TRANSMISSION LOSS OF EXTRUDED ALUMINIUM PANELS WITH ORTHOTROPIC CORES

PACS REFERENCE: 43.40-Rj RADIATION FROM VIBRATING STRUCTURES INTO FLUID MEDIA

Names of the authors:	Kohrs, Torsten; Petersson, Björn A.T.
Institution:	Institut für Technische Akustik, Technische Universität Berlin
Address:	Sekretariat TA 7, Einsteinufer 25
Town:	D-10587 Berlin
Country:	Germany
Tel:	++49 +30 314-22931
Fax:	++49 +30 314-25135
E-mail:	tkohrs@cs.tu-berlin.de; b.a.t.petersson@tu-berlin.de

ABSTRACT

An approach is investigated to predict the airborne sound transmission through extruded aluminium plates with orthotropic web stiffener cores often used in train carriages. As classical analytical methods fail to predict the transmission loss, a hybrid method is applied consisting of finite element calculations for extracting the frequency-dependent bending stiffnesses via the wave number distribution in combination with an analytical transmission loss model for orthotropic plates. The features of the approach will be discussed and results compared with measurements.

INTRODUCTION

Extruded aluminium profiles are often used for train carriages. It is a typical light-weight configuration having some advantages for the production. Acoustic requirements on modern railway vehicles become more and more important. The customer expects low interior noise, which can be fulfilled only by carriages with high sound insulation. With the main sound sources of modern multiple unit trains located underneath the floor, the transmission loss of the floor is of primary interest. Compared with single panels of the same mass per unit area, the transmission loss of extruded profiles is poor. The important parameters for transmission loss of extruded profiles are unknown and only few investigations of such profiles [1],[2],[3] have been reported. In Geissler and Neumann's work, extruded profiles are modelled using statistical energy analysis whereas tools like finite and boundary element methods are applied in Waroquier's thesis. Acceptable result were achieved at frequencies above 1000 Hz using a sandwich SEA-model. Waroquier modelled transmission loss only up to 315 Hz because of computational limitations. Hence, there is a lack of a prediction tool for the mid-frequency range. Pure numerical calculations using FEM and BEM have an upper frequency limit which is often set by memory and time. At high frequencies, where the modal density of the subsystems is high, SEA seems to be useful for extruded profiles. In the literature, analytical approaches are presented for different kinds of panel designs. At low frequencies, the extruded profile can possibly be modelled as a single panel. Other models are the double wall with sound bridges (line connections), a sandwich system or an orthotropic plate. The approach attempted in this work for transmission loss estimations consists of structural FE-calculations, extraction of frequency-dependent bending stiffness and calculation of transmission loss by an orthotropic plate model.

TRANSMISSION LOSS MEASUREMENTS

Measurement Object

Transmission loss measurements of the extruded aluminium floor profile were performed on a 3 m long floor section comprising the whole width of the vehicle cf. Figure 1. In accordance with ISO 15186-1, intensity technique was employed in a test rig using similar boundary conditions (static rotational stiffness) as in the built-in situation of the carriage.

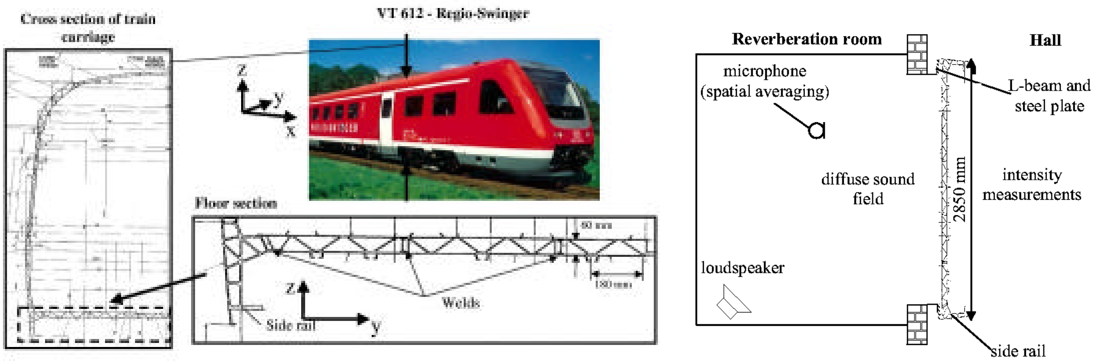

Figure 1: Cross-section of train carriage and measurement set-up of floor element

A commonly used profile is shown in Figure 2. The overall thickness of the profile is 60 mm, the web stiffeners are located at a distance of 180 mm and the thickness of the plates is 2.5 mm. The mass per unit area is about 31 kg/m^2.

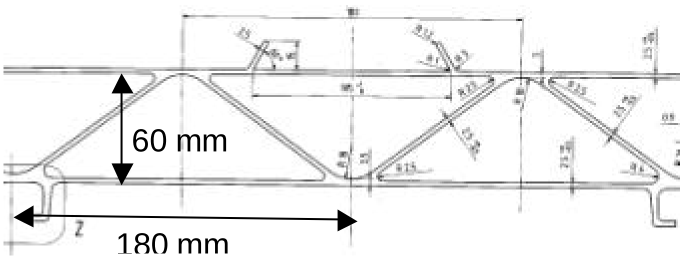

Figure 2: Dimensions of the investigated extruded profile

Measurement Results

In Figure 3 are presented the results from measurements obtained by scanning the surface and alternatively using discrete points. Despite a high reactivity index of about -10 dB the different procedures yield consistent results. Three main ranges distinguished from the transmission loss curve:

1. In the 1/3 octave bands up to 125 Hz there is a constant increase of TL with a slope of about 7 dB per octave. The transmission loss reaches about 23 dB at 125 Hz.
2. Above a dip in the 160 Hz band, the TL stays constant around 20 dB up to 630 Hz.
3. There is a strong growth of sound insulation from 800 to 1000 Hz. At high frequencies the TL increases slowly and irregularly.

TRANSMISSION LOSS PREDICTION

Classical Approaches

The mass law can be used for single panels below the critical frequency f_c. Herein the mass law for field incidence conditions is used with an empirical correction of 5 dB [4]

$$R = 10 \log \left[1 + \left(m'' \pi f / (\rho_0 \, c_0) \right)^2 \right] - 5 \qquad (1)$$

The result for m''=31 kg/m^2 is presented together with the measurements in Figure 4. Sharp shows in [5] a possibility to estimate the TL of double walls with line bridges. The result is a TL-curve that is higher but parallel to that of the mass law from the fundamental mass-air-mass resonance of the configuration. The result is included in Figure 4.

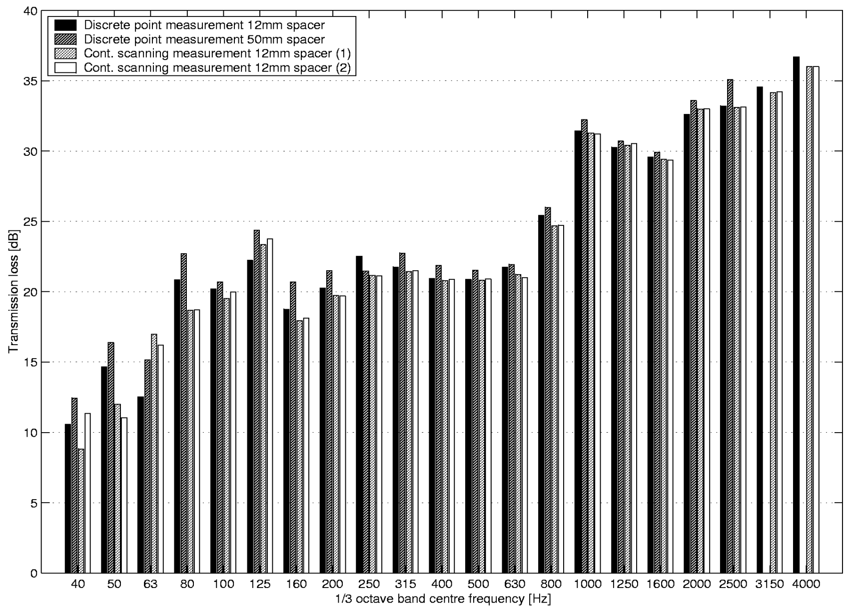

Figure 3: Measured transmission loss of the floor section in 1/3 octave bands

Orthotropic panels are characterised by different bending stiffnesses in the in-plane directions. As the core of the extruded profile is orthotropic, such a model establishes another alternative for TL-prediction. Therefore the (static) bending stiffnesses of the plate have to be calculated. The bending stiffnesses of the floor panel studied are B_x'= 403 400 Nm and B_y'= 394 800 Nm respectively. This leads to a critical frequency at about 160 Hz. For TL-prediction the model of Hansen is used [6]. Following Hansen [6], the wave impedance Z_{orth} of orthotropic panels for plane wave incidence under angles φ and θ can be expressed by

$$Z_{orth} = j\omega m''\left[1-\left(\frac{\omega}{c_0^2}\sqrt{\frac{B_y'}{m''}}\cos^2\varphi + \frac{\omega}{c_0^2}\sqrt{\frac{B_x'}{m''}}\sin^2\varphi\right)^2 \sin^4\theta\,(1+j\eta)\right] \quad (2)$$

from which it is possible to evaluate the transmission coefficient $\tau_{\theta\varphi}$

$$\tau_{\theta\varphi} = \left|1+\frac{Z_{orth}\cos\theta}{2\rho_0 c_0}\right|^{-2} \quad (3)$$

To obtain the diffuse field transmission coefficient τ_d, it is necessary to average over all sound wave angles of incidence

$$\tau_d = \frac{2}{\pi}\int_0^{\pi/2}\left[2\int_0^{\pi/2}\tau_{\theta\varphi}\cos\theta\sin\theta\,d\theta\right]d\varphi \quad (4)$$

The results are included in Figure 4 assuming a loss factor of η = 0.02. The comparison of predicted and measured results shows that the classical approaches used fail to describe the transmission loss of the extruded floor profile. Only at low frequencies (< 150 Hz) the mass law gives a good representation. Also, the dip observed at 160 Hz coincides with the coincidence frequency as predicted by the orthotropic plate model.

A hybrid method

The inadequacy of classical models necessitates improved prediction methods for this kind of structure. The hybrid method applied in this work consists of structural dynamic FE-calculations to extract the frequency-dependent bending stiffnesses and transmission loss calculation using an analytical orthotropic plate model with the bending stiffnesses as input parameters.

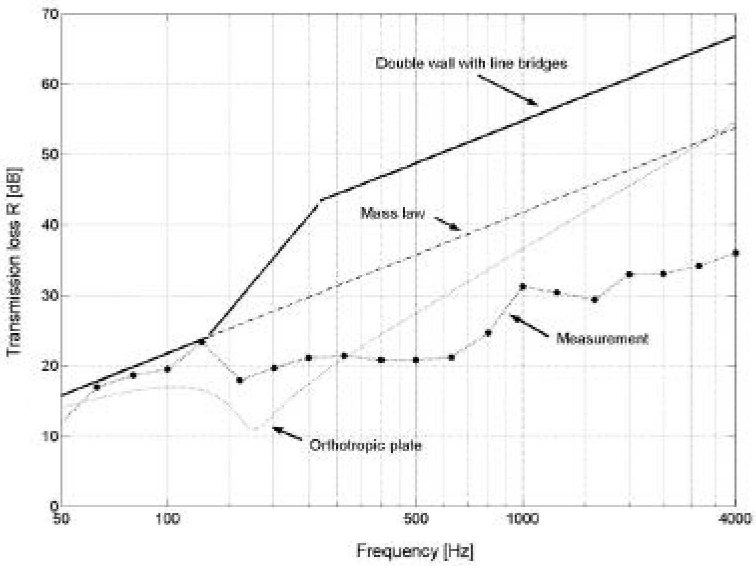

Figure 4: TL prediction using classical methods

The structural dynamic behaviour is investigated by finite element eigenmode and moment excitation calculations. The resulting velocity distribution of the interior plate is spatially Fourier transformed to the wave number domain. Because of computational constraints and the large extension in x-direction, a two-dimensional model is used for the components in the y-direction, with the plate assumed infinite in x-direction. For the x-direction components, a floor strip is used; 3000 mm long in x-direction and 900 mm wide in y-direction. The calculations are detailed in [7]. The resulting wave number distributions are presented in Figure 5. The waterfall plots visualize the energy distribution among the waves.

A qualitative investigation of sound transmission can be made from a comparison of the structural wave numbers and the acoustic wave number. Owing to the fact that the structural vibrations are composed of many waves with different wave numbers it is proposed that the major contribution to the sound radiation stems from those above coincidence ($k_B < k_0$). The distribution in x-direction shows 'mountain ranges' which often combine at characteristic wave numbers of 17.5 rad/m and 35 rad/m (300 Hz, 1000 Hz, 1200 Hz). The corresponding wavelengths are 360 mm and 180 mm which are directly associated with the periodic adjacent web stiffener spacing. The smaller wave number represents eigenmodes dominated by a half wavelength between the stiffeners and the bigger to a whole wavelength. The wave numbers in y-direction show a typical dispersion behaviour where wave number is proportional to square root of frequency. At each frequency, the most energetic wave number in the region $k_B < k_0$ is chosen under the assumption that this wave dominates the radiation. In order to condense the information to a single panel description, frequency-dependent bending stiffnesses are calculated under the assumption that the whole surface mass of the extruded profile is located in the single panel. The bending stiffness $B'(f_i)$ for each calculation frequency f_i is

$$B'(f_i) = 4p^2 f_i^2\, m'' / k_B^4 \quad (5)$$

with the corresponding dominating wave number k_B and the total surface mass m''. The dominating wave numbers and the resulting frequency-dependent bending stiffness are presented in Figure 6.

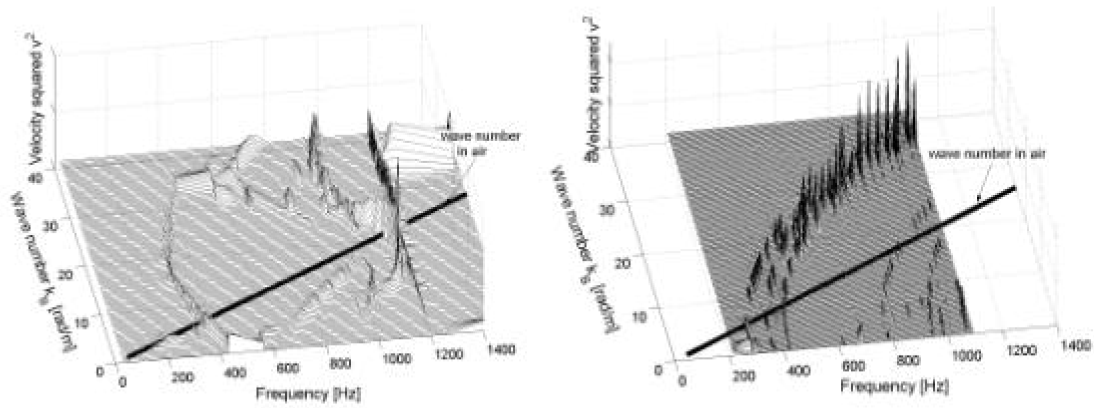

Figure 5: Wave number waterfall plots
left: two-dimensional FE-eigenmode calculation in y-direction
right: FE-eigenmode calculation in x-direction using three-dimensional model

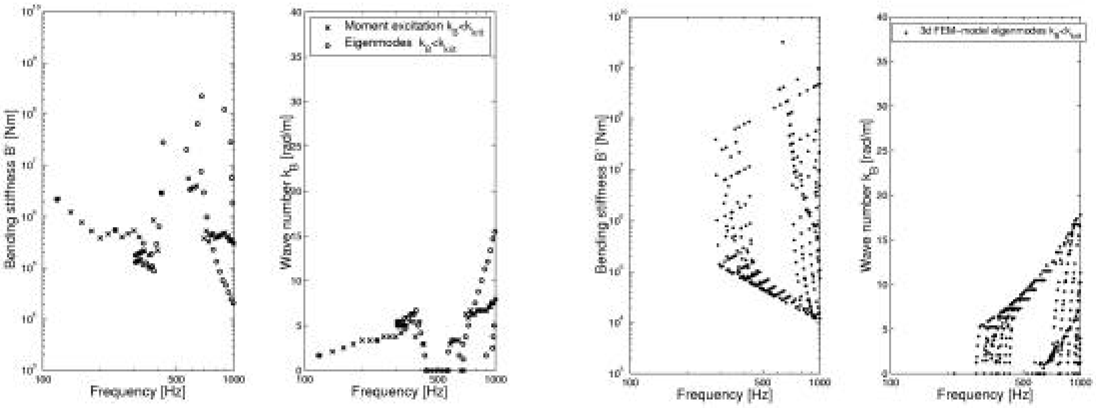

Figure 6: Frequency-dependent bending stiffness and dominating wave number
left: B_x' for eigenmode and moment excitation calculation in y-direction
right: B_y' for eigenmode calculation in x-direction

Finally, the transmission loss is calculated by substituting the frequency-dependent bending stiffnesses into the orthotropic plate model. In contrast to the static bending stiffnesses, being almost equal in the two directions, the dynamic or frequency-dependent stiffnesses extracted differ significantly and the application of an orthotropic plate model is required. The wave impedance in equation (2) is calculated with the frequency dependent bending stiffnesses. The resulting diffuse field transmission loss is presented in Figure 7 for the range 125 to 1000 Hz. The maximum deviation of the calculated curve to measured values is less than 10 dB. Around 200 Hz, only the moment excitation calculation is useful since the modal density is low and thus the eigenmode calculation struggles. The characteristic TL-rise measured at about 700 to 1000 Hz is shifted in the calculation to lower frequencies (approximately one 1/3 octave band).

CONCLUDING REMARK

The used hybrid model for transmission loss prediction seems to be a useful method to evaluate the sound insulation of extruded profiles in the low to mid-frequency range (<1000 Hz). To ensure the validity of the method for profiles of similar geometry it is necessary to extend this work generically.

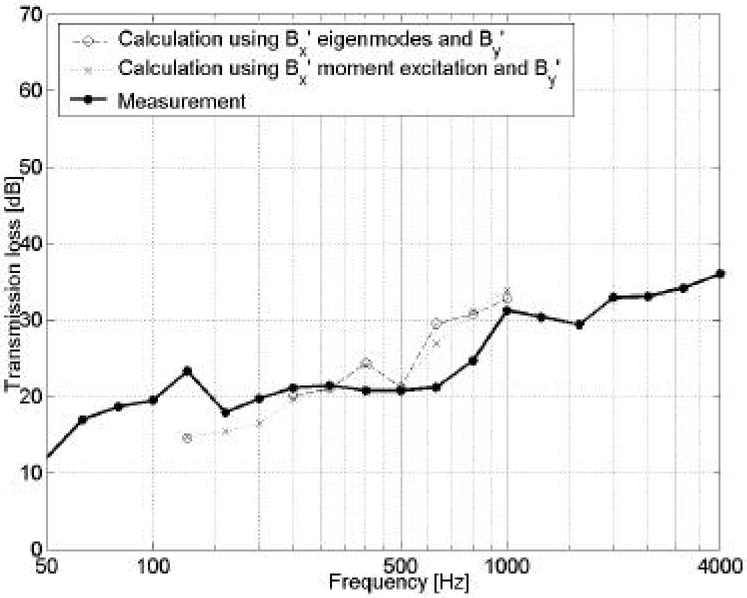

Figure 7: Measured and calculated transmission loss of the floor section using Hansen's orthotropic plate model and frequency-dependent bending stiffnesses

ACKNOWLEDGEMENT

The support received from Bombardier Transportation, Hennigsdorf, Germany is gratefully acknowledged.

REFERENCES

[1] Geissler, P.; Neumann, D.: *SEA modelling for extruded profiles for railway passenger coaches*, Proceedings of Euro Noise 1998, Munich, (1998).
[2] Geissler, P.; Neumann, D.: *Modelling extruded profiles for railway coaches using SEA*, Proceedings of the 1999 ASME Design Engineering Technical Conferences, September 12-15, Las Vegas, Nevada, (1999).
[3] Waroquier, J. L.: *Numerical analysis of the transmission loss of standard profiles for train carbodies*, Universite de Technologie de Compiegne, ADtranz, diploma thesis, (2001).
[4] Callister, J.R., George, A.R., Freeman, G.E.: *An empirical scheme to predict the sound transmission loss of single-thickness panels*, Journal of Sound and Vibration Vol. 222(1), 145-151, (1999).
[5] Sharp, B.H.: *Prediction methods for the sound transmission of building elements*, Noise Control Engineering Vol. 11, 53-63, (1978).
[6] Hansen, C.H.: *Sound transmission loss of corrugated panels*, Noise Control Engineering Journal Vol. 40(2), 187-197, (1993).
[7] Kohrs, T.: *Structural acoustic investigation of orthotropic plates*, Institut für Technische Akustik, Technical University Berlin; Bombardier Transportation, diploma thesis, (Jan. 2002)
[8] Fahy, F.J.: *Sound and structural vibration: radiation, transmission and response*, Academic Press Inc., Orlando, (1985).