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Evaluation of the effectiveness of the acoustic remediation carried out on an industrial machinery

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ABSTRACT. Many workers in different occupational sectors are exposed to potentially dangerous noise levels, a careful Risk Assessment and Management, resulting quality measures and programs should be developed to protect them from noise-induced hearing loss. The characterization of the noise source allows to establish a rigorous quality and control program, and can help you quickly understand when to implement noise mitigation measures. For this reason, an acoustic mitigation action was carried out on an industrial machine with a view to soundproofing the entire operating unit of the company.

Key words: *Noise, acoustic remediation, worker's exposure, industry.*

RIASSUNTO. Molti lavoratori in diversi settori professionali sono esposti a livelli di rumore potenzialmente pericolosi, un'attenta valutazione e gestione del rischio, e le misure e i programmi di qualità che ne derivano dovrebbero essere sviluppati per proteggerli da perdite uditive causate dal rumore. La caratterizzazione della sorgente di rumore consente di stabilire un rigoroso programma di controllo e di qualità e può aiutare a comprendere rapidamente quando implementare misure di attenuazione del rumore. Per questo motivo, è stata eseguita un'azione preliminare di attenuazione acustica su una macchina industriale al fine di insonorizzare l'intera unità operativa dell'azienda.

Parole chiave: Rumore, bonifica acustica, esposizione dei lavoratori, industria.

1. Introduction

Today, in many parts of the world, great attention is paid to the Occupational Risk Assessment and Management (1), in many working environments such as industry, agriculture, health care and hospitals. According to estimations by the World Health Organization, after air and water pollution, the noise is the third cause of pollution (2). In particular, it is estimated that about 30 million of workers in the European Union are exposed to potentially harmful level noise (3). The significant noise pollution, present in the living environment, worsens the effect of occupational noise exposure for workers. Epidemiological studies show that occupational noise exposure is the leading cause of hearing loss and tinnitus (4). Furthermore, beyond the best known effect of hearing loss, noise can also has extra-auditory effects such as the induction of cardiovascular diseases, effect on the endocrine system and the central nervous system and contributes to increase stress and risk of injury (5-8). The European legislation on Safety and Health at work (9) provides general provisions about the obligations for the protection of the workers, in particular for the prevention of hearing damage; the provision indicates the measures to prevent and protect against occupational exposure to noise in relation to the type of activity, starting from the minimization/elimination of the Hazard Factor, e.g. the replacement or modification of obsolete or particularly noisy machinery. A careful characterization of the emission source, through well-designed and precisely performed measurements, makes possible both to design effective noise mitigation solutions and to verify their effectiveness, for an actual protection of Safety and Health of workers, in compliance with the relevant Safety regulation. The objective of this paper is to present an assessment of an acoustic remediation carried out on an industrial machinery, namely a punching press, performed at an Italian metalworking company engaged in the production of punched metal sheets through pressing, cutting, bending, welding, painting and anodizing. It is useful both for the reduction of the sound power of the machinery and for the potential exposure to noise of the worker assigned to the same machinery. This action was carried out experimentally and preliminarily in view of a soundproofing intervention of the entire working unit of the company.

2. Materials and Methods

Methodology

To evaluate the noise produced by the punching press, sound pressure level measurements were performed according to the technical requirements of UNI EN ISO 3744:2010 standard (10) *ante* and *post operam* of the acoustic remediation. The standard reports the determination of the sound power level using the level of sound pressure measured on a surface enveloping the noise source which was placed in an environment that approximates an acoustic free field. In this study, the machinery was positioned on a reflecting surface and the measurements were carried out in several points located on a fictitious measurement surface defined as the lateral surface of a parallelepiped with an area equal to S, which includes the source, whose sides are parallel to the sides of the referring parallelepiped and are placed at a distance equal to 1 m (Fig. 1). According the quoted standard, the average sound pressure level $L_{p'}$ on the measurement surface determined under real conditions, once corrected to eliminate the influence of residual noise and environmental reflections, expresses the average sound pressure level on the measurement surface in free field conditions, L_{pf}. This level is representative of the power level per unit area, so the sound power level L_w of the machine will be then obtained by referring to the entire measurement surface. The L_{pf} level, expressed in dB, is given by following formula:

$$L_{pf} = L_p{'} - k_1 \quad (1)$$

where:
Lp' = average sound pressure level on the measurement surface;
k_1 = correction factor related to background noise;
k_2 = correction factor related to environmental reflections.

The Lp' level is the average of N sound pressure levels L_i, measured in N different measurement points on the machinery's envelope surface, as reported in following formula:

$$Lp' = 10\ log \frac{1}{N} \sum_{i=1}^{N} 10^{0.1L_i} \quad (2)$$

The correction factor k_1, expressed in dB and reported in equation 3, refers to the background noise, which includes all the sound sources except the one in question:

$$k_1 = -10\ log\left(1 - 10^{-0.1\Delta L'}\right) \quad (3)$$

where ΔL is the difference between the average sound pressure levels measured on the measuring surface while the machine is operating and when the machine is switched off.

If ΔL is greater than 15 dB, k_1 is assumed to be zero, if it is less than 6 dB, the measurement does not reach the required accuracy of the standard UNI EN ISO 3744: 2010.

The correction factor k_2 was calculated considering the equivalent absorption of the environment by estimating the equivalent absorption area, using the following formula:

$$k_2 = 10 \log\left(1 + 4\frac{S}{A}\right) \quad (4)$$

where:
S = measuring area (m^2)
A = equivalent absorption area (m^2)

The equivalent absorption area (A) was calculated as the sum of the surfaces present in the environment multiplied by their apparent sound absorption coefficient; the acoustic coefficients of the materials used here are reported in Sharland (11).

Finally, the sound power level of the machine L_w, expressed in dB, is given by:

$$L_w = L_{pf} + 10 \log \frac{S}{S_0} \quad (5)$$

S = measuring area of the envelope parallelepiped (m^2);
S_0 = unit surface (m^2).

Measurements

The acoustic remediation was performed on a punching press, whose basic components were: a) loading cell for the steel roll, b) raw material unwinding belt, c) loading lifting platform; d) drilling and shearing press, e) steel sheet exit roller conveyor, f) final flattener. The measurement of sound pressure levels was performed using: 1) a precision integrating sound level meter (Larson Davis model 831C) complying with the requirements of EN 61672-1: 2013, EN 61672-2: 2013 and EN 61672-3: 2013 (class I), 2) a 1/2" prepolarized condenser microphone for free field (Larson Davis 2560 model), 3) a sound pressure calibrator (Larson Davis mod. CAL 200). The recorded measures included: i) time-history of the noise level, ii) real-time frequency analysis in 1/1 and 1/3 octave according to IEC 61260:2014 Class 1, in the range from 6.3 Hz to 20 kHz, iii) acquisition of sound events with their level-time-frequency profile and audio signal.

As reported in Figure 1, the sound pressure measurements L_i, measured in octave bands were carried out on the surfaces of a fictitious parallelepiped built at a 1 meter

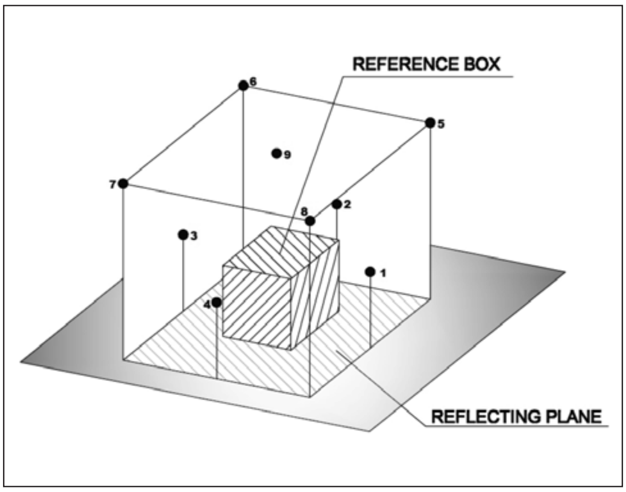

Figura 1. ***Scheme of the measurements point. The internal box represents the machinery and the circles on the external grid represent the measurement points***

distance around the machine. The measurements were carried out *ante* and post *operam* in order to evaluate the effectiveness of the acoustic remediation.

The sound pressure level L_p at a distance r from the sound power source L_w (in room) is calculated as:

$$L_p = L_w - 10\, log_{10}\ (4\, \pi\, r^2) \quad (6)$$

If the worker stays for 8 hours in the location where the sound pressure level L_p is evaluated, this can be preliminary useful information for the definition of the actual workers exposure, requiring further evaluations (e.g. source directivity, details on the working operations, etc.).

Mitigation activities

The mitigation action consisted of the partial encapsulation of the machinery. For the attenuation of the noise level, sound-absorbing panels made of materials suitable for noise abatement in industrial field and for complex soundproofing solutions, were used. Each panel was made with a sandwich structure with a total thickness of 100 mm, consisting of an outer part of a 2 mm thick pickled plate and an internal part consisting of:

- 3 mm thick bituminous sheath
- 50 mm thick rock wool
- internal core in 1 mm thick sheet
- 3 mm thick bituminous sheath
- 40 mm thick rock wool
- reinforced glass veil

3. Results and discussion

The Italian legislation, through the Legislative Decree n. 81/2008, states the necessity to protect the Safety and Health of workers through the Assessment and Management of all the work-related risks (employer' obligation that cannot be delegated), risk arising from the occupational noise exposure included. Similarly, the focus on improving the acoustics of non-industrial workplaces should increase, in particular when even the poulation in public places, such as schools, hospitals, offices, is exposed. According to the hierarchical order of Prevention measures, in terms of effectiveness, the techniques of acoustic remediation of industrial machines are generally structured in three successive steps, i) the action on the noise source, ii) intervention on the systems of transmission and propagation of noise, iii) interventions on work organization. The intervention on the noise source is certainly the most effective if compared to reduce the risk of noise in the workplace.

In this work, the acoustic remediation was carried out directly on the source that was partially encapsulated. In this type of intervention, the technical legislation does not provide any theoretical indication on the acoustic remediation, it only identifies an engineering method in order to determine the (without the burden of creating an anechoic test chamber) an engineering method for determining the sound power that allows to obtain a grade 2 accuracy in normal environments with low reverb.

In Tables I and II, respectively, starting from the measurements of sound pressure levels carried out *ante* and *post operam*, the major results are reported. In particular, the following quantities were determined:

1) the average sound pressure level L_p', from the sound pressure levels L_i, carried out on the envelope surface
2) the sound pressure level L_{pf} on the surface of the machinery corrected for factors k_1 and k_2
3) the sound power level L_{wm} calculated taking into account the envelope surface
4) the sound power level of the machinery, L_w

Table I. ***Results of sound pressure level measurements and sound power calculated ante operam***

	Frequencies for octave band (Hz)											
	8	**16**	**31.5**	**63**	**125**	**250**	**500**	**1 K**	**2 K**	**4 K**	**8 K**	**16 K**
L_p' (dB(A))	26.7	40.1	67.9	85.3	80.4	96.6	89.0	84.1	80.6	75.2	70.3	60.1
L_{pf} (dB(A))	88.3											
	8	**16**	**31.5**	**63**	**125**	**250**	**500**	**1 K**	**2 K**	**4 K**	**8 K**	**16 K**
L_{wm} (dB(A))	48.0	61.4	89.2	85.3	80.4	96.6	89.0	84.1	80.6	75.2	70.3	60.1
L_w(dB(A))	97.9											

Table II. ***Results of sound pressure level measurements and sound power calculated post operam***

	Frequencies for octave band (Hz)											
	8	**16**	**31.5**	**63**	**125**	**250**	**500**	**1 K**	**2 K**	**4 K**	**8 K**	**16 K**
L_p' (dB(A))	23.4	39.1	60.6	82.7	79.0	92.3	85.4	82.8	78.8	73.3	66.7	62.2
L_{pf}(dB(A))	83.9											
	8	**16**	**31.5**	**63**	**125**	**250**	**500**	**1 K**	**2 K**	**4 K**	**8 K**	**16 K**
L_{wm}(dB(A))	44.6	60.3	81.8	82.7	79.0	92.3	85.4	82.8	78.8	73.3	66.7	62.2
L_w(dB(A))	94.1											

The L_{pf} values were obtained using the correction factors $k_1 = 0$ and $k_2 = 0.9$ as the background noise was noticeable because the measurements were performed with the equipment switched off.

Although in the design of acoustic reclamations the sound spectra are generally expressed in dB, in the present case study it was preferred to express the experimental data in dB (A), to allow an immediate comparison with the noise exposure indicators.

In Table III, the sound pressure values calculated *ante* and *post operam* at a distance of 0.8 m from the machinery using formula (6), are reported (remember that for an exposure time of 8 hours, Lp = L_{AEX8h}).

Table III. ***Theoretical levels of noise exposure calculated ante and post operam***

	Ante operam	*Post operam*
Lw [dB(A)]	97.9	94,1
[a]Lp = L_{AEX8h} [dB(A)]	88.8	85,0

[a]For an exposure time of 8 hours, Lp = $L_{AEX,8h}$

As shown in Tables I and II, the acoustic remedial action taken has produced a reduction in the level of pressure and sound power of about 5 dB and 3 dB, respectively. This result, as is known, corresponds to a reduction of 50% of the sound impact. The acoustic remediation therefore, allowed to reclassify the risk from exposure to noise in the least dangerous class, ie average risk (80 dB - 85 dB). In the industrial field, the measurement of the sound power of a machinery can be performed with intensimetric measurements, described in the UNI EN ISO 9614-1 and UNI EN ISO 9614-2 standards, or with sound pressure level measurements, described in the series of standards ISO 3740 - ISO 3747. Although the intensimetric method allows to perform measurements in conditions of very high background noise and to study the emission of specific components of the machines, it requires however a very sophisticated instrumentation and long measurement times. For this reason, in this study it was decided to use the ISO 3744 standard, besides it can be considered a good compromise between the information achievable and required resources: the method is less restrictive with respect to test environments and requires a limited number of measurement positions compared to the other available methods. The choice of the measurement method therefore has a strong impact on the economic commitment for the conduct and management of the acoustic remediation activities. An alternative method for evaluating noise risk can be to use the preventive software based on different calculation models such as, semiempirical formulas of the semi-reverberant field, Ray Tracing, Cone Tracing, Beam Tracing, Pyramid Tracing. However, this approach is in many cases very expensive as well as being highly complex. Such software, in fact, requires the modeling of the industrial environment and the knowledge of the acoustic behavior of the different materials. Furthermore, in some cases the analysis software can underestimate frequency-dependent phenomena (loss by reflection, shielding attenuation, etc.) or can be applied to environments that follow Sabine's laws (not always industrial ones). The adoption of a simple solution such as the processing of the data measured with a sound level meter using a calculation sheet is therefore still of interest, for the purpose of assessing the potential exposure to noise in the operator station proximal to the machinery.

4. Conclusion

A pilot study has been carried out to evaluate the sound mitigation action performed on common industrial machinery. The expected improvement was, besides the reduction of the general enviromental noise, also the reduction of the noise not only in the operating area of the machine but even in the line behind.

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