24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

# NOISE CLASSES FOR THE OUTDOOR MACHINES SUBJECT TO NOISE LIMITS

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One of the main targets of the Directive 2000/14/EC is to inform and educate consumers by providing meaningful information on the noise emissions and then encouraging the choice of quieter equipment. Information on noise emissions are currently provided by a mandatory noise emission marking that shows the guaranteed sound power level. This label, however, has proven to be inadequate for the defined target due not only to the difficulties in interpreting the given information in decibel but also to the limitation of information given by the label itself. The only knowledge of the guaranteed sound power level is meaningless as it does not explain how noisy a given product is compared to similar ones. The assessment of this comparative information requires the definition of a certain number of noise classes ranging from the lowest noise emission to the highest one. In a previous paper authors defined a statistical procedure able to cluster the declared sound power levels into three classes. This study aims at analysing in more detail this procedure when applied to the outdoor equipment subject to noise limit and different possible criteria driving the definition of noise classes are considered in light of several important aspects. An extract of the EU NOISE database containing the declared guaranteed sound power levels in the period 2006-2015 was used for this purpose. A further selection of the data was performed in order to exclude all the erroneous and incomplete data. Unfortunately, the application of this procedure to the revised database brings to the result that the procedure is applicable only in three cases. In all the other cases, the criterion that no more than 30% of the available data is assigned to the noisiest class is not fulfilled. Therefore, new and reasonably consistent criteria are proposed for the noise data clustering process.
Keywords: Directive 2000/14/EC, EU noise label, noise control, outdoor machines, noise limits.

## 1. Introduction

Noise limits and noise marking are the milestones of the EU noise policy guaranteeing a common and uniform approach across Europe to reduce the noise pollution in the environment by machinery. Noise limits, in particular, force machine manufacturers to take into account the noise emission problem and have the consequent effect to ensure that excessive and unnecessary noise emissions are avoided. On the other hand, noise marking turns out to be an extremely important legal instrument, complementary to noise limits, to provide information on noise emissions which then will stimulate a gradual disappearance of the noisiest equipment from the market. The sensitivity to noise problems has increased over the past decade. Recent and ongoing studies by the World Health Organisation (WHO) on the health effects of noise are now of public knowledge and provide a better understanding of the risks caused by noise expositions [1]. Consequently, the effects of proper information on machine noise emissions through effective noise labels can really become an important strategy for the gradual dismission of the noisiest products.

The directive 2000/14/EC regulates noise emission in the environment of 57 different types of equipment for use outdoors: it requires noise marking for all types and it sets noise limits for 22 out of these. In addition, it establishes the mandatory sound power test codes for each equipment type and requires the collection and the periodical publication of the noise data for all the compliant machines [2]. Referring to all machines and equipment in the scope of this directive, the information on noise emissions is provided by a mandatory noise emission label that shows the guaranteed sound power level, in dB(A). This label must be affixed to each item of equipment in a visible form. Unfortunately, its effectiveness in guiding consumers or professional customers to choose the quietest equipment types has proved to be extremely poor. The main reason for this failure is the absolute lack of useful indications for the comparison of the noise emitted by similar products and, in addition, the difficulties in interpreting the dB levels. Consequently, the replacement of this noise emission marking with a different and more understandable label scheme seems an attractive option. Such a label could explain how noisy a given product is compared to similar ones but it requires the division of the noise data relevant to each equipment type into a certain number of noise classes ranging from the lowest noise emission to the highest.

In a previous paper, the authors set up a possible statistical procedure in order to cluster the declared sound power levels of each equipment type into three noise classes [3]. Only few examples of application were considered based on the data taken from the EU NOISE database, an online tool for managing the conformity processing in relation to directive 2000/14/EC on noise emissions [4], which reports the guaranteed sound power levels of compliant equipment types.

In this paper the procedure is evaluated in more detail and different possible criteria driving the definition of noise classes are considered in light of several important aspects. The investigation was limited to the equipment types subject to noise limits only and an extract of the EU NOISE database containing the declared guaranteed sound power levels in the period 2006-2015 was used for this purpose. A further selection of the data was performed in order to exclude all the erroneous and incomplete data, reject the under-represented equipment types and make a distinction among different models (electric/combustion engine driven (CE-driven), wheeled/rubber-tracked/tracked) for those machines whose limits were amended by directive 2005/88/EC [5].

## 2. Procedure for the definition of noise classes

From a technical point of view the definition of noise classes for the machines and equipment in the scope of the directive 2000/14/EC is practicable. A mandatory sound power test code for each equipment type is required and then the comparison of the noise data relevant to each equipment type from different manufacturers and models is meaningful. On the other hand, the collection and the periodical publication of the noise data for each equipment type is also required; then the EU NOISE database turns out to be a noise data source feasible for the clustering process.

Because of these preconditions, a statistical procedure based on ISO 11689 [6] had already been defined by the authors with the purpose of grouping the different models of the same equipment type into three noise classes (A, B, C) on the basis of their noise emission data, ranging from the lowest noise emission to highest [3].

### 2.1 The EU NOISE database

The EU NOISE database contains the declared guaranteed sound power levels of the equipment types in compliance with Directive 2000/14/EC, starting from 2001. For the purposes of this study the analysis was limited to the noise data relevant to the equipment types subject to noise limits in the period 2006-2015. In such a way all the noise data pertain to the period of validity of the second stage limits (noise limits still in force). This extraction of data contained 16872 records relevant to 22 different equipment types.

Subsequently, an accurate analysis was performed for each equipment type, aimed at:

- excluding the records: with omitted data, with guaranteed sound power levels higher than the noise limits, with measured sound power levels higher than the guaranteed ones, with some parameter out of range;
- excluding duplicate records;

- separating the electric models from the CE driven and the wheeled/rubber-tracked/tracked models for those machines whose limits were amended by directive 2005/88/EC.

After this data reduction, the final database contained 4159 records, differently distributed over the several equipment types. Some of them (builders' hoists for the transport of goods, construction winches, wheeled-loaders < 500 kW, graders < 500 kW, landfill compactors < 500 kW, tracked-loaders < 500kW, paver-finishers, tower cranes and welding generators) were not included in the analysis due to the extremely low number of data available. At the end, a database of 4022 records became available for the application of the noise class procedure. These records belong to 14 different equipment types subject to noise limits and to 28 subgroups of equipment types with different noise limit values.

Table 1 summarises some statistical data for each equipment type under investigation. The characteristic parameter reported in the second column indicates a non-acoustic quantity which characterizes each equipment and identifies the characteristic of the machine which is more related to the noise emission: P is for "net installed power" in kW, Pel is for "Electric power" in kW, m is for "mass of appliance" in kg, and L is for "cutting width" in cm.

Table 1: Final noise database used for the application of the noise class procedure

| EQUIPMENT TYPE | | CHARACTERISTIC PARAMETER | N. RECORDS | % $L_{Wg}$=Lim | % Lwg=Lim and $L_{Wg}$-$L_{Wm}$=0 | % Lwg=Lim and $L_{Wg}$-$L_{Wm}$>3 |
|---|---|---|---|---|---|---|
| 9. compressors | | P ≤ 15 kW | 69 | 52% | 6% | 25% |
| | | 15 kW < P < 350 kW | 142 | 98% | 7% | 1% |
| 10. concrete-breakers | (CE-driven) | m ≤ 15 kg | 26 | 73% | 11% | 37% |
| | | m > 15 kg | 32 | 13% | 0% | 0% |
| | (electric) | m ≤ 15 kg | 37 | 70% | 0% | 31% |
| | | 15 kg < m < 30 kg | 15 | 0% | - | - |
| 16. dozers (only steel tracked) | | 55 kW < P < 500 kW | 26 | 92% | 13% | 29% |
| 18. dumpers (< 500 kW) | | P ≤ 55 kW | 42 | 36% | 7% | 20% |
| | | 55 kW < P < 500 kW | 52 | 81% | 36% | 0% |
| 20. excavators | | P ≤ 15 kW | 45 | 71% | 31% | 0% |
| | | 15 kW < P < 350 kW | 362 | 58% | 27% | 0% |
| 21. excavator-loaders | | P ≤ 55 kW | 5 | 40% | 0% | 0% |
| | | 55 kW < P < 500 kW | 34 | 79% | 4% | 0% |
| 29. hydraulic power packs | | P ≤ 55 kW | 24 | 54% | 8% | 0% |
| 32. lawnmowers | | L ≤ 50 cm | 824 | 66% | 8% | 10% |
| | | 50 cm < L ≤ 70 cm | 334 | 88% | 4% | 13% |
| | | 70 cm < L ≤ 120 cm | 260 | 98% | 16% | 2% |
| | | L > 120 cm | 342 | 96% | 18% | 21% |
| 33. lawn trimmers | | L ≤ 50 cm | 223 | 62% | 4% | 38% |
| 36. lift trucks | | P ≤ 55 kW | 24 | 58% | 0% | 7% |
| | | P > 55 kW | 133 | 79% | 18% | 1% |
| 37. loaders (wheeled) | | P ≤ 55 kW | 164 | 81% | 14% | 0% |
| | | 55 kW < P < 500 kW | 177 | 64% | 27% | 4% |
| 38. mobile cranes (single-engine) | | P > 55 kW | 68 | 60% | 0% | 39% |
| 40. motor hoes | | P < 3 kW | 50 | 90% | 4% | 7% |
| 45. power generators | | Pel ≤ 2 kW | 41 | 32% | 8% | 8% |
| | | 2 kW < Pel ≤ 10 kW | 290 | 46% | 31% | 2% |
| | | 10 kW < Pel ≤ 400 kW | 181 | 25% | 49% | 0% |
| **OVERALL** | | | **4022** | **69%** | **14%** | **10%** |

The table reports information on:

- the name of the equipment with the numerical id reported in the directive (Annex I);
- the range of the characteristic parameter identifying a specific sub-group;
- the No. of records in the sub-group;
- the percentage of records with a declared guaranteed sound power level ($L_{Wg}$) equal to the limit value (*Lim*). The cases with a percentage value lower than 30% are shown in grey background colour.

In addition, within the group of records with $L_{Wg}=Lim$, the table shows:

- the percentage of records with a declared guaranteed sound power level ($L_{Wg}$) equal to the measured sound power level ($L_{Wm}$), i.e. $L_{Wg}=L_{Wm}$
- the percentage of records with a declared guaranteed sound power level ($L_{Wg}$) much greater than the measured sound power level ($L_{Wm}$) ), i.e. $L_{Wg}-L_{Wm}$ >3 dB

It is worth reminding that the *guaranteed sound power level* should be calculated from the measured sound power level by adding an estimated value that accounts for the uncertainties due to production variation and measurement procedures.

## 2.2 The application of the noise class procedure

According to the noise class procedure defined in [3], the three noise classes were defined as such: Class A identifies the models with the lowest noise emission, i.e. the best ones as far as the noise impact on the environment is concerned; Class B groups the models with noise emissions halfway between the highest and the lowest levels and then with an average noise impact on the environment and Class C identifies the models with the highest noise emission, i.e. the worst ones as far as the noise impact on the environment is concerned.

These three noise classes are separated by the two percentile lines $L_1$ and $L_2$, both parallel to the limit curve. $L_1$ is chosen as the percentile curve greater than or equal to $L_{70}$ (with the maximum distance from the limit curve) and $L_2$ is the percentile curve at the fixed distance 2 dB from $L_1$. These criteria guarantee that no more than 30% of the data is assigned to the noisiest class. No specific justifications were given for this choice, apart from the necessity of avoiding an overcrowding of data in the noisiest class C.

The application of this procedure to the revised database resulted in the procedure being applicable only in three cases: 10. concrete-breakers (CE-driven) with $m$>15 kg, 10. concrete-breakers (electric) with 15 kg<$m$<30 kg, and 45. power generators with 10 kW<$P_{el}$≤400 kW.

In all the other cases, the criterion that no more than 30% of the available data is assigned to the noisiest class is not fulfilled. This result is clearly shown by the statistics reported in Table 1, i.e. 21 cases out of 28 have more than 50% of machines with a guaranteed level coincident with the limit.

The noise classes obtained for power generators are shown in Figure 1. Since there was a significant percentage of noise data concentrated in a narrow range of levels around the limit, $L_1$ turned out to be only 1 dB below the limit, while $L_2$ is 2 dB below $L_1$, according to the above mentioned definition. The machines within Class C all have a guaranteed sound power level coincident with the limit. In ascending order of noise emission, the classification is as follows:

- 58.0 % of machines in Class A (the quietest machines with $L_{Wg} \leq L_2$);
- 17.1 % of machines in Class B (with $L_2 < L_{Wg} \leq L_1$);
- 24.9 % of machines in Class C (the noisiest machines with $L_1 < L_{Wg} \leq Limit$).

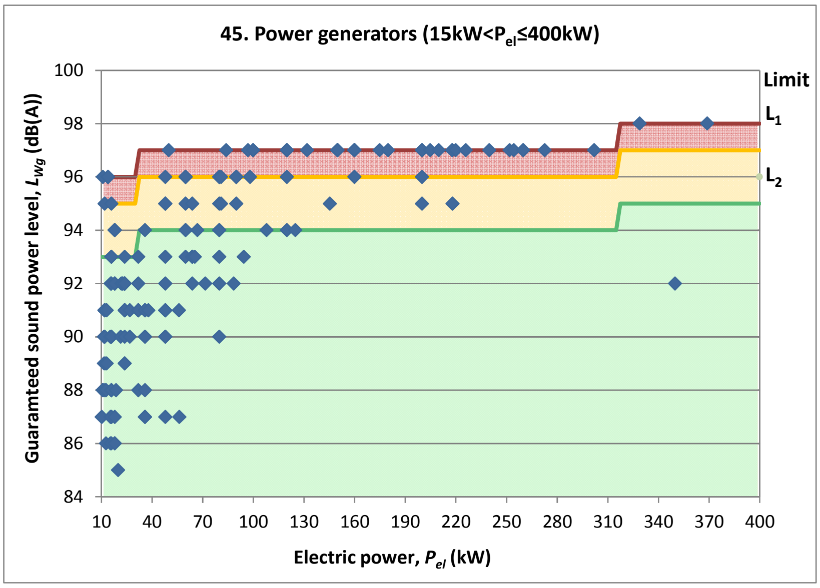


Figure 1: Noise classes for power generators with 10 kW<$P_{el}$≤400 k

## 3. Representativeness of the guaranteed sound power level

Figures in Table 1 show that more than 69% of the machines have a declared level equal to the limit. This may be interpreted as a dramatic situation because it means that the great majority of the machines have a very high noise emission, close to the limit. Analysis in depth shows that this is probably not reflecting the real noise emission of these machines because 18% of them have a measured level which differs more than 2 dB from the guaranteed level. This may rather reflect a clear choice made by manufacturers to declare the maximum admissible level in order to be sure not to exceed this level.

In order to identify the best criteria for the noise data clustering it is fundamental to know whether the declared guaranteed sound power levels may be considered representative of the current situation concerning the noise emitted by outdoor equipment.

For this purpose, the state of the art of noise control technologies already available for outdoor equipment together with the existence on the market of quieter versions were investigated. Assuming that noise limits should have forced manufacturers to move closer to the state of the art of noise performance, this investigation was limited to the outdoor equipment subject to noise limit.

### 3.1 Technology trends

In bibliography, some studies and patents can be found showing that several developments have significantly affected the noise reduction capacity of outdoor machines. Hybrid engines are increasingly used especially due to the fact that the market dynamics on fuel consumption are pushing in this direction [7]. Similarly, the use of electrically powered equipment instead of combustion engine (CE) driven is quickly growing particularly for small and medium size machines, mainly due to the improving performance and lower cost of battery-powered units [8]. Referring to CE driven machines, almost all the equipment of medium-high size have replaced the noisier 2-stroke engine with the quieter 4-stroke one. In addition, quieter fans and improved airflow design are available to reduce the noise emitted by the engine cooling systems [9]. Also the use of electronic controls able to drive efficiency and noise reduction, are advanced [10].

On the market, some quieter versions of outdoor equipment subject to noise limits are available, even if at a higher cost compared to the standard version of the same machine. Quieter models generally have sound power levels 2 to 4 dB lower than the standard versions of the same machine. Referring to equipment types with high noise contributions coming from the working process rather than from the machine itself, such as hydraulic hammers or concrete-breakers, great differences can be found (5÷10 dB) among sound power levels of models having similar mechanical power, suggesting that machines with different noise emissions are on the market. In some cases, new working principles have been developed resulting in significant noise reduction (for example robotic lawnmowers).

### 3.2 New scenario

Based on the outcome of the above investigation, the real noise emitted by outdoor equipment subject to noise limits could be different from that inferable from the noise data in the EU NOISE database. For this reason, a new scenario was defined and the guaranteed sound power level declared in the EU NOISE database was replaced by a different parameter, $L_{new}$.

For the definition of this new parameter, it is important to note that the average difference between guaranteed and measured sound power levels over all equipment types was $L_{Wg}$-$L_{Wm}$=1.7 dB. Considering the whole set of data, 673 machines out of 4022 (16.7%) had a measured sound power level more than 3 dB lower than the guaranteed one. This means that a large uncertainty value was applied and probably there was a sufficient gap for lowering the guaranteed sound power levels. The new parameter $L_{new}$ was then defined as reported in Eq. (1). The level remains equal to $L_{Wg}$ when the difference between the guaranteed and the measured sound power levels is lower than 3 dB, otherwise it is replaced by the measured sound power level increased by 2 dB, which is a reasonable estimate of the total uncertainty.

$$\boldsymbol{L_{new}} = \begin{cases} \boldsymbol{L_{Wg}} & \boldsymbol{L_{Wg} - L_{Wm} < 3\ dB} \\ \boldsymbol{L_{Wm} + 2} & \boldsymbol{L_{Wg} - L_{Wm} \geq 3\ dB} \end{cases} \tag{1}$$

where:
$L_{Wg}$ is the guaranteed sound power level;
$L_{Wm}$ is the measured sound power level.

The noise class procedure was then applied to this new set of noise data in order to test the effects on the data distribution and to verify whether the division in classes is now applicable. Table 2 shows the results.

In this table, the original percentage of records with a declared guaranteed sound power level equal to the limit value (% $L_{Wg} = Lim$) is still shown in order to facilitate the comparison with the new percentage given by (% $L_{new} = Lim$). Apart from three cases (those for which the original procedure was applicable), for all the others (highlighted with a grey background colour) the percentage value decreases from a minimum of 7% (dumpers) to a maximum of 46% (CE-driven concrete breakers with m ≤ 15 kg). Furthermore, the table reports also the distance of $L_1$ from the limit (1 or 2 dB) and the percentage of machines assigned to each class.

Table 2: Noise class procedure applied to the new noise data set

| EQUIPMENT TYPE | | CHARACTERISTIC PARAMETER | % $L_{Wg}$=Lim | % $L_{new}$=Lim | Lim-$L_1$ | Class C | Class B | Class A |
|---|---|---|---|---|---|---|---|---|
| 9. compressors | | P ≤ 15 kW | 52% | 23% | 1 | 23% | 33% | 43% |
| 10. concrete-breakers | (CE-driven) | m ≤ 15 kg | 73% | 27% | 1 | 27% | 58% | 15% |
| | | m > 15 kg | 13% | 13% | 2 | 25% | 47% | 28% |
| | (electric) | m ≤ 15 kg | 70% | 30% | 1 | 30% | 35% | 35% |
| | | 15 kg < m < 30 kg | 0% | 0% | 2 | 0% | 87% | 13% |
| 18. dumpers (< 500 kW) | | P ≤ 55 kW | 36% | 29% | 1 | 29% | 64% | 7% |
| 29. hydraulic power packs | | P ≤ 55 kW | 54% | 29% | 1 | 29% | 46% | 25% |
| 33. lawn trimmers | | L ≤ 50 cm | 62% | 30% | 1 | 30% | 21% | 50% |
| 45. power generators | | Pel ≤ 2 kW | 32% | 22% | 1 | 22% | 10% | 68% |
| | | 10 kW < Pel ≤ 400 kW | 25% | 25% | 1 | 25% | 17% | 58% |

The criterion to have no more than the 30% of data in the noisiest class turns out to be appropriate for 10 subgroups out of the 28 listed in Table 1. Apart from 2 cases, 1 dB is the highest possible distance between $L_1$ and the limit curve.

Consequently, a "first stage" classification could be based on the definition of noise classes following the criteria reported in Eq. (2); they seem indeed to be reasonably consistent with the above reported data and turn out to be the only possible compromise to take into account also the possible economic impact on manufacturers.

$$\begin{cases} \boldsymbol{L_1 < L_{new} \leq Lim} & \textbf{Class C} \\ \boldsymbol{L_2 < L_{new} \leq L_1} & \textbf{Class B} \\ \boldsymbol{L_{new} \leq L_2} & \textbf{Class A} \end{cases} \quad (2)$$

## 4. Conclusions

A noise class procedure defined by the authors in a previous paper [3] was applied to all the outdoor equipment within the scope of directive 2000/14/EC and subject to noise limits.

The investigation was performed on a selection of data extracted from the EU NOISE database which contains the declared guaranteed sound power levels for these machines/equipment. The selection permitted to exclude all the erroneous and incomplete data and to ignore all the certificates emitted before the current limits (II stage limits) entered into force (3rd January 2006). The data reduction brought to a final database of 4022 records belonging to 14 different equipment types subject to noise limits and to 28 subgroups of equipment types with different noise limit values.

The application of the noise class procedure ended up with the result that the procedure is applicable only in three cases. In all the other cases, the criterion that no more than 30% of the available data is assigned to the noisiest class is not fulfilled. Moreover, it appeared that more than 69% of the machines have a declared level equal to the limit. A deeper analysis showed that this is probably not reflecting the real noise emission of the machines but it rather reflects a clear choice made by the manufacturers to declare the maximum admissible level in order to be sure not to exceed this level.

A survey on the state of the art of noise control technologies already available for outdoor equipment revealed the existence on the market of quieter versions of different equipment types. For this reason, there is the doubt that the real noise emitted by outdoor equipment subject to noise limits could be different from that inferable from the noise data in the EU NOISE database. Then, a new scenario was defined and the guaranteed sound power level declared in the EU NOISE database was replaced by a different parameter, $L_{new}$. The application of the noise class procedure to this new set of noise data brought to the conclusion that the division in classes is applicable and a "first stage" classification may follow the procedure already defined.

On the other hand, the definition of noise classes makes it possible the design of a new "graduation label scheme" (similar to the energy labelling used for domestic appliances) which would show the guaranteed sound power level for each equipment type and the relative noise emission of that equipment type compared with the current full range of noise emission marking [11]. The meaning and the transparency of this label should lead to multiple advantages: it would gradually educate people in preferring low-noise products; it would incentivise the demand for quieter products; last but not least, it would push manufacturers to declare guaranteed sound power levels that represent the real status of noise emission of their production.

Once the label system is properly developed and understood, a "second stage" classification will be necessary to have noise classes with higher dB ranges.

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