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How to avoid the noise ceiling? Accommodating traffic growth by smooth and silent track

Ard Kuijpers[a]
Wout Schwanen
M+P – consulting engineers
P.O. Box 2094
NL-5260 CB Vught, The Netherlands

ABSTRACT

A substantial growth of traffic is anticipated for the future on the dense railway network in the Netherlands. According to Dutch law, the environmental burden of this traffic growth has to be compensated. For the sound emitted by railways this means that a noise emission increase due to traffic growth should not lead to an exceeding of a maximum allowed sound level ("a noise ceiling"). At certain locations the capacity of the railway can only be enlarged by taking acoustic countermeasures to accommodate for the traffic growth.
One of the most promising noise reduction measures is dedicated rail grinding. Rail grinding is a source measure as it reduces the excitation mechanism of rolling noise: the combined roughness of wheel and rail. By lowering the roughness of the rail, the energetic sum of wheel and rail roughness is lowered and less rolling noise is emitted by the wheel/rail system. Lowering the roughness of the rail is accomplished by low roughness grinding maintenance.
In the Dutch noise innovation programme, we have investigated all practical aspects of smooth rails as a noise reduction measure. The measure consists of regular monitoring of the rail roughness condition and scheduling and performing low roughness grinding maintenance when the roughness exceeds a certain limit. This monitoring is done by a newly developed monitoring system called ARRoW. The main benefits of rail roughness control as a noise reduction measure are the cost-effectiveness and the flexibility.

1. INTRODUCTION

The Dutch railway system consists of a dense railway network in a densely populated area with intense traffic (at least two intercity and two commuter trains per hour per direction on most routes). Needless to say, this puts a large environmental burden on the people living close to the railways. Dutch legislation aims at protecting these people against the danger, damages and nuisance resulting from the railway noise.
For the near future, two important changes are foreseen that will require extra efforts from the Dutch railway infrastructure provider ProRail to mitigate the railway noise. Firstly, the Dutch government has laid down the ambition to intensify the traffic on the main railway corridors to obtain a metro-like timetable so passengers will always be able to catch a train within 10 minutes. The program to achieve this is called PHS ("Programma Hoogfrequent Spoorvervoer", i.e. program for high-frequency railway transport).
At the same time, a major change in the Dutch noise legislation for roads and railways will become effective in two years, the so-called noise emission ceilings (NECs). These ceilings are introduced as a solution to one of the major problems with the current legislation: the unlimited growth of the traffic in noise-sensitive areas. In the current legislation, the maximum noise of infrastructure is only evaluated in the planning phase of new or reconstructed infrastructure. If

[a] Email address. ArdKuijpers@mp.nl

the traffic is more intense than was anticipated, there is currently no legal obligation to take extra measures. The NECs will solve this legislative loophole. Furthermore, it will make the current legislation less complicated, less regulations and more simple standards.
The idea of the NEC is to have a network of virtual evaluation points next to the roads and railways. On each of these points, a maximum noise level is determined by calculation and the infrastructure providers have to ensure that these maximum noise levels will never be exceeded.
So with the ambition of more intense traffic on the main corridors, ProRail has to make sure that this growth is accommodated by appropriate measures to stay below the NECs. ProRail has a number of measures at its disposal to accommodate the traffic growth. On the infrastructure side, the noise can be reduced by sleeper renewal (exchange wooden sleepers with concrete ones), rail dampers and noise barriers. However, these infrastructure measures require substantial investments and it takes a while to implement them on the track. On the vehicle and network usage side, ProRail can (financially) stimulate the use of silent trains or can choose to decrease the traffic intensity or lower the average traffic speed. Of course, the two latter measures are not compatible with the ambitions of the PHS.
In the framework of the Dutch innovation programme noise (IPG), ProRail has investigated rail roughness control as an alternative noise reduction measure for the infrastructure that is relatively cheap and fast to implement. This paper explains how rail roughness control works and how it can be implemented as a noise reduction measure on conventional railways.

2. RAIL ROUGNESS CONTROL

Rail roughness control is a noise mitigation measure that reduces the rolling noise of trains at the source. By reducing the rail roughness, the combined (wheel/rail) roughness is reduced. This decreases the excitation of rail and wheel vibrations, which leads to a lower sound radiation into the surroundings.
Rail roughness control as a noise reduction measure is not a novelty. In Germany this measure has already been used in practice during the last decade and in the Netherlands the measure is used on the HSL-Zuid, the new high speed line that runs from Amsterdam down to the Belgian border. The challenge is not in making the measure work, but to find a strategy to make this measure work in practice, both effectively and efficiently.
Rail roughness control has two fundamental pillars: monitoring and grinding. To make the measure viable, we have to find efficient techniques for both monitoring and grinding and they should be cost-efficient as well.

A. Monitoring

Monitoring is a periodical evaluation of the roughness state of the track. Monitoring is required to 1) make it possible to use a state-driven maintenance strategy: only grind when it is necessary and 2) to demonstrate to the public and the relevant authorities that the track is maintained adequately and that the maintenance regime is continually lowering the roughness and hence lowering the rolling noise.
For monitoring the rail roughness we can apply two measurement techniques, the direct and indirect method. In the direct method a high-precision instrument directly measures the roughness level of the track. This method has various advantages. It is very precise and it yields absolute roughness results that can be translated directly into a sound reduction number ($C_{b,c}$-value). However, for monitoring purposes this method has two severe disadvantages. It is very time-intensive and for safety reasons the track needs to be put out of service. These disadvantages make it less suitable for larger track sections.
To be able to measure larger track sections we developed a new measurement system, called ARRoW. This system measures the noise levels which can be translated into roughness levels, since these parameters are directly related to each other. This approach is not unique. In Germany the SchallMessWagen (SMW) is in use for years to measure the rolling noise. For the

Netherlands, we chose to design a new measurement system to be able to use the latest developments in instruments and data analysis. The main features of the ARRoW system are:

1. The rolling noise is measured at four wheels simultaneously. This not only results in more signals and a more robust system if one microphone malfunctions, but we also achieve a better signal/noise ratio. Furthermore, it is possible to distinguish between the left and right rail;
2. We measure the noise levels close to the wheels which increases the signal/noise ratio and minimizes the disturbing influence of absorbing ballast;
3. The ARRoW system uses GPS to measure the vehicle speed. In doing so we also accurately record the position. Furthermore this makes the system independent of any on-board speed measurement systems and thus makes it more flexible;
4. The system is usable at conventional rolling stock material but also at light-rail vehicles and trams.

Because the direct method is accurate yet impractical for large track sections and the indirect method yields only relative results, we have developed a new methodology in which the results of the indirect method are "calibrated" against direct roughness measurements on a limited number of reference sections[1].

The method has proven its usability in a comparison test between the ARRoW and the SMW[2]. This Round Robin test revealed that the SMW and ARRoW yield very similar results. The repeatability of both systems is within 1 dB. Concerning the reproducibility it became clear that the resulting $C_{b,c}$-values of both system were within ± 1 dB (95%CI). It also turned out that both measurement coaches predict slightly higher noise reductions than the direct measurements predict. The differences between both systems are of a more practical nature, e.g. the ability to distinguish left from right rail, the accessibility of microphones, the portability etc.

B. Maintenance

The second pillar in rail roughness control is the grinding maintenance. At this moment there are two techniques to achieve a rail roughness that is low enough to have a beneficiary effect on the rolling noise generation. Based on the machinery that is used for grinding, we distinguish oscillating grinding and rotating grinding. At the moment the oscillating grinding tends to produce a lower rail roughness but the rotating grinding has a higher production speed. Which technique is preferred depends on the desired end-result (see section 3).

Our study has shown that it is very cost effective to integrate the grinding activities for the acoustic treatment and the "normal" grinding to prevent mechanical failure of the rail. The grinding interval that is required to prevent RCF and head-check problems is similar to the interval to treat the rail surface to lower the rolling noise. Integrating both tasks in the same grinding machine and/or works shift reduces the total cost of the rail grinding as an acoustic measure significantly. This is explained in section 4.

C. Rail roughness life cycle

The roughness level of wheel and rail are generally not constant in time. Therefore. the sound reduction by lowering the rail roughness alters in time, but so does the rail roughness on untreated track. Figure 1 shows a schematic illustration of the noise reduction behavior over time. Immediately after grinding the roughness is lowered. Due to the grinding process however some residual grinding marks are still present. The first traffic removes these residual marks and after a short time the minimum roughness level is achieved. For a certain period the noise reduction level maintains this value and will then gradually increase. The reason for this stable period is the fact that the rail roughness after grinding will in general be much lower than the wheel roughness. In the stable period, the total roughness is dominated by the wheel roughness and the wheel roughness thus determines the maximum noise reduction that can be achieved.

After some time, the rail roughness will be in the same order as the wheel roughness and that marks the end of the period where the noise reduction is relatively stable.
At the end of this stable period the roughness level starts increasing faster until the point at which the rail is ground and this cycle repeats itself. This cycle takes place in a time period of normally several years, of course dependent on the traffic intensity. Hence, an average value for the noise reduction during this time cycle is calculated to take the lifetime behavior of the noise reduction due to roughness control into account.

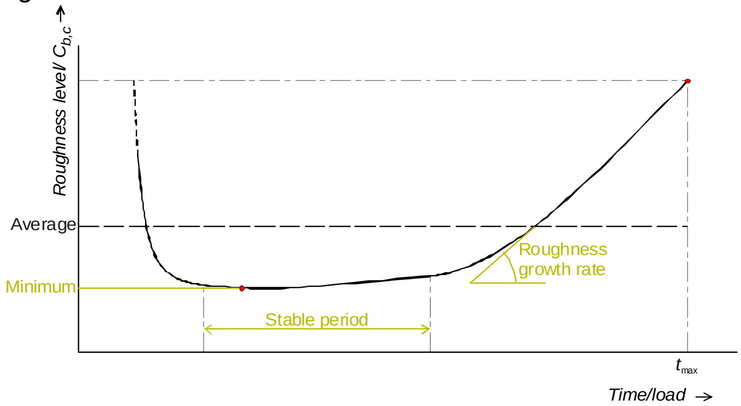

Figure 1: Typical life cycle of rail under rail roughness control.

3. ROUGHNESS CONTROL PARAMETERS AND SCENARIOS

The amount of noise reduction due to rail roughness control depends on the actual average roughness wavelength spectrum that is achieved with the grinding and monitoring maintenance regime. In the Dutch calculation scheme, roughness control is only considered as a noise reduction measure when the rail roughness is considerably lower than the average Dutch (NL) rail roughness. In figure 2 we have shown some typical rail roughness spectra.

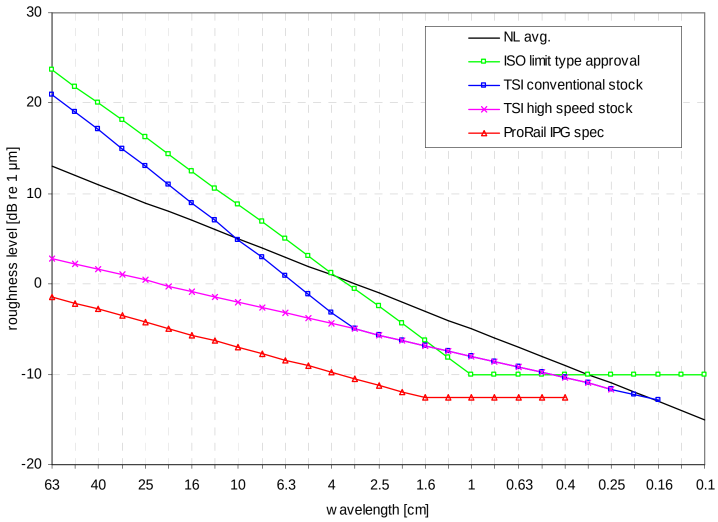

Figure 2:Typical rail roughness spectra.

In the Dutch calculation scheme it is possible to compute the noise reduction resulting from a certain average rail roughness spectrum. This noise reduction is always computed with respect to Dutch average rail roughness:

$$C_{bb,i,c} = C_{bb,i} + (L_{i,rtr,actual} \oplus L_{i,rveh,c}) - (L_{i,rtr,NL} \oplus L_{i,rveh,c})$$

With $C_{bb,i,c}$ as superstructure correction term at octave band i, L_{rtr} as the track roughness, L_{rveh} as the vehicle (wheel) roughness and $\oplus$ denoting energetic summation. For the average Dutch roughness, assuming the wheel roughness of disc braked wheels the above rail roughness spectra correspond to the following noise reductions: the $C_{b,c}$ is defined as the A-weighted overall noise reduction level of a certain noise reduction spectrum $C_{bb,i,c}$.

Table 1: *Some roughness spectra and the corresponding noise reduction according to the Dutch calculation scheme, assuming 100% disc braked traffic.*

specification/measurement	**noise reduction $C_{b,c}$**
Dutch average roughness	0 dB
ISO limit type approval	-0.1 dB
TSI conventional stock	-1.5 dB
TSI high speed stock	-2.0 dB
ProRail IPG specification	-3.0 dB

But the rail roughness spectrum is not the only variable in the equation. The effectiveness of roughness control as a noise reduction measure also depends on the wheel roughness of the traffic that runs on the track. The excitation mechanism for rolling noise is the combined roughness of wheel and rail. This combined roughness level is the energetic sum of the wheel and rail roughness. By lowering the wheel roughness (below the level of the rail roughness) the contribution of the rail roughness to the total roughness level increases. In that case, the effectiveness of noise reduction by rail roughness reduction increases. On the other hand, when the wheel roughness is much higher than the rail roughness, rail grinding is not an effective measure to reduce the rolling noise, since reducing the rail roughness does not significantly lowers the combined roughness.

If we take the rail roughness to be the desired ProRail IPG specification, then, theoretically, a sound reduction of 10 dB can be achieved when the wheel roughness is infinitely low. At the moment we can achieve a noise reduction of 1 dB for traffic consisting of 100% cast-iron block braked wheels and around 3 dB for a fleet with 100% disc braked wheels. With a large scale use of composite blocks (K, LL blocks) a noise reduction of 3 to 4 dB is feasible.

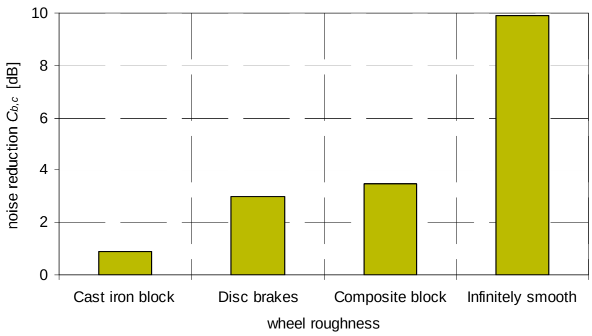

Figure 3: The noise reduction caused by rail grinding strongly depends on the wheel roughness level

So in the grinding strategy, the rail roughness and the wheel roughness are two major quantities. However, there are more steering parameters. The noise reduction can be influenced by the grinding technique and the grinding interval.

The grinding technique determines the initial roughness. In general, a lower initial roughness implicates a lower average roughness level and hence a higher noise reduction. However, besides the initial roughness level we can also use the grinding interval to achieve the same average noise reduction, which is illustrated in figure 4. It shows that a shorter interval between grinding leads to an increase of the average noise reduction.

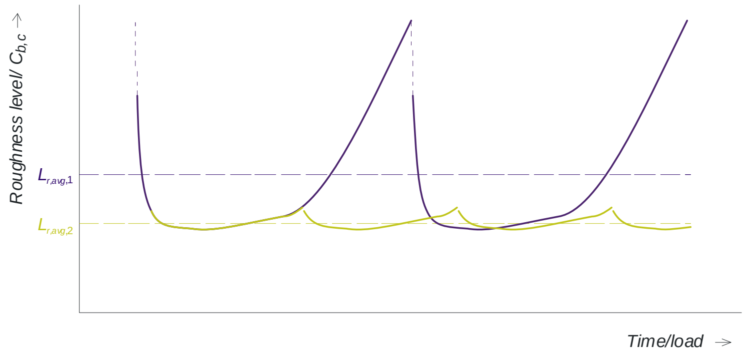

Figure 4: Controlling the average noise reduction with the grinding interval.

Hence we are able to obtain a certain sound reduction by the grinding technique (or the initial roughness level) in combination with a certain grinding interval. This is further illustrated in figure 5, which shows that with two different grinding regimes the same average roughness level can be achieved: when the minimum roughness is lower, the period between the grinding activities has to be shorter. Hence, in practice there are different options to arrive at a certain average noise reduction with respect to rails with the Dutch average roughness level.

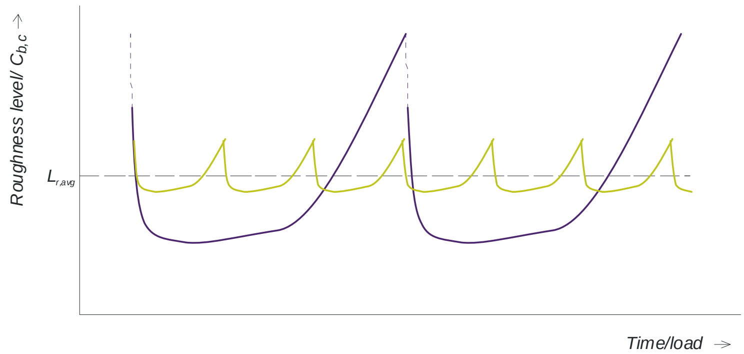

Figure 5: Matching the minimum roughness level and grinding interval to achieve a certain average noise reduction.

4. COST-BENEFIT

Various parameters influence the costs for rail grinding:

- the desired initial noise reduction, which mainly determines the choice for the grinding technique;
- grinding production speed;
- cost of the grinding maintenance technique;
- required/desired monitoring activities;
- possible integration of acoustic finishing with cyclic grinding.

We performed a case study to estimate the costs for the measure rail roughness control. This not only revealed the costs for rail roughness control but also showed that a cost reduction of 70% is feasible when integrating acoustic finishing with cyclic grinding.

Table 2: *Cost estimates for rail roughness control.*

Acoustic finishing separate from cyclic grinding	€ 14/m
Acoustic finishing integrated with cyclic grinding	€ 4/m
Monitoring	€ 0.15-0.50/m

To study the viability of the measure rail roughness control we compared the costs and benefits of the measure "roughness control" with two other noise reduction measures, noise screens and rail dampers. Over a period of 30 years we calculated the life cycle costs of five different scenarios:

- one sided noise screen of 4 meter height,
- one sided noise screen of 2 meters height;
- rail dampers;
- acoustic finishing integrated with cyclic grinding for mixed traffic 70% disc brakes and 30% composite block brakes;
- acoustic finishing integrated with cyclic grinding for mixed traffic of 70% disc brakes and 30% percent cast iron block brakes.

Figure 6 shows that rail roughness control is a very cost efficient measure for reducing rail traffic noise, although the maximum noise reduction is limited.

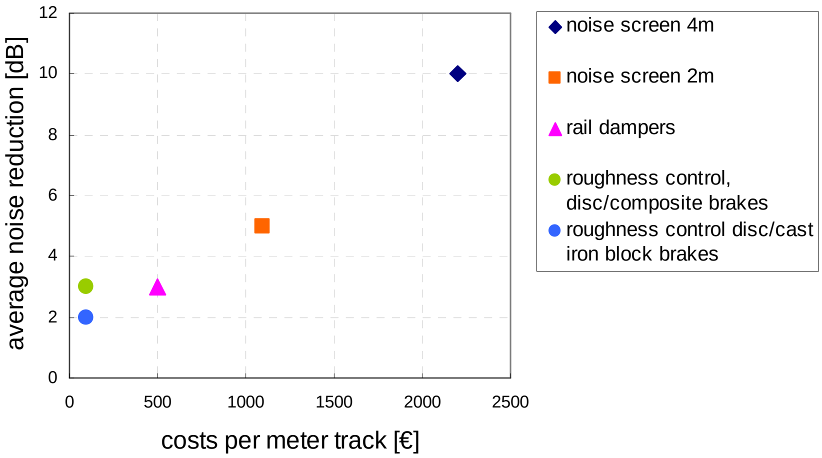

Figure 6: Cost benefits of five different noise reduction measures

The cost/benefit analysis showed that at the moment rail grinding is a measure that achieves a moderate noise reduction with minimum costs. It also showed that the measure will be very competitive with rail dampers in the future when the (freight) traffic fleet will have smoother wheels. Then, rail roughness control is about 10 times cheaper for the same benefit.
Rail roughness control is not very effective on lines with mainly freight wagons with cast-iron block brakes. However, when rail roughness control is applied to enlarge the environmental capacity for passenger traffic, the benefits can already be utilized today, even when there is a large fraction of cast-iron braked vehicles. In order to realize the PHS program, a substantial growth in the railway traffic for passenger transport is foreseen. Doubling the traffic intensity means that a 3 dB noise reduction for these trains is required to stay within the same NEC noise limits. But, since the growth will be realized with disc-braked vehicles, rail roughness control to achieve the IPG specification for rail roughness (see table 1) will be enough to accommodate the traffic growth because it will result in noise reduction of exactly 3 dB. This shows that rail roughness control is very (cost-)effective to counteract the increased environmental impact of growth in passenger transport by rail.

A last benefit is that rail grinding is a maintenance measure and not an hardware measure, which requires no major investments in advance and can be used in a flexible manner. It is applicable at locations where and when it is necessary. And the grinding measure can be stopped again if it is no longer necessary without significant loss of investment costs.

5. CONCLUSIONS

Smoothening the rails can reduce rolling noise by 1 to 3 dB depending on the traffic mix, i.e. the average wheel roughness of the passing traffic. This might seem a small reduction but in terms of capacity this translates into a capacity growth of 25 to 100%, which is enough to compensate for future traffic growth, especially when the growth is realized with modern vehicles with disc or composite brakes to ensure smooth wheels.
A first estimate of the life-cycle costs has revealed that the measure is very competitive compared to other measures such as rail-dampers. The noise measure is most cost-effective when the low roughness rail grinding is integrated into the regular grinding maintenance programs. The flexibility of the noise reduction measure comes from the fact that it is a maintenance measure and not a hardware measure. Hence smoothening the rails can be applied only where and only when it is needed.

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