Mobility Measurements of a Standing Human Body in the Context of Impact Sound Auralisation

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Introduction

For the auralisation of impact sound of a person walking on a floor the assumption of an ideal source with negligible source mobility does not hold in conjunction with lightweight floors. Instead of assuming an ideal source, the coupling between source and receiver mobility has to be taken into account. To investigate this the amount of coupling was looked at by comparing mobility measurements found in the literature and mobility measurements made on a special setup.

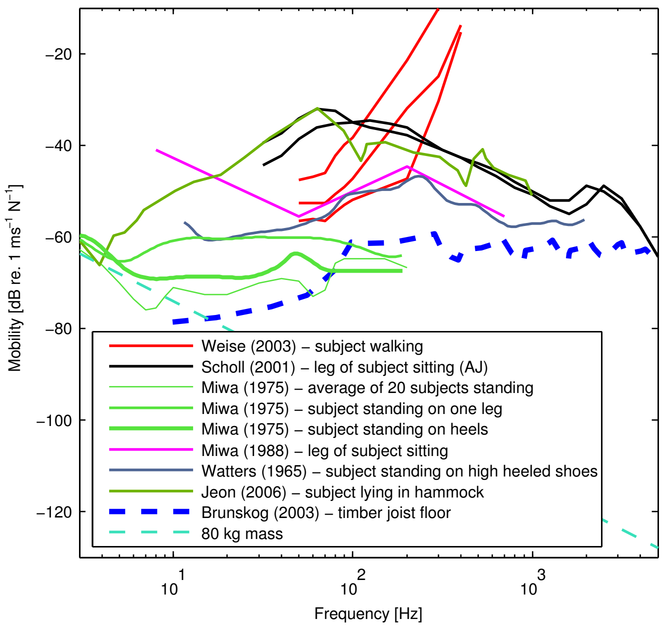

Figure 1: Comparison of the mobility of a human body and a common lightweight floor construction after [1, 2, 3, 4, 5, 6].

Power transfer between source and floor

A simplified model of the impact sound caused by a person walking on a floor can be modelled as a source mobility ($\bar{Y}_S$) coupled to a receiver mobility (($\bar{Y}_R$) and excited by a blocked force source ($\bar{F}_{BS}$). The power transfer from the source to the receiver for this system is defined as: $P(\omega) = \frac{|\bar{F}_{BS}|^2 |\bar{Y}_S|^2 \Re(\bar{Y}_R)}{2|\bar{Y}_R+\bar{Y}_S|^2}$. This frequency model holds only for a linear system with a constant coupling, i.e. for example the rebound of a dropped source is ignored. A realistic model of a person walking would involve many more aspects but this is not important for the current investigation. In this study the extend of the coupling between source and receiver is looked at in more detail.

Most important is the fact that for the source mobility to play a significant role in the power transfer into the floor, the mobility has to be in the same order of magnitude as the mobility of the floor.

Floor mobility versus human body

Source mobilities of the human body have been measured in the past either during walking or while standing. Figure 1 gives an overview of the measurements found in the literature. Additionally the mobility curve of a lightweight floor according to a simulation is shown. At low frequencies the mobility deviates from the mobility of an infinite gypsum board ($Y = 1/8\sqrt{BM}$) as the beam plate structure starts behaving as a homogeneous plate. Impact sound on lightweight floors is predominantly a low frequency problem. For this reason it was aimed to present the low frequency mobility of the floor as accurately as possible. Alternatively measured floor mobilities could be used. Depending on specific floor dimensions and particular floor components large deviations are expected.

A comparison between the source mobilities and the floor mobilities shows that for some of the measurements a coupling between floor and source is impossible to occur. The measurements by Miwa on the other hand are much lower which support the fact that strong coupling between source and receiver exists. To clarify the large range of mobility measurements the setup presented in the next section was build.

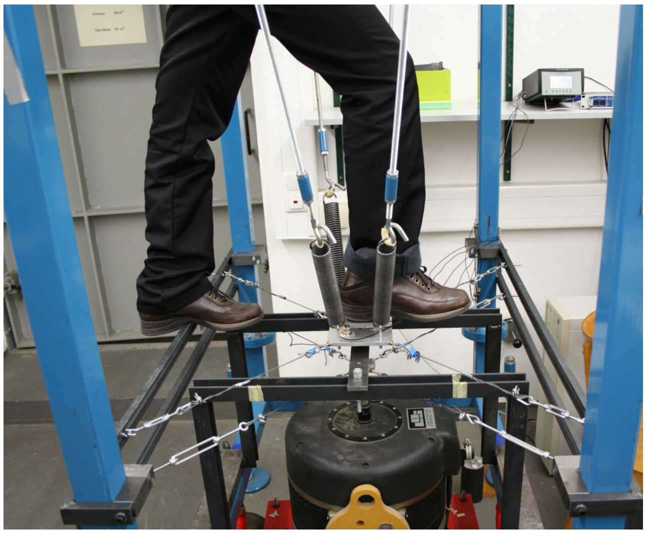

Figure 2: Mobility measurement setup to support the human body.

Mobility setup

Figure 2 shows the setup to measure the mobility of a human body. It consists of an LDS 501 shaker connected to a plate which is suspended by four springs ($k = 1.93\,kN/m$) of adjustable height and 8 steel cables. With a body mass of 80 kg this would result in a resonance frequency of 2.8 Hz if the shaker stiffness is accounted for. The cables avoid the plate to move in the horizontal direction. On top of the plate a second aluminium plate (100x100x15 mm) is attached by three B&K 8200 force transducers. The mobility is calculated by use of a B&K 4507 accelerometer mounted in the middle of the top plate. The first resonance frequency of the top plate is at about 2500Hz. Below this frequency, the force signals can simply be added to get the total force acting on the plate.

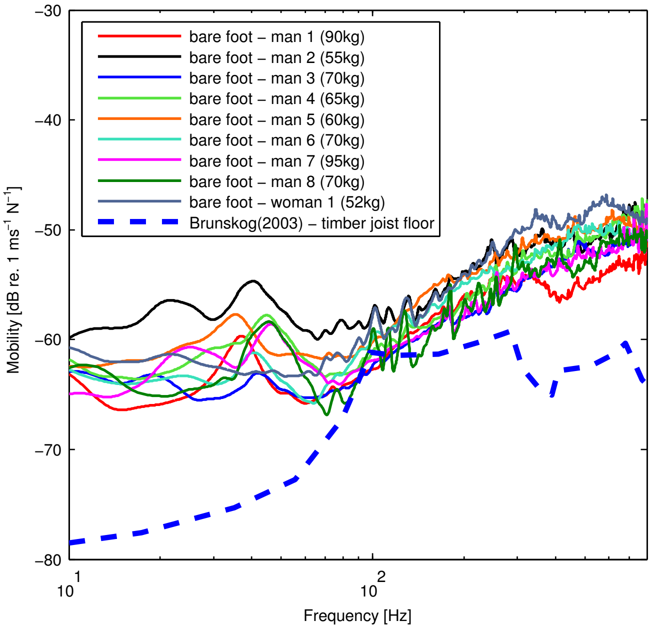

Figure 3: Mobility measurements of different subjects standing on one heel while keeping their leg fully extended.

Mobility measurements

Using the simple model of the coupling between a person walking and a floor the most dominant mobility occurs during the contact phase when the person hits the floor while supporting the bodyweight with one heel and keeping the leg fully extended and the muscles tense. This posture was used to measure the mobility of nine subjects of different weight. The results are seen in Figure 3. The curves can be divided into two main sections: A section below 100 Hz dominated by damping and a section showing spring behaviour above 100 Hz. Although a strong correlation between the curves and the body weight cannot be found, the spread is larger below 100 Hz in the damping region. Above 100 Hz the mobility is determined by the stiffness of the flesh of the heel and the sock and is more similar for all subjects. A comparison of these measurements with the mobility of a lightweight floor reveals that only in the region around 100 Hz strong coupling is likely exists.

The effect of different shoes on the mobility is shown in figure 4. Compared to the previous plot a third region is clearly seen for some of the measurements. Above 300 Hz an additional mass regions occurs for the walking boot and the shoe with leather sole. This is due to the larger weight of the shoe combined with the high stiffness of the sole. A two DOF system with $m1 = 0.3\,kg, k1 = 2.5e6\,N/m, m2 = 8\,kg, k2 = 0.4e6\,N/m$ is plotted as model for the human body with walking boot. This kind of model could be a first attempt in modelling the human body as structure borne sound source in the frequency region between 30-800 Hz. Care has to be taken as the model assumes constant contact between the source and the receiver. If the model with its much lower weight compared to the original source, is for example dropped onto a floor the rebound would result in a phase of infinite source mobility.

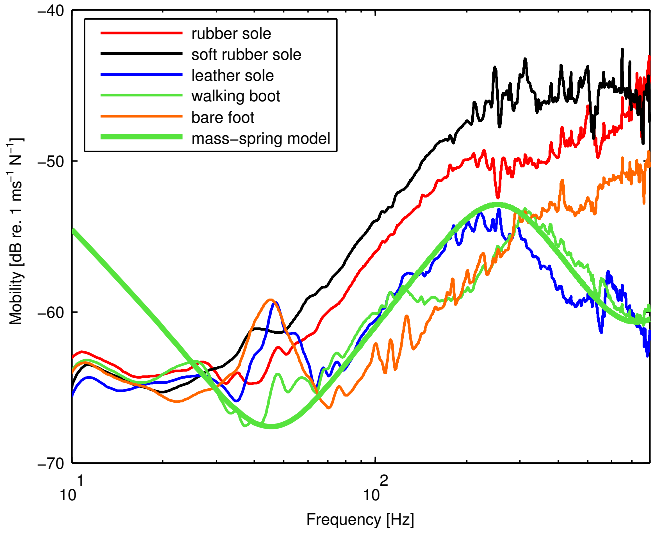

Figure 4: Different mobilities for various shoes of a man of 70 kg standing on one heel.

Conclusion

Measurements of the mechanical mobility of a human body were carried out to compare with measurements found in the literature. It was shown that the mobilities are comparable in magnitude with mobilities of common lightweight floors. Therefore it is important for the calculation of the power transfer from a human body into a lightweight floor to take the source mobility into account.

References

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