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STUDY OF THE EFFECT OF BALLAST PROPERTIES AND WHEEL GEOMETRY ON ROLLING NOISE

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ABSTRACT

Railway rolling noise can have pernicious effects on human health, especially in urban areas. To address this issue, the present work aims to reduce the total rolling noise radiated by the wheel, rail and sleeper through a comprehensive vibroacoustic model of the wheel and track that incorporates their dynamic interaction. The methodology associated with the acoustic calculation includes the characterization of the wheel using an axisymmetric approach with a view to reducing the computational requirements. The mitigation strategy focuses on analyzing the influence of wheel geometry and ballast characteristics on the radiated sound. Statistical techniques are used to quantify these effects and identify design modifications that minimize noise emission.

Keywords: *wheel geometry, ballast properties, rolling noise, mitigation.*

1. INTRODUCTION

Railways are a sustainable means of transport, since they are climate friendly for both passengers and goods. Therefore, it is expected that railway traffic will increase in the future, which brings the risk of an increase of noise emissions and the associated effects on people and ecology [1]. According to the World Health Organization (WHO), railway noise can produce annoyance, an increase in the risk of IHD and hypertension, sleep disturbance, hearing impairment, with increasing evidence for other health impacts such as adverse birth outcomes and mental health problems [2]. In this sense, in a previous work the influence of the wheel geometry on the sound power level (SWL) was carried out by the research group [3] and the main parameters affecting the rolling noise were determined to provide a guide for sound mitigation design. It should be noticed that to calculate the rolling noise, a comprehensive model was used. This model took into account several railway elements such as the wheel, the rail and the sleeper. Nevertheless, in that study, the ballast properties were considered constant. Thus, in order to extend the previous work, in the current study, the properties of the ballast are modified to analyze their influence in the wheel geometry for the rolling noise reduction.

2. METHODOLOGY

2.1 Vibroacoustic model

The dynamic behaviour of the wheel has been obtained by means of the Finite Element Method (FEM) considering an axisymmetric model [4]. When the wheel interacts with the rail, a contact force appears between them. The vibration of the wheel is characterized through its vibration modes, which can be classified by the number of nodal diameters (number of nodal lines crossing the wheel through its centre) of each modeshape [5]. Subsequently, the modes influencing the wheel motion are grouped to assess the acoustic radiation resulting from the vibrational field on the wheel surface [5]. In addition, the contact force generates structural waves that travel along the track. These waves can be analyzed by means of the model proposed by Mead [6]. It proposes to use a FE approach for a finite track, enabling the calculation of the displacement at any point on the track as a superposition of waves [7]. In this study, the sound emission of the track takes into account the contributions from both the rail and the sleeper. Additional details of the acoustic models of these two components can be found in references [7, 8], where the 2D radiation of the track cross section is calculated and expanded to a 3D

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acoustic field. It is worth mentioning that the acoustic power is proportional to the dynamic response of a component. Consequently, the radiation of the devices constituting the track can be evaluated as the superposition of the contribution of each wave. The above-stated contact force between the rail and the wheel is assessed by means of the interaction approach proposed by Thompson in reference [9]. In the current study, the interaction force is evaluated from the wheel and the rail roughness, since it serves as an excitation source generating vibrations in the railway components. The roughness spectrum considered in this work is available in EN13979-1 [10].

2.2 Influence analysis of the wheel and ballast parameters on the radiated noise

The main objective of the current study is to analyse the influence of the railway wheel geometry and the ballast properties on the total sound radiation contributed by the wheel and the track (rail and sleeper). The sound emission of the isolated wheel has not been considered because the track and the wheel are coupled through the interaction force. The cross section of the wheel geometry has been defined considering three main design variables (see Fig. 1), while keeping the rest of the geometry constant. These variables were obtained from a previous work, where they demonstrated to be the most relevant parameters [4]. Thus, the design variables under study for the wheel are the angle of the web (c_{web}), the height of the tyre (h_{tyre}) and the radius of the wheel (r_{wheel}). The ballast properties being evaluated are the stiffness ($k_{ballast}$) and damping ($\eta_{ballast}$).

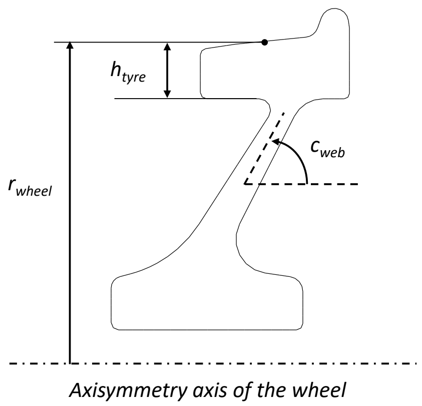

Figure 1. Parameters defining the wheel geometry.

Therefore, in order to assess the influence of these parameters on the total sound emission, a factorial design has been carried out, where all the possible combinations have been taken into account. Then an ANOVA has been performed to study the influence of each variable on the sound radiation. The results provide an insight into the effects of these variables on the acoustic behaviour. The total acoustic power has been calculated considering the energy contained in the frequency spectrum for the A-weighting sound levels.

The influence of each parameter describing the wheel geometry and the ballast properties and its importance (see Fig. 1) is quantified following the approach proposed by Pratt [11] from the set of designs provided by a factorial combination. With the purpose of quantifying the influence of each one of these variables, a polynomial regression has been implemented and it can be written as

$$\hat{y} = \sum_j \alpha_j x_j \tag{1}$$

where $\hat{y}$ is the adjusted response of the total sound power (wheel + track) for each combination of the set of designs (each one of them requires to be previously standardized to unit variance and null mean), x_j the standardized j^{th} effect and α_j the j^{th} coefficient. It is necessary to point out that an effect does not necessarily have to be a variable, but it can be an interaction between two different parameters, or it can incorporate a term raised to a power.

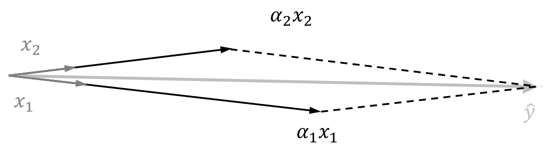

Figure 2. Vector subspace of the regression model.

As depicted in Fig. 2, the $\hat{y}$ value can be obtained from a vector space constructed from a linear combination of the standardized factors x_j. Accordingly, the importance of the j^{th} effect can be calculated from the projection of $\alpha_j x_j$ onto $\hat{y}$ as follows

$$d_j = \hat{y} \cdot (\alpha_j x_j) \tag{2}$$

d_j being the proportion of variance in $\hat{y}$ related to the j^{th} effect. Thus, the coefficient of determination R^2 of the regression model can be obtained considering the cumulative importance contributed by all the significative effects.

3. RESULTS

In order to study the influence of the wheel design parameters and the ballast properties on the total SWL, an

analysis has been carried out considering 3 levels for each parameter under study and all the possible combinations between these variables. These sets of designs allow assessing the total sound power for each configuration through the computational tool previously described in Section 2.1. The significant effects have been evaluated in an ANOVA according to Pratt's methodology to obtain the importance of each effect.
The results of this analysis show that the most relevant parameter explaining the total sound emission is the web angle (c_{web}) with an importance of 69.13%, followed by the ballast stiffness ($k_{ballast}$) with an importance of 8.08%, as well as by the height of the tyre (h_{tyre}), the damping of the ballast ($\eta_{ballast}$) and the radius of the wheel (r_{wheel}) with an approximately 4% each one of them, as it can be inferred from Fig. 3.

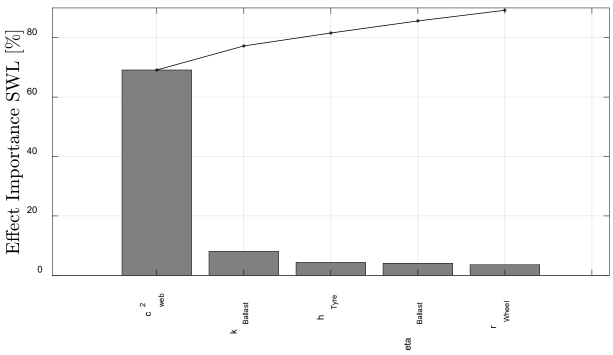

Figure 3. Importance and cumulative value of the significant effects.

The design patterns identified for the wheel in [4] can be observed once again in the present study, that is, sound radiation increases as the inclination angle of the web deviates from 90°, which can be attributed to the coupling between the radial and axial dynamics of the wheel, resulting in higher SWL. Concerning the wheel radius, the general trend indicates that larger radii correspond to higher sound emissions. Additionally, sound power decreases as the tyre height increases. Nevertheless, when compared to the results obtained in a previous study [4], the height of the tyre seems to have more importance than the wheel radius as a result of the inclusion of ballast properties as variables. These new variables show that as the values of the stiffness and damping increase, the sound power level decreases.
The total sound power of the optimal solution is 98.1 dB, while the worst configuration presents a noise emission of 107.4 dB, leading to a difference of approximately 9.3 dB between both configurations. The parameters for the wheel design and for the ballast properties are shown in Tab.1.

Table 1. Values for the optimal and worst wheel design parameters and ballast properties.

	c_{web} (º)	h_{tyre} (mm)	r_{wheel} (mm)	$k_{ballast}$ (MN/m)	$\eta_{ballast}$
Best	90	90	625	150	2
Worst	60	55	625	50	1

The SWL of the optimal and the worst configurations is shown in Fig. 4. It should be noticed that both configurations have the same radius. The explanation of this can lie in the fact that, for the optimal design, the contribution of the rail and the sleeper is higher than the contribution of the wheel. In addition, the interaction between the wheel and the track increases for wheels with smaller radii.

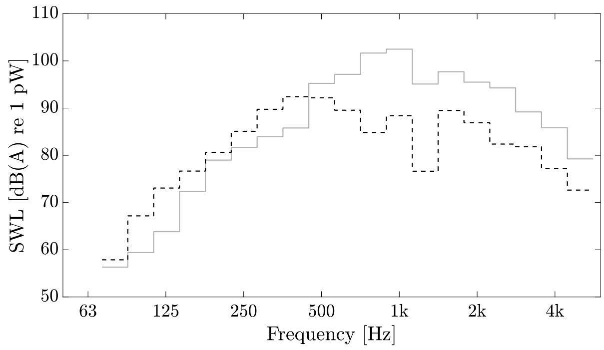

Figure 4. SWL in one-third-octave bands for optimal (---) and worst (—) designs.

4. CONCLUSIONS

A parameterization for the wheel geometry and the ballast properties has been carried out in order to define a set of experiments to assess the influence of these elements on the SWL. The wheel geometry has been defined according to its three main parameters, that is, the inclination angle of the web, the radius and the heigh of the tyre, while the ballast is defined by its stiffness and damping. The SWL includes both the sound emissions of the wheel and track (rail and sleeper), since they can be affected due to the coupling with the wheel through the interaction force.
The study has shown that the main variables contributing to the sound emission are the inclination angle of the web of the wheel and the stiffness of the ballast. It has been found that, as a general trend, the lowest emissions are achieved by webs placed at 90° (straight webs), smaller wheel radii, and higher values of the height of the tyre, the stiffness and

damping of the ballast. The optimal design found presents a sound power level 9.3 dB(A) lower than the worst design of the wheel and ballast.

5. ACKNOWLEDGMENTS

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