MEASUREMENT UNCERTAINTIES IN THE DETERMINATION OF MACHINERY SOUND POWER LEVELS

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1. INTRODUCTION

Legislation to be introduced by 1993 in order to implement the EC Machinery Directive, 89/392/EEC [1,2], requires noise emission information to accompany all machinery. The declared noise levels will be dependent upon stated values of statistical confidence of the measurement results, based on data on the reproducibility of measurement methods. These uncertainty data enable purchasers and authorities to verify the declared noise emission values.

Many International Standard test codes for the determination of the noise emission of different types of machinery have been published, often reproducing the inadequate information on measurement uncertainty given in existing Standards which specify the basic methods for determining the sound power levels of noise sources using sound pressure level measurements, ISO 3740-ISO 3747 [3]. The clauses on measurement uncertainty in these Standards, which are currently under revision, are being harmonised and clarified but lack comprehensive data on the reproducibility of measured sound power levels.

Experimental work has been carried out to investigate the reproducibility of sound power determination from sound pressure measurements in hemi-anechoic environments. A number of machine types have been tested under a wide range of measurement conditions permitted by the relevant standard; initial results are discussed and it is concluded that further work is necessary to enable meaningful declaration of machinery noise emission levels.

2. BACKGROUND

2.1 Requirement for Information on Measurement Uncertainties

The EC Machinery Directive, 89/392/EEC, includes essential health and safety requirements relating to machinery noise emission. From 1 January 1993, legislation to implement the requirements of this Directive will oblige machinery manufacturers to minimise the noise emitted by their products and to declare information concerning the sound power level of the machine and the sound pressure level at specified points (termed "work stations") around the machine. Noise levels are to be measured using "the most appropriate method",

which must be selected from numerous Standards defining different procedures and grades of accuracy, and from test codes specifying the procedures that are relevant to particular types of machinery.

To enable the verification of noise levels, the declared values have to be statistical maxima for particular mounting and operating conditions, Higginson [4]. In order to make such a declaration a manufacturer must have data on the variability of the measurement results, expressed in terms of standard deviations of reproducibility of measured noise levels. The conditions necessary for reproducibility measurements are that the noise source is tested by the same method, in different laboratories, by different operators, using different equipment.

2.2 International Standards

Standards for measurement of machinery sound power levels and emission sound pressure levels are currently being produced or revised by ISO/TC43/SC1/WG 28, for adoption as European Standards by CEN. One task for this Working Group has been to ensure that statements of uncertainty within all the new standards are harmonised, and to provide standard deviations of reproducibility for each particular method of noise emission measurement. It will then be possible to state that a noise emission level, determined using the appropriate Standard method, is likely to differ from the true value within any specified statistical confidence limit.

However, the uncertainty data currently available for the different methods are insufficient to give comprehensive information about reproducibility uncertainties.

ISO 3740-ISO 3747 specify methods for determining the sound power levels of noise sources from measurements of sound pressure level around the machine. These Standards originated in the mid-1970s, and are currently undergoing extensive revisions. The revisions include the provision of tables of standard deviations of reproducibility appropriate to the individual Standards and their respective grades of accuracy, but almost all the data from the original versions are retained.

3. INVESTIGATION OF SOUND POWER LEVEL UNCERTAINTIES

3.1 Sources of Uncertainties

A study by Higginson & Hanes [5] of previous work on the variability of sound power determinations has established that certain test conditions contribute to the overall uncertainty of measured sound power levels. The sources of the variability (excluding variations in the source noise output) which contribute to the overall standard deviation of reproducibility are the following:

the influence of the acoustic near-field of the source,
the variation between inter-laboratory measurements,
the test room or outdoor environment used,
background noise levels,
type and calibration of instrumentation,
the number and arrangement of measurement positions.

However, the magnitudes of the contributions to variability are unknown and require investigation in order to provide definitive information concerning the reproducibility of sound power levels.

3.2 Experimental Work

In order to provide information on uncertainties suitable for incorporation into Standards, NPL has a programme of experimental work on methods for determining the sound power levels of machinery. Measurements have been made on some widely-used machine types according to the latest Draft revision of ISO 3744 (ISO/DIS 3744.2). Three outside test laboratories have been sub-contracted to provide sets of sound power levels suitable for estimating standard deviations of reproducibility.

4. DESCRIPTION OF MEASUREMENT PROGRAMME

The measurement programme requires sound power levels to be determined from sound pressure level measurements in a free-field over a reflecting plane, to an engineering grade of accuracy.

4.1 Noise Sources

Measurements were made on four machines, using different reference box dimensions:

Machine type	Reference box dimensions (m)
Electric drill	0.30 x 0.06 x 0.32
Lawnmower (two-stroke engine)	0.72 x 0.50 x 0.43
Diesel generator	0.70 x 0.50 x 0.65
Air compressor	1.60 x 1.18 x 1.19

4.2 Measurement Surfaces
In order to study the effect of size and shape of the measurement surface on sound power determination, six different surfaces, each satisfying the requirements of the Draft Standard, were selected for use with each machine.

Three radii were used for hemispherical measurement surfaces, see Figure 1:

a) the smallest possible radius for the noise source (ie the greater of 1 m or twice the characteristic source dimension d_0)
b) the closest preferred radius to a) (as given in ISO 3744) that is larger than a)
c) the radius that is two steps greater than b) in the series of preferred measurement surface sizes.

For each radius, measurements were made at ten microphone positions, all subtending equal angles at the centre.

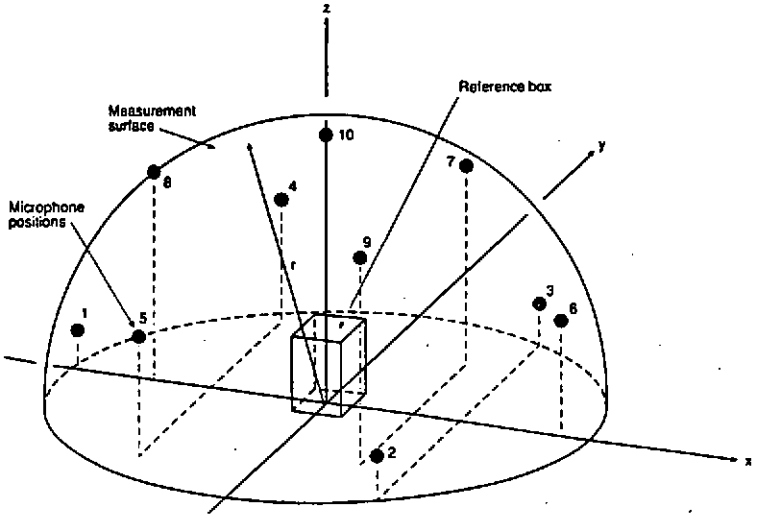

Figure 1. Hemispherical measurement surface

Three parallelepiped measurement surfaces were used, see Figure 2, with measurement distances, d, of:
d) 0.25 m,
e) 0.5 m,
f) 2 m.

The number of microphone positions ranged from 9 to 61, varying with the size of machine and inversely with the measurement distance.

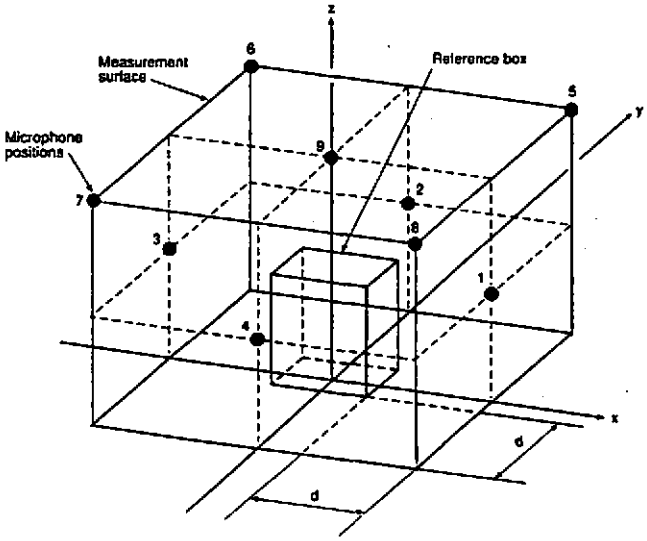

Figure 2. Parallelepiped measurement surface

4.3 Measurement Requirements
For each measurement surface, eight sets of repeat measurements were made in one-third-octave bands of centre frequency 100 Hz to 10 kHz, and the band-limited A-weighted level was determined. The data were all stored in a spreadsheet format.

The following atmospheric conditions were also recorded:
ambient temperature (°C)
ambient pressure (mbar)
relative humidity (%)
wind velocity (m s^{-1}),
along with equipment details and any other pertinent information.

5. DATA ANALYSIS

ISO 5725 [6] describes the basic method for determining the repeatability and reproducibility of measurements from inter-laboratory experiments. Expressions are given for the calculation of the standard deviations of repeatability, σ_r, and of reproducibility, σ_R, of experimental measurements.

At the time of writing this paper, the measurement programme is still in progress, and so data for all four machines from each laboratory are not yet available. However, a preliminary analysis of the results has been carried out. Standard deviations of reproducibility for measurements on hemispherical and parallelepiped measurement surfaces have been calculated from the repeatability variances and between-laboratory variances.

Initial results have indicated values of σ_R generally in the range 0.5 dB to 2.0 dB over most of the frequency range. However, large between-laboratory variances sometimes occur in lower frequency bands for smaller measurement surfaces and in higher frequency bands for larger measurement surfaces; here σ_R values of up to 5 dB occur. σ_R for A-weighted sound power levels are generally within the range 0.4 dB(A) to 1.1 dB(A).

6. CONCLUSIONS

The requirement of recent EC Directives for information on noise emission levels to be provided with new machinery, and the consequent need for verification of machinery noise levels, have highlighted the current lack of information on reproducibility uncertainties in machinery noise measurement.

NPL's experimental study of the variability of machinery noise measurements has so far produced, in the form of values of standard deviations of reproducibility, information on measurement uncertainties in determinations of machinery sound power levels according to the latest revision of ISO 3744. Further analysis of experimental data will enable a more detailed evaluation of the factors contributing to measurement uncertainties.

The knowledge gained from this programme of measurements comprises the first step towards a full understanding of the sources and magnitudes of uncertainties in determination of noise emission levels. More work, based on the findings of these experiments, is required to produce comprehensive uncertainty data on all measurement methods.

7. REFERENCES

[1] Council Directive of 14 June 1989 on the approximation of the laws of the Member States relating to machinery, 89/392/EEC. *Official Journal of the European Communities*, No L 183, pp 9-32, 29.6.1989

[2] Council Directive of 20 June 1991 amending 89/392/EEC on the approximation of the laws of the Member States relating to machinery, 91/368/EEC. *Official Journal of the European Communities*, No L 198, pp 16-32, 22.7.1991

[3] ISO 3740-ISO 3747, Acoustics - Determination of Sound Power Levels of Noise Sources

[4] R F HIGGINSON, 'Measurement Uncertainties In Determination of Noise Emission', *Proceedings of InterNoise 1990*, pp 625-628

[5] R F HIGGINSON & P HANES, 'Measurement Uncertainties In Determination Of Noise Emission', (to be published)

[6] ISO 5725, Precision of Test Methods - Determination of Repeatability and Reproducibility for a Standard Test Method by Inter-Laboratory Tests