Force Measurements of a Person Walking on a Lightweight Floor

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Introduction

The interaction between a person walking on a lightweight floor is investigated by comparing the directly measured structure borne sound power with the calculated power according to a simple mobility model. The model assumes time-invariance of the source mobility. This assumption allows for a certain measured body posture to be taken as a constant source mobility during the onset of the impact with the floor. In this way the source mobility can be measured relatively easily without the need to analyse the variation of the mobility in time. The direct power measurement in comparison to the calculated power according to the mobility model as it is presented here, shows to what extent this simplification is valid for the prediction of impact sound on lightweight floors.

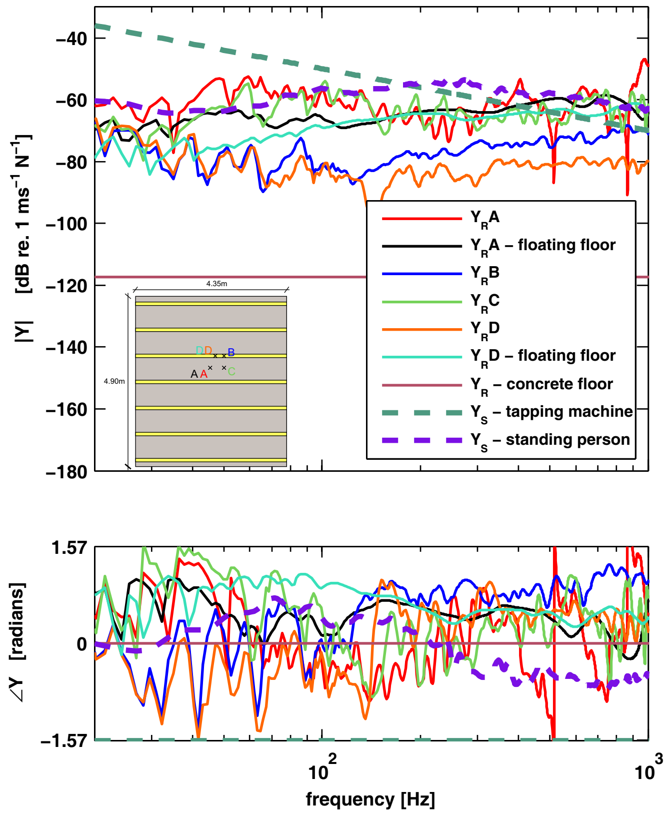

Figure 1: Floor and source mobilities

Power transfer

The human body is represented by its source mobility $\bar{Y}_S$ and the blocked force term $\bar{F}_{BS}$. The floor is characterised in the form of a receiver mobility $\bar{Y}_R$. The main argument for the use of a time-invariant model is the importance of the first 100 ms of the blocked force after high-pass filtering the blocked force at 10 Hz (c.f. [1]). Therefore if the acoustically relevant excitation dominates during the first 100 ms and the source mobility is assumed constant during this very short period of time as well, the system is reduced to a time invariant system.

The transferred power for the mobility model is: $W(\omega) = \frac{|\bar{F}_{BS}|^2 |\bar{Y}_S|^2 \Re(\bar{Y}_R)}{2|\bar{Y}_R+\bar{Y}_S|^2}$. This calculation is compared to the directly measured power, $W(\omega) = \frac{1}{2}\Re[\bar{F}_R \bar{v}_R^*]$ and to the power transfer in the case of an ideal force source, $W(\omega) = \frac{|\bar{F}_{BS}|^2}{2}\Re(\bar{Y}_R)$. For an ideal force source the very high source mobility is neglected compared to the receiver mobility and the transferred power becomes independent of the source mobility. This assumption can only be used for the characterisation of different floor constructions if all sources (e.g. tapping machine, person walking, ...) acting on a range of floors behave as ideal force sources. In the case of "light" sources on "heavy" floors this assumption is generally valid. For lightweight floors the tapping machine is an ideal force source only below 100 Hz as shown in figure 1. A person walking on a lightweight floor is not an ideal force source.

Measurement setup

To test the coupling in the mobility model it is important to investigate receiver mobilities of the same order of magnitude as the source mobility. Four points on a 4.35 x 4.9 m wooden joist floor were investigated as shown in figure 1. Two of the points are on a joist and the other two points are in between two joists. The floor consists of 20 x 10 mm joists with a 21 mm fibre board on top. Additionally, a floating floor (20 mm Fermacell reinforced gypsumboard and 10 mm wood fibre board) was installed on the same wooden floor and point A and D were measured again. The floor mobilities shown in figure 1 were measured with an impulse hammer. The source mobility of a person standing was measured on a special shaker setup described in [2]. The measured source mobility is also shown in figure 1. Due to the overlap of the curves it serves as a suitable case to analyse the coupling between source and receiver. To calculate the power according to the mobility model the blocked force during walking was measured with a force plate on an immobile floor. A walking pace of 2 steps per second was kept constant.

The power was also directly measured by recording the velocity and the excitation force while walking 40 times over each point. The force and the velocity was averaged in time after peak alignment of all time histories. The walking pace was kept as constant as possible to ensure a constant source activity. The velocity can easily be measured with an accelerometer attached to the floor. For the direct measurement of the force, a shoe with a force plate mounted to the heel was built as shown in figure 2. The shoe was calibrated by walking on an second force plate that was fixed on an immobile floor. The force measured with both force plates showed only small deviations of 1 dB in the frequency region 10-1000 Hz. The deviation caused by changing the walking pace was investigated in a separate experiment on an immobile floor. It was shown that the amount of 40 averages was sufficient to reach a reproducible blocked force even if the experiment was repeated the day after.

For the calculation of the power in the case of an ideal force source only the blocked force and the floor mobility have to known.

Figure 2: Shoe to measure force directly

Results

The floor mobilities A and C in figure 1 correspond to a point between two wooden joists and reveal a high mobility level. At high frequencies the mobilities go towards the mobility of an infinite fibre board of 21 mm. Points B and D have a much lower mobility. At frequencies below 100 Hz the beam behaviour can be seen. At higher frequencies the difference between B and D is due to the distance to the nearest screw. The floating floor generally has a higher mobility and behaves as an infinite plate. Even at low frequencies below 100 Hz the beam mobility is not predominant. For the combination of source and receiver mobility high coupling is expected for all points except of B and D. The phase information in figure 1 is also important. If source and receiver mobility are out of phase the denominator in the power formula would become very small resulting in high power transfers. Comparison between the phase curves shows that this is very unlikely to occur so we are expecting a rather moderate coupling.

The power measurements are presented in figure 3. The direct measurement is shown in the middle graph. The prediction with the mobility model is shown on the left hand side and the ideal force source model is shown on the right. The direct measurement corresponds better to the mobility model than to the ideal force source model. Especially at low frequencies below 200 Hz the deviations associated with the force source model are very high. To make it easier to compare the difference between the curves, figure 4 presents the same results in reference to point B. At frequencies below 200 Hz it can clearly be seen that the mobility model produces much better results than the ideal force source. Above 200 Hz the mobility model predicts smaller differences between the points on the floor. The reason for this could be the variation in floor mobility close to the point that was measured with the impulse hammer. As this measurement corresponds only to a specific point on the floor it also has to be hit precisely when walking over it.

Acknowledgement

The measurements on the wooden floor were done at the Stuttgart University of Applied Science. I gratefully acknowledge their support in providing the measurement laboratories.

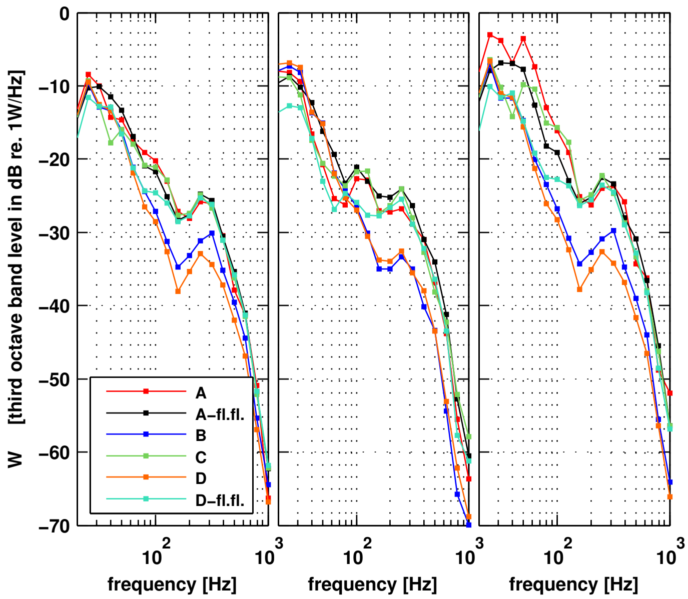

Figure 3: From left to right: power according to mobility model, measured power, power according to ideal force source.

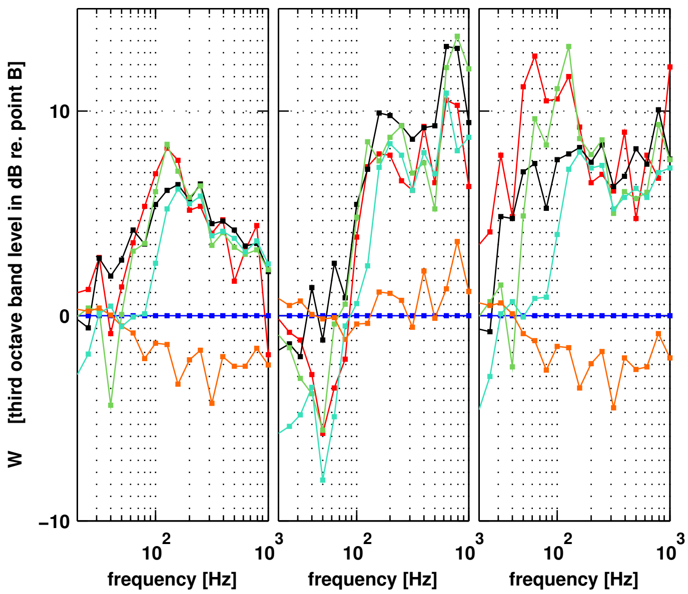

Figure 4: Identical to figure 3 but curves use point B as reference.

References

[1] Lievens M., Proceedings of the ICA, 2007.

[2] Lievens M., Fortschritte der Akustik, 2007.