inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 8.1

A PROPOSED NEW SERIES OF INTERNATIONAL STANDARDS FOR DETERMINING SOUND POWER LEVELS OF MACHINERY

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Keywords:
STANDARDS, SOUND POWER, MACHINERY, MEASUREMENT

ABSTRACT
A new series of international standards is proposed, to replace ISO 3741-3747, giving methods of determining sound power levels using measurements of sound pressure. The new series covers the same variety of test environments, but comprises only four standards instead of the present seven. Two will require the use of qualified reverberant and free-field rooms. The others will be for use in situ, intended to give working methods for everyday use in declaring and verifying sound power levels. The latter two will give information on how to tailor the reproducibility of the results to the amount of measurement effort. The results are reported of extensive trials of measurement reproducibility in a hemi-free field, from which the data to support one of the working methods were drawn.

1 - INTRODUCTION
The methods available by which the sound power levels of noise sources can be determined fall into two groups, one using measurements of sound intensity and the other using measurements of sound pressure. It may be that at some time in the future, sound intensity methods will come to be used for all applications where the sound power level is required to be known, since they evaluate energy flow directly and they have certain practical advantages. However, at present, the great majority of sound power level determinations made for use in noise declaration and verification are obtained using sound pressure, and this appears likely to continue to be the case for some time yet.
The standard methods in use for sound power determination using sound pressure are the international standards ISO 3741 through ISO 3747. This series of standards has undergone major revision during the past ten years, and indeed this process is not yet quite completed. Even so, the basic structure of the standards remains unchanged from that originally laid down during the 1970s. The seven methods are identified with the different kinds of environment where they are applied, and they are also broken down by three grades of accuracy. Users of the standards find this variety confusing. Moreover, an aspect increasingly important to regulations on machinery noise emission, that of measurement uncertainty, is dealt with in a way that is unsatisfactory from several respects. This paper outlines proposals which have been made to ISO for a completely new series of standards with a simplified structure and addressing measurement uncertainties more adequately.
Of all the methods available, that used most commonly for noise declaration is the one for a free field over a reflecting plane, specified in different ways in ISO 3744 and ISO 3746. Users prefer ISO 3746 for its simplicity, but they would prefer to quote values of measurement reproducibility from the more complex ISO 3744. In practice, some sweeping assumptions in this area are often made, usually based on little or no experimental evidence. Extensive investigations of reproducibility have now been made by the present authors. Some of the results are reported here, and they have been used as the basis for a radically new draft standard which is one of the four in the new series now proposed.

2 - THE PROPOSED STANDARDS
The titles proposed for the new series of standards are as follows:

ISO xxxx1	Noise emitted by machinery and equipment − Determination of sound power levels using methods of sound pressure − Reference methods for reverberation rooms.
ISO xxxx2	Noise emitted by machinery and equipment − Determination of sound power levels using methods of sound pressure − Reference methods for free-field and hemi-free-field rooms.
ISO xxxx3	Noise emitted by machinery and equipment − Determination of sound power levels using methods of sound pressure − Methods for an essentially free space over a reflecting surface.
ISO xxxx4	Noise emitted by machinery and equipment - Determination of sound power levels using methods of sound pressure - Comparison methods using a reference sound source.

Table 1.

None of the titles include the accuracy grade of the method, but by implication the first two, being reference methods, are laboratory methods of the highest precision. All of the standards will give data on measurement reproducibility and information on factors affecting measurement uncertainty.

ISO xxxx1 would replace ISO 3741:1999. The overall approach is unchanged, retaining a direct method and a comparison method, but modifications include the addition of methods for determining the sound energy level for a source which emits impulsive noise or bursts of noise, and methods for determining sound power levels and sound energy levels under both the barometric conditions for the test and under reference barometric conditions.

ISO xxxx2 would replace ISO 3745:200x. Again, methods are added for determining the sound energy level, the sound power levels and the sound energy levels under the barometric conditions for the test and levels normalized to reference barometric conditions.

ISO xxxx3 would replace ISO 3744:1994 and ISO 3746:1996. The procedures for obtaining sound power levels and sound energy levels in frequency bands will remain as they are already, but those for determining the A-weighted levels (most commonly used for noise declaration) will be radically different. Data will be given relating the number of microphone positions on the measurement surface to the overall measurement reproducibility, for noise sources having different directivity characteristics. The experimental basis for this approach is described below in section 3.

ISO xxxx4 would replace ISO 3743-1:1994 and ISO 3747:200x.

3 - EXPERIMENTAL BASIS FOR ISO xxxx3

A program of inter-laboratory measurements designed to obtain estimates of the standard deviation of reproducibility associated with sound power level determinations in a hemi-free-field environment has been carried out. To obtain reproducibility data, it is necessary for the noise emission levels of a particular noise source to be measured by different laboratories using a given method in different locations, different personnel, different measurement apparatus and at different times. The program was drawn up following the guidance of ISO 5725-2, to provide the best balance between the number of repeated measurements and number of laboratories performing the tests, with statistical confidence.

The standard deviations of reproducibility given in ISO 3744:1994 apply to both hemispherical and parallelepiped measurement surfaces, and so the measurement effort here was concentrated on only one surface shape, a hemisphere.

Four laboratories carried out sound power level determinations, with frequency weighting A and in one-third octave bands of mid-band frequencies from 50 Hz to 10 kHz, on three noise sources of differing acoustic complexity and maximum directivity indices ranging from 0.8 dB to 6.9 dB. Each laboratory used an open test site consisting of a hard, flat ground surface, of either asphalt or concrete, so that the environmental correction factor, K_2, could be assumed to be negligible. Sound power levels were determined using several microphone arrays with differing distributions on the measuring surface, and with between one and twenty measurement positions. Standard deviations of reproducibility were calculated for each array, and for the purposes of a comparison between the results, the sound power levels determined using 20 microphones were taken as reference values.

Measurements were made on all three noise sources by each laboratory over two weeks, within an overall period of about two months. Each sound power level determination was repeated three times in order to assess measurement repeatability. Measurements were also carried out by one of the laboratories on all noise sources at each of the different test sites as soon as practicable after the respective laboratories had completed the required measurements. The latter measurements were made to verify the long term stability of the noise sources, and they also permitted an estimate to be made of any variability between the different test sites. These variabilities, which we termed "intra-site repeatability", were, so to speak, a half-way house between those of strict repeatability and reproducibility, and provided information on the contributions to the final reproducibility values of factors associated with differing sites and differing laboratory conditions.

The standard deviations of repeatability in the case of A-weighted sound power levels were generally less than 0.15 dB, and for the reference 20-microphone array were of the order 0.05 dB. The standard deviations of intra-site repeatability showed a marked increase as the number of measurement positions was reduced to one. The magnitude of this increase was dependent on the noise source, being smallest for those with a low maximum directivity index and largest for those with a high maximum directivity index. For the 20-microphone array, the standard deviations of intra-site repeatability ranged from 0.29 dB to 0.42 dB. Values for other arrays were larger and were in excess of 7 dB for a single microphone position and a highly directional noise source.

Although the four test sites could all have been considered as having negligible K_2 values, an adjustment for the actual values of K_2 reduced the intra-site repeatability values for the 20- and 10-microphone arrays. This was not the case for data obtained using arrays with less than 10 measurement positions. For arrays with less than 10 microphones, the major contribution to intra-site repeatability was from variations in sound power determination resulting from inadequate spatial sampling, with minimal contributions due to repeatability and variability between different measurement sites.

Standard deviations of reproducibility were similar to those for intra-site repeatability. This means that when several laboratories make a sound power determination using a specified procedure, the variability in the results is not significantly different from that associated with repeated measurements by a single laboratory. The magnitude of reproducibility standard deviations depends not only on the number of microphone positions in the array and the maximum directivity index of the noise source, but also on the distribution of the microphones over the measurement surface. It is clear, therefore, that for the purpose of estimating reproducibility standard deviations, a specification only of the number of microphone positions is insufficient. Assuming that the microphone positions are evenly distributed over the surface, the standard deviations of reproducibility vary directly with the number of microphones in the array, being smallest for a 20-microphone array and largest for a single microphone. A table of reproducibility values is therefore proposed in ISO xxxx3 (see right) that will, for a given value of maximum directivity index, enable the user of the standard to assess how many microphone positions are required in an array to obtain a required value of reproducibility, or to assess the reduction in reproducibility that will follow by increasing the number of microphone positions. The majority of machines in practice have been found to have a maximum directivity index between 1 dB and 3 dB. It is proposed in the draft standard that if a noise source under test is known to have small directivity indices in all directions (e.g. a reference sound source) then reproducibility values corresponding to a maximum directivity index of 1 dB should be assumed; if on visual and aural inspection a machine does not radiate sound strongly in any one direction (the case for most machines) then a maximum directivity index of 3 dB should be assumed; if the machine evidently radiates sound predominantly in one direction, a maximum directivity index of 5 dB should be assumed.

	Maximum Directivity Index dB		
number	1	3	5
of mics	Standard deviation of reproducibility, dB		
≥10	0.4	0.7	1.0
7	0.4	0.8	1.1
6	0.5	0.9	1.3
4	0.6	1.2	1.8
3	0.9	1.8	2.7
1	1.3	2.3	3.3

Table 2.

4 - DEVELOPMENT OF THE NEW STANDARDS

Fully drafted versions of ISO xxxx1 −xxxx3 will be presented in August 2000 to working group 28 of ISO/TC 43 Sub-committee 1 for their consideration. A draft for ISO xxxx4 is expected to be prepared during 2001.