Proceedings of the Institute of Acoustics

PERIODIC VERIFICATION OF MEASUREMENT MICROPHONES

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1. INTRODUCTION

The price of a full high accuracy calibration may be more than twice the price of the microphone. Even a simple regular calibration may cost in the range from 20 % to 50 % of the price of the microphone.

It is therefore important to consider what the requirements for calibration actually are. In some cases specific quality assurance policies, or legal requirements, demand a regular full-scale calibration of all equipment by a certified laboratory. In other situations it is more a question of having confidence in the measurements and a check that the microphone has not changed or been damaged will be sufficient.

Calibration of microphones consists of basically two parts: a level calibration and a frequency response calibration. The level calibration, most often done at 250 Hz, determines the absolute sensitivity of the microphone and gives the relationship between an input sound pressure signal and the output voltage signal. The frequency response calibration gives the deviation at other frequencies from the response at 250 Hz. This response is normally established using the electrostatic actuator method. This gives the microphones pressure response and the free field response is then calculated by adding the predetermined free field correction values to the pressure response.

2. LEVEL CALIBRATION TECHNIQUES

The level calibration of microphones can be done in a variety of different ways i.e. reciprocity calibration, comparison calibration or pistonphone calibration. The reciprocity calibration technique is normally considered as the most accurate method, but is very elaborate and expensive to perform. The comparison method where the sensitivity of the microphone under test (DUT) is compared with the known sensitivity of a reference microphone is simple and can be established with widely available equipment with only minor investments. Combined with a precision pistonphone, figure 1, and a precision barometer the comparison method will give a highly reliable and robust calibration method. The pistonphone and barometer for static pressure correction will give a highly reliable absolute sound pressure level. By using this set-up the sensitivity of the reference microphone, the preamplifier and subsequent equipment can be checked. For example, the output from the reference microphone will be directly proportional to the polarisation voltage. It would therefore be necessary to check the polarisation voltage directly on the microphone output terminal to ensure correct readings. If however the output of the microphone is checked with the absolute level from the pistonphone any variations in the polarisation voltage can be detected.

A normal microphone calibration involves the determination of the Open Circuit Sensitivity. This gives the output from the microphone for a given input signal when there is no electrical load on the microphone's output terminal. An alternative method of expressing the microphones sensitivity is the Closed Circuit Sensitivity; this is dependant on the specific type of preamplifier to which it is connected and can vary from one preamplifier type to the next. The loading from the preamplifier will reduce the output signal from the microphone and the Closed Circuit sensitivity will therefore be lower than the Open Circuit Sensitivity.

The Open Circuit Sensitivity is determined with the Insert Voltage technique using a special preamplifier, where a test signal can be injected directly on the preamplifier input terminal to off set the loading effects. The Open Circuit Sensitivity is important when the microphone may be used with different measurement set-ups and hence the loading conditions are not known. In larger organizations having several measurement microphones it may be necessary to establish the open circuit sensitivity and a simplified method of achieving this is the subject of another paper.

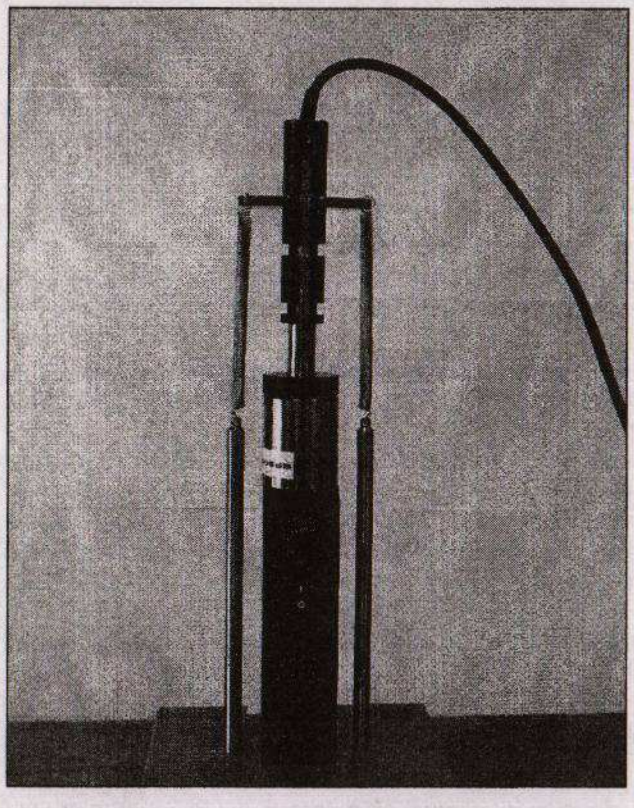

Figure 1 Pistonphone with microphone and preamplifier

It is common practice for the measurement microphone to always be used in connection with a known preamplifier and hence the loading of the microphone is known. In these conditions the Closed Circuit Sensitivity can be determined from the Pistonphone calibration value, by simply measuring the output from the preamplifier with the pistonphone signal applied to the microphone input. If the pistonphone calibration value, corrected for the barometric pressure, is for example 113.8 dB re. $2*10^{-5}$Pa and the output from the preamplifier is for example 456 mV then the Closed circuit sensitivity of the microphone is:

$$S_{Closed} = \frac{456mV}{2*10^{-5}Pa*10^{(113.8/20)}} = \frac{456mV}{9.795Pa} = 46.55mV/Pa \qquad [1]$$

This Closed Circuit Sensitivity is in principle only valid for this particular combination of preamplifier and microphone, and includes the loading of the microphone by the preamplifier as well as any gain in the preamplifier.

3. FREQUENCY RESPONSE MEASUREMENTS

The frequency response of measurement microphones can be presented in different ways i.e. pressure response, free field response and diffuse field (random incidence) response. These three values arise from diffraction and other effects due to the microphones presence in the sound field and are directly related to one another for any one type of microphone. The general procedure is to measure the pressure response and then corresponding free field and diffuse field responses are calculated by adding corrections to it. The correction factors are established for each type of microphone and are assumed identical for all individual microphones of that type.

The pressure response is determined by the electrostatic actuator method. This method requires no special acoustic laboratory facilities and can be established with only minor investments. The method is described in IEC 61094-6 Working Draft Standard "Measurement microphones – Part 6: Measurement of frequency response using electrostatic actuator". The electrostatic actuator consists of an electrically conductive, rigid plate, which is mounted close to and parallel to the microphone diaphragm, figure 2.

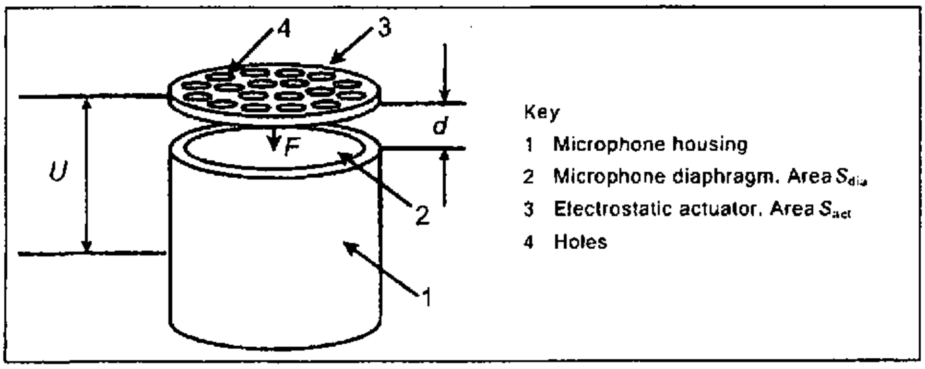

Figure 2 Principle of microphone and electrostatic actuator

When a voltage U is applied between the microphone housing and the electrostatic actuator the microphone diaphragm will be acted upon by a force F given by:

$$F = -\frac{\varepsilon_{air} \cdot S_{act}}{2 \cdot d^2} \cdot U^2 \qquad [2]$$

where ε_{air} is the dielectric constant of air, S_{act} is the actuator area and d is the distance between the diaphragm and actuator.

This force is equivalent to a pressure P acting on the diaphragm given by the relationship:

$$P_{act} = \frac{F}{S_{dia}} = -\frac{\varepsilon_{air}}{2 \cdot d^2} \cdot a \cdot U^2 \qquad [3]$$

where a is the ratio between effective actuator area and active diaphragm area.

The method is normally used with a DC voltage U_0 and a superimposed AC signal u. The resulting corresponding electrostatically generated pressure signal on the microphone is:

$$p(t) = \frac{\varepsilon_{air} \cdot a}{2 \cdot d^2} \left(U_0 + u \cdot \sqrt{2} \cdot \sin(\varpi t)\right)^2 \qquad [4]$$

This results in three components where the static component is not of interest here. The other two components are a component of interest with the frequency ϖ and a second harmonic component. The fundamental frequency component is given by:

$$p = \frac{\varepsilon_{air} \cdot a}{d^2} \cdot U_0 \cdot u \cdot \sqrt{2} \qquad [5]$$

As can be seen, the output signal is proportional to the static voltage and inversely proportional to the square of the distance d. To maximise the output signal the distance d should be minimised and the static voltage U_0 should be maximised. In practice one has however to consider that very small distances d and very high voltages U_0 will result in short circuit of the polarisation voltage. The ratio of the second harmonic component to the fundamental component is given by:

$$D = \frac{u\sqrt{2}}{4 \cdot U_0} \cdot 100\% \qquad [6]$$

It can be seen that as the static voltage is lowered the second harmonic contribution will increase.

4. PRACTICAL SET-UP FOR ACTUATOR MEASUREMENTS

Figure 3 shows a practical set-up for measuring the actuator response of a microphone using a standard two-channel frequency analyser. The example is shown with a SRS 785 analyser, but other types of analysers with built in signal generator may be used. An alternative solution would be to use a sine generator for the signal generation and a Sound Level Meter to measure the result. If the Sound Level Meter has build-in filtering this may be used to improved the signal to noise ratio.

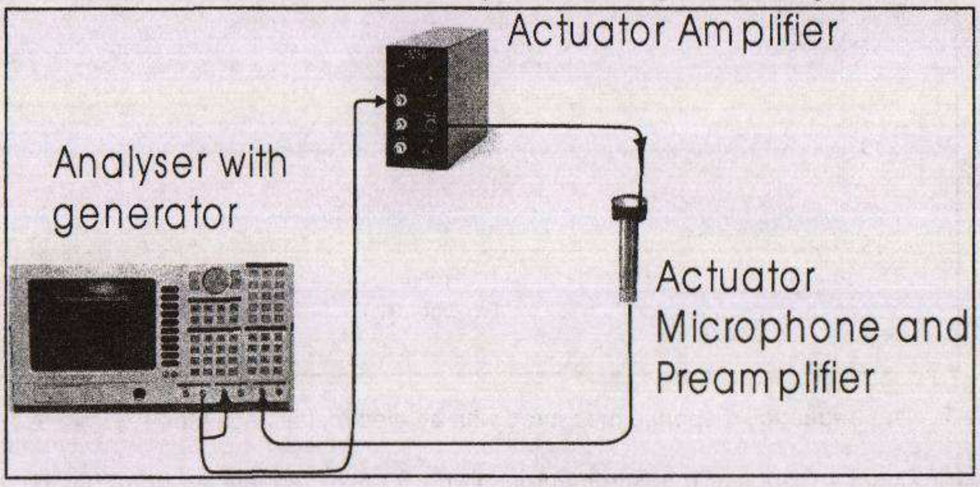

Figure 3 Measurement set-up for frequency response measurements

The 14AA Electrostatic Actuator Amplifier generates 800 VDC supply for the static voltage and amplifies the generator signal from the frequency analyser by 40 dB. The amplified signal is superimposed on the 800 VDC and is fed to the electrostatic actuator mounted on the microphone. The output signal from the microphone preamplifier is connected to one channel of the frequency analyser simultaneously with the input signal to the other.

For an output signal from the analyser of 1 V, the ratio of the second harmonic component to the fundamental component will be approximately 4.4 %. Using the analyser in the sine sweep mode it will generate a series of sine wave signals and these will be sequentially analysed with a discrete Fourier transformation. As the analyser only measures the input signal at the frequency generated by the output generator the second harmonic contribution will not be included and background noise contributions will be reduced. This means that the frequency response of microphones can be measured in normal environments and does not requires special sound insulated test chambers, as long as the back ground noise level is reasonably low.

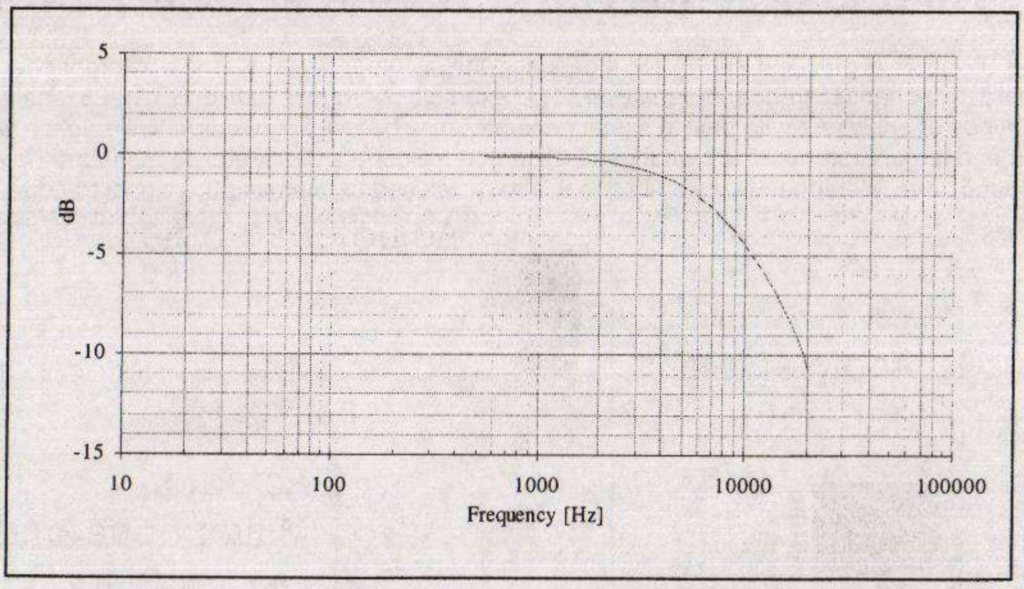

Figure 4 Typical frequency response measured with an electrostatic actuator

A typical frequency response measurement involving 60 test frequencies from 100 Hz to 20 kHz can be performed in less than 30 s. Figure 4 shows a typical pressure response for a free field microphone measured with an electrostatic actuator.

To obtain the free field response of the microphone, the free field correction factors are added to the pressure response. The free field correction factors are normally available from the microphone manufacturer and extra frequency values can be obtained by interpolation.

5. CONCLUSION

Measurement microphones can be calibrated accurately and reliably with simple and cost effective set-ups. Using a standard frequency analyser and an electrostatic actuator amplifier the frequency response of microphones can be checked and verified without the need for any special acoustic measurement facilities.

Proceedings of the Institute of Acoustics

THE MEASUREMENT AND ASSESSMENT OF GROUNDBORNE NOISE AND VIBRATION

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1. INTRODUCTION

The Association of Noise Consultants formed a Working Group to develop Guidelines[1] on the measurement and assessment of groundborne noise and vibration. The need arose following difficulties with the use of the British Standard documents such as the 1992 version of BS 6472 for vibration assessment, the lack of suitable measurement equipment for vibration dose values, the widely different measurement data obtained by various organisations, the different criteria adopted by consultants and local authorities and their current involvement in major projects involving groundborne noise and vibration issues.

Although a wide range of vibration issues and sources is covered in the document, particular attention has been paid to railway vibration and groundborne noise, as a result of a number of major projects under development. While the guidelines cover a broad range of issues, one of the most important topics is guidance on the use of the VDV index.

2. FUNDAMENTAL ISSUES IN THE MEASUREMENT OF VDV

British Standard 6472:1992 Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)[2] introduced into UK vibration assessment practice the concept of Vibration Dose Value (VDV), as an extension of the root-mean-quad approach which appeared in the previous version.

VDV is a complicated index, and the text of BS 6472 is extremely compact, with the result that interpretation of the guidance on the calculation and application of VDV is frequently misunderstood.

The major issues arising from the application of BS 6472, and in many respects the general use of weighted and/or dose-related vibration indices are these:

i) Correct use of weighting functions
ii) Appropriate use of time-integration methods

Flowcharts reproduced from the ANC Guidelines are given in Charts 0 to 4 to aid users in applying the procedures of BS 6472.

2.1 Weighting Functions

There are two issues associated with the use of weighting functions. The first is correct choice of weighting curve and the second is the application of the weighting curve.

Earlier versions of BS 6472 and ISO 2631[3] introduced weighting curves as charts which appeared analogous to rating systems used in noise assessment, such as Noise Criterion (NC) or Noise Rating (NR) curves. In these cases, the required technique involves plotting an octave-band spectrum on a set of curves and reading off the index value by inspecting for the highest curve reached in any band. It is true that for the case of vibration at a single frequency, it is appropriate to enter the amplitude on a set of vibration assessment curves and merely read off the curve number. However, many real-life vibration signals are not primarily single-frequency. Use of the noise rating analogy would suggest that in the case of a vibration signal containing several components all that is required is to plot the components on the curve chart and read off the highest curve value.

However, the appearance of BS 6841[4], which includes Laplacian domain expressions for the generation of vibration weighting curves, made it clear that the curves of BS 6472 and ISO 2631 are not of the NC/NR family, but are in fact akin to noise weighting scales such as the 'A-weighting'. In other words, all components of a spectrum should be taken into account by weighting according to the value of the weighting curve at each frequency, and taking the power sum of the weighted components.

An important side issue is the correct choice of weighting curve from BS 6841. Although confined to a note, there is a clear statement that weighting W_g is the curve which corresponds to the curves for z-axis, as inspection of the curve characteristics clearly confirms. However, the main text of BS 6841 indicates that W_b should be used in the z-axis for comfort assessment, and this frequently gives rise to confusion. Added confusion arises from the fact that different weighting curves are proposed by the sister standard ISO 2631, and that ISO 2631[5] itself has undergone curve changes through its various versions. For the x-axis and z-axis, BS 6472 uses weighting curves W_d.

Given that the weighting curves are analogous to noise weighting curves, it follows that true measurement of weighted acceleration requires the use of an instrument with an appropriate weighting network. Although the printed curves in BS 6472 suggest that weighted acceleration or weighted velocity can be used, care is required because it is necessary to preserve the phase characteristics of the Laplacian domain weighting functions of BS 6841 when dealing with signals with a high crest factor.

As in noise assessment, approximations to weighted values can be made by the use of 1/3 octave spectra, manually weighting the band levels and re-combining them. In restricted circumstances the resulting error is not significant.

It is important to note that plotting the 1/3 octave spectrum of a broad-band vibration signal on to one of the curve charts in BS 6472 and reading off the highest curve number does not give the correct answer.

2.2 Time Integration

Where VDV differs markedly from analogous noise indices such as SEL is that it is based not on integration of the square of the signal, but on integration of the fourth power of the signal. For signals with low crest factors, the relationship between the fourth power integral and the second power integral can be estimated, and BS 6472 indicates a multiplier of 1.4 (based on typical signals). This gives rise to the concept of estimated VDV, or eVDV.

When the crest factor is low (not more than 6), and the variation over time is simple, eVDV can be estimated from r.m.s. average values by multiplying by 1.4 and by the duration over which the average has been obtained, raised to the power of 0.25.

2.3 VDV manipulation

BS 6472 gives guidance on the acceptability of vibration in two ways. For simple cases, where the vibration is predominantly of one frequency and of easily definable duration, determination of a curve number and associated multiplying factors enables use of a table of satisfactory magnitudes. In other cases, VDV is determined for periods corresponding to daytime and night time, and used to estimate the probability of "adverse comment". Unlike the noise analogy, where a dose-related unit such as SEL is used to compute a time average over an assessment period, VDV is used directly, as a dose concept. This means that for the same level of vibration, the VDV value for a 16-hour day is by definition higher than the VDV value for an 8-hour night. Manipulation is required where VDV values are known for vibration events or periods shorter than the assessment period. If only one vibration event occurs, its period VDV will be the same for any period, of whatever length, that is longer than the duration of the event. Where several events of known or identical VDV values occur within the assessment period, they can be combined by raising each to the fourth power, summing them, and taking the fourth root. Because of the use of the fourth root, this means that VDV is not very sensitive to number of events or duration.

Tables are presented in BS 6472 indicating threshold VDVs for "low probability of adverse comment","adverse comment possible" and "adverse comment probable". However, analysis of the derivation of the tables shows that they are only precise for z-axis vibration. This arises from the fact that the x- and y- axis curves in BS 6472, at their most sensitive frequencies, have a base value lower than that for the z-axis (0.00357 ms^{-2} as opposed to 0.005 ms^{-2}). By contrast, the weighting functions in BS 6841 are all equal to unity at their most sensitive frequency. Strictly speaking, it is necessary either to revise the weighting curves, or to revise the table of adverse comment for use in the x- and y-axes. However, given the lack of international agreement of weighting functions, this anomaly is only one of several uncertainties associated with the assessment of vibration.

2.4 Instrumentation for the measurements of VDV

Because of the uniqueness to the UK of BS 6472, and its choice of weighting curves, and the international nature of most measuring instrumentation, it is important in choosing instruments for the direct measurement of VDV to ensure that they employ weighting W_g for z-axis and W_d for x- and y-axes. The term "VDV" described only the 4^{th} power integration concept, and does not define the weighting curve. An instrument may faithfully measure VDV, but to a standard quite different from that of BS 6472 and BS 6841.

3. WIDER ISSUES IN THE ASSESSMENT OF VIBRATION

The use of VDV is but one aspect of the topic of vibration measurement, assessment and prediction. For example, the much longer established index "peak particle velocity" (PPV) is in widespread use, not only as an alternative to VDV for vibration from blasting, or as a simpler and more easily monitored measure of construction vibration.

While the effect of vibration on humans is a major area of interest, VDV is only relevant to this area, and is inappropriate to the other major area of interest, the effect of vibration on buildings. Potential for structural damage is normally monitored using PPV. Despite the simpler nature of the PPV index, there is still conflicting advice on British Standards[6,7] on thresholds for vibration damage to buildings.

Besides issues related to the mathematical nature of the vibration index, there are many equally important issues such as method of measurement. While variations in the impedance of the transmitting medium can normally be neglected in noise measurement (with issues such as façade effects and meteorological influences being the only significant considerations) vibration is transmitted in media with widely differing impedances. Since the only vibration quantities readily measurable are displacement, velocity or acceleration, all of which are sensitive to the impedance of the medium such that for the same power a low impedance medium (such as a suspended floor in resonance) will exhibit amplitudes many times greater than a high impedance medium such as a large piece of mass concrete embedded in the ground. Furthermore, the effect of vibration on humans depends on vibration at the point of entry into the human body. For low impedance locations, such as resonant floors, the presence of the human body modifies the vibration characteristics.

In many cases, the main consideration is the likely effect of vibration in the environment (for example from an existing railway on the surface or underground) on a proposed new building. This may involve the assessment of vibration in "free-field", i.e. on an area of bare ground. Not only is it necessary to have regard to the effect of the presence of the proposed building on the ultimate vibration amplitudes, but also the choice of transducer and transducer installation affects the values measured in the ground. Widely differing practices are evident, from driving spikes into the earth to burying transducers in the ground. In buildings transducers may be attached to the structure in different ways, and the choice of location on the structure will produce significant differences in the results.

4. GROUNDBORNE NOISE

Vibration is a concern not only as a direct stimulus to humans or as a potential cause of building damage, but also indirectly by re-radiation of vibration as noise. This occurs classically where underground railways pass beneath noise-sensitive buildings.

From its point of generation to the re-radiating surface, the vibration which causes ground-borne noise differs from "classical" vibration only to the extent that acoustic frequencies are involved and significant levels of noise can be radiated by vibration at amplitudes below the threshold of perception by the sense of touch.

While indices such as VDV and PPV are appropriate to vibration affecting humans, and in the latter case buildings, re-radiated groundborne noise is assessed using conventional noise assessment indices. The relationship between the amplitude of vibration in the surfaces of a receiving room is complex, although rules-of-thumb are used.

5. PREDICTION OF GROUNDBORNE NOISE AND VIBRATION

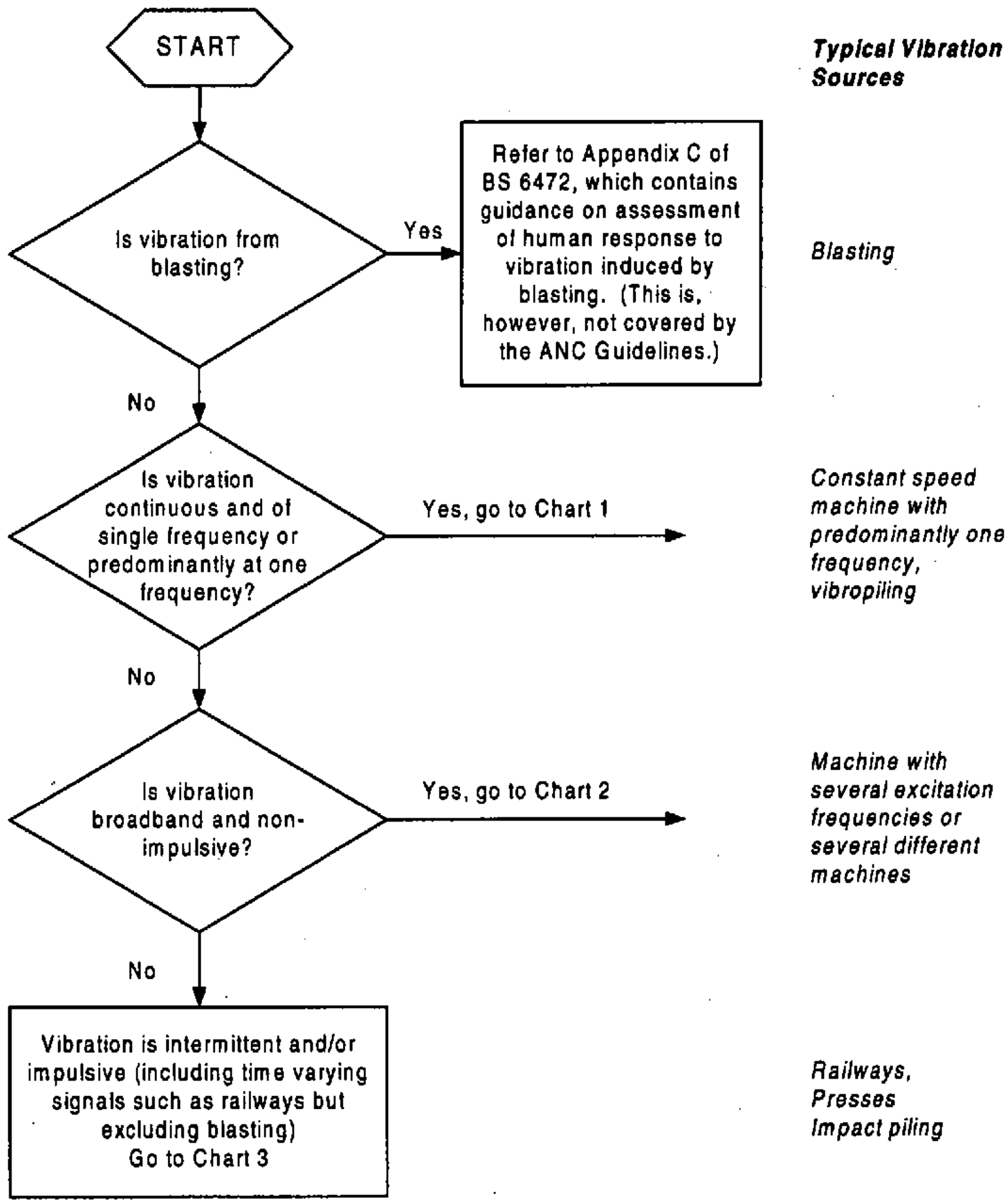
Because of the wide variety of the characteristics of the media through which vibration is transmitted, the prediction of vibration and groundborne noise is much more complex than the prediction of airborne noise.

Not only are structural dynamics involved, but the effects of layered media and the existence of at least three different types of wave propagation (shear waves, body waves and surface waves), and in some cases more, with widely differing wavespeeds and propagation characteristics, make the prediction of received levels far from straightforward. Techniques are available ranging from simplified algebraic methods only acceptable in restricted simple cases, through empirical methods to detailed computer modelling. The appropriate choice of technique depends on the purpose for which the prediction is required. Scoping models for use in the preliminary assessment, preliminary design and environmental impact assessment models and detailed design models require different levels of complexity. Simple models with few input parameters are appropriate for scoping purposes, while models capable of considering all the parameters that are critical to determining the absolute levels of groundborne vibration and the benefits, or otherwise, of different design and mitigation options are needed for environmental assessment and preliminary design models. For detailed design models, numerical approaches which can model vibration in the time domain in 3-dimensions may be appropriate.

REFERENCES

1. Measurement & Assessment of Groundborne Noise & Vibration, Association of Noise Consultants, 2001.
2. BS 6472:1992, Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)
3. ISO 2631-2:1989, Evaluation of human exposure to whole-body vibration. Continuous and shock-induced vibration in buildings (1 to 80 Hz).
4. BS 6841:1987, Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.
5. ISO 2631-1:1997, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – general requirements.
6. BS 7385-2:1993, Evaluation and measurement for vibration in buildings – Guide to damage levels from groundborne vibration.
7. BS 5228 Part 4:1992, Noise control on Construction & Open Sites. Code of Practice for Noise and Vibration Control Applicable to Piling Operations.

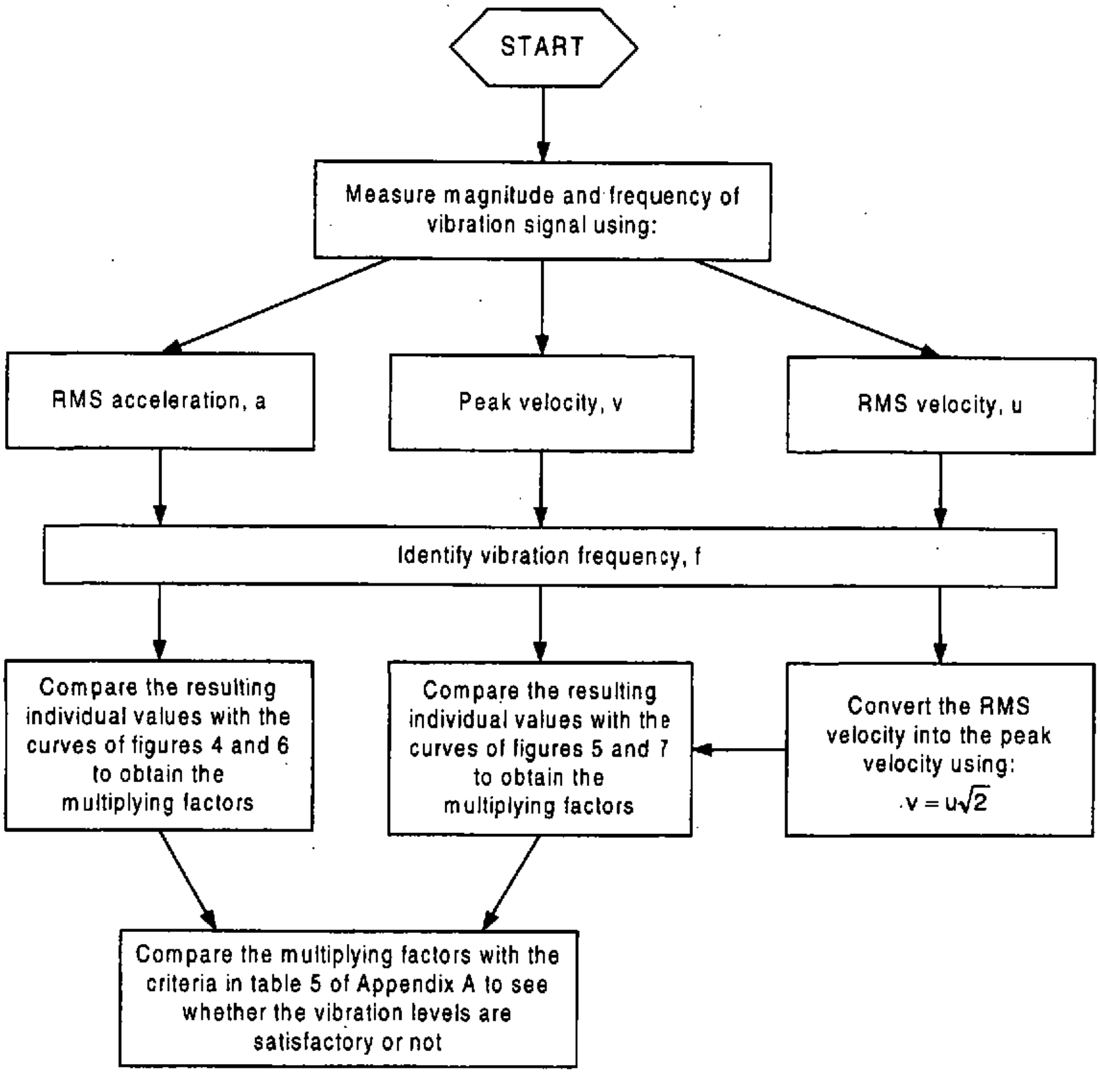
Chart 0 Guide to use of Charts 1 - 4



Notes

1. See Chart 4 for exposure correction.

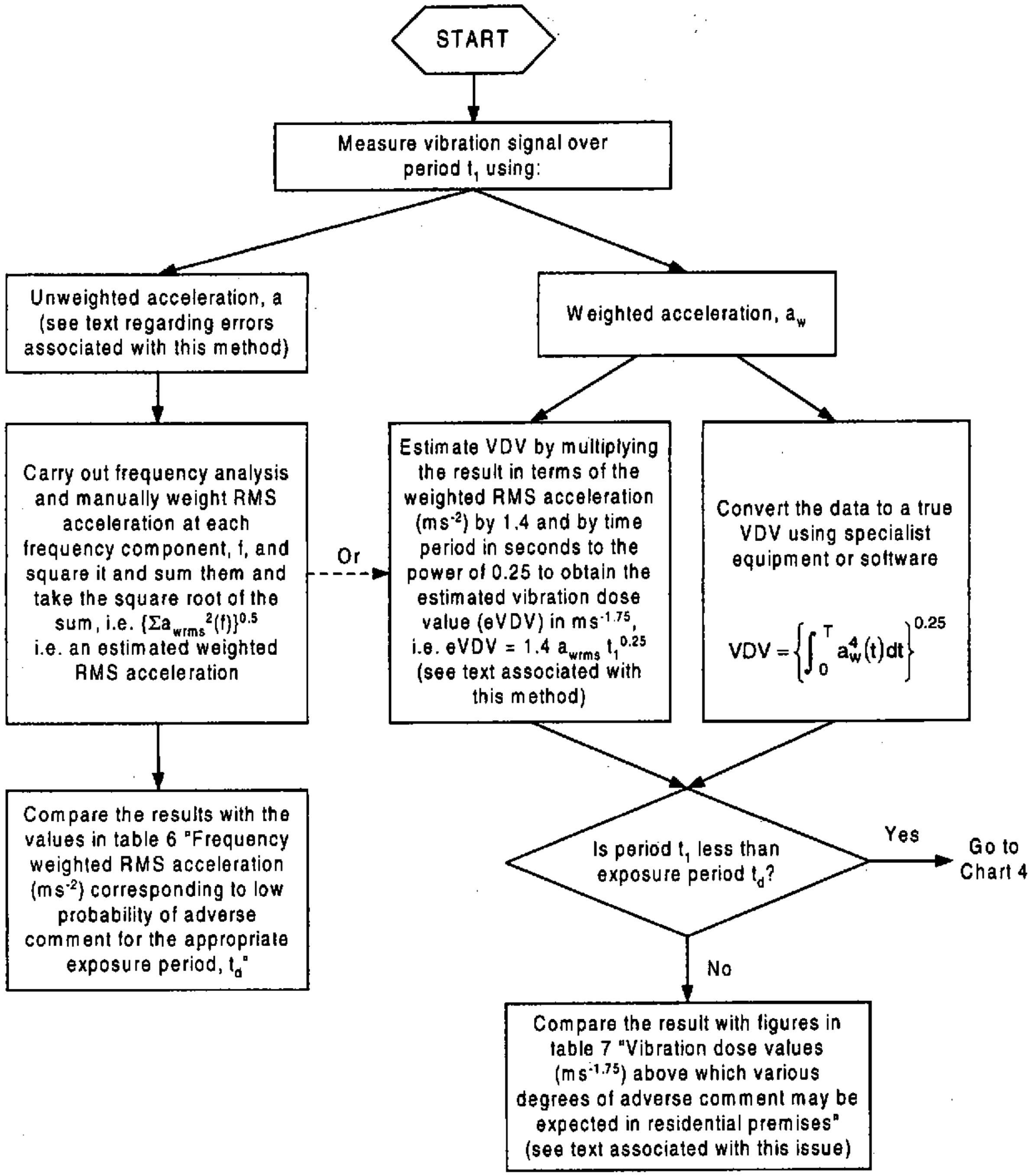
Chart 1 Continuous vibration of single frequency or predominantly at one frequency



Notes

1. For single frequencies (sinusoidal vibration) unweighted RMS acceleration, a is given by: $a \cong \omega u \cong \omega v/\sqrt{2}$, where $\omega = 2\pi f$
2. This includes signals where vibration energy is predominantly within a single 1/3 octave band or less.
3. Figure and table numbers refer to those in BS 6472: 1992

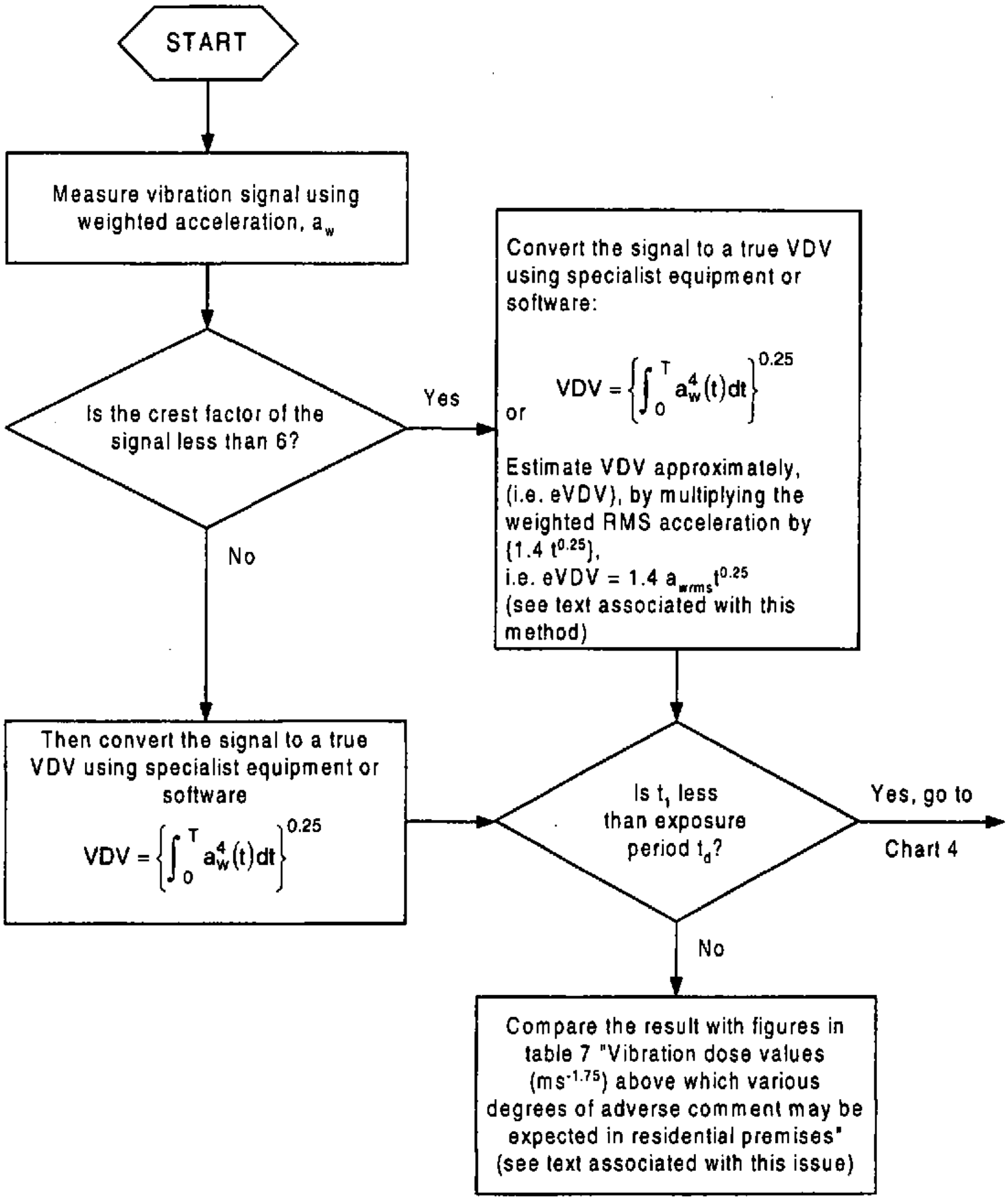
Chart 2 Broadband and non-impulsive vibration



Notes

1. For information on weighting curves see BS 6841: 1987
2. Table numbers refer to those in BS 6472: 1992
3. t_d = exposure period (in s). This is the length of time over either day or night that the vibration occurs. The exposure period may be equal to or less than the total day or night-time periods.
   Example (1): The vibration continues all day: the value of t_d = 16x60x60 = 57,600 s.
   Example (2): The vibration continues all night: the value of t_d = 8x60x60 = 28,800 s.
   Example (3): The vibration occurs for 4 hours of a day or night: the value t_d = 4x60x60 = 14,400 s.
4. a = unweighted RMS acceleration
   a_{wrms} = frequency weighted RMS acceleration, measured over period t_1
   $a_w(t)$ = instantaneous time varying value of the weighted acceleration.

Chart 3 Intermittent and/or time-varying vibration



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3. a_{wrms} = frequency weighted RMS acceleration, measured over period t_1
   $a_w(t)$ = instantaneous time varying value of the weighted acceleration.

Chart 4 Exposure correction

From Chart 2 or Chart 3 → START

Where vibration conditions are constant (or regularly repeated) throughout the day, only one representative period, in seconds, (of duration t_1) need be measured. If the measured vibration dose value is VDV_1, the total vibration dose value for the day, (VDV_d) will then be given by the following equation :

$$VDV_d = (t_d/t_1)^{0.25} \times VDV_1$$

where:

t_d is the duration of exposure per day (in s).(Note 2)

If, in a day, there is a total of N periods of various durations with vibration dose value, VDV_n, the total vibration dose value for the day is given by:

$$VDV = \left(\sum_{n=1}^{n=N} VDV_n^4\right)^{0.25}$$

or if all events have the same dose value

$$VDV = (N)^{0.25} \times VDV_1$$

Compare the result with figures in table 7 "Vibration dose values ($ms^{-1.75}$) above which various degrees of adverse comment may be expected in residential premises" (see text associated with this issue)

Notes

1. For information on weighting curves see BS 6841: 1987
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   Example (3): The vibration occurs for 4 hours of a day or night: the value t_d = 4x60x60 = 14,400 s.
3. Figure and table numbers refer to those in BS 6472: 1992
4. The above also applies to eVDV

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BS 6472: FACT OR FICTION?

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The latest revision of BS 6472:1992 Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz) has once again raised issues as to whether or not the guidance given in terms of satisfactory magnitudes has any basis in the real world and indeed whether or not the descriptors themselves are even appropriate for assessment purposes.

Such continuing debate, whilst perhaps disheartening for the more idealistic of those involved in the original and/or subsequent revisions of this Standard, is nevertheless a valuable and necessary contribution towards a better understanding of human response to vibration. It is also very much a reflection of the complex nature of the subject.

To standardise measurement parameters and how such measurements should be undertaken is difficult enough, but for a standard to then proceed to define magnitudes of vibration at which precise responses are likely across the population at large is, in reality, impossible. Human nature alone is too varied for such a standardised response let alone the numerous other relevant factors linked to such things as the vibration's characteristics and the presence of secondary effects.

Nevertheless, there has long been a need for a document such as BS 6472 as a reference in order to be able to objectively evaluate concern over an existing situation or for an assessment of likely future responses to a proposed situation. Hence the great value of this Standard from 1984 to date despite the wide range of views often expressed over its accuracy at representing human response in the real world.

The current document is recognised as in need of amendment by the revision panel with the major aim being to make the Standard easier to use and more logical in its approach.

Discussion has taken place concerning the value of the current guidance on satisfactory magnitudes and whether or not the descriptors of VDV and Particle Velocity are adequate for the Standard's purposes.

The consensus view is that despite the criticism of these factors no better descriptors or magnitudes of those currently in use are known to exist, at least not backed up by the necessary quality and quantity of detailed research that has led to the contents of the current Standard.

The current Standard gives some very specific guidance on satisfactory magnitudes of building vibration which for many users is its great value and hence a feature that must be retained. For others it is this very feature that causes a problem.

Despite the ranges of values given, many covering a magnitude factor of 2, users frequently comment that the reaction suggested in the Standard does not reflect the reaction of the individuals concerned in the survey under consideration.

In order to reflect many of the factors known to affect human response not only does the Standard introduce a considerable range in terms of satisfactory or other magnitudes but also consideration is given to some of the other relevant aspects such as vibration duration, time of day and the purpose of building occupancy. Blast vibration being perceived as a rather specific and identifiable source of input is addressed in a separate Appendix and it is intended that this separation be maintained in the latest revision.

Despite this and the associated commentary within the Standard over, for example, its application in civil engineering projects there is no doubt in my mind that some of the criticism is correct.

For example, it is, in my own experience, not difficult to recall situations where the Standard is suggesting that no complaint should be forthcoming and yet I am standing in front of some rather upset neighbours of an adjacent industrial process or transport system that clearly generates vibration at their property which they do not consider as satisfactory.

This situation seems equally valid for investigations in terms of both peak particle velocity and vibration dose values.

It is, however, also the case that the opposite situation is not at all uncommon, ie. that measured vibration levels well in excess of those deemed satisfactory by the Standard are seemingly quite acceptable to the local community.

So, is the Standard wrong in the guidance it gives? Is it the case that specific figures for human response should not be given irrespective of the perceived need for such advice?

Perhaps the least controversial of vibration levels able to be safely quoted are those associated with the thresholds of perception.

Approximately half the people in a typical population can be expected to perceive a continuous weighted peak acceleration of 0.015 ms^{-2}. This means that the most sensitive quarter of the people would perceive a vibration of 0.01 ms^{-2} and that the least sensitive would need vibration of 0.02 ms^{-2} peak or more for the onset of perception.

Hence we are fully aware of the fact that different people will always be expected to exhibit differing opinions even to the threshold of perception.

Perhaps then it should be no surprise that as the vibration level increases these differences of opinion still exist and perhaps even increase as the numerous other relevant factors concerning the environment and the individual's variables including personality come into play.

If we wish for a Standard to only express vibration levels at which no complaints are likely from the population at large, which is very often the request made of surveys in which we are involved, then surely the only applicable criterion is that of imperceptibility, presumably taken as at least the lower value of the interquartile range of 0.01 ms^{-2} peak.

Such a criterion would be draconian in application and would not result in a particularly useful Standard.

What we need to recognise in using the Standard, is that it is normal to have a relatively large variation in terms of human response.

As practitioners who respond to concerns expressed over vibration levels generated within residential and industrial properties we should also not lose sight of the fact that we will in general be investigating a biased sample of the population ie. those more likely to be disturbed by any given vibration. Hence an investigation which results in an assessment according to BS 6472 that suggests a low probability of adverse comment despite the complaint that has generated our presence, must be expected on occasion and should not necessarily be taken as an indication that the Standard is incorrect.

It is not at all unusual for a community of many households to be exposed to a very similar level of vibration and yet only one or two households consider that the vibration warrants investigation and / or control.

Hence our experience is that while we find that the Standard is an adequate descriptor in many cases it is not usual for complaints to be received at or below 'satisfactory' levels and, conversely, for levels well in excess of such values to be well accepted by a local community.

In 1998, a DETR, report undertaken by Vibrock Limited was published which included the details of a number of surveys that are relevant to this debate.

The report entitled "The Environmental Effects of Production Blasting from Surface Mineral Workings" was the culmination of a three year study into a number of factors associated with open pit blasting of which perhaps the prime one was groundborne vibration as relevant to Appendix C of the current BS 6472 Standard.

Over the study period a number of very detailed surveys were undertaken in order to realise the aim of the project which was to offer guidance to DEFRA, local authorities and the minerals industry on how best to minimise the adverse effects which may arise during production blasting from surface mineral workings whilst still maintaining viable and economic production.

The study therefore required to not only detail the likely environmental consequences of production blasting but also most importantly, how these effects are perceived by a site's neighbours and hence the need for the surveys.

The surveys, four in number, each targeted a specific interested party, namely Mineral Planning Authorities (MPAs), Environmental Health Officers (EHOs), the site operators and the general public neighbouring sites that were currently blasting.

Every MPA, some 168, were a questioned together with each Environmental Health Department, approximately 400 in number. Mineral operators were contacted via their trade organisations with replies from a total of 195 quarries and 26 opencast coal sites. These surveys were followed by face to face interviews, by professional interviewers, with 744 residents living adjacent to operational sites.

Hence over the period of this study an immense amount of data was able to be collected and collated from interested parties and, specifically, from those likely to be directly affected by any environmental effects, one of which was clearly groundborne vibration.

In this respect three main findings became evident:-

i) that despite ever decreasing allowable vibration criteria, a corresponding reduction in blast related complaints has not been evident

ii) that there is no correlation between vibration magnitude and complaint level once the threshold of perception is exceeded

and iii) that the value of a good public relations programme is paramount.

There is no doubt that the planning conditions by which all mineral sites must now operate have become progressively more restrictive in terms of their ever decreasing allowable vibration criteria. This is largely as a result of MPAs seeking to reduce the number of complaints. However a corresponding reduction in blast related complaints is not evident.

Once the threshold of perception is crossed there is no correlation between vibration magnitude and complaint level and hence once this is recognised it should be no surprise that the progressive reduction in criteria does not reduce complaint levels, unless, of course, this reduction results in imperceptibility, which is simply not a viable option for the vast majority of operations.

A good example of the situation was given by a Mineral Planning Officer who reported that a site working under an old permission with no blasting conditions regularly subjected some of the adjacent properties to a vibration level of between 10 to 20 mms^{-1}. Only when vibration exceeded 20 mms^{-1} were complaints likely. At the same site, however, when investigating a particularly vociferous complaint in a different area several blasts were monitored all of which gave rise to less than 1 mms^{-1} at the property concerned.

Thus acceptability is very much a personal matter and what may be acceptable to one individual may not be to another.

Perhaps this range in tolerance is far greater then that suggested through the Standard and / or that the revised Standard should explain more clearly to its user that this range exists.

The third main survey finding of the DETR report was the overriding value of a good public relations programme that informed local residents of site operations on a regular basis. Such programmes were strongly welcomed by all of the parties interviewed.

Raising neighbours' awareness and understanding of surface mineral operations has a significant beneficial effect in terms of minimising complaints and is thought to be very often the main factor in determining complaint thresholds in terms of acceptable vibration magnitudes.

It is also our experience that the importance of how the potential complaint views those operations that he or she considers as responsible for the disturbance is of prime importance in many other situations unrelated to blasting, such as in civil engineering projects, traffic induced vibration and that produced by a local factory unit etc.

In a perfect world we would be able to quantify this effect and factor it into the Standards' suggested criteria but in reality, we are not yet at that stage and maybe we never will. However, what we can do is to recognise its importance in relation to the Standard.

Perhaps we are expecting too much from the Standard. One or two parameters are never going to be enough to fully explain human response, especially scientific ones devoid as they must be of emotion.

Evidence from the discussed specific area of research suggests that such parameters, whilst both necessary and useful, can only be one aspect of what determines complaint level.

Nevertheless, the Standard is a very useful asset to practitioners in this field and it is anticipated that its revision will further enhance its value.

MEASURING AND ASSESSING THE SOUND YOU INTEND, NOT EVERYTHING ELSE INSTEAD.

Richard A. Collman Acoustical Control Engineers Limited and Belair Research Limited

1. INTRODUCTION

This paper was originally presented at the Autumn 2000 conference and subsequently edited in the July/August edition of Acoustics Bulletin. Since the original paper, the author has refined the technique and noted that this often requires less measurement and analysis time than would be the case for conventional statistical parameter assessments. Therefore this approach provides superior data; enabling more detailed and reliable analyses; in less time and consequently at lower cost, than would otherwise be the case.

In order to make sound measurement more accessible, a great deal of very useful work has been undertaken towards simplifying the expression of sound levels, first by transforming frequency content to a single number, in terms of dB(A). Even though it is also mis-applied on occasions, the use of this single figure 'A' weighted sound level has provided many benefits including acting as a platform for further simplification.

The subsequent development of statistical parameters such as L_{Aeq}, L_{A90} and L_{AMax}, integrating variation with time, into the single figure value, has further assisted with the measurement and assessment of acoustic environments. Indeed this approach underpins many standards, guidance documents and even legislation, such as BS4142: 1997, PPG 24 and the Noise at Work Act.

Long term averaging is appropriate for many assessments of 'environmental noise' and noise sources that are relatively stable or change gradually such as road traffic noise. However, this is not suitable for other noise sources, such as those that produce significant variations of sound level over short periods of time, particularly when such changes are themselves subject to considerable variation.

One of the greatest difficulties faced by many practising acousticians is that of obtaining reliable sound level measurements under site conditions rather than in a laboratory. The author and other colleagues have successfully used this technique for many varied projects and different applications for several years. Throughout this time the methodology has consistently provided high quality, reliable data that has facilitated subsequent analysis of the measurements obtained, whilst minimising the overall costs of the measurement and analysis involved.

2. EXISTING MEASUREMENT AND ANALYSIS TECHNIQUES

There are certain principles involved in the measurement and analysis of sound levels when using long term statistical parameters. These can be broadly summarised as follows.

2.1 Measuring the sound level

Identify suitable measurement locations to quantify the required sound level and minimise extraneous noises, which should also be quantifiable. Measure the sound level for the required period of time, using consistent averaging periods unless there is a valid reason for not doing so such as changing from day to night at 11pm for an assessment in accordance with BS 4142:1997. If extraneous noises affect the measurement either re-start the measurement, or use a 'Pause' function, whilst ensuring the extraneous noise is excluded before it affects the measurements.

One possibility is to concurrently tape record the sound so that more detailed analyses can be undertaken later, particularly if extraneous noises affect the 'on site' parameter measurement. Whether measurements are paused or not, it is necessary to ensure that the statistical parameters reflect a combination of the intended source noise and of other ambient noise levels.

Record a concurrent timed 'log' with details of all acoustically significant events that may affect the subsequent analysis, so it can be identified which parameters each such event has affected.

2.2 Analysing the data

Record the statistical parameters for the various time periods. Compare the statistical parameters and the timed notes, trying to quantify the various compromising effects of extraneous noise so that different statistical parameters can be reliably compared to achieve an appropriate assessment. Report on the findings of the analysis including an estimate of any uncertainties such as that due to extraneous noise sources.

3. AN ALTERNATIVE MEASUREMENT TECHNIQUE

The preceeding discussion shows that, for a reliable assessment of long-term statistical parameters, it is critical to ensure that the effects of extraneous noise sources are minimised and quantified. However, even where it is possible to undertake such an assessment, there are many situations where it is not appropriate to consider only one or two parameters condensing many subtleties of time and frequency into a single number. This is due to the loss of information that occurs when all the variation with time is coalesced into a single, average value.

The reliability of the measurement and analysis techniques above is usually significantly affected by extraneous noise sources such as passers by asking 'what you are doing'; dogs barking; or any of the many other noise sources that always appear as soon as a sound level meter is switched on.

A further complication arises when assessing noise sources with different characteristics. An assessment of the acoustic impact on residents living beside a road, of the noise associated with deliveries to a factory, should consist of at least two comparisons. The vehicular noise should be compared to road traffic noise, but unloading activity has very different acoustic characteristics.

The problem with the use of a long term eg. 5 minutes or 1 hour, statistical average is that this averaging process destroys most of the information about different acoustic characteristics of the noise sources. In addition to this, such long term averages are almost always affected by several different noise sources, making it even more difficult to accurately quantify the significance of any specific noise producing activity.

3.1 Principle of the method

The principle is very straightforward – instead of averaging value over the measurement period, it is better to monitor how the sound level changes constantly and to use this information for any assessment of the noise. It is then possible to more accurately quantify the effects of the noise source under consideration and of other extraneous noise sources. With suitable instrumentation, little additional work is required to obtain this information. The original paper considered that 'overall time for measurement and analysis will not be significantly different' however further consideration has shown that the measurement time can often be significantly reduced. The analysis will also be far more specific than is possible with only long term average data, allowing a more reliable analysis, providing better information and possibly enabling other cost savings.

In order to monitor how the sound level changes over time, the only difference compared to taking a longer term average measurement is using the sound level meter to log consecutive short duration L_{eq} values and then down-loading this data for subsequent analysis.

For most applications, a convenient short duration measurement averaging time is one second. This is short enough to provide several samples for most events such as vehicles passing; conversation; or intermittent plant operation, but does not result in unmanageable quantities of data. For very short duration events such as impulsive sound, a shorter period such as 0.1 seconds may be appropriate. The latter period also has the advantage that the maximum or minimum value during a specific measurement period is a good approximation of the L_{Max} or L_{Min} value.

Most applications involving statistical parameters are concerned with the 'overall noise level', rather than more detailed data such as octave band frequency analyses for noise control purposes. Where just the overall noise level is of interest, it is only necessary to log the single figure 1 second L_{Aeq} values. Where spectral information is required, it is often possible to measure this relatively quickly and investigate the time dependent characteristics of the overall sound level separately.

A good estimate of a longer term L_{A90} (or other statistical parameters) can be derived from the 90th centile of the consecutive 1 second L_{Aeq} values ranked in descending value. From the author's experience, if the sound level meter also logs 1 second L_{A90} values (even though these are relatively meaningless in isolation), the 90th centile of the 1 second L_{Aeq} and of the 1 second L_{A90} values will bracket the longer term L_{A90} value that the meter would calculate. Under most conditions these two values are consistent to within a few tenths of a decibel for periods of 5 minutes or more. This means that in addition to the better quality data available from the consecutive 1 second L_{Aeq}s, the longer term statistical values can also be derived, for comparison with other data.

4. FOUR EXAMPLES OF A MORE DETAILED LOOK AT THE VARIATION OF SOUND LEVEL WITH TIME

These examples provide an indication of the power and flexibility of this approach.

4.1 Assessing railway noise as part of the ambient sound level

This project involved the assessment of the ambient noise level and particularly the contribution from railway noise, around a proposed residential development site. The site is adjacent to a railway line, near Heathrow airport and subjected to road traffic noise. In addition to this, an enthusiastic guard dog complete with rattling chain protected the neighbouring commercial site.

With the variety of different noise sources having different propagation and other acoustic characteristics, any long term statistical parameter could not provide suitable information about the relative significance of the different ambient noise sources. This information was essential for any modelling of acoustic propagation around the proposed residential development, particularly with the proposed acoustic barrier towards the railway line and the lack of any screening benefit for aircraft noise. In addition to this, the noise from the guard dog had to be excluded from the assessment because the presence or absence of a guard dog is not a significant planning issue.

Using consecutive 1 second L_{Aeq} values together with a synchronised log of events, it was relatively easy to determine the contribution from the different noise sources. The example Graphs 1 to 3 together with the log in Table 1 show this analysis. The black lines on each graph identify the time when that particular source was dominant, whereas other sources dominance is shown in grey. Where colour graphs are used, a single graph with the different noise sources shown in different colours, makes visual comparisons even more straightforward.

Table 1 – Example log of acoustically significant events (T-Train, A-Aircraft, O-Other, B-Barking)

Start Time	Duration	T	A	O	Details
07:15:10					Gate opening
07:15:35	19s				Dog barking – 8m
07:16:02					Dog moving - chain noise
07:16:13				B	
07:16:37	43s		A		
07:17:10		T			
07:17:22					Barking & car noise
07:25:56					Pigeon
07:28:13					Adjacent premises activity – speech / impulsive
07:30:15	15s				Adjacent premises – roller shutter door

Graphs 1 to 3 show that the long term L_{Aeq} of 69dB(A) is affected by the neighbouring dog almost as much as train noise. Also, a reduction of the train noise level by 10dB(A) would make the aircraft noise equally dominant and other sources such as road traffic noise would become most significant at this location. None of this could be determined by only using long term statistical data.

4.2 Assessing the effect of delivery vehicle noise

This project concerned the acoustic impact on neighbouring residents from early morning deliveries. A few months before the author's involvement, a separate survey had been undertaken, based only on long term statistical parameters. Some data provided in a report of this survey is in Table 2.

Table 2 – Example of delivery noise log (based solely on long term averaging)

Time	L_{Aeq}	L_{AMin}	L_{AMax}	L_{A90}	Notes
05:07	45.8	37.6	62.6	39.6	Roller shutter door opened, trolley wheeled outside
05:19	44.9	39.5	58.4	41.1	
06:03	48.8	41.9	67.4	44.1	3+ cars from cul de sac
06:14	48.1	42.9	65.4	44.1	2 cars from cul de sac
06:24	48.0	42.8	65.1	44.1	
06:57	56.1	44.2	82.3	45.6	Gate open, 2 del vehicles in, 2 cars on side road
07:09	52.9	44.8	70.7	46.1	1 del vehicle out
07:20	54.0	45.1	74.1	46.6	2 cars from cul de sac, van on side road

Based on the variation in L_{Aeq} and L_{A90}, the perhaps surprising conclusion, was that deliveries were not acoustically significant because 'deliveries did not significantly alter L_{Aeq} or L_{A90} values'. However, the opposite conclusion could also be drawn from the L_{AMax} value of 82.3dB(A) from 06:57. This contradiction shows problems that can arise when using only long term statistical data.

The author subsequently recorded series of consecutive 1 second L_{Aeq} values, together with synchronised logs of events at different locations both during deliveries and without deliveries occurring. Graph 4 shows some of the information obtained and this is summarised in Table 3. Based on this more detailed information, it can be seen that at the residential cul de sac, the underlying background noise level varies between 43dB(A) and 49dB(A) at this time of the day. Vehicles on the Ring Road or side road typically produce levels of 50dB(A) to 55dB(A) whereas delivery vehicles typically produce levels of 47dB(A) to 51dB(A), however the delivery vehicles also produce maximum levels of 59dB(A).

Table 3 – Comparison of noise levels based on consecutive 1 second L_{Aeq} graphical analysis

	Facing Ring Road	From Ring Road	Cul de sac
Underlying background noise level	50+	45-50	43-49
Vehicles on Ring Road	65-75 typ, 90 max	60-70 typ, 75 max	50-54 typ.
Vehicles on Side Road			55 typ.
Delivery Vehicles			47-51 typ, 59 max

4.3 Gathering reliable data in a short period of time

Aside from the cost savings of gathering sufficient data in a shorter time, this is often a major advantage with limited time when the weather is suitable for taking measurements, or restricted times when specific noise events can be measured. Graph 5 shows the data gathered in a twenty minute period after 5pm. Conventionally, a 1 hour L_{Aeq} and L_{A90} would be measured providing two numbers to assess the acoustic conditions from. Even using more statistical data such as L_{A10}, L_{AMax} and L_{AMin} would still provide relatively little information. However in twenty minutes, the underlying noise level is clearly shown together with the significance of overground trains on tracks 1-4 and underground trains on tracks 5-6.

4.4 Assessing forklift activity noise breaking out of a warehouse

This application is more complicated than the previous examples and requires more sophisticated instrumentation. In this case consecutive one third octave band L_{Eq} and the single figure L_{Aeq} values were logged every second for two minutes. The aim was to compare the noise level of forklift truck activity inside the building with, and to assess the effect on, the ambient noise level outside the building. The upper line on Graph 6 shows the ambient noise level, the middle line shows the 315Hz one third octave and the lower line shows the 2500Hz one third octave. Previous work showed that the forklift truck activity produced noticeable increases at 315Hz inside the building and the forklift hooting produced most energy in the 2500Hz band.

Graph 6 shows that any 315Hz noise due to forklift activity was masked by the ambient noise but the forklift hooting produced measurable increases, which were subjectively noticeable outside the building. However this clearly shows that the forklift hooting noise level is significantly below the overall ambient noise level and the overall ambient noise level is not affected by the forklift truck activity. Undertaking this assessment using longer term measurements would have taken considerably longer to gather any data, which would also have been of limited use for the analysis.

5. COMPARISON OF THE TWO TECHNIQUES

5.1 Similarities and differences

Although the two techniques of long term averaging and consecutive short duration logging may appear to be fairly similar, there are some very distinct differences due to the very different philosophies behind the two methods. Both methods involve measuring the sound level for periods of time such as 5 or 10 minutes to 1 hour or longer. Conventional long term averaging aims to gather a few values that provide an overview of the acoustic environment, but which are often significantly affected by extraneous noise sources. This method aggregates all noise sources into single figure values for each averaging period, making assessments of different noise sources extremely difficult and unreliable.

Consecutive logging aims to show how the noise level varies over time, in a way that allows individual events to be easily identified and quantifiable. This provides a much clearer understanding of how the acoustic environment is constituted, facilitating better analysis of alternative attenuation schemes for example. However, consecutive logging also enables single figure long term average values to be easily derived, where these are required for a broader overview, or for comparison with other data.

5.2 Suitable instrumentation

By today's standards, the basic technique does not require particularly sophisticated instrumentation and a large proportion of the integrating sound level meters that provide long term statistical data can also provide the necessary logging and downloading capabilities for this analysis. With apologies to organisations that have been omitted from the list, the following is an alphabetical list of several different providers of acoustic instrumentation that the author understands, produce suitable instrumentation for this methodology. This list does not reflect any views that the author may have regarding different providers of acoustic instrumentation.

AcSoft - Bruel & Kjaer - Casella CEL - Castle Group - Cirrus Research - Norsonic

6. CONCLUSION

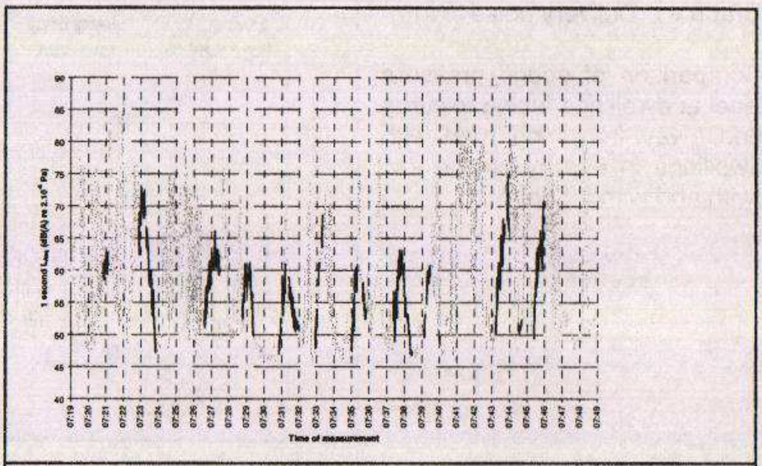
Although the developments in producing single figure parameters have a wide range of uses for the assessment and comparison of sound, there are also many situations where these are misapplied and more detailed information is required. The advantages of a single figure dB(A) value combined with a visual (graphical) analysis of the variation with time, provide a powerful technique for identifying and quantifying what is actually happening, rather than the more obscure information provided by only using long term statistical parameters.

Far better quality data can be often gathered in less time than would be required for conventional techniques and the analysis time may also be reduced. The overall result is more specific data and a more reliable analysis, providing clients and other interested parties with a better understanding of what the numbers actually mean to the listener. This technique is effectively a hybrid of older methods plotting sound pressure level, together with newer methods of averaging, combined using modern instrumentation and computerisation.

Graph 1 – Railway noise

Aircraft dominated sound pressure level (black line) L_{Aeq} 56dB(A).

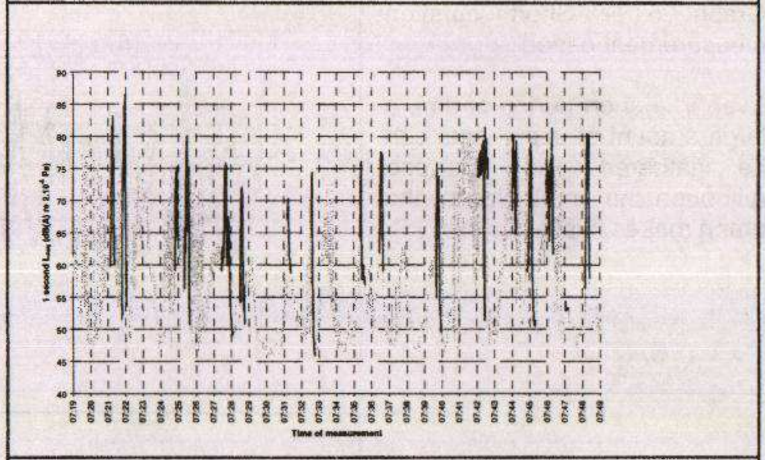
Overall (grey line) L_{Aeq} 69dB(A)



Graph 2 – Railway noise

Train dominated sound pressure level (black line) L_{Aeq} 66dB(A).

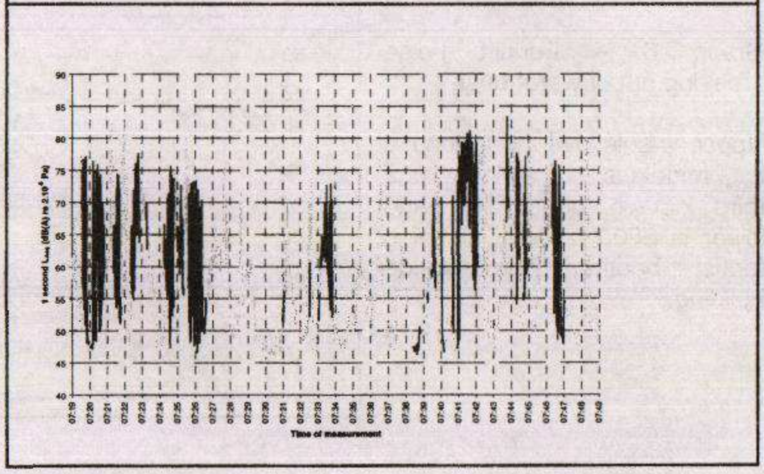
Overall (grey line) L_{Aeq} 69dB(A)

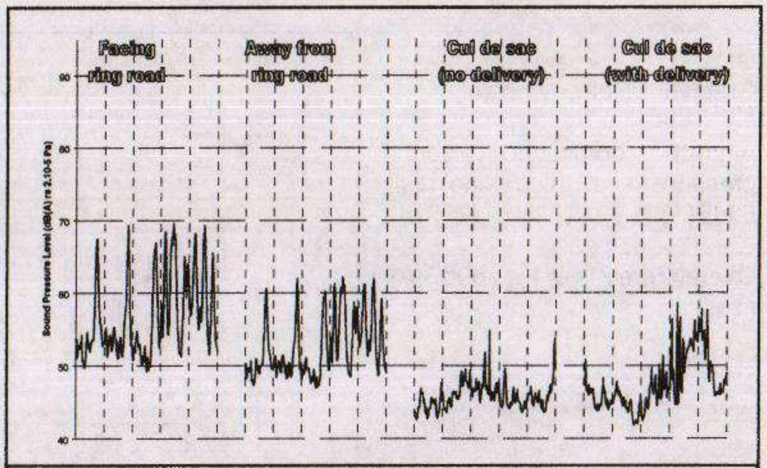


Graph 3 – Railway noise

Dog dominated sound pressure level (black line) L_{Aeq} 65dB(A).

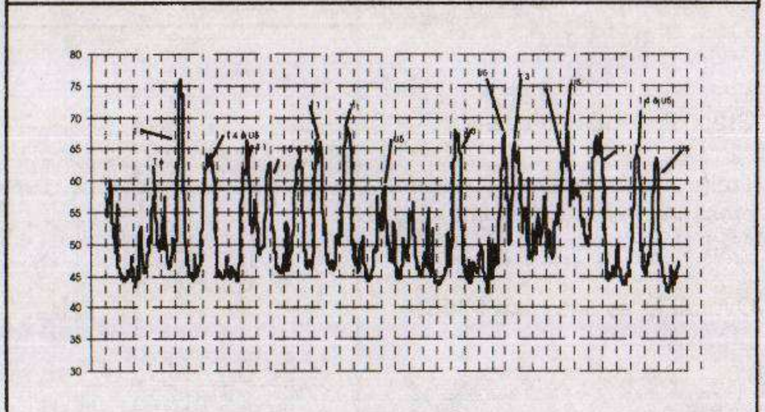
Overall (grey line) L_{Aeq} 69dB(A)





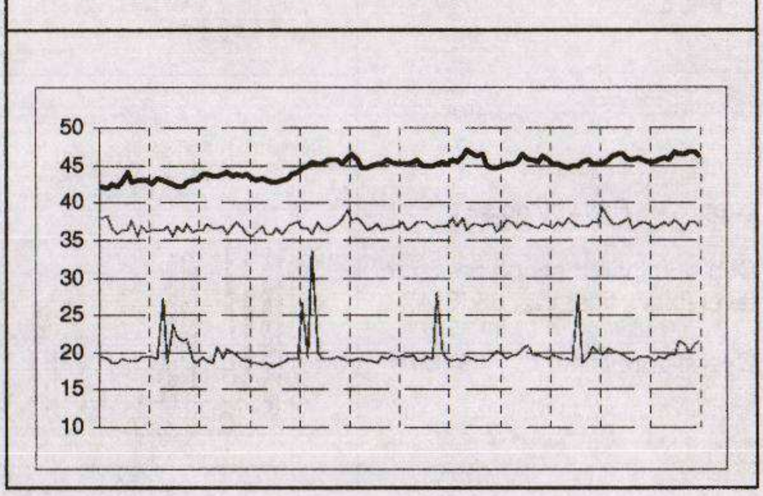
Graph 4 – Delivery noise

Comparison of sound pressure level at dwellings facing towards and away from ring road with dwellings in nearby cul de sac (with and without delivery).



Graph 5 – Short duration measurement period

Even in a short period of time a large amount of useful data can be gathered and analysed (although the small size of the graph makes this less clear)



Graph 6 – Forklift noise breaking out of warehouse

Upper line is overall 1 second L_{AEq}, middle is 315Hz linear, one third octave band data and lower is 2500Hz data, showing forklift hooting from inside building.

GLASTONBURY FESTIVAL - NOISE MEASUREMENT AND CONTROL

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1. INTRODUCTION

This paper describes the mechanisms by which Mendip District Council monitor and regulate noise at one of Europe's premier music events - Glastonbury Festival of Performing Arts. Prior to each event Mendip's EHOs are involved in a considerable amount of planning and preparation, starting some 6 months before the festival event. Noise control duties typically involve 20 to 25 staff undertaking around 70 shifts. Monitoring noise at the event consists of a range of duties such as assisting with setting PA levels, noise compliance checks, dealing with complaints, monitoring market traders PA systems, dealing with unlicensed sources and checking compliance with Noise at Work Regulations. In recent years the introduction of relatively low-cost remote noise monitoring using general purpose noise measuring instrumentation has opened up a whole new way of controlling environmental noise.

2. HISTORICAL DEVELOPMENT

In 1970, an entrance fee of just £1.00 permitted about 1500 "free spirits" to enjoy a weekend of listening to the likes of Quintessence, Marc Bolan and T-Rex, whilst at the same time savouring the undoubted "delights" of free raw milk!!

Almost three decades later, and at slightly greater expense, over 100,000 people now enjoy the delights and unique atmosphere of Europe's premier outdoor music event with over **250** acts performing on **twelve** stages, as well as many other attractions ranging from cabaret, theatre, comedy and circus, to numerous children's activities on a 700 acre site. This is Glastonbury Festival, millennium style.

Before the Noise Council's Code of Practice on Outdoor Music Events was even in its embryonic stages, the Festival was limited to an off-site noise Condition of 60dBL_{Aeq} (15min) measured at a nearby residential property. This Condition was specifically designed to control noise from the then "Pyramid Stage" which was unfortunately destroyed in a fire shortly before the 1994 festival. The re-named Main Stage which replaced it was used for 5 festival events, then for the Millennium a new Pyramid Stage was constructed – a phoenix rising from the ashes!

The logic or even the "hunch" behind the 60dBA off site limit has unfortunately been lost in the midst of time. However, the level has been found, over a long succession of events, to correlate very well with a basic "no nuisance" criterion and therefore continues to be the yardstick on which the off-site Noise Conditions continue to be based.

As the event has grown, and consequently the number of stages have grown from one to **twelve**, there has been a need to expand the number of locations at which the 60dBA limit is applied in order to limit the impact on local residents. The task of monitoring such a limit, at what is now four off-site locations over a period of three days, where the line up of bands on each stage is such that music is almost continual between 10.00 hours and 00.30 hours daily (midnight finish on Sunday), is somewhat challenging. If you add to this the fact that, whilst the main stages shut down at 00.30, various entertainment and market traders play music until the sun rises, it can be seen that noise control is no mean task. The culture and size of the event is such that it is not considered practical to impose a time limit on all cabaret and other activities so in recent years the site never sleeps over the 3 day event!

3. PLANNING AND PREPARATION

Noise is but one of many aspects that the Council must seek to control by way of conditions, with 15 specific Conditions attached to the 2000 licence. However, it is undoubtedly one of the few areas which, if it all goes wrong, has the potential for causing the greatest disturbance to nearby (and not so nearby) village residents.

The question for the Council therefore is, how do you effectively control noise from 12 open air stages, countless additional attractions and some 800 market traders, many of whom have their own sound systems with combined sound power outputs of in excess of 30KW? Not to mention the general noise associated with the permitted 100,500 festival goers and the possibility of unlicenced raves or other rogue noise sources!

Each year the strategy to deal with noise has been tweaked following past experiences and future concerns. For the Millenium event, Mendip's strategy at the planning stage was to :

- Take all reasonable steps to prevent pre and post festival noise problems arising.
- Ensure that the Licencee provide improved information on site distribution of sound sources likely to be operating on site at any one time.
- Specify which stages, cabaret and other entertainment to be limited to core hours (10.00am - 00.30am).
- Identify full details of any entertainment venues wishing to operate outside these hours.
- Provide training session and improved training pack for all noise staff.
- Operate prior PA approval system for market traders.
- Take steps to ensure that provision made for dedicated security teams to accompany staff during night time "graveyard" shifts.

This strategy involved many hours of planning, meetings and checking of information submitted to the Council by the Licensee, prior to the start of the event. This is a very different process to just a decade ago when the first involvement for Noise Officers was to draft a few conditions and the next, to go on site at the beginning of the event to undertake a sound test!

4. THE MONITORING STRATEGY

In summary monitoring of the 2000 event consisted of the following approach:

I. To maintain flexibility and responsiveness in order to both adequately monitor noise from the Festival, and also to deal with unforeseen problems as they occurred.

II. To maintain close liaison with each other and with the Sound Engineers at the main stages to ensure compliance with the Licence Conditions.

III. To patrol the site each night until approximately 05:00 hours in order to monitor compliance with the Licence Conditions.

IV. To monitor the market areas so as to ensure that the approved sound systems only are operated.

V. To ensure, so far as reasonably practicable, compliance with the Noise at Work Regulations, 1989.

The main tools and techniques for enabling the monitoring strategy are as follows:

- The use of Pre-emptive Noise Abatement Notices.
- Using hand held sound level meters to sound test and check compliance of main noise sources.
- The use of fixed analysers at suitable locations!
- The use of hand held radios, phones, and four wheel drive vehicles.
- An Off site Village Office and an on site Office.

The process of noise control involves the deployment, both on-site and off-site, of Teams of officers equipped with often temperamental radios, with the specific task of ensuring that off-site levels are not exceeded. This requires the on-site teams to establish a level ($L_{Aeq(1min)}$) at the mixer positions (or "front of house") which correlates with non-exceedance of the off-site limit. Continual dialogue between the on and off-site Teams over the duration of the event thereafter should ensure satisfactory compliance.

For many years, the 4 off-site noise monitoring locations have been equipped with Continuous Noise Analysers programmed to monitor a range of statistical parameters averaged over fifteen minute periods. Whilst this has been generally acceptable, there are clear disadvantages to this method of monitoring, in as much as they;

- require regular officer attendance in order to adequately monitor the event
- are not real-time measurements
- do not benefit from the capability to carry out real time frequency analyses

In an attempt to overcome these problems, and to generally improve the efficiency and effectiveness of noise control, the Council liaised closely with Bruel and Kjaer who had kindly offered to allow the Council to conduct a trial of a developing remote noise monitoring system, for the 1999 festival.

The system (see Figure 1) consisted of an outdoor microphone feeding acoustic and calibration signals to a Type 2260B Investigator linked to a GSM mobile telephone. A laptop computer running Type 7820 Evaluator software completed the system and was located at the temporary Environmental Health office positioned within the Festival site itself.

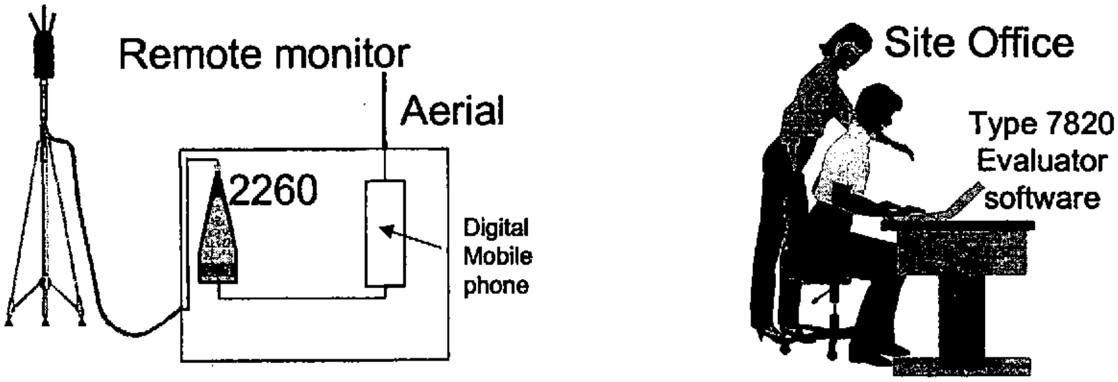

Figure 1: Schematic diagram of the noise monitoring system
(acknowledgements Bruel and Kjaer)

The real-time noise analyser, was set to measure and store a vast range of noise parameters, including one third octave frequency analyses, at five minute intervals during the sound tests, and at 15 minute intervals at all other times.

In this way, the current and past results were available at any time by requesting the Evaluator software to call the monitoring station and download its latest measurements. This procedure resulted in many practical benefits to the Environmental Health Teams, including;

- instant access to results, without the need for often difficult and time-consuming journeys to remote monitoring locations.
- the ability to give an immediate response to the Sound Engineer's requests to increase the volume!!! Indeed, where necessary, changes could be monitored immediately at the appropriate location and quick decisions made.
- The ability to respond to changes in meteorological conditions and the effects of wind gradients.
- identification of extraneous noise within the ambient noise profile by referring to simultaneous frequency analyses.
- the ability to interrogate the stored information during the post-event period, and during quiet periods of the Festival!!

This is a completely independent noise monitoring system requiring no challenging connections, other than the site office land line telephones. It should however be noted that a strong GSM network signal is required, and that this is very much area dependent. Without doubt, the trialled remote noise monitoring system proved to be highly successful in permitting considerably more effective and efficient control of noise from the Main Stage in 1999. It permitted not only a quick assessment of complaints, but also facilitated a quick response to the Sound Engineers inevitable requests for increased amplification!!

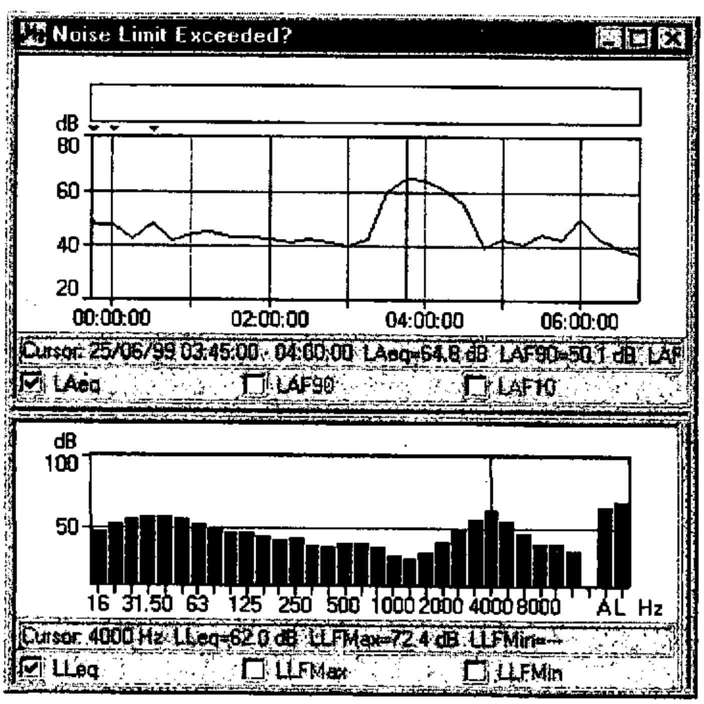

Figure2 : Results showing that the exceedance of the 60dBA ($L_{Aeq,15mins}$) limit is caused by a high-frequency source: the dawn chorus!

5. APPRAISAL OF NOISE CONTROL MEASURES

Looking ahead, the potential for the remote noise monitoring system is considerable, both at Glastonbury Festival and also for other applications. In particular, the following are highlighted as potential developments and/or uses;

- general-purpose short- to medium-term automatic monitoring of any noise-sensitive event (e.g. music festivals, pubs and clubs, motor sports, water sports etc.). It could well be used to monitor noise abatement zones.

- monitoring and control of low-frequency noise for music festivals – immediate effects can be observed from the remote station and mixers adjusted accordingly.

- recording of the audio signal at the remote station for subsequent replay or analysis.

- noise source location investigations by observing the (remote) effects of switching on and off potential sources in turn, or comparing frequency spectra.

Notwithstanding its clear advantages, there are a number of issues which need to be appraised before deciding on the extent of reliance on remote noise monitoring (this is a particular consideration at festivals or other events of short term duration). It is necessary to ensure that the phone network has a strong enough signal in the locality; that chosen monitoring locations are secure and have suitable mains power (battery pack may be available), and there are other means of monitoring should there be a power failure/fault with the system. Experience has shown that adequate pre-planning and contingency plans are invaluable; it is prudent to retain other noise monitoring options rather than use the remote system as a substitute to them.

One of the problems to overcome for annual events is that a site that is suitable one year, may not be suitable the next for a variety of reasons (eg changes to property/occupancy, to festival infrastructure, public and emergency services, arrival of travellers etc).

During recent festivals it has been a requirement of the licence that sound engineers monitor noise levels at the mixer position for main stages using an IEC Type 1 instrument to ensure that they can comply with levels which are set by the Licencing Authority. In future this could be expanded so that the readings at front of house are downloaded to a Laptop at the mixer or other locations for interrogation. Another option is that the sound engineer could also dial up a remote monitor at an off site position!

There is concern that the gradual increase in the number and output of large sound sources on site in recent years now makes it difficult for the Festival Organiser to comply with the 60 dBLAeq (15min) particularly if wind conditions are unfavourable. In order to comply with this level, can mean reducing levels at the main stages to the point where audience satisfaction is reduced, with the risk of crowd safety problems arising. At any future Licence application, proposals for additional venues may well be resisted if there is any likelihood of increasing the ambient level of noise at any noise sensitive dwelling.

Noise issues surrounding the markets and ancillary entertainment venues appear to be effectively controlled by the noise monitoring strategy, but the arrival of travellers with their large PA systems led to breaches of the Noise Abatement Notice and a subsequent successful prosecution.

6. GLASTONBURY FESTIVAL 2002 AND BEYOND ?

Mendip District Council and the Police Authority are reviewing the process of granting a Licence for future events. It is considered that the organiser will need to provide a comprehensive risk assessment covering all the major issues in detail to the satisfaction of the Authorities prior to granting a licence.

Since the festival has grown and grown over the years, with each year bringing new challenges, Council Officers have progressively become enmeshed into assisting the organiser in avoiding breaches of the licence. In future the festival organisers management strategy will have to include noise. Therefore consideration is being given to the fact that the Licencee may (sooner or later) need to appoint their own noise consultants, rather than rely so heavily on the District Council to ensure compliance. The role for the Councils Noise Officers in future is therefore likely to move towards auditing the noise control measures and liaison with an appointed Noise Consultant - Anyone interested in the job??