DIAGNOSTIC TESTING OF SOUND INSULATION USING AN IN-SITU TRANSFER PATH ANALYSIS METHOD

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1 INTRODUCTION

The sound insulation of a building element is usually rated by relevant parts of ISO 10140[1] to give a single number quantity R_w - the Sound Reduction Index (SRI). These standard tests however, do not provide any information on how the sound is transferred through such an element or the contribution of the transfer paths involved to the total sound observed at a receiver position. Similar problems are also encountered in the automotive industry while dealing with NVH issues and these are generally tackled by use of methods such as Transfer Path Analysis (TPA). Such TPA techniques provide diagnostic information about the sound transfer paths in the structure subjected to an applied excitation usually structure borne sound. This paper highlights and discusses the novel use of an in-situ TPA technique adapted to the problem of diagnosing sound insulation transfer paths in cavity constructions subjected to airborne excitation. The accuracy of this method is dependent on the spacing of measurement points with respect to incident wavelength. Results are presented for the sound transmission through a cavity-backed plate and point connected plate constructions.

2 TRANSFER PATH ANALYSIS

In applying TPA method, at first the system is discretized into a source-path-receiver model. In the passive test, the source is disconnected from the receiver side to measure the transfer functions or Frequency Response Functions (FRF's). In-situ approaches[2,3] also known as iTPA have been developed so that source is not required to be separated for FRF measurements. The active test is the operational phase where the source excites the system and operational responses are measured. In iTPA, the blocked forces are then found as per equation (1). In equation (1), **A** is the accelerance matrix formed from FRF measurements, and a' is the operational acceleration vector; capital letters denote a matrix and lower case letters a vector. In this way, the blocked forces can be mapped onto the receiver surface points with the help of the path FRF's to determine the path contributions as will be explained below. Similar approaches such as 'Panel Contribution Analysis' or 'Source Path Contribution Analysis' can be found in literature[4,5] but this method differs in because the structure borne TPA, or rather iTPA is used to analyze the transfer of airborne noise through a partition.

$$\mathbf{f_{bl}} = [\mathbf{A}]^{-1}\mathbf{a}' \tag{1}$$

2.1 TPA for Airborne Sound Transmission

Unlike a structure borne sound source with finite connections with the receiver and transfer paths, the sound field produced by an airborne source (where air is effectively the source) results in a continuum over receiver resulting in an infinite number of paths to the receiver position. The intuitive TPA approach might be to measure the acoustic FRF (pressure to volume velocity). However the blocked forces of the source can be measured which can be mapped as the sound field over the receiver surface. These blocked pressures (blocked forces per area) represent the blocked sound field on the surface. In a sense, the accelerometers used in measurement of the blocked forces then act as pressure sensors over the paths which are otherwise used in conventional TPA for finding the acoustic FRF's. This blocked sound field can then be mapped with the vibroacoustic FRF's (pressure to force) to predict the path contributions to the final pressure.

The current work is presented in two parts. The first deals with verifying the methodology of this TPA approach with respect to airborne sound transmission presented in section 3. The second part deals with its application to a point connected partition with structure born excitation presented in section 5. The schematic of the experiment is shown in Figure 1.

With impact testing, the accelerance for the plate and vibroacoustic FRF's for the receiver points inside the cavity are measured. In the second phase, operational measurements of accelerations over the plate and pressures inside the cavity are measured. After finding the blocked forces over the plate, they can be used with the vibroacoustic transfer functions to predict the pressures inside the cavity.

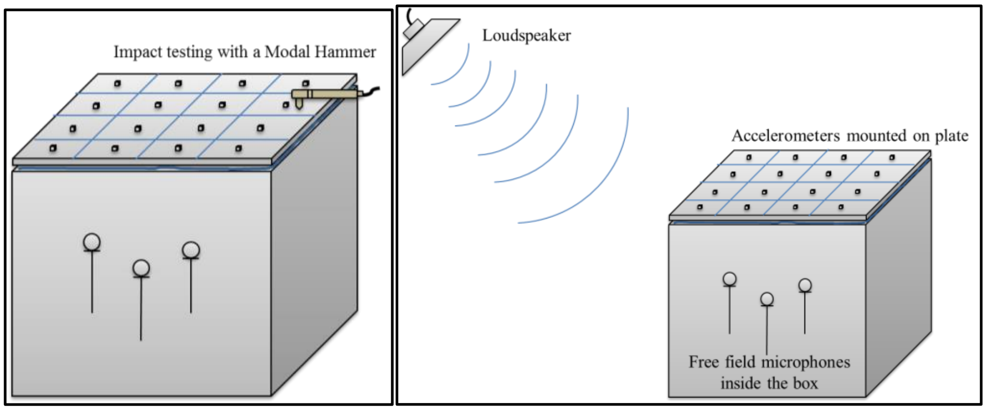

Figure 1 Phase 1-Passive test (left), Phase 2-Operational test (right).

3 PRESSURE VALIDATION TEST: SETUP & MEASUREMENTS

The wooden box representing the cavity and the plate on top representing a plate backed cavity is shown in Figure 2. Silicone sealant was used between the plate and box edges to minimize any flanking transmission from the walls to the plate. However some flanking could be still expected especially at low frequencies.

Figure 2 Test setup- the wooden box (left), Perspex plate assembled with the box (right).

Accelerometers were placed over the plate surface and Type MCE 212 (free field) microphones were used inside the box. With impact testing on the plate, the FRF measurements yield an accelerance matrix as,

$$[\mathbf{A_{ij}}] = \begin{bmatrix} \mathbf{a_1/f_1} & \cdots & \mathbf{a_1/f_j} \\ \vdots & \ddots & \vdots \\ \mathbf{a_i/f_1} & \cdots & \mathbf{a_i/f_j} \end{bmatrix} \quad (2)$$

'A_{ij}' represents the FRF matrix with transfer functions (a/f). 'a' is the acceleration and 'f' is the impact force, 'i' are the response points and 'j' the excitation points. Simultaneously the vibroacoustic FRF's were measured for the forces on the plate and pressures inside the box with the help of pressure microphones.

$$[\mathbf{H_{kj}}] = \begin{bmatrix} \mathbf{p_1/f_1} & \cdots & \mathbf{p_1/f_j} \\ \vdots & \ddots & \vdots \\ \mathbf{p_k/f_1} & \cdots & \mathbf{p_k/f_j} \end{bmatrix} \quad (3)$$

H_{kj} represents the vibroacoustic FRF matrix with transfer functions (p/f). 'p' is the pressure at a point inside the cavity and 'f' is the impact force over the plate, 'k' is the number of pressure points. A loudspeaker with pink noise excitation acts as an airborne sound source which excites the plate and the sound field in the cavity. The operational accelerations and pressures were measured with respect to the driving voltage of the noise generator which ensures that the signals are synchronous. With the operational accelerations over the plate, the blocked forces are calculated as

$$\mathbf{f_{bl}} = [\mathbf{A_{ij}}]^{-1}\mathbf{a_i}' \quad (4)$$

'f_{bl}' represent the block forces over the plate and 'a'' the operational accelerations. These blocked forces map the sound field on the plate by using vibration responses instead of pressure responses. The pressure inside the box can thus be predicted as

$$\mathbf{p_p} = [\mathbf{H_{kj}}]\mathbf{f_{bl}} \quad (5)$$

'p_p' is the pressure predicted at points inside the cavity. These predicted pressures were then compared with the operational pressures at the same points to check the validity of the applied TPA method. The pressure contributions 'p_c' of a path 'n' can then be calculated as

$$\mathbf{p_{c_n}} = \mathbf{H_n f_{bl_n}} \quad (6)$$

3.1 Pressure Validation Results

For the single plate backed cavity experiment, accelerometer grids of 4x4 and 8x8 (yielding 16x16 and 64x64 accelerance matrix sizes respectively) were used. A loudspeaker was driven by pink noise excitation which acts as an airborne source. Pressure inside the cavity was then predicted using equations (4)-(5) and results against the measured pressure are shown in Figure 3 and Figure 4. From the results, it can be seen that the pressure validation improves with the spatial resolution. Even without the use of regularization, the validation results look convincing up to1 kHz range with 8x8 grid size assuming sound transmission only through the plate. The difference in 80-120 Hz region might be attributed to the sound transmission through the walls at low frequencies. Overall, the results verify the TPA methodology and provide confidence in applying it towards a much complex structure such as a ribbed structure or a point connected structure as described in section 4.

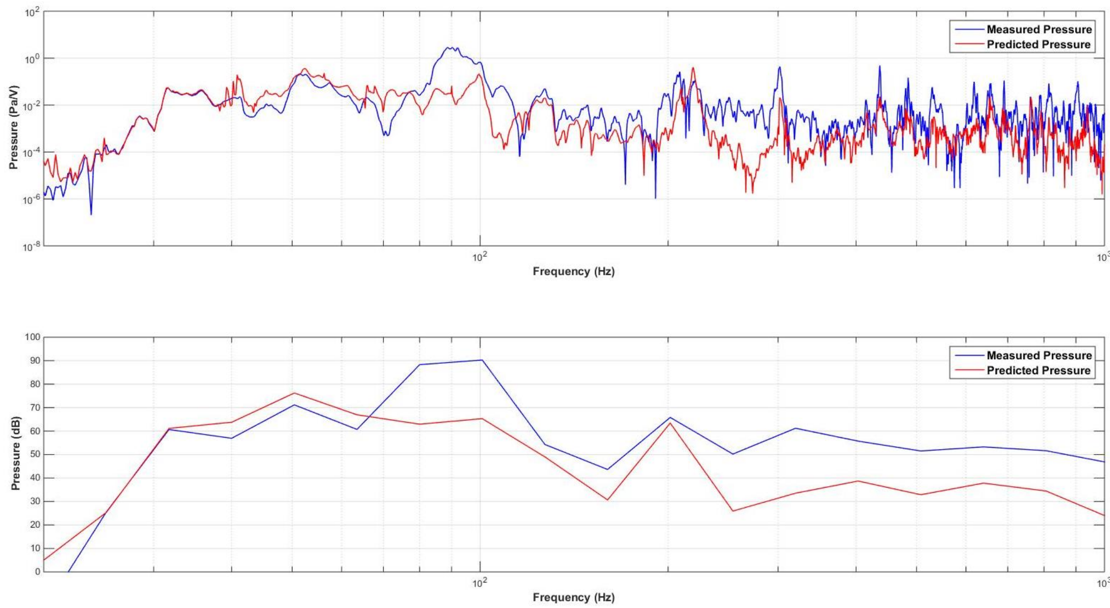

Figure 3 Pressure validation results for a 4x4 measurement grid over the plate.

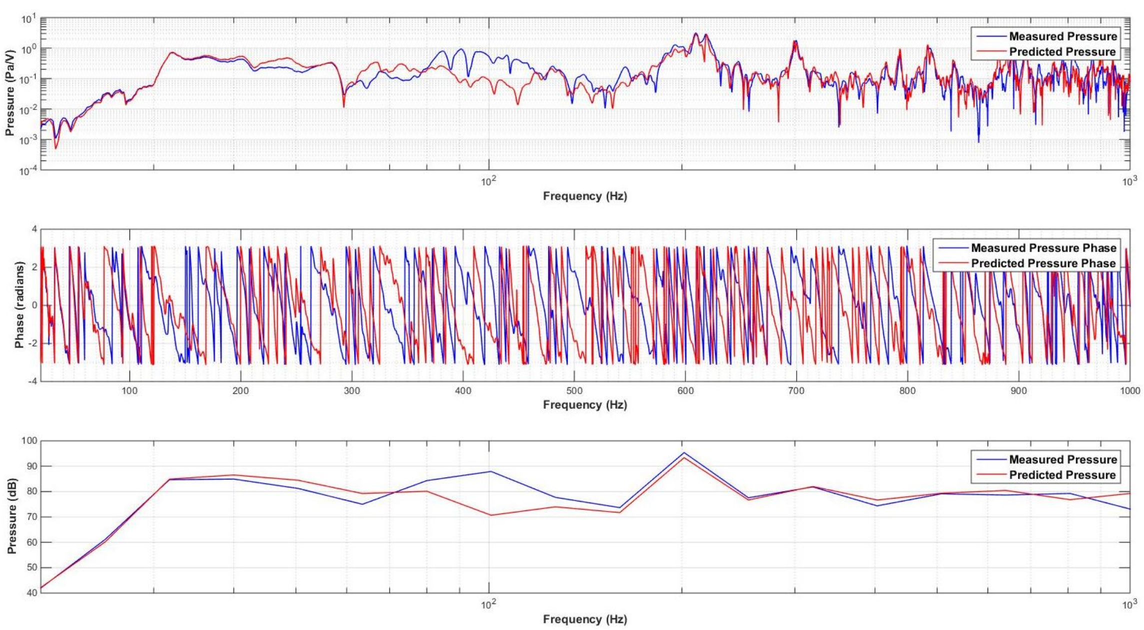

Figure 4 Pressure validation results for an 8x8 measurement grid over the plate.

4 POINT CONNECTED SYSTEM

Having verified the TPA approach by the cavity backed plate experiments, the approach was applied to a point connected partition with structure borne excitation. Figure 5 shows the point connected partition with mineral wool infill.

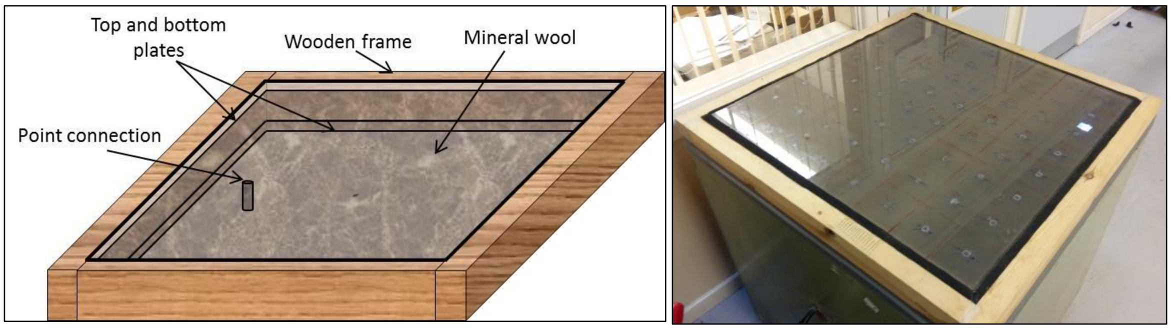

Figure 5 Point connected partition (left) fitted with the box (right)

The point connection represents a direct structure borne path for sound transmission between the top plate and bottom plate. As such, the point connection could provide higher sound transmission at some mid/high frequency region which is also noted in literature[6,7]. With the TPA approach outlined in section 3, it should be theoretically possible to quantify its contributions. As per section 3, the accelerance matrix is measured over discrete locations all over the plate. In the operational test, a stinger forces the top plate with pink noise excitation. Note that the stinger location is different from the point connection location. Then the blocked forces are calculated according to equation (1), the validity of which could be checked by doing a similar pressure validation as in section 3.1. The results are shown in figure 6 which appear satisfactory in the given frequency range from 200 Hz to 1kHz..

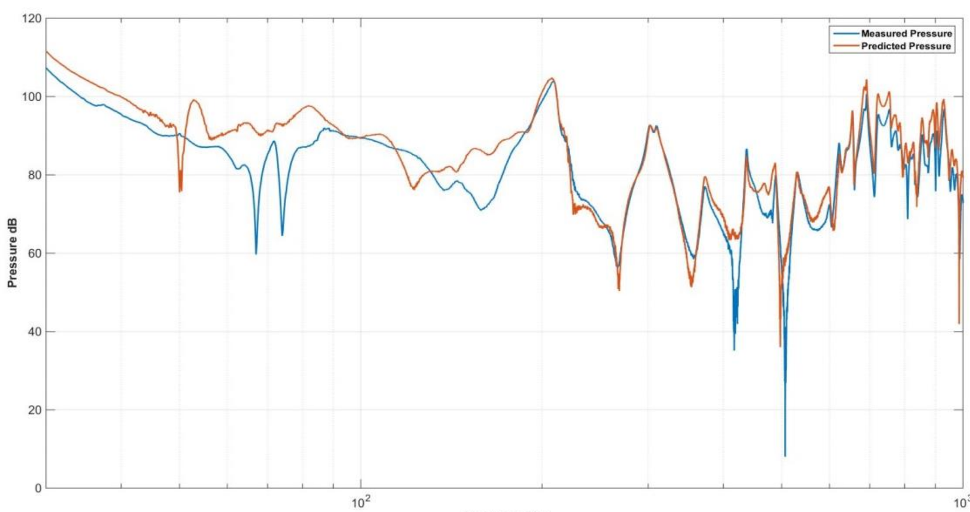

Figure 6 Pressure validation results for point connected partition with structure borne excitation

For the structure borne excitation, only one external point force acts on the top plate through the stinger, and there are no externally applied forces on the rest of the plate. As this is known, we should obtain only one dominant force through the blocked forces calculation. From figure 7, it is evident that the blocked force at the stinger position is higher than on rest of the plate. Interestingly, it can also be seen that the blocked forces on rest of the plate are not zero in spite of the external forces being zero there. This might be possibly due to the fact that the plate is bending and the moments acting on these points are not accounted in this method which would need further investigations to be confirmed. The blocked forces now can be used for calculating the path contributions to the pressure inside the cavity as per equation (6). The path contributions are shown in figure 8.

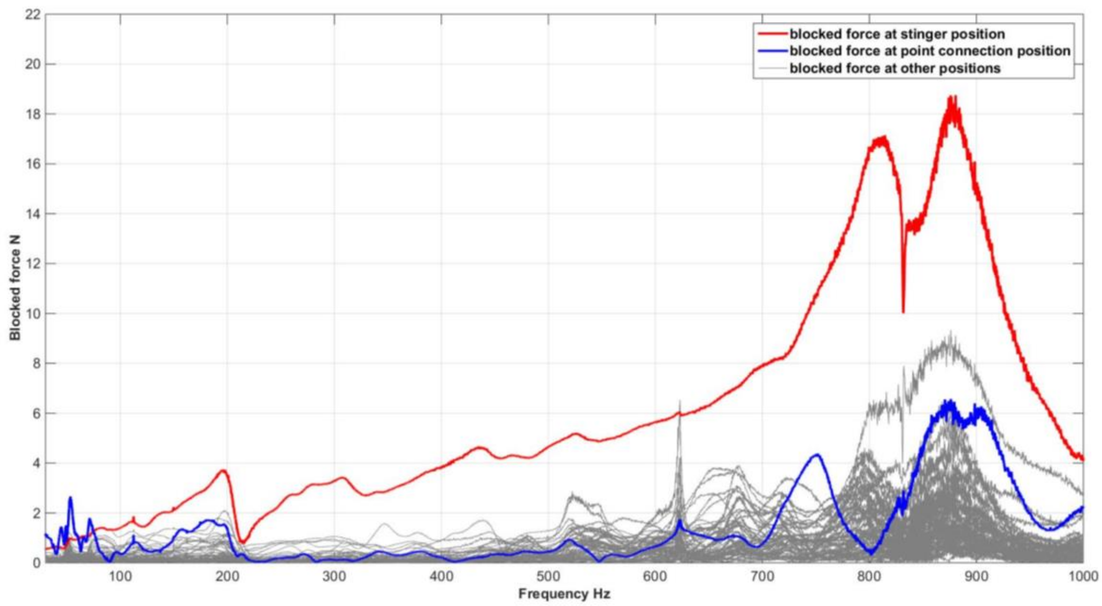

Figure 7 Blocked forces over different paths on the top plate.

This presents an interesting potential of the blocked force technique in identifying the source location. As the inputs (accelerance and operational accelerations) are obtained purely from measurements, this technique could be a better alternative for source localization than other approaches which use computational methods[8].

The path contributions show that the path contribution for the stinger location is highest till 1 kHz. This is expected because the pressure contribution is directly related to the blocked force (equation 6) and also the blocked force at the stinger position is higher as discussed above. The point connection path contribution increases with frequency and is the second most dominant path above 800 Hz. However that is not the case with the blocked force there. So even if the blocked force is not higher, its path contribution is still dominant. This demonstrates the potential of this TPA method which gives us a quantitative estimate of how different parts of a complex building element contribute to the total sound transfer. Following the trend, the point connection may become the most dominant path at higher frequencies above 1 kHz and a finer grid size could be used to investigate and improve the method. Further, this same approach is now being used for airborne sound transmission; however flanking has to be minimal in order for good pressure validations in this case.

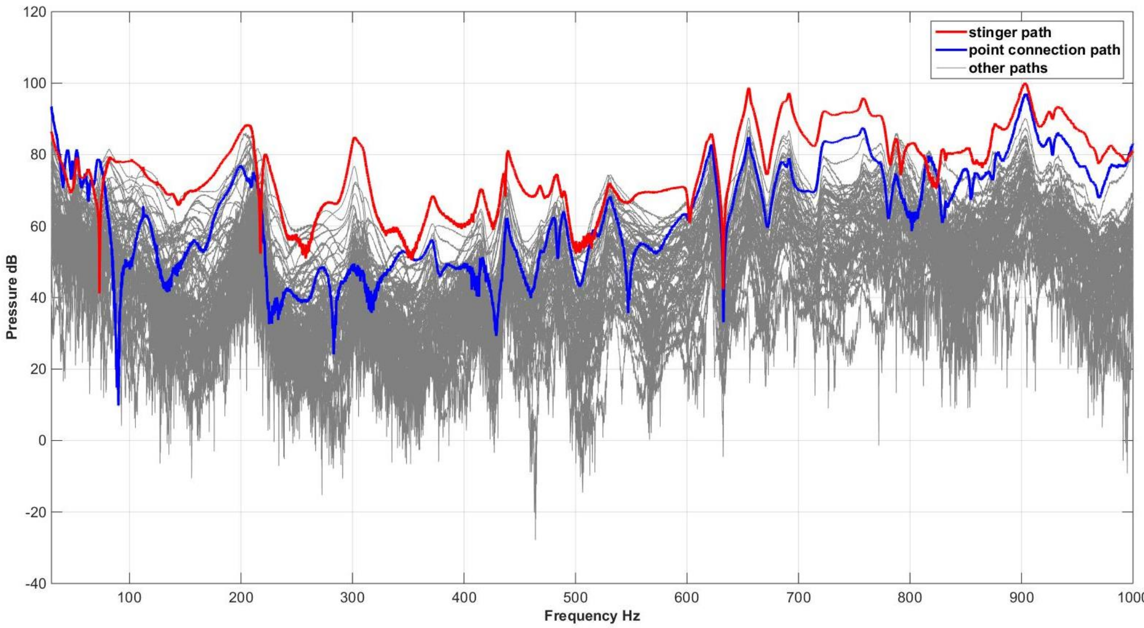

Figure 8 Path contributions of the point connected partition

5 CONCLUSIONS

A novel application of TPA on Building elements has been developed where the sound field can be mapped onto the receiver (partition) using blocked forces which are then used for predicting the sound transfer through the partition inside a cavity according to section 3. The pressures have been predicted with good confidence inside the cavity for airborne sound transmission through a single plate and for structure borne transmission through a point connected partition.

The spatial resolution of the measurement points on the plate determines the frequency range of incident wave field captured and hence determines the applicability of the method in the required frequency range of interest. This follows from the Nyquist theorem which calls for use of more than 2 points per wavelength of a signal to capture/measure that wavelength effectively.

The theory has then been applied to quantify the path contributions in the point connected partition subject to structure borne excitation, and it is shown that it provides useful diagnostic information about its sound insulation properties. Its application with respect to airborne excitation is being tested currently.

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