Comparison of different methods for the determination of the structure-borne noise reverberation time

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Introduction

Due to the implementation of new measurement standards in building acoustics (ISO 140 series, EN 12354 etc.), measurement of the structure-borne noise reverberation time (in the following referred to as T_s) has become necessary for the determination of some measurands of building acoustics, especially the total loss factor [1]. As the basic procedure is similar to that for the airborne noise reverberation time, there are some significant differences due to the special nature of the test objects and the excitation methods. Based on earlier research, further measurements have been performed to obtain knowledge about some open questions of this measurement method. The results of this research will be presented in this article.

Test program

Measurements of T_s performed in the past left some questions open. There seemed to be a systematic difference between the results obtained with either hammer or shaker excitation. Systematic differences at certain frequencies have also been observed for different shaker configurations. The measurements were performed on a 24 cm sand-lime brick wall with a plaster layer on both sides.

Hammer measurements

Four different hammers were used: one modal hammer and three conventional hammers with different masses as shown in fig. 1. All hammers had a hard plastic tip or plastic cap, which is convenient to cover the required frequency range of 100 Hz to 5 kHz. An accelerometer with a mass of 16 g was used as a receiver. 4 excitation points and 3 receiving points were used, yielding 12 independent decays for each measurement.

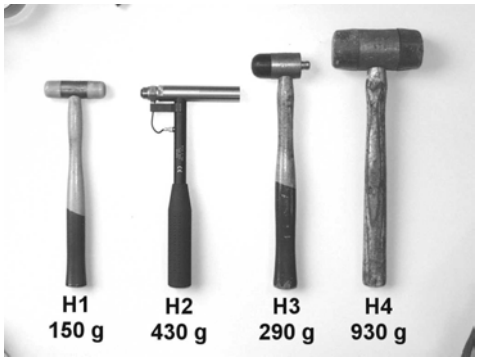

Figure 1: Hammers used for excitation of the test wall

Shaker measurements

Two shaker configurations were used in these investigations. Set-up 1 consists of a large B&K 4809 system mounted on a special rig to be clamped between floor and ceiling or opposite walls. Set-up 2 uses a much smaller B&K 4810 shaker mounted on a conventional microphone support. This configuration was chosen because differences from set-up 1 had been observed when a similar set-up was used, set-up 2 produced a "peak" at 2 kHz. Set-up 2 is also easier to handle than set-up 1. Both shakers were coupled to the wall using a force transducer and a magnet. The same receiver and measurement positions as in the hammer measurements were used, but now the receiving positions were used as excitation positions and vice versa. The shaker measurements were performed using the MLS-technique.

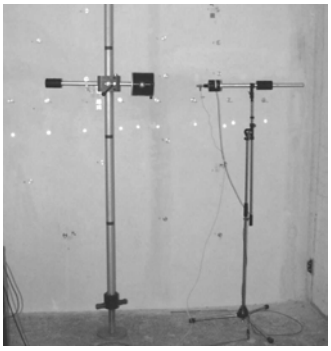

Figure 2: Shaker set-up 1 (left) and 2 (right)

Data acquisition and evaluation

For data acquisition and evaluation, a PC–based AD/DA system with commercially available software was used. This software is also able to provide time-reversed filtering, which is necessary because the reverberation time of normal 1/3-octave band filters is in the same range as the T_s of the test object. When using time-reversed filtering, shorter T_s values can be measured. Self-written software served to carry out the backward integration and the evaluation of the T_s values. The evaluation range usually was –5 to –25 dB, thus resulting in T_{20} reverberation times. Sometimes, however, T_{10} or T_{15} had to be used because of a lack of signal dynamics. It is to be pointed out once more that backward integration is mandatory and the reverberation time must not be evaluated using the impulse response directly, even if sometimes similar results are obtained, because the physical approach is wrong [2].

Measurement results

If not stated otherwise, the measurement values are represented as the correction term ΔR_η for sound transmission loss which is calculated using

$$\Delta R_\eta = 10 * \log\left(\frac{\eta}{\eta_{ref}}\right) \mathrm{dB}$$

where η is the measured total loss factor and η_{ref} the minimum total loss factor as required in ISO 140-1. In this way the influence of the measurement results on the calculated sound transmission loss is directly expressed.

Figure 3 shows the results for both, hammer and shaker measurements. The results of the hammer measurements agree quite well with each other, though hammer 4, which is the heaviest one, seems to deliver systematically higher results in the middle frequency range. The shaker measurements also show a smaller systematic difference from each other. It is apparent that in a wide frequency range from 300 Hz to 2 kHz the hammer measurements furnish a significantly higher loss factor than the shaker measurements. This was already observed by *Meier* in earlier

research (also [1]). Even then it was suggested that this is due to a non-linear behaviour of the test object, although this could not be definitely proved.

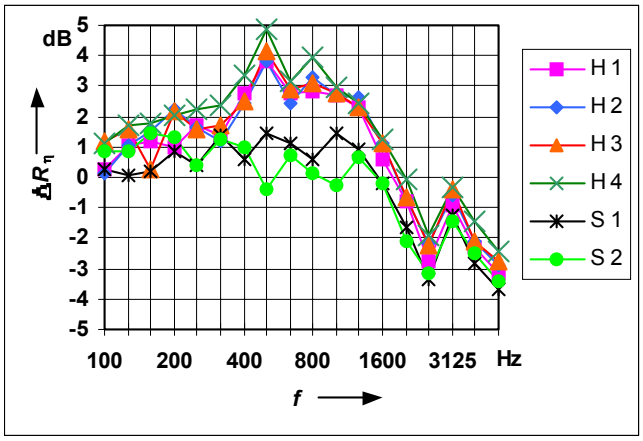

Figure 3: Measurement results for hammer and shaker excitation

To investigate this difference, some impulse responses showing a very great difference between shaker and hammer excitation at certain positions were examined in more detail. It soon was shown that the reverberation times measured with shaker excitation were longer (thus resulting in smaller loss factors) because a resonant mode in the observed 1/3-octace band decayed at a slower rate than with hammer excitation. As *Meier* suggested non-linearity as a possible reason, a new test was made with hammer 2, using the same excitation and receiving positions as in the shaker measurement. The measurement was carried out three times varying the impact force in a range of 20 dB. The resulting reverberation times varied with a factor of approximately 2 between the weakest and the strongest hammer blow in the 500 Hz 1/3-octave band. The reverberation time achieved with the weakest blow was in the range of the reverberation time measured with the shaker set-up. Figure 4 illustrates the effect in the frequency domain:

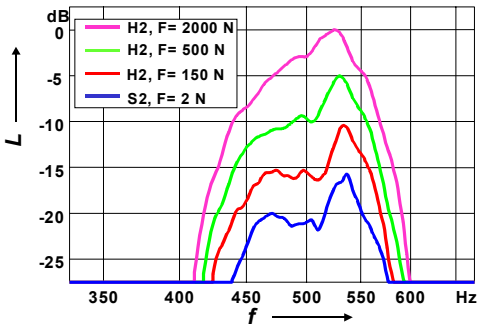

Figure 4: Transfer function in the frequency domain for different types of excitation, 500 Hz 1/3-octave band. The curves are artificially displaced on the level axis for better comparability.

It can clearly be seen that the resonant peak at the frequency of about 530 Hz broadens with increasing excitation force, and the resonance frequency shifts to a lower value. Both effects indicate an increased damping of the mode when the structure is excited with greater force. The fact that the heaviest hammer delivers the highest loss factors also supports the assumption that the damping of the measured structure depends on the force it is excited with. It should be taken into account that for the measurements shown in figure 4 the peak force produced by the hammer is in the range of 500 N while the force generated by the shaker is in the range of 2 N. Another test measurement was done using shaker 2 and varying the excitation force in three steps in a range of 20 dB with a minimum force of 0.5 N and a maximum force of 5 N. In contrast to the hammer measurements, no change could be observed. This indicates that the excitation force at which the alleged non-linear behaviour occurs is much higher than the force normally applied by a shaker. One should also keep in mind that non-linearities lead to a decreased s/n ratio when using the MLS technique, so a sufficient s/n ratio is a good indicator for linear behaviour of a test object. A possible explanation for the better agreement between shaker and hammer measurements at frequencies above 2000 Hz is that the force spectra of the hammer blow starts to roll off at 1 kHz and goes down to force values that are in the same range as those produced by a shaker.

Effect on sound transmission loss

As the measured loss factor of the tested wall seems to be dependent on the excitation force, the question arises whether it is hammer excitation or shaker excitation which better represents the behaviour of the test object when carrying out a sound transmission loss measurement. As a first investigation the peak acceleration values measured on the test wall when using airborne sound excitation at building acoustics level (100 dB lin, pink noise) was compared to the acceleration that occurs when hammer or shaker excitation is used. For hammer and shaker excitation the acceleration was measured in the reverberant field (distance from excitation point > 1m) as well as next to the excitation point.

H2, RF	H2, NF	S2, RF	S2, NF	Airborne
1,6 ms^{-2}	23,0 ms^{-2}	0,1 ms^{-2}	0,6 ms^{-2}	0,3 ms^{-2}

Table 1: Peak acceleration measured on the test wall for different types of excitation. H = hammer, S = shaker, NF = near field, RF = reverberant field.

The measurements show that the acceleration value generated by the hammer blow in the near field is significantly higher than the other values. Also, the acceleration measured using shaker excitation is in the same range as with airborne excitation. This could indicate that the observed non-linearities are a "local" effect which occurs mainly in the area of the excitation point. One possible reason could be the fact that there is no mortar between the face surfaces of the bricks, causing a change from static to sliding friction when sufficient force is applied.

Conclusions

When measuring T_s to determine the total loss factor of a building element, the results obtained with hammer excitation are different from those obtained with shaker excitation due to non-linear effects. The reason for this non-linear behaviour cannot be properly explained yet. In any case, shaker measurements appear to give a better representation of the wall behaviour with respect to airborne-noise excitation. In the future further research is necessary to get a better explanation of the non-linear effects and to investigate the behaviour of different wall types.

References

[1] *Meier, A.*: Die Bedeutung des Verlustfaktors bei der Bestimmung der Schalldämmung im Prüfstand; Dissertation RWTH Aachen, Shaker Verlag 2000

[2] *Schroeder, M.R.*: New method of measuring reverberation time. J. Acoust. Soc. Amer. **37** [1965], p. 409-412