Fraunhofer-Institut für Bauphysik IBP

Forschung, Entwicklung,
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Institutsleitung
Univ.-Prof. Dr.-Ing. Gerd Hauser
Univ.-Prof. Dr.-Ing. Klaus Sedlbauer

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# Improved Noise Abatement for Buildings by Active Vibration Control of Technical Equipment

## (Verbesserter baulicher Schallschutz durch aktive Körperschallisolation haustechnischer Anlagen)

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The authors are responsible for the content of this report

Project leader: Dr. Moritz Späh
Authors: Dr. Moritz Späh, Dr. Lutz Weber,
Benjamin Hanisch

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**Fraunhofer-Institut für Bauphysik IBP**
Nobelstraße 12 | 70569 Stuttgart
Telefon +49 711 970-00
Telefax +49 711 970-3395
www.ibp.fraunhofer.de

Institutsteil Holzkirchen
Fraunhoferstr. 10 | 83626 Valley
Telefon +49 8024 643-0
Telefax +49 8024 643-366

Projektgruppe Kassel
Gottschalkstr. 28a | 34127 Kassel
Telefon +49 561 804-1870
Telefax +49 561 804-3187

# Content

## 1 Introduction

Noise is increasingly recognised as one of the most important environmental issues. Noise reduces the ability to concentrate and reduces the intellectual receptiveness, and in addition, it can cause insomnia, which may lead to enduring health disorder. Therefore, noise impact should be low in our environment, but especially in buildings, because the majority of time is spent indoors. Modern, well planned buildings offer good protection from outdoor noise, for example increasing traffic noise.

Because of higher technical regulation and rising comfort standards in office and residential buildings, the number of installations in buildings is increasing. These are for example electrically driven roller shutters, shades, installations for ventilation, lifts, pumps for heating, cooling and solar systems, and sanitary installations like whirlpools with pumps and fans. All installations may cause unwanted noise in buildings. This noise is considered most disturbing, as it reveals information about the noise source. Especially in sensible rooms like bedrooms and in environments with low background noise, these annoyances are frequently sources of complaints. In most cases, frequencies below 1000 Hz are generally most problematic.

The standard approach for noise abatement are passive means, which consist of elastic interlayers between the installation and the building. They bring a reduction of the inserted structure-borne sound power at higher frequencies above the resonance frequency of the system. At the resonance frequency, however, these systems increase the inserted sound power. Below it, the systems are ineffective. Because of static or constructive reasons, a certain stiffness has to be maintained, which results in a limitation of the performance of the passive system.

As alternative for, or as addition to passive vibration isolation, active systems can be employed. They are generally more effective at low frequencies and combine well with the high frequency performance of passive systems. In this case, an electro-dynamic actuator is used for the active system, which is implemented at the contacts of the source to the receiving building element. With this approach, a reduction of the annoyance in the building is achieved.

The approach is to reduce the structure-borne sound power input at the contact of the source with locally and independent systems, also for sources which have multiple contacts to the building structure. Therefore, simple and uncomplicated Systems can be employed, which do not need high level signal processing.

The goal of this project is to construct and test a robust active vibration isolation element, suitable for the application in buildings. This element is combined with a passive element, as its performance combines well with the high frequency performance of standard passive elastic elements. This is tested on an simple model setup, to test the principles of active vibration control and to evaluate the performance of it. Further, the system is tested on real sanitary installations in a building-like-situation to evaluate the performance in situ.

## 2 Handling of the research project

At the start of the project a literature search on active systems was conducted. There is a great number of literature available, as the field of application of active sound and vibration reduction is broadly developed. Therefore, only the relevant literature for structure-borne sound applications were studied and the suitable approaches were studied in depth. A product search for the appropriate sensors and actuators was performed. Further on, the acoustical data for structure-borne sound sources was extracted from literature and compared to own data. Then, measurements were performed on typical sources of installations to characterise their dynamic behaviour and to enable the dimensioning of active vibration isolation systems.

Based on this information, an active isolation model setup was designed and build, where the fundamental characteristics of the source and the excited building structure was incorporated. The model setup was a simple construction, which offered good reproducibility and was easily accessible for installation of sensors. With this setup, fundamental investigations on active vibration control were conducted on a 10 cm thick concrete reception plate as receiving element. These tests were compared to theoretical models of active vibration control, which were adapted to the model. For the control algorithm, a very simple strategy was applied, so that analogue devices were used. The application of filters was discarded.

As the results of the tests on the model setup were encouraging, the system was applied on a real source, a shower tray. The procedure was to start from simple sources, step by step, to a more complex source with multiple contacts.

Then, as a final step, active systems were tested on the model setup and on real sources in a building-like-situation. With this investigation, the systems were examined for sources in heavy weight building structures. The tests were carried out at different sanitary installations, for the active systems at a rigid interface and for the combination of active with passive vibration isolation.

# 3 Model setup

The model setup of a structure-borne source contact with active vibration isolation is shown in figure 1. This simple model represents practical applications like a pipe clamp or the foot construction of bath or shower tray. As source of excitation, a commercially available electro-dynamic shaker was employed. It was fastened to an auxiliary construction above the setup. By a connecting element, the shaker was connected with a threaded rod, which was the actual foot construction of the source. Fastened to this rod was the active system with its main part, the actuator. The construction is shown in figure 2. The used sensors is schematically also shown in figure 1.

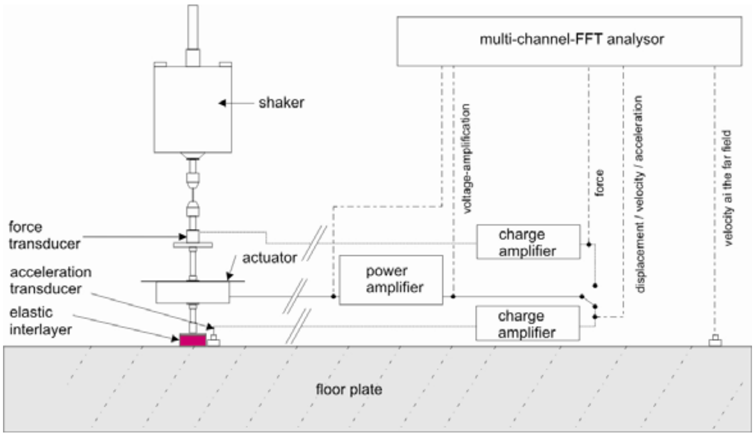

Figure 1: Sketch of the model setup with elastic interlayer (active and passive vibration isolation) and schematics of the instrumentation.

Figure 2: Model setup without passive elastic interlayer (left) and elements of the electro-dynamic actuator (right).

The actuator was a commercially available electro-dynamic device, sometimes termed „structure-borne loudspeaker". It was used as an inertial shaker, as it produces a force from accelerating its ring mass. The actuator consists of a permanent magnet, which is centrally pierced. Through this hole, the threaded rod is inserted and the actuator is tightened by two nuts to the rod. The ring of the actuator is connected to the magnet by two plastic springs, and carries the coil. At exciting the actuator, it implements a force onto the threaded rod. The signal from the appropriate sensor is amplified and, if necessary, integrated by a charge amplifier. Further, it is again amplified by a manually adjustable power amplifier, see figure 1. As system strategy, force feed-forward from the force transducer and feedback of acceleration, velocity and displacement of the acceleration sensor on the floor plate was investigated. The force feed-forward was most successful, for the feedback strategy, the velocity feedback was the most reasonable approach. Unfortunately, it showed especially at the combination of active with passive vibration isolation a reduced performance. Filters or other signal conditioning were not involved in the system. As sensors, piezo-electric high performance measurement equipment was applied. The charge amplifiers provided the integration of the signal, when necessary. Alternative low cost sensors were theoretically regarded, but not employed for tests within this project.

The investigations considered both the rigid connection of the model setup, without elastic interlayer (see figure 2 left side), but also the combination of the active system with a passive vibration isolation by an elastic interlayer, figure1. The elastic interlayer was a commercially available material of polyurethane foam (Sylomer S900-6, by Kaldewei).

# 4 Results

The performance of the passive system is shown in figure 3

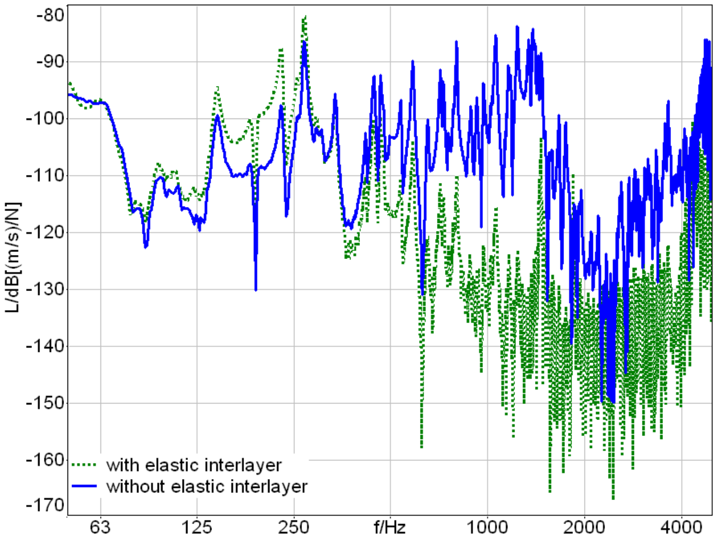

Figure 3: Transfer mobility between velocity in the far field and input force of the shaker for the rigid and elastically isolated model setup.

A high number of measurements were conducted on a reception plate. As reference signal, to evaluate the performance of the system, the velocity in the far field on the receiving element was taken, as it is nearly proportional to the inserted structure-borne sound power. In this case, the receiving element was the reception plate, a 10 cm thick concrete plate. In figure 3 the transfer mobility between the velocity in the far field of the plate and the excitation force of the shaker is shown. In the low frequency region, the mobility is very similar, because the passive isolation is ineffective. Between 125 and 270 Hz the transfer mobility is higher for the passive isolation, as this is the frequency range of the resonance. Above 270 Hz, the positive effect of the passive isolation system sets in and increases with rising frequency. At and above 1000 Hz the velocity in the far field reaches the background noise of the plate.

Further reported results are obtained at the installation test facility of the IBP. This facility has been used since years for measurements on installation noise and suitability tests of installations. The facility consists of four rooms, of which two are situated in the cellar, the two others on the ground floor above the ones below. The source was placed on the floor plate in the sending room above. As reference signal, to evaluate the performance of the system, again the velocity of the floor plate in the far field was used. Additionally, the sound pressure level in the room diagonally below was recorded and used to evaluate the performance. Results of this value are shown below. This situation describes the transmission into the next room to protect (for example an other apartment) according to DIN 4109. The measurement was conducted by a highly sensitive 1 ''-microphone at a single measurement position. This can be given as A-weighted sound pressure level, which can be compared to requirements of DIN 4109. Unfortunately, at the date of measurement, building work was going on and at low frequencies, background noise was high and might have influenced the measurement results at low frequencies. The conducted measurements can not be taken as suitability tests, but they show the possible reduction of the noise in buildings by the active system.

The performance of the active system on the model setup in the installation test facility with rigid contact is shown in figure 4, with the power amplifier level given for the best performance of the system. At higher amplification, the signal was at some higher frequencies overcompensated and the performance was reduced.

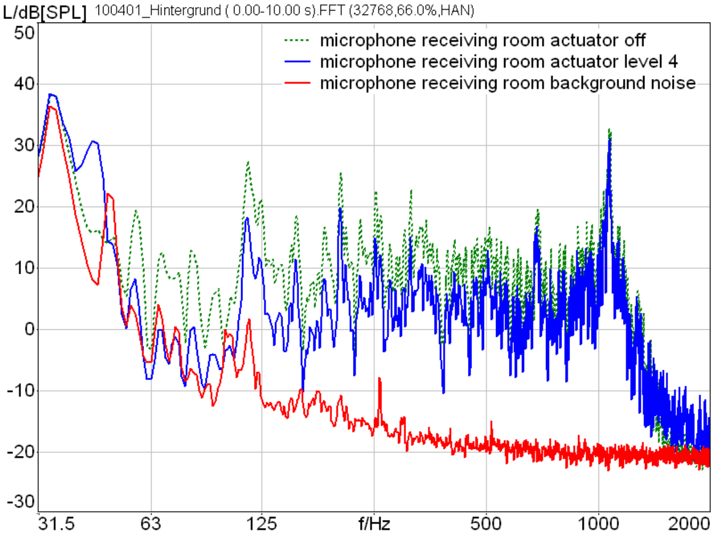

Figure 4: Sound pressure level in the receiving room with excitation of the rigid model setup. Active system with force feed-forward, excitation by pink noise.

In the receiving room, as well as in the far field of the floor plate, the reduction of the level by the active system at low frequencies was significant. Between 50 and 250 Hz the reduction was highest, with values of over 10 dB. The A-weighted sound pressure level was reduced by 2.4 dB. The reason for the low reduction is the resonance of the rigid model setup at about 1100 Hz, which was only marginally reduced by the active system, but has big influence on the A-weighted sound pressure level. Further, the reduction in the A-weighted level is depending on the excitation spectrum. In this case it was pink noise, which is more broad-band as the low-frequency dominated signal of real installations. The increase in signal at about 50 Hz, caused by the resonance of the actuator is less important for the A-weighted level.

Next, the model setup was combined with an elastic interlayer, shown in figure 1. In this setup, the active system is combined with the passive system by the elastic interlayer. The elastic interlayer is fixed to the model setup by a plastic clamp, which is used in a commercially available foot for bathtubs. The results of the sound pressure level in the receiving room diagonally below for the rigid connection without passive isolation, with elastic interlayer and, additionally, with active system is shown in figure 5. The primary excitation of the setup was similar in all cases.

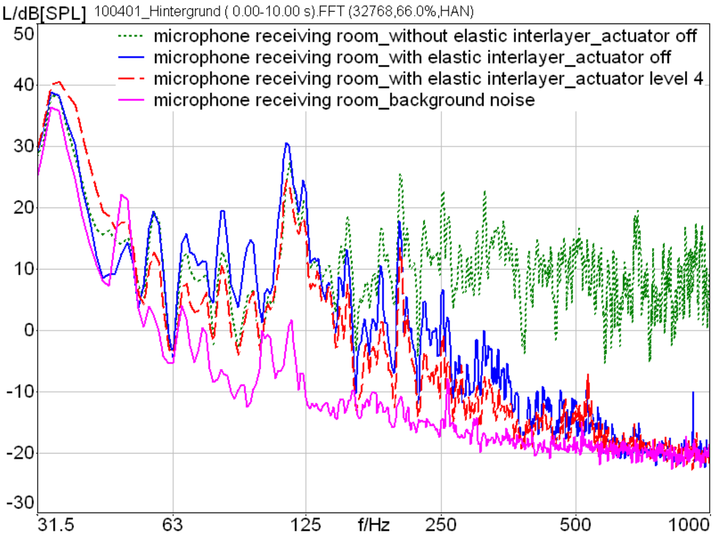

Figure 5: Sound pressure level in the receiving room for the rigid connection, the passive and the passive + active system at the model setup. Active system with force- feed-forward, excitation by pink noise.

This setup shows for the passive isolation a reduction above 125 Hz. Between 50 and 125 Hz higher levels occur, caused by the resonance of the elastic interlayer. The active system shows at very low frequencies a little increase in level, caused by the resonance of the actuator. At higher frequencies, a considerable reduction is achieved, mostly between 50 and 125 Hz. Above 125 Hz the reduction is somewhat lower, but up to 500 Hz it is existing. The reduction of the A-weighted level by the passive isolation was 21.2 dB(A), the active system reduced the level additionally by 2.9 dB(A). The results show, that both systems combine well and result in a broad band reduction between 50 and 5 kHz, which single passive systems can not achieve.

In the following measurements on real sources are shown. For this, four active, independent systems with elastic interlayer at all four feet of a shower tray were operated. The amplification of the signals was the same level for all systems. The active systems were driven by force feed forward. The shower tray was excited by a shaker, the signal was a shower signal, which was recorded beforehand by water falling onto the shower tray from a shower head. The sound pressure level in the receiving room diagonally below is shown with and without active system in figure 6.

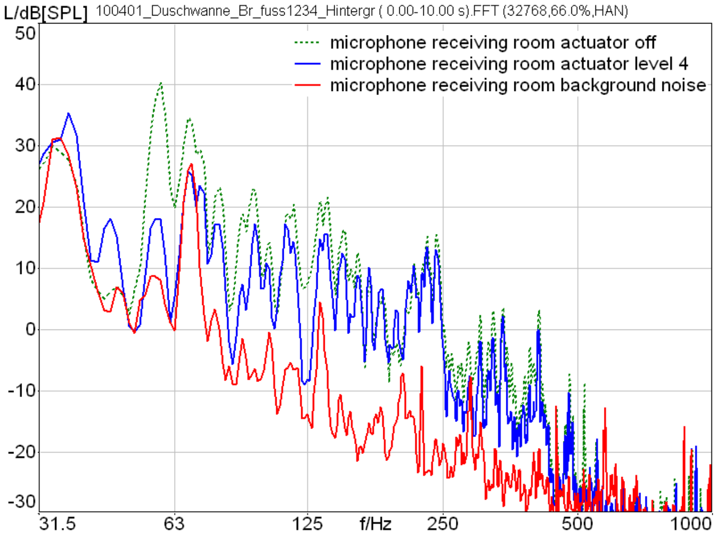

Figure 6: Sound pressure level in the receiving room. Excitation of the shower tray with four active systems and with elastic interlayer (passive and active). Active system with force feed forward, excitation by shower signal.

The measurement shows partly a high reduction of the Level by the active systems, for example at 63 Hz of about 15 dB. The reduction up to 500 Hz is recognisable. The A-weighted sound pressure level is reduced by the active systems by 4.7 dB(A).

Further investigations were conducted on two different whirlpool baths. At this sources it was found, that the active systems with and without passive element had a similar performance at low frequencies to the results at the shower tray. With the combination of passive and active Isolation, the performance of the active systems was reduced in the case, when the source supporting frame was more elastic. For such sources an improvement can be achieved by adjusting the frame construction to the requirements of the active system.

Over all it can be stated, that with this simple active system a considerable reduction of structure-borne sound input of up to 10 dB at low frequencies is possible. In combination with a passive isolation, a system was developed which reduces very broadband from 50 to 5 kHz the structure-borne sound power input into the building structure. The only drawback was an increase in power input at the resonance of the actuator. This can either be eliminated by filters, or easily be shifted to very low frequencies in buildings, that are unproblematic. This shifting is possible by changes in the construction of the actuator.