Prediction of the sound radiation from a plate excited by a structure-borne sound source

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Introduction

The prediction of the power flow from a source with mobility Y_S to a receiver with mobility Y_R has been investigated for many years now [1][2]. Different prediction approaches ranging from a coupled multipole system, a system coupled through independent connection points or very basic ideal force and velocity cases have been investigated. It is clear that some sort of simplification is needed if the practical implementation in building acoustics is aimed for. A prediction of the radiation from a washing machine standing on a lightweight floor could be one of the practical examples.

Until now the emphasis has always been the prediction of the structure borne sound power. However, the ultimate goal of all of the structure borne sound calculations is the prediction of the sound radiation to some degree of accuracy. Instead of comparing different methods of structure borne sound prediction the next few experiments focus on the radiated sound field. The main question to be answered is: what simplifications in the structure borne sound prediction are allowed whilst still achieving a desirable degree of accuracy in the sound field?

Measurement Setup

The source consists of an electrical motor with a rotating disc connected to an aluminium plate as shown in Figure 1. Three B&K 8200 force sensors are connected to the plate and resemble the feet of the structure borne sound source. A series of out-of-balance masses can be attached to the rotating disk to vary the degree of source excitation. The input voltage is varied between four voltages (6, 7, 8 and 12 V) to change the rotational speed (1700, 2100, 2600 and 3350 rpm).

The receiver plates are simply supported by a rubber seal on the edges of the receiving. The receiving room is a box made out of 40 mm MDF plates. The dimensions are 1.25-by-1-by-0.75 m^3.

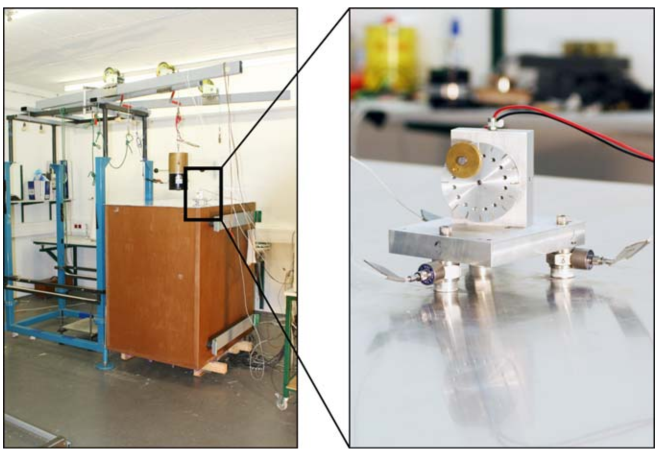

Figure 1: left: complete setup, right: source

Structure Borne Sound Power versus Sound Radiation

Through the use of three force sensors and three accelerometers at the feet of the source it is possible to accurately measure the in-situ structure borne power in the *z*–direction (normal direction to the plate), $P_{\text{SBS-in-situ}}$ c.f. matrix multiplication in Equation (1). Moment excitation and forces in the other directions are neglected.

$$P_{\text{SBS-in-situ}}(\omega) = \frac{1}{2}\Re(\mathbf{V}_{\text{in-situ}} \cdot \mathbf{F}_{\text{in-situ}}{}^{\mathrm{T}*}) \quad [\mathrm{W}] \qquad (1)$$

$$P_{\text{SBS-in-situ}}(\omega) = \frac{1}{2}\Re(V_{\text{in-situ}} \cdot F_{\text{in-situ}}{}^{*}) \quad [\mathrm{W}] \qquad (2)$$

$$\mathrm{TP}_{\mathrm{F}}(\omega) = \frac{p}{F_{\text{in-situ}}} \ , \ \mathrm{TP}_{\mathrm{V}}(\omega) = \frac{p}{V_{\text{in-situ}}} \qquad (3)$$

$$P_{\text{SBS-in-situ}}(\omega) = \frac{1}{2}|p|^2\,\Re\left(\frac{1}{\mathrm{TP}_{\mathrm{F}}\,\mathrm{TP}_{\mathrm{V}}{}^{*}}\right) \quad [\mathrm{W}] \qquad (4)$$

$$P_{\text{SBS-in-situ}}(\omega) = \frac{1}{2}|p|^2\,H^{-1}(\omega) \quad [\mathrm{W}] \qquad (5)$$

The intention is to find a parameter in the sound field that correlates well with the induced structure borne sound power measured in-situ. Once a perfectly correlating sound field parameter is found, different structure borne sound prediction approaches can be compared and rated. By measuring or predicting the in-situ force and velocity some simplification will usually be made. Ideally six degrees of freedom should be taken into account to characterise the physical system completely. This is however impractical or even impossible to achieve if a practical measurement procedure is aimed for. The approach here is to use the radiated sound to assess whether a certain simplification is allowed. The goal is to simplify the structure borne sound system to the degrees of freedom that are necessary to predict the radiated sound to a certain degree of accuracy.

By using the concept of power at a certain point in the system the interaction with any other system connected is ignored. So the feedback from the sound field on the plate is always ignored.

By using the acoustic transfer path between the excitation points on the plate and a single microphone position in the room it is possible to monitor the structure borne input power in the sound field. The derivation for the single contact point is found in Equation (2)-(5).

The theory was first of all experimentally verified by measurements on the scale model. The transfer path factor $H(\omega)$ was measured from three points on a plate (c.f. Figure 2) to a single microphone position in the receiving room as shown in Figure 4. A shaker was then used as structure borne sound source to ensure perfect transverse excitation. A multi-tone spectrum at the third octave band centre frequencies was synthesized to simulate the excitation of a real structure borne sound source. The three different points on the plate were excited and the sound pressure level in the receiving room was recorded. Figure 3 shows the correlation between the structure borne sound power and the squared pressure. The level varies depending on the excitation position and includes the influence of the sound field in the receiving room. Those levels cannot be used to check for correlation between structure borne sound power and pressure. The method using the transfer path factor is presented in Figure 5. The levels are all identical according to the theory. From those results it can be concluded that the shaker excitation was measured accurate enough to represent the radiation because it correlates with the sound pressure in the receiving room. A shaker is an ideal source and is likely to excite the structure in the transverse direction because it is connected with a flexible stinger.

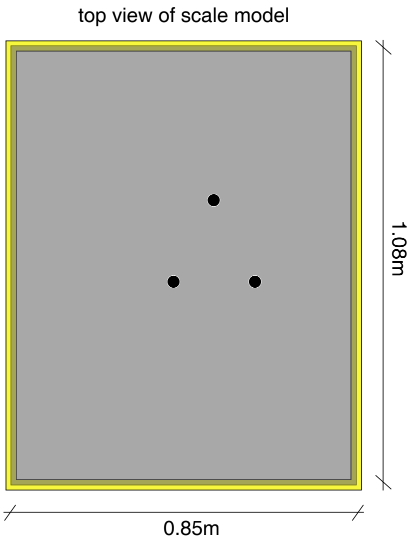

Figure 2: Excitation points on the plate

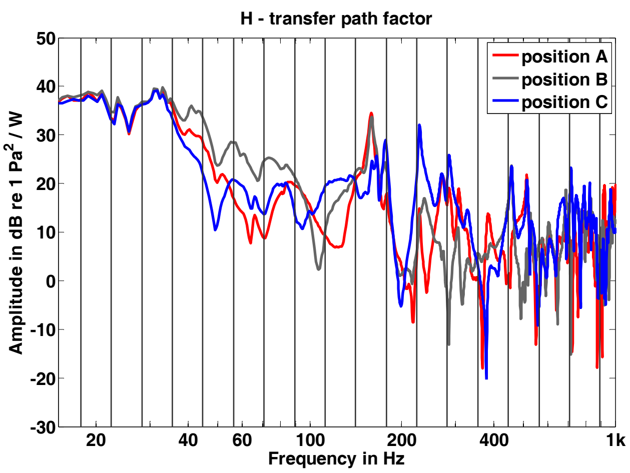

Figure 4: Transfer path factor measured with shaker excitation.

The same measurement procedure was repeated but the electrical motor was used as structure borne sound source. One source position on a 3 mm aluminium plate was excited with different states of the source: 6 different out-of-balance masses and 4 rotational speeds were used. The results in Figure 6 show deviations of about ±5 dB from the expected 0 dB line. This means that the accuracy may be acceptable for survey tests and estimations, but it is clear that some excitation components of the structure borne sound source are missing in the measurement. It should be pointed out again that only transverse forces and velocities were measured. The remaining five degrees of freedom were ignored. The results reveal that the characterisation of the scale model has to take into account more degrees of freedom if a more accurate prediction of the sound radiation is desired.

This procedure will be used to reduce the complexity of the excitation by structure borne sound sources. The scale model will be investigated in more detail to find out what degrees of freedom lead to a perfect correlation of the structure borne sound power and the radiated pressure. Once this is achieved, source characterisation predicted by using independently measured source and receiver mobility will be looked at and different degrees of complexity of the source characterisation will be compared.

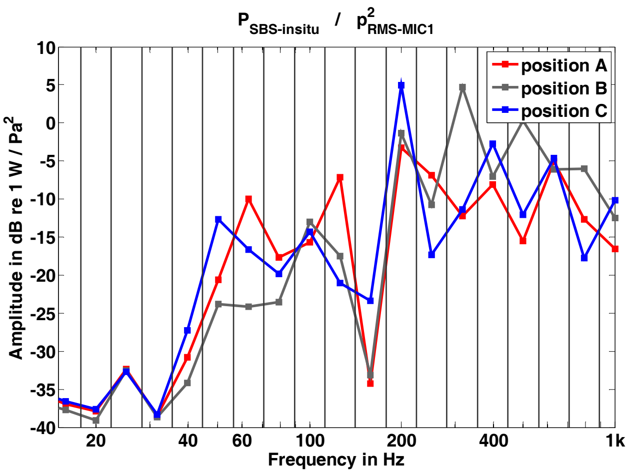

Figure 3: Ratio of structure borne power and sound pressure for ideal transverse excitation.

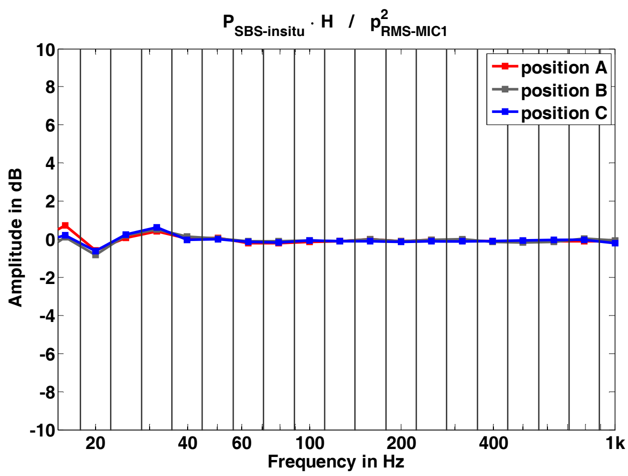

Figure 5: Ratio of structure borne power and sound pressure for ideal transverse excitation. Transfer path factor is included.

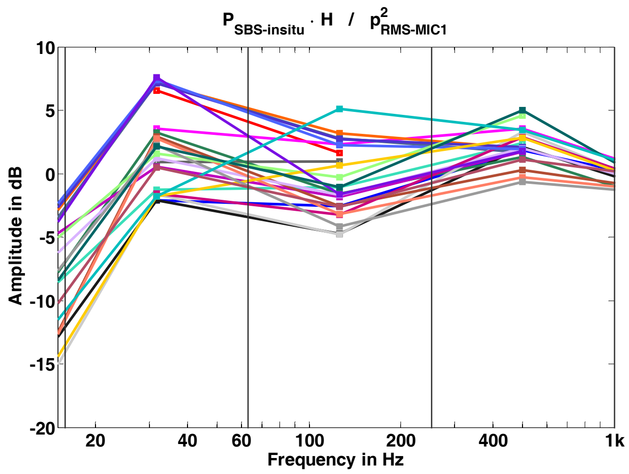

Figure 6: Ratio of structure borne power and sound pressure for small electrical motor. The transfer path factor is included.

Conclusion

The sound radiation from a plate excited by a structure borne sound source was investigated. It was shown that by using a transfer path factor it is possible to achieve a perfect correlation between the structure borne sound power and the radiated pressure in the receiving room. This was empirically verified for the case of an ideal transverse excitation. The correlation for the case of a scale model of a structure borne sound source showed deviations up to ±5 dB which means that the complexity was reduced (transverse excitation only) too much to characterise the radiation to a reasonable degree of accuracy.

References

[1] B. Petersson and J. Plunt. On effective mobilities in the prediction of structure-borne sound transmission between a source structure and a receiving structure, part 1: Theoretical background and basic experimental studies, *Journal of Sound and Vibration*, 82(4):517-529, 2004.

[2] A. T. Moorhouse. On the characteristic power of structure borne sound sources. *Journal of Sound and Vibration*, 248(3):441–459, 2001.