Responding to the Environmental Noise Directive by demonstrating the benefits of rail grinding on the GB railway network

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Abstract—This paper investigates a significant reduction in environmental noise attributable to changes in the Network Rail grinding strategy. It also considers how these findings could inform noise mapping and action plans required by the Environmental Noise Directive. Acoustic Track Quality (ATQ) is a measure of the surface roughness of the running rails and is proportional to wayside rolling noise levels during the passage of a train. Levels of ATQ have been determined for the East and West Coast mainlines from wayside noise measurements made during the pass-by of Network Rail's New Measurement Train and data collected by an under-carriage microphone system fitted to this train. The results show a substantial apparent reduction in rail surface roughness and associated wayside noise levels since a similar study was undertaken in 2004. Whilst these findings require further verification they are supported by initial direct rail head roughness measurements which also show low levels of roughness.

Keywords—Environmental Noise, Acoustic Track Quality, Acoustic Rail Roughness, Grinding.

I. EU NOISE POLICY CONTEXT

The last decade has seen the publication of a growing body of evidence describing the impact of environmental noise on public health [1], [2], [3]. This has moved the debate on noise regulation beyond annoyance to include more serious health effects associated with long term stress and sleep disturbance. Commensurate with this, there have been developments in legislation and regulation, particularly at a European level.

Noise limits for new rolling stock are set out in the Technical Specification for Interoperability for noise from conventional railways [4]. For the existing fleet, provisions have been included in the recast of the first railway package to govern Noise Differentiated Track Access Charging.

Although direct EU regulation of infrastructure contributions to railway noise is difficult to reconcile with the principle of Subsidiarity, there is indirect pressure resulting from the Environmental Noise Directive (END) [5]. The END requires noise maps and noise management action plans to be produced on a repeating 5 year cycle for the rail network (as well as for roads, airports and industrial noise sources). The Relevant Rail Authorities (in GB these are Transport Scotland, DIT & ORR) are required to investigate locations with the highest noise exposure and implement noise management actions, or secure a budget for action. Network Rail has supported the Relevant Rail Authorities via the cross industry Noise Policy Working Group.

This paper presents work commissioned by Network Rail to demonstrate the reduction in noise emissions achieved between the first and second rounds of END noise mapping.

II. RAILWAY NOISE AND END NOISE MAPPING

In GB, the Calculation of Railway Noise 1995 (CRN) [6] was used as the methodology for the first and second rounds of END noise mapping. Whilst there are a number of sources of noise associated with the operational railway, CRN focuses on rolling noise and traction noise. Curve and brake squeal are not currently included in the mapping results. Aerodynamic noise has little relevance to the majority of the GB network.

Rolling noise is currently the most important noise source associated with the GB railway. It is generated by roughness of the wheel and rail. The combined roughness excites both the wheel and track, which then radiate noise. Wheel roughness tends to stabilise at a level determined by the vehicle braking system. Typical GB rolling stock have relatively smooth wheels due to the preference for composite brake blocks and disc brakes over cast iron brake blocks. Rail roughness tends to increase over time in proportion to the gross tonnage and can be controlled by grinding.

The highest noise emissions shown on the maps indicate sections of the network with both high line speed and high traffic volume.

III. 2004 STUDY OF ACOUSTIC TRACK QUALITY

In 2004 a study was completed by AEA Technology Ltd on behalf of Defra [7] which considered the implications on noise predictions of a level of rail roughness different from that assumed in CRN.

The study used the NoiseMon system to perform indirect measurements of rail ‘acoustic’ roughness. The NoiseMon system consisted of a microphone mounted beneath the floor of British Rail Mk 3 coaches together with a data acquisition system inside the coaches. Measurements were taken for normal operations on the East Coast and West Coast Mainlines in the early 2000s to determine statistically the variation in the condition of the rail running surfaces on the GB network.

A relationship between the under-floor noise level recorded with the NoiseMon system and the noise level measured at track side was determined by measuring a transfer function between the under-floor noise level and the level at a point 25m from the nearest rail during the passby of the NoiseMon system or similar rolling stock.

Having established this relationship, the under-floor noise level that produces a pass-by noise level equal to the value...
predicted by CRN at 25m from the track was calculated.

The difference between the level that was produced by the Mk 3 coach carrying the NoiseMon system and the level that would be predicted with CRN at 25m from the nearest rail at a given location was termed the Acoustic Track Quality (ATQ), defined as:

\[ ATQ = SEL_{Mk\text{ 3,160}} - SEL_{Mk\text{ 3,160,CRN}} \]  

where, \( SEL_{Mk\text{ 3,160}} \) is the wayside noise level measured 25m from a Mk 3 coach and normalised to 160 km/h and \( SEL_{160,CRN} \) is the noise level that would be measured 25m from the Mk 3 coach at 160 km/h while running on rails with a surface roughness at the level that is implicit within CRN.

It is not feasible to measure wayside noise of train passbys at a statistically large-enough number of measurement locations to evaluate the ATQ for the whole network or to measure directly the rail roughness of the whole network. A feasible alternative used in the 2004 AEA study is to:

1. measure under-floor noise using the train-borne NoiseMon system on large sections of the GB network
2. estimate the corresponding wayside noise using a transfer function measured during the passby of the Mk 3 coach carrying the NoiseMon system;
3. compare this to the reference single vehicle SEL, for a Mk 3 coach given in CRN; and use statistical analysis to derive the relative distribution of ATQ on the GB Network.

A positive value of ATQ indicates that the level produced by the Mk 3 coach would exceed the level that would be predicted by CRN at that location, suggesting a higher contribution of noise caused by increased rail roughness.

The ATQ determined from the 2004 AEA study presented in terms of its distribution over a large section of the network is reproduced in Fig 1.

The mode of the ATQ shown in Fig 1 is +4dB. This indicates that the noise produced by a Mk 3 coach on the GB Network would, on average, be 4dB higher than the equivalent level that would be predicted by CRN. This analysis was based on data collected in the early 2000’s and was assumed to be valid in 2004.

Consequently the +4dB ATQ was used as the basis for deriving the operational assumptions for the GB network used in the first round of noise mapping undertaken by Defra in response to the END.

IV. CHANGES TO THE NETWORK RAIL GRINDING STRATEGY

Between 2002 and 2004, NR developed a new preventative maintenance grinding strategy to address rolling contact fatigue. This involved the purchase of three new 64 stone grinding machines. These machines work on a cyclic basis across the heavily used parts of the network with the grinding trains travelling as ‘slow moving trains’ within revenue service traffic. This has enabled greater productivity by allowing grinding to be undertaken outside of possessions.

Currently, this strategy is applied to lines carrying more than five million tonnes of traffic per year. From 2003 grinding was carried out based on curvature and tonnage and originally was carried out at every 15 Equivalent Million Gross Tonnes (EMGT) on curves <2500m radius and every 25 to 30 EMGT on curves and straight track > 2500m radius.

This frequency was reviewed in 2007 and the frequencies of grinding changed to better reflect measured rail wear rates on straight track. From 2009, grinding of straight track was revised so that it was planned to be carried out every 45 EMGT with curves continuing to be ground every 15 EMGT.

Currently therefore a typical section of main line track might be ground every one or two years on straight sections and every six months on curves.

No cyclic grinding was undertaken on the network for the 10 year period prior to 2002. Grinding was limited to the use of small machines on a site-specific basis.

While the purpose of the grinding is not to reduce noise, rail grinding is proven to reduce wayside rolling noise levels generated by the railway. It can therefore be expected that the grinding strategy introduced between 2002 and 2004 would have an effect of reducing wayside noise levels on main lines.

V. 2012 STUDY OF ACOUSTIC TRACK QUALITY

The objective of this study was to determine an up to date value of Acoustic Track Quality (ATQ) for the GB network and investigate any change attributable to the new grinding strategy.

To maintain consistency, a similar approach to that used in the 2004 AEA study has been adopted. However, the indirect (noise) measurements of roughness were
supplemented by direct rail roughness measurements at one location.

ATQ transfer functions were measured for both the up and down lines at three sites on the East and West Coast Main Lines (ECML & WCML):
- Tring on the WCML;
- Rossington on the ECML; and
- Burton Coggles on the ECML.

Transfer functions were successfully obtained for a total of 6 different tracks, 2 at each location. These were consistent to within approximately 1dB for measurements made on the same day. However the resulting route-averaged transfer functions differ by nearly 5dB between the two lines (measured on different days). This could be due to drift in the NoiseMon system which is discussed in more detail in Section VII.

A key observation from this stage of the study is that the measured SELs of a Mk 3 coach normalised to 160 km/h were consistently lower than the value predicted by CRN of 81dB for all six passbys by 3-5dB.

This indicates that the noise produced by a Mk 3 coach on the WCML and ECML in 2012 would, on average, be lower than the equivalent level that would be predicted by CRN. This result is consistent with the wayside noise levels measured at three sites on the WCML and ECML.

The mode of the ATQ for the combined routes is -4dB. When compared to the 2004 study, this figure suggests that current rolling noise levels for smooth-wheeled trains on the main routes are, on average, 8dB quieter than assumed in 2004. This is a significant number and implies a significant reduction in rail head roughness.

A study [8] carried out by DeltaRail for the Rail Safety and Standards Board demonstrates that the ATQ for TSI-compliant track is approximately -1.7dB. Therefore the current study suggests that the WCML and ECML have, on average, rail roughness levels that are compliant with the roughness limit defined in the Noise TSI.

Another observation is that the shape of the distribution is narrower than that obtained in the 2004 study. This change is consistent with a step change in rail grinding, which eliminates sections of rail with very high roughness (e.g. corrugated rails). This change in distribution shape was also predicted in the 2004 report, as shown in Figure 4.

A significant change in ATQ when compared with the 2004 study has been identified from noise measurements and analysis of data obtained with the NoiseMon system.

Supplementary measurements intended to test findings of the study are described in Section VIII.

VI. ANALYSIS OF PASSBY NOISE MEASUREMENTS

The NoiseMon system is carried on a single Mk 3 coach which is part of the New Measurement Train (NMT). The NMT consists of a rake of 5 Mk 3 coaches and 2 Class 43 power cars. Wayside noise measurements of the NMT consist of the sum of rolling noise from the rake of seven vehicles. It is therefore necessary to “extract” the noise of one Mk 3 coach from the wayside measurements. For the purpose of this study, an approach similar to that outlined in [7] was used where a model of the noise from each vehicle was fitted to the time history of the full train passby to determine the contribution of the Mk 3 coach to the total passby SEL of the complete rake of the NMT.

In the model each bogie is modelled as a dipole source,
such that the NMT can be modelled as a distribution of 14 dipoles. Two reference source strengths were used: one for the power cars and one for the Mk 3 coaches. A higher reference source was required to represent that fact that the Class 43 power cars have cast-iron tread braking combined with disc-braking, rather than the purely disc-braked wheels on the Mk 3.

This model is used to simulate a time history of the $L_{Aeq,64\text{ms}}$ for the passby of the NMT at a reference distance of 25m. The model is then fitted to the measured data by altering the source strengths but keeping the ratio of the Class 43 to Mk 3 source strengths the same. Once a best fit is achieved, the SEL of one Mk 3 coach can be obtained by integrating the area under the graph representing the noise from two bogies.

The scaling of SEL with speed was assumed to follow a $20 \log V$ relationship, where $V$ is the train speed.

Figure 5 shows an example of the dipole model fitted to the time history of the NMT passby at one of the measurement sites. In Figure 5 the contribution to the train passby level of a rake of five Mk 3 coaches, one Mk 3 coach and the individual bogies are also shown.

VII. 2012 NOISEMON DATA, REPEATABILITY AND DRIFT

An additional analysis of seven sets of data collected with the NoiseMon system during different weeks but on the same sections of track has also been completed. This showed variability of more than 20 dB in the absolute noise level measurement between different weeks for the same section of track. However, once the data were normalised to a single value, the data showed good repeatability. This suggests that the gain of the NoiseMon system is “drifting” over different days or long periods.

It was also seen that the NoiseMon to wayside transfer function recorded on different weeks had changed by nearly 5dB within two weeks but was consistent to approximately 1dB within the same measurement day.

It was not possible to access the NoiseMon system within this study to investigate its calibration as the NMT is in constant use. For the purposes of this study it has been assumed that the drift in calibration of the NoiseMon system is negligible during the same measurement day, although this could not be confirmed.

The potential for the calibration of the system to drift limits the data used in the analysis to data that was captured on the same day that the transfer function was measured. This has limited the ATQ derivation to data captured on the ECML and WCML on a single day.

VIII. DIRECT MEASUREMENT OF RAIL ROUGHNESS

As described previously, rail roughness levels lower than the TSI limit spectrum would need to be present on large parts of the GB network to account for the 8dB reduction in ATQ since 2004. A directly measured rail roughness survey was carried out at one of the ATQ test sites to provide direct evidence of rail roughness levels on the network in 2012. The survey was carried out near Rossington, South Yorkshire. Due to site safety restrictions it was not possible to measure roughness on rails at the noise measurement location. The closest available test site was approximately half a mile from the noise measurement location as shown in Figures 6 & 7. These also show the NoiseMon speed-normalised sound pressure data at the separate noise and roughness test sites and on the Up and Down lines.

On the Down line under carriage noise level is similar at both locations. However on the Up line the under carriage
noise level is approximately 2-3 dB higher at the roughness measurement site than the noise measurement sites. This indicates that:

- the Down line will provide the best indication of roughness levels at the noise measurement site; and
- rail roughness levels are expected to be higher on the Up line than the Down line at the roughness measurement site.

The rail roughness was measured using a Rail Measurement Corrugation Analysis Trolley (CAT 3) on 28 April 2012.

Measurements were undertaken in accordance with the methodology specified by EN 15610:2009 Railway applications— Noise emission— Rail roughness measurement related to rolling noise generation [9].

On the Down line measurements were made on both rails. Time constraints only allowed for measurement on one rail of the Up line.

On each rail, measurements were made on a length of rail 15m long to provide enough data to present roughness in the wavelength range 0.63m to 2mm.

On each rail a single running band was observed. The running band was approximately 20mm wide. A minimum of one line of roughness measurement was made on each rail as indicated in Figure 8.

The measured average rail roughness levels for both Up and Down lines are presented in Figures 9 & 10.

The levels are compared with an average UK rail roughness derived from measurements in the 90s [10], and also the TSI rail roughness limit spectrum for reference track for pass-by noise tests. On the Down line, rail roughness levels are lower than the TSI limit values except for the 6.3cm band where distinct corrugation – or more likely rail grinding pitch - has been measured. When applying the “small deviations” procedure [11], this exceedance of the TSI limit would not have a significant effect on the pass-by noise level for vehicles with typical disc-braked wheel roughness. The levels are also lower than the 1990’s average GB roughness in all bands.

On the Up line rail roughness levels are higher than on the Down line. This is consistent with data measured by the NoiseMon system and presented in Figure 7. The levels exceed the TSI limit for wavelengths greater than 3.15cm. At shorter wavelengths the measured levels are below the TSI limit. In the wavelength range 31.5 – 5cm the rail roughness exceeds the 1990’s average GB roughness.

To understand if the measured levels are consistent with the noise data measured at Rossington, a prediction of the relative level of wayside noise that would be expected for two rail roughness profiles if all other parameters remained equal was carried out by:

1. Calculating the combined wheel-rail roughness spectrum for a typical disc-braked wheel (from [12]) and:
   a. the rail roughness measured on the Down line at Rossington – which was considered to be representative of the noise measurement site
   b. The TSI limit level for passby noise measurement
2. Calculating the frequency spectrum for the combined wheel-rail roughness for a train speed of 113 mph - the closest “one-third octave band” speed to the 124 mph operational speed on the Down line during the noise measurements; and
3. Calculating and comparing the overall A-weighted level of each of the combinations

The results of the analysis are shown in Table 1Error! Reference source not found. and are normalised to the combination of the typical disc-braked wheel and the TSI limit values. It can be seen that wayside A-weighted noise
levels at the Rossington site would be expected to be 1.6dB less than a site with a rail roughness equal to the TSI limit values.

In [8] a similar approach was used to estimate that wayside noise levels on track with rail roughness assumptions consistent with CRN would be expected to be 1.7dB higher than on a track with ‘typical’ wheels and rail roughness similar to the TSI limit values. Hence wayside noise levels at Rossington for smooth-wheeled stock are expected to be 3.3dB less than a track which has a rail roughness consistent with the assumptions in CRN.

At the Rossington measurement site the SEL of the single Mk 3 coach was measured at 80.2dB. The SEL of a single Mk 3 coach at 124mph predicted by CRN is 83.2dB, meaning our measured SEL was 3dB less than would be predicted by CRN. Therefore the measured roughness data and noise data are consistent.

<table>
<thead>
<tr>
<th>Combined wheel-rail roughness</th>
<th>Relative overall A-weighted noise normalised to TSI [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical wheel + Rossington DN</td>
<td>-1.6</td>
</tr>
<tr>
<td>Typical wheel + TSI</td>
<td>0</td>
</tr>
<tr>
<td>CRN (from [8])</td>
<td>+1.7</td>
</tr>
</tbody>
</table>

IX. CONCLUSION

This study provides strong evidence to suggest that the Network Rail grinding strategy introduced from 2002 has resulted in a significant improvement in Acoustic Track Quality (ATQ) across the GB network. On the basis of this evidence the authors are confident that the +4 dB ATQ indicated by the 2004 AEA Technology Ltd report is no longer valid. This conclusion is supported by:

- measurements of SEL at three test locations which are lower than would be predicted by the Calculation of Railway Noise methodology;
- direct rail roughness measurements at the Rossington test site which showed levels of roughness that are lower than the TSI limit values and provided a prediction of the wayside noise levels that were consistent with those measured during the tests;
- a narrowing of the ATQ distribution since 2004, which was an effect of grinding predicted in the 2004 study as the very roughest sections of track have been controlled.

A GB network average ATQ value of -4dB has been derived based on a survey of the ECML & WCML. This indicates a very large reduction of 8dB relative to 2004. It also suggests that the majority of the GB network is below the TSI roughness limit. Whilst these results are very interesting, further work is considered necessary to better understand and quantify the significance of the apparent drift in NoiseMon data. Until this issue is fully resolved it is not considered appropriate to use the ATQ -4dB value to directly inform the END noise maps.

REFERENCES

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RRUKA Annual Conference, 7 November 2012