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VERIFICATION CRITERION TO USE IN THE FRAME OF DIRECTIVE 2000/14/EC

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Abstract

In this paper we compare the verification of the declared sound level as outlined in the ISO norms with an alternative proposal of the Notified Bodies and introduce a compromise approach that is put forward by the Belgian competent authority. Using Monte-Carlo simulation it is demonstrated that the compromise approach remains consistent with the objectives of the ISO norms, while the proposal of the Notified Bodies leads to high producer's risks and a high fraction of non-conforming machines. The compromise approach would be easy to implement, because except for the reproducibility standard deviation, all parameters used in the approach are readily available. The compromise approach would be used as a temporary transition method until the parameters required for application of the ISO norms are accurately known.

INTRODUCTION

Directive 2000/14/EC requires a declaration of sound power level for a variety of machines and equipment and independent verification by control bodies. The guidelines to this directive [1] recommend that for this purpose ISO 4871 [2] and ISO 7574 [3] are used. These ISO norms specify the statistical method of verification and also contain recommendations to the manufacturers on how to determine the declared sound level in order to limit the risk of rejection during verification. During sound power tests of equipment the Belgian competent authority, responsible for the enforcement of the directive Outdoor Noise Directive 2000/14/EC, has however found that the previous norms are difficult to use in practice. This is so because two key parameters that are used in the norms (the reproducibility standard deviation σ_R

and the production standard deviation σ_p) are not accurately known for specific types of machines and the reference values recommended in the norms are considered unrealistic by the manufacturers. As a result, different methods of declaration and verification of the sound level circulate.

To remedy this situation, the Notified Bodies have proposed an adjusted method of declaration for uniform use by the industry and an adjusted verification method to be used by control bodies. The proposed method includes specific values for σ_R and allows for the estimation of σ_p by individual manufacturers. Whilst this proposal is more suitable for use in practice, the proposal ignores any estimation errors.

In this article we compare the standard method of ISO 7574 (or equivalent ISO 4871) with the proposal by the NB's for each sub aspect of the problem: specification of the reproducibility standard deviation, specification of the production standard deviation, calculation of the total standard deviation, verification of the sound level and declaration of the sound level. At the same time we introduce a compromise approach that uses a safety factor to account for the estimation errors. Using Monte-Carlo simulation it is shown that the NB proposal leads to declared sound levels that are too low and high levels of rejection during verification, whereas with a proper choice of the safety factor the compromise method achieves results that are consistent with the objectives of the ISO norms.

REPRODUCIBILITY STANDARD DEVIATION

The reproducibility standard deviation σ_R quantifies the variation of the sound level that would be measured if a single machine or piece of equipment is examined under different conditions (i.e. different terrains, different seasons, different laboratories,...). The conditions need to be of course restricted to those allowed by the standards laid down in the measurement method. In ISO 3744 a value of σ_R =1.5 dB is recommended unless more specific values can be justified. This recommended value is considered typical for measurement methods that have an engineering grade of accuracy.

The Notified Bodies propose to use lower values for the reproducibility standard deviation. This is possible by limiting the allowed environmental and operational conditions during the measurement, to the extent that the measurement method remains practical. For instance, the NB's limit the environmental correction characterizing the acoustical quality of a measurement terrain to a value of 0.4 dB whereas ISO 3744 allows 2 dB. The ambient temperature range is narrowed to 10-30 °C.

The proposal of the Notified Bodies also lists actual values for σ_R that are considered representative of such more limited measurement conditions. These values are however expert guesses that have not been verified against actual measurements. If the actual variation of measurements under different conditions allowed by the measurement method would in truth be larger, than the use of these guess estimates would lead to the declaration of too low sound values and high rates of rejection during verification. We therefore strongly advise that in a compromise approach the estimates of σ_R are verified by a series of round-robin tests.

PRODUCTION STANDARD DEVIATION

The production standard deviation σ_p quantifies the variation in the sound emission of different machines of the same model if the sound emission is exactly measured. For this purpose, the reproducibility errors need to be eliminated: i.e. by making measurements under nearly identical measurement conditions such that the variations reflect product variations rather than variations due to measurement conditions. To determine the product standard deviation exactly, all produced machines should be examined. In this case $\sigma_p^2 = \sum_{k=1}^{N}(x_k - \mu)^2 / N$. Upper case N refers to the size of the population (a batch, a lot, a whole production), x_k indicates the measurement for the k-th machine and $\mu = \frac{1}{N}\sum_{i=1}^{k} x_k$ is the population average. In ISO 7574 it is assumed that σ_p is exactly known; if not known, then use of a conservative reference value is proposed. This reference value is however considered by most manufacturers an overestimation of the actual product variation. Measurement of the sound level of every produced item is not practical and would, in most cases, be too costly. The notified bodies therefore propose that a manufacturer uses instead of the population standard deviation σ_p a sample standard deviation s_p that is obtained on the basis of a sample (n randomly drawn specimens from the population) as: $s_p^2 = \sum_{k=1}^{n}(x_k - \bar{x})^2 / n$. $\bar{x} = \frac{1}{n}\sum_{i=1}^{k} x_k$ refers to the sample average. The Notified Bodies propose that values of s_p are accepted in replacement of σ_p when n is larger or equal to 5.

However s_p will never exactly equal σ_p and the difference can be considerable for such a small sample size. When n is much smaller than N and when the sound measurements are normal distributed, results regarding the difference can be derived from statistical theory. For instance, when n=5, the ratio σ_p / s_p will be larger than 2 2.65 for 5% of independent estimates of s_p.

An additional consideration to be made is that the measurements made by the manufacturer will be typically sampled over a short time period during the start-up production before the serial (long-term) production starts (from which the items will be taken for verification of the declared sound level). The variations measured during the short start-up phase are not necessarily representative for the variations in the sound emission of the items produced thereafter.

Market surveillance confirms this suspicion. In 2005 the Belgian competent authority has measured sound emissions of 24 models of chain saws. For each model 3 to 7 specimens were taken and for each model the sample standard deviation s_p has been calculated. These estimates have been compared with the value of s_p provided by the manufacturers (Figure 1). Comparison of these data indicates that the manufacturer underestimates the production uncertainty.

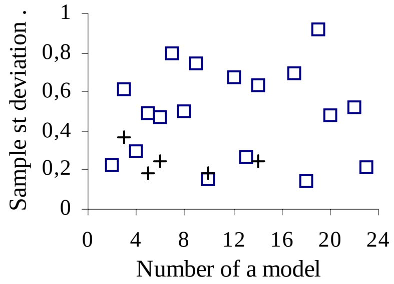

Figure 1 – Production standard deviation estimated by the competent authority (□) in comparison with the data provided by manufacturer(+).

In the compromise approach, we accept the principle that model and manufacturer specific estimates of σ_p, as obtained from a limited number of measurements, are used in the verification of the declared value. However, in order to take the estimation error into account and thus avoid high probabilities of rejection, we propose that a safe estimate of σ_p is used both by the manufacturer in determining the declared value and by the controlling bodies in the verification of the declared value. Then

$$\sigma_p = SF \times s_p, \qquad (1)$$

where SF is a safety factor that is to be determined such that target consumer and producer risks are obtained. How SF can be determined through Monte-Carlo simulation is shown later in this publication.

THE TOTAL STANDARD DEVIATION

ISO 7574 stipulates that the manufacturer should calculate the total standard deviation σ_t for a given model as

$$\sigma_t = \sqrt{\sigma_p^2 + \sigma_R^2}\ . \qquad (2)$$

The Notified Bodies propose instead to replace σ_p by s_p. To emphasize that this leads to an estimate s_t of σ_t only, we write this proposal as $s_t = \sqrt{s_p^2 + \sigma_R^2}$. As explained previously, in our compromise approach we propose to use instead a safe estimate $\sigma_p = SF \times s_p$ that accounts for the estimation error in s_p. Thereafter, Equation (2) as specified in ISO 7574 can be applied.

VERIFICATION AND ACCEPTANCE CRITERION

The acceptance criterion worked out in the ISO 7574 for verification by the controlling bodies basically guarantees that a population in which almost 6.5% of the machines have a sound level above the declared value will be accepted with 95% probability. Both single and double-sampling plans for verification can be used. For the purpose of insight on the advantages and disadvantages of the different proposed methods, it suffices to discuss the single sampling plan.

For the case of a single sampling plan, ISO 7574 stipulates that the controlling institution takes a sample of n machines randomly drawn from a population of N machines (N is assumed to be far larger than n), carries out the sound emission measurements and calculates its average value $L_{average}$. For a lot to be accepted the following criterion should then be fulfilled:

$$L_{average} \leq L_{decl} - k \cdot \sigma_M. \quad (3)$$

The value of k depends on the sample size n. σ_M is a reference standard deviation that without further knowledge is considered representative of the true total standard deviation σ_t. When this is the case, then the objective of the norm (95% probability of acceptance for populations with 6.5% sound emission levels above the declared value) will be met.

The Notified Bodies consider the value of σ_M as a too conservative estimate of σ_t and therefore propose to use in the verification the value of s_t instead of σ_M:

$$L_{average} \leq L_{decl} - k \cdot s_t$$

The value of s_t may however underestimate substantially the true value of σ_t if the estimate of the production standard deviation is based on a small sample of measured sound levels. For such cases, the verification would accept populations of machines in which the fraction of sound emission levels that is above the declared value can be far larger than 6.5%. As a compromise we therefore propose that instead following verification formula is used:

$$L_{average} \leq L_{decl} - k \cdot \sigma_t \quad (4)$$

where σ_t is calculated using a safe estimate of $\sigma_p = SF \times s_p$. Equation (4) is in fact already allowed in ISO 7574, if σ_t is exactly known. Thus the compromise approach remains consistent with the existing norm, but only amends the norm by stating that estimates of σ_t can be used in the verification, in so far these estimates incorporate a safety margin for the estimation error. The compromise solution should be seen as a temporary solution, since in due time accurate values of the reference value σ_M can be established on the basis of the values of σ_t that would be reported for each type of equipment that is verified. Once σ_M is established, the standard procedure of ISO 4871 could again be used.

DECLARATION

ISO 7574 recommends that a manufacturer calculates the declared value L_d as follows:

$$L_d=\mu+1.5\ \sigma_M+k(\sigma_M - \sigma_t) \text{ or, when } \sigma_M = \sigma_t,\ L_d=\mu+1.5\ \sigma_t \quad (5)$$

where the value of k corresponds to the value used in the verification by Equation (4). Use of this formula leads to a 5% probability of rejection during verification if the mean value μ and the total standard deviation σ_t are exactly known.

This is however rarely the case and the Notified Bodies therefore propose to calculate the declared sound level as:

$$L_d = \overline{L} + 1.5\, s_t, \qquad (6)$$

where $\overline{L}$ is the average sound level measured for a limited number of machines (i.e. n=5) and s_t the estimated total standard deviation.

That the true mean μ and the true value of σ_t is approximated by the estimates obtained from the limited number of items already produced is of course unavoidable. For economic reasons, the number of items for which the manufacturer actually performs a sound level measurement may further need to be restricted. However, in Equation (6) the estimation error that results from restricting the number of measurements is entirely ignored. Consequently, the original objective of the ISO standard will no longer be achieved (i.e. the probability of rejection will be higher than 5%; the declared sound level will be exceeded by more than 6.5 % of machines). In our compromise approach, we therefore propose to adjust the proposal of the Notified Bodies as follows:

$$L_d = \overline{L} + 1.5\, \sigma_t\,, \qquad (7)$$

where, as in the verification of the sound level, σ_t is calculated using a safe estimate of $\sigma_p = SF \times s_p$. The value of *SF* that is to be used in Equation (7) can be determined through a Monte-Carlo study of the process of declaration and verification.

MONTE-CARLO SIMULATION

Application of the verification and declaration method in ISO 4871 and ISO 7574 limits the fraction of machines of which the measured sound emission would exceed the declared value ("percent non-conforming") to 6.5% and the probability of rejection (the "producer's risk") to 5%. However, as explained before, the ISO standards assume that the reproducibility standard deviation, the product standard deviation and the mean emission level are exactly known. In practice this is not the case. Both the NB's proposal as the compromise method solve this problem by replacing the unknown product standard deviation with an estimate that is provided by the manufacturer on the basis of a limited number of sound emission levels. However, in the NB's proposal no account is made for the error of such an estimate. In the compromise approach a safety factor *SF* is introduced to compensate for the estimation error.

The value of the safety factor that is necessary to achieve consistency with the goals of the ISO standards (6.5% of non-conforming machines, 5% producer's risk) can be determined through a Monte-Carlo simulation of the process of declaration and verification. As an example, we have examined the following specific scenario. The manufacturer measures the sound emission for 5 machines. Variations in these measurements have been simulated under the assumption that the manufacturer's measurements are error-free and only product variations σ_p apply. The manufacturer then estimates the mean value and the standard deviation on the basis of these measurements and determines the declared value (either using the NB's proposal or using the compromise method for safety factors 1.5, 2, 2.5 or 3). The competent authority randomly selects 3 different machines and again measures the sound emissions of each machine independently (in this case for each measurement an independent reproducibility error applies). The acceptance criterion of Eq.(4) is then verified. The number of rejections is counted and leads to a direct estimate of the producer's risk. For the machines that pass verification, the fraction of machines for which the measured sound level would exceed the declared value can be calculated. The average of this value (for the simulations where the verification passes) then corresponds to the percent non-conforming. This declaration/verification simulation is repeated 10,000 times.

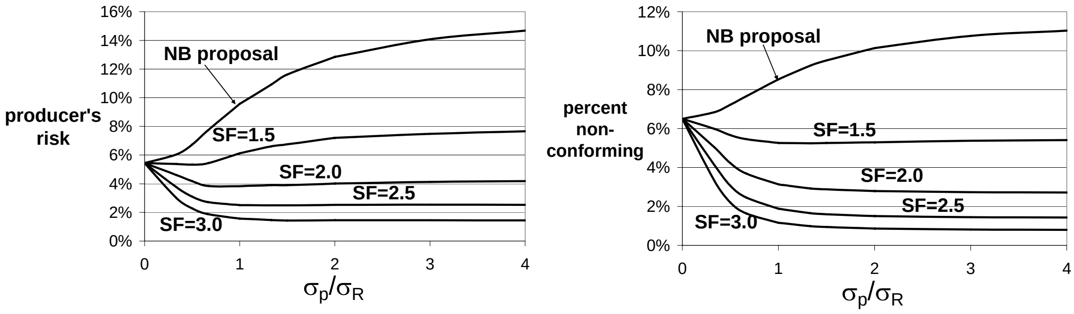

Figure 2 - Percent non-conforming and consumer's risk for alternative methods of declaration and verification for the specific scenario described in this article

Figure 2 shows that when the NB proposal is used both the producer's risk and the percent non-conforming machines rapidly increase above the target values of the ISO standards when σ_p increases. Figure 2 also shows that the introduction of a safety factor *SF*=1.5, corrects for this problem over a wide range of σ_p values. Thus, for this specific scenario a choice of *SF*=1.5 would appear to be a reasonably acceptable compromise.

The MC simulation is an extremely versatile technique that allows to examine any alternative scenario no matter how complex. A correct representation of the random variations of the measurements made by the manufacturer and those made by the controlling body is crucial. For instance, if the verification of the three machines is executed by the same laboratory at the same measurement terrain, then it is more realistic to assume that the reproducibility error is the same for all 3 measurements. If during verification the acceptance criterion of Eq. (4) is still used, then the MC simulation shows that a safety factor *SF* equal to 2 is necessary to achieve the target values of the ISO standards (when σ_p is estimated on the basis of 5 measurements only). However, the MC simulation also shows that in such a scenario the producer's risk and the percent non-conforming are lower than the values required in the ISO norms when σ_p is known or equal to zero. Therefore an adjustment of the verification rule might be considered in such a case.

The Monte-Carlo simulation further demonstrates that a correct assessment of the reproducibility standard deviation is highly important. For instance, a scenario has been examined in which the reproducibility standard deviation is underestimated by a factor of 2. The probability of rejection increases in this case to 15-20% . Because no objective study has been made to establish the value of σ_R, it is suspected that the proposed values of σ_R by the Notified Bodies may lead to such an undesirable situation.

Finally, the Monte-Carlo simulation demonstrates in a very direct manner why a manufacturer will very rarely measure himself rejections of the declared level. The measurements made by the manufacturer are only affected by product variations and repeatability errors, whereas the measurements made by third bodies will include also the reproducibility error. In a scenario where the Notified Body or the competent authority does not perform independent measurements but verifies the measurement protocols of the manufacturer in order to judge the compliancy of ongoing production, then an appropriately adjusted verification rule should be devised that accounts for the fact that the measurements do not include the reproducibility error. Only in this manner consistency with the basic objectives of ISO 7574 can be ensured.

Irrespective of the scenario considered, an appropriate safety factor to counter estimation errors on the production standard deviation will also remain necessary.

CONCLUSION

The method proposed by the Notified Bodies neglects the estimation error on the production standard deviation. It is demonstrated in this paper that this leads to unacceptable high risks of rejection and to a too large fraction of machines for which the measured sound level exceeds the declared value. The compromise method proposed in this article corrects for this problem through the use of a safety factor in the estimation of the production standard deviation and leads to more adequate declared values. It is also shown that if the reproducibility standard deviation is underestimated, the risk of rejection can be very high. Therefore a round-robin test to establish accurate values of the reproducibility standard deviation is highly recommended. Finally, it is found that the verification rule may require adjustment when the verification is performed under circumstances that are not consistent with the assumptions made in ISO 7574.

REFERENCES

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