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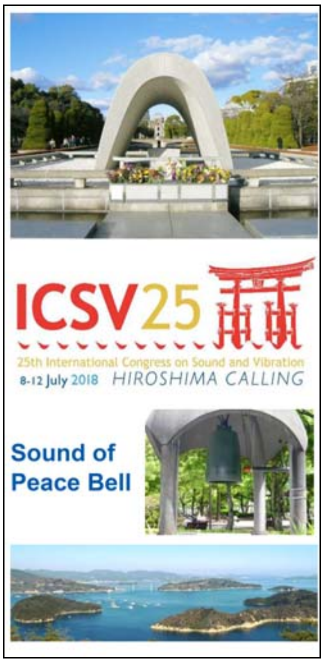

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ON THE DESIGN OF AN ENCLOSURE TO MINIMISE NOISE PRODUCED BY HEAVY INDUSTRIAL MACHINES

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Traditionally in the metal industry, after metal sheets leave the rolling mill they are sent to a punching machine to engrave tracking data on them. The punching operation can produce a significant source of noise, with measurements revealing zones with acoustic pressure levels of more than $110\,\mathrm{dB}$ at over twenty metres from the machine. This paper presents a technical study into the design of an enclosure for punching machines to minimise the level of noise generated during operation. The first step was to perform a series of acoustic measurements at various locations around the punching machine to identify the frequency content and level of the emitted noise. From the analysis, the effective frequency range of noise reduction was found to be between $1{,}000$ and $3{,}000\,\mathrm{Hz}$. To design an effective enclosure, various elements were developed and calculated, including mufflers which allow the metal sheets to cross the structure. The enclosure was compared with other individual protections against noise (IPANs), namely earplugs and protective hearing muffs. Of the three protections considered, results show that the enclosure is the most effective solution for noise minimisation. The enclosure provides a reduction in noise up to $15\,\mathrm{dB}$, improving the welfare of the workers.

Keywords: industrial noise, punching machine, enclosure, IPAN

1. Introduction

The machinery sector is an important part of the engineering industry and the industrial noise is a problematic issue that must be taken into account in most of national laws. The Machinery Directive 2006/42/EC [1], published on 9 June 2006 and applicable since 29 December 2009 imposes to the European Member States to be responsible for ensuring the health and safety on their territory of persons, in particular of workers in relation to the risks arising out of the use of machinery. Noise exposure for workers is also framed by a European law [2] which defines two action thresholds: the lower level corresponds to a $80\,\mathrm{dB(A)}$ daily exposure or a peak pressure of $135\,\mathrm{dB(C)}$ and the higher level to a $85\,\mathrm{dB(A)}$ daily exposure or a peak pressure of $137\,\mathrm{dB(C)}$. Individual protections against noise (IPANs) must be made available to workers when the lower level is reached; above the higher level, the use of IPAN is to be enforced. Daily exposures above $87\,\mathrm{dB(A)}$ (or peak pressures above

$140\,\mathrm{dB(C)}$) inside workers' ears are not acceptable (even with IPANs) and sound exposure must be reduced. These dispositions were incorporated into Belgian law in 2006 [3].

The employer has a liability to maintain noise maps of their facilities and identify the dangerous zones where IPAN must be worn. Limiting emissions at the sources is the most natural way to reduce the noise level. However, engineering solutions are often costly and in practice, many industrials focus on the use of IPANs as the primary countermeasure to noise [4, 5]. Florentin et al. [6] showed how the communication through questionnaires is facilitated in a work environment and can be used to estimate noise levels. Indeed, workers must be informed about the possibility of hearing loss and given protecting equipment which they may choose to wear or not. Sadly, the consequences for not wearing the IPAN are significant. For example, Pelegrin et al. [7] reported on a group of construction workers experiencing high noise exposure and found that 94.1% of those who had never worn IPAN had abnormalities. In addition, ISO 12100 standard [8] strongly prioritizes to reduce the noise (health risk) of a machinery by using inherently safe design measures that reduce the associated risks by a suitable choice of design features of the machine itself and/or interaction between the exposed persons and the machine.

Taking this guidance into account, a noise reduction campaign was recently conducted in a Belgian company, Industeel Belgium. The purpose of this study was to eliminate as much as possible the noise emitted by a punching machine. After measuring the noise in various locations inside the factory, a design of an enclosure was proposed, taking into account its acoustical properties. The efficiency of such insulation measure was compared with various IPANs in order to quantify its acoustical performances and in order to successfully install it on site.

2. Factory and context

Industeel Belgium is a steel company which produces steel sheets and is located in the area of Charleroi, Belgium. This factory employs more than 880 people and realized a turnover of more than 360 million by producing about 175,000 tons of steel per year. Only specific steel sheet types are produced, based on continuous casting. After passing in a rolling mill, they are sent to a plot area where they will be marked (Fig. 1). The marking is achieved by a punching machine. Under the action of punches, tracking data are engraved on them. These data include several pieces of information such as steel grade or number of the casting pool. When metal sheets are engraved by punches, several frequencies are excited at the same time. As the company manufactures steel sheets of different sizes, excited frequencies are different for each size and each steel grade.

Figure 1: View of the punching machine

Unfortunately, the company noticed that the noise emitted during the punching operation was too high and the use of IPANs was not efficient: many workers did not use them systematically. A first measurement campaign was conducted at the proximity of the punching machine. For this purpose, a SVAN 957 sonometer was used and placed at various locations close to the machine. The device was calibrated and used with appropriate signal processing and filtering to record the noise values. Measurements revealed zones with acoustic pressure levels of more than $110\,\mathrm{dB(A)}$, even at over twenty meters from the machine (Fig. 2) in a frequency range between $1{,}000$ and $3{,}000\,\mathrm{Hz}$. This large dispersion of excitation frequencies was due to the different kinds and types of metal sheet to be marked. Additional analyses, including experimental vibration test, could not provide new observations and were left behind. The solution of an enclosure was therefore suggested for a better noise reduction.

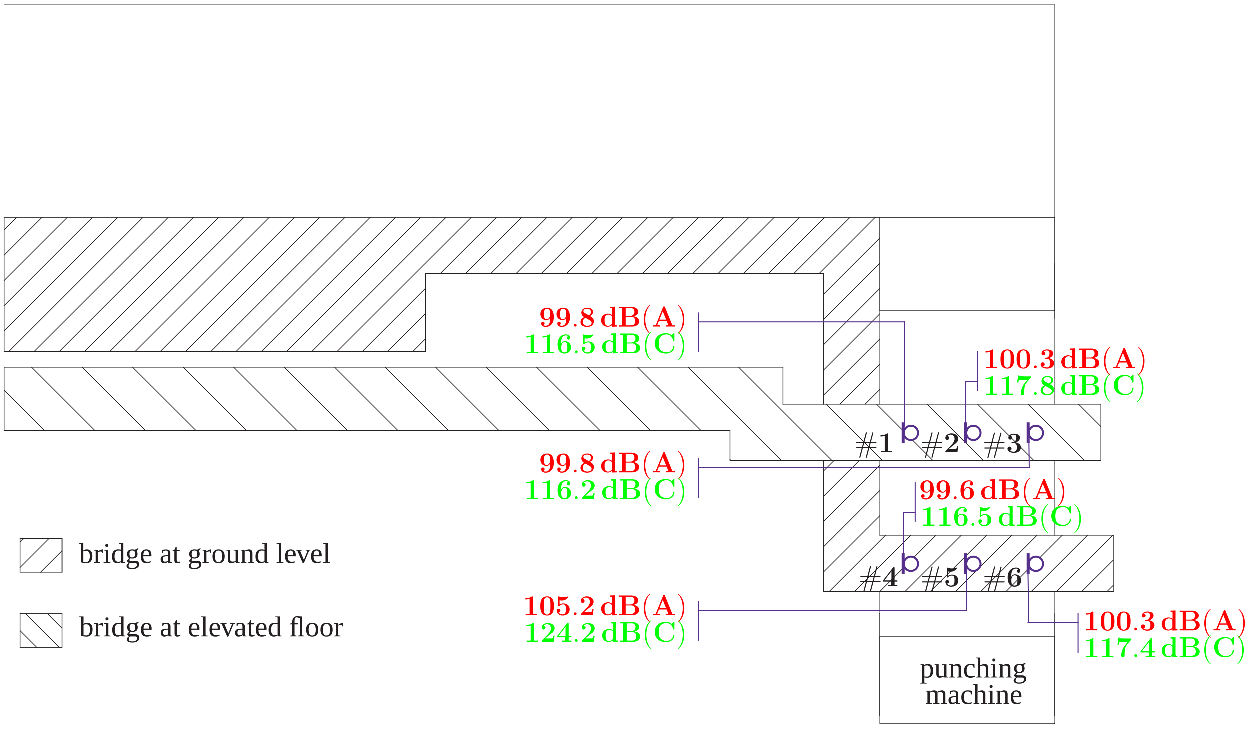

Figure 2: Measured noise map in the vicinity of the punching machine (green: $L_{C,peak}$ in $\mathrm{dB(C)}$; red $L_{A,eq}$ in $\mathrm{dB(A)}$)

3. Design of an enclosure

The purpose of an enclosure is to surround the noise source with a specific material, ideally with no air gaps (Fig. 3). In order to limit the sound transmission outwards, the enclosure design must be achieved with a massive material as rigid as possible (mass effect, with a high sound transmission loss R). The material is generally associated to a low sound absorption coefficient α_S: this results in sound pressure level increase inside the enclosure (rise of reverberation). It is therefore necessary to add an absorbing material in the inner enclosure surface with a high sound absorption coefficient α_S (absorptive material by itself is not effective in reducing noise). If the sound can be transmitted through the floor, then a vibration insulation needs to be considered to decouple the structure-borne connection between the vibrating equipment and the exterior layer [9].

A first design step was to select the absorbing material as efficient as possible in the requested frequency range. Table 1 shows the rate of porosity (air quantity located in the absorbing material) of several materials used in building construction. The more the material is porous, the more the material will be absorbent. It turns out that the best absorbing material is a mineral wool; consequently, glass wool was chosen due to its high absorption coefficient. The thickness of the absorbing material is

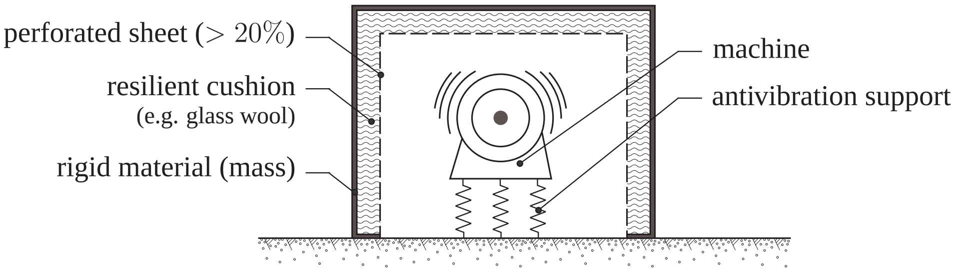

Figure 3: Schematic design of an insulated enclosure

an important parameter: the more the thickness is high, the more the absorption is important, as illustrated in Figure 4. A thickness of $50\,\mathrm{mm}$ was selected, covering an absorption coefficient α_S close to 1 (with respect to Sabine's hypothesis) in the frequency range from 500 to $4{,}000\,\mathrm{Hz}$.

Table 1: Rate of porosity in absorbing materials [10]

Material	**Typical porosities**
Mineral wool	0.92-0.99
Open cell acoustic foams	0.95-0.995
Felts	0.83-0.95
Wood fibre board	0.65-0.80
Wood wool board	0.50-0.65
Porous render	0.60-0.65
Pumice concrete	0.25-0.50
Gravel and stone chip fill	0.25-0.45
Ceramic filters	0.33-0.42
Brick	0.25-0.30
Sinter metal	0.10-0.25
Sandstone	0.02-0.06

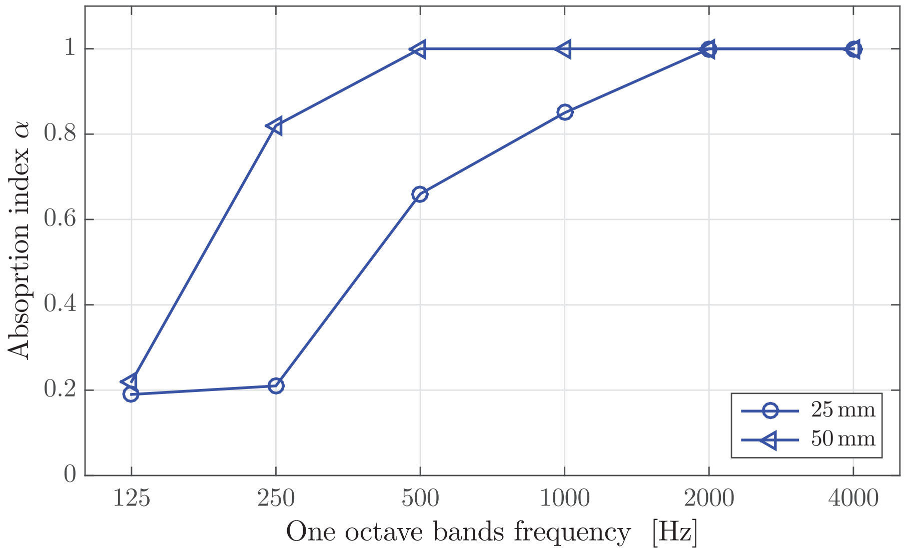

Figure 4: Influence of the thickness on the absorption index (data provided by [10])

After choosing the absorbing material, a multilayer wall was imagined. This type of wall is composed of several layers: a massive wall, the aforementioned absorbing material and a wall keeping the absorber in place. In the first phase, the critical frequency of the massive wall were determined due to the attenuation drop and to verify that this occurs outside the expected target frequency range. This critical frequency can be approximately determined by [9]

$$f_{crit} = \frac{c^2}{1.8e}\sqrt{\frac{\rho(1-\nu)}{E}} \tag{1}$$

where c is the speed of sound in air. Coefficients e, ρ, ν and E are the thickness, the mass density, Poisson's ratio and Young's modulus of the massive wall, respectively. The last layer of the wall is a perforated plate. This metal sheet does not play any acoustic role but is used to maintain the absorber in place. The perforations rate must be more than twenty percent in order to not interact with the transmission of the sound.

The last design step was the inclusion of passive mufflers adapted for the enclosure in order to not interfere with the process. On both side of the structure, acoustics mufflers were proposed to be installed to allow metal sheets to cross it. For such systems, the transmission loss can be evaluated by [11]

$$\begin{aligned} TL &= 10\log_{10}\left[\left(\cosh(\sigma l) + 0.5\left(m+\frac{1}{m}\right)\sinh(\sigma l)\right)^2 \cos^2(kl)\right. \\ &+ \left.\left(\sinh(\sigma l) + 0.5\left(m+\frac{1}{m}\right)\cosh(\sigma l)\right)^2 \sin^2(kl)\right] \end{aligned} \tag{2}$$

with l the muffler length, k the wavenumber, m ratio between the wall section on the muffler section and σ the rate of attenuation per meter of length.

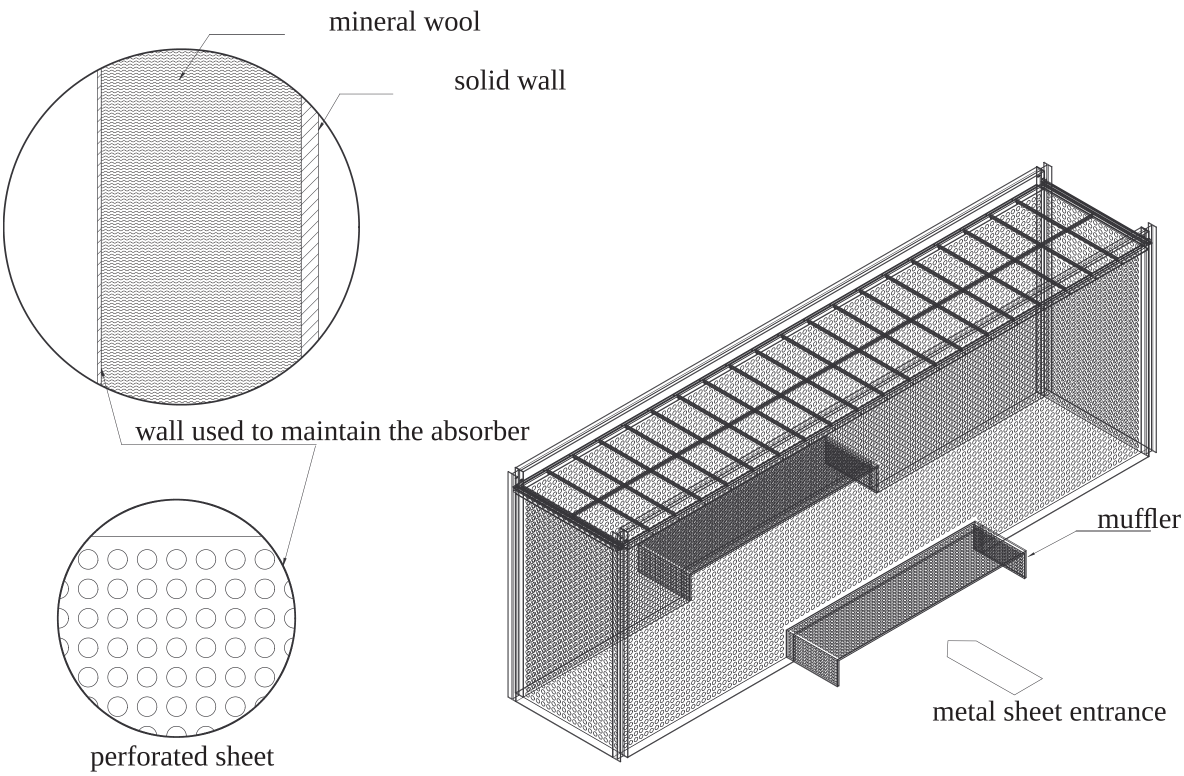

Figure 5: Proposed designed enclosure

Finally, the proposed enclosure is presented in Figure 5 showing an overall 3D view and representing the composition of the multilayer wall and the location of the two mufflers.

In addition to the proposed acoustical design, the mechanical design was naturally studied using the finite element method to verify that the deflection and the deformation of the enclosure due to their own static weight was below the expected limits.

4. Results

4.1 Noise map and daily exposures

From on-site measurements at different points (Fig. 2), it was observed that the equivalent noise level $L_{A,eq}$ was high, around $100\,\mathrm{dB(A)}$. The exposure dose needed to be calculated in order to verify if the acoustic level exceeded the thresholds, according to the European law. The exposition time is obtained by observing and counting the number of striking punches during a workday: workers can hear about 220 punching which lasts 12 seconds each. The value of the exposure dose is

$$L_{ex,8h} = L_{A,eq} + 10\,\log_{10}\left(\frac{T_{exp}}{8\,\mathrm{h}}\right) \tag{3}$$

where $T_{exp} = 0.733\,\mathrm{h}$. For example, for point $\#1$ located at the elevated floor, Figure 6 shows the time history of the equivalent noise level $L_{A,eq}$ and the peak level $L_{C,peak}$ during a period of $16\,\mathrm{s}$. The value can reach $L_{ex,8h} = 89.4\,\mathrm{dB(A)}$, which is beyond the limit exposure value. However, the peak level $L_{C,peak}$ is always lower than the lower exposure value. Such values indicate that IPANs must be worn along the day. However, several drawbacks are present like insulation of workers when they wear individual protection, discomfort, ... This confirms the use of an enclosure since IPANs could not represent the appropriate solution.

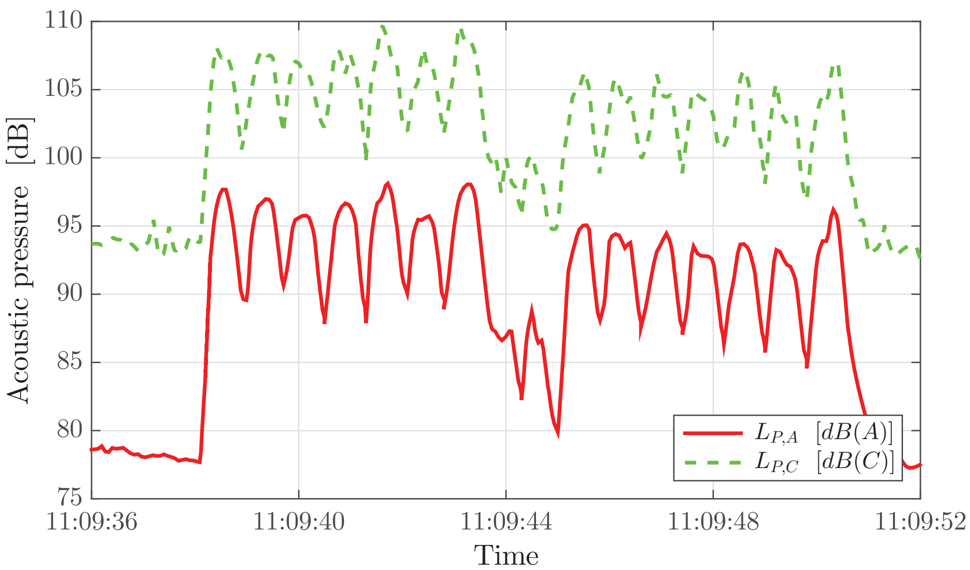

Figure 6: Noise intensity measure on the point 1

4.2 Comparison of IPAN solutions and enclosure efficiency

In order to support the choice of an enclosure, several simulations could be done, based on the possible use of IPANs. Some data are collected from [12] and can be used to calculate such attenuation. Different kinds of IPAN were selected: headbands, hearing muffs and earplugs (molded, premolded, preformed, ...). To overcome the limited condition in the proposed values (obtained in laboratory), the method proposed by the French institute INRS [13] was used. For each IPAN, the effective sound attenuation was obtained from the corresponding mean attenuation m_f and its standard deviation s_f by

$$m_e = m_f - 2s_f \tag{4}$$

in order to obtain a more realistic estimation of the noise attenuation. Afterwards, the training of workers was taken into account by applying a correction (Table 2) on the obtained values depending on the type of IPAN. An example of results is provided in Table 3 in the case of preformed earplugs.

Table 2: Correction to apply on different IPANs [13]

Type of IPAN	Correction
Headbands	-5 dB
Hearing muffs	-7 dB
Earplugs (premolded, preformed)	-10 dB
Molded earplugs	-5 dB

Table 3: Estimated attenuation of preformed earplugs

One octave bands frequency [Hz]	63	125	250	500	1000	2000	4000
m_f [dB]	29.2	29.4	29.4	32.2	32.3	36.1	44.3
s_f [dB]	6	7.4	6.6	5.3	5	3.2	6
m_e [dB]	17.2	14.6	16.2	21.6	22.3	29.7	32.3
Correction [dB]	-10	-10	-10	-10	-10	-10	-10
Estimated attenuation [dB]	7.2	4.6	6.2	11.6	12.3	19.7	22.3

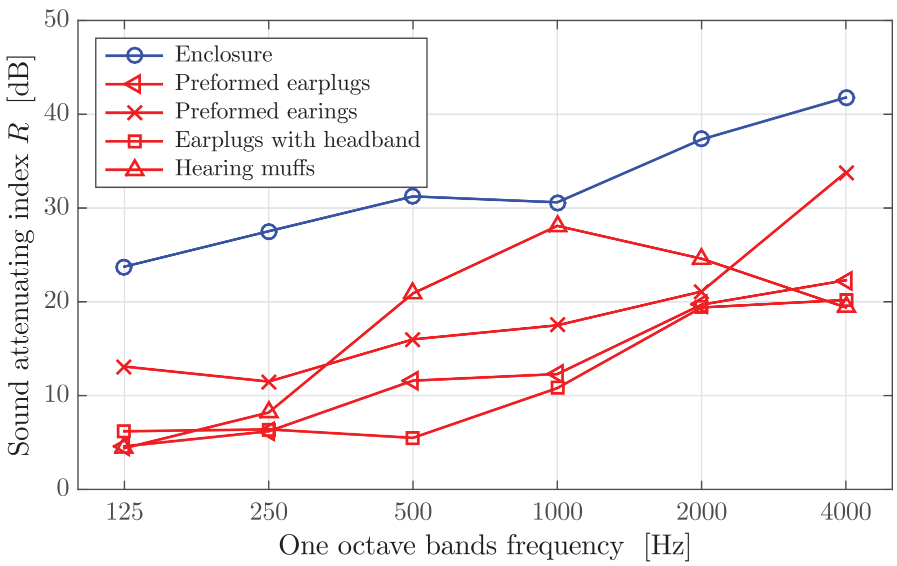

Figure 7: Comparison between the calculated attenuation of the enclosure and different IPANs

Figure 7 shows the calculated attenuation of the enclosure as a function of the frequency, compared to the attenuation of different IPANs according to the aforementioned method. An attenuation of 30–

$40\,\mathrm{dB}$ is observed in the range between 500 and $3{,}000\,\mathrm{Hz}$, while IPANs are less effective. Between $2{,}000$ and $4{,}000\,\mathrm{Hz}$, most of IPANs are less efficient (except the preformed earings).

5. Conclusion

The present study demonstrated the capability of an insulated enclosure to reduce noise emitted by punching machines. A mechanical design was proposed and a special focus was paid on the recommendation of machinery risk reduction, aiming at prioritizing the inherently safe design measures with respect to individual protective measures. With the help of a measurement campaign inside the factory, a quantitative analysis showed the efficiency for reducing noise levels as long as they are properly designed. The further step is to engineer and to install the proposed enclosure and to validate the estimated experimentally noise reduction.

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