inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 0.0

EFFECTS OF TRANSVERSE PROFILES OF WHEELS ON RAILWAY NOISE

R. Van Haaren*, D. Thompson**

* AEA Technology Rail BV, P. O. Box 8125, 3503 RC, Utrecht, Netherlands

** ISVR, University of Southampton, Highfield, SO17 1BJ, Southampton, United Kingdom

Tel.: +31 30 235 5160 / Fax: +31 30 235 7329 / Email: rik.vanhaaren@nl.aeat.com

Keywords:
ROLLING NOISE, TRANSVERSE PROFILES, WHEEL/RAIL CONTACT, ROUGHNESS

ABSTRACT
It can be expected that transverse wheel profiles will affect train rolling noise, although it was unclear from previous work whether hollow wheel profiles would increase or decrease the noise emission. By a combination of acoustic measurements and numerical modelling, the effect of transverse profiles has been analysed in detail. The experiments consisted of detailed roughness, profile and noise measurements of trains having wheels with different transverse profiles. Hollow wheel profiles produced higher noise levels for a given roughness level. The numerical analysis points out that conforming wheel and rail profiles generally lead to an increase in rolling noise, consistent with the experimental results. This is largely due to higher roughness at the edge of the contact region on the wheels studied. Moment excitation, due to variations in contact patch location is found to be a significant excitation mechanism in some extreme cases of conforming profiles.

1 - INTRODUCTION
Rolling noise emitted by trains results from irregularities of the wheel and rail surface. These irregularities, called roughness, induce dynamic forces which excite the wheel and rail, the vibration response of which results in noise radiation. Transverse wheel profiles (the shape of the wheel running surface in the direction transverse to rolling) are thought to affect rolling noise emission. However, it was unclear from previous work whether hollow wheel profiles would increase or decrease the noise emission. Remington and Webb reported theoretical results indicating that conforming profiles may be beneficial to noise reduction [1]. Dings and Dittrich reported experimental results of noise and roughness measurements of wheels having different types of braking system [2]. The wheels with the smoothest surface were not the quietest, and it was suggested that this was caused by hollow wear due to some of the types of braking system.

In the project Silent Freight special attention was aimed at determination of the effect of hollow wheel profiles on noise emission. By a combination of acoustic measurements and numerical modelling, the effect of transverse profiles has been analysed in detail. The experiments consisted of detailed roughness, profile and noise measurements of trains having wheels with different transverse profiles. TWINS, the numerical tool to estimate rolling noise [3,4], cannot be used to analyse the effect of transverse profiles directly, as these affect the rolling behaviour of the wheel and the contact position. A first step in the numerical analysis, therefore, was the calculation of the wheelset dynamics from which stable and unstable wheelset positions were identified.

The influence of various parameters on the noise radiation has been assessed numerically. Transverse wheel and rail profiles affect three parameters that play a major role in the excitation mechanism of rolling noise: lateral contact location, contact stiffness (stiffness of the contact patch) and the effective radii of curvature. In an earlier stage of the project, results have been reported on numerical simulation of the effects of these parameters [5]. Additionally, differences of the wheel roughness across the profiles were assessed. However, differences remained between numerical and experimental results. This paper describes the effect of an additional parameter: moment excitation due to variations in contact patch location.

2 - EXPERIMENTAL RESULTS

Measurements were made of detailed roughness and transverse profiles for both wheel and rail, for three trains having different types of brakes. In total nine similar 920 mm diameter wheels have been measured, three for each type of braking system: disc brakes with additional cast-iron brakes, additional sinter block brakes and additional magnetic brakes. The latter have no tread brakes at all. The wheels were selected to have various levels of wear, having run between 53000 and 489000 km since last reprofiling. The wheel roughness was measured on 25 parallel lines around the wheel, at a spacing of 2 mm. The transverse profile of each wheel was also measured.
During the passage of the trains at 120 km/h, noise was measured at 1 m from the track. A location this close to the track allowed the noise from individual wheels to be separated. Noise levels were averaged over 4 microphones, 1 m apart. The rail roughness and profile were also measured. The rail roughness was recorded over a length of 10 m, and for the 4 m in front of the microphones in greater detail.

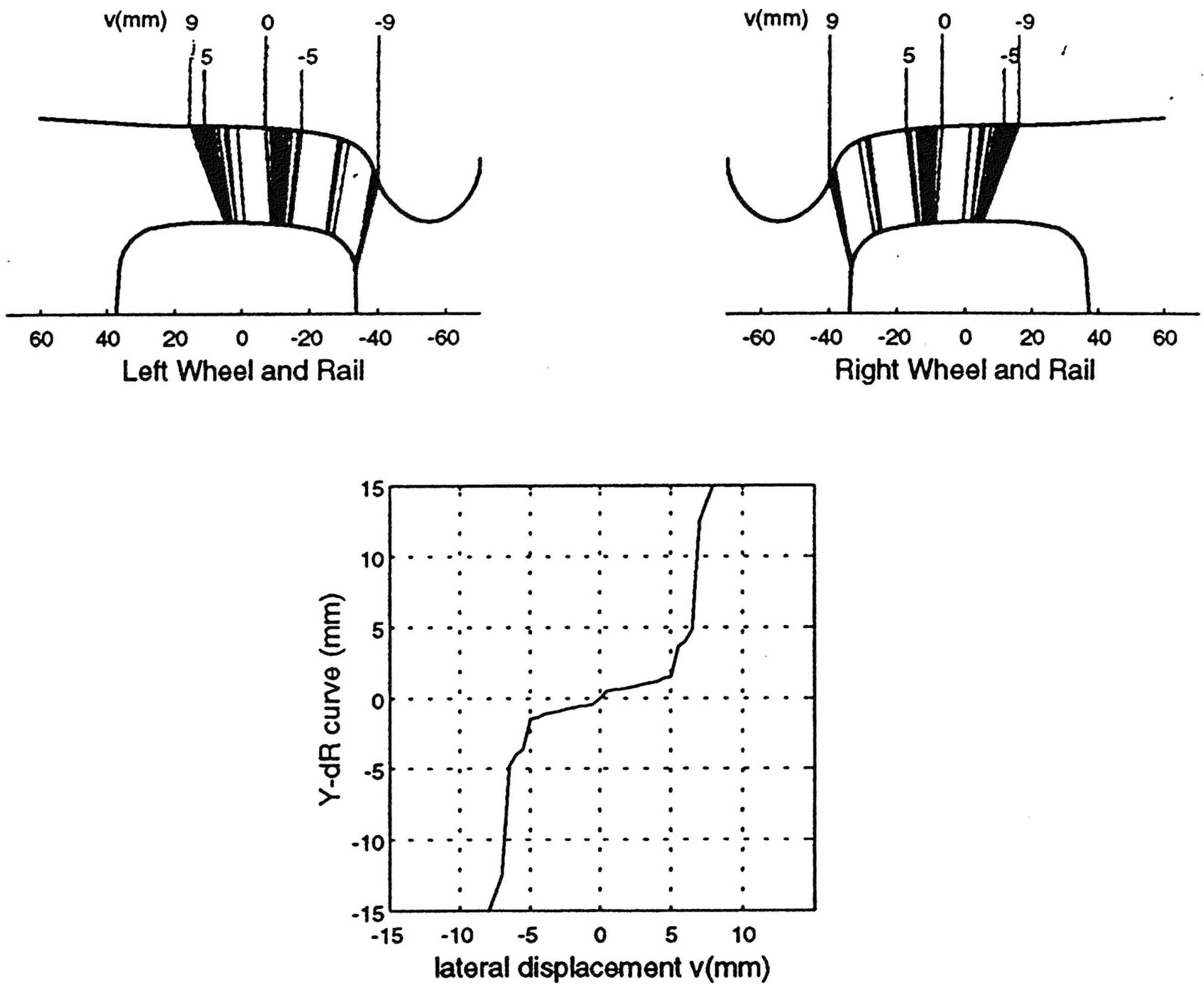


Figure 1: Transverse profile of a standard wheel (S1002) and rail (UIC54) profiles.

The measured transverse profiles of wheel and rail have been used to analyse the contact geometry. Figure 1 shows the contact positions on both wheel and rail, with standard profiles, for each lateral displacement (Y) of the wheelset. The lines join contact points on wheel and rail. The graph plots the difference in rolling radius of the two wheels versus the lateral displacement of the wheelset. In the central position both wheel radii are equal, resulting in a stable position. A change in lateral position will result in a change in rolling radii, which will tend to bring the wheelset back to the central position. Figure 2 shows an example of the contact positions for worn wheel and rail profiles. This time a stable central position does not occur. The graph shows two stable positions, where the rolling radius difference is zero and the curve has a positive gradient. In between these points, there is a third equilibrium position, which is unstable due to the negative gradient.

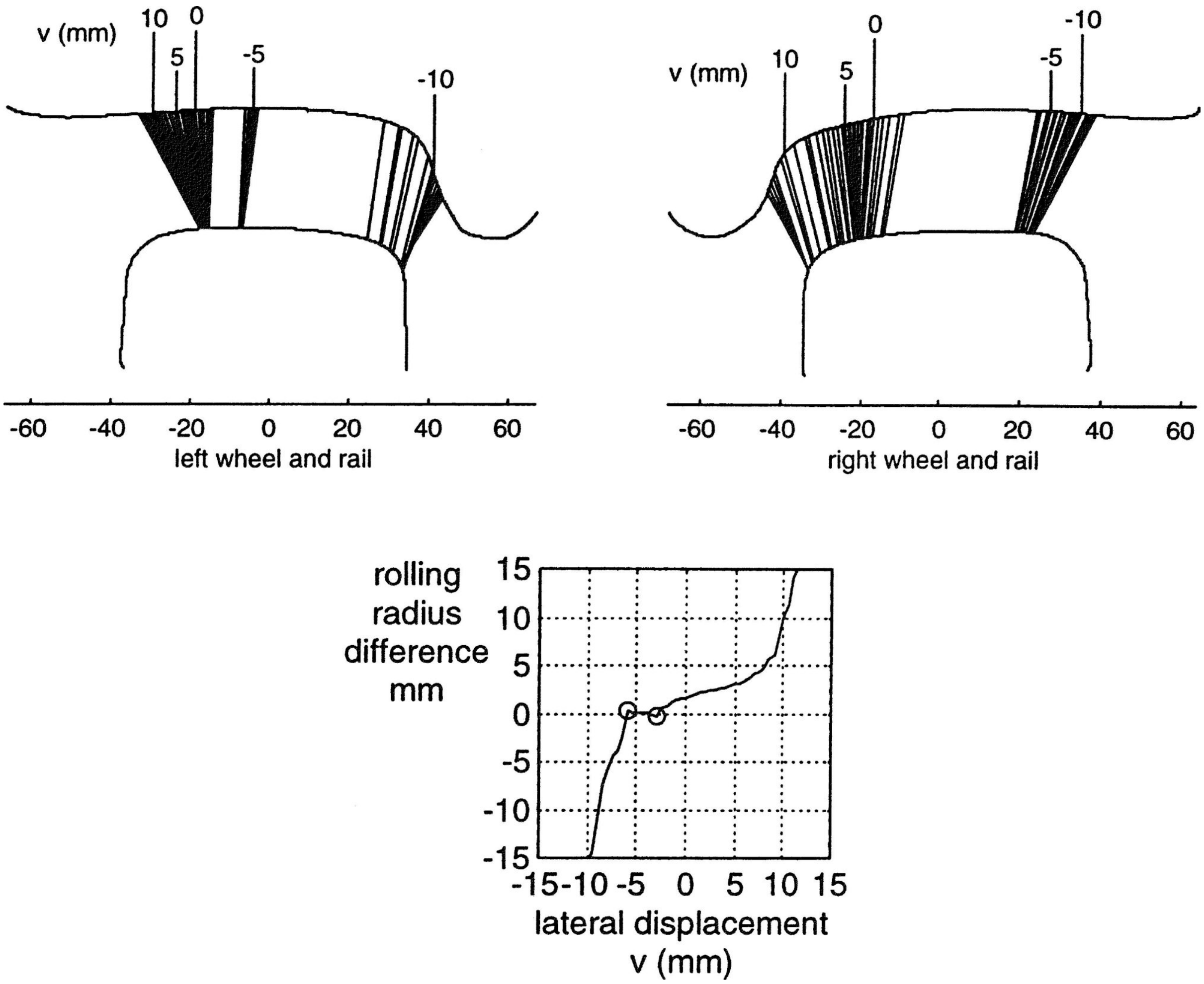


Figure 2: Transverse profile of a worn wheel profile (sinter block tread braked) in combination with a UIC54 rail type.

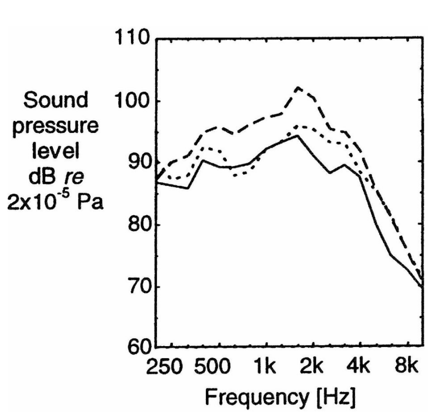
The actual contact location plays a vital role in the excitation mechanism and has been used in the parametric study in order to determine effect of conforming profiles on rolling noise.

Figure 3 shows the actual measured sound pressure and roughness spectra. These are averaged for each type of braking system. Since TWINS [3,4] is a linear model, one would expect differences in roughness spectra to be reflected directly in the noise spectra. As in ref. [2], however, the smoothest wheels (with sinter block brakes) are not the quietest. These were found to have hollow wear, as indicated in ref. [2], but the other worn wheels also exhibited such wear, and this by itself does not explain the anomalies between roughness and noise behaviour in Figure 3.

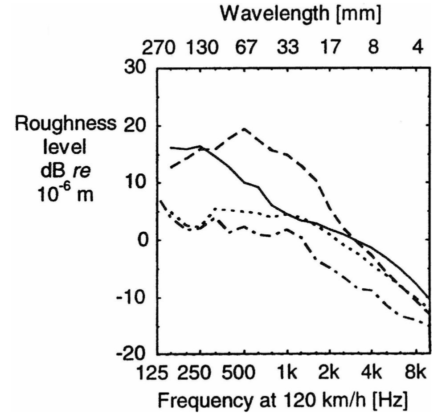
3 - MODEL FOR MOMENT EXCITATION

In a previous paper the effect of a number of parameters has been assessed using TWINS and compared to the above measurement results [5]. The effect of the averaging of roughness across the contact patch has been shown to have a moderate effect on rolling noise. The sensitivity of the contact stiffness was also investigated but found to have only a small effect. The roughness of the sinter block wheels was found to be greater away from the centre of the tread, and very low at the centre. Taking these higher roughness levels into account partly explains the differences in roughness to noise levels of the wheels having different type of brakes. Sinter block braked wheels with conforming profiles showed 4 dB higher average roughness levels taking the roughness at the edge of the contact region into account, than coned wheel profiles. In case of non tread braked wheels this difference was negligible.

Another reason for the differences of Figure 3 could be found in excitation of the wheel/rail system by moment excitation, as a result of variation in the nominal contact location due to surface irregularities.



(a): Average sound pressure levels at 1 meter.



(b): Average roughness at 1 meter.

Figure 3: Continuous: disc brakes, dashed: cast-iron block brakes, dotted: sinter block brakes, dash-dot: rail.

This is investigated in this paper. Looking at Figure 2, it appears that the nominal contact position can jump quite large distances across the running surfaces for small changes in wheelset position. This phenomenon corresponds, in fact, to the *stable* lateral *wheelset* positions. Since roughness is added to these profiles, the exact profile varies slightly with distance along the track, and this may induce fluctuations in the contact position even for a constant wheelset position. If the location of the vertical load moves laterally in an oscillatory way it will induce a fluctuating moment between the wheel and rail relative to a fixed nominal contact position. As indicated in ref. [6] this may be an additional source of excitation of the wheel/rail system. If the lateral motion of the wheelset relative to the track was also included, additional moments could be generated.

In order to investigate this effect a model using TWINS has been developed and applied to the measurement data. It is assumed that the wheelset is at a stable position and a fixed nominal contact position is selected.

The normal load at the contact point between wheel and rail is the sum of the static and the dynamic load $P_{tot}=P_0+P$. In the TWINS calculation model only the dynamic component is used. If the centre of the contact patch moves laterally a distance ε, the normal load P_0+P induces a moment $\varepsilon\times(P_0+P)\approx\varepsilon\times P_0$ about the rolling direction. The variation in this moment supplies a dynamic moment load that excites the wheel/rail system.

Using the DPRS (discrete point reacting spring) module [1] in the TWINS program with the detailed measurements of roughness and transverse profiles described above, the moment about the rolling direction can be derived at each position along the track.

The signal is then converted to the frequency domain by Fourier transformation, and then to third octave bands. The excitation of the wheel/rail system by this moment is described in ref. [6].

4 - NUMERICAL RESULTS

Average roughness levels and moment levels have been determined based on the measurement data for each wheel. Figure 4 shows the results for a cast-iron block braked wheel for different transverse profile radii of the wheel.

This figure clearly shows that the moment excitation increases considerably in importance as the contact becomes more conforming. TWINS calculations have been carried out using this a fixed transverse radius of curvature, which is an assumption in DPRS module. The wheel radius of -330 mm and a rail radius of 300 mm result in an equivalent transverse radius of 3300 mm, which is used for the calculation of the sound power level.

Figure 5 shows the calculated noise levels due to roughness and moment excitation, for the same wheel as the figures above. In case of the coned wheel the moment excitation is not significant. The conforming profile increases the noise due to moment excitation by 16 dB so that it is only 7 dB(A) less than the conventional roughness excitation.

Sets of roughness data for the other measured wheels result in moment excitation noise levels that vary between 2 and 15 dB(A) below the roughness excitation. Therefore, it may be concluded that moment excitation can be a significant additional mechanism for conforming profiles in extreme cases comparable

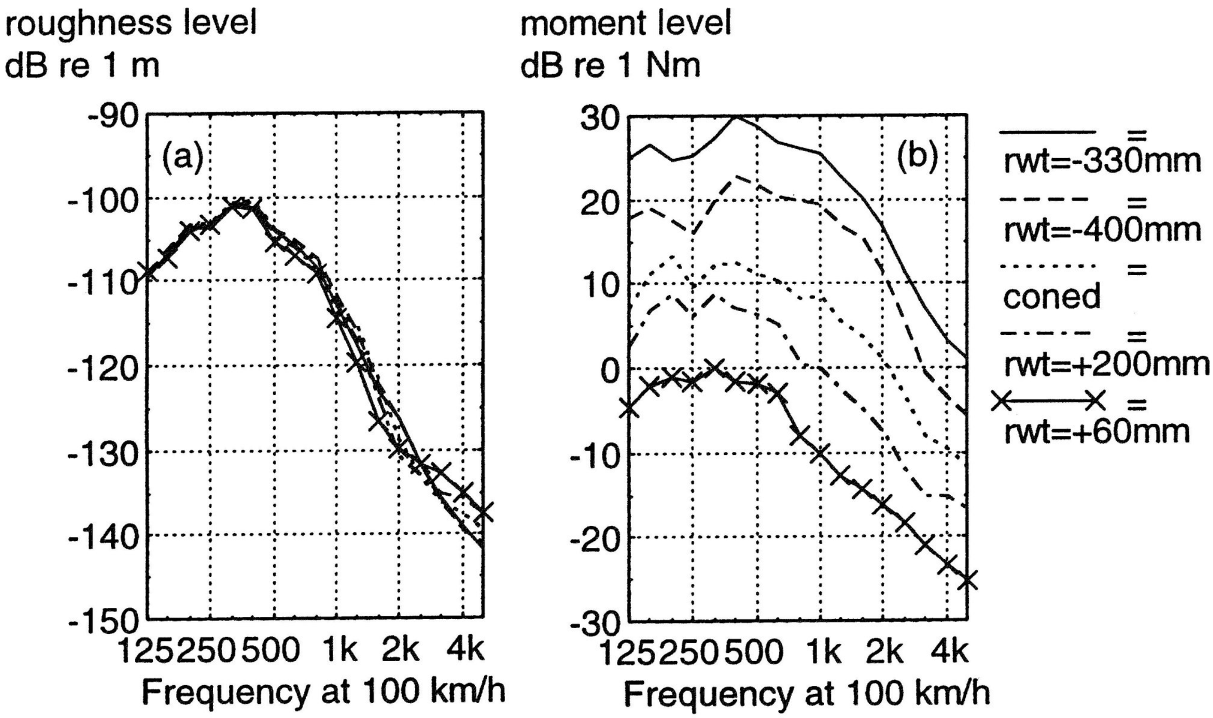


Figure 4: Equivalent roughness level and moment level from measured roughness and different transverse radii.

to conventional roughness excitation.

5 - CONCLUSIONS

Acoustic measurements show that hollow wheel profiles produce higher noise levels for a given roughness level. The numerical analysis points out that conforming wheel and rail profiles generally lead to an increase in rolling noise, consistent with the experimental results. This is largely due to higher roughness at the edge of the contact region on the wheels studied. Additionally, moment excitation due to variations in contact patch location has been analysed quantitatively. In extreme cases of conforming wheels and rails, the noise level due to this excitation mechanism is comparable to that of roughness excitation.

ACKNOWLEDGEMENTS

This work was performed within the EU Brite Euram project Silent Freight (BE95-1238), coordinated by ERRI. The wheel roughness measurements were carried out by TNO-TPD.

REFERENCES

1. **P.J. Remington, J. Webb**, Wheel/rail noise reduction trough profile modification, *Journal of sound and vibration*, Vol. 193, pp. 335-348, 1996
2. **P.C.G.J. Dings, M.G. Dittrich**, Roughness on Dutch railway wheels and rails, *Journal of sound and vibration*, Vol. 193, pp. 103-112, 1996
3. **D.J. Thompson, B. Hemsworth, N. Vincent**, Experimental validation of TWINS prediction program for rolling noise, Part 1: Description of the model and method, *Journal of sound and vibration* , Vol. 193, pp. 123-135, 1996
4. **D.J. Thompson, P. Fodiman, H. Mahe**, Experimental validation of TWINS prediction program for rolling noise, Part 2: Results, *Journal of sound and vibration*, Vol. 193, pp. 137-147, 1996
5. **D.J. Thompson, P.J. Remington**, The effect of transverse profiles on the excitation of wheel/rail noise, *Journal of sound and vibration*, Vol. 231, pp. 537-548, 2000
6. **D.J. Thompson**, *Wheel/rail noise - theoretical modelling of the generation of vibrations*, Ph.D. thesis, University of Southampton, 1990

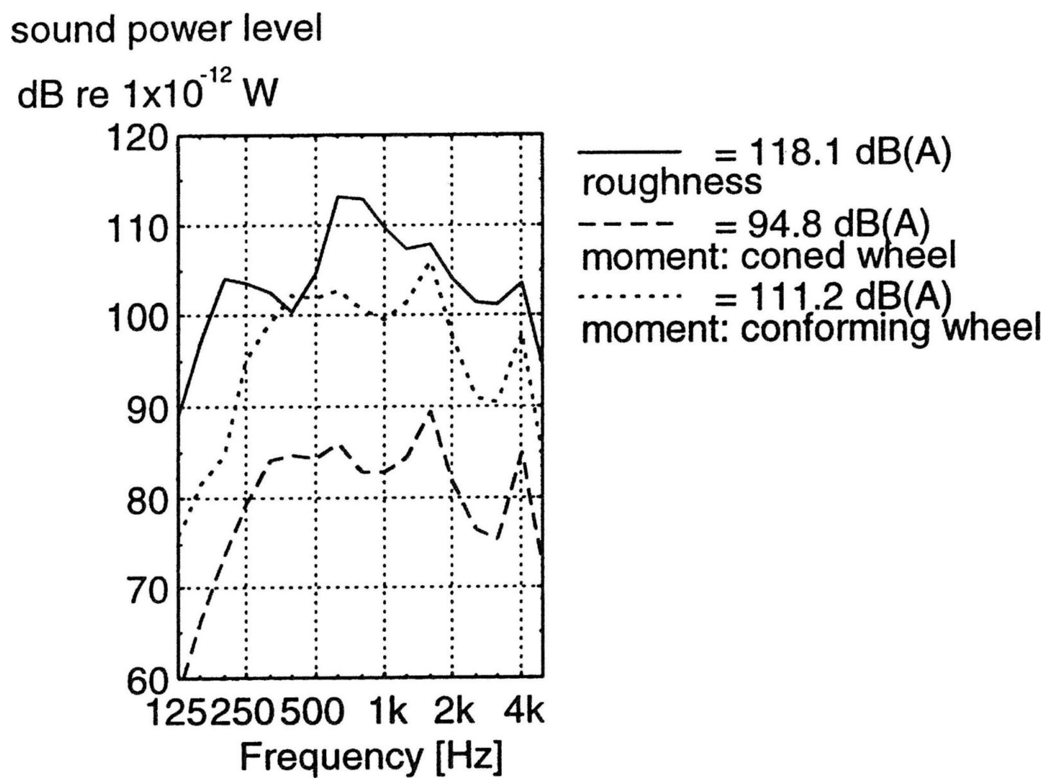


Figure 5: Sound power level due to roughness and moment excitation, for a cast-iron braked wheel, with standard (coned) and conforming wheel profile.