise by reduction of train speed, subject, of course, to the "noise floor" imposed by other sources. Unfortunately, there is not a strong function between wheel-rail noise and train speed, being only some 9 dBA change for a factor of two in train speed. The rate of change of the equivalent continuous sound level, $L_{Aeq,24hr}$, the index commonly used to characterise wayside reaction to railway noise is even slower, some 6 dBA per factor of two.

The use of train speed variation to control train noise is therefore not a practical option. Given that the operating speed must be a largely commercial decision, the acoustic design will have to cope with the consequences of the operating speed selected, whether the track is in the open or in a tunnel.

3.2 Effect of Wheel Roughness

Increased wheel roughness will always lead to a higher noise level: the wheels of the train should therefore be produced and maintained to be as smooth as possible.

On the basis of best current practice, this means the use of disc brakes with effective wheel-slide protection. The traditional and time-honoured form of railway vehicle braking, developed over many decades, has been use of cast iron block tread brakes acting on the running surface of the wheels. Unfortunately, this form of brake system leads to the formation of wheel corrugations during braking which do not subsequently "run out" in use. These corrugations are not as severe as rail corrugation (see below) can become, and hence do not lead to the same extreme enhancements of generated noise. Even so, they do increase the noise level by some 10 dBA over the levels which can be acheived by disc-braked stock on smooth track.

Disc brakes, acting on wheel-cheek mounted or axle-mounted brake discs, do not roughen the running surfaces of the wheels. When allied to effective wheel-slide protection which prevents the consequential formation of wheel-flats, the lowest noise levels currently achievable are obtained.

3.3 Effect of Rail Roughness

The most common and potentially widespread roughening of the rails is due to the phenomenon of rail corrugation. When corrugation occurs, a short wavelength ripple forms on the railhead with a pitch of a few tens of millimtres and a depth ranging from a few tens of microns to perhaps 0.1 mm or more. The rippling leads to enhancement of the noise from trains, and the increase can be quite severe. Where stock with disc brakes is running over corrugated rail, the increase may be as much as 20 dBA compared with the same stock on smooth rail.

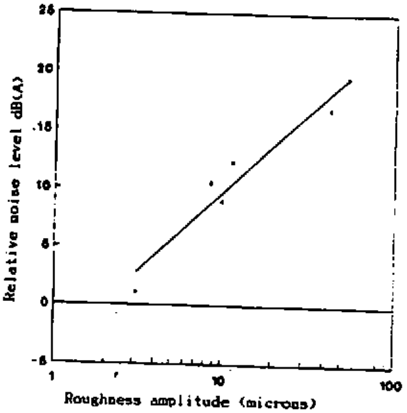

FIG.4 Wayside noise level as a function of rail roughness: disc-braked stock at 160 km/h

It is therefore essential that significant corrugation of the rails is not allowed to take place. Figure 4 illustates the way in which wheel-rail noise depends on the measured roughness of the rail surfaces (filtered to emphasise the corrugation amplitude in the 'short wavelength' band) when they are trafficked by disc-braked rolling stock: it is clear that corrugation depths in the short wavelength band greater than some 10 microns should not be allowed to build up. It will therefore be necessary to establish a rail grinding regime which allows this sort of rail surface characteristic to be maintained. It is known that this smoothness of rail surface finish can be achieved on BR track with available rail grinding trains.

4.0 FUTURE POSSIBILITIES FOR WHEEL-RAIL NOISE REDUCTION

4.1 Basic Requirement

It was mentioned in the introduction that there was an approximately equal split between wheel and rail in their contributions to wheel-rail noise in normal rolling: this is illustrated in figure 5 for a combination of rough

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wheel and smooth rail, but the proportions are similar for other combinations. At the lower frequencies, the rail forms the principal source of noise, whereas in the higher freqency part of the spectrum there is a significant contribution from both wheel and rail.

The following sections discus how the wheel and rail components of the system might be treated to reduce each of their contributions, and, in combination, the total noise.

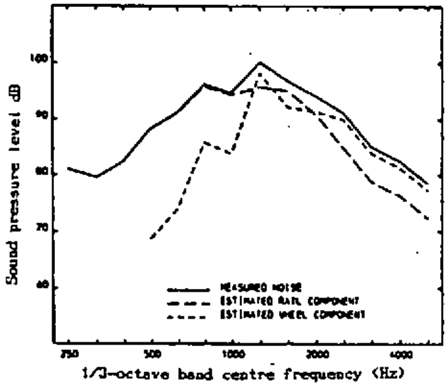

FIG.5 Average proportions of noise from wheel and rail spectrum at 2m; Rough wheel/smooth rail; 160 km/h

4.2 Wheel treatment

The vibration behaviour of the rolling wheel is strongly resonant, particularly at the higher frequencies where the wheel has its strongest influence on the wayside noise. This resonant response can be treated by surface damping, involving the application of constrained layer damping to the web of the wheel. This consists of a layer of visco-elastic material bonded to the wheel web, on one side, covered by (for example) a metal layer shaped to a close fit. This treatment has also been shewn to be very effective in the control of flange squeal on tight curves.

An alternative, or additional, technique would involve the use of smaller diameter wheels, which because of their reduced mass and increased stiffness would have much higher resonant frequencies, most of the resonant frequencies then being outside the range of excitation.

The introduction pointed out that the frequency range of excitation at the wheel-rail contact is limited by the length of the contact patch: roughness wavelengths less than the contact patch length are averaged-out mechanically, so that the range of frequencies excited strongly is limited to below about 4 kHz. Although the smaller wheel would have a shorter contact patch length, and thus suffer excitation to somewhat higher frequencies, for a given axle load the effect would be small for (say) a *halving* of diameter.

At higher train speeds, the contribution of wheel radiation to the total radiated noise becomes a greater proportion of the total, although the rail element always remains significant. For the highest traffic speeds envisaged, up to 300 km/h in France, it is likely that wheel treatment alone could result in a worthwhile reduction in overall wheel-rail noise, perhaps by up to 4 dBA.

4.3 Rail Treatment - Low Frequencies

Rail treatment is more complex (but clearly equally necessary) and requires the more subtle application of acoustic principles.

The low freqencies are best treated by reducing the cross-section of the rail, which has the effect of reducing its radiation efficiency, so that less noise is radiated for a given amplitude of motion. This is the basis of the "Hush" rail section which is some 50 mm lower than conventional rail such as 113A. Figure 6 illustrates the difference in the cross-section of the two rail types.

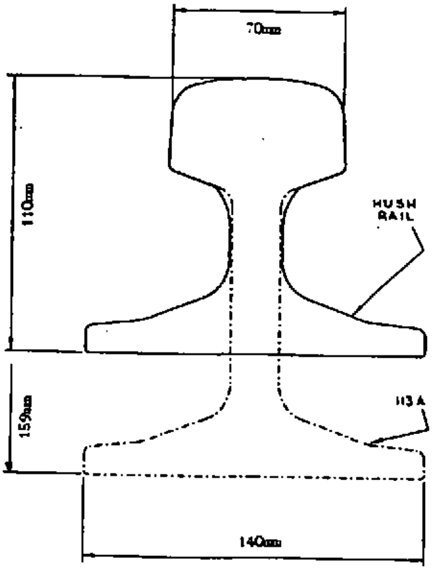

FIG.6 Comparison of "Hush" rail and 113A rail cross-sections

The change in radiation efficiency for the theoretical case of a vibrating cylinder is shewn in figure 7, and illustrates that for a given amplitude of vibration, a halving of the diameter

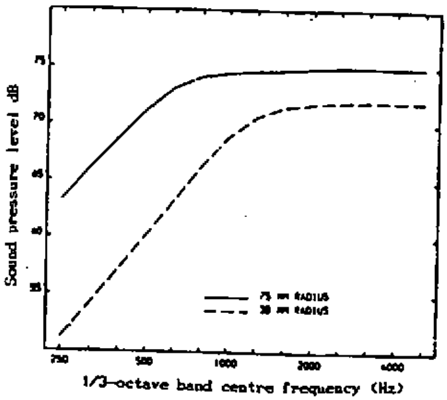

FIG.7 Noise radiated by vibrating circular cylinders: 1m distance; 1m/s amplitude

results in 12 dB less noise at a given (low) frequency. Where the diameter is well below the wavelength of sound in air at the frequency considered, the cylinder case would apply equally to other fairly compact sections. With the "Hush" rail section there should be about 6 dB reduction at low frequencies.

4.4 Rail Treatment - High Frequencies

At high frequencies it is necessary to reduce the radiating length of the rail.

Experiment has shewn that vibration impressed into the rail at the point of contact with the wheel propagates along the rail with relatively little attenuation on normal track, yielding a relatively large radiating length. Damping of the rail foot provides an effective means of increasing the attenuation of the vibrations propagating along the rail, and thus reducing the effective radiating length. The damping technique which can be applied is again use of constrained layer damping. This consists of a continuous layer of visco-elastic material bonded to the rail foot, with a layer of steel metal bonded immediately on the other side of the visco-elastic material. One possible form of the system with the damping applied to the underside of the foot is sketched in figure 8, but damping can also be applied successfully to the upper side of the rail foot.

A short demonstration length of this "Hush" rail track has recently been laid on a BR route near Derby carrying both passenger trains and freight trains with an axle load of up to 25 tonnes. This test section will allow assessment both of the new section under traffic and, when the rail running surface has worn to a stable condition, the effectiveness of "Hush" rail as an acoustic technique for reducing the noise from railways.

The section of test track has been laid on timber sleepers, which have been installed at closer pitch than usual in recognition of the greater flexibility of the "Hush" rail section. For heavier duty "Hush" rail might equally or preferably be laid on a continuous concrete strip foundation, yielding continuous support of the rail.

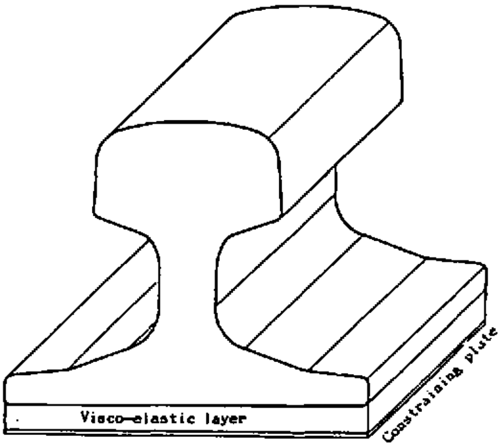

FIG.8 "Hush" rail with visco-elastic foot damping

5.0 CONCLUSIONS

- \- There is a strong stimulus to reduce wheel-rail noise to a minimum, particularly for tunnel-bound vehicles.

- \- Wheel-rail noise is caused by the wheel and rail roughnesses exciting the wheels and rails into vibration.

- \- The radiated noise arises about equally from the wheels and from the rails: it is therefore necessary to reduce the effect from both to achieve the greatest result.

- \- Wheel radiation could be controlled by damping of the wheels, possibly allied with a reduction in their diameter.

- \- For the fastest trains, wheel damping alone may be worthwhile.

- \- Rail radiation reduction requires both a reduction in the cross-section of the rail and foot damping of the rail to reduce its radiating length.
- \- A test length of the "Hush" rail embodiment of these principles has been laid on a BR route carrying both passenger trains and 25 tonne axle freight trains.

6.0 ACKNOWLEDGEMENT

Thanks are due to the Director of Research. British Rail Research. for permission to publish this paper.

7.0 REFERENCES

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