Protection of workers from risks caused by loud sound fields. Comparison between the European and the United States standards.

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ABSTRACT

Workers protection from risk arising from prolonged exposure to loud acoustic fields plays a key role in the safeguard of people physical and mental wellbeing. In workplaces, depending on level and time of exposition, annoyance or permanent damage may occur. Furthermore, other parameters such as impulsive events, spectral composition, and phenomenon variability can influence the hazard connected to the sound and can, eventually, reduce protection. Among the most evolved systems used to ensure workers protection from noise, there are the European and the United States Standards. In Europe, safeguard is ensured through Directive 2003/10/EC of the European Parliament and of the Council of February 6th, 2003. It supplies the minimum health requirements to assure health-care and protection from loud sounds to those workers who are exposed to noise as a result of their work. In the United States, the OSHA Standard number 1910, subpart G "Occupational Safety and Environmental Control" regulates the procedures. In this work, noise produced in different work activities is measured using dosimeters and real-time analyzers. The results are then analyzed using the two different Directives to show whether they supply different protection levels and to highlight possible weaknesses in the individuation of protection from loud sounds.

Keywords: Directive 2003/10/EC; OSHA Standard 1910; Protection from noise; Workers.

1. INTRODUCTION

The number of people exposed to potentially dangerous noise because of their work is extremely high. It is estimated that every year in the United States about 30 million people - engaged in various business activities - are subject to noise, which may cause hearing loss (1).

There, the problem of safety in the workplaces has been addressed since 1970, when the Congress enacted the Occupational Safety and Health Act establishing the Occupational Safety and Health Administration (OSHA). OSHA is part of the Department of Labor of the United States and one of its goals is to ensure safe work conditions by setting and enforcing standards, providing training, outreach, education and assistance.

With regard to problems concerning the workers safeguard from noise, OSHA through Standard 1910 (2), poses limits to noise exposure in the workplaces. The evaluation is based on the idea of absorbed dose. The maximum exposure level (PEL – Permissible Exposure Limit), to which a worker can be exposed during a nominal eight-hours working day (3), it is equal to 90dB(A). Indeed, according to what is stated in the Standard, if sound pressure level (SPL) increases the allowed exposure time diminishes. This assumption permits worker to do not overcome the maximum allowed dose.

With the Occupational Safety and Health Act, the National Institute for Occupational Safety and Health (NIOSH) was also instituted. NIOSH is a federal agency responsible for conducting research and adopt recommendations for the prevention of accidents at work. But, unlike OSHA, NIOSH is not

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a regulatory agency; it does not publish health and safety standards enforceable under the law of the United States. It has to be observed that, despite both systems refer to the same legislative network; the provided recommendations are extremely different. For instance, NIOSH - based on a framework of studies and researches carried out in its institutional mandate - recommends that all workers' exposure to noise should be contained below the A-frequency weighted equivalent continuous sound pressure level $L_{A,eq}$ of 85dB(A) for a nominal eight-hours working day. This consideration is based on information obtained from literature reviews, which show that a significant noise-induced hearing loss occurs at exposure levels equivalent to the OSHA's PEL [90dB(A)]. Furthermore, NIOSH recommends halving exposure time whenever the level increases by 3dB(A), because any increase in the level of 3dB corresponds to a doubling of the sound energy (4); while OSHA rules require halving exposure time whenever the $L_{A,eq}$ increases by 5dB(A). To be more specific, OSHA Standard allows an eight-hours stay for a $L_{A,eq}$ of 90dB(A), reducing it to a two-hours stay if the level is equal to 100dB(A). NIOSH recommends a stay of eight hours only with $L_{A,eq}$ less than or equal to 85dB(A), reducing the exposure limit to fifteen minutes if the $L_{A,eq}$ is 100dB(A).

Instead, in Europe the protection of workers from damage arising from prolonged exposure to sources of noise is assured by Directive 2003/10/EC of the European Parliament and of the Council of February 6th, 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (5). This directive defines health and safety requirements and creates a minimum guaranteed level of protection for all European Community workers. The Directive supplies the minimum safety prescriptions to ensure health-care and protection from noise to those workers who are, or are likely to be exposed to risks from noise as a result of their work. It also suggests giving priority to reducing risk at the source, to reduce the level of exposure to noise by incorporating preventive measures in the design of workstations and to select suitable personal protective equipment (PPE). Furthermore, it promotes provisions relating to work equipment and methods, thus contributing to the protection of the workers involved.

In this article the OSHA Standard 1910 will be examined first and then applied in the analyses of several practical cases. The same data will be analyzed using prescriptions provided by the European Directive and compared with the results obtained with the OSHA recommendations.

2. OSHA STANDARD 1910 FOR THE PROTECTION OF WORKERS IN THE U.S.

The calculation for the evaluation of workers exposure levels can be carried out using two easy-to-use procedures, which allow obtaining immediate results. The first one considers the measured value of the A-frequency weighted equivalent continuous sound pressure level $L_{A,eq}$. Protection against effects of exposure to noise shall be provided when SPLs, measured using the Slow time-constant, exceed those shown in the table below:

Table I – Allowed noise exposure levels and exposition time

Daily exposure (h)	$L_{A,eq}$ [dB(A)]	Daily exposure (h)	$L_{A,eq}$ [dB(A)]
8	90	1.5	102
6	92	1	105
4	95	0.5	110
3	97	≤ 0.25	115
2	100		

The second one is used when the measure is carried out using an octave-bands analysis. The A-frequency weighted equivalent continuous SPL can be determined considering the levels of each octave-band and applying a graphic procedure. The recorded values are plotted on the graph shown in Figure 1, and the point of maximum penetration into lines of equivalent sound pressure levels is determined. The A-frequency weighted equivalent continuous SPL of the signal is that corresponding to this point. The SPL determined using this procedure is different from the actual $L_{A,eq}$ evaluated on the whole signal, but it is used to determine exposure limits of Table I.

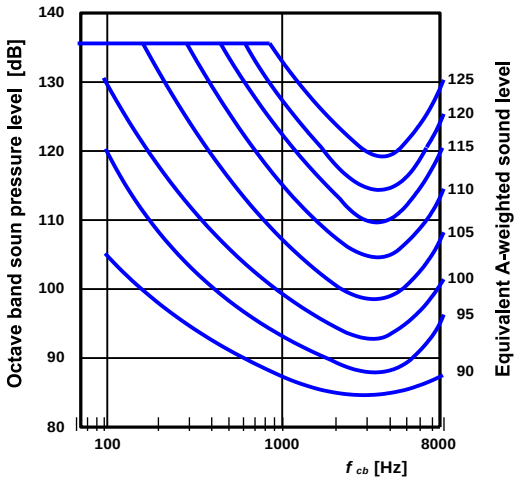


Figure 1 – Plot for the determination of the $L_{A,eq}$ for octave-band analyses.

The Standard also supplies information for determining the daily noise exposure when it is made of two or more periods having different levels. In this case, their combined effect should be considered rather than the individual effect of each period. Applying the following equation:

$$\left[\frac{C(1)}{T(1)}+\frac{C(2)}{T(2)}+\frac{C(3)}{T(3)}+.....+\frac{C(n-1)}{T(n-1)}+\frac{C(n)}{T(n)}\right]>1 \qquad (1)$$

where *C(i)* represents the total time in hour of exposure at a specific noise level and *T*(*i*) is the total time in hours of exposure permitted at that level, it is possible to determine the total noise exposure. If the value of the sum presented in eq. (1) overcomes one, the total noise level is higher than the limit value and necessary remediation activities have to be achieved.
In any case, according OSHA Standard 1910, exposure to impulsive noise should not exceed an un-weighted peak sound pressure level p_{peak} of 140dB.

When workers are exposed to SPLs higher than those listed in Table I, administrative or technical controls have to be used to reduce the noise to levels lower or equal to the above-mentioned limits. If remediation activities cannot succeed, then the employer must supply workers with personal protective equipment (PPE) to reduce the incident energy on the auditory system. For the purposes of hearing protection programs, occupational exposure to noise should be calculated in accordance to recommendations provided in the Appendix A, using the data shown in table G-16a (2), and without taking into account the attenuation provided by PPE. In particular, if one of the following scenarios occurs, the employer is forced to arrange an effective hearing protection program as described in the standard:

a) measurements made using the A-frequency weighted curve and the Slow time-constant show that exposure level is equal to or higher than 85dB(A), which corresponds to a time-averaged SPL referred to an interval of eight hours (*TWA*);
b) the value of the noise dose D, evaluated as described in the following paragraph, is at least equal to 50%.

Since overcoming one of these two values means for the employer the necessity to develop monitoring programs (aimed at identifying employees to be included in hearing-protection programs and to allow proper selection of PPE), both parameters have to be intended in terms of “lower levels of action”. To insure protection in a wider range of cases, the standard prescribes the employer to carry out the measurements selecting a sampling mode, which better matches the monitoring requirements laid down in rule. It is applied in the case of high mobility of workers, significant changes of SPL in time, and presence of a significant component of impulsive noise. Monitoring should be repeated at each change in production, process, and equipment, which may increases exposure to noise. The Standard also recommends that for workers whose exposure equals or exceeds the action level of 85dB(A), the employer arranges an audiometric testing program, performed by licensed otolaryngologists, ENT specialists, and occupational physicians. Data are made available to all

employees whose exposures equal or exceed a *TWA* of 85dB(A). In addition, the employer is required to train each worker, who is exposed to a time-weighted average of noise exposure levels for a nominal eight-hour working days equal to or greater than 85dB(A), by organizing courses and safety trainings.

To finish, it is important pointing out that similarly to what is expressed in the European Directive, the OSHA standard integrates the continuous, intermittent, and impulsive (from 80dB to 130dB) SPLs into the noise measurement. Therefore, all these events just contribute in the calculation of the previously mentioned action values and they are not considered phenomena capable to stress the hear organ by themselves.

2.1 Calculation of noise exposure

Calculation of workers exposure to noise is carried out using data contained in the table G-16a of OSHA Standard 1910. In the present work, those data will be reported by means of a chart shown in Figure 2 and expressed through Equation 2 obtained by interpolation.

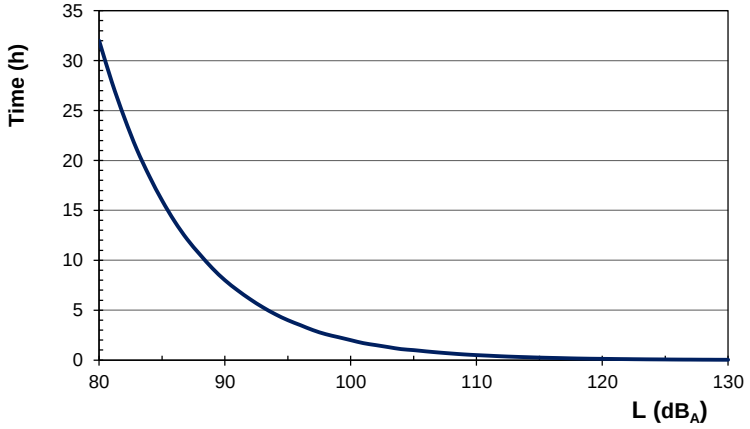


Figure 2 – Variation in the duration of *T* corresponding to the measured reference sound pressure level

The absorbed dose *D* is calculated using the chart as follows:

a) when the measured A-frequency weighted equivalent continuous sound pressure level L is constant for the entire work shift, the percentage of the noise dose *D* is given by:

$$D = 100\ \frac{C}{T} \tag{2}$$

where *C* is the total duration of the working day in hours and T is the length corresponding to the measured SPL as specified in Figure 2. The value of *T*, depending on the level, can be evaluated from Figure 2 or, in alternative, calculated as follows:

$$T = \frac{8}{2^{(L-90)/5}} \tag{3}$$

b) when noise exposure is composed of two or more periods of noise having different A-frequency weighted equivalent continuous sound pressure level $L_{A,eq}$, the percentage of total noise dose *D* during the whole working day is given by:

$$D = 100\ \left[\frac{C(1)}{T(1)} + \frac{C(2)}{T(2)} + ... + \frac{C(n)}{T(n)}\right] \tag{4}$$

where *C(n)* indicates the total time of exposure to a specific noise level and *T(n)* indicates the duration for that level as determined with Figure 2 or Equation 3.

The SPL is determined as function of exposure to noise at work and its magnitude is usually measured with a dosimeter, which gives a reading in terms of “dose”. To better understand the data, the dosimeter readings can be converted to a time-weighted average of noise exposure levels for a nominal eight-hours working day, *TWA*.

The conversion between the dose absorbed by the worker and the *TWA* is done using a table in the appendix A of the Standard, which is reported here in the form of graph in Figure 3 and with Equation 5, obtained by interpolation.

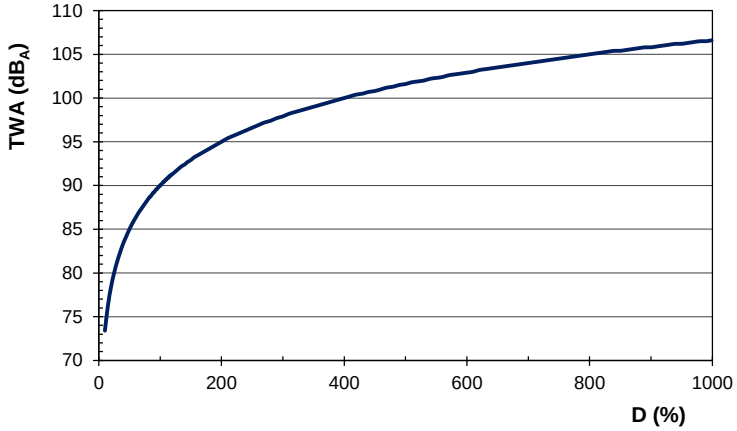


Figure 3 – Chart for the determination of the *TWA* starting from the percentage of noise dose *D*

$$TWA = 7.2107 \ \ln\left(D\right) + 56.794 \tag{5}$$

If the dose read on the dosimeter is lower or higher than the values in Figure 3, the *TWA* value can be calculated using the following equation:

$$TWA = 10.61 \ \log\left(\frac{D}{100}\right) + 90 \tag{6}$$

3. DIRECTIVE 2003/10/EC FOR THE PROTECTION OF WORKERS IN THE E.U.

In Europe, to avoid discordant analyses on the measured phenomena, worker protection from damage arising from prolonged exposure to noisy processes is upheld by Directive 2003/10/EC of the European Parliament and of the Council of February 6th, 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). The Directive supplies the minimum safety prescriptions to ensure health-care and protection from noise to those workers who are, or are likely to be exposed to risks from noise as a result of their work. It also suggests giving priority to reducing risk at the source, to decrease the level of exposure to noise by incorporating preventive measures in the design of workstations, and to select suitable PPE. Furthermore, it promotes provisions relating to work equipment and methods, thus contributing to the protection of the workers involved. All member states must conform their national legislation according to what is stated in this Directive.

The European standard uses the following parameters, calculated with a reference pressure of 20µPa, for the protection of workers (5):

a. Daily noise exposure level ($L_{EX,8h}$);
b. Weekly noise exposure level ($L_{WE,8h}$);
c. Peak sound pressure ($p_{peak,C}$).

The daily noise exposure level $L_{EX,8h}$ is the time-weighted average of noise exposure levels for a nominal eight-hours working day, the weekly noise exposure level $L_{WE,8h}$ is the time-weighted average of noise exposure levels for a working week of five days and eight-hours day. Whereas, the peak sound pressure $p_{peak,C}$ represents the maximum value of the instantaneous C-frequency weighted noise pressure. Still in reference to the pressure of 20µPa, the Directive establishes that peak sound pressure maximum admissible value (exposure limit value) is $p_{peak,C}$ = 200Pa [140dB(C)]. Moreover, it states that the maximum value for which the use of individual hearing protection devices is not obligatory (lower exposure action values) is $p_{peak,C}$ = 112Pa [135dB(C)], while the maximum value for which usage of individual hearing protection devices is obligatory (upper exposure action value) is $p_{peak,C}$ = 140 Pa [137dB(C)]. Practically, this means that, in those working environments where $L_{EX,8h}$ is below 80dB(A) (daily noise exposure level limit) and if the $p_{peak,C}$ levels are less than 135dB(C), the employer can refuse to supply workers with headsets and other

PPE.

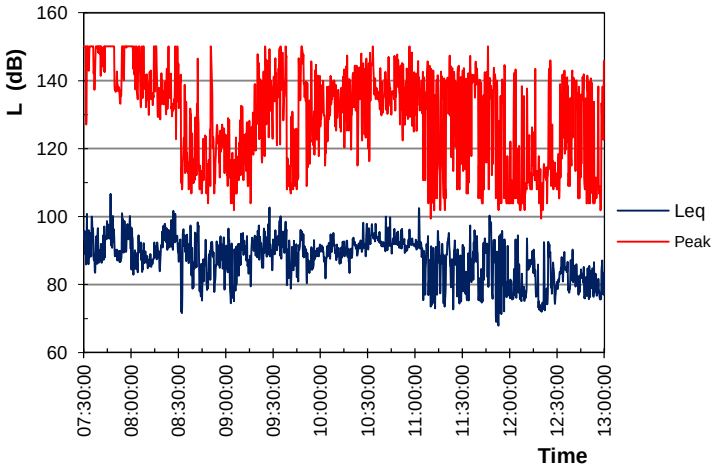
To sum up, Directive 2003/10/EC provides that analyses have to be carried out by sampling the maximum C-frequency weighted value of the instantaneous sound pressure level and the A-frequency weighted equivalent level normalized to a standardized eight-hours working day. No record of any other physical-quantity temporal evolution such as impulsive events is required. Therefore, according to the Directive, for environments in which noise exposure levels are below the threshold, a simple evaluation of the $p_{peak,C}$ value is enough for evaluating possible risks to the human ear. Even if these cases - in which, peak sound pressure levels are high (but still lower than the exposure action value) and noise exposure levels are below the action levels - may seem rare, they are extremely common situations in those workplaces characterized by occasional loud impulsive sounds but a short temporal persistence. Examples of these activities are, for instance: material stress testing laboratories, mechanical workshop activities, metal-plates pressing operations, furnaces' crucible cleaning after the production of ferrous materials, etc.

As it is possible to observe and how will be demonstrated in this study, the Directive lacks to supply a complete worker protection. Indeed, one of the main assumptions of this procedure is that impulsive events just contribute in determining an exposure value and their evaluation converges in the calculation of the previously mentioned action values ($L_{EX,8h}$, $L_{WE,8h}$). They are not considered separately as dangerous effects in the acoustic phenomenon. This is undoubtedly a simplification that can lead to failures in workers protection (6). By acting in this way, a specific determination of these potentially harmful events is omitted and the risk of underestimating these components becomes extremely high (7 - 9).

4. SAMPLED DATA ANALYSIS AND DIRECTIVES COMPARISON

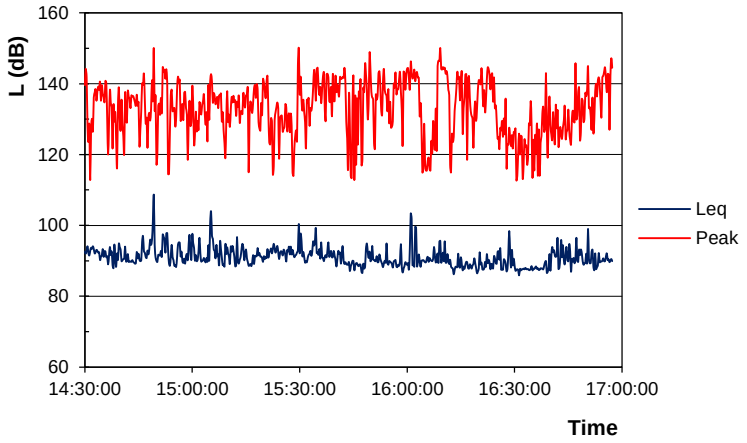
The analyses presented in this study refer to various work and industrial activities in which workers are exposed to loud sound fields as a result of their work. Evaluation of noise exposure is made comparing the actions of protection required when the European Directive 2003/10/EC and the OSHA Standard 1910 are applied.

Figure 4 and 5 plot the time histories for SPLs recorded in a plant for cast iron material production. In particular the equivalent continuous A-weighted sound pressure level $L_{A,eq}$, the un-weighted peak sound pressure level p_{peak}, and other main acoustic descriptors (A-weighted single event level L_{AE}, *A-weighted* daily noise exposure level on 5.5 hours $L_{AEX,\,5.5}$, *A-weighted* daily noise exposure level on 2.5 hours $L_{AEX,2.5}$*A-weighted* daily noise exposure level normalized to 8 hours $L_{AEX,8h}$ and percentile levels L_{max}, L_{10}, L_{30}, L_{50}, L_{70}, L_{90}, L_{min}) are shown. During this study the Larson Davis 705 model was used for recording the signals. It allows measures in the dynamic range 70 – 140 dB, the possibility to store the equivalent continuous sound pressure level L_{eq}, the un-weighted peak sound pressure level p_{peak}, the A-weighted single event level L_{AE} and the percentile levels L_n in three different frequency-weighted scales: A, C, and un-weighted, according to the ANSI S1.4 1983 norm (10). The device was placed with a microphone on the shoulder of the subject being tested to detect the effective SPLs acting on his ear.



L_{EA}	134.2
L_{Aeq}	92.8
$L_{AEX,5.5}$	91.2
$L_{AEX,8}$	89.6
L_{max}	112.3
L_{min}	65.4
$peak_{,L}$	151.6
$peak_{,C}$	146.3
L_{10}	94.5
L_{30}	91.0
L_{50}	87.6
L_{70}	82.4
L_{90}	75.5

Figure 4 - $L_{A,eq}$ and p_{peak} time histories recorded in the cast iron material production plant (morning).



L_{EA}	131.9
L_{Aeq}	97.4
$L_{AEX,5.5}$	92.4
$L_{AEX,8}$	87.3
L_{max}	118.9
L_{min}	83.3
$peak_{,L}$	148.4
$peak_{,C}$	137.4
L_{10}	94.0
L_{30}	91.1
L_{50}	89.8
L_{70}	88.7
L_{90}	87.4

Figure 5 - $L_{A,eq}$ and p_{peak} time histories recorded in the cast iron material production plant (afternoon).

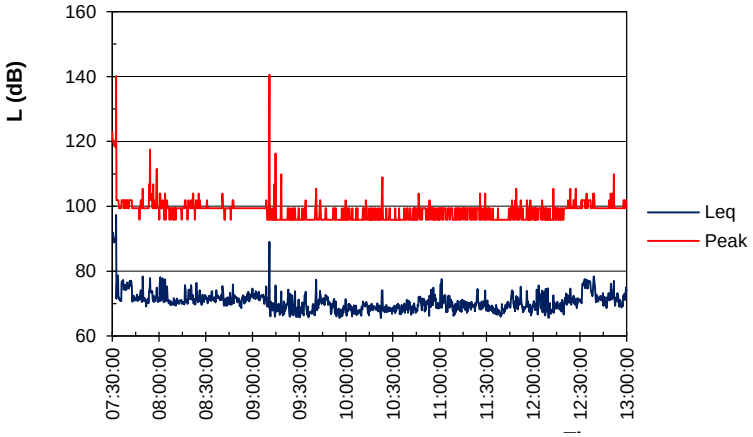
When OSHA standard is applied for the cases shown in Figure 4 and 5, it evaluates the daily noise exposition based on the two exposition periods which have different levels $L_{A,eq}$ (92.8dB(A) and 97.5dB(A)) using equations 1 and 3. Since sum of the ratio *C(i)/T(i)* is bigger than the unit (1.89), the worker is subjected to SPLs which overcome the limit presented in the Standard. Therefore, all the administrative and technical controls have to be pursued to reduce risk for the hearing organ. Furthermore, during his tasks, the worker is subjected to an un-weighted peak sound pressure level p_{peak} higher than 140dB (151.6dB and 148.4dB). Due to the operative conditions connected to the particular tasks carried out by the worker, in this specific case is not possible reduce the SPL by means of administrative or technical control; therefore, the works has to be supplied with PPE to reduce the absorbed dose to levels below the threshold reported in Table I.

To determine the typology and the efficiency of the PPE, an evaluation of the exposition to noise has to be carried out. Exposition to noise is evaluated according to what is stated in the Appendix A, without considering the attenuation obtained through the usage of the PPE. Using Equation 4, it is possible to evaluate the noise dose *D*, equal to 189.4%. The time-weighted average of noise exposure levels for a nominal eight-hours working day, *TWA* depends on the noise dose and it is evaluated using the chart in Figure 3 or equation 5. The value of *TWA* evaluated for the cases shown in Figure 4 and 5 is equal to 94.6dB(A), higher than the threshold value of 85dB(A). Therefore, the employer is required to organize a program of hearing protection as described in the Standard. It consists of a monitoring program, in the identification of employees to include in the hearing protection program, in a series of audiometric tests, and in the organization of safety trainings for the exposed employees.

On the other hand, when the same data are analyzed using prescriptions provided by Directive 2003/10/CE, the following results are obtained. For the first case of study, the daily noise exposure level averaged on a nominal eight-hours working day, $L_{EX,8h}$ is equal to 89.6dB(A), while the un-weighted peak sound pressure level p_{peak} is equal to 151.6dB, which becomes 146.3dB(C) when the C-weighted curve is applied. Since all values are higher than those reported in the Directive, the achieved remediation activities are the same of those suggested by the OSHA Standard.

Different results are obtained when data reported in Figure 6 are analyzed. They refer to activities carried out within the same working process shown in Figure 4, by an operator having different tasks.

The daily noise exposure level $L_{EX,8h}$ is equal to 72.5dB(A), which is below the threshold of 80dB(A) indicated in the Directive 2003/10/EC. Therefore, the only parameter that could oblige the worker to enforce the use of PPEs is the C-frequency weighted peak sound pressure value $p_{peak,C}$. The un-weighted peak sound pressure level p_{peak} is equal to 140.6dB, which is a value bigger than the threshold of pain and therefore capable to stress the hearing organ (11). When it is scaled and the C-frequency weighted curve required by the Directive is applied, the peak sound pressure is lowered and becomes 134.3dB(C). This value is smaller than the lower exposure action values [135dB(C)] presented in the legislation; therefore, the use of individual hearing protection devices is not obligatory. It should be noted if the value of the parameter adopted in the previously used Directive 86/188/CEE (which refers to the un-weighted value) was still stored; the worker would have to be supplied with PPEs (12).

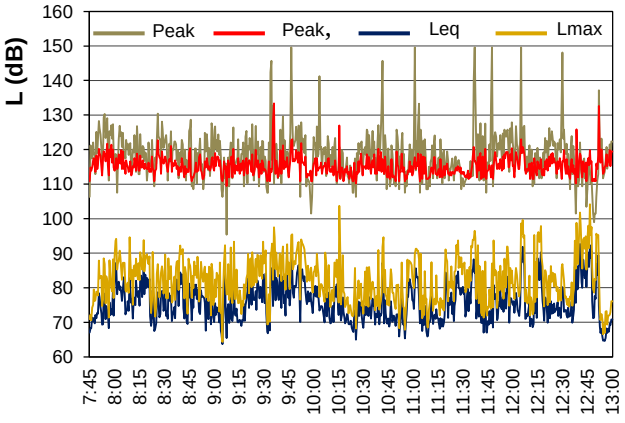


L_{EA}	114,3
L_{Aeq}	75.8
$L_{AEX,5.5}$	74.2
$L_{AEX,8}$	72.5
L_{max}	107.2
L_{min}	65.4
$peak_{,L}$	140.6
$peak_{,C}$	134.3
L_{10}	73.9
L_{30}	71.4
L_{50}	70.0
L_{70}	68.5
L_{90}	66.5

Figure 6 - $L_{A,eq}$ and p_{peak} time histories recorded in the cast iron material production plant (morning).

On the other hand, if analyses are carried out using prescriptions contained in the Standard 1910, the following results are obtained. Using equations (2) and (6), the absorbed noise dose D is equal to 9.6%, while the time-weighted average of noise exposure levels for a nominal eight-hours working day, TWA is 73.1dB(A). These values are below the threshold reported in the Standard, but since the maximum value of the peak sound pressure is equal to 140.6dB, the employer has to supply the worker with PPE. As can be observed, OSHA standard, contrary to Directive 2003/10/EC, provides for an effective protection of workers' health.

Another interesting example to proof the differences between the regulations in pointing out the presence of risks to the organ of hearing, it is the noise to which public urban transportation drivers are exposed. Several surveys were carried out during the working hours of public transportation drivers in the city of Cosenza, Italy. In this study measures carried out on an IRISBUS 203e 9.27/CNG are reported. The studied vehicle is methane-fueled and is used on the "Circolare veloce" route. This line connects the Northern with the Southern bound of the city with a low penetration (about 30% of the whole route) in the urban fabric. The IRISBUS 203e 9.27/CNG has a length of 9.00 meters, a width of 2.35 meters, and weighs 9000 kilograms. Figure 7 plots the surveys made for a work shift of 5.25 hours.



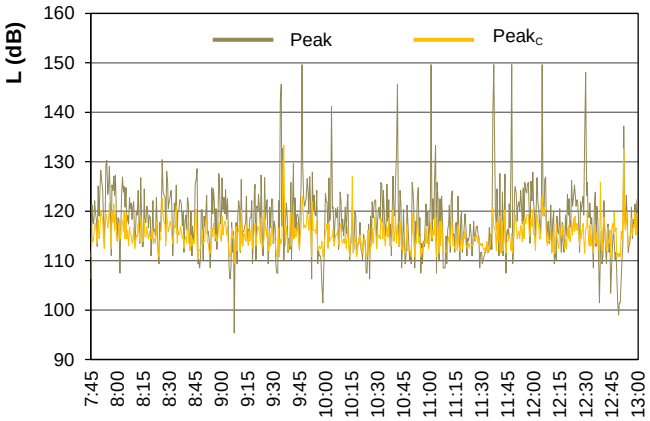
L_{EA}	120.6
L_{Aeq}	79.4
$L_{AEX,5.5}$	77.8
$L_{AEX,8}$	76.2
L_{max}	104.2
L_{min}	64.3
$peak_{,L}$	149.6
$peak_{,C}$	133.4
L_{10}	87.6
L_{30}	84.7
L_{50}	76.9
L_{70}	73.3
L_{90}	70.7

Figure 7 - $L_{A,eq}$, L_{max}, p_{peak}, and $p_{peak,C}$ time histories for the driver of the IRISBUS 203e 9.27/CNG bus

Through the analysis of data it is possible to observe how the daily noise exposure level is below the limit expressed in the Directive. It is equal to 77.8dB(A) and becomes even smaller when it is scaled and normalized to 8 hours [76.2dB(A)]. One more time, the most important observation can be done on the peak sound pressure. The un-weighted peak sound pressure value p_{peak} is equal to 149.6dB, which evaluated using the C-frequency weighted curve becomes $p_{peak,C}$ = 133.4dB(C). One can observe that when the un-weighted conditions are considered, the maximum peak value is even higher than the upper exposure action value (value for which usage of individual hearing protection devices is obligatory). Nevertheless, when the C-frequency weighted curve is applied it becomes smaller than the

lower exposure action values [135dB(C)] presented in the legislation. Therefore, the use of individual hearing protection devices is not obligatory. In this case, since values for daily exposure and peak sound Through the analysis of data it is possible to observe how the daily noise exposure level is below the limit expressed in the Directive. It is equal to 77.8dB(A) and becomes even smaller when it is scaled and normalized to 8 hours [76.2dB(A)]. One more time, the most important observation can be done on the peak sound pressure. The un-weighted peak sound pressure value p_{peak} is equal to 149.6dB, which evaluated using the C-frequency weighted curve becomes $p_{peak,C}$ = 133.4dB(C). One can observe that when the un-weighted conditions are considered, the maximum peak value is even higher than the upper exposure action value (value for which usage of individual hearing protection devices is obligatory). Nevertheless, when the C-frequency weighted curve is applied it becomes smaller than the lower exposure action values [135dB(C)] presented in the legislation. Therefore, the use of individual hearing protection devices is not obligatory. In this case, since values for daily exposure and peak sound pressure are both smaller than the lower value of action, there is no obligation for the employer to provide workers with PPE, even if they are exposed to sounds potentially harmful to the ear.

Figure 8, related to the same measurement, plots the difference between the temporal evolution of the SPLs when they are evaluated using the un-weighted curve and the C-frequency weighted curve. A big difference can be observed due to the fact that C-frequency weighted curve represent the inverse of the 100-phon equal-loudness contour. When a signal is processed using the C-frequency weighted curve it is artificially lowered in low frequencies up to 160 Hz and from 1600 Hz on. As a result the total energy of the signal decreases. This artificial operation can dangerously underestimate the effective stress to which the hearing organ is subjected in terms of pressure applied on the internal ear (13).



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L_{50}	87.6
L_{70}	82.4
L_{90}	75.5

Figure 8 - p_{peak} and $p_{peak,C}$ time histories comparison for the driver of the IRISBUS 203e 9.27/CNG.

When the same signal is analyzed using the prescriptions contained in the Standard 1910, the following results are obtained. The daily noise exposition *D*, evaluated using equation 2 and 3 is equal to 15.5%, which corresponds to a TWA of 81.4dB(A). Since this value is below the limit of 90dB(A) the employer does not have any obligation for supplying workers with PPE; in addition, because the value is even smaller than the lower action level of 85dB(A), the employer is not forced to arrange any effective hearing protection program either. Nevertheless, being the peak sound pressure value equal to 149.6dB, higher than the value of 140dB reported in the table G-16, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of table G-16, PPE shall be provided and used to reduce sound levels within the levels of the table.

Based on the exposure dose only, both legislations do not prescribe the adoption of special measures for the protection of workers' health. Nevertheless, OSHA Standard considers the peak pressure value as dangerous for the hearing organ and it provides for the adoption of suitable measures. On the contrary, Directive 2003/10/EC considers the peak pressure value lower than the maximum allowed limit.

5. CONCLUSIONS

In this study an evaluation of the noise to which workers are exposed is carried out. The determination of the exposure levels is achieved using two different approaches: the first one

following the prescriptions of the American OSHA Standard number 1910, subpart G "Occupational Safety and Environmental Control", the second the recommendations supplied by the European Directive 2003/10/EC of the European Parliament and of the Council of February 6th, 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Goal of the study is to show whether they supply different protection levels and to highlight possible weaknesses in the individuation of protection from loud sounds.

Both legislations integrate the continuous, intermittent, and impulsive SPLs into the noise measurement. Therefore, these events all just contribute in the calculation of the action values and they are not considered phenomena capable to stress the hear organ by themselves. This is definitely the main weakness of both Directive 2003/10/EC and Standard 1910.

The European Directive is more focused on the effect stationary sounds may have on the hearing organ. It has been observed that the exposure limit prescribed by the Directive ($L_{EX,8h}$) is equal to 80dB(A), 10 dB(A) lower than the value provided by the American Standard for a nominal eight-hours working day. This approach can individuate the most common critical situations and it is more conservative regarding the average SPL a worker may absorb, but it shows all its limitation in guaranteeing an effective protection of the most sensitive parts of the ear (e.g. the tympanic membrane) from impulsive and extremely loud sounds. The choice of using the C-frequency weighted curve for the evaluation of the peak pressure levels, artificially decreases the energy value of the signal at the low and very high frequencies, where the protection mechanisms of the human ear are less effective. On the other hand, the American Standard, considering the effective, un-weighted peak pressure level p_{peak}, ensures a better protection from loud sounds having intensity higher than the threshold of pain of the human ear.

It has been proved, from analyses carried out in this study, that both legislations fail in a whole protection of workers from noise. The limit of 90dB(A), proposed in the Standard, is too high for an accurate workers' health protection. From this point of view the limit fixed in the Directive seems to be more reasonable. Analogously, the use of the C-frequency weighted curve, proposed in the Directive, does not assure the necessary protection for workers, as the use of the un-weighted value would do. For this reason the authors would suggest merging the two systems to ensure a more accurate protection of workers from risk arising from noise.

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