The Influence of Wheel and Track Parameters on Rolling Noise

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Railway noise from conventional meter-gauge lines in Japan mainly consists of rolling noise and traction-motor fan noise. Rolling noise is generated by vertical vibration of the wheel and rail, which is induced by relative displacement between the two due to the roughness on their surfaces. Through field tests, it was found that the excitation of rolling noise is determined by both the wheel/rail roughness and the vibratory behaviour of rolling stock and tracks. A theoretical model for rolling noise (such as TWINS) was then applied to Japanese railways, with the predictions showing a close correlation to the measured values. In terms of noise spectra, the rail was found to contribute more to rolling noise than the wheel in much of the frequency range. An attempt to estimate the effect of wheel and track parameters on rolling noise was also made using the TWINS model. The stiffness of the rail pad was found to affect the balance between the rail and sleeper components of noise, and additional damping for the rail was deemed effective in reducing the rail component of noise.

Keywords: railway noise, conventional meter-gauge lines, rolling noise, wheel, rail

1. Introduction

The Environmental Agency established the Guidelines for Noise Abatement Measures in the Construction of New Lines and Large-scale Improvement of Conventional Railways in 1995. In these guidelines, noise abatement regulations are specified to preserve the living environment and prevent noise-related problems. Although they do not specifically address noise control for existing meter-gauge railway tracks, the guidelines are also implicitly applied to such lines in response to strong social demand. It is therefore important to effectively reduce railway noise.

Railway noise is generated by various track and vehicle components such as rails, wheels, engines or traction motors and other components. For the conventional meter-gauge railway lines found in Japan, noise generated by railway vehicles mainly consists of rolling noise and traction-motor fan noise. Rolling noise is generated by vertical vibration of the wheel and rail, which is induced by relative displacement between the two due to the roughness on their surfaces. Figure 1 shows a schematic diagram of how rolling noise is generated by wheel/rail interaction. Traction-motor fan noise is a type of aerodynamic noise generated by the fan that cools the traction motor. In terms of the contributions of these two noise components to total wayside noise, that of rolling noise is larger in recent modernized vehicles [1]. This is because traction-motor fan noise has been considerably reduced by the introduction of a newly developed traction motor. In order to reduce wayside noise further, a better understanding of rolling noise is now required.

Studies on theoretical models of rolling noise (such as TWINS [2]) have been carried out in Europe. Figure 2 shows a diagram of the theoretical model on which TWINS is based. In order to estimate rolling noise, wheel and rail roughness spectrum values are needed as calculation parameters, and the frequency responses of railway wheels and tracks are also required for input to the
TWINS model. In this paper, the characteristics of rolling noise are first presented based on field tests. Then, the TWINS model is applied to and validated for Japanese railways. After confirming the applicability of the model, an attempt is made to estimate the effects of wheel and track parameters on rolling noise.

2. Characteristics of rolling noise

2.1 Relationship between rolling noise and wheel/rail roughness

The dominant excitation of rolling noise mainly comes from roughness on wheel and rail surfaces. The wavelengths responsible for rolling noise generation are typically 7 - 70 mm with amplitudes ranging from 0.1 to 100 μm. These values correspond to the frequency components of 500 - 2,000 Hz when a train runs in the velocity range of 50 - 120 km/h (λ=V/3.6f, λ: wavelength (m), f: frequency (Hz), V: velocity (km/h)). Figure 3 shows the spectral difference between roughness before and after grinding the rails at a particular site, and also gives the corresponding difference in noise. For the roughness measurements, the spatial data on the surfaces of the wheel and rail were measured separately. Then, after spectral transformation of the raw data, the wavelengths were related to the relevant frequencies using equation f=V/λ, and the energy summation of 1/3 octave bands was taken. Sound measurements were performed for trailers at a speed of 85 km/h. This is because, as trailers do not have driving devices, the noise they generate consists of rolling noise only. The results of the wheel/rail roughness measurement show trends similar to those of the noise. This suggests that wheel/rail roughness and rolling noise have a broadly linear relationship, and that the excitation of the wheel-rail system is caused by the surface roughness of wheels and rails.

![Fig. 3 Spectral difference in roughness and noise between levels before and after grinding rails](image)

2.2 Wheel/rail roughness

In order to investigate the wheel and rail roughness typical of conventional meter-gauge railway lines in Japan, the surface roughness on both was measured. For the rail, roughness measurements were made at 12 sites on commercial lines (with grinding work: 6 sites, without grinding work: 6 sites). The roughness on wheels used in service was measured for three braking systems ((a) resin block only, (b) sinter block only, (c) disc + resin block). In the measurement procedure, the rail and wheel surfaces were scanned independently of each other. The roughness in terms of amplitude was measured using displacement transducer systems that touch the surface directly. Figures 4 and 5 show the setup of the roughness measurement. The raw data were processed using the maximum entropy method [3] to produce roughness spectra with wavelengths from 2.5 to 250 mm. When processing the data, some consideration had to be taken for small holes (known as pits) on the surface as shown in Fig. 6. These holes can have a significant effect on the high-frequency roughness spectrum, although the wheel/rail does not always trace their profile. Such holes should therefore be dealt with appropriately in the data [4]; they are removed by superimposing the curvature of the wheel onto the roughness data, and by finding the height of the first point to come into contact with a flat surface. Then, the wheel is rotated by one data point, and the height is found again. Figure 7 shows the influence of pits on the wheel roughness spectra. Their removal from the data in this way leads to a significant modification of the spectrum in the wavelength range of less than about 40 mm.

Figure 8 shows the spectra of mean roughness and the range of maxima/minima for two rail conditions (with and without rail grinding work). The surface roughness of the rail with grinding work is about 5 dB smoother.
than that without. For both rail conditions, the variations in the results are in the range of +/-5 dB.

Figure 9 shows the average spatial spectra of all wheels for each category. It is found that, for wavelengths between 7 and 70 mm, spectral differences of less than 5 dB occur for wheels with the three braking systems mentioned above. This indicates that the roughness levels of these wheels were similar to each other in the range of wavelengths where surface roughness is important in rolling noise generation. For the three systems, the variations in the roughness spectra are also in the range of +/-5 dB (not shown here). Comparison of the rail and wheel results shows that the rail without grinding work has a greater level of roughness than the wheels with the three braking systems. This suggests that wheel roughness is maintained to a suitable level, and that rail roughness is more responsible for the generation of rolling noise.

2.3 Vibratory behaviour of tracks and wheels

The excitation of rolling noise is also determined by the vibratory behaviour of rolling stock and tracks, which consist of wheels, rails, rail pads, the roadbed and other components. Figure 10 shows an example of the decay rates of vertical rail vibration for two types of track. These rates were measured by hitting the railhead at many positions along a rail with an instrumental impact hammer. It can be seen that the track decay rate depends on the track type. This indicates that the track type has an influence on the vibratory and acoustic behaviour of the rail. For the wheel, the vibratory and acoustic properties are also dependent upon the type of wheel used [5].
3. Influence of wheel and track parameters on rolling noise

3.1 Validation work for the TWINS model

Measurement sessions were carried out to evaluate and verify the effectiveness of the TWINS model for use in the Japanese system. Train running measurements were carried out for four sites at various speeds in the range of 70 to 300 km/h. Since it is necessary to determine appropriate calculation parameters for use in the TWINS model, static tests were also performed for wheels and tracks separately. For track testing, the parameters in the TWINS model were adjusted appropriately using the measured values. For the wheels, the modal bases were predicted using finite element software and the modal superposition method. It was also necessary to arrange the modal damping ratios of the wheels appropriately using the measured values obtained through the static measurements. In order to evaluate noise and vibration with the TWINS model, a roughness spectrum is required for input to the calculations. The roughness on the surface of wheels and tracks was measured before or after the measurement sessions.

Figure 11 shows the predicted noise plotted against the measured noise in terms of A-weighted levels. The individual points represent the noise for different train runs at one of the four sites. The solid line corresponds to the mean difference between the predictions and measurements (which is +1.0 dB(A)). It is found that the predictions show close agreement with the measured values. Figure 12 shows the individual contributions of noise from the rail, wheel and sleeper to the total prediction in the form of spectra separately. The measured spectra are also shown for comparison. The results indicate that the predicted total noise values agree closely with the measurements. It can be seen that the sleeper is the most important noise source below around 250 Hz, while the wheel is predominant above 2,000 Hz, and rail noise becomes dominant in the frequency range of 500 – 1,600 Hz.

Fig. 10 Example of vertical rail vibration decay rates

Fig. 11 Predicted noise plotted against measured noise for all cases. Symbol key: ○ = Shinkansen railway line; △, ◊, □ = meter-gauge railway lines. The measurement points were located close to the track.

Fig. 12 Predicted and measured noise at 90 km/h. The rail was a single-track type of ballasted construction. Measurement points were located close to the track.

3.2 Effect of track and wheel parameters

The validity of the TWINS model was confirmed in the previous section. To develop measures to reduce rolling noise, this section attempts to investigate the effects of track and wheel parameters on rolling noise using the TWINS model.
3.2.1 Wheel/rail roughness

In order to control rolling noise, it is important to reduce the excitation force in the wheel/rail contact region directly. The simplest way to achieve this is to reduce the roughness amplitudes on the running surface of the wheel and rail. In general, there are a number of useful techniques for wheel- and rail-smoothing, including (1) rail grinding, (2) wheel turning, and (3) the application of a resin (or sinter) abrasive block to the wheel tread.

Here, an attempt to examine the effect of wheel/rail roughness on rolling noise is made by referring to the measured values (see Figs. 8 and 9). Table 1 shows the relative noise levels in dB(A) of five wheel/rail roughness combinations. Through rail-smoothing treatment, the noise could be reduced by up to about 5 dB (Cases A, B and C compared with Case E) because of a spectral difference of about 5 dB results from grinding the rail surfaces until they are smooth. The noise reduction caused by the wheel-smoothing treatment was also found to depend on the conditions of rail roughness. For the rail where grinding work was conducted, a slight noise reduction of about 1 dB(A) was obtained as a result of the wheel-smoothing treatments (Cases A and C). However, the treatments had no noise reduction effect for the rail where no grinding work was conducted (Cases D and E). This is because the roughness level of the rail with no grinding work is greater than that of the wheels (see Figs. 8 and 9).

In general, the running surfaces of rails are smoothed using grinders. However, grinding traces are left on the rail surface, possibly resulting in increased rolling noise. The wavelength of the traces is determined by both the running speed of the rail-grinding machine and the rotation speed of the grinding stones. An attempt is therefore made to control the wavelength of the traces by reducing the running speed of the rail-grinding machine [6].

![Figure 13](image_url)

**Table 1** Effect of wheel/rail roughness on rolling noise generated by trailers running at 100 km/h

<table>
<thead>
<tr>
<th>Case</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth treatment</td>
<td>○</td>
<td>○</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Roughness</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Difference in dB(A)</td>
<td>-3.7</td>
<td>-5.5</td>
<td>-4.8</td>
<td>-0.4</td>
<td>0</td>
</tr>
</tbody>
</table>

3.2.2 Track and wheel parameters

Another effective way of reducing the wheel and rail components of noise is to control the vibratory behaviour of wheels and tracks, and various measures to achieve this have been developed. These include adding damping, structural modification and the use of vibration isolation. For wheels, various dampers have been used in practice, including tuned resonance devices with laminated cover plates, tuned absorbers and constrained-layer damping [7]. An attempt has also been made to develop resilient wheels with a rubber insert between the tread and the inner part of the wheel. For the track, as the noise generated by the rail closely depends on the stiffness of the rail fastening, it is useful to arrange a well-tuned rail pad between the rail and sleeper. Another appropriate method is to increase the decay rate of rail vibration by adding a rail damper to the rail [8].

Figure 13 shows the effect of the two track parameters (rail pad stiffness and additional rail damping treatment) on rolling noise. It can be seen that both variables have a significant influence on noise. The stiffness of the rail pad affects the balance between the rail and sleeper components of noise. Soft rail pads cause the rail to become uncoupled from the sleeper at lower frequencies, and the noise from the rail is increased [9]. Conversely, with stiff pads, the contribution from the rail is reduced, but that from the sleeper is increased [10]. Figure 14 shows the effect of rail pad stiffness on the vertical response of the rail. A softer rail pad lowers the frequency at which the rail resonates on the rail pad, which results in a greater rail response on a soft rail pad at lower frequencies. Damping treatment is effective in reducing the rail component of noise. Figure 15 shows the decay rate of the rail for two damping conditions, and indicates that additional damping for the rail has the advantage of creating a high decay rate for rail vibration. As a result of the treatment, waves propagating along the rail therefore travel over a shorter distance, and noise from the rail is in turn reduced significantly.

Wheel noise depends on the type of wheel used, since the response of wheels is affected by their geometry. Table 2 shows the relative noise in dB(A) of three types of wheel compared with the results of the A-type wheel. The C-type wheel has a straight web, and the web region of the A-type wheel is singly curved in the radial direction. For A-type corrugated and NA-type corrugated wheels, the web is doubly curved in both the radial and circumferential directions. It is found that the C-type wheel is qui-
eter than the others, and the noise of wheels with thinner webs is greater. This suggests that the noise radiation of wheels depends on the wheel web configuration. Figure 16 shows the noise of each wheel type relative to the results of the A-type wheel. It can be seen that, for the C-type wheel, the variations in relative noise are smaller in the frequency range where the wheel is the predominant noise source (i.e., above 2,000 Hz).

<table>
<thead>
<tr>
<th>Wheel condition</th>
<th>C-type wheel (web thickness: 28 mm)</th>
<th>A-type corrugated wheel (web thickness: 10 mm)</th>
<th>NA-type corrugated wheel (web thickness: 12 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise level in dB(A) relative to the results for the A-type wheel (web thickness: 18 mm)</td>
<td>-3.5</td>
<td>1.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

4. Conclusions

Field tests showed that the excitation of rolling noise is determined by both the wheel/rail roughness and the vibratory behaviour of rolling stock and tracks. In terms of roughness, the rail with grinding work was about 5 dB smoother than that without, and spectral differences of less than 5 dB occurred for the wheels with the three braking systems outlined above. To validate the TWINS model for rolling noise prediction, a comparison with measured values was carried out for Japanese railways. In terms of noise spectra, the rail contributes more to rolling noise than the wheel in much of the frequency range. An attempt to estimate the effects of track parameters on rolling noise was also made using the TWINS model. It was found that the stiffness of the rail pad has a great influence on the balance between the rail and sleeper components of noise. Additional damping for the rail is effective in reducing the rail component of noise.

References


