Proceedings of the Seventeenth International Conference on
Civil, Structural and Environmental Engineering Computing
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 6, Paper 13.2
Civil-Comp Press, Edinburgh, United Kingdom, 2023
doi: 10.4203/ccc.6.13.2
©Civil-Comp Ltd, Edinburgh, UK, 2023

Optimization of the Sound Insulation Performance of a Train Body Profile in the Pantograph Area of a High-speed Train

S.S. Ding, A.Q. Tian, Y.J. Zhao, J. Du, Y. Chen

Engineering Research Centre
CRRC Qingdao Sifang Co., Ltd, China

Abstract

In this paper, the sound insulation characteristic of high-speed train body profile in pantograph area is simulated and optimized based on the hybrid finite element-statistical energy analysis (FE-SEA) method. After optimization, the new profile structure is determined according to the noise characteristic of pantograph area, which parameters are: the thickness of upper plate, lower plate and rib plate is respectively 2.8mm, 3.3mm, and 1.5mm, and the angle of rib plate is 63 degrees. Maximum weighted transmission loss shown in this case. Compared with original profile model, the transmission loss data of optimized model increased by 4.2dB, and the mass data increased by 5.2%.

Keywords: high-speed train, train body profile, sound insulation, hybrid finite element- statistical energy analysis method, simulation, optimization.

1 Introduction

With the rapid development of high-speed train noise research, people have more in-depth and detailed studies on complex noise characteristics and mechanisms of different vehicle components. Aiming at the focus area of noise research on high-speed train, train body profile is not only the main bearing structure, but also the key component of the sound insulation of the high-speed train body. Analysis and optimization on sound insulation characteristics of the roof profile is always been the research priority for many experts and scholars [1].

Many scholars do plenty of relevant studies centring on this topic, including theoretical research, experimental research and numerical simulation research. Kohrs and Petersson [2] predict the wave propagation and vibrational behaviour in lightweight plates with truss-like cores using periodic sub-structure method. Orrenius and Kunkell [3] establish the roof structural acoustic model with pantograph of high-speed train based on finite element method and statistical energy analysis, and calculate the contribution of exterior acoustic source to interior noise under different transmission paths. Cotoni and Langley [4] build hybrid FE-SEA model of train body profile and predict its sound insulation using wave-based SEA method. Strano and Genovese [5] create periodic structural model of roof profile using the VA One software, studies show that the sandwich structure made of composite materials provides good results in terms of weight and vibro-acoustic behaviour. Xie and Thompson [6] study on sound insulation characteristics of aluminium profiles based on SEA method, further studies show that predicated structural response essentially agrees with the experimental results when force excites the structure, while certain differences exist under acoustic excitation. Yao and Zhang [7] propose a lightweight design instruction approach based on the vibration response of railway floating floor structures in commercial software VA One and Isight.

The above literatures mainly focus on theoretical research and numerical simulation. However, the complexity of profile structure leads to many difficulties- such as heavy workload and long experiment period- on the way to improve its sound insulation performance. The simulation results are very sensitive to the change of design parameters. Many studies are not suitable for the evaluation of noise reduction scheme in the initial stage of product design, for they need repeated modelling and calculation, or there exists a certain degree of uncertainty.

In this article, we study approach referring to above research methods, combined with the actual engineering background, and establish optimization model of profile based on the hybrid FE-SEA method, further researches studied on improving the sound insulation characteristics of train body profiles in pantograph area.

2 Simulation on Sound Insulation of Profile

For train body profile in pantograph area, we choose the periodic reinforcement structure in the middle of the profile for simulation analysis, considering the solving time cost of optimization simulation. The profile is composed of three parts: upper plate, lower plate and rib plate, as shown in Figure 1.

Aluminium alloy profile has a density of 2700kg/m^3, an elastic modulus of 7.0GPa and a Poisson's ratio of 0.3. Total length of the profile is 1200mm, and the stretching length is 1500mm.

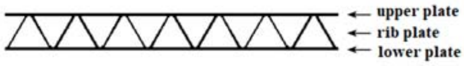

Figure 1: Sectional view of profile.

Variables	Thickness of upper plate [mm]	Thickness of lower plate [mm]	Thickness of rib plate [mm]	Angle of rib plate [°]	Total thickness [mm]
Value	3	3	1.5	60	50

Table1: Parameters of profile.

The simulation of sound insulation of train body profile in pantograph area is based on hybrid method of finite element and statistical energy analysis. Considering that profiles are mainly composed of thin plates, two-dimensional shell element is adopted in order to improve the accuracy of simulation and reduce time of optimization calculation.

Define the properties of material, including density, Poisson' ratio, Young's modulus, and physical properties, such as the thickness of plates. Set fixed translation constraint on the nodes around the edges of profile. Define the finite element model of train body profile as structural grid, which is the deterministic subsystem in the hybrid model. Create diffuse acoustic field on the outside of train body, set semi-infinite field inside the train body, and apply measured acoustic excitation data. Simulated the incident sound field and radiation sound field respectively as the uncertain subsystem in the hybrid model. Calculated sound insulation in the frequency range of 100-4000Hz. This hybrid model for calculating sound insulation performance based on FE-SEA method is shown in Figure 2.

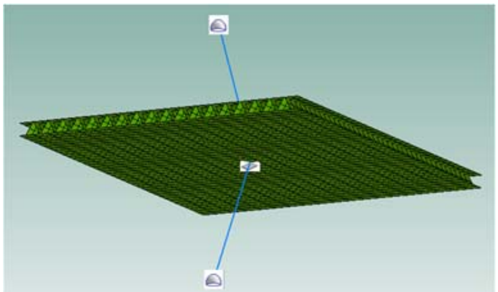

Figure 2: Simulation model of sound insulation.

3 Sensitivity Analysis of Design Parameters

Based on sensitivity analysis method, the main design parameters affecting sound insulation characteristics of the train body profile structural in pantograph area are found out, such as thickness of upper plate, thickness of lower plate, thickness of rib plate and angle of rib plate. Create script files in VA One software to drive parameter changes and automatically create profile sound insulation simulation model, integrate ModelCenter software for sensitivity analysis, and adopt DOE full factor algorithm in the process.

In the optimization model of sensitivity analysis, ranges of design parameters such as the thickness of upper plate, the thickness of lower plate, the thickness of rib plate and the angle of rib plate angle are shown in Table 2:

Variables	Lower bound	Upper Bound
up thick	2mm	3mm
down thick	2mm	3mm
rib thick	1mm	2mm
Degree	40degree	70degree

Table 2: Setting of variables in sensitivity analysis.

The result of the sensitivity analysis is shown in Figure 3, after calculation of 81 runs.

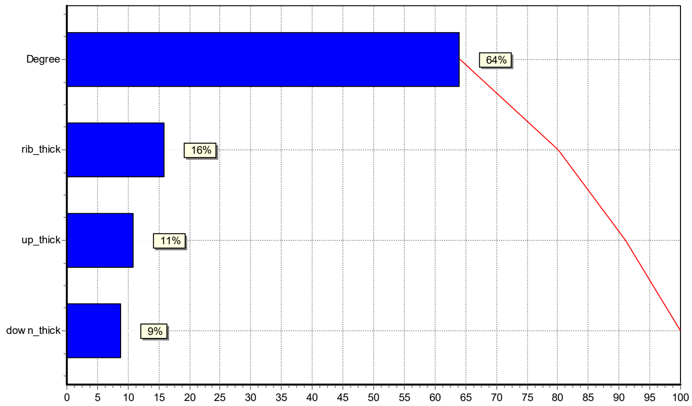

Figure3: Result of sensitivity analysis.

As we can see from the figure, for the main design parameters of profile structure in pantograph area, angle of rib plate is the key design parameter that should be mainly considered in the multi-parameter optimization, which has a great influence on the results (64% as shown in the figure). In the next place, the other main design parameters are thickness of rib plate (16%), thickness of upper plate (11%), and thickness of lower plate (9%) ordered by contribution. The following emphatic analysis is the influence of the change of key design parameter in the sound insulation performance of train body profiles.

4 Impact Analysis of Changed Key Parameter

Through the results of sensitivity analysis above, we choose the key design parameter-angle of rib-which affects the sound insulation performance of train body profile, and use the DOE algorithm to complete a single variable optimization analysis.

The angle of rib plate is taken as the design variable, and other parameters remain unchanged. By calculating the weighted transmission loss (Rw) of the model, the variation law of sound insulation quantity is obtained as the angle of rib plate changes. Define the design variable as the rib of angle, and set the variation range of angle parameter to 39-70 degrees, with optimization iteration by every 1 degree.
After 32 iterations, the optimization analysis result of rib angle parameters is shown in Figure 4.

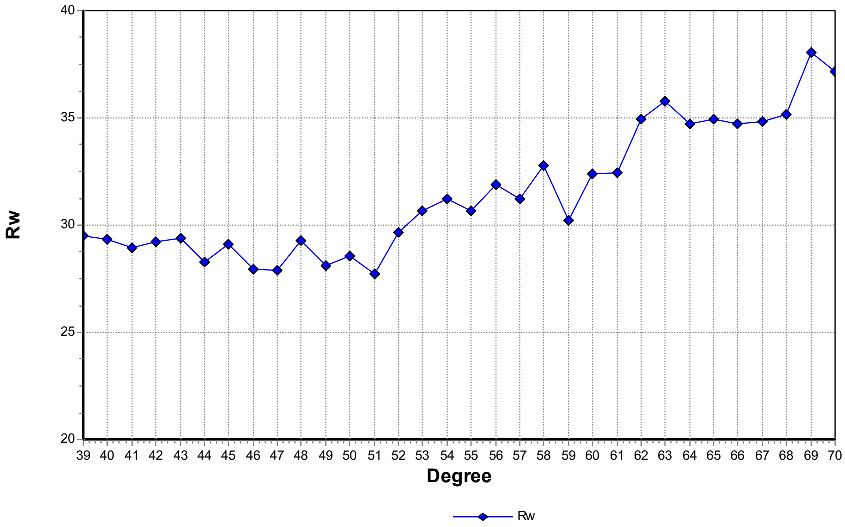

Figure4: Result of rib angle analysis.

As we can see from the figure, the overall transmission loss of profiles grow as the angle of rib plate increases. There are four local maximum value, namely 48degrees, 58degrees, 63degrees and 69degrees. The increase of the angle of rib plate will lead to the increase of the number of rib plate, and thus the increase of the overall weight of profiles. During the design phase, we should analyse combined with the weight parameters comprehensively and select the optimal angle parameter of profiles reasonably.

5 Optimization Analysis of Design Parameters

The results of the analysis of key design parameters above indicate that the influence rule of the change of rib angle on the sound insulation performance of profiles. According to the lightweight demand at the design phase, we choose the thickness of upper plate, the thickness of lower plate, the thickness of rib plate and the angle of rib plate as the design variables, and use the Darwin genetic algorithm to analyze the multi-parameter optimization. The constraint condition is that the mass gain should not exceed 10% of the initial value.

In the multi-parameter optimization analysis model, the variation range of the design variables are shown in table 3:

Variables	Lower bound	Upper Bound	Note
up thick	2mm	3mm	changed by 0.1mm each time
down thick	2mm	3mm	changed by 0.1mm each time
rib thick	1mm	2mm	changed by 0.1mm each time
Degree	40degree	70degree	changed by 0.1mm each time

Table3: Setting of variables in optimization analysis.

The optimal solution parameters are obtained after multiple optimization iterations, as shown in table 4. At this time, there exists a maximum value of the weighted transmission loss.

Variables	Transmission loss [dB]	Gain of transmission loss [dB]	Mass [kg]	Gain of mass [kg]
Thickness of upper plate=3mm Thickness of lower plate=3mm Thickness of rib plate=1.5mm Angle of rib plate=60°	32.39	/	41.78	/
Thickness of upper plate=2.8mm Thickness of lower plate=3.3mm Thickness of rib plate=1.5mm Angle of rib plate=63°	36.63	4.2	43.96	2.18

Table4: Comparison of parameters before and after optimization.

As can be seen from the chart, the transmission loss data of optimized model increased by 4.2dB compared with original profile model, and the mass data increased by 2.18kg. The result curves of the sound insulation before and after optimization is show in Figure 5. After optimization, the sound insulation of the profile improves in the frequency band between 400-800Hz and above 1250Hz compared with the original profile.

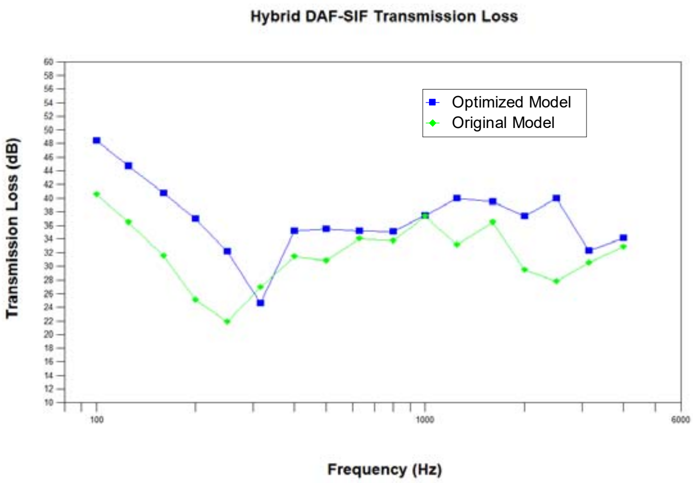

Figure5: Comparison of sound insulation curves before and after optimization.

6 Conclusions and Contributions

This paper mainly concentrates on the simulation and optimization of the sound insulation characteristics of a high-speed train body profile in the pantograph area. The weighted transmission loss of the original profile structure is 32.4dB and the weight is 41.78kg, while the weighted transmission loss of the optimized profile is 36.6dB and the weight is 43.96kg. Compared with original profile model, the transmission loss data of the optimized model is increased by 4.2dB, and the mass data increased by 5.2%, meeting the requirements of the lightweight index of the profile sound insulation optimization design.

References

[1] F.B. Liu, "Investigating the vibro-acoustic characteristics and noise reduction measures of pantograph flat roof of high-speed train", Southwest Jiaotong University, Chengdu, Sichuan, China, 2021.

[2] T. Kohrs, B. Petersson, "Wave beaming and wave propagation in lightweight plates with truss-like cores", Journal of Sound and Vibration, 321(1-2): 137-165, 2009.

[3] U. Orrenius, H. Kunkell, "Sound transmission through a high-speed train roof", //"Proceedings of the 18th International Congress on Sound and Vibration", Rio de Janeiro: International Institute of Acoustic and Vibration, 2392-2399, 2011.

[4] V. Cotoni, R.S. Langley, P.J. Shorter, "A statistical energy analysis subsystem formulation using finite element and periodic structure theory", Journal of Sound and Vibration, 318(4-5): 1077-1108, 2008.

[5] S. Strano, A. Genovese, "Structural behaviour and vibro-acoustic analysis of a composite rail vehicle car body roof", //"Proceedings of the World Congress on Engineering", London: Imperial College London, 2: 826-831, 2016.

[6] G. Xie, D.J. Thompson, J.C. JONES. "A modelling approach for the vibro-acoustic behaviour of aluminium extrusions used in railway vehicles", Journal of Sound and Vibration, 293: 921-932, 2006.

[7] D. Yao, J. Zhang, R.Q. Wang, X.B. Xiao, J.Q. Guo, "Lightweight design and sound insulation characteristic optimization of railway floating floor structures", Applied Acoustics, 156: 66-77, 2019.