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Low Frequency Sound Radiation from Aluminium Extrusion, Part I: Experimental Study

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ABSTRACT

The floors on high speed trains are often constructed from composite aluminium extrusions. Noise is a major issue with such configurations, as the internal plate lattice physically bridges the top and bottom panels. The coupling of the panels typically results in poor acoustic performance. In this paper, Finite Element Method (FEM) was used to model the vibratory responses of the extrusion in the low frequency range. Experimentally, the transfer mobilities and vibration energy of the panel were measured for a given mechanical excitation. The direct method was used to estimate the radiation efficiency of the panel. Later studies coupled FEM with Statistical Energy Analysis (SEA) and Boundary Element method (BEM) to predict the sound radiation from the aluminium extrusion to cover higher frequencies.

INTRODUCTION

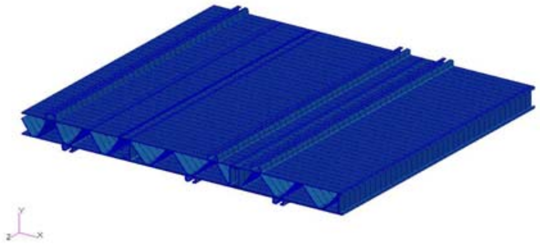
Aluminium extrusions have been widely used in the construction of high speed train bodies in recent years. Such configuration typically consists of three major components, the two outer flat aluminium skins and a series of interconnected panels which forms trapezoidal like sound chambers within the structure. There have been many studies on the prediction of sound radiation from this type of extrusion. The work presented in this paper is part of a series of research works performed on China High Speed Trains with the focus centred on the prediction and optimisation of acoustic performance of train bodies. The typical aluminium extrusion used in railway vehicles makes up the ceiling, the floor and the two side walls of the train. The sample aluminium extrusion investigated in this paper is part of the floor structure on the train. It is referred to as the panel hereafter.

Xie et al[1-4] have presented in a number of paper where Statistical Energy Analysis (SEA) method was used for the prediction of vibroacoustic behaviour of a typical railway aluminium extrusion. The configuration was subjected to both mechanical and acoustical excitations. A four-subsystem approach was adopted in their model. As a preliminary study, only low frequencies, namely up to 600 Hz are considered in this paper. As shown by Xie et al, at low frequencies, the dominating modes are those associated with the global behaviour of the system. Hence, Finite Element Method (FEM) was used for modelling the vibratory response of the extrusion and Boundary Element Method (BEM) was used for modelling its radiated sound power. In a later paper, it will be shown that FEM and SEA are combined to cover a much wider frequency range for studying the acoustic behaviour of the system. This paper presents the experimental work carried out on the panel and these test data were later used to validate numerical results.

MECHANICAL EXCITATION

Modal Model Validation

FEM was used to model the dynamic behaviour of the extruded Aluminium panel. The FE model contains simplifications on some geometrical details. The panel is assumed to be simply supported at the point of contact with the surrounding structure. In order to fine tuning the FE model so that it is a true representation of the actual structure, the experimental modal tests were carried out where modal properties were extracted and then used to update the preliminary FE model. Fig. 1 shows the FE mode and the experimental model of the panel. The FE results obtained before and after the updating process are shown in Table 1. It was found that the actual boundary condition lies somewhere between free-free and simply supported case. The first six mode shapes are shown in Fig. 2. The point of contact between the panel and the supporting frame were modeled using spring elements where the stiffness values were tuned to give a more realistic representation of the physical boundary conditions.



(a)

(b)

Figure 1. The panel a) the FE model, and b) the test model

Table 1. Natural Frequencies of the Plate

	EMA		Before Update (Hz)		After Update
Mode	Free	Constrained	Free	Simply Supported	Constrained
1	189	124	188	238	130
2	232	182	250	254	197
3	345	253	335	366	255
4	370	362	370	469	370
5	430	432	432	557	450
6	556	544	556	662	563
7	701	667	710	762	685
6	826	748	811	813	756

FEA method predicts all possible modes of the structure including those associated with the local deformation of internal plates. The modal test performed in the laboratory, however, only records the vibration response of the external surface of the panel. Any localized internal plate movement which did not induce sufficient movement of the outer panel would not have been picked up by the surface accelerometers. Therefore, the FEA model predicted more modes than the measured ones for the same frequency range.

Radiated Sound Power

Experimental works were carried out to measure a number of factors related to sound radiation. The radiated sound power given in Eqs 1 is directly proportional to mean square velocity as well as the radiation efficiency. The former requires a measurement of spatially averaged surface velocity of the panel and the latter can be obtained using either a direct or a reciprocal method [3]. Both methods tested in the experiment for comparison purpose. The direct method measures sound radiation through sound intensity method. The radiation efficiency can be determined using Eqs 2.

$$W = \frac{1}{2}\rho c S \left\langle \left| v^2 \right| \right\rangle \sigma \qquad (1)$$

$$\sigma = \frac{2W}{\rho c S \left\langle \left| v^2 \right| \right\rangle} \qquad (2)$$

Mean-Squared Velocity and Mobility

To obtain the vibration response of the panel under mechanical excitation, a Bruel & Kjaer electrodynamic shaker was attached to a force transducer which in turn was affixed to one corner of the baffled panel. The shaker excited the panel with a constant force. Two roving accelerometers were used to record the surface velocity of the panel in the receiving room. The spatially averaged mean-square velocity of the panel was obtained by averaging the responses from a total of 190 measurement points. The corresponding mean-square mobility of the panel was determined by averaging the ratio of the velocity response function and force excitation function at each measurement location. The experimental setup is shown in Fig. 2. The results are shown in Fig. 3 through to Fig. 5.

Figure 2. Experimental setup for the shaker test.

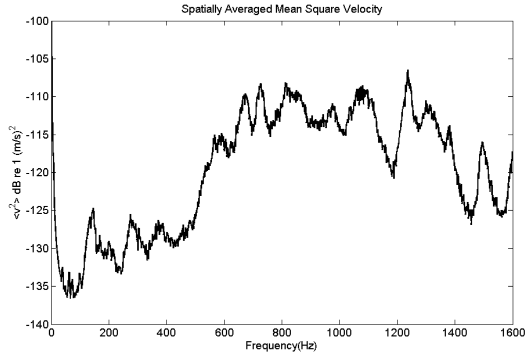


Figure 3. Spatially averaged mean square velocity of the panel.

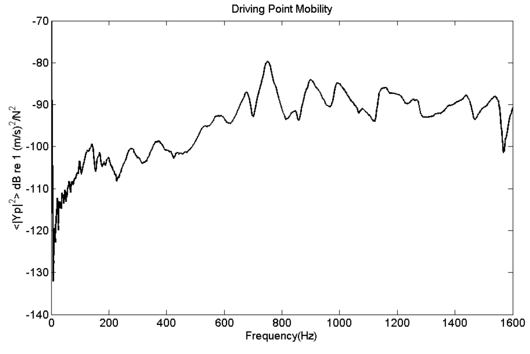


Figure 4. Input mobility of the panel.

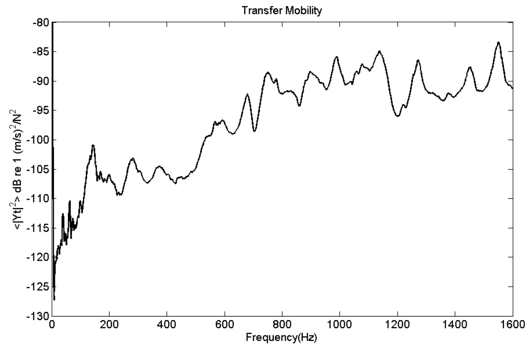


Figure 5. Spatially averaged transfer mobility of the panel.

Experimental SWL and Radiation Efficiency

The sound power levels measured using sound intensity method is given in Fig. 6.

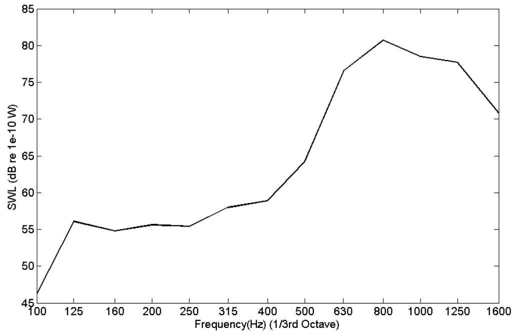


Figure 6. Experimental SWL of the panel under shaker excitation.

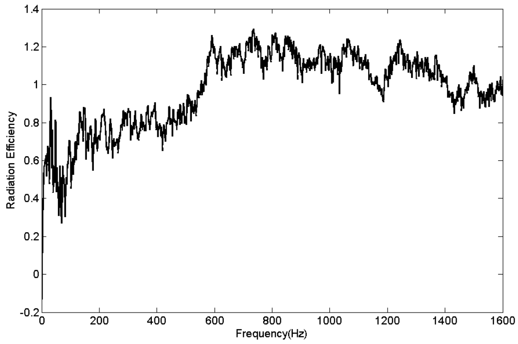


Figure 7. Experimental radiation efficiency of the panel.

Fig.7 shows that the critical frequency of the panel is at around 560Hz.

ACOUSTICAL EXCITATION

Sound Transmission Loss

In addition to the mechanical excitation, the floors on the railway vehicles are also subjected to acoustical excitations arising from various sources such as that from the wheel/rail interaction and other external environmental noise. Experimentally, the sound transmission loss of the panel can be determined using Eqs 3[4].

$$R = L_i - L_r + 10\log_{10}\left(\frac{A}{S\overline{\alpha}}\right) \tag{3}$$

where L_i and L_r are the sound pressure levels recorded in the source and receiving room, respectively. A is the area of the test panel; S is the total surface area of the receiving room, and $\overline{\alpha}$ is the mean Sabine absorption coefficient. The sound transmission loss is shown in. Fig. 7.

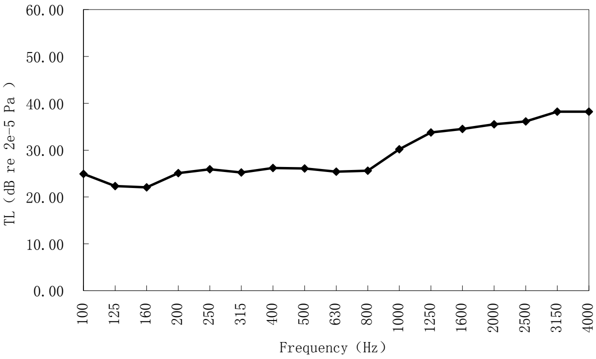


Figure 8. Experimental TL for the panel.

CONCLUSION

This paper presents measured vibration and sound transmission loss of the extruded Aluminium panel commonly used on high speed trains in China. In a later paper, the test data are used to validate numerical results. Optimization will also be carried out to increase the transmission loss for both vibration and sound across the structure.

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