Noise Sources Analysis in a Wood Manufacturing Company

Claudio Guarnaccia, Nikos E. Mastorakis and Joseph Quartieri

Abstract**—**The need for noise assessment in occupational health is a growing necessity, especially in production activity during which high sound pressure levels occur. A continuous exposure to relevant noise dose can lead to several effects on human health and quality of life.

A resume of the auditory and non-auditory effects is given as an introduction to an experimental activity performed in a wood manufacturing company. The different sources are characterized by means of single source noise emission measurements performed during specific periods out of working time. In addition, the acoustic climate is evaluated with measurements taken during normal working activity. The emission of each single source operating in idling phase or with a sample load is highlighted and the correspondent spectrum is used as an identification pattern.

The possibility of creating a database of noise spectra is suggested as a first step towards specific mitigation actions and monitoring tools tuned on frequency analysis.

Keywords**—** Noise Control, Acoustical Dose, Source Characterization, Emission Spectrum.

I. Introduction

ONE of the most important problem to be faced in environment impact analysis and in occupational health is the acoustical noise control. Noise, in fact, is one of the "polluting" agent that must be considered in areas in which human activities are performed, together with air quality, electromagnetic fields, natural radioactivity, climatic factors, etc.. In [1] the authors presented an environmental quality index, in which the impact of several agents has been analysed and included in a synthetic composite index.

Regarding acoustical noise, transportation infrastructures and industrial areas represent the most relevant sources in urban or sub urban environments, while in closed areas, especially in working places, the main sources are usually related to anthropic activities and to services systems and plants. The effects of noise on human life has been investigated and several studies can be found in literature. For instance, exposure to transport noise may disturb sleep quality (see for instance [2]). In general, noise interferes in complex task performance, modifies social behaviour and causes annoyance. Studies of occupational and environmental noise exposure suggest an association with hypertension, raised catecholamine secretion, reading comprehension and long-term memory impairment, etc..

The importance of noise control, therefore, is evident, especially in the domain of occupational activities. In [3], the World Health Organization (WHO) describes how to quantify the burden of disease associated with hearing impairment from occupational noise, while in [4] it reports an assessment of the global disease burden from occupational noise, as part of a larger initiative to assess the impact of 25 risk factors in a standardized manner. Usually, local governments issue particular regulations on occupational noise, according to international guidelines, that fix the exposure thresholds and the duties of workers and employers about personal and collective safety equipment.

The main parameters that are considered in noise control on working places are defined as follows.

$L_{Aeq,i}$ is the measurement of the level of the single *i*-esim working activity (in our case study, i.e. a wood manufacturing company, cutting, nail gun packing, goods transportation, etc.).

$L_{Aeq,Te}$ is the daily exposure level, obtained by the single $L_{Aeq,i}$ measurements, knowing the exposure time of the single working activity, and it's defined as:

$$L_{Aeq,Te} = 10 \log \left[\frac{1}{\sum t_i} \cdot \sum_{i=1}^{n} \left(10^{\frac{L_{Aeq,i}}{10}} \cdot t_i \right) \right] \quad (1)$$

L_{EX} (*8h*) is the daily personal exposure evaluation, referred to T_0 = 8 hours:

$$L_{EX,8} = L_{Aeq,Te} + 10 \log \left[\frac{T_e}{T_0} \right] \quad (2)$$

$L_{EX,w}$ (*week or 40 h*) is the weekly personal exposure evaluation, referred to 5 working days per week:

$$L_{EX,w} = 10 \log \left[\frac{1}{5} \sum_{k=1,\ldots,m} 10^{0,1 (L_{EX,8})_k} \right] \quad (3)$$

Let us remind that Italian regulation D.L. 81/2008, on the improvement of safety on working places, with the implementation of the European nose regulation 2003/10/CE, fixes the following exposure limits and action values:

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- Exposure limit values are L_{EX} =87 dBA or p_{peak} = 200 Pa (140 dBC, referred to 20 μPa)
- Upper action values are L_{EX} = 85 dBA or p_{peak} = 140 Pa (137 dBC, referred to 20 μPa)
- Lower action values are L_{EX} = 80 dBA or p_{peak} = 112 Pa (135 dBC, referred to 20 μPa)

where L_{EX} is the daily personal exposure evaluated on 8 hours, $L_{EX,8}$, defined in (2)

In this paper, a wood manufacturing company, placed in Fisciano (SA), is considered as a case study. This typology of factory is usually characterized by high sound pressure levels during the production activity. Noisy machineries, such as band and circular saws, hammers, nail guns, etc., are adopted to work on wooden components and workers are often obliged to use these tools in very hard noise conditions, operating alone or in parallel, depending on the productive phase. 12 workers are employed in the production of this specific company, but the flexibility of the request can make this number vary from 8 to 20 units. These workers have fixed timetables based both on the company needs and on the worker rights.

The performed experimental session shows that, according to Italian regulation, special mitigation actions are not required by regulation; the company needs to provide individual safety equipment but this equipment is not compulsory. We will not focus on this point, since the aim of the paper is to present the noise emissions and to highlight peculiarities and features of the most relevant noise sources.

In section 2, a brief review of the impact of noise on human health is reported. The acoustical experimental campaign is described in section 3. The equivalent level produced by the most relevant noise sources is presented and the results are reported and commented. The development of a kind of "archive" of source typical emission spectrum "in opera" is suggested because noise emission and impact are strongly related to functioning conditions and surrounding environment, quantitatively deviating from emission values declared by manufacturer.

II. Noise impact on health

Generally acoustical noise can have different effects on human health. The most important one is, of course, the damage on auditory apparatus, with consequent hearing loss and/or frequencies detection reductions. Beside this effects, a great variety of “non-auditory” effects can be highlighted. In the following, a brief review of these effects is given.

A. Auditory effects

In literature there are several studies that face this problem and it has been evidenced that a continuous exposure to noise of 85–90 dBA, particularly over a lifetime in industrial settings, can lead to a progressive loss of hearing, with an increase in the threshold of hearing sensitivity (see for instance [5]).

The main auditory effects are four: acoustic trauma, tinnitus, temporary hearing loss and permanent hearing loss.

The acoustic trauma is the sudden hearing damage that occurs in case of short extremely loud noise event, such as a gunshot, reaction engine burst, etc..

The tinnitus is the ringing or buzzing that is experienced in the ear because of a cochlear cells or auditory nerve damage.

The temporary hearing loss occurs immediately after exposure to a high level of noise. It is “temporary” in the sense that there is a gradual recovery after spending time in a quiet place. Complete recovery depends on many factors and may take several hours. It is also known as temporary threshold shift.

The permanent hearing loss growths in time, if noise exposure is not interrupted or protection equipment are adopted. It is hard to be cured by medical treatment. The main feature is that when noise exposure is suspended, the hearing ability is not recovered. This effect, that is also known as permanent threshold shift, can be combined with other effects, such as hearing loss related to ageing.

B. Non-auditory effects

Noise affects not only the hearing apparatus, but it is generally experienced that it disturbs human activities and communication, causing annoyance. In some cases, annoyance may be responsible of stress responses [6]. Moreover, besides annoyance, noise may directly have impact on health. Different features of sound, for instance intensity, frequency, complexity of sound, duration, etc., may influence response to noise.

Noise and sleep disturbance

Sleep is affected by noise from both objective and subjective point of view [7].

Exposure to noise disturbs sleep proportional to the amount of noise experienced in terms of an increased rate of changes in sleep stages and in number of awakenings. Habituation occurs with an increased number of sound exposures by night and across nights. There may also be after-effects during the day following disturbed sleep; perceived sleep quality, mood and performance (in terms of reaction time) decrease after sleep disturbed by noise exposure. Studies on noise abatement show that, by reducing indoor noise level, the amount of REM sleep and slow wave sleep can be increased [8]. It thus seems that, although there may be some adaptation to sleep disturbance by noise, complete habituation does not occur, particularly for heart rate.

Noise exposure and performance

Human performance is impaired by noise exposure [9]; in particular noise may reduce mental tasks such as text comprehension, it may slow rehearsal in memory and it may influence processes of selectivity in memory and choice of strategies for carrying out tasks.

There is also evidence that noise may reduce helping behaviour, increase aggression and reduce the processing of social cues seen as irrelevant to task performance [10].

Noise and cardiovascular disease

There are scientific evidences of physiological responses to noise exposure, such as increase in heart rate and blood pressure, peripheral vasoconstriction and thus increased peripheral vascular resistance. Usually an almost rapid habituation to brief noise exposure occurs, while prolonged noise can lead to a very slow or null habituation [8].

The strongest evidence of the effect of noise on the cardiovascular system comes from studies of blood pressure in occupational settings [11]. Many occupational studies have suggested that individuals chronically exposed to continuous noise at levels of at least 85 dB have higher blood pressure than those not exposed to noise. In many of these studies, noise exposure has also been correlated to other factors, both physical and psychosocial, which are also associated with high blood pressure.

Other non-auditory effects

Noise may cause several other effects, such as endocrine modified responses, psychiatric disorder, psychological symptoms, combined effects of noise exposure and other stressors, etc.. For a complete review, the reader may refer to [12].

III. Experimental Session Description and Results

The measurement campaign has been planned from 8:00 to 16:00 o'clock, during a working day. Three operators have been involved, with 4 acquisition channels and first precision class instruments. All the measurement have been taken in fulfillment of ISO standards requirements.

In the morning, measurements have been taken during normal production phase, considering the duration of different activities. These measurements, taken during work time, were of 10 minutes each, with receivers placed in different strategic positions. During lunch break, the single source emission has been characterized, measuring noise produced by each machinery operating in stand-alone mode, in three different conditions: before switching on (with powder aspirator as a background noise), after the switch on but without any load, i.e. idling, and with a sample load.

A. Noise sources

Let us briefly describe the noise production and emission of sources operating in the working area depicted in Fig. 1.

Band saw

This machinery is one of the most used in wood manufacturing. It is usually associated to quite strong noise levels, both in idling phase that during operation time. In order to reduce this emission, one cannot easily act on the machinery, because of the complex geometry and composition of the tool. Thus, it is important to underline that a good positioning of the wood item to be manufactured, a correct tuning of automatic steps in the cycle and the improvement of the bounding disturbing conditions during the operating phase, can reduce the noise level on a large time scale, e.g. an eight hours working shift.

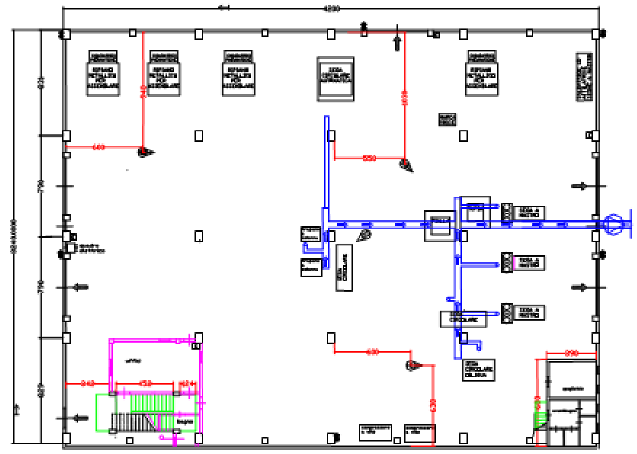

Fig. 1: Layout of the working area. The blue line represents the powder aspirator, while the various boxes are the different machineries. The purple area is the administrative office.

Circular saws

Circular saws are largely used in all wood factories. Noise produced by these saws is the sum of two components: the first one is due to the aerodynamic phenomena related to the rotatory motion (even without any load) of the blade, while the other is due to the friction between the blade disk and the wood piece. The spectrum of the noise produced by idling circular saw is expected to have a maximum in the medium/high range of frequencies. While cutting, noise is expected to grow in the entire spectrum about 5-10 dB with respect to the idling phase, because of blade-wood interaction.

Powder aspirator

This source is of primary importance in the daily noise level since it is continuously functioning, during the entire working time, i.e. 8 hours.

Part of the noise is produced by fan vibrations that are transmitted by metallic pipes with connections and splits all inside the factory. The other major component of the noise produced is due to aerodynamic fluxes and vortexes that occur in the conduits where air is strongly sucked to have the aspiration effect. In addition, an impulsive emission is present, due to bumps of particles in the metallic pipes: this emission becomes more evident during cut phases.

Nail guns

The emission of these sources is mainly related to the functioning system that forces part of the 10 bar compressed air to be expelled through an air valve. The compressed air activates a striker that hits nails and fires them in the wood. Sometimes, the workbench is used to hit back the nail and bend it, so that a greater force is applied to the assembled components. This emission is strongly impulsive.

Other sources

Other sources are represented by the grinder, that it's used daily to sharpen saws, and by the diesel lifter, that it's used when benches of products need to be moved inside the factory or to be stored before delivery. In this study, these sources are not considered since they do not operate constantly during the working time but only in short periods and when needed.

B. Measurements results

The results of the measurements on the five main sources, that are the two band saws, the two circular saws and the nail guns, are reported in Table 1.

Table 1: measured sound levels for different sources.

Operating condition	**Idling**	**With sample load**
	L_{eq} [dBA]	L_{eq} [dBA]
Band saw 1	79,7	86,2
Band saw 2	85,5	90,9
Circular saw 1	89,1	93,5
Circular saw 2	84,9	90,4
Nail Guns	---	94,8

From Fig. 2 to Fig. 7, the time histories of different measurements are reported. It is easy to see that each source has a typical noise emission both in idling and operating phase.

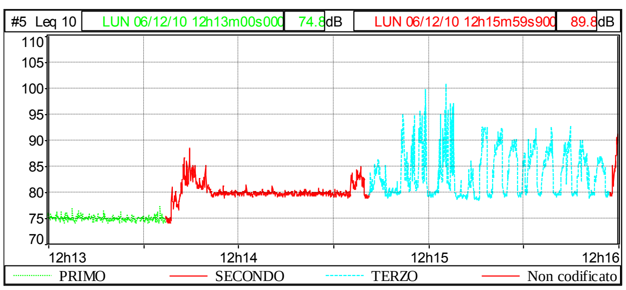

Fig. 2: Time history of the Leq signal for band saw 1. Different colours highlight the different operating state: green is off, red is idling, light blue is with sample load.

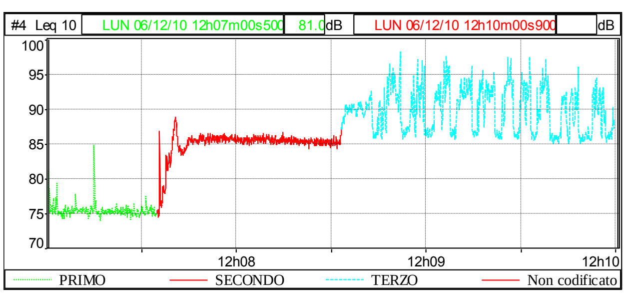

Fig. 3: Time history of the Leq signal for band saw 2. Different colours highlight the different operating state: green is off, red is idling, light blue is with sample load.

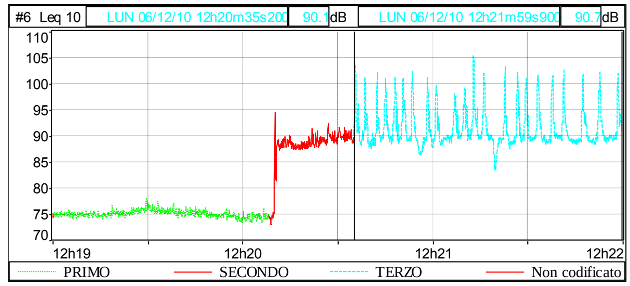

Fig. 4: Time history of the Leq signal for circular saw 1. Different colours highlight the different operating state: green is off, red is idling, light blue is with sample load.

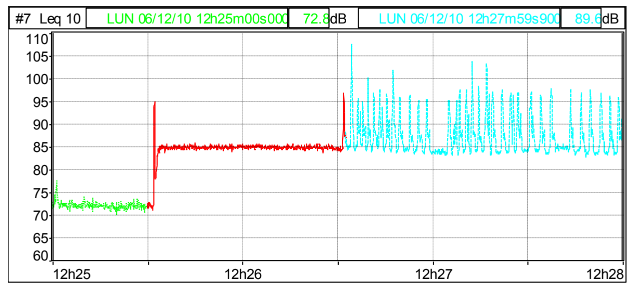

Fig. 5: Time history of the Leq signal for circular saw 2. Different colours highlight the different operating state: green is off, red is idling, light blue is with sample load.

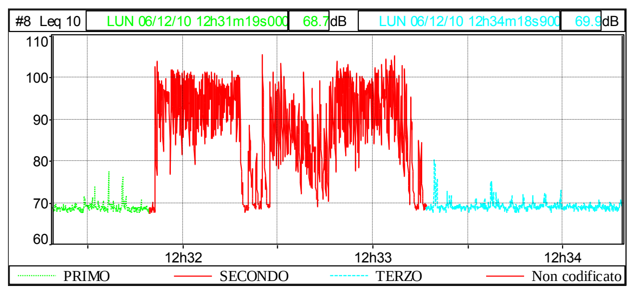

Fig. 6: Time history of the Leq signal for assembly and package workbench. Different colours highlight the different operating state: green is background noise, red is nail guns operating (both pneumatic and manual), light blue is items positioning.

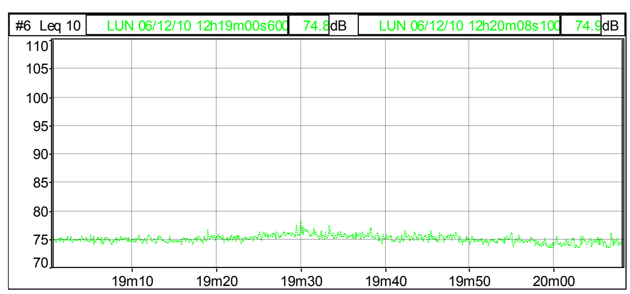

Fig. 7: Background sample measurement.

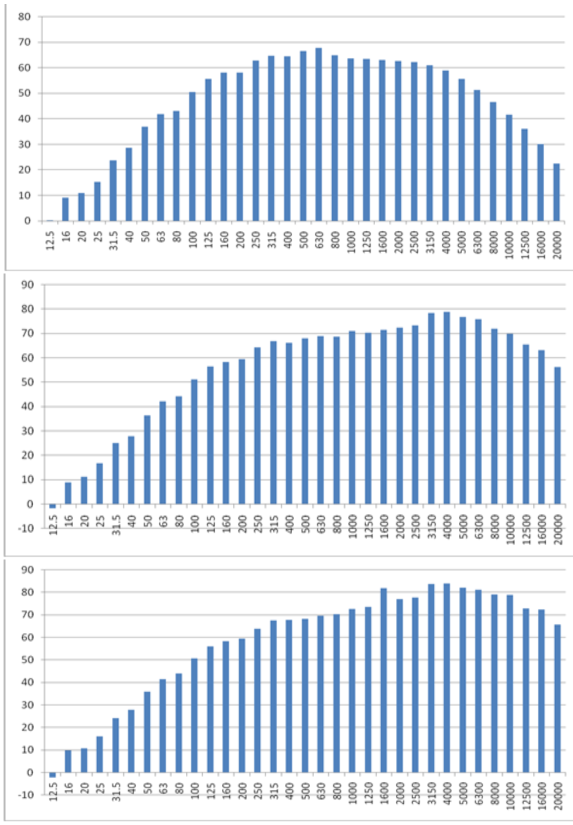

Fig. 8: Noise spectrum of band saw 2 in different operating conditions: background noise, i.e. saw off (up), saw on, idling (middle), with sample load (bottom).

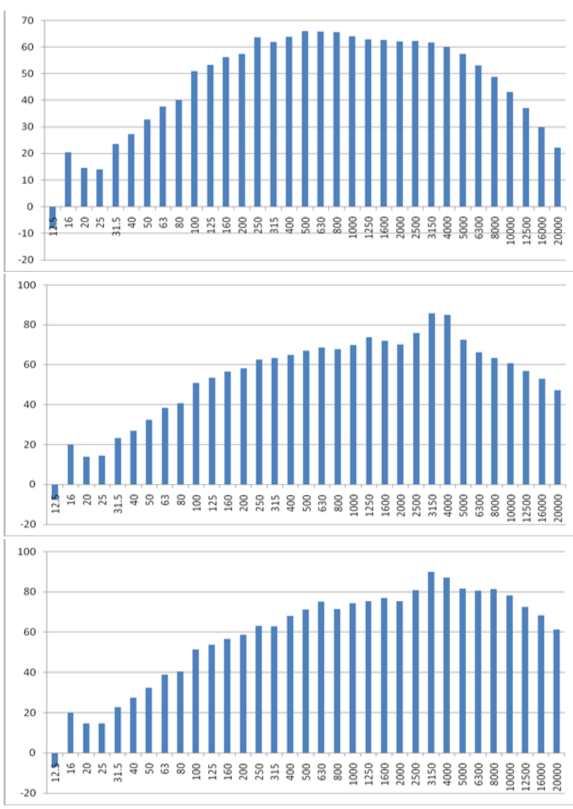

Fig. 9: Noise spectrum of circular saw 1 in different operating conditions: background noise, i.e. saw off (up), saw on, idling (middle), with sample load (bottom).

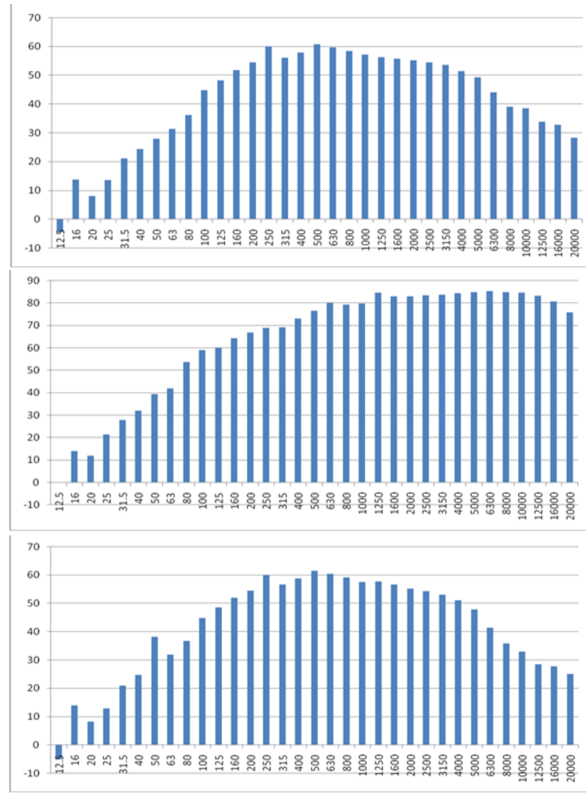

Fig. 10: Noise spectrum of workbench operations: background noise (up), nail guns operating (both pneumatic and manual) (middle), items positioning (bottom).

From Fig 8 to Fig 10, respectively band saw, circular saw and workbench operations noise spectra are reported. It is easy to notice that, when the saws are switched on (middle spectra of Fig. 8 and 9), the medium/high range of frequencies levels are raised up significantly (let us notice that the vertical axis scale changes from upper to medium spectrum). This is confirmed when a sample load is cut (bottom spectra). The difference between the three spectra represents a kind of "finger print" of the machinery operating noise both in idling and cutting phases. For instance, in the circular saw case, Fig. 9, it is evident a tonal sound in the 4000 Hz octave, that is specific of this source functioning. By acquiring the emission spectra of all the machineries in the production framework, it is possible to define a "spectra database" and thus to identify the operating noise source just looking at the real time (or average) sound production. Moreover, if any damage occurs at the machinery, e.g. blade imperfections, lubricant missing, wrong functioning, etc., the noise emission will deviate from the "standard" emission.

Thus one can check the production progress and control the maintenance duties in real time, monitoring the noise emission of the machinery, when operating in known conditions.

In addition, since the noise acquisition can be monitored in real time even on a remote terminal, any technician trained to read the data can acquire information on the operating conditions of any machinery from any location, simply looking at the noise emission time history and spectrum.

IV. Possible Mitigation Actions

Sources that have been analysed and characterized in the previous section require different approaches in order to reduce the noise production. Only the most used and the most noisy (averaged on time) machineries, that are the band saws, the circular saws and the powder aspirator are presented in this section.

A. Band saw

In order to reduce the noise emission of the band saws, an intervention on the mechanical parts (flywheels) that are connected to the blade can be performed. In particular, a 4 mm layer of cork is put on the flywheels of the band saw 1. This cork piece is glued on the external part of the flywheels and it is interposed between the blade and the metallic surface.

The effect of this intervention is visible in the noise emission measured during the experimental session and resumed in Table 1 and Figg. 2 and 3.

The comparison of the emission spectra of band saw 1 and 2 is reported in Fig. 11 and 12, respectively idling and cutting a sample load.

B. Circular saw

The possible mitigation actions on the circular saw are mainly related to the vibration of the blade.

A first approach consists in the replacement of the transmission belt based saw with a model in which the blades are directly mounted on the engine axis. The transmission, in fact, is a relevant source of vibration and micro bumps. The circular saws presented in section 3 belong both to the latter model, thus it's not possible to furnish a comparison with the former model emission, either to estimate the reduction due to this intervention.

Another possible action is the choice of special blade, with appropriate carvings aimed at the reduction of the vibrations, both in idling and in operating phases. These, so-called, "vibration damping slots" (Fig. 13) are adopted by means of laser application and, besides noise reduction, improve the cut quality too.

In addition, in order to reduce the vibration and thus the noise emission, one can apply on the blade different materials, such as viscoelastic polymeric layers or rubber coating.

Finally, a further action is represented by the interposition of rubber anti-vibrating elements between pavement and saw support desk, or between saw engine part and working bench.

C. Powder aspirator

The screening of powder aspirator is very difficult and, on the other side, very important because this machinery strongly contributes to the background noise. In general, mufflers can be adopted, based on absorption or resonance. In this company case, the resulting pipe restrictions could be not advisable because of powder stagnation occurrences. Thus, the best solution seems to be the application of sound proof panels on the pipelines, in order to reduce noise produced by particles bumps sucked with high speed.

In addition, between different parts of the pipeline, elastic dampers can be applied, in order to improve the elasticity of the conduit.

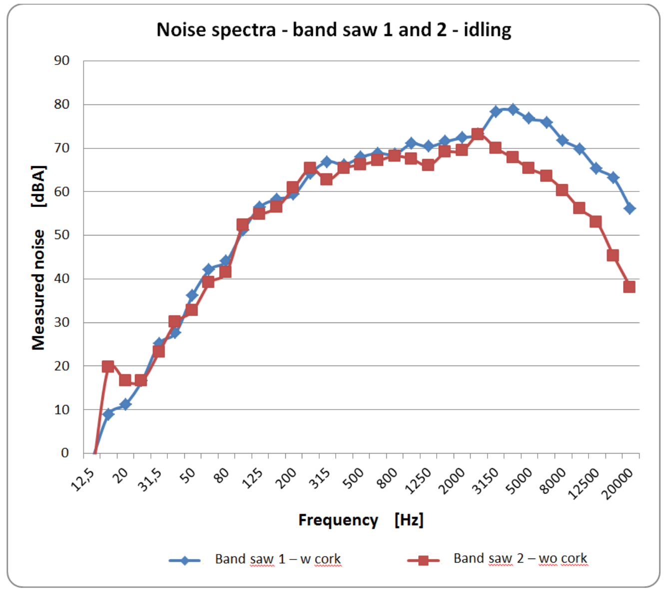

Fig. 11: Noise spectra of band saw 1 (with cork layer – blue diamonds) and band saw 2 (without cork – red squares), in idling phase.

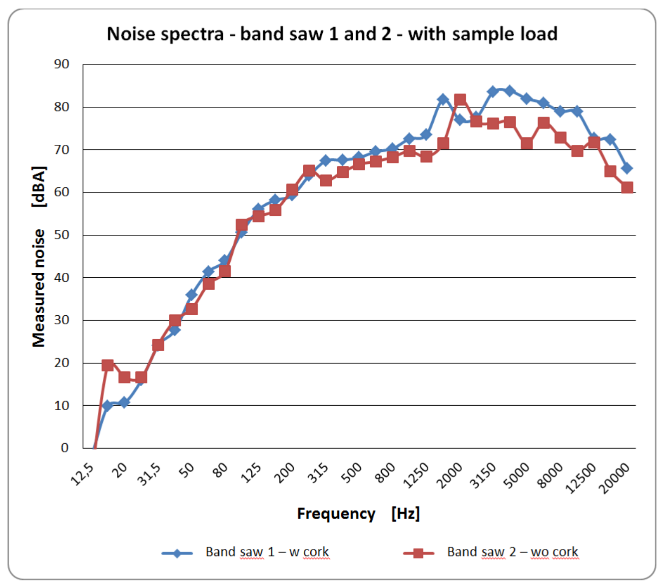

Fig. 12: Noise spectra of band saw 1 (with cork layer – blue diamonds) and band saw 2 (without cork – red squares), operating on sample load.

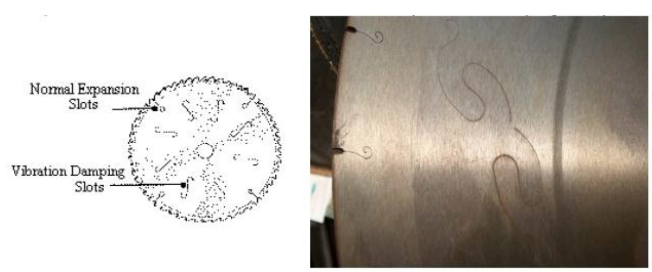

Fig. 13: Vibration damping slots on circular saw.

D. Reverberation reduction

Another relevant effect that worsen the acoustic climate is the high reverberation that occurs in the working area. This is a very important phenomenon because the persistence of sound in the air brings to a raise in the noise dose experienced by the workers.

The reverberation time is generally used to evaluate the acoustical response of an internal area and it is defined as the time that sound takes to reduce its level of 60 dB. According to the intensity level interval used for the evaluation of the linear regression, the reverberation time can be defined as RT60, RT30 or RT20 [13].

An empirical formula has been proposed by Sabine [14] :

$$RT_{60} \cong 0{,}16 \frac{V}{\sum_{i=1}^{n} \alpha_i S_i} \qquad (4)$$

where V is the volume of the room (in m^3), α_i is the absorption coefficient of the i-esim surface and S_i is the area of the i-esim surface (in m^2).

According to (4), an evaluation of the actual reverberation time and a prediction of the modification of this parameter after the insertion of sound proof panels, can be done. The panel chose for the simulation is an ashlar layer and it's placed along the entire area of the roof. The absorption coefficients per frequency octaves of the panel are taken from the technical datasheets. The results for the estimated reverberation time are reported in Table 2.

Table 2: Estimated reverberation time in the real configuration and after the application of sound proof panels to the roof.

	Reverberation Time [*s*]					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Real configuration	17,3	12,9	14,2	11,0	9,9	10,3
Simulated configuration (with sound proof panels)	5,7	3,1	1,8	1,2	1,1	1,1

It is easy to notice that the actual configuration furnishes a very strong sound reverberation. On the contrary, the simulated action produce an excellent attenuation, both because of the high performance of the sound proof panel and of the very large area of the roof. A good compromise for this kind of action is related to the cost of the panels and of the installation.

V. Conclusions

In this paper, the authors described a noise experimental activity in a wood manufacturing company. After having resumed the auditory and non-auditory effects in the first part of the paper, the measurements campaign has been described, reporting the measurements points and features.

The main aim of this study was to characterize the single source noise emission, both in terms of intensity level and frequency spectrum. In particular, the emission spectrum showed to be interesting to highlight the peculiarities of the different sources and to identify the typology of source by means of frequency inspection. The possibility of achieving a database of sources, with particular care to source power level, directivity, frequency spectrum and possible mitigation actions, seems to the authors an interesting starting point for advanced occupation health actions. A real time spectrum monitoring can be helpful to control the good functioning of the machinery and to assess the noise dose exposition of the worker.

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