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Evaluation of AkuLite measurements of buildings – a comparison between sound pressure stemming from tapping machine and impact ball excitations

Jörgen Olsson
SP - Technical institute of Sweden
Växjö, Sweden

Kirsi Jarnerö
SP - Technical institute of Sweden
Växjö, Sweden

Andreas Linderholt
Linnaeus University
Växjö, Sweden
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Abstract
The impact ball has shown to give excitations in close resemblance with the excitation from a human step. However due to practice and practical measurement reasons, it is interesting to use the tapping machine in low-frequency measurements. Here, the two excitation techniques; the tapping machine and the impact ball, are compared in terms of statistical dispersion. In the AkuLite project light weight apartment buildings were measured using a tapping machine and a (Japanese) impact ball in the low frequency range down to 20 Hz. The results showed that the tapping machine gives more narrow/better confidence interval in the test compared to the test using one excitation point together with the impact ball. The t-test of the consistency of the difference between the impact ball and tapping machine for the same measurement objects shows weak correlation, which implies that the results from the tapping machine are not normally possible to be interchanged with impact ball results and vice versa, without using a correction factor.

1. Introduction
The ISO tapping machine has shown to be a useful tool for impact sound measurements. However, in the low frequency range, which is important for perception of sound in light weight buildings, there are alternative excitation methods such as the impact ball from Japan, standardized according to ISO 10140-5 [1]. Compared to the tapping machine the sound excitation with the impact ball has a better correlation with the excitation by a human step. Jeon et al [2] made a comparison between an impact ball, a bang machine and an ISO tapping machine. It was shown that the ball represents the excitation characteristics of humans’ walking on light weight floors better than the alternative excitation devices. Another benefit of the impact ball, also seen in the results, compared to the tapping machine is that the signal to noise ratio is 10-20 dB larger in the 20 – 100 Hz range in light weight wooden buildings. This is an important field measurement aspect since background noise is omnipresent. There are efforts made in order to give the tapping machine characteristics that better corresponds to human walking. For instance Scholl [3, 4] developed a modified set up of the tapping machine, used in test standard ISO 10140-5 [1], with rubber between the points of impact and the tapping pistons.

The question investigated in the present work is if the results from the tapping machine are consistent enough to be weighted in the low frequency range and if results similar to the ones stemming from impact ball excitations or vice versa could be achieved in such a way.

The correlation between the impact ball and the tapping machine is made by utilizing the test results from the former project AkuLite, in which measurements are made in different light weight wooden buildings in Sweden. Four building objects [5, 6, 7, 8] are included in this analyze. The differences of sound pressures levels stemming from tapping machine and impact ball tests for each building are studied. These spectra are compared between all the buildings. The hypothesis is that if the differences between test data related to the tapping machine and the impact ball are constant between each measured room, for all the measurement objects, then the ball measurement and the tapping machine are interchangeable with each other. Since the measurements...
with the two methods have been made at the same occasion and thereby with the same furnishing, there should not be any need for correction against reverberation time when comparing each room. The 95 % percentile interval borders for both types of measurements are calculated in order to see if there is a quality difference between the two measurement techniques. The different buildings are given anonymous labels according to the AkuLite numbering system.

2. Method

There are more measurement objects in the AkuLite project than these here chosen for correlation. However, for some of the objects; measurements of impact sound stemming from a tapping machine as well as an impact ball in the same room are lacking. In addition, data from one measurement is not sufficient to give a statistical variance. In order to calculate the variance of measurements, measurement results stemming from both a tapping machine and an impact ball for exactly the same room type are selected. This narrows the qualified objects that are included in this study.

For the object 1 measurements; living rooms 1001, 2001, 3001, 4001 and 5001 and also the bed rooms (included in the variance results) 1004, 4004 and 5004. For the object 2 measurements; the rooms 1104, 1201, 1202 and 1204. For the object 3 measurements; the rooms 302, 402, 502, 502S.

The object 10 measurements; the rooms V1201, V1203, S1201, SA1203, SB1203

2.1. Tapping machine

According to the AkuLite test protocol, the measurements and their results are made according to the ISO 140-7, ISO 717-2 and SS 25267 standards but with the extended frequency range 20-5000 Hz. The values presented is the impact sound pressure level $L'_n$ in 1/3 octaves.

2.2. Impact ball

The excitations are made according to the AkuLite test protocol; on the center of the joist floors with 1.0 m drop height. Sound pressures are measured in two positions in the receiving room. The microphone positions are 1.0 m above the floor in the center of the room and 1.0 m above the floor at one corner of the room. The measure presented is $L'_{ZFMax}$; Linear (Z) total maximum sound pressure level in 1/3 octave with Fast integration (the time constant for fast is 125 ms), using a reference pressure of 20 µPa.

3. Results

Examples of measurement results for the impact ball and tapping machine used in the statistical evaluation for each building are presented in Figure 1 - Figure 4 below.
3.1. T-test

The average differences between impact ball sound pressure levels and tapping machine sound pressure levels for the same floor and building are presented in Figure 5 and Figure 6. There are significant differences; the signals from the impact ball are in average roughly 20 dB stronger in the mid room measurements and 25 dB in the corner measurements, in the lowest frequency range around 20 – 40 Hz. The point in the mid room measurements where the tapping machine signals are getting stronger in the mid room measurements is around 200 Hz. The corresponding point in the corner measurements is slightly over 200 Hz. The spread between the signals is largest in the lowest frequency range.

In order to have a statistical measure of how consistent the differences are, a t-test is made between each batch of difference values for each measured room type and building. The purpose is to see if different measurement objects have similar mean values of difference. This is made for both the mid room meas-

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Figure 1. Object 1, impact ball measurements, excitation from the room above, microphone in the middle of the room 1 m above the floor. The descriptor numbers above in the figure represent the room measured.

Figure 2. Object 1, impact ball measurements, excitation from the room above, microphone in the corner of the room 1 m above the floor. The descriptor numbers above in the figure represent the room measured.

Figure 3. Object 1, living room, tapping machine measurements with excitation from room above. The descriptor numbers above in the figure represent the room measured.

Figure 4. Object 1 bed rooms, tapping machine measurements with excitation from room above. The descriptor numbers above in the figure represent the room measured.
urements and the corner measurements. All the measurements made in the different buildings are correlated crosswise against each other. The averaged results of these t-tests are presented in Figure 7 and Figure 8. The correlation is low, the lowest correlation value is around 0.3 in probability of having the same mean difference values in the lowest frequencies. At higher frequencies the correlation value is steadily increasing. At 500 Hz, the correlation is approximately equal to 0.5.

![Figure 5](image1.png)  
**Figure 5.** Difference between impact ball measurements in the mid room and tapping machine in average for each building.

![Figure 6](image2.png)  
**Figure 6.** Difference between impact ball measurements in the corner of the room and tapping machine in average for each building.

![Figure 7](image3.png)  
**Figure 7.** T-test of sound pressure level differences. Impact ball minus tapping machine in mid room.

![Figure 8](image4.png)  
**Figure 8.** T-test of sound pressure level differences. Impact ball minus tapping machine, corner of the room.

### 3.2. Measurement variance

The rooms which are of the same size and type of construction are comparable for the estimation of a confidence interval. This is made separately for each kind of measurement, including the following measurements:

- For the object 1 measurements; living rooms 1001, 2001, 3001, 4001 and 5001 and also the bed rooms 1004, 4004 and 5004.
- For the object 2 measurements; the rooms 1104 and 1204.
- For the object 3 measurements; the rooms 302V, 420V, 502V.

The object 10 measurements were not made in exactly the same kind of rooms and is therefore excluded in this comparison.
The object 1 living rooms measurements with an impact ball plotted with the 95 % percentile interval are presented in Figure 9 and Figure 10. The corresponding measurements with a tapping machine are shown in Figure 11. The results of each 95% percentile interval is linearly weighted to the total 95% percentile interval based on the number of measurements that contributed in relation to the total number of measurements. The curves for the 95 % percentile interval for the measurements included are presented in Figure 12. For the measurements with impact ball in the middle of the room the average 95% percentile interval in the range of 20 – 500 Hz is 4.1 dB. In the corner the range is 5.7 dB and for the tapping machine the range is equal to 2.7 dB. Compared to the tapping machine, the impact ball mid room measurements have an average value that is approximately 50 % larger. For the corner measurements the average value is more than 100 % larger (106 %).

![Figure 9](image9.png)  
**Figure 9.** Measurements with impact ball with a microphone in the middle of the living room of object 1.

![Figure 10](image10.png)  
**Figure 10.** Measurements with impact ball with a microphone in the corner of the living room of object 1.

![Figure 11](image11.png)  
**Figure 11.** Measurements with tapping machine from the living room above of Object 1.

![Figure 12](image12.png)  
**Figure 12.** Average 95 % percentile ranges for the three different measurement procedures.

### 3.3. Discussion and conclusions

From the t-tests it is found that the mean difference correlation between tapping machine measurements and impact ball measurements are low. In the lowest frequencies, the probability to achieve the same results is around 20-30%. This implies that the measurement results from the impact ball are not well reproducible with the tapping machine and vice versa. There are only a few sets of data qualified for the 95% Percentile variance comparisons between the tapping machine and the impact ball; 13 measurements
The results show that the tapping machine, on average, gives a narrower confidence interval. The probable reason is that the tapping machine with its five excitation points, placed on at least on four locations on the floor, together with spatial averaging of microphone positions gives enough data for more stable average values. Dropping the ball five times in the middle of the room gives less statistical data. The repeatability for one excitation point and microphone point has shown to be good with the impact ball in the low frequency range (seen in for instance ref. 9). However this might be a disadvantage since the five excitations not become statistical of the spread in the floor properties or the room modes in the room below that is measured. The five excitations could be seen as one good sample, point to point rather than an average value of the measured room.

The results of Homb [9] for instance show that the accelerance transfer function for excitation of one period of joist could differ 10-15 dB within the frequency range 10-100 Hz depending on if the excitation is made on a beam or between beams. This implies that it is important to have several excitation points also for the impact ball.

Since the repeatability for the impact ball is good, the standard error of the mean (SE) becomes the standard deviation (s) divided with the root of the sample size (n):

\[ SE_x = \frac{s}{\sqrt{n}} \]

Considering the mid room value as one sample, it would imply that five different excitation points and room sample points would decrease the standard deviation in the results to less than half and thus become close to the range of the tapping machine measurements.

Although there are a number of different building objects in the AkuLite project, the useful data for the 95% percentile intervals are few in this investigation. Proposed further work is to include more objects for which excitations are made with more impact ball excitation points were for instance Jeons Sound field correction method [11] for heavy/soft impact sound sources will be implemented, together with more microphone measurement points, in order to further investigate if the tapping machine and the impact ball are interchangeable.

Since none of the excitation methods measures the force at excitation, no true transfer function can be calculated. If forces were measured at excitation, transfer functions could be calculated and thus could be offered better normalization and correlation possibilities with different excitation methods. Such measurements are also part of the planned future work.

References


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