Design for Sound Transmission Loss through an Enclosure of a Generator Set

Matthew Cassidy[a1], Richard Gault[a], Richard Cooper[a], and Jian Wang[a]

[a] School of Mechanical and Aerospace Engineering, Queen's University Belfast.

Abstract: Estimation of the sound transmitted through an enclosure is crucial in its design, so there is the need for a simple but accurate method required for the design team. One such method is the mass law which calculates the transmission loss from the mass of the partition in relation to frequency. It is the purpose of this paper to establish if the mass law is suitable for predicting the sound transmitted through a canopy. In order to carry out this study transmission loss tests were completed using an international standard.

Keywords: Mass law, sound transmission loss.

1 Introduction

The facilities consist of a hemi-anechoic chamber (Figure 1), and a reverberation room. They are used for measuring the sound emissions of generator sets and acoustic properties of lining material. An aperture between the rooms is used for research and transmission loss of canopy panels.

Transmission loss is the property of a wall or barrier that defines its effectiveness as an isolator of sound. It is also referred to as the sound reduction index, and is computed from the logarithmic ratio of sound power incident to sound power transmitted, eq (1).

$$TL = 10\log\frac{SoundPowerInside}{SoundPowerTransmi} \qquad (1)$$

From previous work for the test facilities, the method to find the transmission loss is the International standard for measurement of sound insulation in buildings and of building elements using sound intensity, ISO 15186. This standard uses sound intensity to calculate the transmission loss for a reverberation room to hemi-anechoic chamber. A rotating microphone recorded the sound pressure level in the diffuse field, and an intensity probe measured the transmitted sound. Tests were

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[1] School of Mechanical and Aerospace Engineering, Queen's University Belfast, Ashby Building, Stranmillis Road, Belfast. E-mail: mcassidy06@qub.ac.uk

Figure 1. The hemi-anechoic chamber.

carried out on a steel plate and a lead sheet and compared with transmission loss based on the mass law.

2 Theory

Laboratory measurement of sound transmission of a partition mounted in large side walls may give different results due to other transmission paths from the source room to the receiving room. Examples include radiation of sound due to excitation of fixings and transmission through the structure into the walls. There is a limit to the insulation obtained by improving only the adjoining partition known as the flanking limit. The test facilities have a sufficiently high flanking limit, (Figure 2).

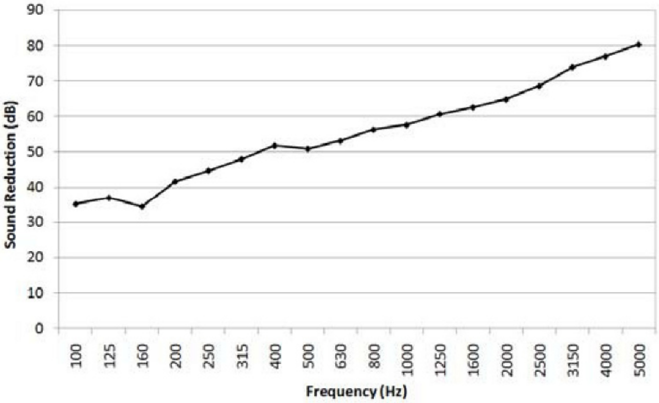

Figure 2. Test facilities flanking limit.

Sound reduction of a partition can be calculated using the mass law, eq (2).

$$TL(reference) = 20\log m + 20\log f - 4 \tag{2}$$

m surface density, *kg/m²*
f centre frequency of the third octave band

This is derived from eq (1) as follows, [1]:

$$TL = \tag{3}$$

P_i incident sound pressure
P_t transmitted sound pressure

$$TL = 10\log[1 + (\frac{m\omega}{2\rho c} \tag{4}$$

ω frequency
ρ density
c speed of sound

For sufficiently high ω eq (4) becomes:

$$TL = 20\log \tag{5}$$

$$TL = 20\log m + 20\log f - 20\log \tag{6}$$

For standard air properties eq (6) becomes eq (2).

The mass law assumes that only the mass of the partition is significant in determining the transmission loss, therefore ignoring the effects of stiffness and damping. Resonances at low frequencies and coincidence effect at high frequencies cause a deviation from the mass law. Stiffness and damping are important at these frequency regions. The mass law assumes a mass spring system, and above the fundamental frequency, the response is governed by the mass of the system. The sound transmission properties of a partition can be divided into three distinct regions, (Figure 3).

Region 1 is where stiffness and resonance is critical, whereas region 2 is mass controlled, but once again region 3 is stiffness controlled which occurs above the critical frequency. There is also control due to damping in region 3.

Given that the purpose of this study is to establish the accuracy of the mass law, it is necessary to find these regions to show the frequency range for which the mass law is applicable.

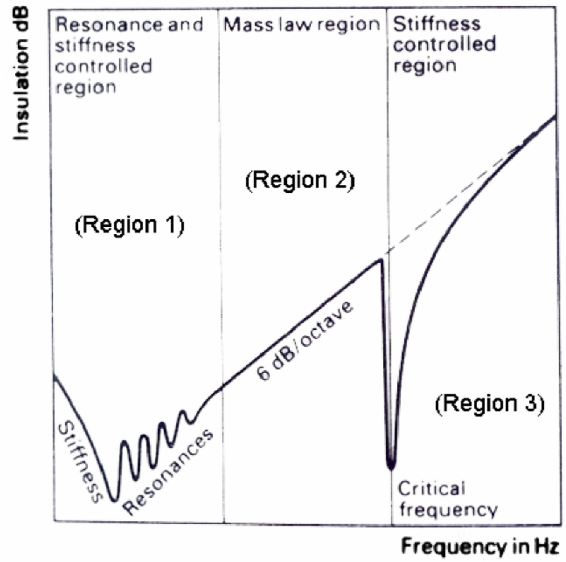

Figure 3. Sound reduction and the relationship with frequency, [2].

3 Method

3.1 Setup

Equipment required includes the reverberation room setup containing two speakers and a diffuse field microphone on a rotating boom. Other items are coaxial cables, networks leads, microphone calibrator, data acquisition unit, and a computer with the relevant software. The intensity probe is mounted on rods and fixed on a tripod but this is not at a fixed position and moves over a box grid as shown in Figure 4 and Figure 5.

The initial step is to detect all connections to the software, this includes the speakers as outputs, the diffuse microphone and the intensity probe is the inputs. For the test the signal generated for the reverberation room through the speakers is sourced from the software with white noise through one speaker and pink noise through the other. The diffuse field microphone in the reverberation room is set on a rotating boom with a 64 second cycle.

After calibration of recording equipment the background sound levels are recorded in both rooms for a check to be carried out later. The next step is to use the graphics equaliser to adjust the source sound levels in the reverberation room. When this is complete the transmitted sound can be recorded. The ISO 15186 test recommends a minimum of 10 seconds recording per point, for this setup 18 second averages were recorded. There are 96 points to measure, and the average calculated for each one third octave band frequency.

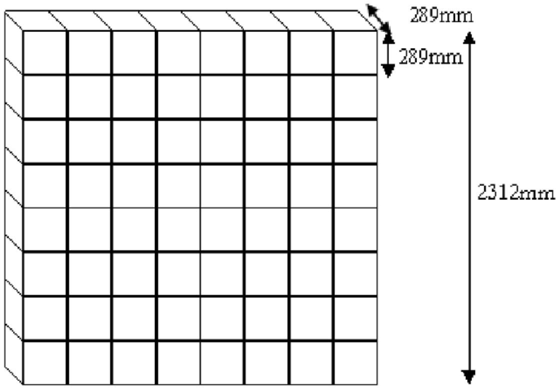

Figure 4. Measurement grid for the ISO 15186

Figure 5. Intensity probe used for the ISO 15186 tests

Measurements are exported from the software to a spreadsheet where calculations are carried out. Also exported are the calibration data and background levels to complete the necessary checks.

3.2 Calculations

Sound transmission loss is the logarithmic ratio of sound power incident to sound power transmitted as shown in eq (1). It can be evaluated from eq (1) that:

$$TL = 10\log \qquad (7)$$

W_1 incident sound power
W_2 transmitted sound power

For ISO 15186 the sound intensity is measured therefore using power is equal to intensity times area:

$$W_1 = \tag{8}$$

$$W_2 = I_2 \tag{9}$$

I_1 incident sound intensity
I_2 transmitted sound intensity
S area of the test specimen
S_m area of the measurement surface, Fig4

Since sound pressure levels are recorded in the reverberation room, the effective intensity in one direction of a diffuse field is [3]:

$$I_1 = \tag{10}$$

P_1 is the source sound pressure
ρc is the acoustic impedance

From eq (8) and eq (10)

$$W_1 = ! \tag{11}$$

therefore from eq (7), eq (9), and eq (11)

$$TL = 10\log\frac{P_1^{2}S}{4\rho c\, I} \tag{12}$$

$$TL = 10\log P_1^{2} + 10\log(4\rho c) - 10\log I_2 + 10\log \tag{13}$$

To convert sound pressure into sound pressure level, and sound intensity to sound intensity level:

$$TL = 10\log\frac{P_1^{2}}{P_0}P_0 + 10\log(4\rho c) - 10\log\frac{I_2}{I_0}I_0 + 10\log \tag{14}$$

P0 is the reference sound pressure (2 x 10-5Pa)
I_0 is the reference sound intensity ($10^{-12}W/m^2$)

Eq (14) then becomes:

$$TL = L_{P1} + 10\log P_0 + 10\log(4\rho c) - L_{I2} - 10\log I_0 + 10\log \tag{15}$$

L_{P1} average source sound pressure level
L_{In} average transmitted sound intensity level

Substituting the values for the constants eq (15) becomes:

$$TL = L_{P1} - 6 - [L_{In} + 10\log \qquad (16)$$

Eq (16) is used to calculate the transmission loss for the international standard ISO 15186.

4 Results

Fig6 shows the transmission loss of the 6mm steel plate using the ISO 15186. From this graph it is observed that there is very good correlation for the frequency range 100Hz to 1250Hz. The difference between the mass law and the measured data is shown in Figure 7, these large differences at the higher and lower frequencies can be accounted for by stiffness and damping.

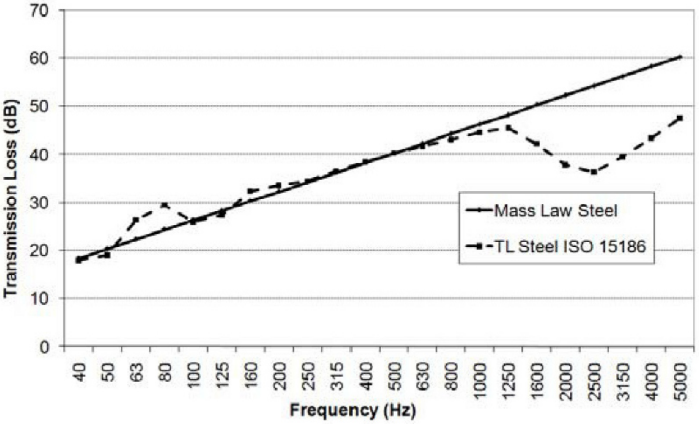

Figure 6. Transmission loss of steel using the ISO 15186.

Another comparison is the 3mm lead sheet tested using the ISO 15186 to compare its accuracy with the mass law for lead. Both Figure 8 and Figure 9 show acceptable correlation for the 100Hz to 1250Hz, the same as the steel. The issues arising due to the stiffness and damping are observed again, but are not as large due to lead being a limp material.

5 Discussion

It is shown in the results that there is a good correlation between the mass law and the measured transmission loss for both the steel plate and the lead sheet. This is specifically concentrated in the frequency range of 100Hz to 1250Hz, from Figure 6 and Figure 8, with a difference of less than 2dB. This is the region controlled by the mass as shown in Figure 3, therefore region 1, due to stiffness and resonance, lies below 100Hz, and region 3, controlled by damping and stiffness lies above 1250Hz. For steel the critical frequency is 2500Hz, but since lead is a limp material there is no obvious critical frequency as there is very little difference between the mass law and the measured over the tested frequency range.

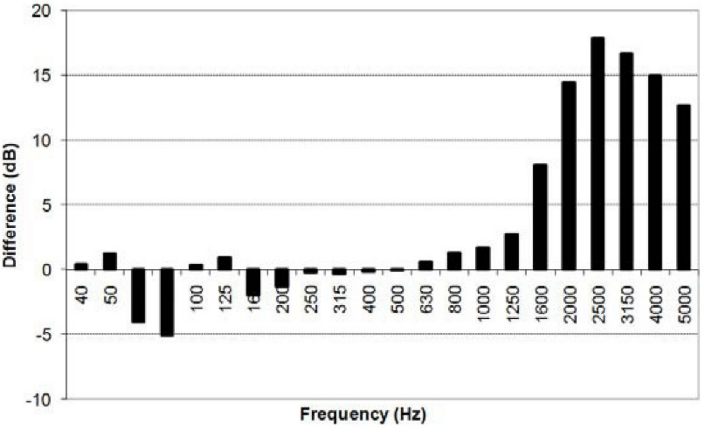

Figure 7. Difference between mass law and measured for steel.

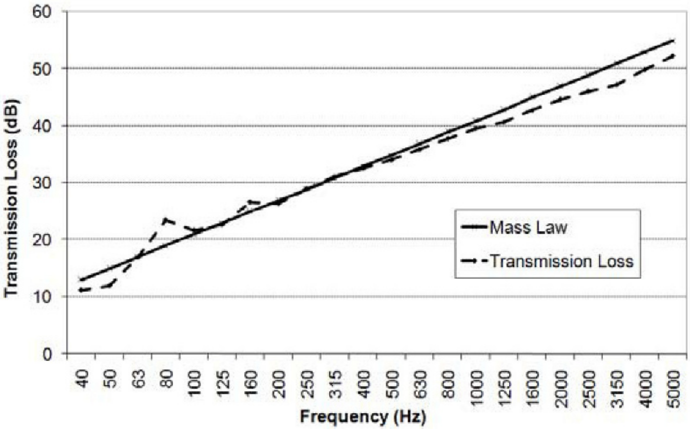

Figure 8. Transmission loss of lead using the J1400.

In order to accurately predict the transmission loss through a partition it is important to know the relevant frequency range because anything below 100Hz and above 1250Hz will not be accurately estimated by the mass law. However, in region 1 low frequency structural modes dominate. These modes can be identified through finite element (FE) analysis, and through rearrangement of stiffeners, resonances can be avoided. In region 3, stiffness and damping affects the sound emission, but noise can be reduced using absorption lining. For this reason the design team can use the mass law for estimating transmission loss for the frequency range 100Hz to 1250Hz.

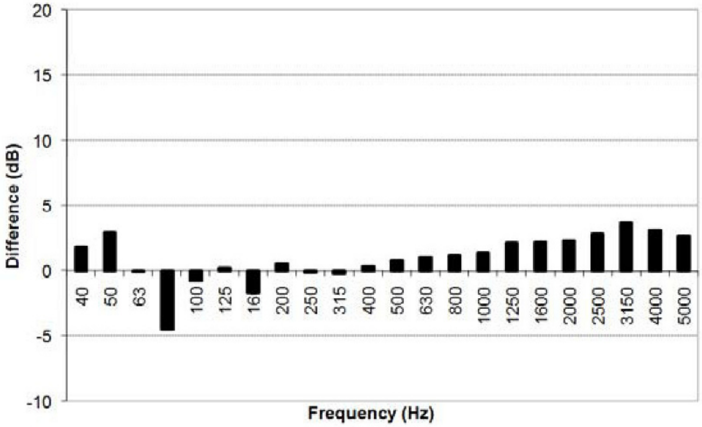

Figure 9. Difference between mass law and measured for lead.

6 Conclusion

As a simple method of calculating the transmission loss for a partition the mass law is ideal. However if a greater accuracy is required or for an important frequency lying outside the mass controlled range, estimation using the mass law cannot satisfy the knowledge required for design.

7 Acknowledgements

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8 References

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