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A BASIC INTRODUCTION TO SOUND POWER AND ITS MEASUREMENT

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1. INTRODUCTION

With the introduction of the EC Machinery Directive and the Health and Safety at Work Act, manufacturers, suppliers and employers are all under pressure to be aware of and reduce noise levels generated by machinery. The pressures on each of these groups is different. Manufacturers must, from January 1995, quote "machine" noise levels for their product. If the noise Equivalent Continuous Sound Pressure Level, L_{eq}, at workstations (or 1 m from the machine if there is no designated workstation) exceeds 85dB(A) re 20μPa then the Sound Power Level, L_w, must be measured. Apart from the legal requirement to measure noise levels this will place additional commercial pressures on them in any competitive market. Employers have a duty to protect their workforce from hazardous noise levels and consequently need to know, preferably at time of purchase, how much noise a particular piece of equipment will generate in his workplace. Suppliers of equipment need to have noise levels available so that they can pass these on to users and may be asked to advise on the noise level that will result when a machine is used in a particular environment.

For each of these three groups a basic understanding of the concepts behind Sound Power, its measurement and its relationship with Sound Pressure, would assist them in coping with these pressures. The purpose of this paper is to provide this basic understanding.

2. WHAT IS SOUND POWER ?

Sound Power is a unique measure of the actual acoustic power output of a machine. It is measured in Watts and is independent of the acoustic environment in which the machine is used.

Sound Pressure on the other hand is the pressure fluctuation in the air produced by using a machine in a given environment. Sound pressure is a function not only of the machine's basic capacity to generate noise (i.e. its Sound Power) but also of the environment in which it is used and how far the receiver is from its surface. A good analogy can be drawn with the case of an electric heater and the temperature that would result by using the heater in a given room. If a heater with a known power, say 1 kW, is used in a small room then the resultant temperature will be high and will be a function of the amount of ventilation in the room and the thermal properties of the walls and furnishings. If however that same heater is used in a large room, or even outdoors, then the temperature of the surrounding air will be much lower than it was in the small room because the energy of the fire is being dissipated over a larger area.

This is much the same case as with noise; power is the unique parameter of the machine; pressure is a function of the environment.

3. HOW IS SOUND POWER RELATED TO SOUND INTENSITY & SOUND PRESSURE ?

If we take a source with sound power W (Watts), fig 1, and measure a given distance, r, from it then the power of the source will be distributed over the total area, S (m^2), of the measurement surface. This results in a power density or "Intensity", I (Watts/m^2), on the surface given simply by;

$$I = W/S$$

or conversely $W = I.S$ (1)

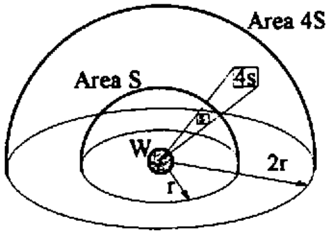

Figure 1.

Normally Sound Power and Sound Intensity figures are quoted as "Sound Power Level", L_w, in dB(re 10^{-12} Watts) and "Sound Intensity Level", L_I, in dB(re 10^{-12} Watts/m^2) respectively. Decibels are simply a ratio of two power like quantities expressed on a logarithmic scale and the level in brackets after the dB shows the reference level used as the basis of the scale. The reference should always be included to avoid confusion with other units. The relationship between L_w and L_I is therefore:

$$L_w = L_I + 10.\log_{10}S \quad (2)$$

If we double the distance from the source, fig 1, the area increases by a factor of four. This corresponds to a 6dB reduction in L_I.

Under *idealised* conditions (i.e. with no reflections) the Sound Intensity, I, is directly related to the square of the Sound Pressure, P (N/m^2), in much the same way that electrical power is related to the square of Voltage. Sound Pressure is normally also quoted as a "Level" in dB hence "Sound Pressure Level", L_p, in dB(re 20μPa). Note that the reference level for L_p is 20μPa; this is the smallest pressure that the human ear can detect. When this small pressure is converted into an Intensity under standard atmospheric conditions the result is to obtain the 10^{-12} Watts/m^2 reference used for L_I. The relationship with Sound Power then becomes:

$$L_w = L_p + 10.\log_{10}S \quad (3)$$

Under *realistic* conditions (i.e. ones where reflections are present) the Intensity is no longer simply related to the square of the Sound Pressure (it now depends also on the phase between the acoustic pressure and the acoustic velocity) and an "Environmental Correction Factor", K, is introduced to compensate. This gives a new form to the Sound Power equation:

$$L_w = L_p - K + 10.\log_{10}S \quad (4)$$

4. MEASUREMENT OF SOUND POWER

There are a number of International Standards that describe how to measure Sound Power but essentially these can be grouped into two categories:

a) those based on measurement of L_p using some variant of equation (4),
b) those based on measurement of L_I using equation (2).

The main standards are the ISO 3740 series, [1]-[7], which are based on measurement of L_p and ISO 9614, [8]-[9], which is based on measurement of L_I. Other standards, e.g. [10] and [11], are particular to specific types of machines and are commonly based on [5] or [7].

The concept that is common to most Standards is the fact that the Sound Power emitted by the source is spread out over the entire measurement surface. The approach taken is generally to split the measurement surface into a number of segments and to measure L_p or L_I in each segment. The total power is then obtained by adding up the power from each segment.

For the case of Sound Pressure based standards, for equal segment areas, this is normally done by averaging the sound pressure over all the measurement segments and then using the full surface area in equation (4). Some standards however scan the entire surface rather than doing fixed point measurements to obtain an average Sound Pressure.

Generally the measurement surface can either be hemispherical or a rectangular box (referred to as a "parallelepiped"). The shape of the surface is normally chosen to suite the shape of the source being tested.

The two Intensity based standards offer the choice between a fixed point method, [8], or a scanning method, [9], but their approach is similar in that they segment the surface into a number of smaller, more manageable portions.

The standards based on the use of Reverberation Rooms, [2]-[4], are slightly different in that they assume the noise from the source is fully contained in the room and consequently the Sound Pressure builds up. They use a particular form of sound power equation which is more complex than equation (4) but conceptually the approach is similar in that a correction factor is applied to the measured Sound Pressure Level.

5. ACCURACY OF THE STANDARD METHODS

The essential difference between the standards is the accuracy that each one will give and the allowable test environment. It will be no surprise to learn that a large number of measurement points, tight control of acoustic environment and minimisation of extraneous noise will all result in a more accurate determination of sound power.

Standards are essentially classed into one of three grades of accuracy;

a) "Precision" giving a standard deviation of approximately 1dB,
b) "Engineering" 2dB,
c) "Survey" . . . . 4 dB.

ISO 3746, [8], for example is a "Survey" grade and uses a basic 6 points for small machines and an allowable K factor of 7dB for the environment. ISO 3745, [6], is a "Precision" method by contrast and uses at least 11 points with strict limitation of the room environment which effectively limits the K factor to less than 1.5dB.

Some standards, [7], include a graph showing how the K factor can be evaluated for a given environment. Other Standards do not explicitly include a K factor in the calculation of L_w but derive their own version of equation (4) to include a more complex correction term to account for the room acoustics. Generally the value of K can be determined in one of three ways;

a) by use of a reference sound source,
b) direct measurement of reverberation time,
c) by calculation based on assumed room absorption values.

The actual standard being used should be consulted for the form of sound power equation actually applied.

The Intensity based standards are somewhat different in their approach to accuracy since the measurements have to be performed first, generally using a larger number of points, and checks carried out on the data so that an accuracy grade can be determined. There is no set limit on the allowable K factor. Their advantage is however that the intensity technique is tolerant of the environment and the level of extraneous noise so can be used in locations where other Standards would fail.

6. HOW DO I USE SOUND POWER ?

As previously mentioned, the Sound Power is a unique property of a source and is independent of the environment.

It can therefore be used to compare the acoustic output of two machines that may have been tested under different environmental conditions; the one with the higher sound power will generate more noise in a given environment. Care should be exercised when comparing L_w values to take into account the accuracy of the test method used to obtain the sound power. New guidance on the declaration of noise levels, [12], can add 1.6 standard deviations to the measured value to protect against the "declared" value being a non-representative sample. If possible, use the declared value, [12]-[13], or find out the ISO Standard used and take the accuracy of this into account.

Another use is to predict the Sound Pressure Level that would result from operating a particular machine in a given environment. To do this we can apply equation (4) in reverse. i.e.:

$$L_p = L_w + K - 10.\log_{10}(S) \qquad (5)$$

Hence, knowing L_w for a specific machine we can obtain L_p from a knowledge of the K factor for the environment and, since the surface area S is a function of distance, the distance away from the source.

Sound power can therefore be thought of either as a direct method of comparing machines or as a means of transferring noise levels measured under one condition to deduce the level that would be developed in a different environment.

7. CONCLUSIONS

The main focus of this basic introduction to sound power has been to stress the following points:

a) Sound Power is a property of a machine and is independent of the acoustic environment.

b) Sound Power Level, L_w, can be deduced by making Sound Pressure Level, L_p, measurements on a surface then averaging these. The L_w is then obtained by adding a correction factor based on the measurement surface area and subtracting a factor, K, for the environment.

c) L_w can also be derived using Acoustic Intensity measurements and this method is more tolerant of extraneous noise and test environment.

d) The accuracy of any L_w measurement is directly affected by the number of measurement points, the acoustic environment in which measurements are made and the level of extraneous noise.

e) L_w values can be used to estimate the L_p value at an average distance from a machine in a given environment.

Hopefully, the purpose of this paper has been fulfilled in giving the reader a basic understanding of the concepts and approaches used in the measurement of sound power.

8. REFERENCES

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