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NOISE CONTROL FOR A BETTER ENVIRONMENT

Experimental investigation of noise re-radiation of lightweight floating floors

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ABSTRACT

Gym floors can be excited by different activities such as falling weights (dumbbells, Olympic weight lifting, medicine balls....), treadmills and jumping. Different standard indicators and tests are available to determine the efficiency of floating floors for noise and vibration transmission such as Ln,w and Rw or STC/IIC. Despite of efficient isolation performances of floating floors in gyms to control the noise and vibration transmission towards the rooms below, the people living in apartments above the gym are often complaining about noise generated by gym activities. The present work aims to investigate the noise re-radiation due to vibrations of the gym floating floors. To determine the level of noise re-radiation, the radiation coefficient and normalized sound power are measured for different setups of lightweight CDM-GYM floors. The floors were structurally excited by means of a shaker, and the response of the floors were measured by means of a Laser Doppler Vibrometer (LDV). The effects of structural modifications in floors on the radiation coefficient and normalized sound power are discussed.

Keywords: Radiation efficiency, lightweight floating floor, Laser Doppler Vibrometer
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1. INTRODUCTION

In the noise/vibration sensitive area where the transmission loss of existing structural floor is not sufficient to mitigate the generated noise and vibration, floating floors are employed as a common solution. Gym floors particularly, can be excited by different activities such as falling weights (dumbbells, Olympic weight lifting, medicine balls....), treadmills and jumping. For the zones where a wet floor is not permitted to be constructed or be added to the existing floor because of structural stability issues or limited room height, a lightweight or dry floating floor can be proposed. Lightweight floors are cost effective and fast and easy to install or remove, [1]. The dry floor system consists of 2-3 layers of wooden or cement board mounted on elastomeric pads, Figure 1.

Different standard indicators and tests are available to determine the efficiency of floating floors for noise and vibration transmission such as Ln,w and Rw or STC/IIC. Despite of efficient isolation performances of floating floors to control the noise and vibration transmission towards the rooms below, the people living in apartments above the gym are often complaining about generated noise of gym activities.

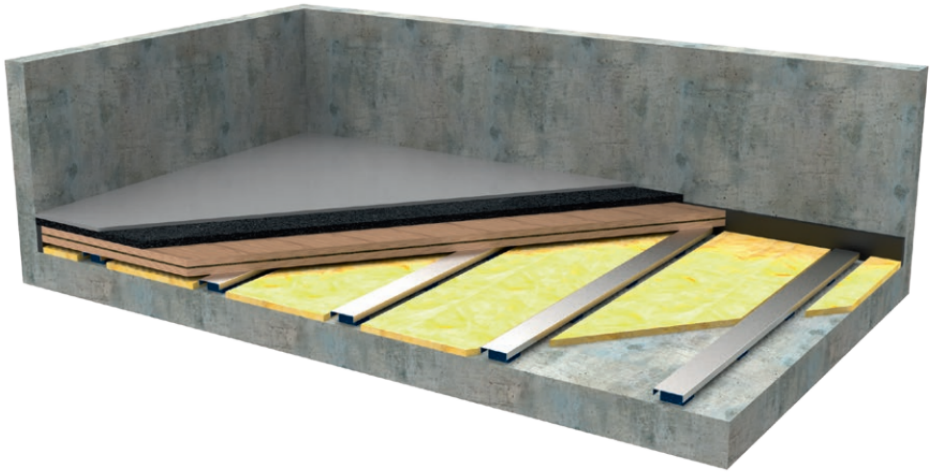

Figure 1: Scheme of CDM-GYM lightweight floor type CDM-GYM-HP-L50.

The level of the noise in above rooms depends directly to the sound power generated inside the receiving room due to the vibration of floating floor. The sound power (W) radiated by a vibrating floor is related to: (1) the level of vibration in the floor ($< V^2 >$ mean square velocity) and, (2) the radiation efficiency (σ) of the floor, and it can be determined as follows [2]:

$$W = \rho c \sigma S < V^2 > \quad (1)$$

where ρ is the density of air, c is the sound speed in air, and S is the surface area of the vibrating plate.

A floor installed on flexible bearing vibrates higher than that fixed on rigid supports. Therefore, the radiated sound from this floating floor which is directly related to its vibration level, might be consequently increased. However, the radiation efficiency of a floating floor is supposed to be less than that supported rigidly at its boundaries.

Determination of sound radiation efficiency of finite and baffled plates with different boundary conditions has been the subject of several studies using the numerical and

experimental methods [3–5]. To determine the level of noise re-radiation of CDM-GYM floors, in this study, a hybrid experimental-numerical methodology proposed by N.B. Roozen et al. [5, 6] has been used. In the proposed methodology, the vibrational response of the floor is measured by an advanced a Scanning Laser Doppler Vibrometry (SLDV) measurement technique. Then, the sound power radiated by the vibrating panel into the receiving room, is numerically calculated using Rayleigh integral method, Boundary Element method (BEM) or Finite Element Method (FEM) [6].

In this study, the floor is excited by means of a shaker from below and the response of the floor at its vibrating surface on top, is measured using SLDV measurement system. The LDV signals at a grid of several points on the floor surface and the force cell signals are stored for a duration of 10 seconds for each response position. The floor response in frequency domain is obtained using Welch method with a frequency resolution of 0.5 Hz and being averaged with 75% overlap. Thus, even though the responses at each point of the floor are measured sequentially in time by the SLDV measurement system, the phase between the responses at different points of the grid is retained using a reference signal (the excitation force in this case), [7].

Figure 2: Scheme of the floor test setup

2. MEASUREMENT SETUP AND CONFIGURATION

The radiation efficiency and the sound power of different lightweight CDM-GYM floors are experimentally determined. In different floors, the influence of floor characteristics such as the type of isolation pad, the floor bending stiffness and the floor weight on the radiation efficiency as well as on the radiated sound power were examined.

The floor system had a surface of about 9 m^2 (3.20 m $\times$ 2.60 m) and was mounted on a wooden frame to create enough space below the floor for the installation of the shaker, figure 2. Different setups have been tested and compared with a reference floor setup (CDM-GYM-HP-L50). The reference floor consists of 2 layers of Plywood with an intermediate damping layer which acts as a CLD (constrained layer damping). This floor is mounted on C-channels and resilient CDM discrete pads (CDM-LAT system). In addition, the surface of the floor is covered with a total of 30 mm-thick rebounded rubber sheets including 10 mm of sport floor layer. The floor configurations are listed in Table 1.

Table 1: Lightweight floor configurations

Setup	Isolation system	dBooster	Panel configuration	Finishing
CDM-GYM-HP-L50	CDM-LAT-50	-	PW19+CDM-DAMP-5+PW19	CDM-GYMPACT-20 + CDM 10mm Sport floor
CDM-GYM-HP-L60-dBooster		Yes		
CDM-GYM-XP-L50		-	PW19+CDM-DAMP5+PW19 +CDM-DAMP5+PW19	
CDM-GYM-XP-L50-FC			PW19+CDM-DAMP5 + FC + CDM-DAMP5+PW19	
CDM-GYM-HP-15050	CDM-LAT-15050		PW19+CDM-DAMP-5+PW19	

The second floor type in Table 1 refers to "dBooster^{TM}" lightweight floor system in which a resilient strip layer is installed between the C-chanel and the panel. Reducing the panel fixation conditions by leaving it free floating with reduced friction in the interface with the chanels, acoustically results in more efficient performance [8].

3. MEASUREMENT RESULTS

The floors were structurally excited at three randomly chosen positions by a shaker. The vibration excitation has been applied as a form of white and Pink noise, and the associated response was measured in different point over the floor surface in a grid of 16×13 = 208 points by means of a Scanning Laser Doppler vibrometry (SLDV), [7]. The force signal was measured by means of a force cell (Bruel & Kjaer, type 8001).

The floor response at each point was measured and for each floor a representative spectrum was given by spatially averaging the floor response over the whole floor surface. Figure 3 displays the velocity spectrum of the reference floor setup (CDM-GYM-HP-L50). Results are presented for different shaker positions and show a consistency in both low and high frequency range. At low frequency, the peak at about 15 Hz refers to the resonance frequency of the floor.

Figure 4 shows the mobility of all five setups. The floor setup CDM-GYM-HP-L50-FC which is the heaviest floor (almost 85 kg/m^2) shows the lowest resonance frequency at 13 Hz and the floor type CDM-GYM-HP-15050 with the pads stiffer than those used in the other setups, shows the highest resonance frequency at about 18 Hz.

Note that the isolation pad in floor type CDM-GYM-HP-15050 has higher damping compared to that used in the reference setup. The effect of higher damping directly results in a lower mobility level at resonance frequency of floor type CDM-GYM-HP-15050. However, this effect is less pronounced at high frequencies.

Figure 5 shows the spatial averaged velocity in one-third octave band frequency. Results display that despite a significant difference of vibration level at low frequencies, at high frequency (>60 Hz), all setups, except the heaviest one, show almost similar vibration level. The spatially averaged velocity will be used for the calculation of radiated sound power.

3.3.1. Sound radiation calculation

Assuming that the floor is baffled and radiating into a semi-infinite acoustic domain, the sound pressure can be computed by means of Rayleigh integral method [2]. The acoustic pressure $p(\mathbf{r}, \omega)$ at position $\mathbf{r}$ in the acoustic field, caused by the vibrating surface, is calculated as:

$$p(\mathbf{r}, \omega) = \frac{\mathrm{i}\omega\rho}{2\pi} \iint_S v_n(\mathbf{r_S}, \omega) \frac{e^{-\mathrm{i}k\mathcal{R}}}{\mathcal{R}} dS \tag{2}$$

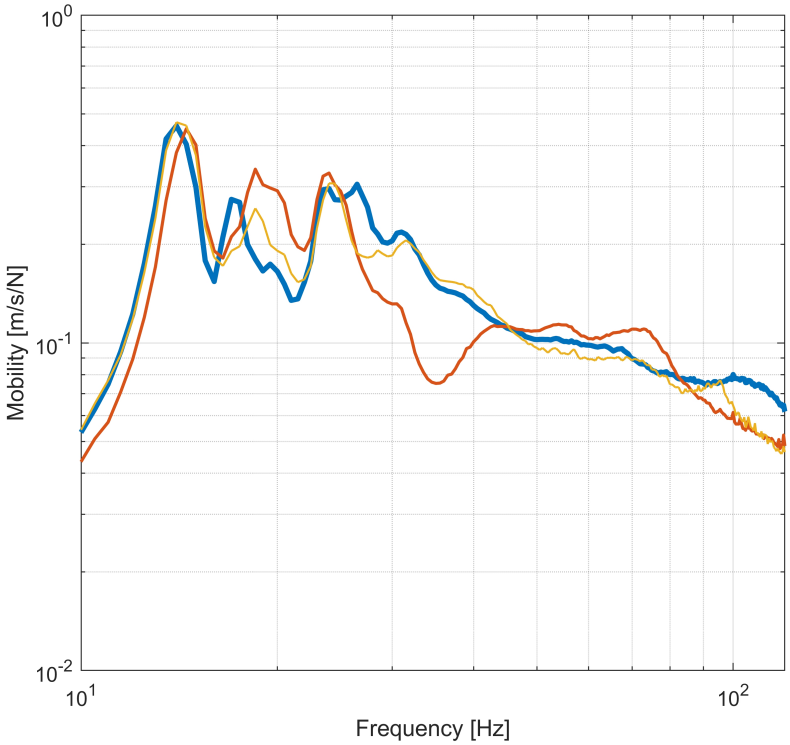

Figure 3: Spatially averaged mobility of reference setup measured for different shaker positions.

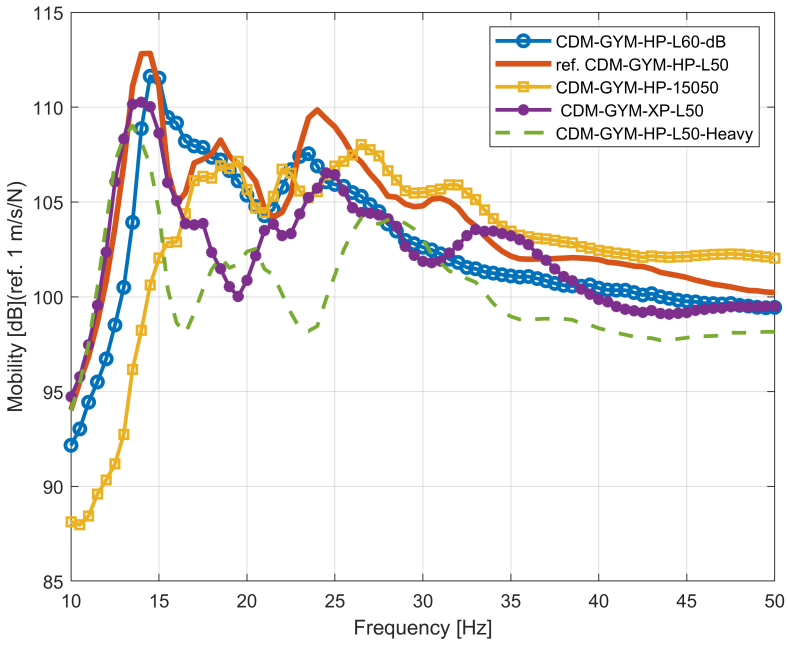

Figure 4: Spatially averaged mobility measured for different setups.

where $v_n(\mathbf{r_S}, \omega)$ denotes the normal velocity at position $\mathbf{r_S}$ on the vibrating surface, S denotes the area of the vibrating surface, $\mathcal{R}$ is the distance between the field point $\mathbf{r}$ and the surface point $\mathbf{r_S}$, ρ is the air density, ω is the angular frequency of the vibration, c is

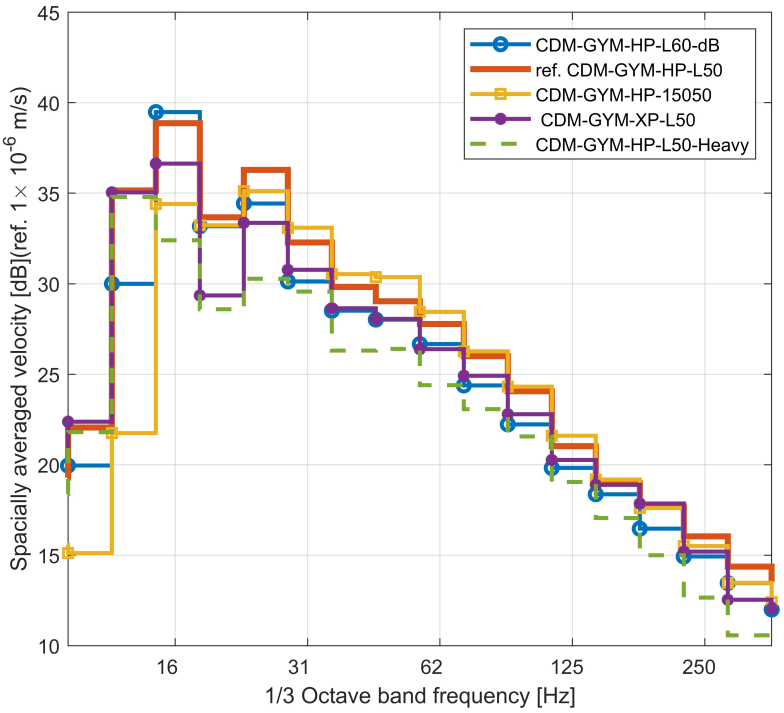

Figure 5: Spatially averaged velocity spectrum due to a pink noise form excitation obtained for five different floor setups.

the sound speed in the air, $k = \frac{\omega}{c}$ is the wave number, and i is the imaginary number.

The total radiated sound power can be calculated by the following equation:

$$W(\omega) = \iint_S I(\mathbf{r_S}, \omega)\, dS \tag{3}$$

where the acoustic intensity I_n along the vibrating surface S can be written in terms of the acoustic pressure $p(\mathbf{r}, \omega)$ and the floor velocity v:

$$I_n(\mathbf{r_S}, \omega) = \frac{1}{2}\mathrm{Re}\left[p(\mathbf{r_S}, \omega)\, v_n^*(\mathbf{r_S}, \omega)\right] \tag{4}$$

In the Equation 4,"Re" denotes the real part of a complex quantity, the asterisk "*" denotes the complex conjugate.

An overview of the total radiated sound power is given in Figure 6. The sound power spectrum associated with the floor velocity is calculated by means of Rayleigh Integral method (Equation 3).

Using the equation 1, the radiation efficiency is calculated for different floor setups. Figure 7 shows the variation of radiation efficiency for different setups. Although at low frequency, the radiation efficiency varies with the resonance frequency of the floors, but, at frequencies higher than 100 Hz, despite small dips and peaks, in general, all setups shows almost similar radiation efficiency.

Note that the reliability of the sound power obtained by the proposed methodology is limited to a certain frequency which is related to the distance between the measurement points (the grid size). For the actual grid size, the results are reliable for the frequencies up to 500 Hz.

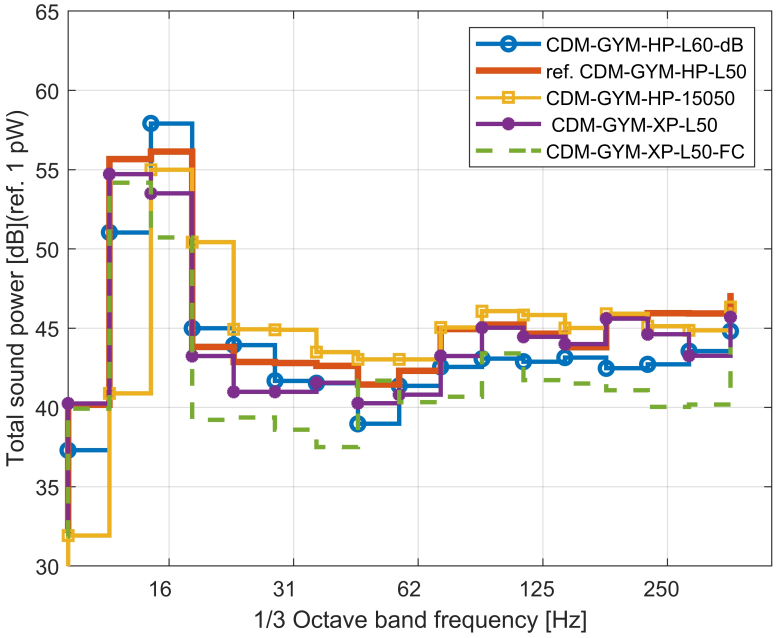

Figure 6: Total sound power spectrum calculated for different floor setups.

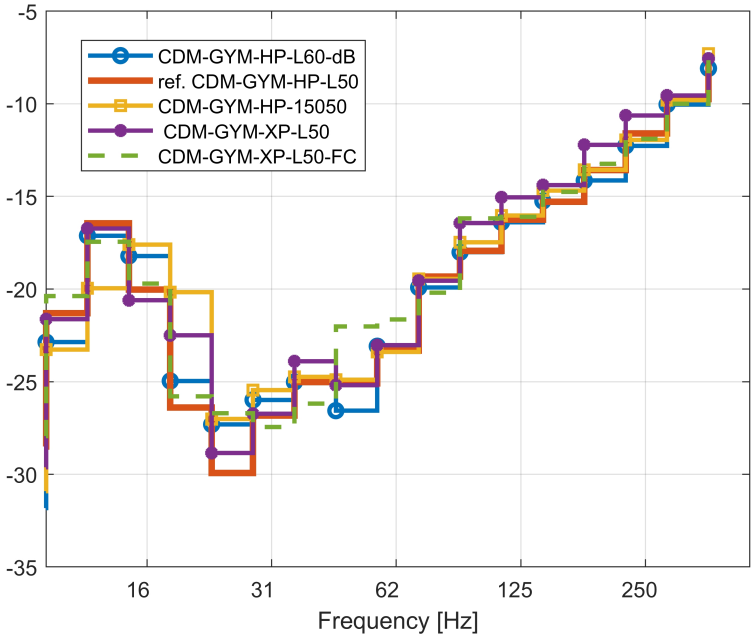

Figure 7: Radiation efficiency spectrum calculated for different floor setups.

In the following the influence of the floor characteristics on the radiated sound power are discussed.

3.1.1 Effect of isolation pad stiffness and damping

Comparing the results of CDM-GYM-HP-15050 with the reference floor shows that the stiffness of the isolation pads has no significant effect and at frequencies higher than 63 Hz, the radiated sound power would be at almost the same level, Figure 8. In addition,

it can be seen that higher damping in isolation pad has no effect on the noise re-radiation.

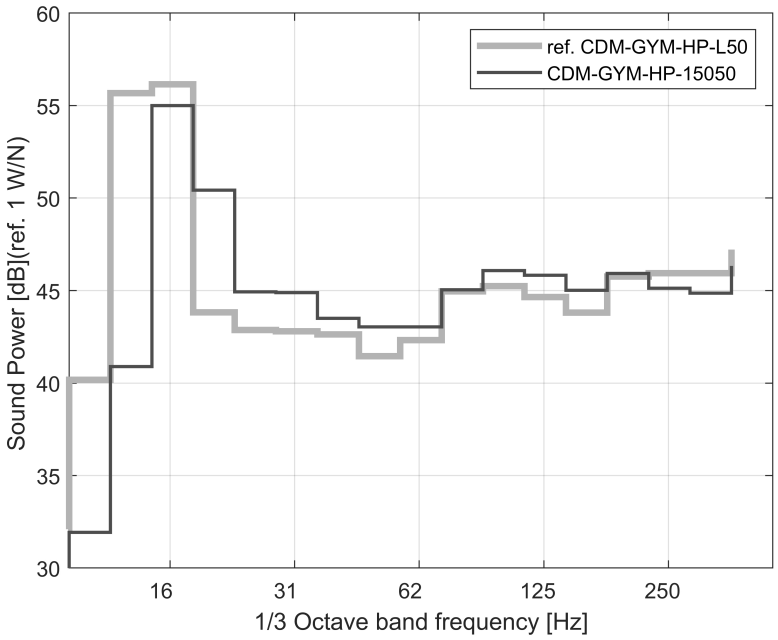

Figure 8: Total sound power spectrum calculated for different floor setups.

3.1.2 Effect of bending stiffness and weight of the floor

The influence of the floor bending stiffness has been investigated by adding an extra panel to the reference floor setup. Figure 9 shows the influence of the floor stiffness and the floor weight. It can be seen that there is no significant reduction in radiated sound power obtained by adding one extra Plywood panel to the reference setup. However, replacing the Plywood panel (at the middle) with a heavier Fiber Cement panel, results in a significant reduction in radiated sound power.

3.1.3 Effect of dBooster

Figure 10 display a comparison between the reference floor and CDM-GYM-dBooster floor. Results show that employing the dBooster resilient layer between the C-chanel and the wooden panel can significantly reduce the radiated sound power.

4. CONCLUSIONS

In this study, different floating floor solutions with different configurations have been tested and the influence of the floor characteristics as the isolation pad stiffness, the floor bending stiffness, the floor weight, and the dBooster resilient layer on the radiated sound power have been investigated.
Results of this experimental investigation show that:

– Radiation efficiency has no important role in determination of sound power compared to the effect of vibration level at frequencies higher than 60 Hz.

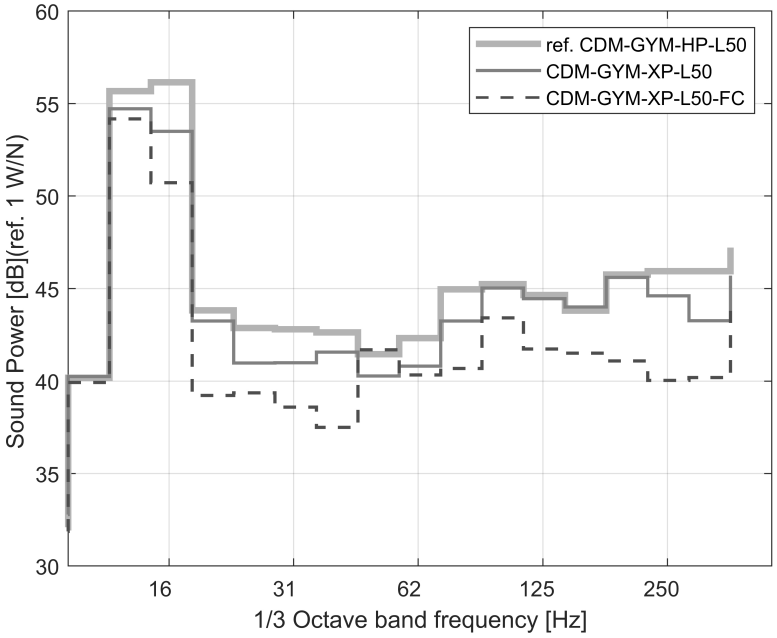

Figure 9: Total sound power spectrum calculated for different floor setups.

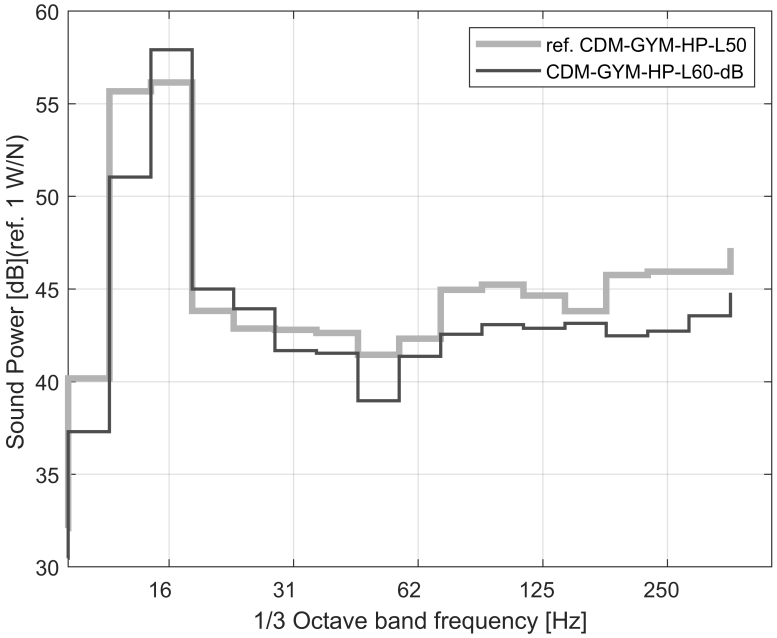

Figure 10: Total sound power spectrum calculated for different floor setups.

– The structural damping may control the vibration level and consequently, the sound power level at resonance frequencies, but its effect is less pronounced on radiation efficiency coefficient.

– Among different setups, the setup CDM-GYM-HP-15050 (with the stiff pad) is generating the highest sound power level.

– The setup with dBooster resilient layer CDM-GYM-HP-dB radiates less than the

reference setup without dBooster.

– Increasing the floor mass can significantly control the generated sound power.

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