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COMPARISON OF METHODS FOR THE DETERMINATION OF GUARANTEED SOUND POWER LEVELS OF MACHINERY

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INTRODUCTION

With respect to the determination of sound power levels /SWL/ of machines a number of internationally accepted standards have been prepared /See e.g. ISO 374o to 3748/. However, characterization of the noise emission of machines are discussed in two drafts only [1,2]. While [1] establishes detailed requirements for verifying the noise emission values /sometimes also called "noise labels" or "guaranteed noise levels"/, both [1] and [2] give only a broad outline for the determination thereof.

The aim of this paper is to compare the possibilities for determining the noise emission values with special regard to those situations when the number of measurements is limited. The accuracy of the noise labelling procedures is analyzed by means of analytical and numerical methods. It is shown that the uncertainties in noise labelling can remarkably influence the accuracy of the whole qualification procedure.

REVIEW OF NOISE LABELLING SCHEMES

The noise label represents a guaranteed value usually in statistical sense, i.e., the noise label is not lower than the SWL of the majority of machines to be labelled. Consequently, the labelling yields a quantile of high order of the SWL distribution, generally based on sampling. Supposing that the distribution function is normal, the noise label can be computed from the sample by

$$L_l' = m + k_\lambda \cdot s \qquad (1)$$

where m is the mean value and s is the standard deviation /s.d./ of the sample. /It is assumed that s represents both the production and reproducibility standard deviations./ The constant k_λ can be computed by means of the standard normal distribution if the quantile λ is given. Depending on agreement between the producers and consumers, k_λ varies from 0 to 3 [3]. Usual values, also suggested for standardization, are 1.5 or 1.645, providing the o.935 or o.95 quantile.

Recalling the normality, the confidence intervals for both terms in (1) can be determined [4,5,6]. The o.95 confidence level intervals for the population mean and 1.645 times population s.d. are depicted in Fig.1. as a function of sample size. It can be seen that the uncertainty in the s.d. determination predominates the accuracy of the noise label estimation and considerable errors can be expected also for relatively large sample sizes. Consequences of these errors are discussed numerically below.

The main disadvantage of (1) lies in the relatively high probability of negative errors. The philosophy of the noise label as a guaranteed value implies that the proportion of items meeting certain requirements should not be less than a given percent. If we wish to determine specification limits in such a manner that we will have a degree of confidence q that the proportion of good items will be at least λ, the tolerance analysis of the mathematical statistics has to be relied upon [5]. The estimation is given by

$$L_2 = m + k_{n;q,\lambda} \cdot s \qquad (2)$$

where $k_{n;q,\lambda}$ is the one-sided tolerance factor. Unlike k_λ in (1), the tolerance factor depends on the sample size and, for obvious reasons, (2) results in higher estimators than those derived from the normal distribution. /Numerical values of the tolerance factor can be found e.g. in [6]./ However, (2) can be correctly used for small sample sizes, too.

NUMERICAL INVESTIGATIONS

Normality tests on SWL data

The theoretical considerations are based on the assumption that the SWLs in the population is distributed normally. The first thing to be investigated is therefore the normality of the SWLs. Samples were taken at random in two factories at the end of the production lines from seven machine types, representing three families of machines. The SWLs were measured according to engineering ISO methods. The normality of samples were tested by means of Shapiro-Wilk test in case of sample sizes lower than 5o and chi-square test for the rest. The results of the tests are summarized in the table below as well as in Fig.2. on a Gaussian lattice.

The hypothesis of normality could be accepted for each samples, although not always at the lower level of significance o.95. The figure reveals that the straight lines, characteristic of a normal distribution, are somewhat bent toward higher SWLs. /This effect would be even more pronounced in terms of sound power data instead of logarithmic levels./ In summary, the normality of SWLs of machines is quite probable but the available data ore not perfectly convincing.

Simulation of noise labelling

The accuracy of noise labelling procedure was checked by a computer simulation method. We assumed that the three large size samples constitute lots from different machine types of one family of machines. 2o samples of different size were randomly taken from each lot, the noise label was determined according to (1) and (2) and the average, highest and lowest noise labels were determined. The average of these values was compared to the o.95 quantile of the lots in Fig.3. /The figure gives the average dispersion of labels as deviations from the quantile of the lots normalized with the s.d. thereof as a function of the sample size./

The simulation shows distinct simililarities with the confidence intervals in Fig.1. (1) results in unbiased estimation for large sample sizes while a small but systematic negative shift can be found for low values of n. /This is probably attributable to the discrepancies in normality discussed above./ The range of labels are unsimmetrical for small sample sizes, supporting that the uncertainty of s.d. estimation is predominant. As expected from the confidence intervals, the dispersion of labels decreases toward higher sample sizes but remains considerable also for relatively large values.

The estimation based on (2) results in higher average noise labels than those computed from the whole lot; this systematic deviation decreases toward higher sample sizes. The range of noise labels are wider for every sample sizes, caused by higher coefficients in (2) than in (1). As opposed to the theoretical properties of the tolerance analysis, the simulation results a number of lower noise labels then the label of the lot.

The effect of the erroneous estimation of noise labels can be visualized by considering the true proportion of machines having lower SWL than the estimated noise label /See the right ordinate scale in Fig.3./. Let us take a sample of size 2o, resulting in an erroneous /normalized/ noise label -o.75. The corresponding proportion of machines exceeding the labelled value is o.19 instead of o.o5. The verification process according to[1] will accept the lot with a probability of acceptance o.7o in n=3 and what is less, o.35 if n=lo. Similarly, in case of a noise label +o.75 the appropriate figures will be higher than o.99. One can therefore conclude that the reliability of the qualification procedure is highly dependent on the uncertainty of the noise labelling. This shall also be allowed for by producers when determining the risk they are willing to bear.

REFERENCES

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NORMALITY TESTS OF SWL DATA

Machine type	n	Test	Significance
I/1	40	Sh-W	0.95
I/2	10	Sh-W	0.95
I/3	10	Sh-W	0.95
II/1	10	Sh-W	0.95
III/1	152	chi^2	0.975
III/2	150	chi^2	0.95
III/3	90	chi^2	0.975

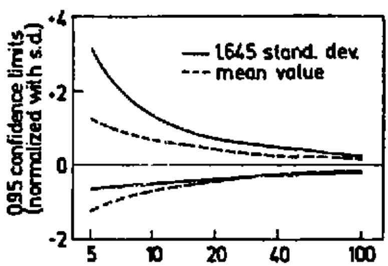

Fig. 1.

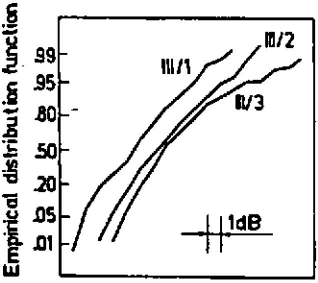

Fig.2.

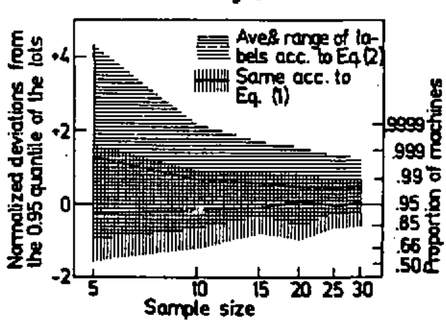

Fig.3.