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Evaluation of the Exposure Risk to Ultrasound Emitted by Ultrasonic Cleaner Machines: A Case Study

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ABSTRACT

Ultrasonic washing machines are now increasingly widespread for both industrial and domestic use, and their inappropriate use can be hazardous to health. This paper presents a study on the ultrasonic emissions of these types of washing machines and their evaluation in compliance with current regulations. Since no threshold values or exposure limits for ultrasound are defined in the Italian and European legislation, some of the most stringent criteria, valid in other European and non-European countries, have been adopted to define a set of rules for the evaluation. Since 2015 a new methodology has been developed in the context of the collaboration between Eni S.p.A. (an Italian multinational oil and gas company) and CNR (Italian National Research Council) to assess the risk related to ultrasound emission. As a case study, an analysis of various ultrasonic washing machines of different sizes and power will be presented.

Keywords: Exposure risk, Ultrasound, Cleaner machine, Assessment

INTRODUCTION

Ultrasounds are sound waves with frequencies above human hearing, starting from around 20 kHz. They can be emitted by both natural and man-made events, especially in the industrial sector. Their detection requires instruments with more advanced characteristics than the sound level meters used in the acoustic field.

For their assessment, we referred to the methodology developed in the context of our collaboration Eni - CNR in 2015 (F. Lo Castro et al. 2018a, F. Lo Castro et al. 2018b, F. Lo Castro et al. 2018c, F. Lo Castro et al. 2019). To date, the Italian legislation, especially the Legislative Decree 81/2008 (D.Lgs 81/2008), does not specify the criterium that has to be followed for the risk evaluation, even if it names ultrasounds among the physical agents to be considered in the assessment. However, there are regulations and legislation present in Europe and non-European countries, as shown in Table 1. Here limits are specified only for the third-octave band because most ultrasounds are emitted by human activities or machinery, which have tonal and narrowband emissions. But looking at the values of the limits defined in the different countries there is no absolute convergence and a spread in SPL (Sound Pressure Levels) is present between them. At 20 kHz, the maximum audible frequency, SPL values are between 75 dB and 110 dB, while from

Table 1. Maximum permitted SPL in dB re 20 μPa for airborne ultrasound in various countries with no contact of the body with other means.

Country	Frequency [kHz]								Reference
	20	25	31.5	40	50	63	80	100	
Japan	110	110	110	110	110				(JIS C 1010-1:2014)
Russian Federation	100	105	110	110	110	110	110	110	(СанПиН 2.2.4./2.1.8.582-96)
Sweden	105	115	115	115	115	115	115	115	(AFS 2005)
ACGIH	105	110	145	145	145	145	145	145	(ACGIH 2021)
Canada	75	110	110	110	110				(Safety code 24 1991)
IRPA	75	110	110	110	110	110	110	110	(IRPA 1984)
Poland	90	105	110	110					(Dz.U. poz. 1286 2018)

frequencies above 25 kHz they are between 105 dB and 145 dB. Therefore, we have studied each of them and considered their positive aspects to safeguard the worker, establishing threshold values and exposure limits between the most restrictive ones, but do not in contrast with other national legislation, especially in acoustic frequencies close to the ultrasound where the threshold limit is 85 dBA or 80 dBA without any activation of actions to protect the workers (ISO 9612:2011, UNI 9432:2011).

Several studies on the human auditory and extra-auditory effects of airborne ultrasound conducted between the 1950s and the 1980s show that the adverse health effects are directly correlated to their level and exposure time, but their results have been insufficient to finalize a unique international occupational health and safety guideline for ultrasound risk (Leighton 2016). For example, the literature does not analyze always eight hours of exposure, the frequency range of the source also includes audible sound few subjects were selected for the tests, experiments were conducted sometimes on animals, or there is no evidence of related effects to the presence of particular substances. The ACGIH, the American Conference of Governmental Industrial Hygienists, citing precedent studies states that subjective annoyance and discomfort may occur at SPL levels between 75 and 105 dB for the frequency bands from 10 kHz to 20 kHz especially if are tonal in nature (ACGIH 2021). Increasing the SPL over 110 dB at these frequencies can cause severe auditory and subjective effects such as headaches, nausea, tinnitus, and sensation of pressure in the ears (Acton 1974, Acton 1975). For frequencies in one-third-octave bands equal to or greater than 20 kHz and the SPL higher than 110 dB, the risk is an increase of the auditory threshold (Parrack 1966). Dobroserdov observes a temporary threshold shift (TTS) after 1-h exposure to SPL of 120 dB at 20.6 kHz (Dobroserdov 1966); Dallos et al. observe that the TTS is due also to sub-harmonics (Dallos et al. 1966). At SPL greater than 145 dB at 20 kHz Danner et al. found that mouse skin exposed to airborne ultrasound increases in temperature over time. At 150 dB the temperature increases by approximately 1°C/min; after 15 minutes at 155 dB, the temperature of the mouse reached about 50°C, killing it. (Dallos et al. 1954). Parrack, considering the skin absorption coefficient, calculated that death in a human occurs at least 181 dB after 40 minutes of exposure (Parrack 1966).

Our method used for airborne ultrasound in the range of 20 kHz ÷100 kHz is based on the total energy incident to the worker during 8 hours of work and the peak level. In the next paragraphs, the method will be shown and applied in a case study, which will be tested in various ultrasonic washers of different specifications.

METHOD

Six ultrasonic cleaner machines of different models and brands were examined in this study (see Figure 1 and Table 3). For each one the unweighted equivalent sound level in the ultrasonic bands and the peak level, L_{peak}, were measured, at the receiver, close to the operator at the height of his ears, generally standing 0.5 m in front of the device. The tests were conducted on devices normally used by workers according to the manufacturer's instructions specified in the user manual, with only water inside the tank, and with or without a lid. Further information such as the year of fabrication and the maintenance operations was not considered. The instrumentation used for the measurements includes a 204 kHz acquisition card, and a class I microphone with a bandwidth up to 70 kHz, all certified as a class I sound level meter. To assess the exposure of the worker to the ultrasonic noise emitted during his task, it is necessary to know both the level emitted by the source and the exposure time, that is related to the ultrasonic energy received.

The ultrasonic parameters observed were the equivalent unweighted emitted level in each band and the peak level. The relative uncertainty was calculated for each observed indicator.

The exposure times were provided by the employer. To calculate the daily exposure level, the same method as described in ISO 9612:2011 was adopted, although referring to the acoustic range. So the exposure level for 8 hours of exposure, $L_{ex\text{-}8h}$, has been calculated for each one-third octave band in the ultrasonic range.

$$L_{ex,8h} = 10\log_{10}\left(\sum_{i=1}^{M}\frac{T_i}{T_0}10^{0.1L_{eq,i}}\right)\ [dB(Lin)] \qquad (1)$$

where

- i is the index that indicates the i-th task (with i =1….M, and M is the number of tasks performed daily);
- T_i is the exposition time during i-th task;
- T_o is the reference time equal to 8 hours;

$$L_{eq,i} = 10\log_{10}\left(\frac{1}{T_i}\int_0^{T_i}\left(\frac{p\,(t)}{p_0}\right)^2 dt\right);\ [dB(Lin)] \qquad (2)$$

- $p_o = 20\ \mu Pa$.

It should be noted that L_{ex} levels do not consider the effects of any personal protective equipment.

In addition, it has been defined a new sound indicator L_v, i.e. the level measured with the ultrasonic high pass filter V defined in F. Lo Castro et al.

Table 2. Adopted ultrasound risk classes.

Risk Class	Risk	Exposure Level (8 h) [dB(lin)] (note 2)		Lv_{peak}	Action
		20 kHz	25 kHz ÷ 100 kHz	dB(Lin)	
Class 0	Low	$L_{EX,8h} < 90$	$L_{EX,8h} < 105$	< 137	No Action
Class 1	Medium	$90 \le L_{EX,8h} \le 95$; $L_{eqV} \le 107$ with $T_i = 30$ minutes	$105 \le L_{EX,8h} \le 110$; $L_{eqV} \le 122$ with $T_i = 30$ minutes	< 137	It is suggested to carry out additional actions (note 1)
Class 2	High	$90 \le L_{EX,8h} \le 95$; $L_{eqV} > 107$ with $T_i = 30$ minutes	$105 \le L_{EX,8h} \le 110$; $L_{eqV} > 122$ with $T_i = 30$ minutes	< 137	Take actions to reduce the exposure levels, such as reducing dwell times related to tasks/activities characterized by significant exposures and shielding the source.
Class 3	Not accettable	$L_{EX,8h} > 95$	$L_{EX,8h} > 110$	< 137	Unacceptable level of exposure

Note 1: Implement suitable measures to ensure that the levels are maintained within the limits shown on the side, for example, periodic monitoring of the sources, and evaluating changes in the exposure scenarios.

Note 2: The exposure limits must be respected for each ultrasonic band and not for the total energy.

Figure 1: Tested ultrasonic cleaner.

2018c. Thus, the levels obtained were compared with the limit values shown in Table 2.

RESULTS AND DISCUSSION

For each ultrasonic cleaner, the ultrasonic level was measured for each 1/3 octave band from 20 kHz to 80 kHz. The uncertainty level was 2.8 dB for the equivalent level and 2.4 dB for the peak level. The presence of the lid,

Table 3. Specification of the tested ultrasonic cleaner.

Model	Ultrasonic Power [W]	TANK [L]	Nominal frequency [kHz]
Branson 8210	200	20.8	44
Tecna Falc LBS1 3H	100	3.0	50
Julabo USR8	n.a.	10.0	35
Bradson 1200	30	1.9	47
Aver 2000A	n.a.	50.0	35
Uesseti UST 45/9	450	45.0	38

Table 4. Ultrasound level measured at 0.5 m distance from the device and around 1.5 m height close to the ear more exposed.

Model	Frequency [kHz]	Level [dB(Lin)]	Peak [dBLin]	Risk Level
Branson 8210[1]	45	111.2	129.3	Class 3
Tecna Falc LBS1 3H[1]	33	117.9	109.0	Class 3
Julabo USR8[1]	40	118.5	116.4	Class 3
Bradson 1200[1]	48	107.8	126.8	Class 1
Aver 2000A[2]	33	101.1	122.6	Class 0
Uesseti UST 45/9[2]	38	113.8	124.1	Class 3

[1)]no lid; [2)]with lid.

depending on the model, performs several main functions: quickly increase the temperature inside the tank, prevent the solution from lowering due to evaporation, and protect against splashing during operation.

Some models, although covered by the lids, have exceeded the exposure limits, defined in Table 2, for continuous 8h working days, up to class III risk level, but the peak level, L_{peak}, has never been exceeded (see Table 4).

The evaluation criterion we have developed is one of the most restrictive criteria to safeguard the worker as much as possible. Although the criterion is stringent, it is possible to find simple and inexpensive solutions that can be implemented if the limits are exceeded.

There are several ways the employer can take to reduce the risk:

1) if possible, decrease the power of the ultrasonic transducers, resulting in longer wash or sonication times.
2) use of barriers/shields between source and receiver, such as closing the tank with a lid, placing the sonicator/ultrasonic cleaner under a hood or a closed housing, or using a purely mobile barrier;
3) reduce operator exposure times and delimit the area of greatest exposure;
4) the use of protective devices, such as caps, goggles, and gloves.

The tests were repeated by covering the tank with a lid or inserting it under the hood with the glass door closed (5 mm thick glass), also following the suggestions of the owner user manual. The worst-case in which the operator stands in front of the washing machine for 8 hours at a distance of 0.5 m was also considered. Table 5 and Figure 2 show the exposure levels to which the worker would be exposed without taking precautions and with the suggested corrective actions to cancel the risk for the operator.

Table 5. Ultrasound level measured at 0.5 m distance and around 1.5 m height after taking corrective actions.

Model	Level Lex,8h Before [dBLin]	Action taken to reduce the risk	Level, Lex,8h After [dBLin]	Risk level After
Branson 8210	111.2	Use under the hood	88.6@8h	Class 0
Tecna Falc LBS1 3H	117.9	Use lid	98.9@8h	Class 0
Julabo USR8	118.5	Use under the hood	99.3@8h	Class 0
Bradson 1200	107.8	Use lid	98.7@8h	Class 0
Aver 2000A	101.1	No action	101.1@8h	Class 0
Uesseti UST 45/9	113.8	Case 1: Reduction of maximum exposure time Case 2: do not approach below 4 m	105 @ 1h 105@8h	Class 0 Class 0

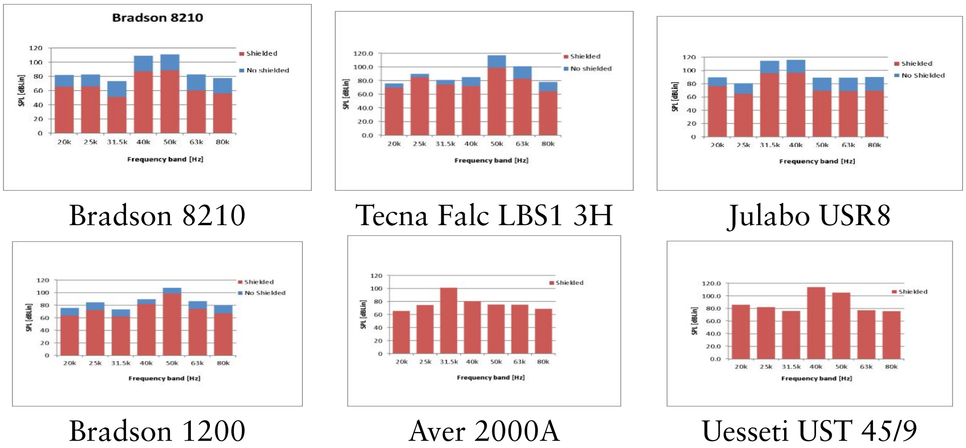

Figure 2: One-third octave bands spectrum of the six tested ultrasonic cleaners.

CONCLUSION

In this study, six ultrasonic washing machines of different powers and tank capacities were examined. The assessments were carried out by applying the methodology developed by us in collaboration with Eni in 2015, based on existing European and international regulations and legislation. It was necessary to develop a measurement method and define risk classes for workers exposed to ultrasound, due to the absence of Italian legislation on the field.

The study has shown that most ultrasound washing machines, with only water inside and shielded with a screen or simply with a lid, fall into the no-risk class. If not, the exposure time can be reduced or the worker's distance from the cleaner device can be increased to reduce the risk.

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