On the use of laser Doppler vibrometry in building acoustics

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Summary
The measurement of the sound reduction index R of building elements is typically performed according to ISO 140, by measuring the sound pressure level in the sending and receiving room, using standardized loudspeaker-microphone instrumentation. Recent proposals for new building acoustic standards taking into account frequencies down to 50 Hz, provoke new questions. At low frequencies (depending on the dimensions of the rooms), the modal density in the rooms is typically too low, impeding reliable measurements following standard techniques. In this paper laser Doppler vibrometry is introduced as an alternative approach for the lower frequency region, to determine the intrinsic sound transmission properties of a building element, independently of the particular properties of the test facility. In addition, laser Doppler vibroemtry offers the additional advantage in that it can identify the actual boundary conditions of a building element, which can be useful for modeling and prediction. A number of applications will be given.

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1. Introduction

In this paper a number of applications of laser Doppler vibrometry measurements in building acoustics are summarized, i.e.

- Reliable sound power assessment at low frequencies
- Increased understanding of the physical phenomena on sound insulation characteristics of building elements
- Material characterization of building elements

These aspects are briefly summarized in the following sections.

2. Sound power determination using laser Doppler vibrometry measurements

A standardized manner to determine the sound reduction index R of a building element in laboratory conditions, is described in ISO 10140:2010. It is known that the acoustic characteristics of the transmission suite can influence the measured sound reduction index, especially at low frequencies. More specifically, a large uncertainty of the sound insulation of a test wall is caused by two factors. One factor is a measurement uncertainty which is caused by the fact that at low frequencies the pressure fields in the receiving room (and sending room) varies significantly in space. A second aspect is caused by the modal coupling between modes in the source room and the modes of the partition being tested. At low frequencies this aspect makes that the radiated active acoustic power is significantly affected at the modal resonance frequencies of the receiving room.

Both aspects can be dealt with when measuring the structural response of the building element by means of laser Doppler vibrometry, and compute the radiated sound power from the measured response. The computation can be done for any real or virtual room in which the building element radiates sound, thus being able to take the effect of the room acoustics of the specific room into account. Significant effects of the room acoustics occur in the low frequency range [1]. This approach also circumvents the mentioned measurement uncertainty at low frequencies. Indeed, a discrete sampling by microphones (as is done in standardized approaches) is replaced by a numerical simulation that takes the full vibrational field of the building element into account. The laser Doppler scan of the building element contains all information that is necessary to compute the radiated sound power exactly [1], also in case of low modal density of the receiving room modes.

Another approach is to compute the sound radiated by the building element by means of a Rayleigh integral [1]. Using the Rayleigh integral the room acoustics of the receiving room is not taken into account, meaning that the sound power thus computed is the intrinsic sound power radiated by the building element. This has the crucial advantage in that a true assessment of a building element can be performed, without the deteriorating effects of the room acoustics of the receiving room[1]. Thus, the sound power that would be determined in this manner will not be laboratory dependent, which is a serious problem in the assessment of the performance of building elements at low frequencies when using conventional techniques.

Experiments were performed in the transmission suite of the Laboratory of Acoustics of KU Leuven to demonstrate the new approach. Two building elements were measured, a lightweight double wall and a gypsum block wall. Laser Doppler vibrometry measurements were conducted on these walls and sound powers were determined numerically, using both Finite Element (FEM) and Boundary Element (BEM) models to take the room acoustics of the receiving room into account. In addition the Rayleigh approach was used to compute the intrinsic sound power of the walls [1]. The results were compared with standardized microphone-based measurement methods, showing a reasonable agreement in the higher frequency range, but significant differences in the lower frequency range due to the room acoustics of the receiving room and the non-diffuseness of the receiving room in this frequency range [1].

3. Influence of panel fastening on the acoustic performance of lightweight structures.

It is known that workmanship has significant influence on the sound insulation characteristics of lightweight construction building elements, e.g. timber frame partitions. The used method to fasten (e.g. with screws or staples) the panel (e.g. gypsum boards, gypsum fiber boards or chipboards) to the studs has a considerable influence on the sound insulation characteristics, and thus on the single values that are commonly used for rating the acoustic insulation performance.

Laser Doppler vibrometry allows the investigation of these effects in order to obtain a better understanding of the physics causing the differences in insulation performance. For instance, it was found that the effect of the number of screws on the insulation performance can partly be explained by an increase in the radiation efficiency of the panel in case the number of screws is increased or when the screws are fastened tighter [2].

4. Material characterization of building elements by means of laser Doppler vibrometry.

A third application of laser Doppler vibrometry is the assessment of the material properties such as the Young's modulus. Based upon the vibration field as measured by means of laser Doppler vibrometry, the dispersion curves (i.e., curves that describe the frequency-wavenumber relations) could be extracted, from which the material properties can be estimated [2]. Using this approach it is possible to identify possible orthotropy of the material, as well as frequency dependency.

5. CONCLUSIONS

Laser Doppler vibrometry (LDV) can serve a number of purposes in building acoustics. One application of this new measurement approach is to determine the radiated sound power of a vibrating building element. A crucial advantage of the LDV approach is that, by making use of a Rayleigh integral, the intrinsic sound transmission properties of a building element are obtained, independently of the particular properties of the test facility. In addition, uncertainties in the microphone based approaches caused by the spatially varying sound pressure levels at low frequencies as a result of the non-diffuse sound fields in the receiving room, are not encountered when using the LDV approach combined with the Rayleigh integral.

A second application of LDV measurements in building acoustics is to obtain a better physical understanding of the mechanisms that are involved in sound transmission through building elements, such as the effect of fastening methods on the sound insulation properties of a lightweight building element. The LDV approach gives detailed information about the behavior of the building element which cannot be obtained with classical microphone based approaches.

In a third application, the material properties of building elements can be assessed by means of LDV measurements. Using the LDV measurement data, a dispersion analysis can be performed, from which for instance the Young's modulus can be estimated, including possible orthotropy as well as frequency dependency.

References

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